

**Nguyen Duc Thang**

# **3200 ANIMATED MECHANICAL MECHANISMS**

**With**

**Images,  
Brief explanations  
and YouTube links**

## **Part 3**

**Mechanisms of specific purposes**

**31 March 2020**

This document is divided into 4 parts.

Part 1: Transmission of continuous rotation

Part 2: Other kinds of motion transmission

Part 3: Mechanisms of specific purposes

Part 4: Mechanisms for various industries

Autodesk Inventor is used to create all videos in this document.

They are available on YouTube channel “thang010146”.

To bring as many as possible existing mechanical mechanisms into this document is author’s desire. However it is obstructed by author’s ability and Inventor’s capacity. Therefore from this document may be absent such mechanisms that are of complicated structure or include flexible and fluid links.

This document is periodically renewed because the video building is continuous as long as possible. The renewed time is shown on the first page.

This document may be helpful for people, who

- have to deal with mechanical mechanisms everyday
- see mechanical mechanisms as a hobby

Any criticism or suggestion is highly appreciated with the author’s hope to make this document more useful.

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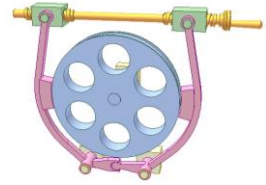
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## 12. Brakes

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[http://youtu.be/\\_q5iKo63rjQ](http://youtu.be/_q5iKo63rjQ)

Nut-screw brake.



### Shaft brake 1

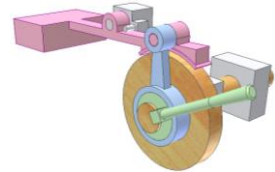
[https://youtu.be/Yn6FK7\\_5Vjl](https://youtu.be/Yn6FK7_5Vjl)

It is an application of 4-bar linkage.

Turn green lever to force pink brake shoes on orange drum for braking orange shaft.

The lever is fixed to an eccentric that has revolution joints with the shaft and blue conrod.

Although only one brake shoe is used but total bending force applied to the shaft is inconsiderable.



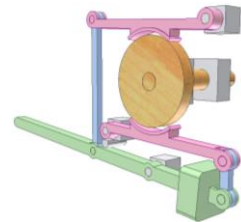
### Shaft brake 2

<https://youtu.be/TGLrUAvWDP4>

It is an application of two 4-bar linkages.

Push down green lever to force pink brake shoes on orange drum for braking orange shaft.

Total bending force applied to the shaft is inconsiderable thanks to symmetric arrangement of the brake shoes.



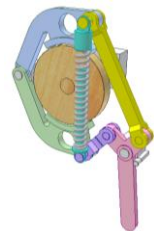
### Shaft brake 3

<https://youtu.be/NDSj0KV6OvU>

Turn pink lever clockwise to force blue and green brake shoes to orange drum for braking orange shaft.

Total bending force applied to the shaft is inconsiderable thanks to symmetric arrangement of the brake shoes.

Pushing spring (in grey) prevents the brake shoes from contact with the drum when not braking.



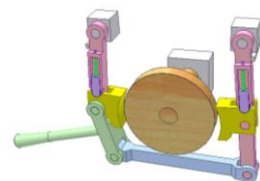
### Shaft brake 4

[https://youtu.be/39gu\\_7dTpkA](https://youtu.be/39gu_7dTpkA)

Turn green lever clockwise to force yellow brake shoes to orange drum for braking orange shaft.

Total bending force applied to the shaft is inconsiderable thanks to symmetric arrangement of the brake shoes.

Spring sliders (in violet) prevent the yellow shoes from contact with the drum when not braking.



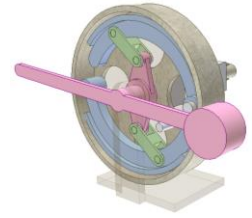
### Shaft brake 5

[https://youtu.be/EiRoXm\\_SeYE](https://youtu.be/EiRoXm_SeYE)

Turn pink lever counter-clockwise to force blue brake shoes to inner surface of brown rim for braking brown shaft.

Total bending force applied to the shaft is inconsiderable thanks to symmetric arrangement of the brake shoes.

A weight on the pink lever prevents the shoes from contact with the rim when not braking.



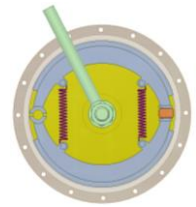
### Motorcycle brake 1

<https://youtu.be/Rwl1PthoGEY>

Turn orange cam to force blue brake shoes to inner surface of grey hub for braking the motorcycle wheel.

Yellow brake body is fixed to the motorcycle fork (in green).

The cam is controlled by a pedal or by a handlebar lever



### Automatic brake in worm hoist

<http://youtu.be/llm5aJLaSCs>

The red arrow represents load (to be raised or descended) applied to the hoist.

The blue arrows represent driving force applied to the hoist.

The yellow worm block can move axially a little so its male cone can contact with the female cone of the pink ratchet wheel.

The video shows three stages for the load:

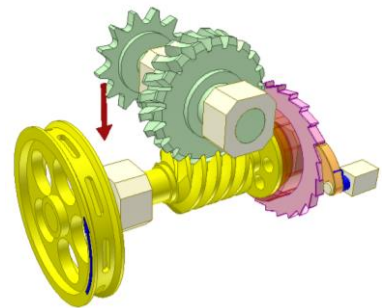
1. Moving up: The worm is turned anticlockwise. Gearing force of the worm drive pushes the worm to the right to contact with the ratchet wheel. The cone clutch closes. The ratchet wheel rotates together with the worm.

2. Stop (no driving force): The load tends to turn the worm clockwise and pushes it towards the ratchet wheel. The cone clutch closes. The orange pawl prevents the load from descending.

3. Moving down: The worm is turned clockwise. Gearing force of the worm drive pushes the worm to the left: no more contact with the ratchet wheel. The cone clutch discloses. The worm wheel can rotate to descend the load. If the load descends faster than worm turning velocity, the situation said in item 2 happens. The moving down is a jerk process.

The key factor is the left hand thread of the worm in this case.

There is no need to use self locking worm drive.



### Automatic brake in spur gear hoist

<http://youtu.be/5X9SoTP1z2E>

Input: Orange shaft of a threaded portion at its middle, on which a blue gear with a friction disk is mounted (helical joint). The blue gear can move axial a little. Its displacement is adjusted by white nuts. The pink ratchet wheel rotate idly on the input shaft. There is a green friction disk behind the ratchet wheel. It is fixed to the input shaft.

Output: grey shaft of a big gear and a chain wheel.

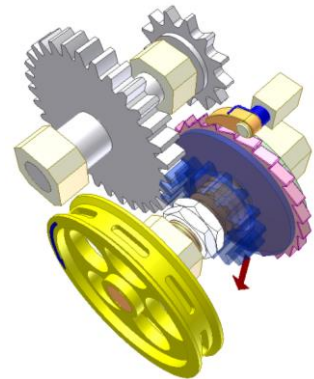
The red arrow represents load (to be raised or descended) applied to the input shaft.

The blue arrows represent driving force applied to the input shaft.

The video shows three stages for the load:

1. Moving up: The input shaft is turned anticlockwise. Force at the helical joint pushes the blue disk to the right to contact with the ratchet wheel (forces it to the green disk). The ratchet wheel rotates together with the input shaft.
2. Stop (no driving force): The load tends to turn the blue disk clockwise and pushes it towards the ratchet wheel. The orange pawl brakes the load from descending.
3. Moving down: The input shaft is turned clockwise. Force at the helical joint pushes the blue disk to the left: no more contact with the ratchet wheel. The output shaft can rotate to descend the load. If the load descends faster than input velocity, the situation said in item 2 happens. The moving down is a jerk process.

The key factor is the right hand thread of the input shaft in this case.



### Safety crank for windlass

[http://youtu.be/6QsLCAuC\\_B0](http://youtu.be/6QsLCAuC_B0)

Output: blue gear with a male cone. The red arrow represents load (to be raised or descended) applied to the gear.

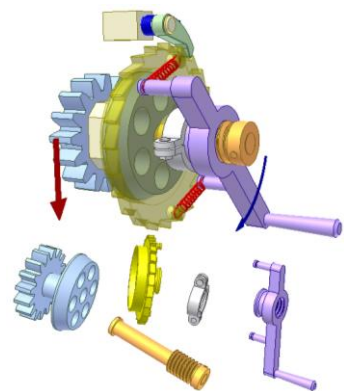
The yellow ratchet wheel with a female cone rotates idly. It is connected to the violet crank by the white ring and two red springs. The crank makes a helical joint with the orange shaft.

The video shows three stages for the load:

1. Moving up: The crank is turned clockwise (the blue arrow). Due to the helical joint the crank presses the ratchet wheel towards the blue gear to close the cone clutch, hence the gear rotates to move up the load. The crank, the ratchet wheel, the gear and the orange shaft rotate together.
2. Stop (no force applied to the crank): The load tends to turn the blue disk anticlockwise but the springs maintain the press from the crank, hence the closing state of the clutch is continued. The pawl brakes the load from descending.
3. Moving down: The crank is pushed (not turned) anticlockwise (the pink arrow). Due to the helical joint the crank moves a little to the right to disclose the cone clutch, hence the gear can rotate to move down the load. If the crank is released, the springs pull the crank to close the clutch to brake the load.

Thus the crank does not rotate during descending the load to avoid accidents.

The key factor is the right hand thread of the orange shaft in this case.



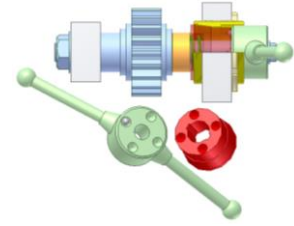
### Automatic brake for hoist 1a

<http://youtu.be/IUntUq-0MBc>

When torque in any direction is applied to green crank, four balls try to move red bush to the left. Its outer cone stops contact with inner cone of yellow fixed socket, the crank and blue gear shaft can rotate together. The torque is transmitted to the gear shaft through the balls.

If the torque is removed, green spring moves the bush to the right. Its contact with the yellow fixed socket brakes the hoist instantly. Orange bush acts as a stopper for the red bush in its motion to the left.

Designer: Joseph Pizzo.



### Automatic brake for hoist 1b

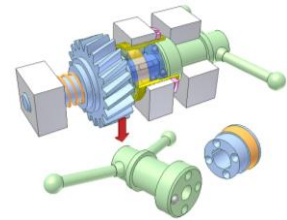
<http://youtu.be/aUO9Kyoj90E>

When torque in any direction is applied to green crank, four balls try to move blue gear shaft to the left. Its outer cone stops contact with inner cone of the yellow fixed socket, the crank and the gear shaft can rotate together. The torque is transmitted to the gear shaft through the balls.

If the torque is removed, orange spring moves the gear shaft to the right. Its contact with the yellow fixed socket brakes the hoist instantly.

Red arrow shows load torque applied to the shaft. By right choice of helix gear direction (left hand in this video) the load helps increasing brake force.

This brake is a suggestion based on the design of Mr. Joseph Pizzo.



### Automatic brake for slider 1a

<http://youtu.be/5gYC986VqCA>

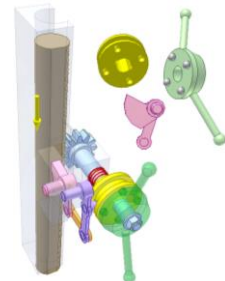
When torque in any direction is applied to green crank, four balls try to move red bush towards. The later via 4 bar linkage stops contact between pink eccentric cam and brown rack-slider, the crank rotating together with the blue gear shaft moves the rack-slider up down. The torque is transmitted to the gear shaft through the balls.

If the torque is removed, red spring moves the bush back and turns the pink cam to brake the rack-slider instantly.

Yellow arrow shows gravity force direction.

Pay attention to design the cam in order that friction between the rack-slider and the cam increases clamping force thanks the gravity force. If not the rack-slider will fall.

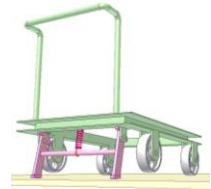
It can be used for moving a working table up down.



### Parking brake for trolley

<https://youtu.be/QayULYC79-A>

Raise the trolley and move forward the pink stand for unbraking.  
Raise the trolley and move backward the pink stand for braking.



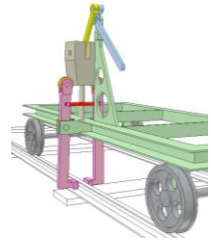
### Parking brake for railway cart

<https://youtu.be/g-NSih-III>

The brown weight causes braking forces applied to the rail. Thanks to a small gap in cylindrical joint between the weight and green chassis both pink brake bars can contact the rail at the same time.

Red spring ensures no contact between the brake bars and the rail when unbraking.

The weight, yellow conrod and blue lever create a slider crank mechanism.

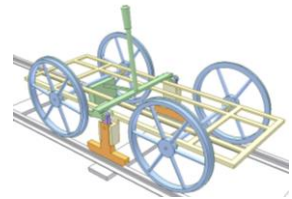


### Hand brake for rail cars

<https://youtu.be/TM6ke9y5QmY>

It is an application of slider crank mechanism.

The friction between orange brake shoes and the railway creates brake force.





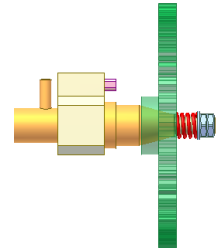
## 13. Safety clutches

### Safety clutch 3

<http://youtu.be/b6uouA9Pqzo>

A cone clutch is formed by mating a taper on the shaft to a bevel central hole in the gear. Increasing compression on the spring by tightening the nuts increases the drive's torque capacity.

An overload condition is represented by the pink slider position.

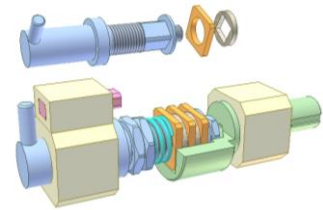


### Safety clutch 4

<http://youtu.be/Rrpg253rWto>

Friction disks are compressed by an adjustable spring. Square disks are locked into the square hole in the right shaft and round disks onto the square rod on the left shaft.

An overload condition is represented by the pink slider position.

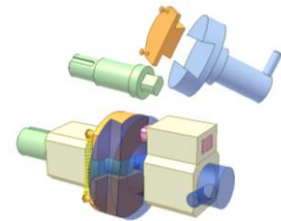


### Safety clutch 5

<http://youtu.be/YSp9pUJTfZI>

Sliding wedges clamp down on the flattened end of the shaft. They spread apart when torque becomes excessive. The strength of the springs in tension that hold the wedges together, sets the torque limit.

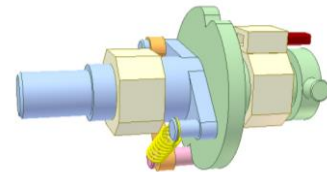
An overload condition is represented by the pink slider position.



### Safety clutch 6 (spring arm)

<http://youtu.be/KJ4pp4CCnTc>

Torque is transmitted from the blue input shaft to the green output one through the pink pin on the orange arm. When overload (represented by position of a red slider), the pin jumps out of the slot on the green shaft, the transmission is interrupted.

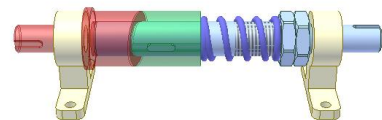


### Safety clutch 7

<http://youtu.be/ynfwLNaXU08>

A cylinder cut at an angle forms a torque limiter. A spring clamps the opposing-angled cylinder faces together and they separate from angular alignment under overload conditions. The spring tension sets the load limit.

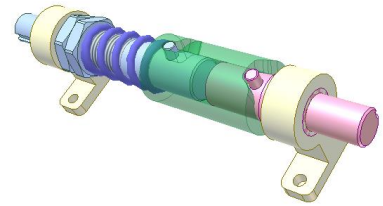
The animation has a weakness: the spring does not rotate as in reality.



### Safety clutch 8

<http://youtu.be/6-cJUOWY9q8>

A cammed sleeve (green) connects the input (pink) and output (blue) shaft of this torque limiter. A driven pin (blue) does not allow the sleeve move to the right. When an overload occurs, the driving pin (pink) pushes the sleeve to the left and the driven pin (blue) drops into the L-shaped slot to keep the shafts disengaged. The limiter is reset by turning the output shaft backwards.



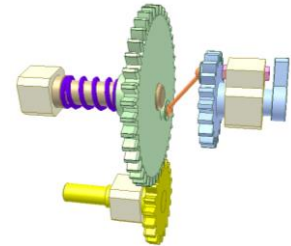
The animation has a weakness: the spring does not rotate as in reality.

### Safety clutch 9 (oblique arm)

<http://youtu.be/ZyfyPQlkXwc>

Input: yellow shaft. The axial force of a spring and the orange driving arm are in balance. An overload condition (represented by the pink slider position) overcomes the spring force to slide the green gear out of engagement.

The animation has a weakness: the spring does not rotate as in reality.

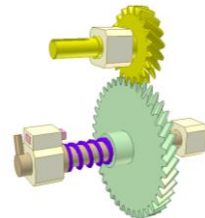


### Safety clutch 10 (helical gears)

<http://youtu.be/sq9AjzaD7Ts>

Input: yellow shaft. The axial force of a spring and the axial component of gear force in the spur gear drive (helical teeth) are in balance. An overload condition (represented by the pink slider position) overcomes the spring force to slide the green gear out of engagement.

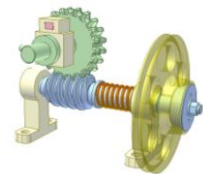
The animation has a weakness: the spring does not rotate as in reality.



### Safety clutch 11

<http://youtu.be/plYw36oOPwY>

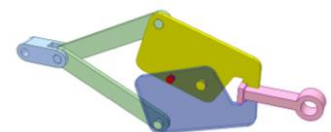
The yellow pulley is input, the green wormwheel is output. The blue worm rotates due to friction between a cone on the worm and a cone hole of the yellow pulley under spring force. When an overload occurs (represented by the pink slider), the blue worm is pushed to the right thus prevents cone contact and interrupts the transmission, reducing wear of cone surfaces.



### Safety clutch 1

<http://youtu.be/IUZAmijQ7MA>

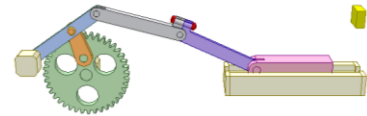
The shearing of a pin releases tension in this coupling. A toggled-operated blade shears a soft pin (red) so that the jaws open and release an excessive load.



### Safety clutch 2

<http://youtu.be/trfFKC7xnTw>

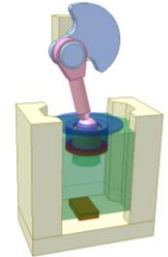
The grey and violet bars are fixed together by the red bolt. When the pink slider crashes with the yellow part, the red bolt is broken, the grey and violet bars are now connected by a revolute joint to prevent overload for other parts.



### Safety clutch 2B

<http://youtu.be/YJbl6bSFY4U>

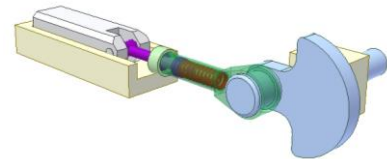
When the green slider of a press crashes onto the brown object, the red disk is sheared (a smaller disk is created) by the yellow cushion. This prevents damage of other parts.



### Safety clutch 12

<http://youtu.be/zd1RT89jKVI>

The conrod consist of two parts that can slide on each other. A spring clamps them together under working condition. When the slider crashes with the red part, the spring is compressed, the two parts of the conrod slide on each other to prevent damage of other parts.



### Safety clutch 13 - Spring pestle

[http://youtu.be/\\_EriVQKos3k](http://youtu.be/_EriVQKos3k)

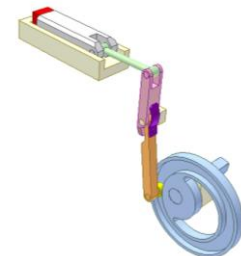
The spring between the slider and the pestle helps to avoid overload and to guarantee no gap between the pestle and the mostar at the lowest position of the pestle.



### Safety clutch 14

<http://youtu.be/Apye3XXRpYU>

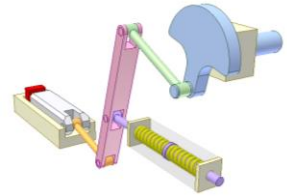
The cam follower consists of two parts (orange and pink) that can rotate in relation to each other. A leaf spring (violet) clamps them together under working condition. When the slider crashes with the red part, the spring is bended, the two parts of the follower rotate in relation to each other to prevent damage of other parts.



### Safety clutch 15 (balance springs)

<http://youtu.be/aUTmtQZtLKo>

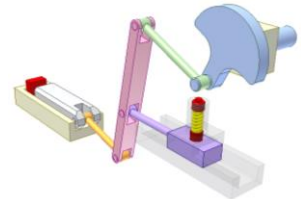
Under normal condition the violet rod is kept immobile by equal forces of the two springs. The pink bar rocks around a pin of the violet rod. When the slider crashes with the red part, the violet rod moves to the right to prevent damage of other parts.



### Safety clutch 16 (friction)

<http://youtu.be/QBOicSYDykk>

Under normal condition the violet rod is kept immobile due to friction generated by spring force. The pink bar rocks around a pin of the violet rod. When the slider crashes with the red part, the violet rod moves to the right to prevent damage of other parts. Repositioning of the violet rod is needed for mechanism restore.



### Safety clutch 17

<http://youtu.be/3E0dW7UV9Ao>

Input: grey shaft having internal cylindrical surface with grooves.

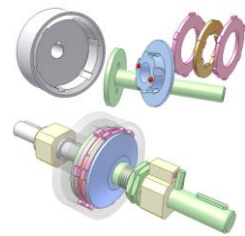
Output: green shaft having cylindrical joint with blue disk.

Pink friction disks engage with the grey shaft.

Orange friction disk engages with the blue disk.

In normal condition the green spring forces blue, pink and orange disks towards the disk of the green shaft to connect the clutch.

When overloading (represented by the pink pin position), the green shaft is kept immobile, the red balls (located in cone holes on faces of the green shaft and the blue disk) push the blue disk to the right, thus disconnect the clutch. At that time there is no contact between the disks so their wear is reduced remarkably.



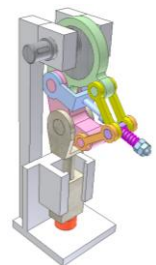
### Safety clutch 18

<https://youtu.be/HuHWI9kjFEc>

Input: grey eccentric shaft.

Output: brown slider.

When the overload happens (the slider crashes with the red part) pink spring is compressed to prevent damage of other parts.



### Safe crank

<https://youtu.be/vBD7xdkyvRA>

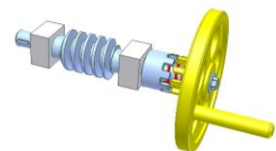
Blue shaft receives motion from two sources: electric motor (not shown) at the left end and human force at the right end.

Red spring tends to disengage the yellow crank and the blue shaft.

When the motor makes the shaft rotate, the crank is idled on the shaft.

Push and turn the crank to make the shaft rotate when the motor is not in action.

Disadvantage: the operator has to push slightly the crank when turning.



### Safety stop for lifting apparatus

<http://youtu.be/-sDqXmD1sEw>

This mechanism is applied for hand powered lifting apparatus.

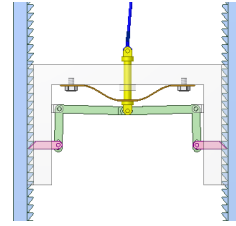
When there is a pulling force in blue cable, the yellow rod compresses brown leaf spring and the grey frame can move up down.

When there is no pulling force in blue cable or the cable is broken, the brown spring via yellow rod and green levers pushes two pink pawls into contact with two stationary racks thus the frame is kept immobile.

The moving down is a jerk process, pulling force in cable is only big enough to prevent the pawls from contact with the racks.

The video shows how the frame goes up, stops, goes down, stops, goes up again and stops when the cable is broken.

Leaf spring can be replaced with helical cylindrical one.



## 14. Mechanisms for indexing, positioning and locking

### 14.1. Angular indexing and positioning

#### Indexing mechanism 1

<http://youtu.be/FktyDQTLi78>

Input: blue rod, each push of which makes green disk rotate 90 deg.

Brown springs and square portion of the green disk contribute to the green disk rotation and to its positioning.

Orange flat spring maintains contact between the pink pawl and the green disk.



#### Indexing mechanism 2

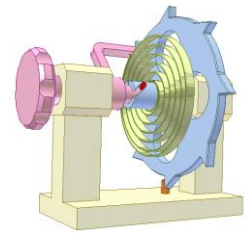
<http://youtu.be/0bRevPdhEco>

Input: pink knob, each around 45 deg. rotation of which makes blue disk rotate 45 deg. exactly.

Outer end of the spiral flat spring is fixed to the pink knob.

Inner end of the spiral flat spring is fixed to the blue disk hub.

The disk moves axially due to helical slot on the disk.



#### Indexing mechanism 3

<http://youtu.be/-6uhkv5A29w>

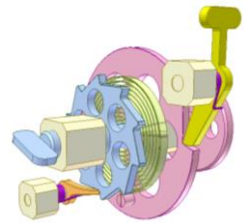
Output: pink ratchet wheel of two teeth, rotating 180 deg. each time when yellow pawl leaves it thanks to a spiral flat spring.

Outer end of the spiral flat spring is fixed to the pink wheel.

Inner end of the spiral flat spring is fixed to the blue ratchet wheel hub.

Orange pawl prevents clockwise rotation of the blue wheel.

The video shows also the winding up the flat spring by turning the blue wheel anticlockwise.



#### Mechanism for 90 deg. rotation 1

<https://youtu.be/8DAIPTBPcME>

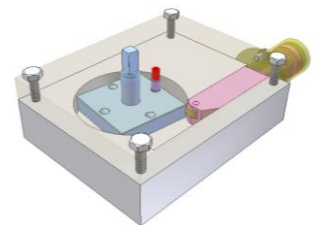
Input: pink slider-pawl driven by yellow pneumatic cylinder.

Output: blue square ratchet wheel (ratchet wheel teeth need not be saw-tooth shaped).

Key factor: when the pawl returns to its initial position, the violet spring pin turns the wheel a small angle but needed for the next 90 deg. rotation.

The mechanism is used only for light duty work because the violet spring pin can't turn the wheel of heavy load.

It is a simplified embodiment of the design of U.S. patent 3548684.



### Mechanism for 45 deg. rotation 1

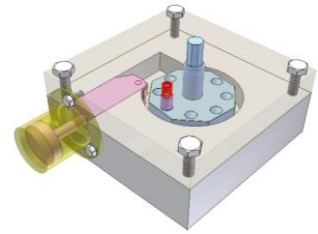
<https://youtu.be/ma6HnHgkHo>

Input: pink slider-pawl driven by yellow pneumatic cylinder.

Output: blue octagon ratchet wheel (ratchet wheel teeth need not be saw-tooth shaped).

Key factor: when the pawl returns to its initial position, the violet spring pin turns the wheel a small angle but needed for the next 45 deg. rotation.

The mechanism is used only for light duty work because the violet spring pin can't turn the wheel of heavy load.



### Barrel cam for 180 deg. rotation 1b

<https://youtu.be/HlwjY53FMHE>

Each push makes blue cam shaft turn 180 deg.

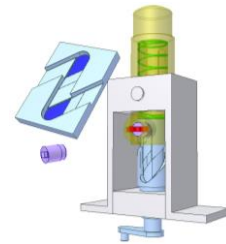
Yellow button has prismatic joint with the base.

Violet pin has prismatic joint with the yellow button.

Red spring forces the pin toward the blue cam shaft.

Key factor is different depths of the cam groove.

Developed cam is shown on the left. Portions in dark blue are deepest.



### Barrel cam for 180 deg. rotation 2b

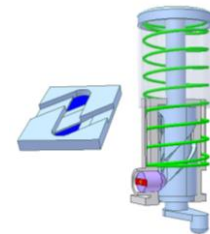
<https://youtu.be/ML31YEnIODk>

Each push makes blue cam shaft go down and turn 180 deg. when going up. Violet pin has prismatic joint with grey base.

Red spring forces the pin toward the blue cam shaft.

Key factor is different depths of the cam groove.

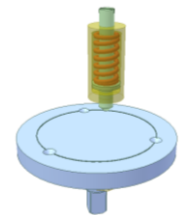
Developed cam is shown on the left. Portions in dark blue are deepest. The base is cut off half for easy understanding.



### Positioning device 1

<http://www.youtube.com/watch?v=6YDWcjRVHzo>

It is used for positioning a disk that rotates interruptedly.



### Positioning device 2

<http://www.youtube.com/watch?v=xwK8Oa4SmX8>

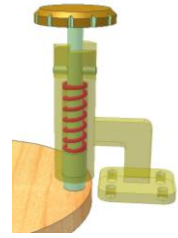
It is used for positioning a shaft that rotates interruptedly.



### Positioning device 3

[http://youtu.be/Uht\\_pvwbwVU](http://youtu.be/Uht_pvwbwVU)

It is used for manual positioning a disk that rotates interruptedly.

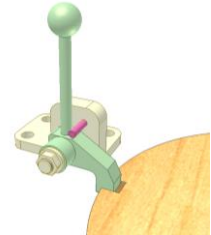


### Positioning device 4

<http://youtu.be/hLpjgtKdf4>

It is used for manual positioning a disk that rotates interruptedly.

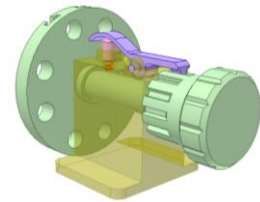
The green lever weight maintains its two extreme positions when creates contacts between the pink pin and the lever.



### Positioning device 6

<http://youtu.be/Edn0JsEvwn8>

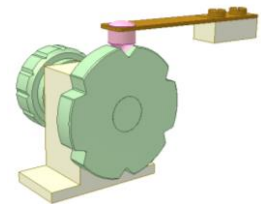
Press pink button via violet lever, turn green shaft to new position and release the button.



### Positioning device 7

<http://youtu.be/pRVqH-dwAzc>

A leaf spring provides limited holding power.



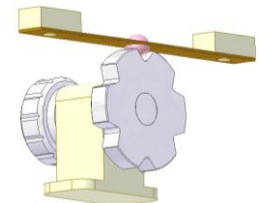
### Positioning device 8

<http://youtu.be/9m3amDpR3Jw>

A leaf spring detent can be removed quickly.

Diameter of the hole for the ball is a little smaller than the ball diameter.

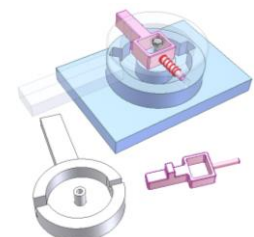
There are gaps in longitudinal direction between base pins and holes on spring ends that causes inaccurate positioning.



### Positioning device 14

<https://youtu.be/cl19RveRfll>

Push pink button, turn white lever to new position and release the button.

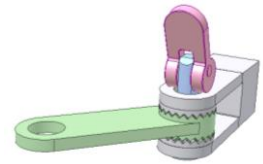




### Mechanism for adjusting angular position of a lever

<http://youtu.be/gK9jWWiTxYQ>

Grey fixed flexible fork enables axial gap for adjusting position of green lever. Pink cam is for clamping the lever after adjustment. The mechanism can work in case without teeth (friction clamping).



### Stepless adjustment for angular position

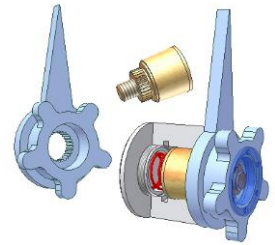
<https://youtu.be/O6oibE9P1R8>

The friction at contact place between orange cone and cone hole of the housing locks the blue hand under red spring force.

Push blue hand to unlock, turn it to new position and release it to lock.

A torque applied to the hand can not turn it if the hand is not at pushed position.

The tapered angle should be small, around 1 to 3 deg.



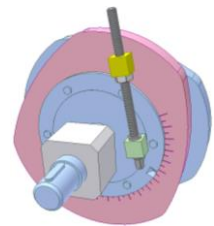
### Angular adjustment of two coaxial cams

<https://youtu.be/lGFk5ZYygsc>

Turn grey screw to adjust angular position between pink and blue cams.

Green bearing of the screw has revolution with the blue cam.

Yellow nut has revolution with the pink cam.



### Differential angular adjustment 1

<https://youtu.be/OWjTHBFNcGk>

Way to get small angular adjustment.

Relative angle between green gear and yellow cam can be adjusted by turning the cam and fixed by pink key.

N1: number of slots on the gear.

N2: number of slots on the cam.

If  $N1 = N2 = 6$ , minimum adjusted angle  $A = 360/N1 = 60$  deg.

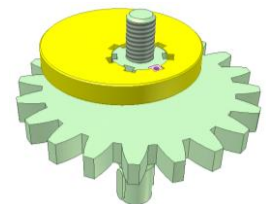
If  $N2 = N1 + 1$ , minimum adjusted angle  $B = 360/(N1.N2)$  deg.

In this video:  $N1 = 6$ ,  $N2 = 7$ ,  $B = 360/42 = 8,57$  deg.

Compare with ordinary way:

<http://youtu.be/gK9jWWiTxYQ>

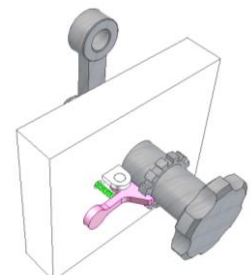
that needs large number of slots to get small adjusted angle.



### Positioning device 18

[https://youtu.be/y-XcG\\_7rCbq](https://youtu.be/y-XcG_7rCbq)

Using the left hand to push the pink latch. The latter no more prevents the gray shaft from turning. Then, using the right hand to set the shaft in desired position. Release the latch to fix the shaft on the new position.



### Stepless positioning device

<https://youtu.be/NOdJ3oQ073c>

Using the left hand to squeeze the cogs.

The latters no more prevent the gray shaft from turning.

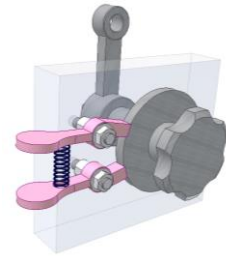
Then, using the right hand to set the shaft in desired position.

Release the latch to fix the shaft on the new position.

The cog right ends are shaped to cause wedge action to the gray disk

The lower cog prevents the gray shaft from clockwise turning.

The upper cog prevents the gray shaft from counter-clockwise turning

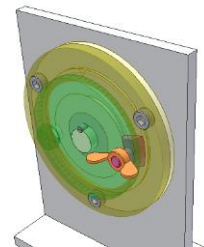


### Positioning device 17

<https://youtu.be/zmR74Bo1Swc>

Green shaft is positioned steadily thanks to circular wedge slider of dovetail section (in pink) and wing nut (in orange).

The dovetail runway is created by two yellow disks fixed together.



### Adjusting angular position of a lever 2

<https://youtu.be/yXYsN-iU3ew>

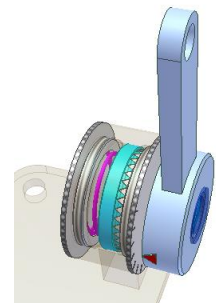
Push the blue lever to unlock, turn it to new position and release it to lock.

White parts are fixed together. Blue parts are fixed together.

Only very large torque applied to the blue lever can turn it at its locking position.

Minimal adjusted angle  $A = 360 \text{ deg.} / Z$

Z is tooth number of toothed disks.



### Stepless adjustment for angular position 2

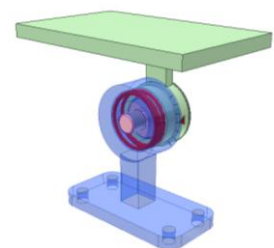
<https://youtu.be/-ip9PIJ7z5Q>

The friction at contact place between fixed pink cone and cone hole of green movable part locks the green part under red spring force.

Push the green part to unlock, turn it to new position and release it to lock.

Only very large torque applied to the green part can turn it at its locking position.

The tapered angle should be small, around 1 to 3 deg.



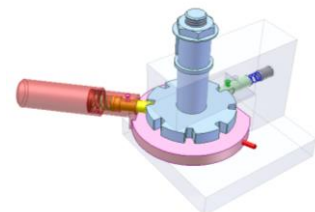
### Indexing mechanism 7 (45 deg.)

<https://youtu.be/oALcppZfF7w>

Turn pink handle back and forth 45 deg. for indexing blue shaft 45 deg. Green plunger keeps the shaft immobile after indexing.

Pink cam retracts the green plunger during indexing.

Red pin on the cam restricts turning angle of the pink handle.



### Fixture for 90 deg. indexing

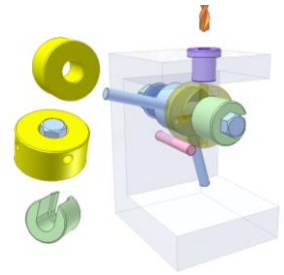
[https://youtu.be/L\\_65RKxn9Ao](https://youtu.be/L_65RKxn9Ao)

Yellow parts represent the workpieces before and after drilling.

One of two blue handles must be kept in contact with pink pin to set the workpiece at drilling position. Turn blue shaft until the second handle contact the pink pin for the next drilling.

Two handles must be more than 90 deg. apart in order to provide 90 deg. indexing. The size of the angle will depend upon the size of the handles, the size of the pink pin and its distance from the center.

Pay attention to the green grooved washer. It helps to load or remove the workpiece quickly (last scene of the video).

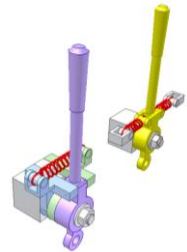


### Lever of stable neutral position 1a

<https://youtu.be/Zq5ursxPGPg>

Mechanism of yellow lever doesn't have stable neutral position and the position depends on stiffness of the two springs.

Mechanism of violet lever doesn't have such disadvantages thanks to the contact between the protrusion of the fixed pivot and two auxiliary levers (in blue and green).



### Lever of stable neutral position 1b

<https://youtu.be/qEPp5tFZt1w>

It is an embodiment of the mechanism shown at:

<https://youtu.be/Zq5ursxPGPg>

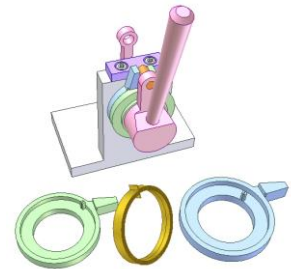
where the tension spring is replaced with a coil flat spring.

The spring outer end is fixed to the green ring.

The spring inner end is fixed to the blue ring.

The rings tend to contact the violet stopper under the action of the spring when no force applied to the pink lever. Thus the pink lever is kept stably in its neutral position.

Thanks to the coil flat spring the pink lever can get a very large rotary angle, even 300 deg.

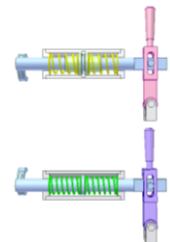


### Lever of stable neutral position 2

<https://youtu.be/8U76DPUmG8o>

Mechanism of violet lever doesn't have stable neutral position and the position depends on stiffness of the two green springs.

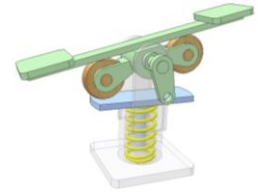
Mechanism of pink lever doesn't have such disadvantages thanks to the contact between the rings (in grey and blue) and two green sliding bushes.



### Lever of stable neutral position 3

<https://youtu.be/gOKQISHL4pU>

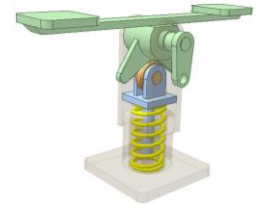
This mechanism keeps green lever firmly at its neutral position when no force applied to it.



### Lever of stable neutral position 4

<https://youtu.be/oFSJE3bYgf0>

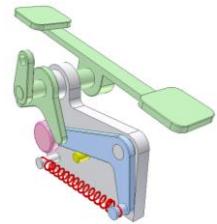
This mechanism keeps green lever firmly at its neutral position when no force applied to it.



### Lever of stable neutral position 5

<https://youtu.be/b2GNBy5G1VA>

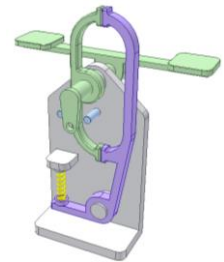
This mechanism keeps green lever firmly at its neutral position when no force applied to it.



### Lever of stable neutral position 6

<https://youtu.be/5zoZn1KJKRE>

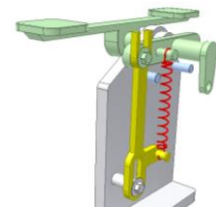
This mechanism keeps green lever firmly at its neutral position when no force applied to it.



### Lever of stable neutral position 7

<https://youtu.be/SMoo4KdiNYg>

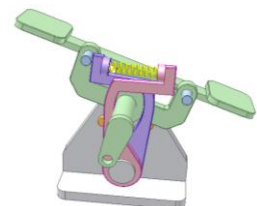
This mechanism keeps green lever firmly at its neutral position when no force applied to it.



### Lever of stable neutral position 8

<https://youtu.be/CZ3KJVQSSXk>

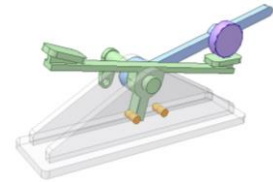
This mechanism keeps green lever firmly at its neutral position when no force applied to it.



### Lever of two positions 1

<https://youtu.be/Cz3lf5XUAC8>

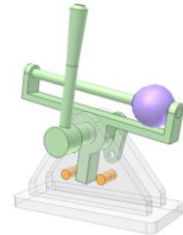
Blue lever brings green lever to one of its two positions.  
The green lever is kept firmly at each position thanks to the gravity.



### Lever of two positions 2

<https://youtu.be/n3PEaU9v2P8>

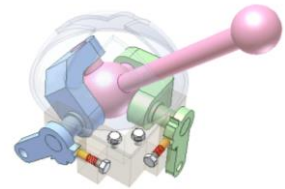
Turn green lever to change its position.  
It is kept firmly at one of its two positions thanks to violet weight.



### Joystick of 5 positions

<https://youtu.be/btuqe4yHB2Y>

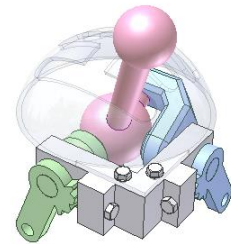
Each crank (blue or green) has 3 positions: Right, Neutral and Left  
Pink joystick has revolution joints with the blue and green cranks.  
One crank can reach Right or Left only when the other crank is at Neutral so this mechanism can get 5 positions.



### Joystick of 9 positions

<https://youtu.be/Kgyis2aJWT4>

Each crank (blue or green) has 3 positions: Right, Neutral and Left.  
Pink joystick has a revolution joint with the blue crank.  
The green crank has a pin that slides in circular groove on the joystick.  
Each crank can reach one of its 3 positions while the other crank is at its any position so this mechanism can get 9 positions.



### Output positions subject to input motion direction 2

<https://youtu.be/nB-epdKNg8I>

Unlike centrifugal governor, where output position depends on input velocity, in this mechanism output position depends on input rotary direction.

When pink pinion rotates clockwise, blue lever gets its right position, stays there till the pinion changes its rotary direction and vice versa.

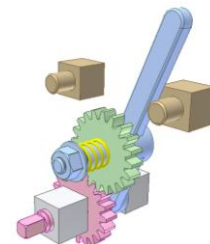
Gear force makes the lever turn. Use blue nut via yellow spring to press green gear toward the lever for adjusting the friction between them, thus the gear force.

Torque from the gear force must be larger than the torque caused by gravity and possible load applied to the lever.

Two brown stoppers set the lever positions.

There is energy loss due to friction between green gear and the lever, if the pink pinion rotates continuously.

The mechanism can be used for automatic position control when input is motion direction.

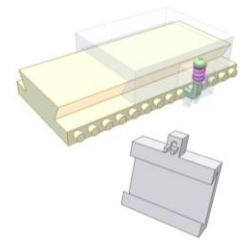


## 14.2. Linear indexing and positioning

### Positioning device 5

[http://youtu.be/\\_01fYaAa56o](http://youtu.be/_01fYaAa56o)

Push green button, move slider to new position and release the button.

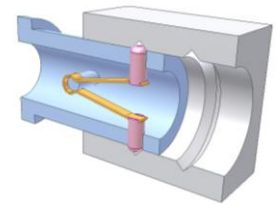


### Positioning device 9

<http://youtu.be/p7KsxHMHbC8>

A V-shaped spring always forces two pink pins towards grey part, circular grooves of which allow rotary motion between the blue part and the grey one.

The parts are cut off half for easy understanding.



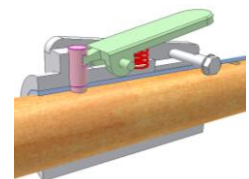
### Positioning device 10

<https://youtu.be/l1JCgkXpPiM>

It is used for positioning orange movable tube in blue stationary tube.

Grey hub is fixed to the blue tube by grey bolt.

Push the green lever to remove the positioning. Move and release the lever for new position of the orange tube.

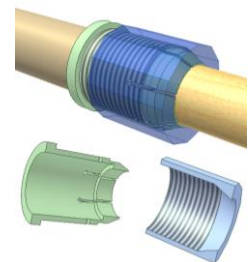


### Positioning device 11

<https://youtu.be/5U2Yns2J4IQ>

Release blue nut and move orange inner tube to new position. Then tight the nut to fix the inner tube thanks to green flexible bush.

Pay attention to tapered portion and longitudinal slots on the green bush. The green bush is fixed to the outer pipe.



### Positioning device 13

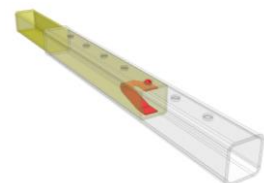
<https://youtu.be/-ORWRYxFYAM>

It is used for positioning glass movable tube along yellow stationary tube.

Push (blue arrow) the red spring to unlock, move the glass tube to new position and the red spring will locks it automatically.

See a real mechanism:

<https://www.youtube.com/watch?v=y3V6o3eca0g>



### Positioning device 12

<https://youtu.be/GjU4ucEkkj8>

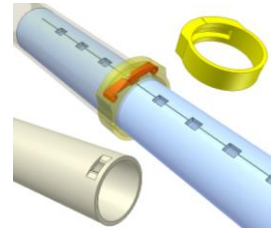
It is used for positioning blue movable tube along beige stationary tube, to which a yellow rim is fixed.

Turn the blue pipe to unlock, move it to new position and turn it back to lock.

At lock position the red spring prevents longitudinal motion of the blue tube but not its rotation.

See a real mechanism:

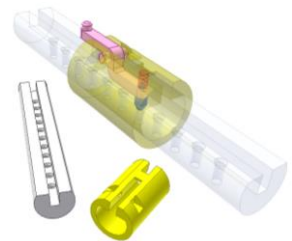
<https://www.youtube.com/watch?v=0kvEeKln-ml>



### Positioning device 15

<https://youtu.be/3Rn80vPBaVo>

Push pink lever, move yellow slider to new position and release the lever. Move the slider slightly if the blue pin on the slider has not faced a base hole.



### Two slider mechanism for quick and fine position adjustment

<https://youtu.be/QPrsoSsHda4>

The video shows in turn:

Turn pink screw anticlockwise to release blue slider.

Push the pink screw to move the blue and green sliders (rough adjustment).

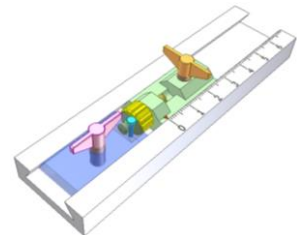
Turn the pink screw clockwise to raise the blue slider for fixing the blue slider.

Turn yellow screw to move green slider (fine adjustment).

Cyan pin is for preventing axial motion of the yellow screw.

Orange screw is used for fixing the green slider after adjustment if needed.

This mechanism finds application in caliper-squares.



### Slider lock 6a

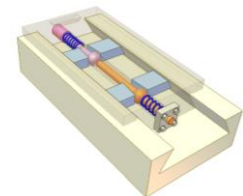
<https://youtu.be/u9GEOyneQQc>

Push the pink button and move glass slider to its new position.

When releasing the button, blue springs push the pink and orange bars and their spheres force four blue wedges aside to clamp the slider thanks to friction.

The button is fixed to the bar by thread.

To ensure that all wedges always contact with the runway when clamping the cylindrical joints between the bars and the slider must have considerable gaps. For the same reason there must be enough longitudinal gap between the pink and orange bars.



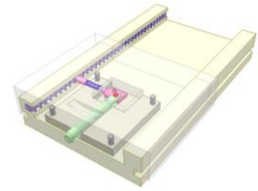
### Slider lock 6b

<https://youtu.be/NxJs6HzO1eQ>

Push green bar to retreat pink cross pin and move glass slider to its new position. Release the green bar to clamp the slider.

Red pin fixed to the green bar moves in 45 deg. inclined slot of the pink pin.

The detachable cover (in beige) is for easy assembling.



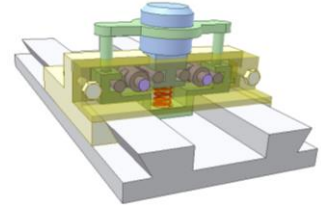
### Slider lock 7

<https://youtu.be/R2N-DOB3IOc>

Push blue button (using thumb) and pull green part (using two fingers) to unlock yellow slider and move it to new position.

Release the blue button and the yellow part to lock the slider.

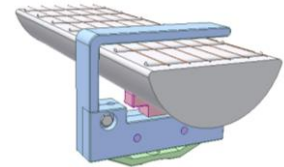
Red spring creates friction force for locking.



### Guitar capo 1

<https://youtu.be/SfyoHsnE7D4>

Press green bar to unlock the capo and move the latter to new position then release the green bar to lock there.



### Guitar capo 2

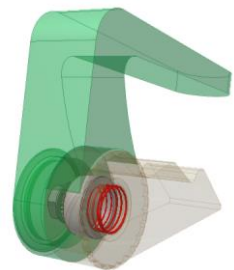
[https://youtu.be/V77FkT0\\_o5w](https://youtu.be/V77FkT0_o5w)

The friction at contact place between grey cone and cone hole of the lower arm under red spring force locks the upper arm with the lower arm.

Squeeze the two arms to unlock, set them to new position and release them to lock.

Tapered angle must be small, around 1 to 3 deg.

Choose the angle and the spring force to get a reliable locking action.



### Slider clamp 5

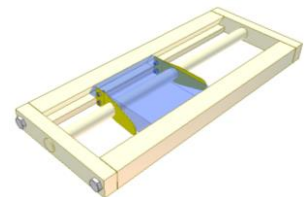
<http://youtu.be/tFh3CFgFBZQ>

Press or release yellow flat springs for repositioning or clamping blue slider.

When pressing, the spring holes are coaxial with the popcorn shaft and the springs do not brake the slider.

When releasing, the spring holes contact the popcorn shaft and friction forces created do not allow the slider moving in both directions.

Motion to the left is prevented by the right spring and vice versa.



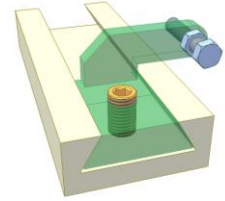


### Wedge mechanism 24

<http://youtu.be/tGYsP0KyO5k>

Loose the screw for moving the stopper to new position and then tighten it.

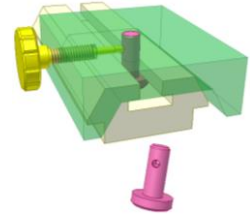
The stopper is kept immobile by wedge mechanism.



### Slider clamp 1

<http://youtu.be/uEAekWR-CsY>

Turn yellow screw for clamping or releasing green slider. Cone portion of the screw raises pink stud for clamping.

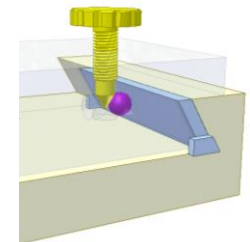


### Slider clamp 2

[http://youtu.be/NI45sSsPk\\_s](http://youtu.be/NI45sSsPk_s)

Turn yellow screw clockwise for clamping or counterclockwise for releasing the transparent slider.

Vertical hole of the slider is tapped. Horizontal hole of the slider contains violet ball that contacts with blue bar of a dovetail runway.

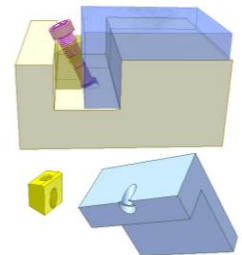


### Slider clamp 3

<http://youtu.be/Vo7-f7tCh4M>

Turn pink screw clockwise for clamping or counterclockwise for releasing the blue slider.

Lower spherical head of the screw contacts with the runway. However its contact with the slider is possible for an embodiment of this mechanism. Axial displacement of the screw is restricted.



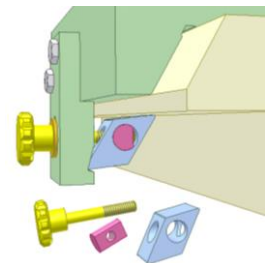
### Slider clamp 4

[http://youtu.be/dx\\_jKVq0gCo](http://youtu.be/dx_jKVq0gCo)

Turn yellow screw for clamping or releasing green slider.

Blue clamp has revolution joint with the green bracket.

Yellow screw, pink nut and blue clamp create a sine mechanism.



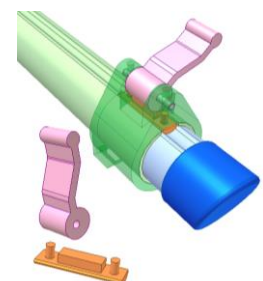
### Positioning device 16

<https://youtu.be/TgnkQ9L-5GA>

Turn pink eccentric counter-clockwise to unclamp blue tube, move the tube to new position and turn the eccentric back to clamp the tube there. Green transparent part is fixed to green tube.

For easy understanding the video shows up-down motion of the orange part. In fact, it is almost immobile.

This mechanism is used for adjusting length of a camera tripod legs.



### Linear ratchet mechanism 1

<https://youtu.be/qFifVwIWxV4>

Yellow slider can be positioned at various positions during going up thanks to pink pawl and the gravity.

Blue spring forces the pawl towards white runway.

At highest position of the yellow slider the pawl is separated from the runway by a wedge. The upper pin (fixed to violet slider) enters the pawl slot thus maintains the separation. Red spring forces the pin on the pawl. The pawl does not contact the runway when going down.

At lowest position of the yellow slider the violet slider is pushed up, the upper violet pin releases the pawl which now comes into contact with the runway.

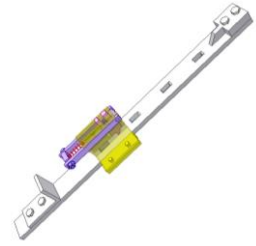
So the engagement of the yellow slider with the runway is controlled automatically.

To get higher position of the yellow slider: move it up.

To get lower position of the yellow slider: move it as high as possible, then move it down as low as possible and raise it to desired position.

Instead of this automatic function pull the pawl and move the slider to desired position.

This mechanism can be used for adjustable backrest of a chair. The backrest is fixed to the yellow slider.



### Linear ratchet mechanism 2

<https://youtu.be/1PzEya9mjLY>

Blue slider can be positioned at various positions during going up thanks to yellow lever of pink pin and the gravity.

Red spring forces the pin towards the teeth of white runway. Small slot on the yellow lever prevents the pin from contact with the runway teeth once the spring enters the slot.

Slanting portions at the ends of long slot of the runway control the meshing of the spring and the slot of yellow lever.

At highest position of the blue slider, the pin is separated from the runway teeth. The pin does not contact the runway teeth when going down.

At lowest position of the blue slider, the spring is pushed out of the lever slot and the pin now can contact the runway teeth.

So the engagement of the pin with the runway teeth is controlled automatically.

To get higher position of the blue slider: raise it until it locates into desired holding position.

To get lower position of the blue slider: move it as high as possible, then move it down as low as possible and raise it until it locates into desired holding position.

This mechanism can be used in

<https://www.youtube.com/watch?v=edAbtqgOhMs>



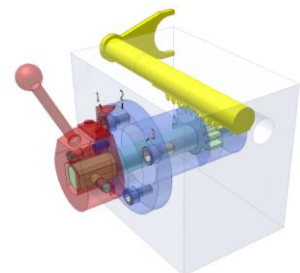
### Shifting lever of 3 positions

<https://youtu.be/gyeWb1TBHMI>

Push, turn and release pink lever to get one among 3 positions of yellow shifting rod.

Blue spring pin forces the tooth on back side of pink lever block into the grooves on the blue bush face after the pink lever is released, thus the yellow shifting rod is positioned.

The pink lever block has revolution joint with green gear shaft.



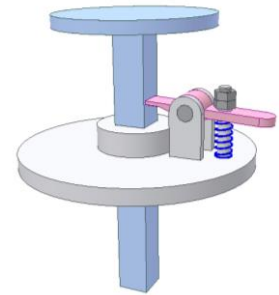
### Friction one-way linear clutch 1

[https://youtu.be/TOqg\\_bJbAFg](https://youtu.be/TOqg_bJbAFg)

Pull blue table to bring it higher.

At the pause position of the table, the pink latch is slanting to the table post. The table can move only in direction that tends to make the latch more slanting i.e. the up direction.

For moving in the down direction press the latch outer end to separate the latch from the table post, the table falls down by its weight.



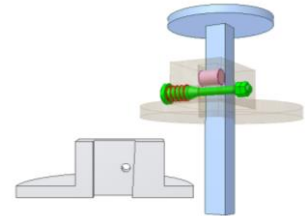
### Friction one-way linear clutch 2

<https://youtu.be/z423coqIU0>

Pull blue table to bring it higher.

At its pause position, the pink roller keeps it immobile by wedging action.

For lowering the table, press green axle. Its tapered portion separates the roller from the table post and the table can fall down by its own weight.



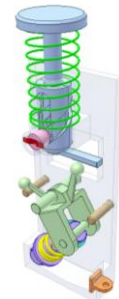
### Push-push switch

<https://youtu.be/qXnld2Yqf7I>

Each push makes blue cam shaft go down and turn 180 deg. For details see "Barrel cam for 180 deg. rotation 2b":

<https://youtu.be/ML31YEnIODk>

Arm on the cam shaft switches on or off the contact between violet and orange parts.



### Push-push button 1

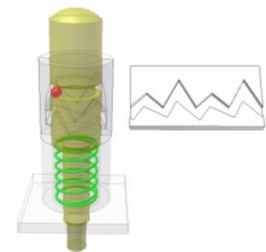
<https://youtu.be/Meltd5Kclqs>

Half of red ball is in circular groove on yellow button, the other half is in internal zigzag groove of grey bush.

Each button push gives one among its two axial positions.

Figure on the right is developed groove of the grey bush.

The button or the bush has assembly structure (not shown) for putting the ball into the grooves.



### Push-push button 2

<https://youtu.be/5JziSsxSsb8>

Pink bar is pivoted on the base.

The groove profile of blue slider ensures that the upper pink pin moves clockwise along heart-shaped groove when the blue button is pushed and released.

Pay attention to the followings (the letters on the sketch denote corners of the profiles):

a' is on the right of a

b' is on the left of b

c' is on the right of c

d' is on the left of d

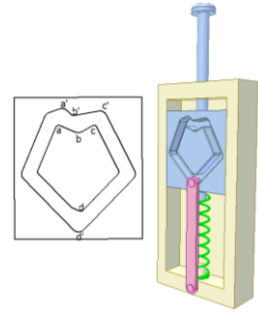
See related videos:

<https://www.youtube.com/watch?v=0dDiXJsmDOQ>

[http://www.makerbothy.com/?page\\_id=220](http://www.makerbothy.com/?page_id=220)

See another mechanism of the same working principle "Push-push button 1":

<https://youtu.be/Meltd5Kclqs>



### Push-push button 3

<https://youtu.be/kJOBlovBWtk>

Pink lever is pivoted on the base and can move up-down. Blue spring forces the pink lever towards the green button.

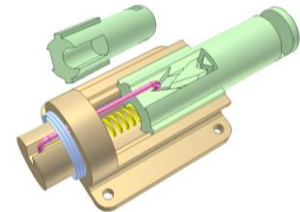
Yellow spring forces the green button towards the right end of the pink bar.

The profile shape and various depths of groove on green button ensures that the right end of the pink bar moves counter-clockwise along the groove when the green button is pushed and released.

The mechanism is used for locking small cabinet windows.

It is more compact than the mechanism shown in:

<https://youtu.be/5JziSsxSsb8>



### Two button mechanism 1

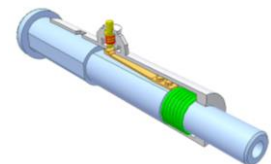
[https://youtu.be/px64\\_pfu-7Q](https://youtu.be/px64_pfu-7Q)

Blue button has prismatic joint with grey base.

Push blue button to reach its protrusive position.

Push yellow button to return the blue button to its hiding position.

The mechanism is applied for moving the tips of ballpoint pens.



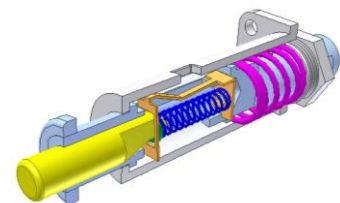
### Two button mechanism 2

<https://youtu.be/RAqWdhAVNI8>

Press blue button to reach its forward position.

Orange leaf spring enters into a hole on the grey base to prevent the blue button go back under action of pink spring.

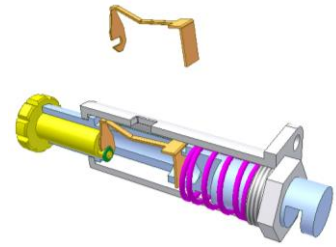
Press yellow button to return the blue button to its initial position. Wedge surface on the yellow button pulls the orange spring out of the hole on the grey base.



### Push-turn button mechanism

<https://youtu.be/lq3ICLRWXf8>

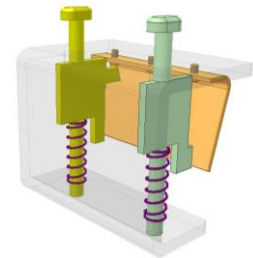
Press yellow button to reach forward position of the blue pin.  
Orange leaf spring enters into a hole on the grey base to prevent the blue button go back under action of pink spring.  
Turn yellow button to return the blue pin to its initial position.  
Eccentric pin of the yellow button pulls the orange spring out of the hole on the grey base.



### On-Off switch 1

<http://youtu.be/LhaU0whb8lo>

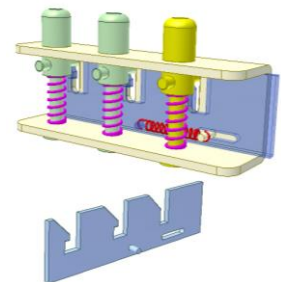
Push green button to get ON.  
Push yellow button to get OFF.  
The orange part is a flat spring.  
The green button is connected to electrical contacts (not shown).



### Switch mechanism for speed selection 1

[http://youtu.be/UwcpsEW\\_PqA](http://youtu.be/UwcpsEW_PqA)

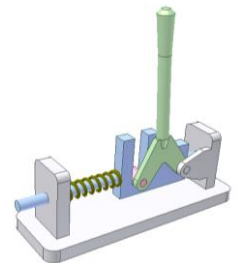
The mechanism is used for speed control of desk fans  
Push first green button to get speed 1.  
Push second green button to release the first one and get speed 2.  
Push yellow button to release the green button in down position and get OFF.  
Half way pushing of the green buttons (in up position) has the same effect as pushing the yellow button.  
The green buttons are connected to electrical contacts (not shown).  
Add further green buttons for more speeds.



### Slider of two positions 1

<https://youtu.be/m6YHJn2tS6M>

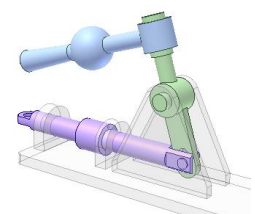
Green lever brings blue slider to one of its two positions.  
The slider is kept firmly at each position thanks to the spring.  
At left position, axis of pink pin is lower than the one of the revolution joint of the green lever. Spring force tends to turn the green lever anticlockwise.  
At right position the things are opposite.



### Lever of two positions 3

<https://youtu.be/j1NAhQ6E5S8>

Turn blue bar 180 deg. to change position of violet slider.  
The slider is kept firmly at one of its two positions thanks to the gravity.

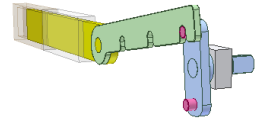


### Rack pinwheel drive 3

<https://youtu.be/NzX2CDXUJtY>

Turn blue pin arm 360 deg. to move yellow latch for locking or unlocking.

Unlike conventional pin gear rack mechanisms this one does not allow the latch move if driving force is applied to the latch at its locking or unlocking positions.



### Output positions subject to input motion direction 1

[https://youtu.be/5xZKDIhF\\_os](https://youtu.be/5xZKDIhF_os)

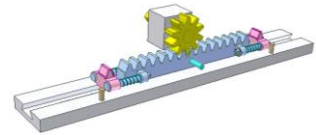
Unlike centrifugal governor, where output position depends on input velocity, in this mechanism output position depends on input rotary direction.

When yellow pinion rotates clockwise, blue rack gets its left end position, stay there till the pinion changes its rotary direction and vice versa.

Pink movable teeth maintain rack - pinion engagement when the rotary direction is changed.

Two brown stoppers in accordance with the rack length set the rack end positions.

The mechanism can be used for automatic position control when input is motion direction.



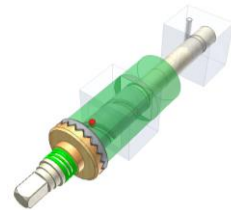
### Output positions subject to input motion direction 3

<https://youtu.be/Zhz2hkQtg6U>

Unlike centrifugal governor, where output position depends on input velocity, in this mechanism output position depends on input rotary direction.

When brown long shaft rotates counterclockwise, green nut gets its left end position, stays there till the shaft changes its rotary direction and vice versa.

Orange clutch has prismatic joint with the shaft and acts as a safety one.



### Output positions subject to input motion direction 4

<https://youtu.be/J9kGUj8Nmzw>

Unlike centrifugal governor, where output position depends on input velocity, in this mechanism output position depends on input rotary direction.

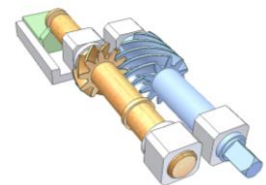
When blue shaft rotates clockwise, green slider gets its forward position, stays there till the shaft changes its rotary direction and vice versa.

Axial force of the helical gear drive moves the slider.

Applications:

<http://youtu.be/x2JieVQlek0>

<http://youtu.be/h6upHEjsp74>

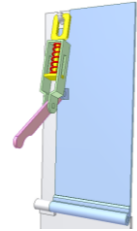


### 14.3. Locking mechanisms

#### Lock for flipping window

<https://youtu.be/CiXxF8VmGVc>

Blue flipping window is locked at its closed position thanks to a lock mechanism consisting of pink lever, yellow slider and green conrod.



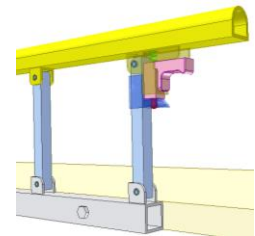
#### Lock for a parallelogram mechanism

<https://youtu.be/aoCaDkl65Rw>

Bed fence.

The red pin keeps the fence steadily at its raising position.

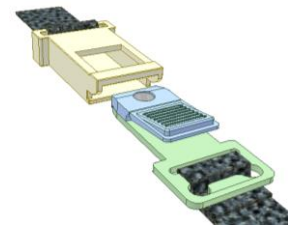
Put on pink trigger to pull its pin out of the hole on the blue glass part and lower the fence.



#### Strap lock 1

<https://youtu.be/cdTN4M4DRBY>

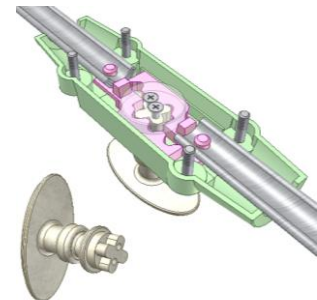
At lock position the blue elastic latch prevents the green part from moving out. The unlock is possible only after pressing down (red arrow) the latch and pull the green part out.



#### Cremone 1

<https://youtu.be/JFvGOIMJmJU>

Ellipse knob is linked by a rack and pinion gear to a pair of half-round rods which slide over the outside surface of the door or window and extend into sockets at the head and sill of the opening. The gear mechanism operates the two vertical rods at the same time; one rod extends up into the door head, and the other extends down into the door sill.

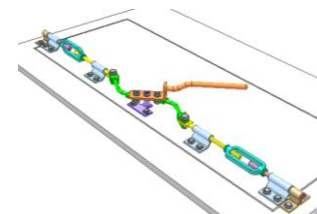


#### Heavy duty cremone

<https://youtu.be/C-3IAeJiwv4>

It uses a double slider-crank mechanism to move pink rods for locking the door.

Cyan nuts of left-right hand threads is for adjusting positions of the pink rods.

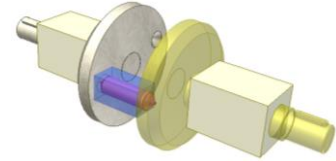


### Interlocking shafts 1

<http://youtu.be/5yr9OeGqnYo>

The pink pin moving in a fixed hole allows only one shaft to turn at a time. The other shaft is locked due to the engagement of its hole with the pink pin. The mechanism is used in case the concurrent motions can cause damage.

Disadvantage: need to bring the mechanism to initial position for changing the moving shaft.

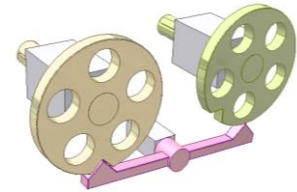


### Interlocking shafts 2

[http://youtu.be/U2Dpf91\\_Dlc](http://youtu.be/U2Dpf91_Dlc)

The pink lever allows only one shaft to turn at a time. The other shaft is locked due to the engagement of its groove with the pink lever. The mechanism is used in case the concurrent motions can cause damage.

Disadvantage: need to bring the mechanism to initial position for changing the moving shaft.



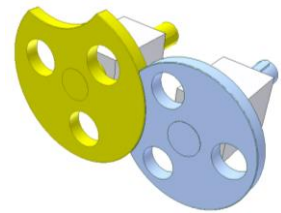
### Interlocking shafts 3

<http://youtu.be/oDN9V8v1cKM>

Only one disk can rotate at a time. The second disk is locked due to the engagement of its concave arc with peripheral surface of the first disk. Radius of the concave arc of one disk is equal to outer radius of the other disk.

The mechanism is used in case the concurrent motions can cause damage.

Disadvantage: need to bring the mechanism to initial position for changing the moving shaft.

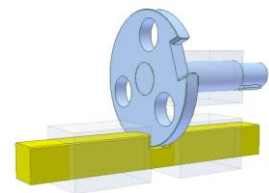


### Interlocking shafts 4

<http://youtu.be/uE8Yk5-Y0y4>

Only one part can move at a time. The second part is locked due to the engagement of its concave portion with outer surface of the first part. The mechanism is used in case the concurrent motions can cause damage.

Disadvantage: need to bring the mechanism to initial position for changing the moving shaft.

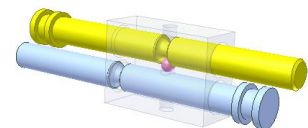


### Interlocking shafts 5

<http://youtu.be/TKpcZcEhji0>

Only one shaft can move at a time. The second shaft is locked due to the engagement of its circular groove with the pink ball. The mechanism is used in case the concurrent motions can cause damage.

Disadvantage: need to bring the mechanism to initial position for changing the moving shaft.



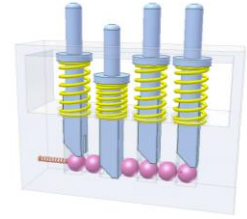


### Interlocking shafts 6a

<http://youtu.be/YtbEjL9oQjE>

Only one shaft can go down full stroke at a time. The other shafts are locked by pink balls.

The mechanism is used in case the concurrent motions can cause damage.

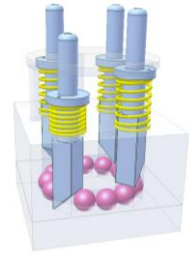


### Interlocking shafts 6b

<http://youtu.be/Qm-l7bLRgJg>

Only one shaft can go down full stroke at a time. The other shafts are locked by pink balls.

The mechanism is used in case the concurrent motions can cause damage.



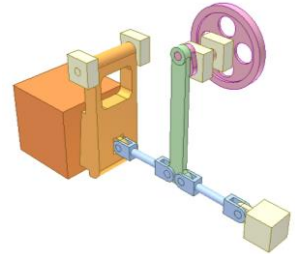
## 15. Toggle linkages

### Toggle linkage 1a

<http://youtu.be/1MmgKShth7w>

Mechanism for a stone crusher.

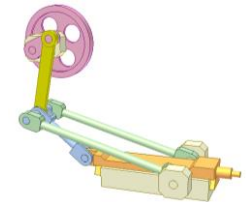
It has two toggle linkages in series to obtain a high mechanical advantage. When green link reaches the top of its stroke, it comes into toggle with the pink crank. At the same time two blue links come into toggle. This multiplication results in a very large crushing force of the orange jaw.



### Toggle linkage 1b

<http://youtu.be/FOe7o0duel4>

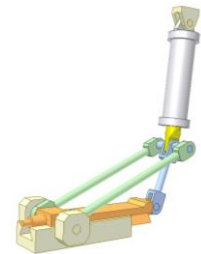
Two toggle links (the green and blue ones) can come into toggle by lining up on top of each other rather than as an extension of each other.



### Toggle linkage 1c

<http://youtu.be/MpuejSIBvjM>

A riveting machine with a reciprocating piston produces a high mechanical advantage. With a constant piston driving force, the force of the orange head increases to a maximum value when green and blue links come into toggle.



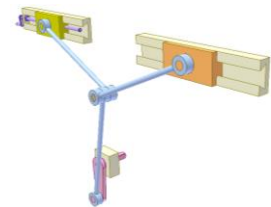
### Toggle linkage 2

<http://youtu.be/dzcvYAQQSL4>

In one revolution of the pink input crank, the orange output slider performs two strokes, one long and one short. At the rightmost point of each stroke, the links are in toggle to get high mechanical advantage and low speed.

The violet screw and the yellow slider are for adjusting stroke position.

The mechanism is applied for cold-heading rivet machines where two consequent blows of hammer (the orange slider) are needed in one revolution of crankshaft.



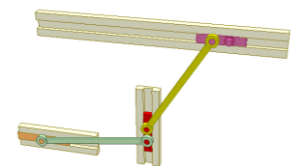
### Toggle linkage 3

<http://youtu.be/U2-SPNLPMeE>

Input: pink slider.

Output: orange slider.

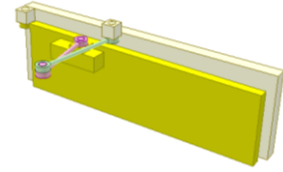
One double stroke of the pink slider corresponds two double strokes of the orange slider, that has long dwell at the left end of its stroke, when the yellow and green conrods come into toggle with the red and orange sliders.



### Toggle linkage 4a

<http://youtu.be/dmbLL-MSkyE>

Door check linkage gives a high velocity ratio during the stroke. As the door swings closed, connecting link (in green) comes into toggle with the shock absorber arm (in pink), giving it a large angular velocity, which helps the shock absorber be more effective in retarding motion near the closed position.

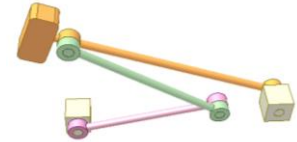


### Toggle linkage 4b

<http://youtu.be/TAPhhX3ti8s>

Pink crank rotates at constant velocity while orange crank moves slowly at the beginning and end of the stroke. It moves rapidly at the midstroke when the orange crank and the green conrod are in toggle. The accelerated weight on the orange crank absorbs energy and returns it to the system when it slows down.

This mechanism is used as an impact reducer in some large circuit breaker.



## 16. Mechanisms for snap motions

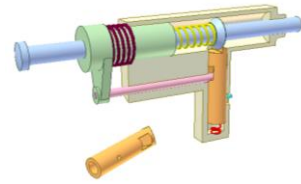
### Snap motion 16

<http://youtu.be/BwABcO1k2I0>

When green part is pushed, pink wedge forces orange slider down and blue rod is shot to the right under action of yellow spring.

Pull back the blue rod for next shot.

Arrows show applied forces.



### Spring toggle mechanism 1

<http://youtu.be/u4oW1ZiiRGA>

Spring toggle mechanism enables to reach end positions of a lever quickly and holds it there firmly.

In this prototype a compression spring is used to bear tension.

The violet sector represents manual action.



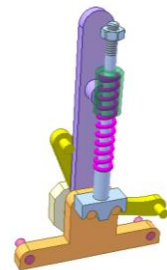
### Spring toggle mechanism 2

<http://youtu.be/T4EoESBFYLw>

Toggle action here ensures that the gear shift lever (violet) will not inadvertently be thrown past its neutral position.

The pink pins are stoppers for the violet lever.

The yellow double crank represents manual action.

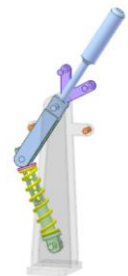


### Spring toggle mechanism 3

[http://youtu.be/l-G\\_uejx0Rs](http://youtu.be/l-G_uejx0Rs)

Spring toggle mechanism enables to reach end positions of a lever quickly and holds it there firmly.

The violet double crank represents manual action.

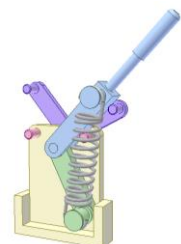


### Spring toggle mechanism 4

<http://youtu.be/KaRBadgcUIU>

Spring toggle mechanism enables to reach end positions of a lever quickly and holds it there firmly.

The violet double crank represents manual action.



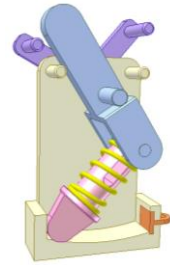
### Spring toggle mechanism 5

<http://youtu.be/vYSJn0U0kXI>

Spring toggle mechanism enables to reach end positions of a lever quickly and holds it there firmly.

The violet double crank represents manual action.

The mechanism is used for electric switches.

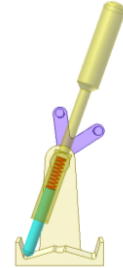


### Cam-guided latch

[http://youtu.be/53\\_QBnREziY](http://youtu.be/53_QBnREziY)

Cam-guided latch has one cocked and two relaxed positions.

The violet double crank represents manual action.



### Spring toggle mechanism 8

<http://youtu.be/ymgxwQHVQUw>

Spring toggle mechanism enables to reach end positions of a lever quickly and holds it there firmly.

The pink double crank represents action from outside.

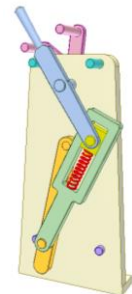


### Spring toggle mechanism 9

<http://youtu.be/TEH9aKqVhOE>

Spring toggle mechanism enables to reach end positions of a lever quickly and holds it there firmly.

The pink double crank represents action from outside.

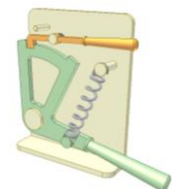


### Snap motion 1

<http://youtu.be/7y-Oez0v2l8>

A orange latch and green cocking lever is spring-loaded so latch movement releases the cocking lever. The cocked position is held firmly. Studs in the frame provide stops, pivots or mounts for the springs.

A coil spring always forces the orange latch to rotate anticlockwise.



### Snap motion 2

<http://youtu.be/tR1LWzVCjk0>

A latch mounted on a cocking lever (blue) allows both levers to be reached at the same time with one hand.

Rotate the latch clockwise to release the cocking lever.

Rotate the cocking lever anticlockwise to get the initial position.

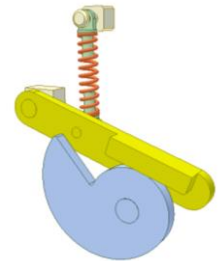
A coil spring always forces the pink latch to rotate anticlockwise.



### Snap motion 6

[http://youtu.be/k1BAA75eR\\_0](http://youtu.be/k1BAA75eR_0)

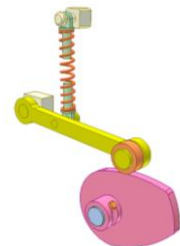
A latching cam cocks and releases the cocking lever with the same counterclockwise movement.



### Snap motion 6B

<http://youtu.be/ieKxnC6DffQ>

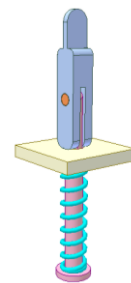
The cam hub has a semi-circular slot in which a pin of the blue driving shaft moves. Snap motion occurs when the moment from the follower spring applied to the cam changes its direction.



### Snap motion 8

[http://youtu.be/FYyIZXn\\_8-M](http://youtu.be/FYyIZXn_8-M)

Push or pull the blue lever to get snap motion. Raise it to get the initial position.



### Snap motion 10

<http://youtu.be/NMuZwvDJ27A>

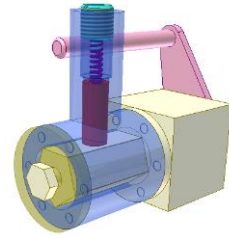
An identically shaped cocking lever and latch allow their functions to be interchangeable. The radii of the sliding faces must be dimensioned for a mating fit. Forces are alternatively placed on both levers.



### Spring toggle mechanism 6a

<https://www.youtube.com/watch?v=YydcGLWbuZg>

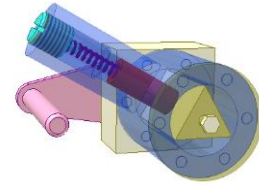
Indexing device. This spring toggle mechanism enables to reach five positions of a lever quickly and holds it there. The pink pin represents action from outside.



### Spring toggle mechanism 6b

<http://youtu.be/VftCJ6mScNQ>

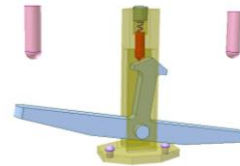
Indexing device. This spring toggle mechanism enables to reach three positions of a lever quickly and holds it there. The pink pin represents action from outside.



### Spring toggle mechanism 7

<http://youtu.be/kjRbsF9gkyl>

Spring toggle mechanism enables to reach end positions of a lever quickly and holds it there firmly. The pink pins represent action from outside.

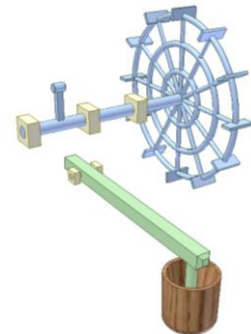


### Snap motion 12

<http://youtu.be/tipTlkBLhdk>

Pestle powered by water flow.

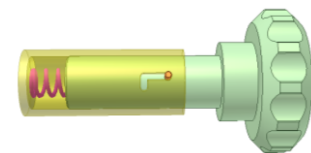
Water flow turns the wheel carrying a toe that raises and suddenly releases the pestle.



### Snap motion 3

<http://youtu.be/7APpliiLzi>

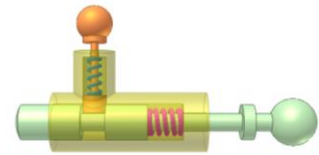
A yellow sleeve latch has an L-shaped notch. A pin in the green shaft rides in the notch. Cocking requires a simple push and twist.



### Snap motion 4

<http://youtu.be/igdo6b4tg9s>

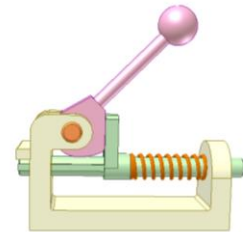
The latch and plunger depend on axial movement for setting and release. A circular groove is needed if the plunger is to rotate.



### Snap motion 5

<http://youtu.be/p4kDKY3UNFI>

In this overcenter lock clockwise movement of the pink latching lever cocks and locks the green slide. A counterclockwise movement is required to release the slide.

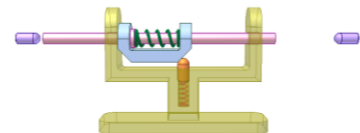


### Snap motion 7A

<http://youtu.be/J8r2zXYFT84>

A blue spring-loaded cocking piece has chamfered corners. Axial movement of the pink push-rod forces the cocking piece against a spring-loaded pin set in frame. When cocking builds up enough force to overcome the pin spring, the cocking piece snaps over to the right.

Move the pink push-rod or the blue cocking piece to the left to get initial position. The violet pins represent manual action.

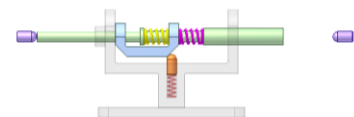


### Snap motion 7B

<http://youtu.be/RYcTAr8j2P0>

A blue spring-loaded cocking piece has chamfered corners. Axial movement of the green push-rod forces the cocking piece against a spring-loaded pin set in frame. When cocking builds up enough force to overcome the pin spring, the cocking piece snaps over to the right.

The action can be repeated in either direction. The violet pins represent manual action.

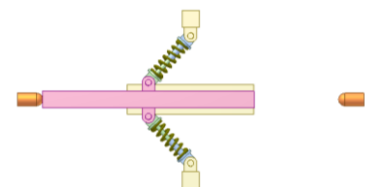


### Snap motion 9

<http://youtu.be/3ggXrotERfo>

Push the pink slider to get snap motion. The action can be repeated in either direction.

The orange pins also play role of stoppers.



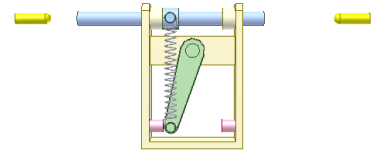


### Spring toggle mechanism 10

<http://youtu.be/HtLDYQnP1QQ>

Spring toggle mechanism enables to reach end positions of a lever quickly and holds it there firmly. However the green lever is not forced against the pink button strongly.

The yellow pins represent action from outside.



### Cable drive for snap switching 1

<http://youtu.be/39GDCZB-vFU>

Pull and release brown tow for snap switching green arm.

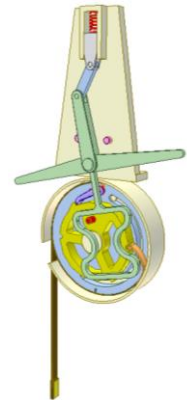
It is a combination of two mechanisms shown in:

<http://youtu.be/VzBulhvWsJY>

and

<http://youtu.be/yngxwQHVQUw>

For reducing pulling stroke length, use three red pins arranged in a symmetric circular pattern then the yellow ratchet disk needs turn only 60 deg.



### Barrel cam for snap switching 1

<http://youtu.be/rKSc1A8HE3Q>

Pull and release green slider for snap switching orange arm.

It is a combination of two mechanisms shown in:

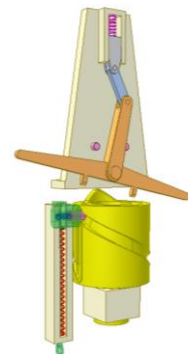
<http://youtu.be/SzoF0VMtc7w>

and

<http://youtu.be/yngxwQHVQUw>

For reducing pulling stroke length, use three face protrusions (instead of one) arranged in a symmetric circular pattern then the yellow cam needs turn only 60 deg. The barrel cam looks like the one in:

<http://youtu.be/nMEpbyMCMdw>



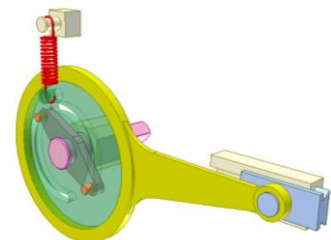
### Slider-crank mechanism of snap motion

<https://youtu.be/4AggSMxEduc>

Input: pink crank.

Green disk is idly mounted on the pink crank.

The interaction between two orange pins fixed to the crank and two slots of the disk under pulling force of red spring causes the snap action.

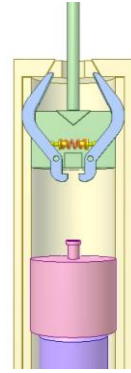


### Snap motion 11

<http://youtu.be/bt58Gw82938>

Releasing-hook, used in pile-driving machines.

When the pink weight is sufficiently raised, the upper ends of the blue hooks, by which it is suspended, are pressed inward by the sides of the slot in the top of the frame. The weight is thus suddenly released and falls with accumulating force on to the pile-head.

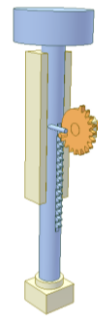


### Snap motion 14

<http://www.youtube.com/watch?v=yg1xDM0GDYM>

The blue plunger carrying a rack suddenly falls when the orange toothed sector leaves the rack.

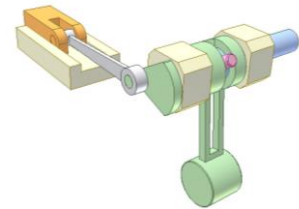
Small pins on the plunger and on the toothed sector are for maintaining a proper engagement of the rack-pinion drive.



### Snap motion 13

[http://youtu.be/p2pdrXalc\\_Y](http://youtu.be/p2pdrXalc_Y)

The hub of a rotary weight has semi-circular slot in which a pin of the blue driving shaft moves. Snap motion occurs due to the falling of the weight.



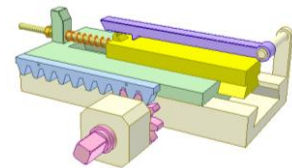
### Snap motion 15

<http://youtu.be/uMwHehjRyVo>

The pink input gear has reciprocating rotary motion.

The green slider has reciprocating linear motion.

The yellow slider linearly reciprocates with dwell and snap motion.

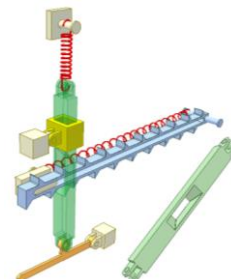


### Interrupted linear motion 1

<http://youtu.be/oDIOWSwk1JQ>

Blue ratchet bar tends to move to the left under the action of red horizontal spring.

Push down and release orange lever to let the blue bar move one tooth pitch.



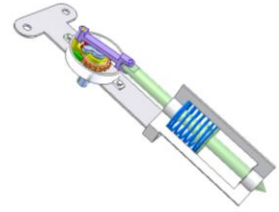
### Slider-crank mechanism of snap motion 1a

<https://youtu.be/W-y-me926B8>

Unlike an ordinary slider-crank mechanism in this stuff speed of green slider is very high at the lower end of its stroke thanks to blue spring.

Yellow crank rotates idly on the input crank (in blue). It rotates together with the input only when the blue crank contacts red pin fixed on the yellow crank. The inertia moves the green slider upward.

The ratchet drive of stationary ratchet wheel is for preventing reverse rotation of the yellow crank. The white rim limits outward rotation (due to centrifugal force) of the green pawl. The green slider has dwell at its upper position.



### Slider-crank mechanism of snap motion 1b

<https://youtu.be/itlBF0dcTsY>

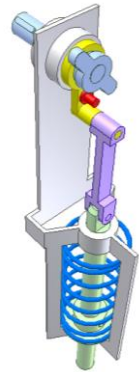
Unlike an ordinary slider-crank mechanism in this stuff speed of green slider is very high at the lower end of its down stroke thanks to blue spring.

Input: blue double crank of continuous rotation

Yellow crank rotates idly on the input crank. It rotates together with the input only when one blue crank contacts red pin fixed on the yellow crank.

The other blue crank prevents the yellow crank from inertial moving upward.

The green slider has dwell at its lowest position.

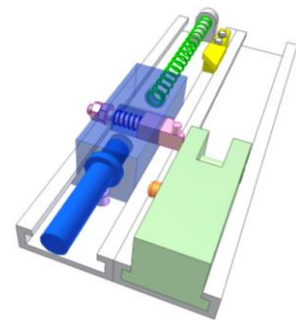


### Linear snap motion 1

<https://youtu.be/2sYakzNk7dM>

Input: green slider linearly reciprocating.

Output: blue slider linearly reciprocating with snap motion and dwell at one end of its stroke.



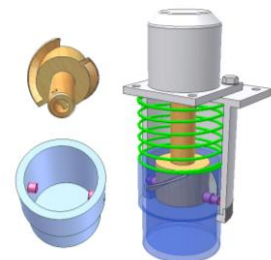
### Barrel cam mechanism of snap motion

<https://youtu.be/v9Rg59cUB8k>

Input: orange shaft of barrel cam rotating continuously.

Blue slider moves up thanks to the cam and moves down very fast under action of green spring.

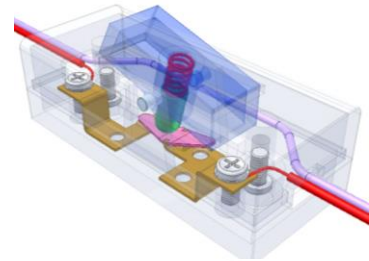
The blue slider has a short dwell at its lowest position.



### Rocker switch 1

<https://youtu.be/q0s3z9t9yK8>

Green spring pin helps pink plate swing suddenly to connect or interrupt the electric current between two contacts (in brass color).

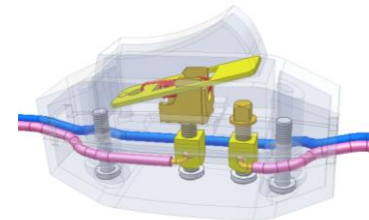


### Rocker switch 2

[https://youtu.be/PsDjcU\\_cmVg](https://youtu.be/PsDjcU_cmVg)

Red spring helps yellow plate swing quickly to connect or interrupt the electric current between two contacts (in brass color).

The original feature of this switch: number of moving links is minimum with snap action.



### On-Off switch 1

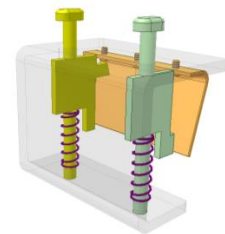
<http://youtu.be/LhaU0whb8lo>

Push green button to get ON.

Push yellow button to get OFF.

The orange part is a flat spring.

The green button is connected to electrical contacts (not shown).



### Switch mechanism for speed selection 1

[http://youtu.be/UwcpsEW\\_PqA](http://youtu.be/UwcpsEW_PqA)

The mechanism is used for speed control of desk fans

Push first green button to get speed 1.

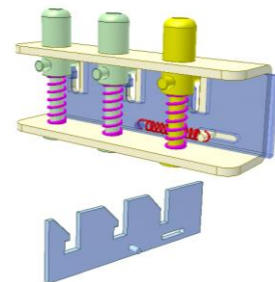
Push second green button to release the first one and get speed 2.

Push yellow button to release the green button in down position and get OFF.

Half way pushing of the green buttons (in up position) has the same effect as pushing the yellow button.

The green buttons are connected to electrical contacts (not shown).

Add further green buttons for more speeds.



## 17. Mechanisms for creating vibration

### Gravity and spring pendulums

<http://youtu.be/NycJBVNkmGI>

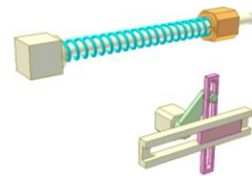
Two pendulums perform harmonic angular oscillations. The right pendulum oscillates thanks to the gravity. The left pendulum oscillates thanks to green disk and flat spiral spring. One end of the spring is fixed to the green disk hub, the other end to base.



### Harmonic motions

<http://youtu.be/FRpUAQICblc>

Orange slider oscillates thanks to cyan spring. Pink slider oscillates thanks to a sine mechanism. Both perform harmonic linear oscillations.



### Spring vibration 2

<http://youtu.be/bgzpOHozRPM>

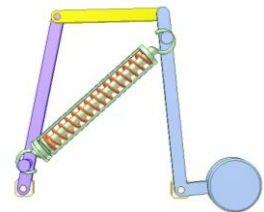
The mechanism is used for anti-vibration suspensions.



### Spring vibration 3

<http://youtu.be/Q7eHZX1iaSQ>

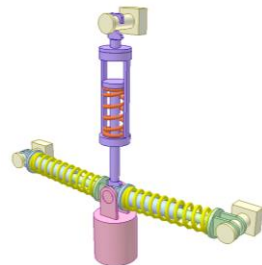
A four bar mechanism in conjunction with a spring has a wide variety of load or deflection characteristics.



### Spring vibration isolation 1

<http://youtu.be/Kwm7c6kgQ70>

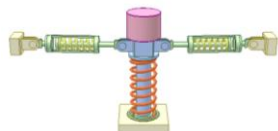
This basic spring arrangement has zero stiffness. The mechanism is used for vibration isolation. The pink part represents the weight to be vibration isolated.



### Spring vibration isolation 2

<http://youtu.be/OpEjNNHcaEI>

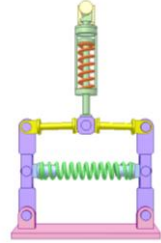
This basic spring arrangement has zero stiffness when the tension springs are in line. The pink part represents the weight to be vibration isolated.



### Spring vibration isolation 3

<http://www.youtube.com/watch?v=vlltfnIVBEc>

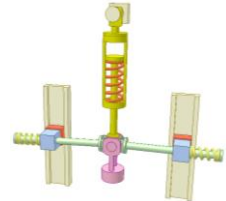
This spring arrangement has zero stiffness when the yellow bars are in line. The pink part represents the weight to be vibration isolated.



### Spring vibration isolation 4

[http://www.youtube.com/watch?v=OECw5X\\_geVE](http://www.youtube.com/watch?v=OECw5X_geVE)

This spring arrangement has zero stiffness when the yellow compression springs are in line. The pink part represents the weight to be vibration isolated.



### Spring vibration isolation 5

<http://www.youtube.com/watch?v=0OB55DXQ5lw>

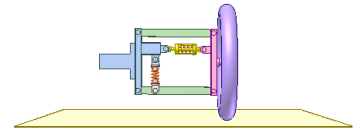
This spring arrangement has zero stiffness (torsion vibration) when the compression springs are in line. The pink part represents the weight to be vibration isolated.



### Wheel spring suspension

[http://www.youtube.com/watch?v=9A9ln\\_SbBfk](http://www.youtube.com/watch?v=9A9ln_SbBfk)

Coil spring suspension of automobiles can be reduced in stiffness by adding an horizontal spring.



### Seat spring suspension

<http://youtu.be/sSJ-qizbep8>

Tractor seat stiffness and transmitted shocks can be reduced with this spring arrangement.



### Eccentric vibrator 1A1

[http://youtu.be/qPrDI5NYk\\_l](http://youtu.be/qPrDI5NYk_l)

Vibrating conveyor.

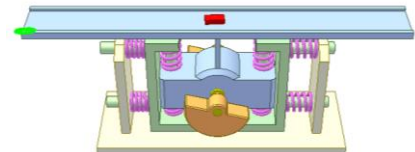
The blue part vibrates in two directions (vertical and horizontal) under centrifugal forces caused by the orange eccentrics and move the material (red).

Angle A between the two eccentrics affects vibration characteristics.

A = 0 deg. for this case.

The green line is locus of a point on the blue part (nearly a proper ellipse)

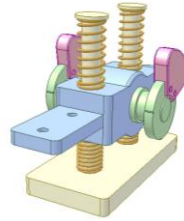
No vibration if A = 180 deg.



### Eccentric vibrator 1A2

<http://youtu.be/7wWUhWTBlw0>

The blue part vibrates in vertical direction under centrifugal forces caused by the pink eccentrics. The mechanism is used in vibration hammers and rammers.



### Eccentric vibrator 2A1

<http://youtu.be/7zFYThhjm3s>

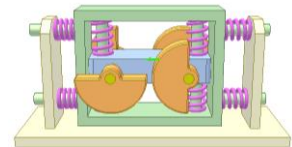
The blue part vibrates under centrifugal forces created by two shafts carrying eccentrics. Vibration characteristics depend on

- rotation direction and velocity of the shafts,
- angle A between the eccentrics on each shaft
- angle B between the eccentrics between the shafts (set before moving).

It is possible to set up the mechanism for vibration only in horizontal (or vertical) direction or in both directions.

For this case there is only horizontal vibration when

- The shafts rotate in opposite directions
- A = 90 deg.
- B = 90 deg.



### Eccentric vibrator 2A2

<http://youtu.be/dHIVU5Uprzw>

Vibrating conveyor.

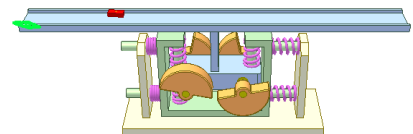
The blue part vibrates under centrifugal forces created by two shafts carrying eccentrics. Vibration characteristics depend on

- rotation direction and velocity of the shafts,
- angle A between the eccentrics on each shaft
- angle B between the eccentrics between the shafts (set before moving).

For this case there are vibrations in both directions when

- The shafts rotate in opposite directions
- A = 90 deg.
- B = 180 deg.

The green line is locus of a point on the blue part (nearly a slant line).



### Eccentric vibrator 3A

<http://youtu.be/6ucruMiqzbY>

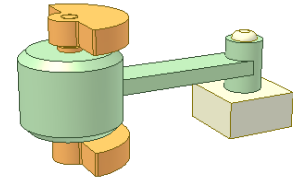
The blue part vibrates in vertical plane under centrifugal forces caused by the eccentrics and the gravity force.



### Eccentric vibrator 3B

<http://youtu.be/uZVF7w9jwLk>

The green part rotates in horizontal plane under centrifugal forces caused by the eccentrics. The initial position of the eccentrics also affects the rotation characteristics.



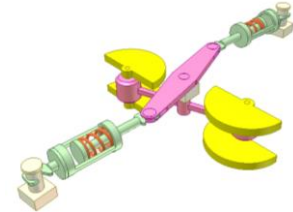
### Eccentric vibrator 3C

<http://youtu.be/8r3M03JvvEq>

Vibrator for torsion vibration.

The pink crank oscillates under centrifugal forces caused by the yellow eccentrics that rotate in the same direction.

The oscillation will not occur if one eccentric shaft turns 180 deg. in relation with the other or the two shafts rotate in opposite directions.



### Eccentric vibrator 4A

<http://youtu.be/zj9yAVBzRWw>

The blue part has complicated motion under centrifugal forces caused by the eccentrics.

The green line is locus of a point on the blue part.

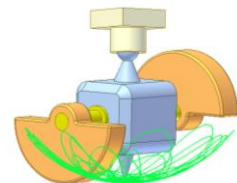


### Eccentric vibrator 4B

[http://youtu.be/Nksp0f3O\\_ul](http://youtu.be/Nksp0f3O_ul)

The blue part has complicated motion under centrifugal forces caused by the eccentrics.

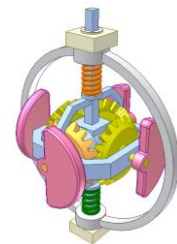
The green line is locus of a point on the blue part.



### Eccentric vibrator 6A1

<http://youtu.be/0GuQCGycMDA>

With this lay-out of the eccentrics the blue part vibrates around vertical axle and reciprocates along vertical axle under centrifugal forces caused by the eccentrics.



### Eccentric vibrator 6A2

[http://youtu.be/CkdOZcf7v\\_8](http://youtu.be/CkdOZcf7v_8)

With this lay-out of the eccentrics the blue part rotates around vertical axle and reciprocates along vertical axle under centrifugal forces caused by the eccentrics.

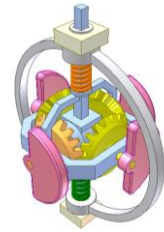




### Eccentric vibrator 6A3

<http://youtu.be/8p66DsDp554>

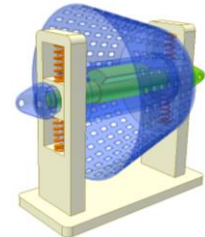
With this lay-out of the eccentrics the blue part only reciprocates along vertical axle (not rocks around it) under centrifugal forces caused by the eccentrics.



### Vibrating screen machine 1

<http://youtu.be/JGF-8mG0OG0>

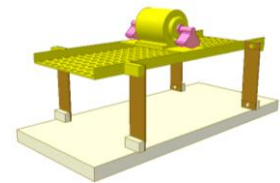
The green inner shaft carrying a long eccentric rotates in a screen of cone shape. The later rotates in bearings supported by springs. The inner shaft and the screen are driven through double cardan joints (not shown).



### Vibrating screen machine 2

<http://youtu.be/KdycXXdN3M0>

Oscilating screen is supported by flat springs. A motor carrying eccentrics is fixed to the screen.

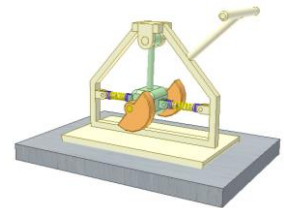


### Ramming machine 1

<http://youtu.be/bX8TEvxAlCo>

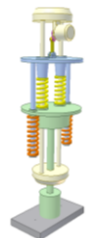
The machine frame vibrates in two directions: vertical and horizontal under centrifugal forces caused by the orange eccentrics. Angle A between the two eccentrics affects vibration characteristics.  $A = 0$  deg. for this case.

Only vertical vibration causes ramming effect. The horizontal one is born by the operator through the grips.



### Ramming machine 2

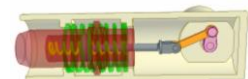
<http://youtu.be/M3foSpmDyEM>



### Hand-held spring hammer

<http://youtu.be/2dg-x5POoAI>

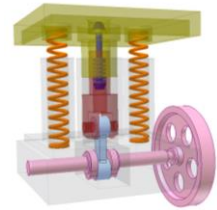
The red slider is born by two green springs, no contact between the slider and the hammer's house. It reciprocates under actions of two green springs, two yellow ones and the slider crank mechanism.



### Sand mold vibrating machine

<http://youtu.be/lq5z7Zk1IPc>

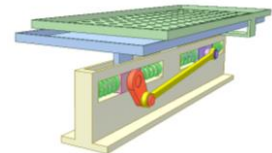
The yellow mold table reciprocates with vibration under actions of three springs and the slider crank mechanism.



### Vibrating screen machine 3

<http://youtu.be/EjE1yw8odMw>

The bearing and the slider of a linkage mechanism supported by springs can slide in a runway. The sieves are fixed to them. The red crank is driven through a double cardan joint (not shown)

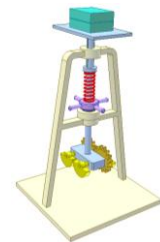


### Vibration table 1

<http://youtu.be/2uMzqueot7Q>

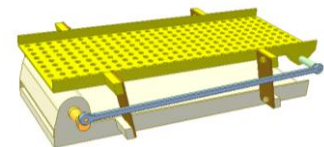
Blue table with a mould on it vibrates in vertical direction due to centrifugal forces caused by four yellow eccentrics.

The violet screw is for regulating table position that may change because of mould weight .



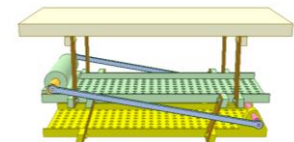
### Vibrating screen machine 4

<http://youtu.be/kfw1IToK4So>



### Vibrating screen machine 5

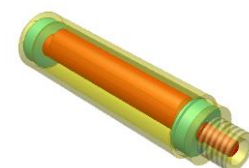
<http://youtu.be/zr99xgCvURM>



### Poker concrete vibrator

<http://youtu.be/9dTloL9WLI8>

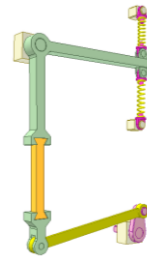
Vibration is created by the rotation of the orange shaft carrying an eccentric mass.



### Flex testing machine

<http://youtu.be/bSPbxa3fIR0>

The specimen (in orange) is tested under variable load.

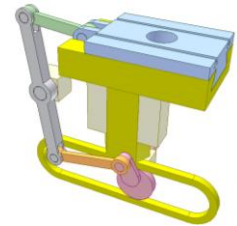


### Vibration table 2

<https://youtu.be/d34CJJQS-kc>

Input: pink shaft having an eccentric and a crank.

Output: blue table oscillating vertically and horizontally simultaneously.



### Vibration propulsor 1

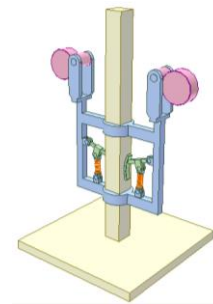
<https://youtu.be/LYhcXjH86cA>

Input: two pink eccentrics rotating in opposite directions. They generate centrifugal forces. Sum of horizontal members of centrifugal forces is null.

Sum of vertical portions of centrifugal forces may point up or down.

In down case green levers and orange compression springs prevent blue frame moving down. In up case they allow it moving up.

Release the green levers time after time for moving down which is a jerk process.

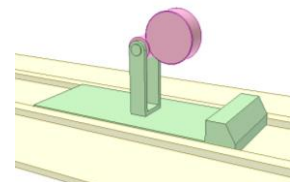


### Vibration propulsor 2

<https://youtu.be/UliytVlaZFQ>

Input: pink eccentric rotating regularly. Change its rotary direction to reverse motion of blue frame.

Green frame moves when centrifugal force caused by the pink eccentric points up.

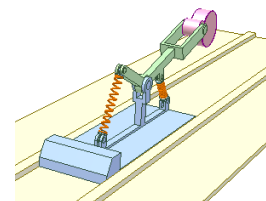


### Vibration propulsor 3

<https://youtu.be/0RJP5WO1ItI>

Input: pink eccentric rotating regularly. Change its rotary direction to reverse motion of blue frame.

Motion of blue frame depends on many factors: geometry of the propulsor, springs parameters, centrifugal force caused by the pink eccentric.



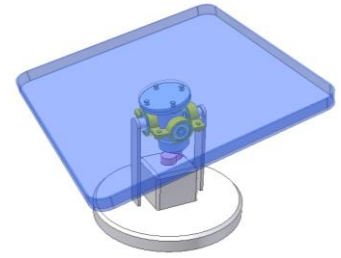
### 3D shaker 1

<https://youtu.be/v5x4P6dMXOj>

It's a laboratory equipment used to mix, blend, or agitate substances in a tube or flask by shaking them.

The blue board performs wobbling motion.

Rotary axes of all revolution joints must be concurrent.



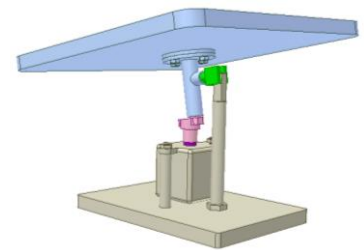
### 3D shaker 2

<https://youtu.be/KkmWr7acl9w>

It's a laboratory equipment used to mix, blend, or agitate substances in a tube or flask by shaking them.

The blue board performs wobbling motion.

Rotary axes of all revolution joints must be concurrent.



### 2D/3D shaker 1a

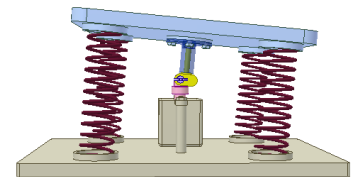
[https://youtu.be/EjwT7V\\_oIR0](https://youtu.be/EjwT7V_oIR0)

It's a laboratory equipment used to mix, blend, or agitate substances in a tube or flask by shaking them.

The blue board can perform 2D (in horizontal plane) or 3D shaking.

The video also shows how to shift from 2D mode (the yellow pin and the pink shaft are parallel to each other) to 3D one (not parallel).

A nut on the top of the yellow pin maintains the revolution joint between the yellow pin and the blue board and compresses the springs.



### Particle damping

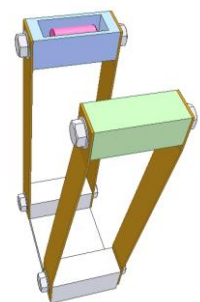
<https://youtu.be/kjyrDEqtdec>

Particle damping is the use of particles moving freely in a cavity to produce a damping effect. The video shows that object P (in pink) freely moving in a cavity of the vibrating object can stamp out vibration.

The video first scene shows vibration without the damping measure.

The video was made based on:

<https://youtu.be/kApmX-OqWNY>



## 18. Mechanisms for drawing lines

### 18.1. Straight lines

#### 18.1.1. Straight lines by mechanisms of all revolute joints

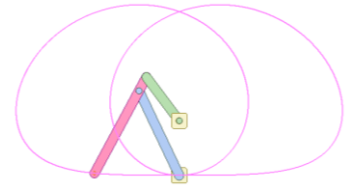
##### Four-bar linkage 1

<http://www.youtube.com/watch?v=afK8PpDYy4Y>

The connecting rod rotates fully.

A motion cycle of the linkage corresponds two revolutions of the connecting rod.

A part of the locus at the bottom is nearly straight.



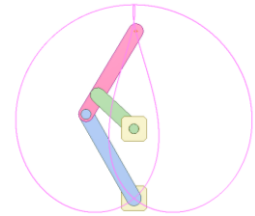
##### Four-bar linkage 2

<http://www.youtube.com/watch?v=SzwolVCGvu0>

The connecting rod rotates fully.

A motion cycle of the linkage corresponds two revolutions of the connecting rod.

A part of the locus at the top is nearly vertical straight.



##### Four-bar linkage 2B

<http://www.youtube.com/watch?v=nyALtYMTraG>

A part of the pink locus is a straight line.

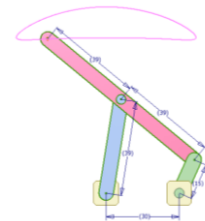
Note: following dimensions are better than the ones given in the video:

Length of green crank:  $a$

Length of blue bar :  $2.5a$

Length of pink bar:  $2.5a + 2.5a$

Distances between stationary bearings:  $2a$ .



##### Tchebicheff's four-bar linkage 3

<http://www.youtube.com/watch?v=IDDPW6NR5TE>

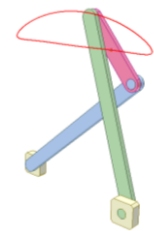
Length of the connecting rod:  $a$

Length of the two cranks:  $2.5a$

Distance between two fixed bearing houses:  $2a$

The connecting rod rotates fully.

A part of the locus of the middle point of the connecting rod is approximately straight.



##### Robert's four-bar linkage 4

<http://www.youtube.com/watch?v=q69bxfp3On4>

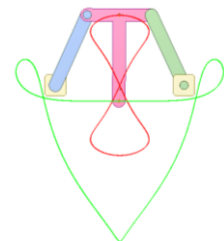
Length of the connecting rod:  $a$

Length of the two cranks: not less than  $1.2a$

Distance between two fixed bearing houses:  $2a$

Not any links have full rotation.

A part of the green locus of the lower point of the connecting rod is approximately straight.



### Grasshopper straight line mechanism

<https://youtu.be/4U8aREBFIDE>

This mechanism is a modification of the Scott-Russel mechanism showed at:

<https://youtu.be/rV2l9bclMk>

It is named so because of its resemblance to a grasshopper's hind leg.  
Input: pink bar turning +/-40 deg.

Point E of green bar traces a vertical nearly straight line (in blue).

$AB = BC = BE$

To get the blue line straighter increase DC while keeping the trajectory of point C (in green) as near as possible to the horizontal line.

Here

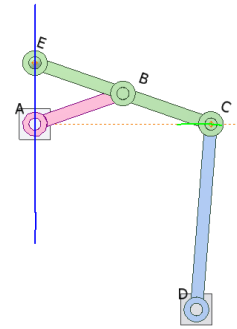
$AB = BC = BE = 30$

$DC = 60$

Distance AD in vertical direction: 59.8

Distance AD in horizontal direction: 52

The video last part shows full trajectory of point E.



### Robert's four-bar linkage 1

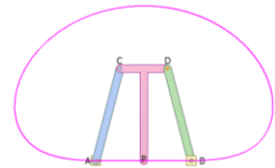
<https://youtu.be/0nS8aTPnUIM>

$AC = BD = AB = CP = DP$

$CD = AC/2$

Pink conrod can turn full revolution.

A part of pink line traced by point P of the conrod is approximately straight.



### Robert's four-bar linkage 2

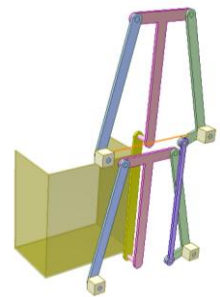
[https://youtu.be/RJkkIBTxU\\_Y](https://youtu.be/RJkkIBTxU_Y)

It is developed from the mechanism shown at:

<https://youtu.be/0nS8aTPnUIM>

Violet bar (creating a parallelogram mechanism with green cranks) ensures the synchronic rotation of two green cranks.

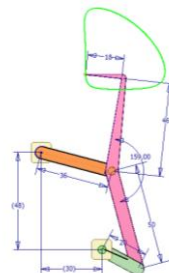
The yellow bar carrying a box translates near linearly.



### D-drive four-bar linkage 5

<http://www.youtube.com/watch?v=7FRRGbw381k>

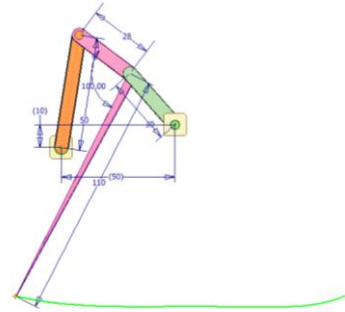
The green locus has two approximately straight parts perpendicular to each other.



### Four-bar linkage 6

<http://www.youtube.com/watch?v=f4N1R8MPZTI>

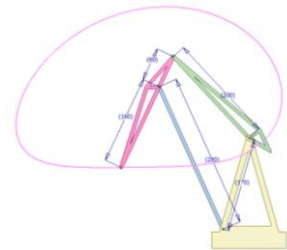
Four-bar linkage produces an approximately straight-line motion. A small displacement of the orange crank results in a long, almost-straight line. It is used for the stylus on self-registering instruments.



### Four-bar linkage crane

<http://www.youtube.com/watch?v=QGKnTEqHSS8>

The end point of the connecting rod draws a straight line. This is used for moving load in horizontal direction.



is

### Watt's Linkage drawing straight line

<http://www.youtube.com/watch?v=KpDpP0ZgKt8>

Length of the two cranks:  $d$

Length of the connecting rod:  $c$

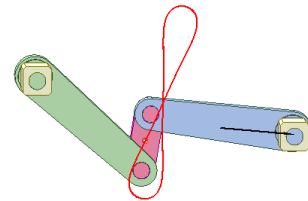
Horizontal distance between crank shafts:  $2d$

Vertical distance between crank shafts:  $c$

The middle point of the connecting rod traces a 8-shaped curve.

Length of the line segment:  $3c/2$

Not any links have full rotation.



### Straight line drawing mechanism 4a

<https://youtu.be/6ZVUsxgcfYk>

Yellow, green and pink links create a parallelogram mechanism.

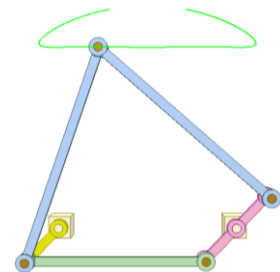
Length of yellow link:  $a$

Length of green link:  $4a$

Length of pink link:  $a + a$

Length of blue links:  $5a$

Center of revolute joint between two blue links traces green line, lower portion of which is approximately straight.



### Straight line drawing mechanism 4c

<https://youtu.be/fsxm2iCkvyg>

Yellow, green and pink links create a parallelogram mechanism.

Length of yellow link:  $a + a$

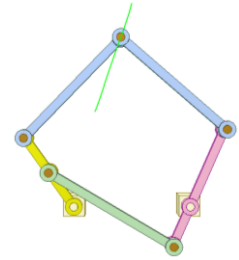
Length of pink link:  $a + 2a$

Length of green link:  $3,4a$

Length of blue links:  $3.25a$

Center distance of two fixed revolute joints:  $2.75a$

Center of revolute joint between two blue links traces a curve, a portion of which is approximately straight (in green).



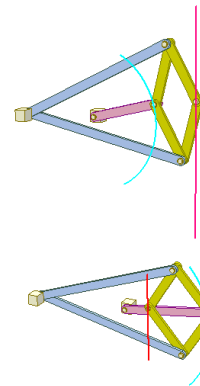
### Peaucellier linkage 1

<http://youtu.be/6fgrTZnO-ZM>

Bars of identical colour are of equal length.

In each mechanism axle distance between the two fixed revolution joints and the pink bar length are equal.

A vertex of the yellow rhombus traces an absolutely straight line (in red).



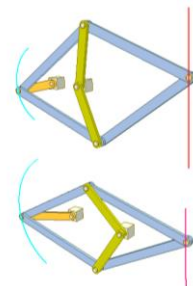
### Peaucellier linkage 2

<http://youtu.be/LhC9RVl2ln8>

Bars of identical colour are of equal length.

In each mechanism axle distance between the two fixed revolution joints and the orange bar length are equal.

An vertex of the blue rhombus traces an absolutely straight line (in red).



### Kite mechanism 1

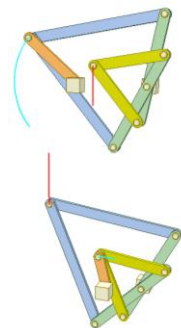
<http://youtu.be/lzaci8CRsNc>

A modification of Peaucellier linkage proposed in 1877 by A. B. Kempe, London.

Bars of identical colour are of equal length.

Axle distance between the two fixed revolution joints and the orange bar length are equal.

An vertex of the blue rhombus traces an absolutely straight line (in red).





### Kite mechanism 2a

<http://youtu.be/kiYIEd7Gj4>

A modification of Peaucellier linkage proposed in 1877 by A. B. Kempe, London.

Length of blue bar:  $a$

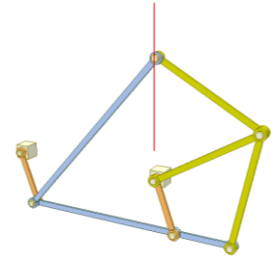
Length of blue bar of 3 joints:  $0.75a + 0.25a$

Length of yellow bars:  $0.5a$

Length of orange bars:  $0.25a$

Axle distance between the two fixed revolution joints  $0.75a$

An vertex of the big kite traces an absolutely straight line (in red).



### Kite mechanism 2b

<http://youtu.be/wuKQcDh4MFw>

A modification of Peaucellier linkage proposed in 1877 by A. B. Kempe, London.

Length of blue bar:  $a$

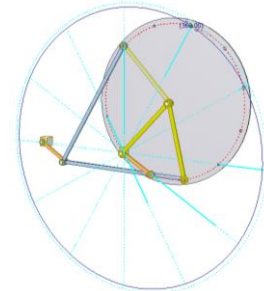
Length of blue bar of 3 joints:  $0.75a + 0.25a$

Length of yellow bars:  $0.5a$

Length of orange bars:  $0.25a$

Axle distance between the two fixed revolution joints  $0.75a$

The grey disk is fixed to the upper yellow bar. On this disk all points laid on small circle of diameter  $a$  (in pink) move along straight lines that are diameters of a big circle of  $2a$  diameter (in cyan). The small circle rolls without slide in the big one. They are of Cardano.



### Linkage to draw two perpendicular straight lines 1

[https://youtu.be/H8C3EVR\\_ezc](https://youtu.be/H8C3EVR_ezc)

Input: one of two yellow bars that turns on stationary bearings.

Violet bar draws two perpendicular straight lines (in blue and green).

The green intersects axes of three stationary bearings.

The blue is perpendicular to the green at its intersection with the axis of the middle bearing.

Length of yellow bars:  $a \cdot \sqrt{2}$

Length of blue bars:  $a$

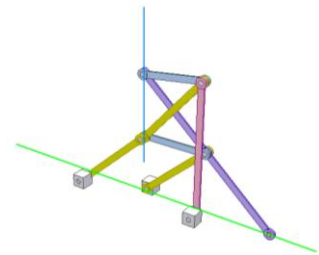
Length of pink bar:  $2a$

Length of violet bar:  $a \cdot \sqrt{2} + a \cdot \sqrt{2}$

Horizontal distances between three stationary bearings:  $a$

If the input turns 360 deg., the pink bar collides the left bearing similarly to case of video:

<https://youtu.be/1H9VWSwfgWM>



### Linkage to draw two perpendicular straight lines 2

<https://youtu.be/1H9VWSwfqWM>

Input: one of two yellow bars that turns on stationary bearings.

Violet bar draws two perpendicular straight lines (in blue and green).

The green intersects axes of three stationary bearings.

The blue is perpendicular to the green at its intersection with the axis of the middle bearing.

Length of yellow bars:  $a\sqrt{2}$

Length of blue bars:  $a$

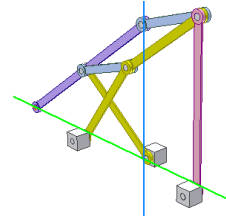
Length of pink bar:  $2a$

Length of violet bar:  $a\sqrt{2} + a\sqrt{2}$

Horizontal distances between three stationary bearings:  $a$

If the input turns 360 deg as shown in this video, the pink bar collides the left bearing. So the input can only turn less than 180 deg. similarly to case of video:

[https://youtu.be/H8C3EVR\\_ezc](https://youtu.be/H8C3EVR_ezc)



### Six-bar linkage for tracing straight line

<https://youtu.be/MNpdFbiuiSw>

Input: one of the bars pivoted on the base.

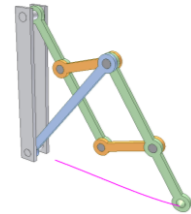
The point at the end of green bar traces a nearly straight line (in pink).

Length of the base bar:  $a$

Length of blue bar:  $a$

Length of green bars:  $0.4a + 0.6a$

Length of orange bars:  $0.4a$



### Four-bar linkage 2C

<https://youtu.be/gaMdZ7oV6M0>

It is developed from mechanism shown at

<http://www.youtube.com/watch?v=nyALtYMTTrAg>

Two such mechanisms are arranged separately in AC direction.

Two pink cranks and violet bar create a parallelogram mechanism.

Yellow plate nearly linearly translates and is always parallel to the ground.

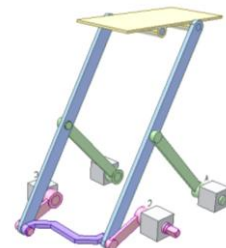
Length of pink cranks:  $a$

Length of green bars :  $2.5a$

Length of blue bars:  $2.5a + 2.5a$

Distances between stationary bearings AC:  $2a$ .

This arrangement can be applied for any tracing mechanism where the translation of a plate along the traced trajectory is needed.



\* For all revolute joint mechanisms having linearly translating link see pages 146 – 148.

## 18.1.2. Straight lines by other mechanisms

### Straight line drawing mechanism 1

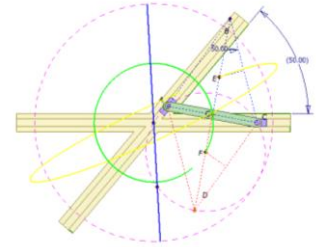
<http://www.youtube.com/watch?v=8WCee-fP9rg>

It is an ellipse mechanism.

Every point of the small magenta circle (circumcircle of isosceles triangle ACD) traces a straight line (in violet).

Circumcenter of triangle ACD traces a circle (in green).

The small magenta circle rolls inside the large fixed magenta one. They are Cardano circles.



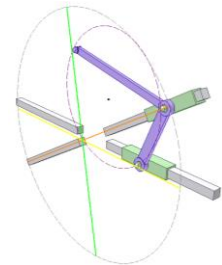
### Straight line drawing mechanism 1b

<https://youtu.be/aySMU4vkp-s>

It is an ellipse mechanism and gives us possibility to draw a line (in green) concurrent with two intersecting lines (in yellow and pink).

Every point of the small circle traces a straight line.

The small circle rolls inside the large fixed one. They are Cardano circles.



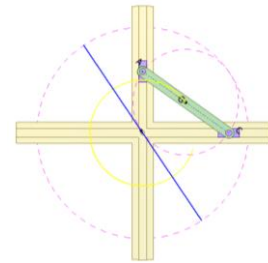
### Straight line drawing mechanism 2

<http://www.youtube.com/watch?v=zaJmNcmvGQQ>

It is an ellipse mechanism.

Every point of the small magenta circle (AC diameter) traces a straight line (in violet).

The small magenta circle rolls inside the large fixed magenta one. They are Cardano circles.



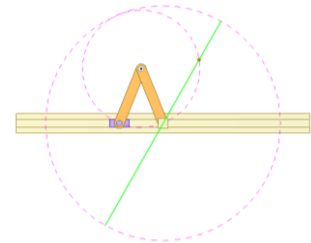
### Straight line drawing mechanism 3a

<http://www.youtube.com/watch?v=JmYyRuiMajw>

It is an isosceles slider-crank mechanism.

Every point of the small magenta circle (fixed with the conrod and its radius is equal to the conrod length) traces a straight line (in green).

The small magenta circle rolls inside the large fixed magenta circle. They are Cardano circles.



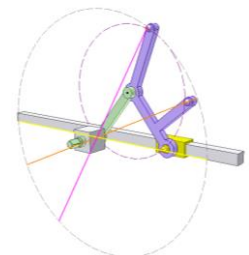
### Straight line drawing mechanism 3b

<https://youtu.be/AaGln6aEXtY>

It is an isosceles slider-crank mechanism.

Every point of the small circle (fixed with the violet conrod and its radius  $r$  is equal to the conrod length) traces a straight line.

The small circle rolls inside the large fixed circle of  $2r$  radius. They are Cardano circles.



### Straight line drawing mechanism 5

<https://youtu.be/UX4yDeBxzWM>

Pink, green and blue links create a slider-crank mechanism.

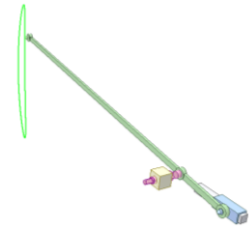
Length of pink link:  $a$

Length of green link:  $4a + 26a$

An end of the green link traces green line, right portion of which is approximately straight. It is an absolutely straight, if center of the middle revolute joint of the green link moves along an ellipse. Refer to:

Drawing Ellipse Mechanism 3

<http://www.youtube.com/watch?v=FoO2LIYLPEc>



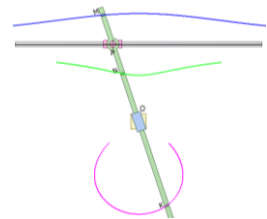
### Conchoids of a straight line

<https://youtu.be/iah7aKMdlu8>

Pink, green and blue links create a tangent mechanism.

Point P of the green link moves along a straight line.

Points M, N and L of the green link trace conchoids (in blue, green and pink) of the said straight line.



### Straight line drawing mechanism 6a

[https://youtu.be/VZSZTB\\_OLPs](https://youtu.be/VZSZTB_OLPs)

Pink, green and blue links create a coulisse mechanism.

Length of pink link:  $a$

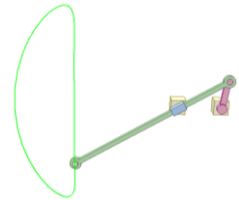
Length of green link:  $6a$

Center distance of two fixed revolute joints:  $1.5a$

An end of the green link traces green line, right portion of which is approximately straight.

It is an absolutely straight, if the other end of the green link moves along a conchoid of a straight line. See pink conchoid in video:

<https://youtu.be/iah7aKMdlu8>



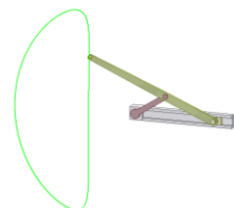
### Straight line drawing mechanism 7b

<https://youtu.be/eKfEyo7YUVA>

Input: pink crank of a radius.

Length of conrod:  $1.4a + 2.2a$

The conrod end traces closed curve, right portion of which is approximately straight. The portion corresponds  $\frac{1}{4}$  revolution of the crank.



### Straight line drawing mechanism 8

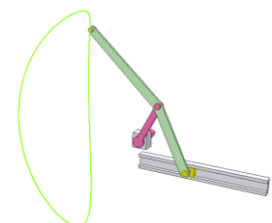
<https://youtu.be/Vbcbno26lZ0>

Input: pink crank of a radius.

Length of conrod:  $1.52a + 2.13a + 3.59a$

Eccentricity of the slider-crank mechanism:  $0.47a$

The conrod end traces closed curve, right portion of which is approximately straight.



### Straight line drawing mechanism 9

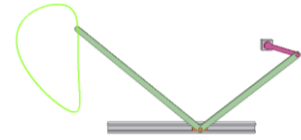
<https://youtu.be/Zwwnr262Wlc>

Input: pink crank of a radius.

Length of conrod:  $4a + 5.25a + 7.15a$

Eccentricity of the slider-crank mechanism:  $2.83a$

The conrod end traces closed curve, right portion of which is approximately straight.



### Straight line drawing mechanism 10

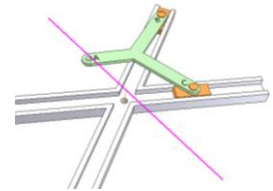
<https://youtu.be/bbP1x33L1U4>

When orange sliders move, point A of green bar traces a straight line.

Condition: ABC is an isosceles triangle ( $AB = AC$ ) and angle BAC = angle between the two runways.

For more see:

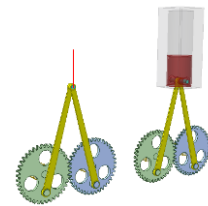
<http://www.youtube.com/watch?v=8WCee-fP9rg>



### Gear and linkage mechanism 1

<http://youtu.be/muF6Y7TUJz8>

A slider crank mechanism of two conrods and two cranks. The latters are fixed to two gears in mesh. Owing to the symmetric arrangement the piston axle moves rectilinearly (even if no cylinder (the left mechanism)). Lateral forces from piston applied to cylinder are negligible.



### Gear and linkage mechanism 2

<http://youtu.be/IDKUj8MV9Xc>

Center of the yellow and pink bars revolution joint moves along a approximately straight line.

Radius of the small gear:  $a$

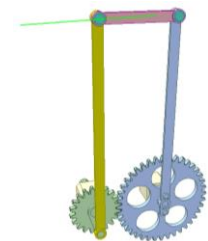
Length of the green crank:  $a$

Radius of the big gear:  $2a$

Length of the pink bar:  $3a$

Length of the blue bar:  $8a$

Length of the yellow bar:  $9a$



### Straight line drawing mechanism 4a

<http://youtu.be/HmnA6E82-Wk>

Input: green crank of length  $L1$ .

Blue pulley of radius  $R1$  is stationary.

Yellow pulley of radius  $R2$  is fixed to yellow bar of length  $L2$ .

$R1 = 2.R2$

$L1 = L2$

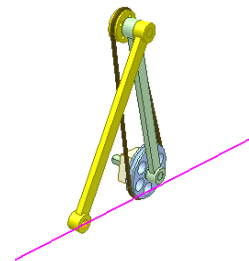
A point on revolution joint of the yellow bar traces a straight line. Its length is  $4.L1$ .

This mechanism has a relation with Cardano cycles.

If  $L1 \neq L2$ , condition to get the said straight line:  $R1/R2 = 1 + (L1/L2)$

The belt should be toothed.

It is possible to use chain drive instead of belt one.



### Pantograph for drawing straight lines 1a

<https://youtu.be/CMQ241yGFtQ>

Blue, orange, green and yellow bars create a pantograph.

Two red pins and blue one are in line.

The blue pin traces a straight line (in green).

Condition for tracing a straight line:

$$R1/R2 = AE/EF$$

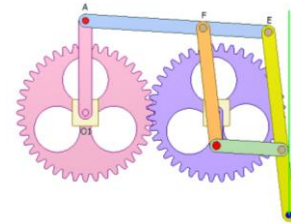
R1: radius of pink crank

R2: radius of violet crank

Its length  $L = 2R2 + 2(R1 + R2)(FE/AF)$

The direction of the line depends on angular position between pink and violet cranks at starting position of the mechanism.

For the starting position in this video, the line is vertical.



### Pantograph for drawing straight lines 1b

<https://youtu.be/ZbiExQK6Crg>

Blue, orange, green and yellow bars create a pantograph.

Two red pins and blue one are in line.

The blue pin traces a straight line (in green).

Condition for tracing a straight line:

$$R1/R2 = AE/EF$$

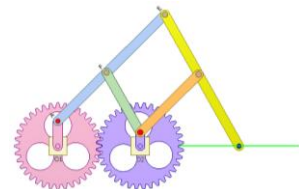
R1: radius of pink crank

R2: radius of violet crank

Its length  $L = 2R2 + 2(R1 + R2)(FE/AF)$

The direction of the line depends on angular position between pink and violet cranks at starting position of the mechanism.

For the starting position in this video, the line is horizontal, in line with O1O2.



### Straight line drawing mechanism 4b

<https://youtu.be/SG5mt-yHwG4>

Input: green crank.

Blue pulley is stationary. Four cranks are of the same length L.

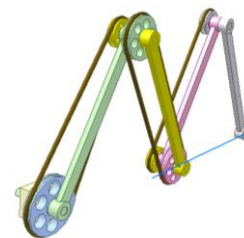
Belt drive on green crank has transmission ratio of 2.

Belt drives on yellow and pink cranks have transmission ratio of 1.

End point of grey bar traces a straight line. It can reach a distance  $D = 4L$  from the blue pulley center.

The belt should be toothed. Using chain drive is possible.

By connection of modules of two cranks and a 1/1 belt drive the distance D can be increased to 6L, 8L, ...



### Straight line drawing mechanism 5

<https://youtu.be/SG5mt-yHwG4>

Input: green slider.

Blue pulley is fixed to blue bar of  $L_b$  length.

Yellow pulley is fixed to yellow bar of  $L_y$  length.

Distances between revolution joints of pink bar is  $L_{p1} + L_{p2}$

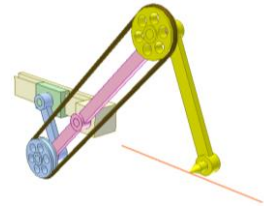
$L_b/L_y = L_{p1}/L_{p2}$

Belt drive on pink bar has transmission ratio of 1.

End point of yellow bar traces a straight line that intersects green slider pivot axis and fixed bearing axis.

It is necessary to set the blue bar parallel to yellow bar for getting the line straight.

The belt should be toothed. Using chain drive is possible.



### Straight line drawing mechanism 6

<https://youtu.be/PmJAGnE1hQI>

Input: blue crank.

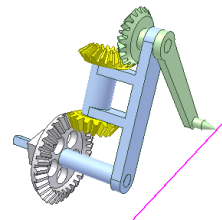
Grey gear is stationary.

Blue and green cranks are of the same length  $L$ .

Grey and yellow gear drive has transmission ratio of 2.

Green and yellow gear drive has transmission ratio of 1.

End point of green bar traces a straight line. Its length is  $4L$ .



### Straight line drawing mechanism 7a

<https://youtu.be/N1AI-C6FxGM>

Input: violet gear.

Green, blue, yellow and pink bars create a parallelogram mechanism.

Length of green bar:  $L_a$

Lengths of blue and yellow bars:  $L_b$

Length of pink bar:  $L_a + L_b$

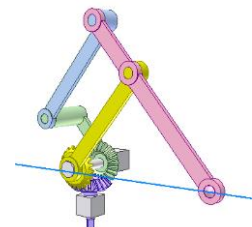
All gears have the same tooth number.

End point of pink bar traces a straight line.

Its length is less than  $4L_b$  (green crank can't make a full revolution).

This mechanism has the same working principle of the mechanism shown in

<http://youtu.be/Z5kFDYcoXS0>



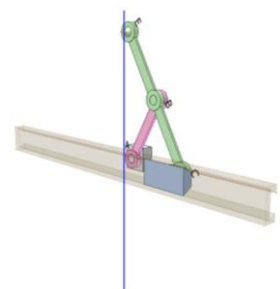
### Scott-Russel straight line mechanism

<https://youtu.be/rV2I9bckMk>

$AB = BC = BE$

Point E of green bar traces a vertical absolutely straight line (in blue).

If the input is pink bar, the mechanism has unstable positions when the pink and green bars are in line.



### Straight line drawing mechanism 11

<https://youtu.be/tT-nLSISMGs>

AB: pink crank length.

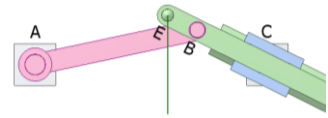
Center distance of the bearings AC = 1.4 AB

BE = 0.2 AB

Point E traces green line, a portion of which is approximately straight.

The straight portion corresponds rotary angle of +/- 12 deg. of the crank.

Distance from A to it: 0.57 AB.



### Straight line drawing mechanism 12

<https://youtu.be/Ahit60Ojrp8>

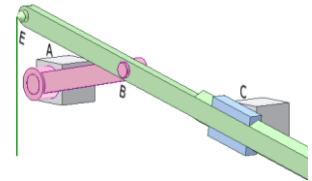
AB: pink crank length.

Center distance of the bearings AC = 2 AB

BE = AB

Point E traces green line, a portion of which is approximately straight.

The straight portion is perpendicular to AC at A and corresponds rotary angle of +/- 12 deg. of the crank.



### Planetary gear of straight line 1

<https://youtu.be/Z2uncDpQXU>

White gear is stationary.

$Z_w / Z_g = 2$

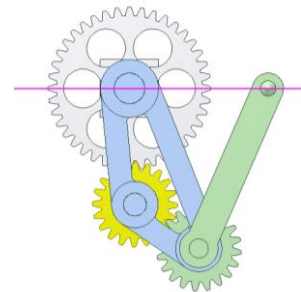
$Z_w, Z_g$  are tooth numbers of white and green gears respectively.

Tooth number of yellow gear is optional.

The point on green crank traces a straight line.

Distance between white and green gear centers = length of the green crank.

The video last scene shows an application of this mechanism: pink table translates vertically.





## 18.2. Conic curves

### Mechanism for drawing circle 1

<https://youtu.be/qhH-oLw-6Cl>

Lengths of short bars: a

Lengths of long bars: a + a

Distance between centers of the two fixed pivots is b.

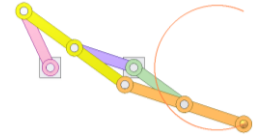
Orange pen draws a portion of a circle of radius a (in orange)

If the pink crank rotates regularly, the pen moves regularly on the circle.

Circle center is on the line that connects centers of the fixed pivots. Distance between fixed pivot center of the pink bar and the circle center is 2b.

This avoids the need to arrange a pivot at the circle center.

The mechanism has dead positions when all bars (except the pink one) are in line.



### Mechanism for drawing circle 2

<https://youtu.be/KN7Rz7LWe7w>

Lengths of short bars: a

Lengths of long bars: b

Pink, green bars and a yellow bar create a parallelogram mechanism.

Pink, violet bars and a yellow bar create an antiparallelogram mechanism.

Orange pen draws orange circle of radius a.

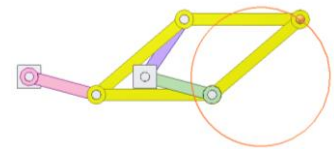
If the pink crank rotates regularly, the pen moves irregularly on the circle.

Circle center is on the line that connects centers of the fixed pivots.

Distance between fixed pivot center of the pink bar and the circle center is 2b.

This avoids the need to arrange a pivot at the circle center.

The mechanism has unstable positions when all bars (except the pink one) are in line.



### Mechanism for drawing circle 3

<https://youtu.be/1VzRxG1Bq04>

Lengths of yellow bars: a

Lengths of blue bars: b

Length of pink bar (input): c

Distance between centers of fixed pivots: d

Orange pen draws a portion of a circle of radius R (in orange).

Circle center is on the line that connects centers of the fixed pivots.

Distance between fixed pivot center of the pink bar and the circle center is L.

$$L = d.(b.b - a.a)/(d.d - c.c)$$

$$R = c.L/d = c.(b.b - a.a)/(d.d - c.c)$$

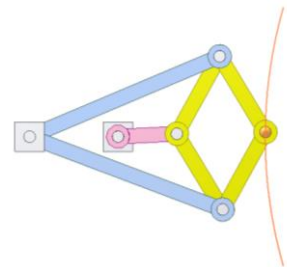
If (d - c) is chosen small, R can be very large.

This avoids the need to arrange a pivot at the circle center.

The mechanism has dead positions when all bars (except the pink one) are in line.

If (d - c) = 0 the circle becomes a straight line. See:

<http://youtu.be/6fgrTZnO-ZM>

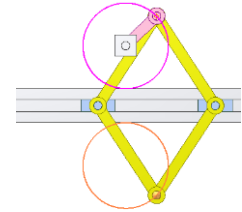


#### Mechanism for drawing circle 4

[https://youtu.be/i-boQdw\\_84c](https://youtu.be/i-boQdw_84c)

Yellow bars have the same length.

Orange pen draws a circle (in orange) that is symmetrical to the pink circle drawn by the pink bar about the centerline of the grey runway.



#### Mechanism for drawing circle 5

[https://youtu.be/BNSU\\_q-gHe4](https://youtu.be/BNSU_q-gHe4)

Pink, blue and yellow bars create a parallelogram mechanism.

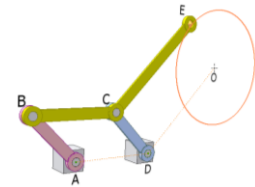
Pen E draws orange circle of center O.

This avoids the need to arrange a pivot at the circle center.

Triangles OAD and EBC are equal.

If the pink crank rotates regularly, the pen moves regularly on the circle.

The mechanism has dead positions when all bars are in line.



#### Mechanism for drawing circle 6

<https://youtu.be/0SSg6C8EbQY>

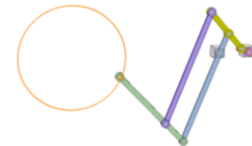
Violet, blue, yellow and green bars create a parallelogram.

Orange pen center, fixed pivot center of the blue bar and center of revolute joint between pink and yellow bars always create a straight line.

While the pink bar draws a circle of radius a (length of the pink bar) the pen draws orange circle of radius R.

$R/a =$  length ratio of the blue bar.

This avoids the need to arrange a pivot at the circle center.



#### Double parallelogram mechanism 2

<http://www.youtube.com/watch?v=U-Vn5SoRWCq>

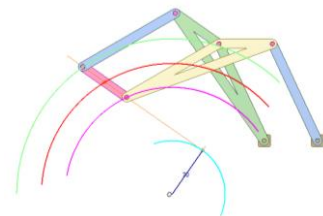
Length of two blue links is 140.

For the two triangular links lengths between the holes are 70 and 140 with angle of 150 degrees.

Lengths of the pink output and the grounded links is 70.

The pink output link rotates around point O.

This avoids the need for hinges at distant or inaccessible spots.



#### Pantograph for drawing circles

<https://youtu.be/BsDpRfXi8-4>

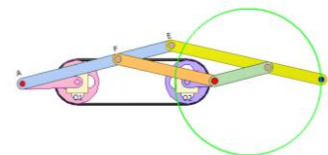
Blue, orange, green and yellow bars create a pantograph.

Two red pins and blue one are in line.

The blue pin traces a circle. Its center O lays on O1O2:

$OO_2 = O_1O_2(FE/AF)$

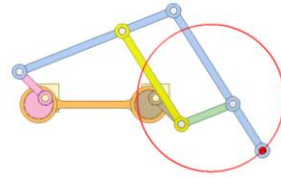
Its radius R depends on angular position between pink and violet cranks and their radii.



### Mechanism for drawing circle 7

<https://youtu.be/-5QuR-bS6xU>

Blue, yellow and green bars create a pantograph.  
 Length of blue bars:  $a + b$ . Here  $a$  is larger than  $b$ .  
 Length of green bar:  $b$   
 Length of yellow bar:  $a$   
 Length of pink crank:  $e$   
 Length of brown crank:  $f$



Pink and brown eccentrics, orange conrod create a parallelogram mechanism to ensure that pink and brown cranks are parallel and rotate in the same direction and with the same speed. A gear drive of transmission ratio of 1 can be used instead.

The red pen traces a circle.

Its radius  $R = e + (e + f) \cdot (b/a)$

Its center  $O_r$  is on the line connecting rotary centers of pink and brown cranks  $O_p O_b$ .

$O_r$  is on the right of  $O_b$ ,

$O_b O_r = O_p O_b \cdot (b/a)$

### Pantograph for drawing circles

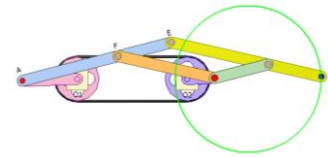
<https://youtu.be/BsDpRfXi8-4>

Blue, orange, green and yellow bars create a pantograph.  
 Two red pins and blue one are in line.

The blue pin traces a circle. Its center  $O$  lays on  $O_1 O_2$ :

$O O_2 = O_1 O_2 (FE/AF)$

Its radius  $R$  depends on angular position between pink and violet cranks and their radii.



### Mechanism for drawing circle 8

<https://youtu.be/paJQN-IsAU4>

This video was made based on the design numbered as 1303 in volume 2, Mechanisms in modern technic, I. Artobolevski.

Angle between two sides of the blue L-shaped bar is 90 deg.

Yellow bar is always perpendicular to green bar.

Orange and green sliders are connected together by a revolution joint.

When pink crank of radius  $r$  rotates, center point of orange slider traces a circular curve of large radius  $R$ .

This avoids the need for hinges at distant or inaccessible spots.

$R = ((OC \cdot OC) \cdot r) / ((OA \cdot OA) - (r \cdot r))$

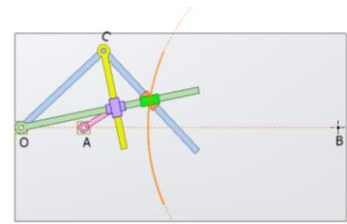
The curve center is at point  $B$ , on the right of  $A$ .

$OB = OA \cdot (R/r)$

If  $(OA - r)$  is small,  $R$  is very large.

If  $OA = r$ , the mechanism draws a straight line perpendicular to  $OA$ .

If  $OA$  is shorter than  $r$ , the curve center  $B$  is on the left of  $A$ .



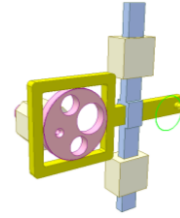
### Cam of two followers 1

[http://youtu.be/x\\_zg9cxr9o4](http://youtu.be/x_zg9cxr9o4)

Input: pink eccentric cam (cam of constant width).

The blue follower linearly reciprocates.

The yellow follower has planar motion: circular translation. Each point on it traces a circle (in green). Its radius = cam eccentricity.



### Mechanism for drawing circle 8b

<https://youtu.be/l1xlg2zF6fM>

This is a case of “Mechanism for drawing circle 8” shown at

<https://youtu.be/paJQN-lsAU4>

when OA is shorter than r. The curve center B is on the left of A.

Angle between two sides of the blue L-shaped bar is 90 deg.

Yellow bar is always perpendicular to green bar.

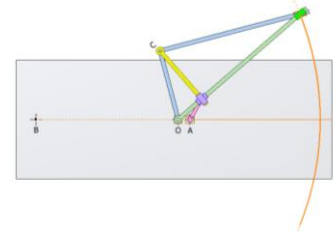
Orange and green sliders are connected together by a revolution joint.

When pink crank of radius r rotates, center point of orange slider traces a circular curve of large radius R.

This avoids the need for hinges at distant or inaccessible spots.

$$R = ((OC \cdot OC) \cdot r) / ((r \cdot r) - (OA \cdot OA))$$

$$OB = OA \cdot (r/R)$$



### Tracing a circle of virtual center

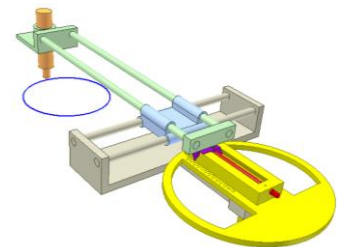
[https://youtu.be/zrX\\_0EqW3vQ](https://youtu.be/zrX_0EqW3vQ)

Input: yellow disk.

Turn red screw to adjust radius of the traced circle.

The video shows how to trace two circles of different radii.

Orange part represents the tool (a plasma torch, for example).



### Pantograph for drawing ellipses

<https://youtu.be/jjhh-qtCTUQ>

Blue, orange, green and yellow bars create a pantograph.

Two red pins and blue one are in line.

$$R1/R2 \neq AE/EF$$

R1: radius of pink crank

R2: radius of violet crank

The blue pin traces an ellipse (in green).

Its size depends on radii of pink and violet cranks.

The direction of the ellipse depends on angular position between pink and violet cranks at starting position of the mechanism.

For the starting position in this video, the ellipse is horizontal.

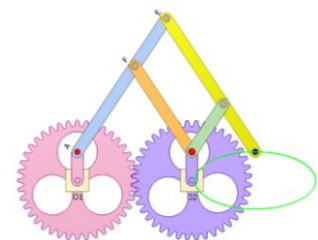
Its semi axes:

$$d = R2 + (R2 + R1)(EF/AF)$$

$$c = R2 + (R2 - R1)(AE/AF)$$

Its center O lays on O1O2:

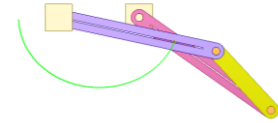
$$OO2 = O1O2(EF/AF)$$



### Inverse Parallelogram Mechanism 4

<http://www.youtube.com/watch?v=A4TvGoHsNyk>

The intersection point of the cranks traces an ellipse.

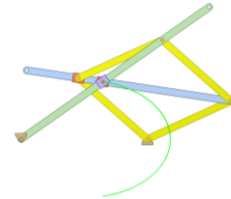


### Conic section drawing mechanism 1

<http://www.youtube.com/watch?v=4UhoyxrRquY>

Drawing ellipses.

The four yellow bars create a rhombus.



### Drawing Ellipse Mechanism 1

[http://www.youtube.com/watch?v=vblYhFK\\_cYw](http://www.youtube.com/watch?v=vblYhFK_cYw)

Lengths of the crank and the connection rod are equal.

The crank, the connection rod and two short links creates a rhombus.

Equation of traced ellipse:  $(x.x)/(a.a) + (y.y)/((a - 2b). (a - 2b)) = 1$

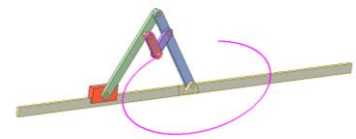
the coordinate origin O is the fixed revolution joint center of the blue crank.

Axis Oy is vertical. Axis Ox is horizontal.

a is length of the crank.

b is length of the short link.

The blue bar can not turn full revolution because of interference between the orange long pin (connecting the pink and green bars) and the violet and blue bars. So the mechanism can draw only less than one-half of an ellipse (left or right).

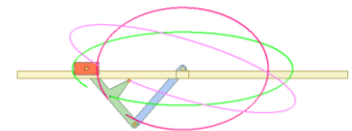


### Drawing Ellipse Mechanism 2a

<http://www.youtube.com/watch?v=Ug7TK4YTRIY>

Lengths of the crank and the connection rod are equal.

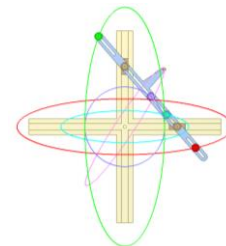
Each point of the green connection rod draws an ellipse.



### Drawing Ellipse Mechanism 3

<http://www.youtube.com/watch?v=FoO2LIYLPEc>

Each point of the blue bar draws an ellipse.



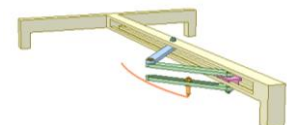
### Drawing Ellipse Mechanism 2b

<http://youtu.be/csg08Sm8okA>

Lengths of blue crank and green conrod are equal.

Each point of the green conrod draws an ellipse.

Adjust position of the orange pen and move it to draw various ellipses. Push the crank or the conrod for overcoming dead points.



### Belt satellite mechanism 2

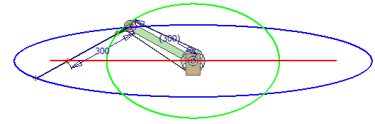
<http://www.youtube.com/watch?v=GBorVkFrhDQ>

Diameter ratio between the fixed large pulley and the small one is 2.

A point on the small sprocket draws an ellipse. For the special case (the red line) it is a straight line.

It is similar to the case of a gear satellite with sun internal gear.

<http://www.youtube.com/watch?v=2ER0rCFoITo>



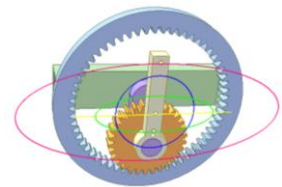
### Drawing Ellipse Mechanism 5

<http://www.youtube.com/watch?v=2ER0rCFoITo>

Tooth number ratio is 2.

Each point of the small gear draws an ellipse.

A point on its rolling cycle draws a straight line (yellow).



### Drawing ellipse mechanism 6

[http://youtu.be/nPz6VfBF\\_-4](http://youtu.be/nPz6VfBF_-4)

Combination of gear drive and linkage mechanism.

Two gears are identical. Axle distances between revolution joints on the pink and yellow bars are equal.

Equation of drawn ellipse:

$$(x/a)^2 + (y/b)^2 = 1$$

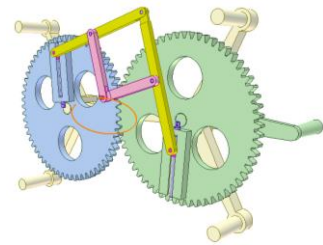
$$a = (m+n)/2$$

$$b = (m-n)/2$$

m, n: center distance of gear axle and its pink slider axle.

Use violet screws to alter m and n, which means a and b, for various ellipse shapes.

To get an ellipse axis coincident with the gear center line, the screws must be arranged in two sides of the line connecting gear centers with an equal angle.



### Drawing ellipse mechanism 7

<http://youtu.be/Z5kFDYcoXS0>

Four slotted bars create a parallelogram. The blue bars rotate with a same speed but opposite directions due to three identical bevel gear drive.

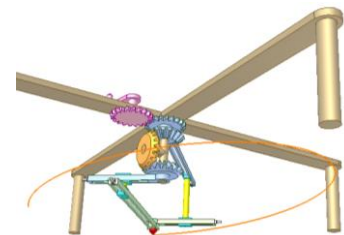
Equation of drawn ellipse:

$$(x/(a+b))^2 + (y/(a-b))^2 = 1$$

a: center distances between pivots of the long slotted bars.

b: center distances between pivots of the short slotted bars.

Use screws to alter a and b for various ellipse shapes.

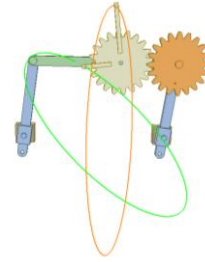


### Drawing Ellipse Mechanism 4

<http://www.youtube.com/watch?v=rH7tMg9sR1w>

Tooth number ratio is 1.

Each point of the yellow gear draws an ellipse.

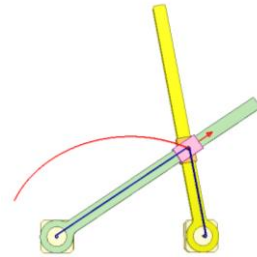


### Cable mechanism for drawing ellipse

<http://youtu.be/UEIuvciAH7c>

The tow wraps on the pivot of small diameter of two sliders. It is possible that the tow passes through a hole of the pivot. The tow ends are fixed to rotation centers of the yellow and green bars. Turn the bars while keeping the tow strained, the center of sliders pivot traces an ellipse.

Basic definition: Ellipse is locus of point P moving in a plane, the sum of its distances from two fixed points is constant (the tow length).



### Drawing ellipse mechanism 8

<http://youtu.be/GmUgfipRRsU>

Grey gear of  $Z_1$  teeth is stationary. The pink crank is fixed to the pink gear of  $Z_2$  teeth.  $Z_1 = 2 \cdot Z_2$

When blue crank turns, the point on the pink crank traces an ellipse (in green).

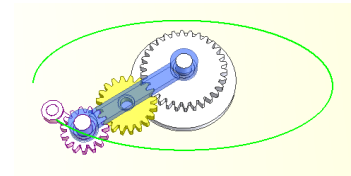
Semi minor axis =  $A - R$

Semi major axis =  $A + R$

A: center distance of the grey and pink gears.

R: radius of the pink crank.

It is possible to improve the mechanism in order that A and D are adjustable.



### Loci in epicyclic gearing BB5

<https://youtu.be/LHjLRiW7aYc>

Input: blue crank.

It is an external epicyclic gear mechanism of two satellite gears.

$Z_f/Z_s = 2$

$Z_f$ : tooth number of stationary grey gear.

$Z_s$ : tooth number of green gear.

Tooth number of yellow gear is arbitrary.

Points on the green gear crank trace ellipses in general.

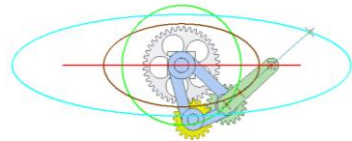
Semi-major axis =  $R_b + R_g$

Semi-minor axis =  $R_b - R_g$

$R_b$ : center distance of the grey and green gears

$R_g$ : distance from the point tracing the line to axis of the green gear

The red is an absolutely straight line because  $R_b = R_g$



### Drawing ellipse mechanism 9a

<http://youtu.be/WDcfFQXtMo4>

Grey gear of Z1 teeth is stationary. The blue frame is pivoted to the grey gear.

Pink gear of Z2 teeth has key sliding joint with the green shaft to which is fixed green gear of Z3 teeth.

Yellow vertical shaft to which is fixed yellow gear of Z4 teeth has yellow tracer.

Tooth numbers are chosen so that 1 rev. of the blue frame corresponds 2 rev. of the yellow shaft. (here: Z1 = Z2 = 20; Z3 = 32; Z4 = 16)

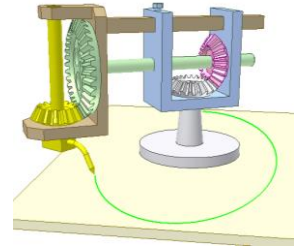
When the blue frame turns, the point of the yellow tracer will trace an ellipse (in green).

Semi minor axis = A - R

Semi major axis = A + R

A: center distance of the grey and yellow gears (adjusted by moving brown slider).

R: distance from the point of the yellow tracer to yellow shaft axis (adjustable).



### Drawing ellipse mechanism 10

<https://youtu.be/8FX81b5i7uc>

Input: green shaft to which blue crank is fixed.

The blue crank traces an ellipse (in pink).

Angle between green and blue cranks A = 0 deg. (in this video) or 180 deg.

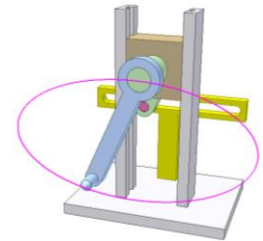
For case A = 0 deg. the ellipse semi-axes are B and (B-G).

For case A = 180 deg. the ellipse semi-axes are B and (B+G)

B: radius of the blue crank.

G: radius of the green crank.

Disadvantage: the input shaft bearing is not stationary.



### Drawing ellipse mechanism 10b

<https://youtu.be/7Mdhsn9ZyRk>

Input: pink crank.

A point on the blue slider traces an ellipse (in red).

Yellow crank (fixed to the pink crank) has red and violet portions. The red one slides in horizontal slot of the green slider. The violet one slides in vertical slot of the blue slider.

P: radius of the pink crank.

Y: radius of the yellow crank.

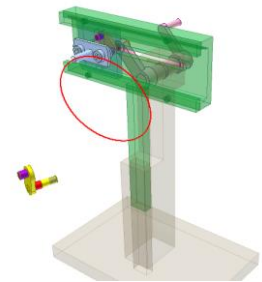
The angle between pink and yellow cranks is A, (A = 0 deg. in the first three scenes of this video).

The ellipse semi-axis lengths are  $(P+Y*\cos(A))$  and P.

For case A = 0 deg. they are (P+Y) and P.

For case A = 180 deg. they are (P-Y) and P (as shown in the last scene of the video).

The ellipse is turned an angle of A/2.





### Drawing ellipse mechanism 11

<https://youtu.be/wxbdGIWYQtE>

Ellipsograph of Leonardo da Vinci.

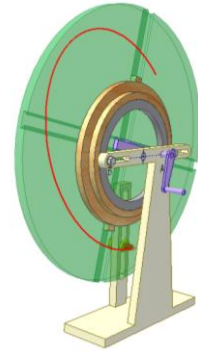
It's developed from ellipse mechanism

<http://www.youtube.com/watch?v=FoO2LIYLPEc>

Stationary red pencil draws on moving disk an ellipse when violet crank is turned.

Alter distance OA for various ellipse eccentricities. When  $OA = 0$ , a circle is gotten.

Alter position of the pencil for various sizes of drawn ellipses (the video last scene).



### Drawing ellipse mechanism 12

<https://youtu.be/p2iq2rqVKAl>

This video was made based on the design numbered as 990 in volume 2, Mechanisms in modern technic, I. Artobolevski.

$AC = a$

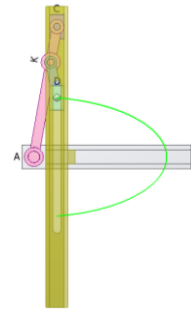
$AK - KC = b$

$KC = KD = (a - b)/2$

Center of green slider traces an ellipse.

Traced ellipse equation:

$(x.x)/(a.a) + (y.y)/(b.b) = 1$



### Drawing ellipse mechanism 9b

<https://youtu.be/HisFPzDzADk>

Brown gear of  $Z_1$  teeth is stationary. The input blue frame is pivoted to the brown gear.

Pink gear of  $Z_2$  teeth has key sliding joint with the green shaft to which is fixed green gear of  $Z_3$  teeth.

Yellow vertical shaft to which is fixed yellow gear of  $Z_4$  teeth has a runway for violet slider.

Tooth numbers are chosen so that 1 rev. of the blue frame corresponds 2 rev. of the yellow shaft. (here:  $Z_1 = Z_2 = 20$ ;  $Z_3 = 32$ ;  $Z_4 = 16$ )

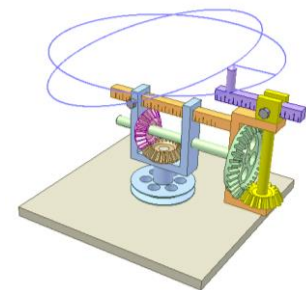
When the blue frame turns, the point of the violet slider will trace an ellipse (in violet).

Semi minor axis =  $A - R$

Semi major axis =  $A + R$

A: center distance of the brown and yellow gears (adjusted by moving orange slider).

R: distance from the point of violet slider to yellow shaft axis (adjusted by moving violet slider).



### Ellipse drawing linkage

<https://youtu.be/in01HCvfTCM>

It is built based on the geometric definition of the ellipse: “An ellipse is a plane curve whose points (M) are such that the sum of the distances from M to two fixed points (the foci, A and B) is constant.”

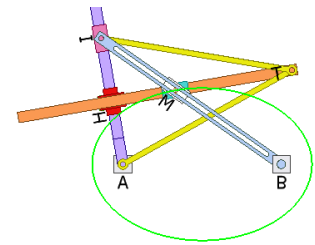
$$MA + MB = MI + MB = BI = \text{const}$$

In isosceles triangle TAI, TH is the altitude to AI, so  $MI = MA$

This linkage contains the isosceles triangle linkage shown at:

<https://youtu.be/wRsJYQ2P1pc>

The linkage has no practical sense because of its complex and bulkiness.



### Reproducing an ellipse

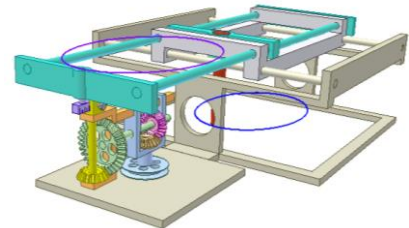
<https://youtu.be/QYENuiRImP8>

An ellipse is traced at distance from the drawing ellipse mechanism shown in

<https://youtu.be/HisFPzDzADk>

thanks to a slider-runway system. It makes the arrangement of the tool (in red) and the workpieces easy and strong. The system is connected to the drawing ellipse mechanism via a revolution joint between the cyan frame and the violet slider.

Input: blue pulley.



### Mechanism for drawing intersection of cylinder and plane 1

<https://youtu.be/V9tQcq-FBkg>

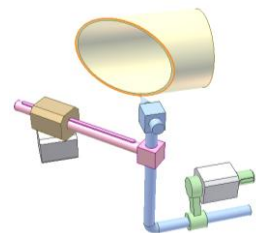
Input: green crank.

Point of blue bar draws intersection (orange ellipse) of yellow cylinder and a plane. The plane is parallel to the one that contains two axes (vertical and horizontal) of pink slider.

Cylinder axis and rotary axis of the green crank are parallel.

Radius of the green crank and radius of the yellow cylinder are equal.

Adjust tilt angle of the brown bearing to get various intersections.



### Mechanism for drawing intersection of cylinder and plane 2

<https://youtu.be/egCSIUkkS9o>

Input: pink crank.

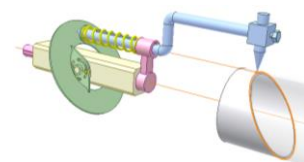
Right point of blue slider draws intersection (orange ellipse) of grey cylinder and a plane. The plane is parallel to the face of the green disk, tilt angle of which is adjustable for various intersections.

Yellow spring forces blue slider toward the disk, maintains the contact between left point of the blue slider and the disk.

If the left point is of a sphere, its radius should be as small as possible to reduce error of the intersection.

Cylinder axis and rotary axis of the pink crank are in line.

The right point of the blue bar lays on sliding axis of the blue slider.



### Mechanism for drawing intersection of cylinder and plane 3

<https://youtu.be/HxfhFikNBaY>

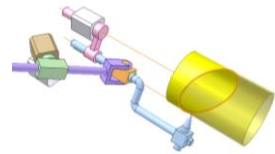
Input: pink crank.

Point of blue slider draws intersection (orange ellipse) of yellow cylinder and a plane. The plane is parallel to the one that is created by the longitudinal axis of violet slider during motion.

Cylinder axis and rotary axis of the pink crank are in line.

Point of the blue slider lays on sliding axis of the latter.

Adjust tilt angle of the brown bearing to get various intersections.



### Mechanism for drawing intersection of cone and plane 1

<https://youtu.be/H0jiYtGkNiE>

Input: pink crank.

Middle point of blue slider draws intersection (green ellipse) of yellow cone and a plane. The plane is parallel to the face of the green disk, tilt angle of which is adjustable.

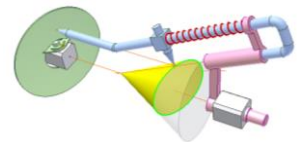
Red spring forces the blue slider toward the disk, maintains the contact between left point of the blue slider and the disk.

If the left point is of a sphere, its radius should be as small as possible to reduce error of the intersection.

Axis of the cone and rotary axis of the pink crank are in line.

Line that connects two points of the blue slider is parallel to rotary axis of the pink crank.

Adjust tilt angle of the green disk to get various intersections.



### Instrument for marking intersection of plane and cylinder

[https://youtu.be/cAHJQFKDg\\_U](https://youtu.be/cAHJQFKDg_U)

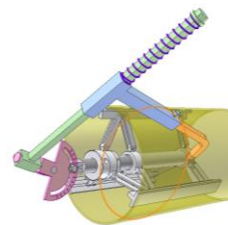
The grey device inside yellow cylinder is for centering instrument.

See:

<https://youtu.be/XDHO9JHIPzI>

Turn green bar to draw the intersection of an inclined plane and the cylinder (orange ellipse).

The inclined angle is adjustable thanks to pink dial.



### Mechanism for drawing intersection of cone and plane 2

[https://youtu.be/-G\\_Pnv725Ak](https://youtu.be/-G_Pnv725Ak)

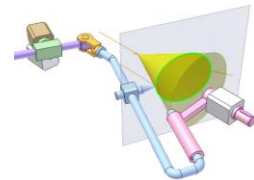
Input: pink crank.

Middle point of blue slider draws intersection (green ellipse) of yellow cone and a plane. The plane is created by axis of sliding joint of green link when it turns.

Axis of the cone and rotary axis of the pink crank are in line.

Axis of revolute joint between the blue slider and orange part contains middle point of the blue slider and is parallel to rotary axis of the pink crank.

Adjust tilt angle of the brown bearing to get various intersections.



### Equidistant curves to an ellipse 1a

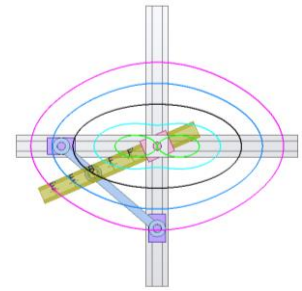
<https://youtu.be/fAgVRTKiG6U>

Point B on blue bar of an ellipse mechanism traces an ellipse (in black). Four other curves are traced by the points on the yellow bar that has revolution joint with the blue bar at B and prismatic joint with the pink part.

They are considered as the result of the black ellipse deformation with constant distance along the direction toward the ellipse center. They are equidistant or parallel curves with respect to the black ellipse.

Input: the pink part. One working cycle corresponds two input revolutions

This method of forming curves is used in designing and manufacturing of profiles, non-circular wheels, cams etc.



### Equidistant curves to an ellipse 1b

<https://youtu.be/dHh-cVZcYiQ>

Point B on blue bar of an ellipse mechanism traces an ellipse (in black). Three other curves are traced by the points on the yellow bar that has revolution joint with the blue bar at B and prismatic joint with the red part.

They are considered as the result of the black ellipse deformation with constant distance along the direction toward the ellipse center.

They are equidistant or parallel curves with respect to the black ellipse.

Input: the red part. One working cycle corresponds two input revolutions.

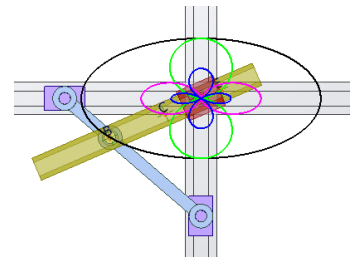
In this video:

$$BC = a; BE = b; BD = (a+b)/2$$

a: length of semi-minor axis of the black ellipse.

b: length of semi-major axis of the black ellipse.

Points C, D and E trace eight-shaped curves.



### Equidistant curves to an ellipse 2

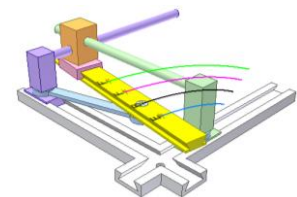
<https://youtu.be/rX4G9p09sJY>

Point B on blue bar of an ellipse mechanism traces an ellipse (in black). Three other curves are traced by the points on the yellow bar that has revolution joint with the blue bar at B and prismatic joint with the pink part.

They are considered as the result of the black ellipse deformation with constant distance along the normals to the black ellipse.

They are equidistant or parallel curves with respect to the black ellipse.

This method of forming curves is used in designing and manufacturing of profiles, non-circular wheels, cams etc.



### Mechanism of ellipse envelope

<https://youtu.be/YC3JTwH5v3Q>

This video was made based on the design numbered as 995 in volume 2, Mechanisms in modern technic, I. Artobolevski.

Angle between two sides of blue bar = angle  $FAO = \varphi$

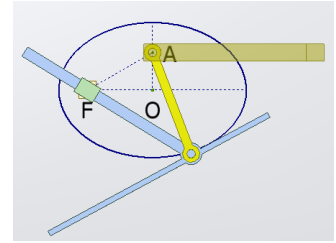
When yellow crank rotates, a side of the blue bar is always tangent to the black ellipse.

O: ellipse center.

F: a focus of the ellipse.

Semi-major axis of the ellipse =  $L \cdot \sin \varphi$

L is radius of yellow crank.



### Mechanism of ellipse envelope

<https://youtu.be/YC3JTwH5v3Q>

This video was made based on the design numbered as 995 in volume 2, Mechanisms in modern technic, I. Artobolevski.

Angle between two sides of blue bar = angle  $FAO = \varphi$

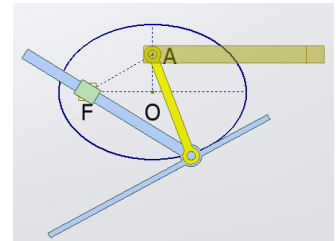
When yellow crank rotates, a side of the blue bar is always tangent to the black ellipse.

O: ellipse center.

F: a focus of the ellipse.

Semi-major axis of the ellipse =  $L \cdot \sin \varphi$

L is radius of yellow crank.



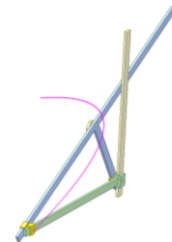
### Drawing Parabola Mechanism 1

<http://www.youtube.com/watch?v=BdiGhqDBWpU>

Equation of traced parabola:  $y \cdot y = b \cdot x$

b: distance between the fixed revolution joint center of the T-bar (blue) O and the centerline of the fixed bar (popcorn).

Axis Oy is vertical. Axis Ox is horizontal.



### Parabola drawing linkage 1

<https://youtu.be/HBMYzPprNGQ>

Move the green bar to trace the red parabola.

Equation of the parabola in coordinate system xOy:

$$y = (x^2)/b$$

b is the distance from O to the stationary guide line for the green bar.

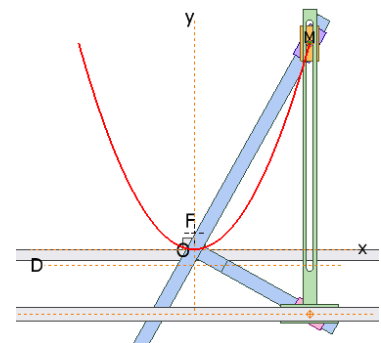
F is the parabola focus.

$$OF = b/4$$

Line D is the directrix of the parabola.

MK is the distance from K to the directrix D.

MF = MK (the geometrical definition of a parabola).



### Parabola drawing linkage 2

<https://youtu.be/zV8Ed1GgKJs>

Move the green bar to trace the red parabola.

Line D is the directrix of the parabola.

F is the parabola focus.

Triangle FSH is an isosceles one (SF = SH).

The longitudinal axis of the cyan bar contains the altitude of

side FH of the said triangle. So always MF = MH

MH is the distance from M to the directrix D.

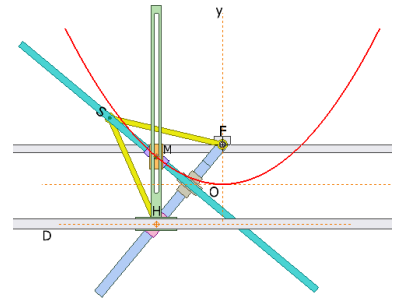
Thus, this mechanism was created based on the geometric definition of a parabola:

A parabola is a curve where any point is at an equal distance from a fixed point (the focus) to a fixed straight line (the directrix)

Equation of the parabola in coordinate system xOy:

$$y = (x^2)/(4f)$$

Focal length  $f = OF$ .

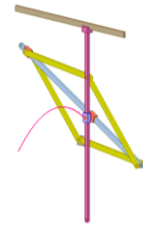


### Conic section drawing mechanism 2

<http://www.youtube.com/watch?v=JRynHxNjihM>

Drawing parabolas

The four yellow bars create a rhombus.

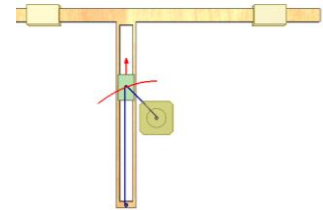


### Cable mechanism for drawing parabola

<http://youtu.be/BsBRUoL2XKE>

The tow wraps on the pivot of small diameter of green slider. It is possible that the tow passes through a hole of the pivot. One tow end is fixed to a immobile point, the other end is fixed to a point of the orange bar. Move the bar while keeping the tow strained, the center of slider pivot traces an parabola.

Basic definition: Parabola is locus of point P moving in a plane, the sum of its distances from one fixed point and from one fixed straight line is constant (the tow length).

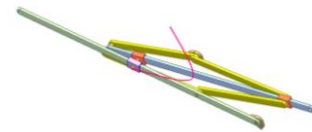


### Conic section drawing mechanism 3

[http://www.youtube.com/watch?v=vtmQpS\\_WJCU](http://www.youtube.com/watch?v=vtmQpS_WJCU)

Drawing hyperbolas

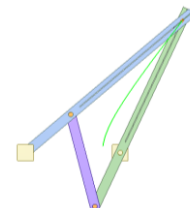
The four yellow bars create a rhombus.



### Inverse Parallelogram Mechanism 5

[http://www.youtube.com/watch?v=i5uj88NBq\\_s](http://www.youtube.com/watch?v=i5uj88NBq_s)

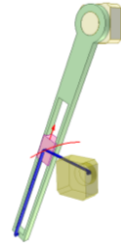
The intersection point of the cranks traces a hyperbola.



### Cable mechanism for drawing hyperbola

<http://youtu.be/72bwAtzubiY>

The tow wraps on the pivot of small diameter of pink slider. It is possible that the tow passes through a hole of the pivot. One tow end is fixed to an immobile point, the other end is fixed to a point of the green bar. Turn the bar while keeping the tow strained, the center of slider pivot traces a hyperbola. Basic definition: Hyperbola is locus of point P moving in a plane, the difference of its distances from two fixed points is constant (the tow length).



### Linkage for drawing hyperbola 1

[https://youtu.be/iUJmd0\\_7sGw](https://youtu.be/iUJmd0_7sGw)

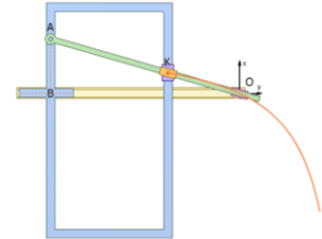
This video was made based on the design numbered as 1006 in volume 2, Mechanisms in modern technic, I. Artobolevski. Orange and violet sliders are connected together by a revolution joint.

When blue frame translates, center point of orange slider traces a hyperbola.

Its equation:  $y = (a \cdot x) / (d - x)$

a is distance between A and B.

d is distance between A and K in horizontal direction (width of the frame).



### Hyperbola drawing linkage

<https://youtu.be/rQB6abVhLo4>

The red pen draws a hyperbola when turning the pink crank.

$F'G = AB = 2CI$

The hyperbola equation in coordinate system xCy:

$$(x^2/a^2) - (y^2/b^2) = 1$$

$$c^2 = a^2 + b^2$$

c is the hyperbola focus,  $F'F = 2c$

a is the distance between C and A (or B),  $AB = 2a$

A, B are the hyperbola vertices.

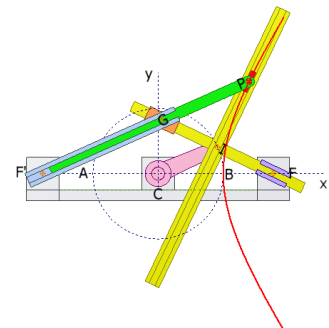
The mechanism ensures:

$PF' - PF = 2a$  (the geometrical definition of a hyperbola)

because CI is mid-segment in triangle FF'G, triangle PGF is an isosceles one,  $PG = PF$ .

This video was made based on:

<https://chestofbooks.com/crafts/scientific-american/sup4/Instruments-For-Drawing-Curves-I-The-Hyperbola.html>



### Linkage for drawing hyperbola 1

[https://youtu.be/iUJmd0\\_7sGw](https://youtu.be/iUJmd0_7sGw)

This video was made based on the design numbered as 1006 in volume 2, Mechanisms in modern technic, I. Artobolevski.

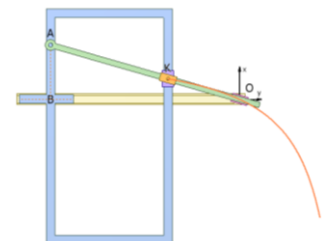
Orange and violet sliders are connected together by a revolution joint.

When blue frame translates, center point of orange slider traces a hyperbola.

Its equation:  $y = (a \cdot x) / (d - x)$

a is distance between A and B.

d is distance between A and K in horizontal direction (width of the frame).



### Conic section compass 1

<http://www.youtube.com/watch?v=EMTJHircC-A>

Drawing ellipses according to US Patent 5870830.

To adjust angles  $\alpha$  and  $\theta$  for each ellipse.

- $\alpha$  angle between the orange axis and the plane of paper
- $\theta$ : angle between the orange axis and the green arm

The green arm rotates around the orange axis to create a cone. Its intersection curve with the plane of paper is an ellipse.



### Conic section compass 2

<http://www.youtube.com/watch?v=Mfi9SgAyrK4>

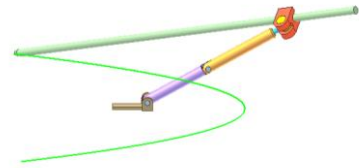
Drawing parabolas according to US Patent 5870830.

To adjust angles  $\alpha$  and  $\theta$  for each parabola.

- $\alpha$  angle between the orange axis and the plane of paper.
- $\theta$ : angle between the orange axis and the green arm.

$\alpha$  is equal to  $\theta$  for parabola drawing.

The green arm rotates around the orange axis to create a cone. Its intersection curve with the plane of paper is a parabola.



### Conic section compass 3

<http://www.youtube.com/watch?v=dsQE7onpTYs>

Drawing hyperbolas according to US Patent 5870830.

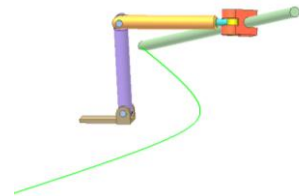
The violet axis is perpendicular to the plane of paper.

The orange axis is parallel to the plane of paper.

To adjust angles  $\theta$  for each hyperbola.

- $\theta$ : angle between the orange axis and the green arm.

The green arm rotates around the orange axis to create a cone. Its intersection curve with the plane of paper is a hyperbola.



### Mechanism for drawing intersection of cone and plane 3

<https://youtu.be/LwCfxlX1pms>

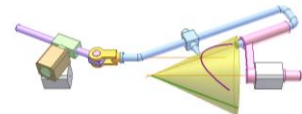
Input: pink crank.

Middle point of blue slider draws intersection (violet parabola) of yellow cone and a plane. The plane is parallel to the green generatrix of the cone.

The plane is created by axis of sliding joint of green link when it turns.

Axis of the cone and rotary axis of the pink crank are in line.

Axis of revolute joint between the blue slider and orange part contains middle point of the blue slider and is parallel to rotary axis of the pink crank.





### Mechanism for drawing intersection of cone and plane 4

[https://youtu.be/6RmK5WZty\\_M](https://youtu.be/6RmK5WZty_M)

Input: pink crank.

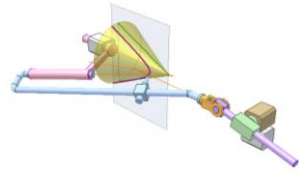
Middle point of blue slider draws intersection (violet hyperbola) of yellow cone and a plane. The plane is parallel to two green generatrices of the cone.

The plane is created by axis of sliding joint of green link when it turns.

Axis of the cone and rotary axis of the pink crank are in line.

Axis of revolute joint between the blue slider and orange part contains middle point of the blue slider and is parallel to rotary axis of the pink crank.

Rotary axes of the pink crank and the green shaft should be skew to ease the motion.



### 18.3. Other planar curves

#### Linkage for drafting a parallelogram

[http://youtu.be/Hbq9J\\_HJsTo](http://youtu.be/Hbq9J_HJsTo)

Input: pink coulisse.

End point of green slider traces a parallelogram (in green)

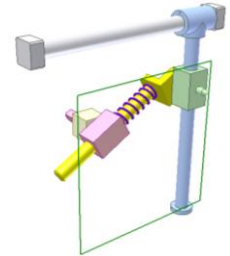
Length of horizontal side = length of grey runway – length of blue slider

Length of vertical side = length of blue runway – length of green slider

Parallelogram angle = angle between grey runway and blue runway (90 deg. for this case).

Rotary axis of the pink coulisse is at intersection of the parallelogram diagonals.

The mechanism has two DoFs. Violet spring always forces blue slider or green slider towards the ends of grey runway or blue runway.



#### Three slider mechanism

<https://youtu.be/qtGZFapSnp8>

A point on red slider draws a trapezoid of small height.

Blue slider moves in rear runway.

Green slider moves in front runway.

Two red pins of the pink slider move in groove of the green slider.

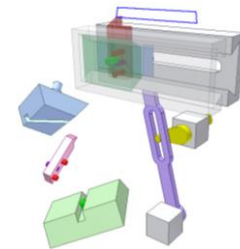
Violet pin of the pink slider moves in 45 deg. oblique groove of the blue slider.

Green pin fixed to the green slider restricts motion of the pink slider in vertical direction when it contacts with the two red pins.

Input: yellow crank gives the blue slider reciprocating linear motion via a coulisse mechanism (violet lever of two slots).

When the blue slider goes to the right, first it pushes up the pink slider (due to its 45 deg. oblique groove) then moves the green slider to the right. The green slider can not move first because of its large inertia and its large friction with the runway.

When the blue slider goes to the left, first it pushes down the pink slider (due to its 45 deg. oblique groove) then moves the green slider to the left.



#### Gear and linkage for drafting a square 1

<http://youtu.be/-VkcLhWsE->

Input: pink crank-gear of Z1 teeth.

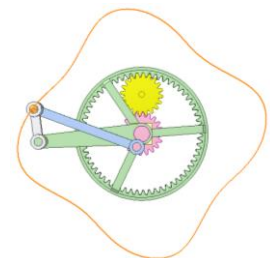
Green crank-gear has Z3 teeth,  $Z3 = 3 \cdot Z1$ .

With appropriate lengths of the 4-bar linkage the orange pin traces a curve nearly square.

Better mechanisms for drafting squares:

<http://youtu.be/ft9gmtesYUE>

[http://youtu.be/Hbq9J\\_HJsTo](http://youtu.be/Hbq9J_HJsTo)



### Loci in Epicyclic gearing A1

<http://youtu.be/usF8GCmD7xM>

R: pitch diameter of the fixed sun gear

r: pitch diameter of the planetary gear

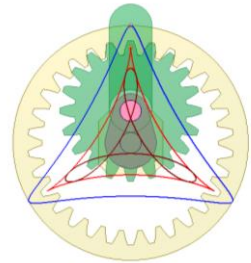
$$k = R/r = 1.5$$

Loci of various points on the planetary gear are shown.

The red is for a point on the pitch circle of the planetary gear.

It is a hypocycloid. The two other loci are hypotrochoid.

1 cycle of the mechanism corresponds 2 revolutions of the input crank.



### Loci in Epicyclic gearing A2

[http://youtu.be/M4Sp2e6\\_BRw](http://youtu.be/M4Sp2e6_BRw)

R: pitch diameter of the fixed sun gear

r: pitch diameter of the planetary gear

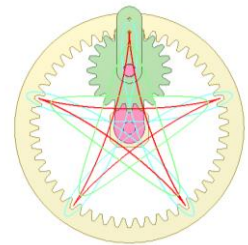
$$k = R/r = 2.5$$

Loci of various points on the planetary gear are shown.

The red is for a point on the pitch circle of the planetary gear.

It is a hypocycloid. The two other loci are hypotrochoid.

1 cycle of the mechanism corresponds 2 revolutions of the input crank.



### Loci in Epicyclic gearing A3

<http://youtu.be/U8vf3DEmWS0>

R: pitch diameter of the fixed sun gear

r: pitch diameter of the planetary gear

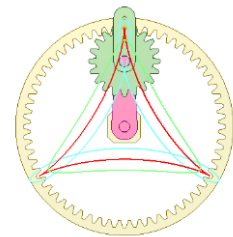
$$k = R/r = 3$$

Loci of various points on the planetary gear are shown.

The red is for a point on the pitch circle of the planetary gear.

It is a special hypocycloid: deltoid. The two other loci are hypotrochoid.

1 cycle of the mechanism corresponds 1 revolution of the input crank.



### Loci in Epicyclic gearing A4

<http://youtu.be/hGu6yUYF8mc>

R: pitch diameter of the fixed sun gear

r: pitch diameter of the planetary gear

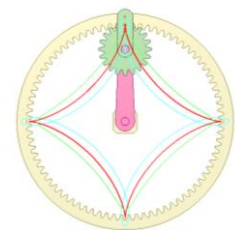
$$k = R/r = 4$$

Loci of various points on the planetary gear are shown.

The red locus is for a point on the pitch circle of the planetary gear.

It is a special hypocycloid: astroid. The two other loci are hypotrochoid.

1 cycle of the mechanism corresponds 1 revolution of the input crank.



### Locs in Epicyclic gearing A4c

<http://youtu.be/4QYQy2akPY0>

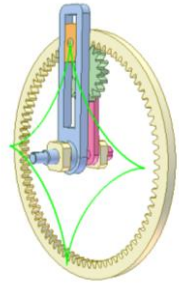
R: pitch diameter of the fixed sun gear

r: pitch diameter of the planetary gear

$$k = R/r = 4$$

A point on pitch circle of the planetary gear traces a special hypocycloid: astroid (green)

The blue slotted crank has 4 dwells in a revolution.



### Locs in Epicyclic gearing A4r

<http://youtu.be/xfwYbT46mKo>

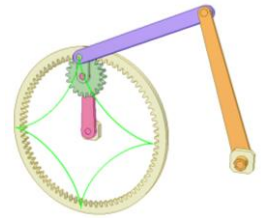
R: pitch diameter of the fixed sun gear

r: pitch diameter of the planetary gear

$$k = R/r = 4$$

A point on pitch circle of the planetary gear traces a special hypocycloid: astroid (green)

The orange crank rocks with a dwell at its rightmost position.



### Locs in Epicyclic gearing A3b

<http://youtu.be/BdXXi4fqli0>

Two identical hypocycloid mechanisms guide the point of the blue bar along the triangularly shaped path.

Distance between the bar holes is equal to distance between the two fixed bearings of the pink cranks.

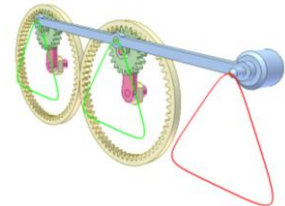
R: pitch diameter of the fixed sun gear

r: pitch diameter of the planetary gear

$$k = R/r = 3$$

Distance between the pin axis and the gear axis of the planetary gear is  $(1/2)r$  for getting a triangle of straight sides.

The mechanism are useful where space is limited in the area where the curve must be described. The mechanism can be designed to produce other curve shapes.



### Locs in epicyclic gearing BB6

[https://youtu.be/iDr2\\_BTUNRY](https://youtu.be/iDr2_BTUNRY)

Input: blue crank.

It is an external epicyclic gear mechanism of two satellite gears.

$$Z_f/Z_s = 3$$

Z<sub>f</sub>: tooth number of stationary grey gear.

Z<sub>s</sub>: tooth number of green gear.

Tooth number of yellow gear is arbitrary.

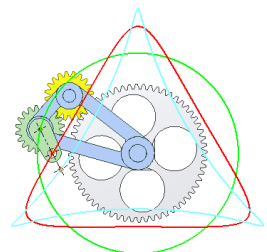
Points on the green gear crank trace various lines.

The red is an equilateral triangle of rounded vertices.

This mechanism is a replacement for the mechanism showed at

<http://youtu.be/U8vf3DEmWS0>

when the gear of internal teeth is not preferable.



### Loci in Epicyclic gearing A0

<https://youtu.be/Wygr39gMr7s>

R: pitch diameter of the fixed sun gear

r: pitch diameter of the planetary gear

$R/r = a/b$

a/b is an irreducible fraction

Here  $a/b = 4/3$

Loci of various points on the planetary gear are shown.

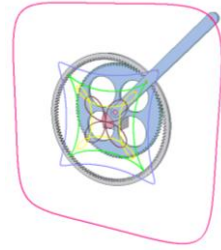
The green curve is for a point on the pitch circle of the planetary gear. It is a hypocycloid.

The other loci are hypotrochoid.

The red curve is a polygon of a sides with rounded corners.

Here  $a = 4$ . Radius of the point that traces the red square is  $R_c = 2.78r$ .

1 working cycle of the mechanism corresponds b revolutions of the input crank. Here  $b = 3$ .



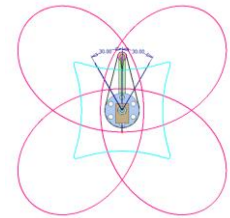
### Belt satellite mechanism 1

[http://www.youtube.com/watch?v=QNlhGtgKn\\_M](http://www.youtube.com/watch?v=QNlhGtgKn_M)

Diameter ratio between the fixed large pulley and the small one is 4.

If the green crank oscillates 60 degrees between the two blue lines, the small pulley makes a 180 degree oscillation.

It is similar to the case of a gear satellite with sun internal gear.



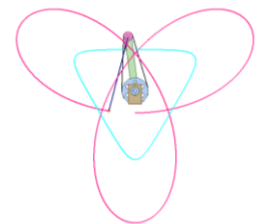
### Belt satellite mechanism 3

<http://www.youtube.com/watch?v=d0cYQsQJP4>

Diameter ratio between the fixed large pulley and the small one is 3.

The blue locus has three approximately straight parts.

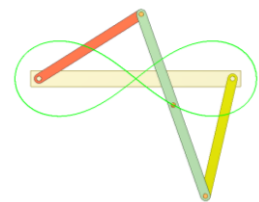
It is similar to the case of a gear satellite with sun internal gear.



### Inverse Parallelogram Mechanism 6

<http://www.youtube.com/watch?v=rjxnoQz4xDs>

The middle point of the coupler link traces a figure-eight shaped curve, a lemniscate.



### Drawing eight-shaped line 1

<https://youtu.be/N893HWEX-Hq>

It is a solution for an YouTuber request: tracing an eight-shaped line with constant velocity.

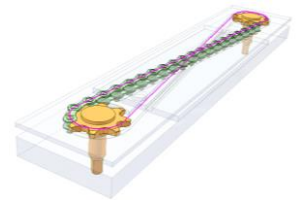
Two sprockets are both driving and of opposite rotary directions.

One among the transmission ways for them is

[http://youtu.be/k0-Gd4PYR\\_o](http://youtu.be/k0-Gd4PYR_o)

Relative angular position between two sprockets can not be arbitrary to ensure that the chain can be in mesh with both sprockets at needed time.

A point on axis of revolute joint of any link draws the required line (in pink).



### Drawing eight-shaped line 2

[https://youtu.be/spgT6mJ\\_QEk](https://youtu.be/spgT6mJ_QEk)

It is a solution for an YouTuber request: tracing an eight-shaped line with constant velocity.

Pin rack consists of grey stationary part and blue moving part.

Its pin number:  $Z_r$ .

Input: orange shaft that is connected to pink pinion of  $Z_p$  teeth via a double Cardan universal joint. Its velocity:  $V_p$ .

A point on the pinion axis draws the required line (in pink).

One working period corresponds  $N$  revolutions of the pinion.

$$N = Z_r / Z_p$$

Motion of the blue part is controlled by violet cam that rotates at velocity  $V_c$ .

$$V_c = V_p / N$$

Device for preventing the pinion from axial displacement is not shown.

Spring device to force the blue part towards the cam is not shown.

Device for motion transmission from the input shaft to the cam is not shown.

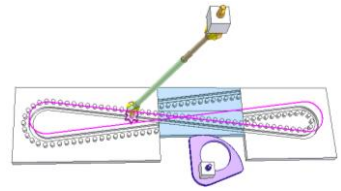
There is considerable necessary backlash because the pinion has to engage with the rack on both sides of the rack.

For more about the double Cardan universal joint see:

<https://youtu.be/aQrnXWo4DxE>

For measures for copying the line to other place see:

<https://youtu.be/fG48K40OWJ8>



### Instrument for drafting Archimedean spiral 1

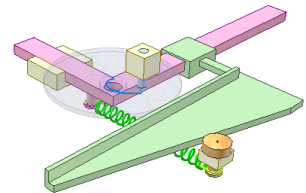
<http://youtu.be/P0IJzgfF5w>

When green wedge moves, the blue pen traces on glass disk an Archimedean spiral. The disk rotates due to the friction with the wedge (using rack-gear drive here is better)

Separation distance of traced Archimedean spiral  $t = \pi D \cdot \tan(\alpha)$

$D$ : outer diameter of the disk.

$\alpha$ : wedge angle.



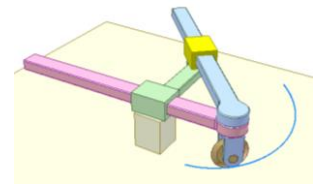
### Instrument for drafting Archimedean spiral 2

[http://youtu.be/Xdgeg\\_Hmu1g](http://youtu.be/Xdgeg_Hmu1g)

When green crank turns, orange roller traces on ground an Archimedean spiral. It is said in a book. However I do not know how to prove this. It is a dynamic problem, not purely kinematic.

Friction between the roller and the ground must be adequate to prevent the roller moving along its rotary axis.

In case no friction contact between the roller and the ground, the mechanism has two degrees of freedom.

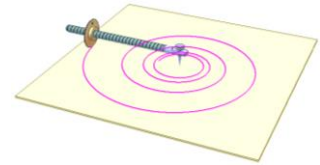


### Instrument for drafting spiral

<http://youtu.be/S2ILP90ATKI>

The orange nut-wheel, by revolving about the fixed central point, describes a spiral by moving along the screw threaded axle either way, and transmits the same to drawing paper on which transfer paper is laid with colored side downward.

The obtained spiral is not an Archimedean one.



### Instrument for drafting Archimedean spiral 3

<https://youtu.be/euvvukuz1TQ>

Input: yellow shaft.

Green pen draws an Archimedean spiral of several turns from blue grooved cam of Archimedean spiral of one turn.

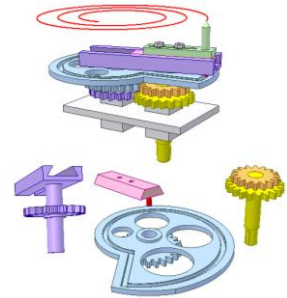
Red pin on pink slider moves along the cam groove.

Pink slider moves in violet runway that rotates coaxially with the cam. System of four spur gears ensures that the cam and the runway rotate in the same direction and the cam rotate slower than the runway.

The less velocity difference  $D$  is, the more turn number  $N$  of Archimedean spiral is.

Here tooth numbers: 20 for yellow and violet gears, 16 for orange gear, 24 for blue gear.

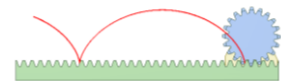
Adjust the green point position on the pink slider to get the drawn spiral bigger or smaller.



### Rack pinion mechanism 2

<http://www.youtube.com/watch?v=RN-6AH52V8U>

A point on the rolling circle of the pinion traces a cycloid.



### Chain drive 4D

[http://youtu.be/eby46\\_IQnU](http://youtu.be/eby46_IQnU)

A chain drive rolls on the ground.

Loci of various points on a link (the pink one) are shown.

The red line is for the link's pin center. The curve portions of the line are cycloids.



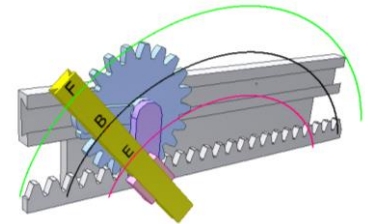
### Equidistant curves to a cycloid

<https://youtu.be/S4oKVYZyc5Q>

Violet slider moves along horizontal runway.

Blue gear pivoted on the violet slider rolls on grey rack.

Pink rotary runway has a revolution joint with the crank of the violet slider. The joint center is always on rolling line of the rack.



Yellow bar slides along the pink runway and has a revolution joint with the blue gear at B. Distance from B to rotary axis of the blue gear is R (gear rolling radius).

Point B traces an cycloid (in black).

Point E and F trace red and green curves.

They are considered as the result of the black cycloid deformation with constant distance along the direction toward the instantaneous center of the gear rotation.

This method of forming curves is used in designing and manufacturing of profiles, non-circular wheels, cams etc.

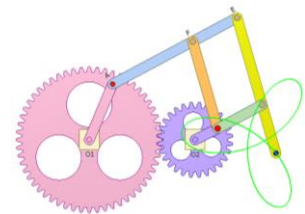
### Pantograph for drawing cycloid curves

<https://youtu.be/jOEqU57FQWU>

Blue, orange, green and yellow bars create a pantograph.

Two red pins and blue one are in line.

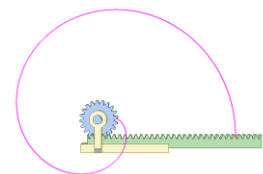
The blue pin traces a curve of cycloid family (in green) subject to radii of pink and violet cranks, gear transmission ratio (2 for this video).



### Rack pinion mechanism 3

[http://www.youtube.com/watch?v=t\\_GxDXfQ0GA](http://www.youtube.com/watch?v=t_GxDXfQ0GA)

A point on the rolling line of the rack traces an involute.

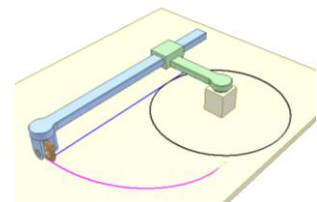


### Instrument for drafting involute of a circle 1

<http://youtu.be/qGTi7ahahTs>

When green crank turns, orange roller traces on ground an involute (in pink) of a circle (in black).

Friction between the roller and the ground must be adequate to prevent the roller moving along its rotary axis. So the blue line fixed to the blue bar rolls without slipping on the black circle and its end traces the involute.





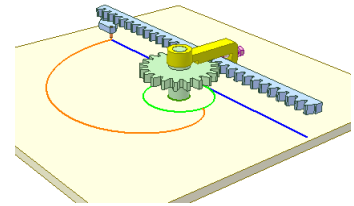
### Instrument for drafting involute of a circle 2

<http://youtu.be/X8RvgKauFzM>

Blue rack has prismatic joint with yellow crank.

When the crank turns, orange pin traces on ground an involute (in orange) of a circle (in green).

Blue line fixed to the blue rack rolls without slipping on the circle and its end traces the involute.



### Cassini oval

<https://youtu.be/NEDkUs6zGEE>

Input: green crank.

Violet pin traces a Cassini oval.

Its equation:

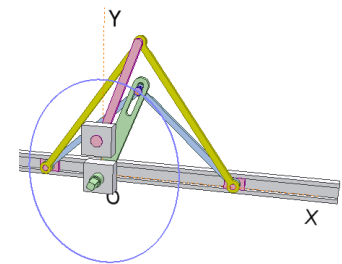
$$(y^2+x^2)^2-2c^2(y^2-x^2) = d^4-c^4$$

$$d^4 = 4(a^2-b^2)c^2$$

a: length of yellow bars

b: length of blue bars

c: distance from rotary axis of pink rocker to center line of grey runway.



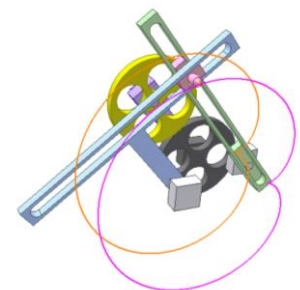
### Oldham mechanism to trace a cardioid

<https://youtu.be/S716y-56Luk>

Center of cross slider (in pink) of an Oldham mechanism traces a cardioid.

For comparison purpose last scenes of the video show a friction planetary drive of two rollers behind the Oldham mechanism. A point on perimeter of yellow satellite roller traces the same cardioid.

The Oldham mechanism in this video differs from the conventional one in offsetting sliding line of a rotary bar (in blue) by a value that is equal axis distance of two rotary bars.



### Mechanism for drawing heart shape 1

<https://youtu.be/Yu37sMYfadc>

Input: green shaft to which a cam and a crank are fixed.

The crank traces a heart-shaped curve (in pink).

Angular position between the Archimedean cam and crank must be as shown in the video (0 deg.) or 90 deg.

The cam profile consists of 4 sections. Each one is an Archimedean spiral of equation in polar coordinate system:

$$\rho = a + (B/360)\varphi$$

a: smallest radius of the profile

B: spiral parameter

$\varphi$ : rotation angle of the cam

If the profile is a concentric circle, the crank traces a circle.

Its equation:

$$x = R\cos(\varphi)$$

$$y = R\sin(\varphi)$$

R: the crank radius.

However the cam moves the bearing and affects the y value so equation of the heart curve in polar coordinate system is

$$x = R\cos(\varphi)$$

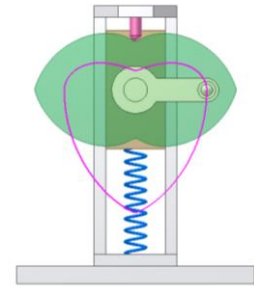
$$y = R\sin(\varphi) \pm (B/360)\varphi$$

For more details about the mathematical basis of this mechanism see Method 1 in:

[http://www.geocities.jp/nyjp07/index\\_heart\\_E.html](http://www.geocities.jp/nyjp07/index_heart_E.html)

Disadvantage: the input shaft bearing is not stationary.

The mechanism can be used for cake decoration.



### Mechanism for drawing heart shape 2

<https://youtu.be/xS5NfAB3rxA>

Input: green shaft to which blue crank is fixed.

The blue crank traces a heart-shaped curve (in pink).

Angle between green and blue cranks  $A = 0$  deg.

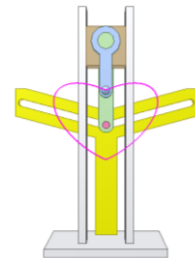
This is a development of the mechanism shown at:

<https://youtu.be/8FX81b5i7uc>

The original ellipse is deformed along the vertical axis due to the yellow cam of V-shaped slot.

Disadvantage: the input shaft bearing is not stationary.

The mechanism can be used for cake decoration.



### Mechanism for drawing heart shape 3

<https://youtu.be/uT7gkK6F5N0>

Input: blue crank.

A pin on violet slider moves along heart-shaped profile of a stationary cam under orange spring force.

The pin center traces a heart-shaped curve (in green).

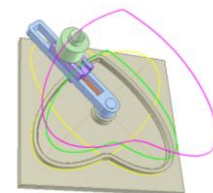
Point of the green part adjustable fixed to the violet slider traces a heart-shaped curve (in pink) that is the equidistant curve of the green heart-shaped one.

The heart-shaped profile of the cam is created from two ellipses (in yellow).

For more about heart-shaped profiles refer to

<http://www.mathematische-basteleien.de/heart.htm>

The mechanism can be used for cake decoration.



### Mechanism for drawing heart shape 4

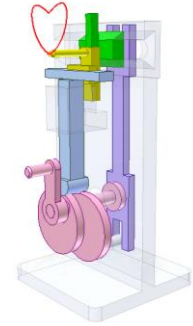
<https://youtu.be/yQePodEEib4>

Input: pink shaft.

Its two eccentrics controls up-down motion of blue vertical bar.

Its eccentric pin controls horizontal motion of green slider.

A point on yellow slider that has prismatic joints with the blue bar and the green slider traces a heart-shaped curve (in red).



### Mechanism for drawing heart shape 2b

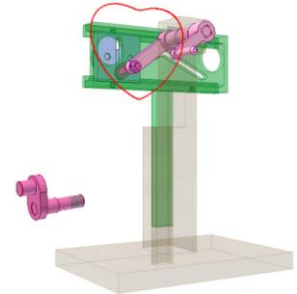
<https://youtu.be/icodQ9JvqOU>

Input: pink shaft.

A point on the blue slider traces a heart-shaped curve (in red).

Pink part (fixed to the crank) has two portions (cylinders) that slide in V-shaped slot of green slider and in vertical slot of the blue slider.

If the said portions are coaxial, the mechanism structure is simpler, but the heart shape is not beautiful, too long (see the last scene of the video).



### Mechanism to draw three-petalled rose

[https://youtu.be/kDXZs\\_lcwIU](https://youtu.be/kDXZs_lcwIU)

Input: pink crank.

Output: green slider. Its center D draws three-petalled rose (in red). Its equation in polar coordinate system OX:

$$OD = a \cdot \sin(3\varphi)$$

$\varphi$ : angle DOX

a: vertical distance between O and the center of the lower revolution joint of the blue part.

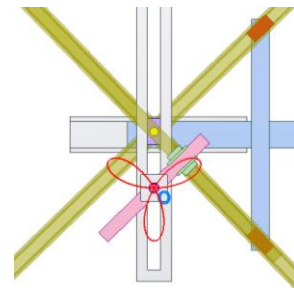
Center distance of two revolution joints of the blue bar = 4a. The joints are symmetric over the horizontal bar of the blue part.

The violet slider has revolution joint with the yellow part.

In one revolution of the pink crank the rose is drawn two times.

For reproducing the same rose at other place refer to the way shown at

<https://www.youtube.com/watch?v=cJZaNy9qA3A>



### Mechanism to draw four-petalled rose

<https://youtu.be/cJZaNy9qA3A>

Input: pink shaft.

Output: violet slider. Its center draws four-petalled rose (in violet).

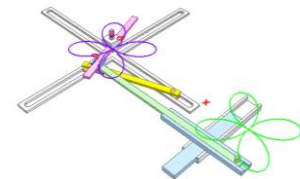
Its equation in polar coordinate system OX:

$$OD = (a/2) \cdot \sin(2\varphi)$$

$\varphi$ : angle DOX

a: length of the yellow bar

Green and blue parts are for drawing green four-petalled rose, a reproduction of the violet one.



### Loci in epicyclic gearing C1

<https://youtu.be/8-4vSUdrFKo>

Yellow motor transmits rotation to yellow crank rotating at speed  $V_1$ .

Blue motor transmits rotation to green gears rotating at speed  $V_2$ .

Tooth number of all small gears is  $Z_1$ .

Tooth number of the large gear is  $Z_2$ .  $Z_2 = 2 \cdot Z_1$

Distance between blue and green gear centers = length of the blue crank.

Blue point on blue crank traces various curves subject to relation between  $V_1$  and  $V_2$ .

If  $V_2 = 0$  the curve becomes a straight line. See:

<https://youtu.be/Z2uncDpQXU>

Blue curve (three petal flower) is for case  $V_2 = -V_1/2$

Pink curve (four petal flower) is for case  $V_2 = V_1/3$

Green curve (five petal flower) is for case  $V_2 = -V_1/4$

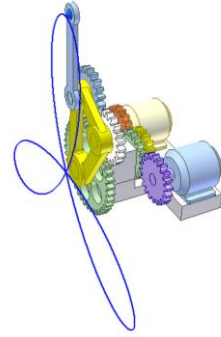
Orange curve (eight petal flower) is for case  $V_2 = -V_1/3$

Red curve (six petal flower) is for case  $V_2 = -2 \cdot V_1$

In case of other length for the blue crank, the flower curve does not go through center point of the mechanism.

If the mechanism aims to get only one determined curve, it's possible to use only one motor (in yellow) and connect yellow gear with green gear with suitable gear train.

This mechanism can be used for cake decoration.



### Loci in Epicyclic gearing A2.1

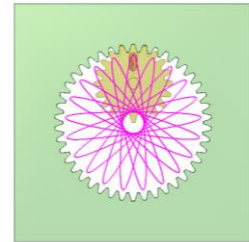
<http://youtu.be/VMG5039DKoo>

Drawing toy Spirograph.

This video shows how the pink pencil traces a 21 wing hypotrochoid.

Tooth number of green gear: 42.

Tooth number of yellow gear: 20.



### Loci in Epicyclic gearing B1

<http://youtu.be/lkwYaPxSUgw>

$r$ : pitch diameter of the fixed sun gear with external teeth.

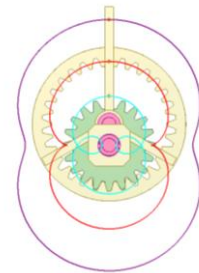
$R$ : pitch diameter of the planetary gear with internal teeth

$k = R/r = 1.5$

Loci of various points on the planetary gear are shown.

The red is for a point on the pitch circle of the planetary gear.

1 cycle of the mechanism corresponds 3 revolutions of the input crank.



### Loci in Epicyclic gearing B2

<http://youtu.be/QzP8eA1h91g>

$r$ : pitch diameter of the fixed sun gear with external teeth.

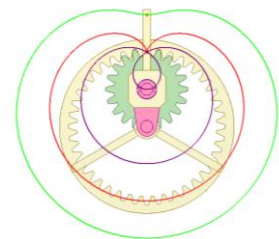
$R$ : pitch diameter of the planetary gear with internal teeth

$k = R/r = 2$

Loci of various points on the planetary gear are shown.

The red is for a point on the pitch circle of the planetary gear.

1 cycle of the mechanism corresponds 2 revolutions of the input crank.



### Loci in Epicyclic gearing B3

<http://youtu.be/tzisrqQ8lls>

r: pitch diameter of the fixed sun gear with external teeth.

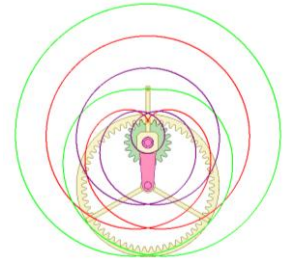
R: pitch diameter of the planetary gear with internal teeth

$$k = R/r = 3$$

Loci of various points on the planetary gear are shown.

The red is for a point on the pitch circle of the planetary gear.

1 cycle of the mechanism corresponds 3 revolutions of the input crank.



### Loci in epicyclic gearing E1

[http://youtu.be/rWe0P63\\_GjI](http://youtu.be/rWe0P63_GjI)

r: pitch diameter of the fixed sun gear.

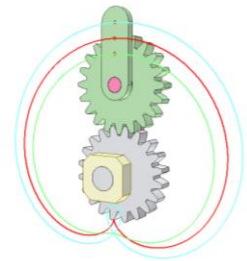
R: pitch diameter of the planetary gear.

$$k = R/r = 1$$

Loci of various points on the planetary gear are shown.

The red is for a point on the pitch circle of the planetary gear.

1 cycle of the mechanism corresponds 1 revolution of the pink input crank.



### Loci in epicyclic gearing E2

<http://youtu.be/ljMCYyT84mY>

R: pitch diameter of the fixed sun gear.

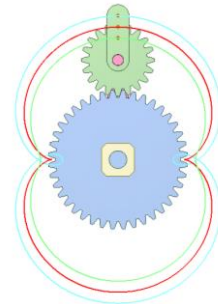
r: pitch diameter of the planetary gear.

$$k = R/r = 2$$

Loci of various points on the planetary gear are shown.

The red is for a point on the pitch circle of the planetary gear.

1 cycle of the mechanism corresponds 1 revolution of the pink input crank.



### Loci in epicyclic gearing E2b

<http://youtu.be/sjJLXzc-vlk>

R: pitch diameter of the fixed sun gear.

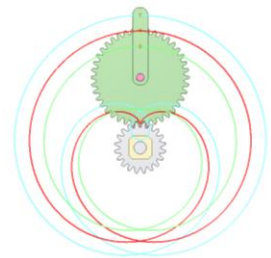
r: pitch diameter of the planetary gear.

$$k = R/r = 0.5$$

Loci of various points on the planetary gear are shown.

The red is for a point on the pitch circle of the planetary gear.

1 cycle of the mechanism corresponds 2 revolutions of the pink input crank.



### Locs in epicyclic gearing E1.1

<http://youtu.be/jq4DZkcoR-A>

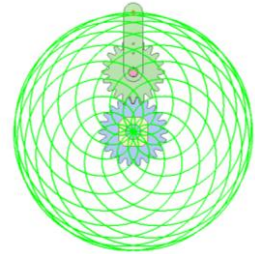
R: pitch diameter of the fixed sun gear.

r: pitch diameter of the planetary gear.

$$k = R/r = 1.1$$

The red curve is locus of point on the pitch circle of the green planetary gear.

1 cycle of the mechanism corresponds 10 revolutions of the pink input crank.



### Locs in epicyclic gearing BB4

<https://youtu.be/XDZAvCDoMhg>

Input: blue crank.

It is an external epicyclic gear mechanism of two satellite gears.

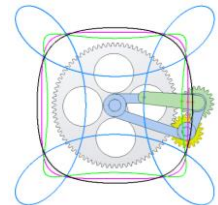
$$Z_f/Z_s = 4$$

Z<sub>f</sub>: tooth number of stationary grey gear.

Z<sub>s</sub>: tooth number of green gear.

Tooth number of yellow gear is arbitrary.

Points on the green gear crank trace various lines.



### Cake decorating machine 1

[https://youtu.be/pTtov\\_mi9N4](https://youtu.be/pTtov_mi9N4)

Input: blue carrier.

It is a combination of satellite gear drive and sine mechanism.

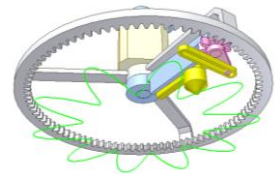
A pastry bag attached to yellow slider pipes green star on a cake (not shown).

Height of the star petal = two times of the pink crank radius.

$$\text{Number of the star petals } N = Z_g/Z_p$$

Z<sub>g</sub>: tooth number of grey gear.

Z<sub>p</sub>: tooth number of pink gear.



### Cake decorating machine 2

<https://youtu.be/KSibMCQV8vo>

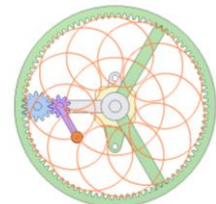
Input: grey carrier and green gear.

The grey carrier rotates continuously. When completing 1 revolution it makes more 1 revolution together with the green gear. The mechanism shown in:

<http://youtu.be/CZhhw9hGUms>

is connected to the two inputs to perform such motion.

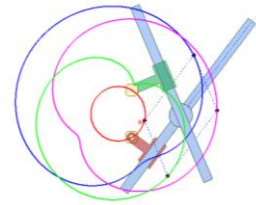
An orange pastry bag attached to violet crank pipes orange line on a cake (not shown). The line consists of a cycloid and a circle.



### Oldham mechanism 1

<http://www.youtube.com/watch?v=Zb2wx3yaCeE>

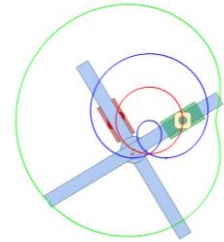
It is the generalized case of Oldham mechanism  
Loci of various points on the X-shaped bar are shown.  
Point A traces a circle two times during 1 revolution of the cranks.



### Oldham mechanism 2

<http://www.youtube.com/watch?v=TBjYJwi4BTsM>

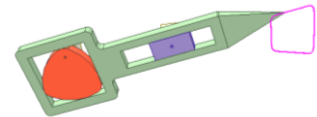
It is the standard case of Oldham mechanism  
Loci of various points on the X-shaped bar are shown.  
Remark: Point A traces a circle (in red) two times during 1 revolution of the cranks. Center of the circle is located in the middle of line segment connecting the two rotation joints.



### Drawing trapezium with Reuleaux triangle

<http://www.youtube.com/watch?v=HEiAhhQwNQ0>

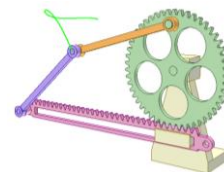
The cam profile is a Reuleaux triangle with rounded vertices.  
The mechanism is used for moving film in cameras.



### Rack and linkage mechanism 1

<http://youtu.be/67GjJMqAWgM>

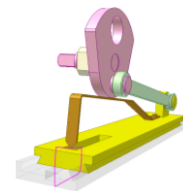
The green input gear oscillates.  
The orange and violet bars have complicated motions.



### Cam and crank slider mechanism 1

<http://youtu.be/TRblqSk2ydl>

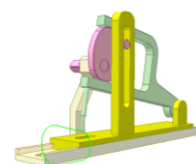
The output flat spring tip traces a trapezium for moving film in cameras.



### Cam and sine mechanism 1

<http://youtu.be/o0bvLIWQYhk>

The tip of the green follower traces a green curve for moving film in cameras.

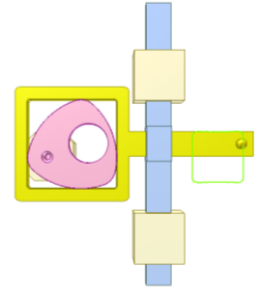


### Cam of two followers 2

<http://youtu.be/58OOKUT9nNY>

Input: pink cam (Reuleaux triangle) (cam of constant width).  
The blue follower linearly reciprocates with dwells at both stroke ends.

The yellow follower has planar motion. Each point on it traces a square (in green). The square side =  $R_2 - R_1$   
 $R_1, R_2$  are radii of the Reuleaux triangle.

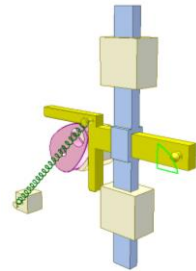


### Cam of two followers 3

<http://youtu.be/ubVPb-KMsZ0>

Input: pink cam causing two motions of blue and yellow followers.  
The blue follower linearly reciprocates with dwell at its highest position.  
The yellow follower has planar motion. Green closed curve is locus of a point on it. There are two straight portions because the cam profile contains a circular sector.

Spring maintains the cam contact with the yellow follower.

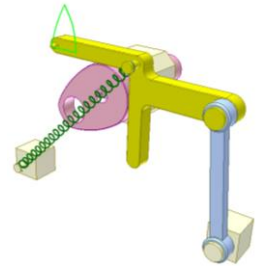


### Cam of two followers 4

<http://youtu.be/kyY9mVDxboM>

Input: pink cam causing two motions of blue and yellow followers.  
The blue follower oscillates with dwell at its leftmost position.  
The yellow follower has planar motion. Green closed curve is locus of a point on it.

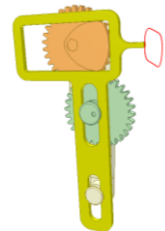
Spring maintains the cam contact with the yellow follower.



### Cam and gear mechanism 7

<http://youtu.be/HbeuoAhQ3kE>

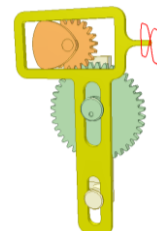
The yellow follower contacts with the orange cam fixed on the orange gear, eccentric portion of the green gear and the fixed lower pin. The cam is of constant width shape. A point of the frame follower traces the red curve that is used for moving film in cameras. Transmission ratio of the gear drive is 1.



### Cam and gear mechanism 8

<http://youtu.be/Mv6IA8nlogs>

The yellow follower contacts with the orange cam fixed on the orange gear, eccentric portion of the green gear and the fixed lower pin. The cam is of constant width shape. A point of the frame follower traces the red curve that is used for moving film in cameras. Transmission ratio of the gear drive is 2.

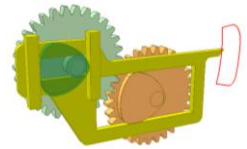




### Cam and gear mechanism 9

<http://youtu.be/8liGR-OqX1Q>

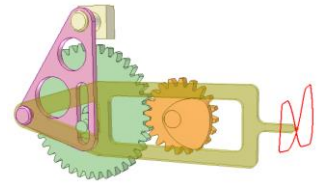
The yellow follower contacts with the orange cam fixed on the orange gear, concentric portion of the green gear and the green cam. The cams are of constant width shape. A point of the frame follower traces the red curve that is used for moving film in cameras. Transmission ratio of the gear drive is 1.



### Cam and gear mechanism 10

<http://youtu.be/dDITwo4j4SA>

The yellow follower contacts with the orange cam fixed on the orange gear. The cam is of constant width shape. The pink plate has a slot in which an eccentric pin of the green gear slides. A point of the frame follower traces the red curve that is used for moving film in cameras. Transmission ratio of the gear drive is 2.



### Gear and linkage mechanism 4

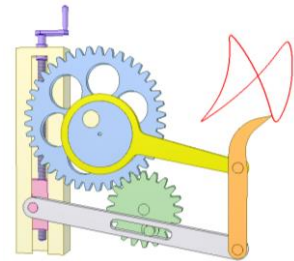
<http://youtu.be/-VLFKkYmY-0>

Orange bar tip traces red curve that is used for moving film in cameras.

Blue and green gears have eccentrics.

Transmission ratio of gear drive is 2.

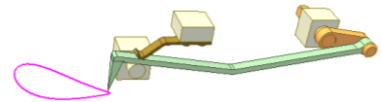
Move pink slider by turning violet screw for various positions of the red curve.



### Spring linkage mechanism 3

<http://youtu.be/DQB1pY3lt08>

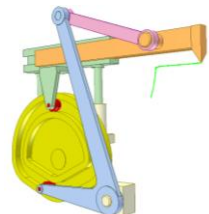
A slot on the green lever of an ordinary coulisse mechanism is not needed if a leaf spring is used to force the lever against the fixed pin.



### Cam mechanism of 2 followers

<http://youtu.be/eOg1P04m8tM>

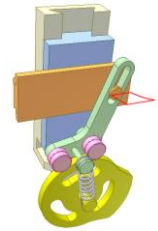
The yellow grooved cam controls motions of two followers (one translating and one rocking). Thus the orange slider has complicated motion.



### Cam and crank slider mechanism 6

[http://youtu.be/JAtnB\\_WAhOE](http://youtu.be/JAtnB_WAhOE)

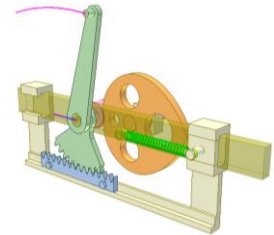
Input is the yellow cam. The green follower has two pink rollers, both in permanent contact with the cam. The orange output slider has complicated motion.



### Cam and gear mechanism 1

<http://youtu.be/nGqN-2ckst8>

Input is the orange cam. Due to gear rack drive, the green output crank has longer stroke (the pink curve, an extended cycloid) than the yellow follower (the violet line).

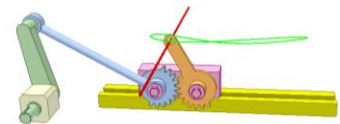


### Gear slider crank mechanism

<http://youtu.be/wq118kbXN1c>

The hole center on the orange lever reciprocates according to the motion rule (the green closed curve) that differs from the one of an ordinary slider-crank mechanism.

This mechanism is applied in wire drawing machines for guiding wire (in red) to its coil.



### Two slider-crank mechanism

<https://youtu.be/FwThFH226GI>

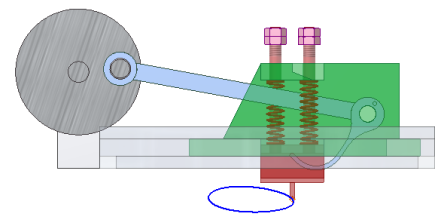
Input: grey shaft rotating continuously.

A point of pink slider traces the blue curve that is used for moving film in cameras.

Green slider move in the white runway.

Pink slider has prismatic joint with the green slider.

Blue hook fixed to blue connecting rod moves the pink slider in up-down direction.



### Simple slider-crank mechanism

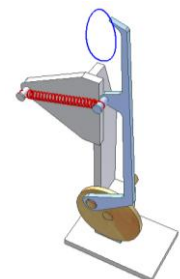
[https://youtu.be/XxhL\\_-rNmb4](https://youtu.be/XxhL_-rNmb4)

It is a simplifier of ordinary slider-crank mechanism. No presence of slider.

The contact between blue conrod and the base replaces the slider role.

Tip of the conrod traces the blue curve that is used for moving film in cameras.

Change shape of contact line between blue conrod and the base (any curve) for various blue curves.



### Gear and linkage mechanism 15

<http://youtu.be/9JErtHWgtk4>

The gears have a same tooth number.

Input : Blue gear rotating regularly.

The red pin traces a complicated curve in general.

This video is for special case, when a part of the red pin locus is linear:

Gear pitch diameters : 50

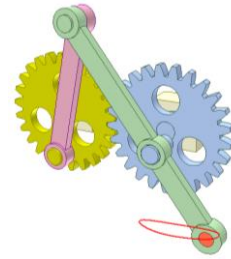
Crank radius of the blue gear : 5

Crank radius of the yellow gear : 18

Length of the pink bar : 62

Length of the green bar : 60 + 38

Assembly position: as start position of the simulation video.



### Double cam and gear rack mechanism

<https://youtu.be/KVXVY27Bh08>

Input: green double cam

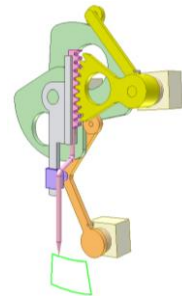
Output: pink awl, the point of which traces green closed line.

Change cam profiles for various shapes of the line.

Grey bar, violet slider and orange lever create a coulisse mechanism.

Pink rack is not always perpendicular to the line connecting cam and gear centers so some tooth gap of the rack-gear drive is needed.

The mechanism is applied in shoe making machines.



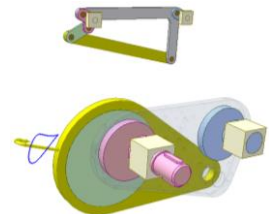
### Linkage for complicated trajectory 1

<https://youtu.be/P-zSCsflIDk>

Five bar mechanism gives knitting needle a complicated trajectory.

The mechanism looks enigmatic because of large revolute joints, purpose of which is to ensure full rotation of the pink input shaft.

Upper figure is kinematic diagram of this mechanism.



### Cam and bar mechanism for complicated trajectory 1

<https://youtu.be/5cseSVc0Wr8>

Input: pink shaft.

Double cam and bars give knitting needle a complicated trajectory.

Grey rollers are forced toward cam by springs (not shown).



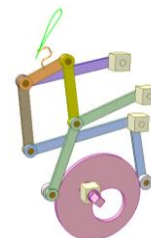
### Cam and bar mechanism for complicated trajectory 2

<https://youtu.be/fjREhx7D8hU>

Input: pink shaft.

Cam and bars give knitting needle a complicated trajectory.

Grey rollers are forced toward cam by springs (not shown).

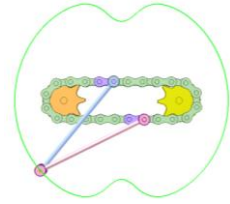


### Chain drive 3E

<http://youtu.be/rCyWwj-QU54>

Two sprockets are identical.

Locus of center of the revolution joint between blue and pink bars is complicated.

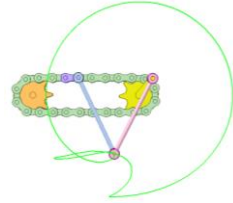


### Chain drive 3F

[http://youtu.be/fCTeC7\\_4bXI](http://youtu.be/fCTeC7_4bXI)

Two sprockets are identical.

Locus of center of the revolution joint between blue and pink bars is complicated.



### Chain drive 5D

<http://www.youtube.com/watch?v=KDUgrrAbn6Q>

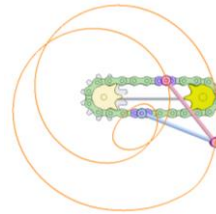
Satellite chain drive.

The popcorn sprocket is fixed.

The popcorn and yellow sprockets have the same tooth number.

The grey crank and gear is driving.

Locus of center of the revolution joint between blue and pink bars is complicated.



### Chain drive 5E

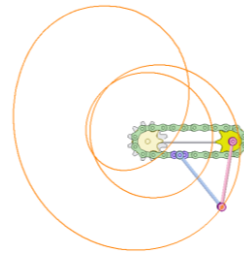
<http://www.youtube.com/watch?v=AOZXWyIFYFQ>

Satellite chain drive.

The popcorn sprocket is fixed. The popcorn and yellow sprockets have the same tooth number. The pink bar has a revolution joint with the yellow sprocket at its center.

The grey crank and gear is driving.

Locus of center of the revolution joint between blue and pink bars is complicated.



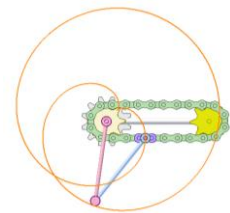
### Chain drive 5F

<http://www.youtube.com/watch?v=FnWojsq3OFo>

Satellite chain drive.

The popcorn sprocket is fixed. The popcorn and yellow sprockets have the same tooth number. The pink bar has a revolution joint with the popcorn sprocket at its center. The grey crank and gear is driving.

Locus of center of the revolution joint between the blue bar and the violet chain link is complicated. The pink bar rotates with dwell.



## 18.4. Spatial curves

### Planetary spur and face gear drive 1

<http://youtu.be/p1fBJH4Fz20>

Input: blue shaft with spur gear (40 teeth) and face gear (60 teeth).  
Yellow carrier rotates idly on the blue shaft.

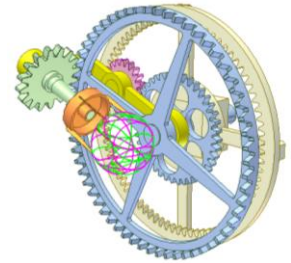
Pink gear (20 teeth) rotates idly on pivot of the yellow carrier.

Green gear (16 teeth) with orange tool rotates idly in bearing of the yellow carrier.

Popcorn internal gear (80 teeth) is stationary.

In 3 revolutions of the input, the yellow carrier makes 1 rev. and the tool makes 7.5 rev. around its own rotary axis. A point of the orange tool traces curve laid on a sphere.

It is said that this mechanism is applied to an apple-paring machine.



### Study of satellite spur and bevel gear mechanism 1

<http://youtu.be/xtB1qzva1gM>

Inputs: green center crank and brown worm.

Three spur gears are of the same tooth number.

Two bevel gears are of the same tooth number.

The orange spur and bevel gears are fixed together.

Axes of the red bar, the yellow and green shafts are concurrent.

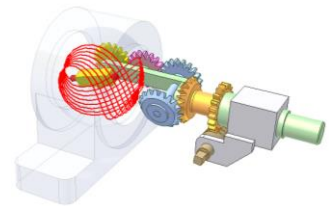
Red spatial curve is traced by the red bar point.

The curve lies on a sphere.

The mechanism can be applied for burnishing internal spherical surfaces.

Using the red bar as a cutter is impossible because the angle between the cutter edge and the red curve changes considerably during motion.

If the brown worm is kept immobile, the red bar point traces a spatial figure-eight shaped curve (spherical lemniscate).



### Worm-rack drive 4

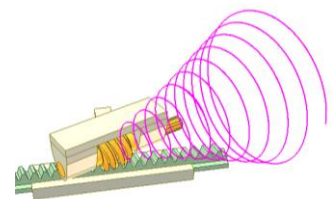
<http://youtu.be/Sm6OHgdqSKI>

The worm is stationary. Input is the rack runway fixed to the worm bearing. The pink curve is locus of a point on rack pitch line (a space involute of a circle?).

Worm: Helix angle  $B1 = 30$  deg., left hand

Rack: Helix angle  $B2 = 0$  deg.

Angle between worm axle and rack moving direction is  $L = 30$  deg.



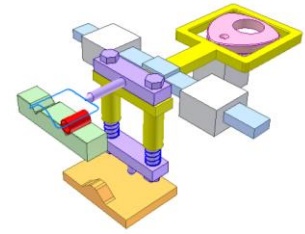
### 3D trajectory creation 1

<https://youtu.be/wpn0KLPlo0o>

Input: pink shaft of Reuleaux triangle.

Output: violet horizontal pin. In the view from above its trajectory is a square. Orange cam makes the pin move in vertical plane while it moves along one side of the said square.

The video shows an application of this mechanism: displacing the red bush.



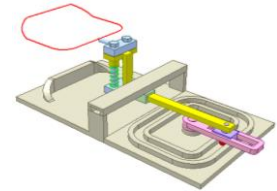
### 3D trajectory creation 2

<https://youtu.be/046t-KP1ffw>

Input: pink shaft.

A point of blue follower traces a 3D curve (in red), plan projection of which is a rectangle.

Change profiles of the beige cams to get other curve shapes.



### 3D trajectory creation 3

<https://youtu.be/FL3PwNuzxXw>

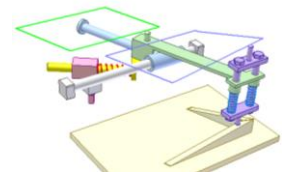
It is a development of the mechanism shown at:

[http://youtu.be/Hbq9J\\_HJsTo](http://youtu.be/Hbq9J_HJsTo)

Input: pink shaft.

A point of green part traces a 2D parallelogram (in green).

A point of violet follower traces a 3D curve (in blue), plan projection of which is the said parallelogram.



### Drawing a spherical helix

<https://youtu.be/bx6Pn9XReq8>

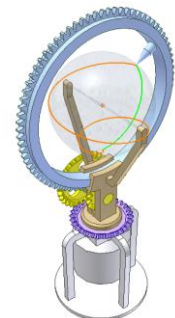
Input: brown shaft.

Blue gear has revolute joint with the brown shaft and is driven via planetary bevel gear drive and spur gear one.

Glass sphere is fixed to the brown shaft.

A point on the blue gear:

- traces on the glass sphere a green circle.
- traces in the space the orange line, a spherical helix.



### Mechanism for drawing intersection of cone and cylinder 1

<https://youtu.be/BDUMUIwKY9M>

Input: green crank.

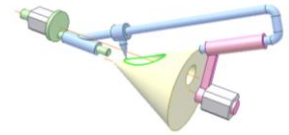
Point of blue slider draws intersection (in green) of cylinder and cone of the yellow work. The cylinder and cone axes are parallel.

Rotary axis of the green crank and axis of the work cylinder are in line.

Rotary axis of pink crank and axis of the work cone are in line.

Angle between axes of two joints of the pink crank =  $0.5 A$ .

A: opening angle of the yellow cone.



### Mechanism for drawing intersection of cone and cylinder 2

<https://youtu.be/kbq0qb4vVYs>

Input: green crank.

Point of blue slider draws intersection (in black) of cylinder and cone of the yellow work. The cylinder and cone axes are in a plane and intersected at an angle B (30 deg.) adjustable by turning brown bearing.

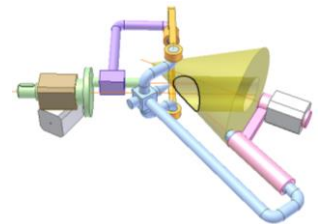
Rotary axis of the green crank and axis of the work cylinder are in line.

Rotary axis of pink crank and axis of the work cone are in line.

Angle between axes of two joints of the pink crank =  $0.5 A$ .

A: opening angle of the yellow cone.

The green crank and the blue slider are connected together through an universal joint (violet and orange links).



### Mechanism for drawing intersection of sphere and cone 1

<https://youtu.be/NTUd5aKKVm8>

Input: orange crank.

Lower point of violet bar draws intersection (violet curve) of yellow hemisphere and cone (inner surfaces).

Hemisphere diameter:  $D1 = 100$ . Cone opening angle  $A = 40$  deg. Their offset:  $E = 25$

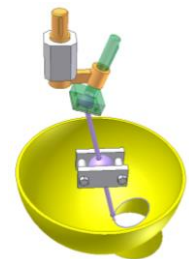
Distance between two spherical joints of violet bar:  $0.5 D1$ .

Distance between lower point and lower spherical joint of violet bar:  $0.5 D1$ .

Center of yellow hemisphere and center of lower spherical joint of violet bar are coincident.

Rotary axis of orange crank lays in plane created by center of lower spherical joint of violet bar and axis of yellow cone. Distance of rotary axis of orange crank and axis of yellow cone:  $2 E$ .

Angle of rotary axis of orange crank and axis of green slider:  $0.5 A$ .



### Mechanism for drawing intersection of two cylinders

<https://youtu.be/zTNFiVohvNc>

Input: green crank.

Orange curve is intersection of two glass cylinders.

Their diameters:  $D1 = 40$  and  $D2 = 30$ . Their offset:  $E = 3$

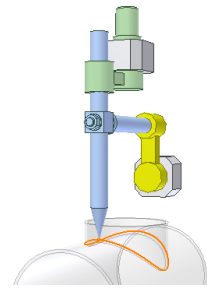
Axes of cylinder  $D1$  and bearing of yellow crank are parallel in vertical plane. Their distance:  $V$

Axes of cylinder  $D2$  and of bearing of green crank are in line.

Axes of bearing of yellow crank and bearing of green crank are skew.

Their distance:  $E$ .

Distance between the point of blue vertical bar and axis of cylindrical joint between blue horizontal bar and yellow crank:  $V$ .



### Mechanism for drawing intersection of sphere and cylinder 1

<https://youtu.be/t9X2cbK2zEA>

Input: pink pulley.

Orange curve is intersection of yellow hemisphere and cylinder (inner surfaces).

Hemisphere diameter:  $D1 = 100$ . Cylinder diameter  $D2 = 30$ . Their offset:  $E = 25$

Length of green bar of two spherical joints:  $0.5 D1$ .

Axis of cylinder  $D2$  and rotary axis of blue crank are in line.

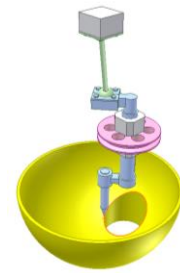
Vertical axis of the hemisphere and vertical axis of the upper spherical joint (fixed) are in line.

Distance between center of the upper spherical joint and center of yellow hemisphere is  $L$ .

Distance between the point of blue bar and center of its spherical joint is  $L$ .

Distance from the point of blue bar to its rotary axis is  $0.5 D2$ .

Distance from center of spherical joint of blue bar to its rotary axis is  $0.5 D2$ .



### Mechanism for drawing intersection of sphere and cylinder 2

<https://youtu.be/TF3exkl6uo4>

Input: orange crank.

Lower point of violet bar draws intersection (violet curve) of yellow hemisphere and cylinder (inner surfaces).

Hemisphere diameter:  $D1 = 100$ . Cylinder diameter  $D2 = 30$ . Their offset:  $E = 25$

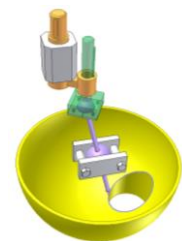
Distance between two spherical joints of violet bar:  $0.5 D1$ .

Distance between lower point and lower spherical joint of violet bar:  $0.5 D1$ .

Center of yellow hemisphere and center of lower spherical joint of violet bar are coincident. Rotary axis of orange crank lays in plane created by center of lower spherical joint of violet bar and axis of yellow cylinder.

Distance of rotary axis of orange crank and axis of yellow cylinder:  $2 E$ .

Axis distance between two revolute joints of orange crank:  $0.5 D2$





### Drawing stepped curve on a cylindrical surface

<https://youtu.be/xEdb15worX8>

Input: pink gear shaft to which a barrel cam is fixed.

Output: green tracer that can rotate and move up-down.

Pink tooth-uncompleted gear controls intermittent rotation of blue gear and thus of the green tracer.

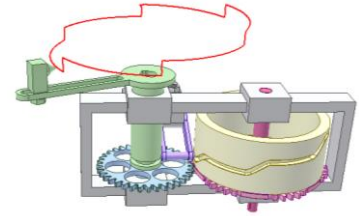
The barrel cam controls the intermittent up-down motion of the green tracer via violet double lever.

The green tracer has prismatic joint with the blue gear.

The tracer rotates 60 deg., when not moving vertically.

It does not rotate when moving vertically.

It can be used for tracing stepped curves on a cylindrical surface.



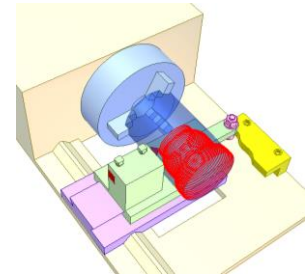
## 19. Mechanisms for copying

### Copying device on lathe 1

<http://youtu.be/kR-dbUTMNuU>

The violet carriage is power-fed along the axis of rotation of the blue workpiece. The green slider carrying pink roller is forced by a spring (between violet and green sliders, not shown) towards the yellow template.

The tool traces a curve that corresponds to the template profile.

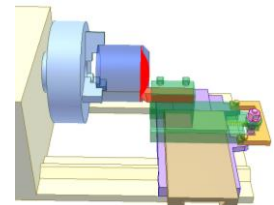


### Copying device on lathe 2

<http://youtu.be/DOd6PZm0iQY>

The brown cross slide is power-fed square to the axis of rotation of the blue workpiece. The green upper slide carrying pink roller is forced by yellow spring towards the orange template.

The tool traces a curve that corresponds to the template profile.

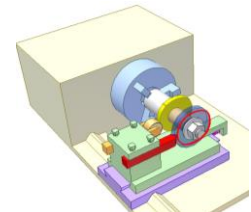


### Copying device on lathe 3

<http://youtu.be/5jUZNPiLxNc>

The violet carriage is power-fed along the axis of rotation of the blue workpiece. The green slider carrying pink roller and red tool is forced by a pink spring towards the yellow template.

The tool traces a curve that corresponds to the template profile.



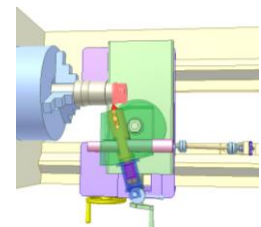
### Copying device on lathe 4

[http://youtu.be/\\_Av-t9bY1wg](http://youtu.be/_Av-t9bY1wg)

The violet carriage is power-fed along the axis of rotation of the workpiece. The orange tool spindle carrying a red tool and a red tracer can slide in the green post that is fixed to the cross slide of the lathe.

The tracer is forced toward the pink sample by a spring. The sample position in relation with the workpiece can be adjusted owing to the violet nut and a conrod of spherical joints (on the right).

Use the green screw of the cross slide to increase the cutting depth. The blue cam is used when moving the tracer to the initial position.



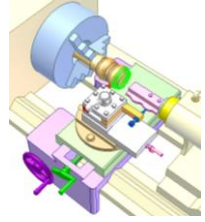
### Manual copy turning

<http://youtu.be/3kEpkg9RdwE>

An immobile pink sample is fixed on the modified center of the tailstock. When turning, the operator uses screws of the compound slide and the cross slide to let the blue screw-tracer follow the sample.

The red tool creates a surface of the orange work corresponding to the sample profile. Cutting depth is adjusted by the blue screw-tracer.

The sample position in relation with the workpiece can be adjusted by using the tailstock.



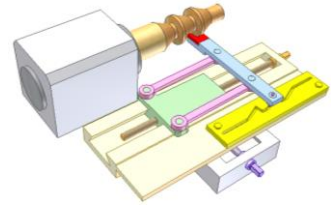
### Copying device for soft workpieces

<http://youtu.be/k7p2FzFgi5s>

Red tool bit is fixed to an end of blue bar and pink tracer to the other end. Pink tracer moves in groove of yellow cam template. Blue tool bar, two pink bars create a parallelogram mechanism that eases the tool bar motion when the pressure angle in the cam is big (compared to cam sliding follower). Tool bar moves along the axis of rotation of orange workpiece thanks to green slider and orange screw.

Use violet screw of the lower runway to withdraw tool bit from workpiece a little in return stroke.

Attention: profile of the workpiece is a little different from the one of the template because the tool bit has three cutting edges (not a point).



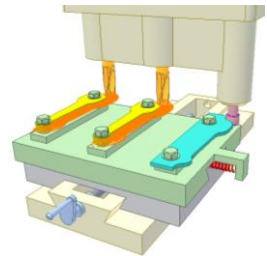
### Copying device on vertical milling machine 1

<http://youtu.be/4xFMKC-NgBE>

Grey table moves in cross direction by a screw drive. Green upper table moves longitudinally by the contact between cyan template and pink immobile tracer. Red spring forces the template towards the tracer. Yellow works are fixed to the upper table.

Orange cutters create surface on the yellow works corresponding to the template profile.

The tracer and the cutter diameters must be equal if profiles of the template and the work are requested to be the same.

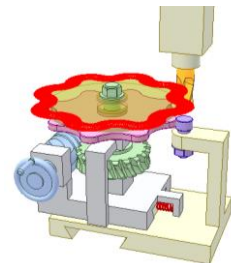


### Copying device on vertical milling machine 2

<http://youtu.be/lLognO-dzOE>

Grey slider carries a worm drive (rotary table in practice). Pink template and yellow work are fixed to worm wheel shaft of the drive. The template contacts violet stationary pin under pressure of red spring and makes the slider move longitudinally when the blue worm is rotated by hand. Orange cutter creates a surface on the yellow work corresponding to profile of the template.

The pin and the cutter must be coaxial and their diameters must be equal if profiles of the template and the work are requested to be the same.



### Wood 2D copy milling machine 1

<http://youtu.be/WJeliwU6OzU>

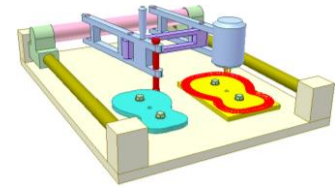
A parallelogram mechanism of violet conrod and two blue cranks can slide on two yellow rods.

Red tracer is on one crank, orange cutter is on the other. Their distances to pink bar pivots are equal (the tracer and cutter can be on the violet conrod also)

Move (by hand) the tracer along profile of fixed cyan template, the cutter creates a surface on fixed yellow work corresponding to the profile of the template.

The tracer and the cutter are kept perpendicular to the ground.

The tracer and the cutter diameters must be equal if profiles of the template and the work are requested to be the same.



### Wood 3D copy milling machine 1

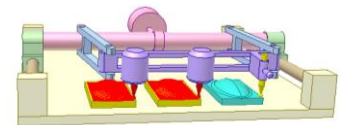
<http://youtu.be/TzBM9iJa5mM>

A parallelogram mechanism of violet conrod and two blue cranks can slide on two brown rods. The pink tube can pivot around the axle that connects green sliders.

Yellow stylus and red spherical milling cutters are on the violet conrod.

Move (by hand) the stylus on upper surface of cyan model, the cutters create corresponding surfaces on yellow works.

The stylus and the cutter diameters must be equal to get cut surfaces and model one identical.



### Wood 3D copy milling machine 2

[http://youtu.be/dxN5TNR\\_4WY](http://youtu.be/dxN5TNR_4WY)

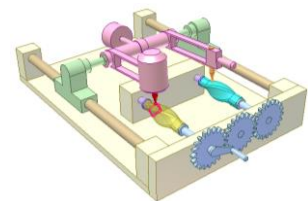
Pink double crank carrying orange stylus and red spherical milling cutter can pivot on axle of green double slider that can move along two brown rods.

Move (by hand) the stylus along the cyan model and turn (by hand) blue gear crank, the cutter create 3D surface on yellow work corresponding to the model surface.

Distances from the stylus and the cutter to base plan must be equal and their spherical diameters must be equal to get cut surface and model one identical.

See a real machine:

<https://youtu.be/dskTOImPJ0o>



### Wood 3D copy milling machine 3

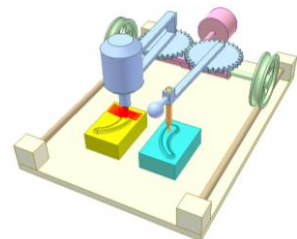
<http://youtu.be/x4zuhNgtR5l>

Pink tube can pivot on axle of green wheels that can roll along two brown rods.

The pink tube carries a drive of two identical gears. Motor with red spherical milling cutter is on one gear, orange stylus is on the other.

Move (by hand) the stylus on upper surface of cyan model, the cutter creates on yellow work a corresponding symmetrical surface.

Distances from the stylus and the cutter to base plan must be equal and their spherical diameters must be equal to get cut surface and model one identical (symmetrically).



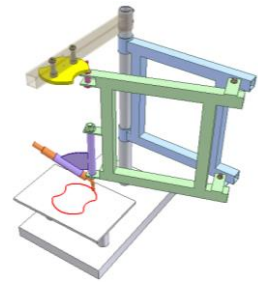
### Plasma tracer

<https://youtu.be/vkNi64cOqK4>

The operator moves pink tracer along stationary yellow sample and orange torch cuts out the product of the sample shape. Blue frame has revolution joints with the base and with the green frame.

The tip of the torch must be set to be always on the pink tracer axis. The animation was made based on video:

<http://www.rottenleonard.com/Plasma-Tracer.html>



### Bar pantograph 1

<http://youtu.be/9H5hSLaRPTQ>

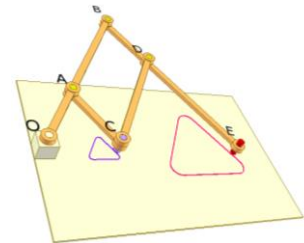
ABCD: parallelogram.

OCE: straight line

O: immobile

$OE/OC = BE/BD = k = \text{constant}$

Figures traced by pen E and pen C are similar. Scale factor is k.



### Bar pantograph 2

<http://youtu.be/p8SDBkLV4mg>

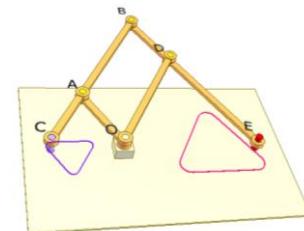
OABD: parallelogram.

COE: straight line

O: immobile

$OE/OC = DE/BD = k = \text{constant}$

Figures traced by pen E and pen C are similar but upside down each other when O is between C and E. Scale factor is k.



### Bar pantograph 3

<http://youtu.be/-Y8lyDkJpL0>

OBCD: parallelogram.

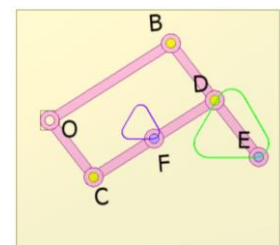
OFE: straight line

O: immobile

$OE/OF = BE/BD = k = \text{constant}$

Point O or F do not necessarily coincide with an vertex of the parallelogram.

Figures traced by pen E and pen C are similar. Scale factor is k.



### Bar pantograph 4

<http://youtu.be/kjlwFXx2GI4>

ABDC: parallelogram.

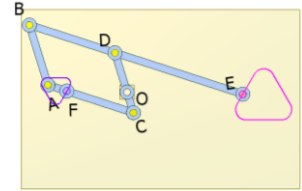
FOE: straight line

O: immobile

$OE/OF = OD/OC = k = \text{constant}$

Point O or F do not necessarily coincide with a vertex of the parallelogram.

Figures traced by E and F are similar but upside down each other when O is between F and E. Scale factor is k.



### Bar pantograph 5a

<http://youtu.be/oAhVbYOCBAK>

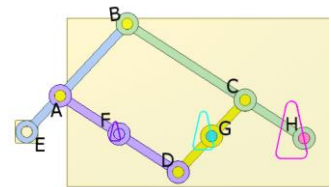
ABDC: parallelogram.

EFGH: straight line

E: immobile

Point E, F, G and H do not necessarily coincide with vertices of the parallelogram.

Figures traced by pens F, G and H are similar.



### Bar pantograph 5b

<http://youtu.be/N0grDs9phHg>

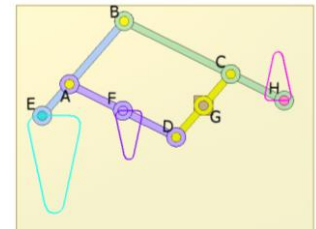
ABDC: parallelogram.

EFGH: straight line

G: immobile

Point E, F, G and H do not necessarily coincide with vertices of the parallelogram.

Figures traced by pens E, F and H are similar.



### Bar pantograph 6

<http://youtu.be/pGTyCtDIqBU>

OABC: parallelogram.

Triangles ADB and CBE are similar.

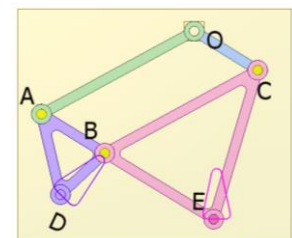
Triangles DAO, DBE and OCE are similar.

Triangles ODE and ABD are similar.

O: immobile

Figures traced by pen E and pen D are similar but figure D is turned an angle DAB in comparison with figure E.

Scale factor is  $k = AD/AB = CB/CE = \text{constant}$ .



### Bar pantograph 7a

<http://youtu.be/ZHWpj2dmMA8>

ABCD: parallelogram

OCE: straight line

O: immobile

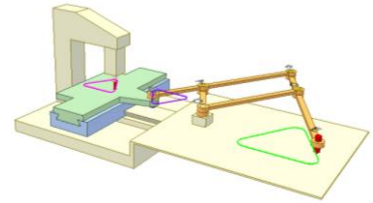
$OE/OC = BE/BD = k = \text{constant}$

Figures traced by pointer E and pin C are similar. Scale factor is k.

This is the case when the red tool is immobile (not installed in place of pin C) and the orange pantograph is connected to a system of two sliders (by pin C and a hole of the green plate). The tool traces pink figure on the upper slider. It has same size with the figure traced by pin C but upside down each other.

Instead of system of two sliders another one can be used, provided that it enables the green plate to move translationally.

Several workpieces can be machined at the same time when many tool spindles are arranged.



### Bar pantograph 7b

<http://youtu.be/E2t-rz36CcM>

ABCD: parallelogram

OCE: straight line. O: immobile

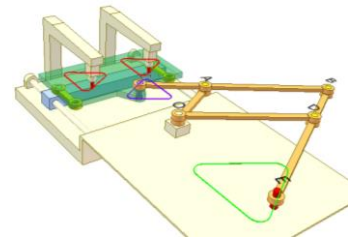
$OE/OC = BE/BD = k = \text{constant}$

Figures traced by pointer E and pin C are similar.

Scale factor is k.

This is the case when the red tools are immobile (not installed in place of pin C) and the orange pantograph is connected to system of slider and parallelogram (by pin C and a hole of the green plate). The system enables the green plate to move translationally.

Red tools trace red figures on the green plate. They have same size with the figure traced by pin C but upside down. Two workpieces are machined at the same time.



### Bar pantograph 8

<http://youtu.be/3h3NMbycOkk>

ABOD: parallelogram

OCE: straight line. O: immobile

$OE/OC = BE/BD = k = \text{constant}$

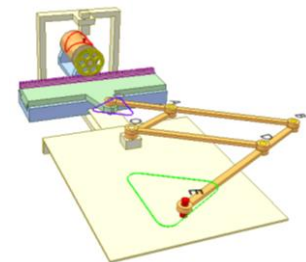
Figures traced by pointer E and pin C are similar.

Scale factor is k.

This is the case when red tool is immobile (not installed in place of pin C) and the orange pantograph is connected to system of two sliders (by pin C and a hole of the green plate).

A rack-pinion drive turns orange cylinder installed on the blue lower slider. Pitch diameter of the pinion and diameter of the cylinder are equal.

The tool traces red figure (having same size with the figure traced by pin C) on cylindrical surface of the cylinder. Meshing place of the rack-pinion drive (at upper or lower portion of the pinion) affects direction of the figure traced on the cylinder.



### Bar pantograph 9

<https://youtu.be/3hy452y4Ccl>

This 3D copying mechanism is based on “Reproducing a planar trajectory 3a” shown in

<https://youtu.be/hOXci0HZcwU>

Brown bar pivots in the vertical plan.

Red tracer of the brown bar moves on yellow sample and blue spherical milling cutter creates 3D surface on the pink work.

Length of blue bars:  $a + b$ . Here  $b = a$

Length of green bars:  $a$

Length of violet bars:  $b$

Reducing copy ratio:  $i = a/(a+b) = 1/2$

Length of orange bar:  $x$

Length of pink bar:  $y$

Distance between two fixed pivots of the blue bars:  $z$

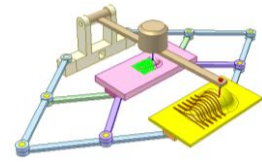
Condition to get orange and pink bars translate:  $(y-x)/(z-x) = b/(a+b)$

Length of brown bar:  $e + f$

Condition to get right reducing copy ratio  $i$  in vertical direction:

$e/(e+f) = a/(a+b) = 1/2$

Because the tracer does not move exactly vertically so there is some error for the created surface.



### Gear pantograph 1

<http://youtu.be/slQuUX2kgxo>

Green and blue gears have same tooth number.

OCD: straight line

AC and BD are parallel.

Triangles OAC and OBD are similar.

$OC/OD = OA/OB = AC/BD = k = \text{constant}$

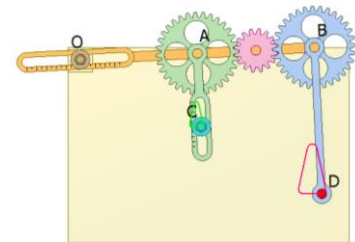
O: immobile

Figures traced by pen E and pen C are similar. Scale factor is  $k$ .

Adjust OA and AC to get various values of  $k$ .

Bar linkage in a conventional pantograph is replaced by gear drive.

Instead of 3 gear drive a rack and two pinion drive can be used.



### Gear pantograph 2

<http://youtu.be/tVe5YADt4KE>

Green and blue gears have same tooth number.

COD: straight line

AC and BD are parallel.

Triangles OAC and OBD are similar.

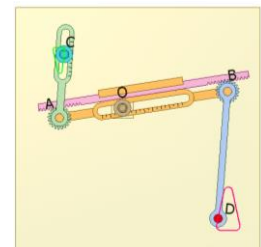
O: immobile

$OC/OD = OA/OB = AC/BD = k = \text{constant}$

Figures traced by pen D and pen C are similar but upside down each other. Scale factor is  $k$ .

Adjust OA and AC to get various values of  $k$ .

Bar linkage in a conventional pantograph is replaced by rack pinion drive.





### Belt pantograph 1

<http://youtu.be/5G4Qb3VeUA>

Green and blue pulleys have same diameter.

COD: straight line

AC and BD are parallel.

Triangles OAC and OBD are similar.

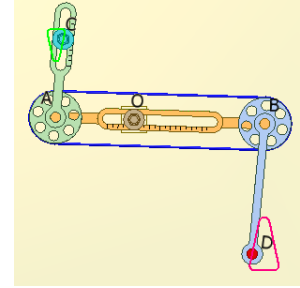
O: immobile

$OC/OD = OA/OB = AC/BD = k = \text{constant}$

Figures traced by pen D and pen C are similar but upside down each other. Scale factor is k.

Adjust OA and AC to get various values of k.

Bar linkage in a conventional pantograph is replaced by belt drive.

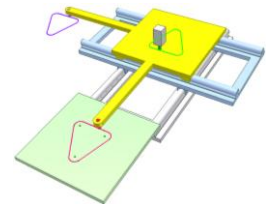


### Reproducing a planar trajectory 1

<https://youtu.be/fG48K40OWJ8>

Red planar trajectory traced by a red point on green table can be transferred to other place thanks to a system of two prismatic joints. The yellow table and blue slider move perpendicularly to each other. The yellow table planarly translates. Each point on it reproduces the red trajectory (violet curve) thus the multiplying is possible.

A stationary point traces on the yellow table a curve that is the red trajectory flipped two times around longitudinal and traversal axes of the mechanism (or turned 180 deg. in its plane).

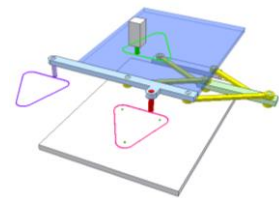


### Reproducing a planar trajectory 2

<https://youtu.be/F8QoiwChTxg>

Red planar trajectory traced by a red point on grey table can be transferred to other place thanks to a system of two parallelogram mechanisms. The blue table planarly translates. Each point on it reproduces the red trajectory (violet curve) thus the multiplying is possible.

A stationary point traces on the blue table a curve that is the red trajectory flipped two times around longitudinal and traversal axes of the mechanism (or turned 180 deg. in its plane).

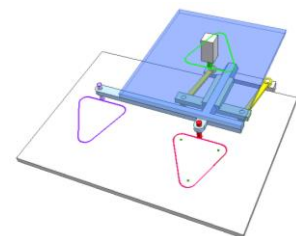


### Reproducing a planar trajectory 3

<https://youtu.be/xM34GYJ4qK0>

Red planar trajectory traced by a red point on grey table can be transferred to other place thanks to a system of a parallelogram mechanism of two yellow rockers and a prismatic joint of green ruway. The blue table planarly translates. Each point on it reproduces the red trajectory (violet curve) thus the multiplying is possible.

A stationary point traces on the blue table a curve that is the red trajectory flipped two times around longitudinal and traversal axes of the mechanism (or turned 180 deg. in its plane).



### Reproducing a planar trajectory 3a

<https://youtu.be/hOXci0HZcwU>

Black planar trajectory traced by the middle point of orange bar can be transferred to other place thanks to a system of two pantograph mechanisms.

Orange and pink bars that connect the two pantographs translate. Each point of the orange bar reproduces the black trajectory (orange curve) thus the multiplying is possible.

Each point of the pink bar gives reducing copies of the black trajectory (green and violet curve).

Length of blue bars:  $a + b$ . Here  $b = 2a$

Length of green bars:  $a$

Length of yellow bars:  $b$

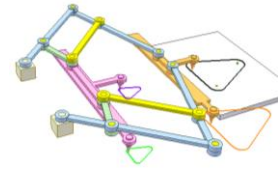
Reducing copy ratio:  $i = a/(a+b)$ . Here  $i = 1/3$

Length of orange bar:  $x$

Length of pink bar:  $y$

Distance between two fixed pivots of the blue bars:  $z$

Condition to get orange and pink bars translate:  $(y-x)/(z-x) = b/(a+b)$



### Reproducing a planar trajectory 3b

<https://youtu.be/DwqNQbo07Sk>

Black planar trajectory traced by the violet point can be copied with reducing ratio to other place thanks to a system of two pantograph mechanisms. They are connected together through violet pin and pink bar.

Each point of the pink bar gives reducing copies of the black trajectory (green curves).

Length of blue and violet bars:  $a + b$ . Here  $b = 2a$

Length of green bars:  $a$

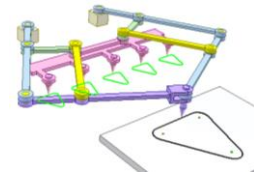
Length of yellow bars:  $b$

Reducing copy ratio:  $i = a/(a+b) = 1/3$

Length of pink bar:  $y$

Distance between two fixed pivots of the blue bars:  $z$

Condition to get pink bar translate:  $y/z = b/(a+b)$



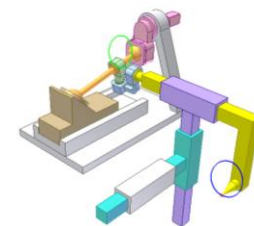
### Reproducing a spatial trajectory 1

[https://youtu.be/pSUHspv\\_BFc](https://youtu.be/pSUHspv_BFc)

Green spatial trajectory traced by a point on orange conrod of a spatial mechanism can be transferred to other place thanks to a spherical joint and three sliders (yellow, violet and cyan) moving perpendicularly to each other. Yellow slider spatially translates. Each point on it reproduces the orange trajectory (blue curve) thus the multiplying is possible.

Here spherical joint between the orange conrod and blue part is replaced with Hook joints. See "Spherical joint of large turning angle  $2\alpha$ ":

<https://youtu.be/XupyXgd30h8>

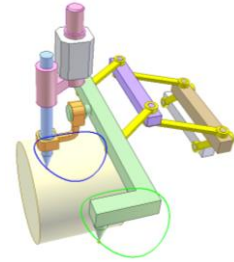


## Reproducing a spatial trajectory 2

[https://youtu.be/W7Y5\\_L0EBdo](https://youtu.be/W7Y5_L0EBdo)

Blue spatial trajectory traced by a point on blue slider can be transferred to other place thanks to a orange joint and three parallelogram mechanisms (green, violet, brown conrods and yellow bars). The green conrod spatially translates. Each point on it reproduces the blue trajectory (green curve) thus the multiplying is possible.

In general the orange joint between the blue slider and the green conrod must be spherical. Center of the spherical joint coincides with the point that traces the blue trajectory. But in this special case no problem if the blue slider and the green conrod are fixed together by the orange part.



## Linkage for tracing inverse figures

<https://youtu.be/1Ov7a7R5fO8>

Lengths of pink and blue bars:  $b/2 + b/2 = b$

Lengths of green bars:  $a$

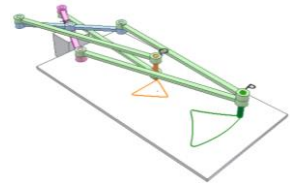
The linkage maintains always:

Points A, P and Q are in line.

$AP \cdot AQ = (a \cdot a - b \cdot b) = \text{constant}$

P and Q trace figures (in orange and green) that are inverse to each other.

If Q moves following a circle, P traces a circle.

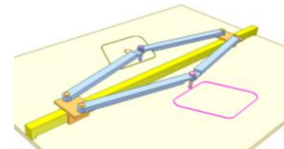


## Instrument for tracing a symmetric curve 1

<http://youtu.be/rpWT0MskXhA>

Blue links have the same length.

Move violet tracer along a given curve (a rhombus in this case), pink pen traces pink curve that is symmetric to the given curve about the centerline of the yellow runway.



## Instrument for directional scaling 1

<http://youtu.be/HHfAIO4CQS8>

Affinograph.

Blue links have the same length.

Green links have the same length.

Blue and green links create a rhombus.

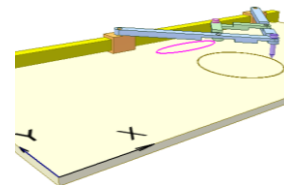
Move violet tracer along a given curve (a circle in this case), pink pen traces pink curve (an ellipse in this case). It is the given curve scaled only in Y direction.

Y-scale factor:  $k_y = B / (B - 2G)$

B: length of the blue link

G: length of the green link

X-scale factor:  $k_x = 1$



### Instrument for directional scaling 2

<http://youtu.be/yBvjB9tYCew>

Affinograph.

Blue, green, violet and pink links create a parallelogram.

Green, brown and pink links create a right triangle.

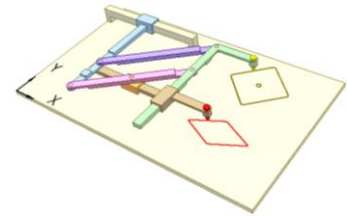
Move yellow tracer along a given curve (a square in this case), red pen traces red curve (a rhombus in this case). It is the given curve scaled only in Y direction.

Y-scale factor:  $k_y = P1/P2$

P1: distance between end revolution joints of the pink link.

P2: distance between middle revolution joint of the pink link and end revolution joint of the blue link.

X-scale factor:  $k_x = 1$

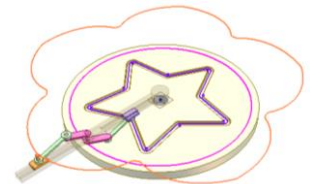


### Symmetry over a circle

<https://youtu.be/KP394x5n0NA>

Orange curve is the symmetric one of the violet curve over pink circle. A double slider crank mechanism ensures that distances from violet and orange curves to the pink circle along its radial direction are always equal.

It can be used in cake decorations.



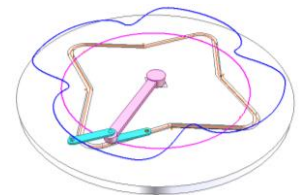
### Symmetry over a point moving on a circle

<https://youtu.be/6tAronouPto>

Blue curve is the symmetric one of the orange curve over a point that moves on the pink circle.

Crank radii of the blue double crank are equal.

It can be used in cake decorations.



### Curve enlarging and reducing 1

<https://youtu.be/owLo-qXPJnA>

Violet part slides in dovetail slot of white crank.

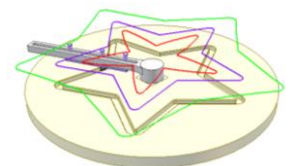
When the crank rotates points of the violet slider trace curves.

Violet curve and center curve of the groove on the yellow cam are identical.

Red and green curves can be considered as created from violet curve.

Distance between two curves along the white crank is constant.

It can be used in cake decorations.



## 20. Mechanisms for math operations

### Cable adding mechanism

<http://youtu.be/56mtxOTCezM>

Two ends of the cable are fixed to the base.

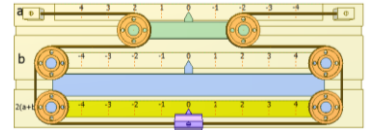
Move the green slider to enter value a.

Move the blue slider to enter value b.

The violet cursor (fixed to the cable) gives value  $2(a+b)$ .

The video shows the operation  $2(0.5 + 1) = 3$  and the return to initial position.

For getting value  $(a+b)$  to connect the violet cursor to further mechanism such as to the pink slider in video "Cable drive 3" of this channel.



### Linkage adding mechanism 1

[http://youtu.be/e\\_zW20jO48I](http://youtu.be/e_zW20jO48I)

Turn the violet crank to enter value X.

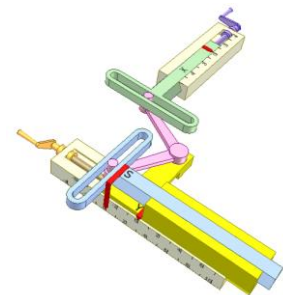
Turn the orange crank to enter value Y.

The red arrow on the blue slider shows  $S = X + Y$  (algebraic addition).

The video shows the operation  $2 + 4 = 6$  and the return to initial position.

The slot on the green slider must be parallel to the sliding direction of the blue slider in order to keep the independence between X and Y entering.

Angle of the pink arm is  $A = 90$  deg. Angle between sliding directions of the green and blue sliders is  $B = 90$  deg. This ensures that the displacements of the green slider and the blue one are equal when the yellow slider is immobile.



### Linkage adding mechanism 2

[http://youtu.be/C\\_OQr\\_8aelU](http://youtu.be/C_OQr_8aelU)

Combination of two pantograph mechanisms.

Yellow and orange bars create a rhombus.

Center distances from middle hole to end holes of yellow bar are equal.

Pink, violet, grey and green bars create a rhombus.

Center distances from middle hole to end holes of pink or green bar are equal.

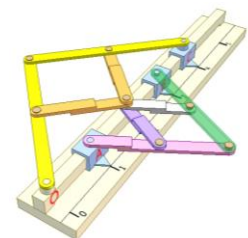
The mechanism ensures:  $OA + OB = OC$

Move slider A to enter value X

Move slider B to enter value Y

Slider C shows  $S = X + Y$

The video shows the operation  $1 + 3 = 4$  and the return to initial position.



### Linkage multiplication mechanism 1

<http://youtu.be/U262eypJ7ik>

Move blue T-bar to enter positive number x

Move yellow slider to enter positive number y

Orange T-bar shows  $z = x \cdot y$

At point C there are 3 pink sliders (sliding in slots of violet, orange and blue bars respectively) connected together by revolution joints. The screw lead must be large enough to avoid self-locking.

The video shows operation  $40 \cdot 50 = 2000$  and then  $50 \cdot 80 = 4000$ .

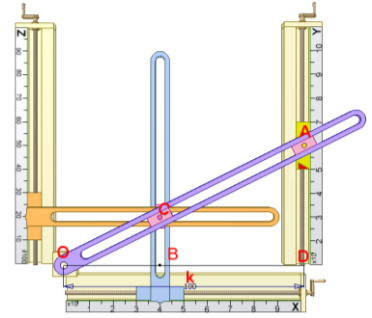
The mechanism works on congruent triangles rule. From triangles OBC and OAD:  $OB/OD = BC/AD$

$OB = x$  ;  $AD = y$  ;  $BC = z$  ;  $OD = k = 100 \text{ mm}$  (constant) then  $z = (xy)/k$

For the X and Y scale, 1 mm corresponds 1 unit.

For the Z scale, 1 mm corresponds 100 units.

The division  $x = z/y$  can be performed on this mechanism: enter z and y and get x.



### Linkage square root mechanism 1

<http://youtu.be/mUGOtdwxvYI>

Move blue T-bar to enter positive number x to be squared.

Orange T-bar shows  $z = x^2$

Move orange T-bar to enter positive number z to be rooted. Blue

T-bar shows  $x = \sqrt{z}$

At point C there are 3 pink sliders (sliding in slots of violet, orange and blue bars respectively) connected together by revolution joints. The screw lead must be large enough to avoid self-locking.

The video shows operation  $40^2 = 1600$  or  $\sqrt{1600} = 40$  and then  $70^2 = 4900$  or  $\sqrt{4900} = 70$ .

The mechanism works on congruent triangles rule.

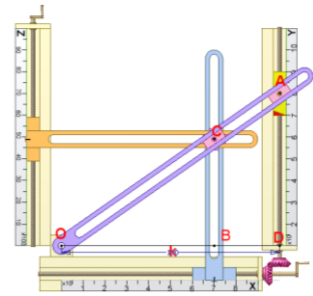
From triangles OBC and OAD:  $OB/OD = BC/AD$

$OB = x$  ;  $AD = y$  ;  $BC = z$  ;  $OD = k = 100 \text{ mm}$  (constant) then  $z = (xy)/k$

Because pink bevel gears have the same tooth number and their screws have the same lead, so  $x = y$  hence  $z = (x^2)/k$  or  $x = \sqrt{z \cdot k}$

For the X and Y scale, 1 mm corresponds 1 unit.

For the Z scale, 1 mm corresponds 100 units.



### Square and cube linkage

<https://youtu.be/6u5mN6Y2NZw>

Move brown slider to enter positive number x to be squared or cubed.

Violet slider shows  $y = (x^2)/k$

Pink slider shows  $z = (x^3)/(k^2)$

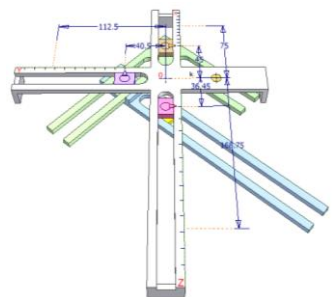
The red letter O is origin of the Cartesian coordinate system.

k: distance between O and center of orange slider (k = 50 in this video).

The video shows:

When  $x = 45$ ;  $y = (45^2)/50 = 40.5$ ;  $z = (45^3)/(50^2) = 36.45$

When  $x = 75$ ;  $y = (75^2)/50 = 112.5$ ;  $z = (75^3)/(50^2) = 168.75$



### Converting polar coordinates to Cartesian coordinates

<http://youtu.be/uBMnVAMafgl>

Turn blue knob A to enter increment of polar angle DA

Turn orange knob R to enter increment of radius DR

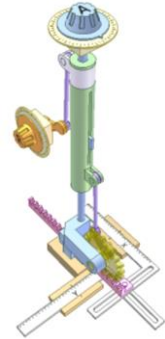
The X scale shows increment along the X axis:  $DX = DR \cdot \cos(DA)$

The Y scale shows increment along the Y axis:  $DY = DR \cdot \sin(DA)$

A pin of the pink rack slides in slots of sliders X and Y.

Two slider-crank mechanisms ensure rotation angles of orange knob and yellow gear equal.

The inverse operation (Cartesian coordinates to polar coordinates) is possible.



### Compass for angle trisection

<http://youtu.be/sxwMGcshJl8>

The compass is created by connecting three similar inverse parallelograms. Similar ratio is 2. Numbering:

0 for the left first fixed prong,

1 for the next prong, ...

and 3 for the last prong,

A1 is angle between prong 1 and prong 0

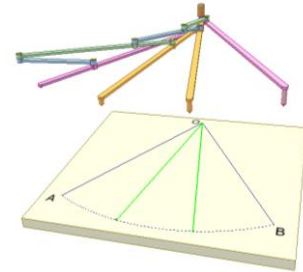
A2 is angle between prong 2 and prong 0

A3 is angle between prong 3 and prong 0

The compass maintains relation:  $A_i = i \cdot A_1$

$i = 1$  to  $3$

i.e.:  $A_2 = 2 \cdot A_1$  ;  $A_3 = 3 \cdot A_1$



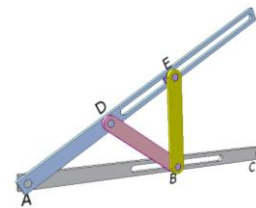
### Linkage for double and triple angles 1

[https://youtu.be/T11ws1\\_tZW8](https://youtu.be/T11ws1_tZW8)

This linkage ensures following angle relations at any position of blue bar:

Angle EDB =  $2 \cdot$  Angle DAB

Angle EBC =  $3 \cdot$  Angle DAB



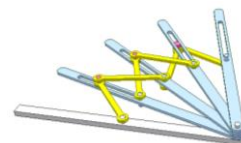
### Linkage for equal angles 1

<https://youtu.be/uTQVi7zskGU>

This linkage ensures that angles between two any adjacent long bars are always equal to each other during motion.

It can be used for the compass for angle trisection shown in

<https://youtu.be/sxwMGcshJl8>



### Bar mechanism of bisector 1

<https://youtu.be/9a3oxnXpOf8>

The grey bar is the bisector of angle between two pink bars at any their position.

Length of blue bars:  $a$

Length of yellow and orange bars:  $a + a$

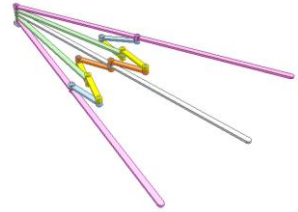
Length of green bars:  $4a$

Distance between revolution joints of pink and grey bars:  $4a$

Green bar is not bisector of adjoining pink and grey bars.

It is a particular case of

<http://youtu.be/gY0oJDQ-uVU>



### Bar gear mechanism of bisector 1a

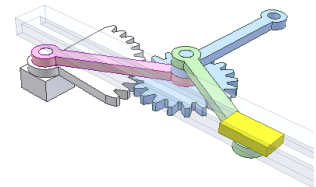
<https://youtu.be/ZBpjnkjSDNw>

If pink bar is set to be the bisector of angle created by green and blue bars at a position of the pink bar, it remains the bisector of the said angle at any other position of the mechanism.

$$Z_g = 2 \cdot Z_b$$

$Z_g$ : complete tooth number of grey gear.

$Z_b$ : tooth number of blue gear.



### Bar gear mechanism of bisector 1b

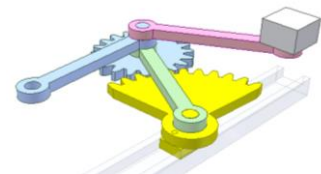
[https://youtu.be/LDsmjUn\\_bvQ](https://youtu.be/LDsmjUn_bvQ)

If green bar is set to be the bisector of angle created by pink and blue bars at a position of the pink bar, it remains the bisector of the said angle at any other position of the mechanism.

$$Z_g = 2 \cdot Z_b$$

$Z_g$ : complete tooth number of yellow gear.

$Z_b$ : tooth number of blue gear.



### Mechanism of proportional line segments

[https://youtu.be/DMMZmRdq\\_o0](https://youtu.be/DMMZmRdq_o0)

Two green bars create a parallelogram.

Two blue bars create a parallelogram.

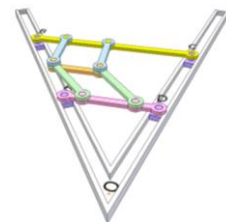
So pink and yellow bars are always parallel.

Mechanism ensures:

$$OA/OB = OD/OC = k = AD/BC = \text{constant}$$

In this video  $k = 1/2$

Point B (or C) moves twice faster than point A (or D).





### Projection of a moving point on a line

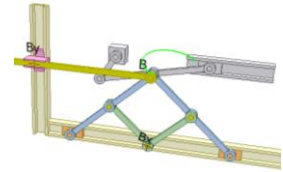
[https://youtu.be/RUAI\\_XvhpDE](https://youtu.be/RUAI_XvhpDE)

Projections  $B_x$  and  $B_y$  of a point  $B$  moving along any curve (in green) on horizontal and vertical axes can be obtained thanks to a pantograph (for horizontal axis in this mechanism) or two slider mechanism (for vertical axis in this mechanism).

Length of blue bars:  $a + a$ .

Length of green bars:  $a$ .

The green curve is created by a slider crank mechanism (in grey).



### Polar planimeter 1

<http://youtu.be/kdxPEZnv-U0>

Instrument for determining the area ( $F$ ) of an arbitrary two-dimensional shape (in red).

Move stylus  $B$  along the periphery of the shape (one complete round), the green roller gives two values:

$B_1$ : initial position angle (in radians)

$B_2$ : final position angle (in radians)

$$F = L.R.(B_1 - B_2)$$

$$L = BC$$

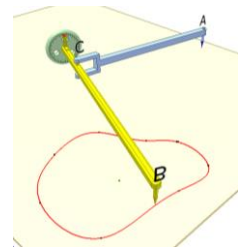
$R$ : radius of rolling circle of the green roller.

The roller rotation axis must be parallel to  $BC$ .

Mathematical basis of the mechanism: integration in polar coordinates.

There must be sufficient friction between the green roller and the ground to prevent slipping.

In real planimeters there is reduction gear drive to ease reading angle values.



### Linear planimeter

<http://youtu.be/qThV6gTaYMI>

Instrument for determining the area ( $F$ ) of an arbitrary two-dimensional shape (in red).

The blue bar can move only linearly in the direction perpendicular to the blue rollers axis.

Move stylus  $B$  along the periphery of the shape (one complete round), the green roller gives two values:

$B_1$ : initial position angle (in radians)

$B_2$ : final position angle (in radians)

$$F = L.R.(B_1 - B_2)$$

$$L = AB$$

$R$ : radius of rolling circle of the green roller.

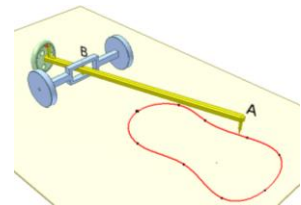
The roller rotation axis must be parallel to  $AB$ .

Mathematical basis of the mechanism: Green's theorem.

There must be sufficient friction between the green roller and the ground to prevent slipping.

Linear planimeters are used for the determination of stretched shapes.

In real planimeters there is reduction gear drive to ease reading angle values.



### Mechanical OR logic gate

[https://youtu.be/\\_UrNLRBwcuQ](https://youtu.be/_UrNLRBwcuQ)

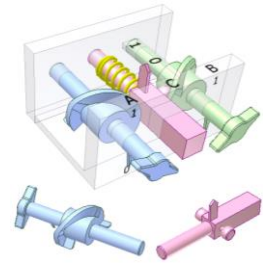
Input: blue and green shafts A, B

Output: pink slider C

Yellow spring forces the slider towards the shaft helical cams.

The video shows four logic states alternately:

1. A = 0; B = 0; C = 0
2. A = 1; B = 0; C = 1
3. A = 0; B = 1; C = 1
4. A = 1; B = 1; C = 1



### Mechanical AND logic gate

<https://youtu.be/Ue9yaG5F4iQ>

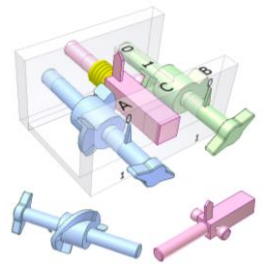
Input: blue and green shafts A, B

Output: pink slider C

Yellow spring forces the slider towards the shaft helical cams.

The video shows four logic states alternately:

1. A = 0; B = 0; C = 0
2. A = 1; B = 0; C = 0
3. A = 0; B = 1; C = 0
4. A = 1; B = 1; C = 1



### Mechanical NAND logic gate

[https://youtu.be/hX\\_d6MkRTJM](https://youtu.be/hX_d6MkRTJM)

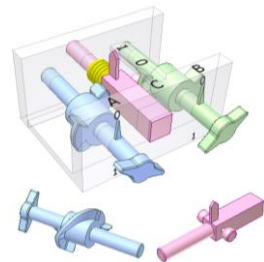
Input: blue and green shafts A, B

Output: pink slider C

Yellow spring forces the slider towards the shaft helical cams.

The video shows four logic states alternately:

1. A = 0; B = 0; C = 1
2. A = 1; B = 0; C = 1
3. A = 0; B = 1; C = 1
4. A = 1; B = 1; C = 0



### Mechanical NOR logic gate

<https://youtu.be/KVkogDxPndA>

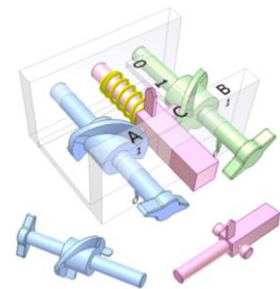
Input: blue and green shafts A, B

Output: pink slider C

Yellow spring forces the slider towards the shaft helical cams.

The video shows four logic states alternately:

1. A = 0; B = 0; C = 1
2. A = 1; B = 0; C = 0
3. A = 0; B = 1; C = 0
4. A = 1; B = 1; C = 0



### Mechanical NOT logic gate

<https://youtu.be/8fBk6GfnHVA>

Input: blue shaft A

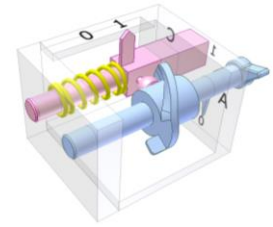
Output: pink slider C

Yellow spring forces the slider towards the shaft helical cam.

The video shows two logic states alternately:

1. A = 0; C = 1

2. A = 1; C = 0



## 21. Mechanisms for object position control

### 21.1. Controlling planar DoF

#### Planar motion control 1a

<http://youtu.be/tZj6O5biJ0M>

Orange object has 3 degrees of freedom in its planar motion: two linear and one angular displacements.

This mechanism can deal with two linear ones.

Relations between coordinates of the object center  $A(x,y)$  and coordinates of pistons ends  $B(t,0)$  and  $C(0,s)$ :

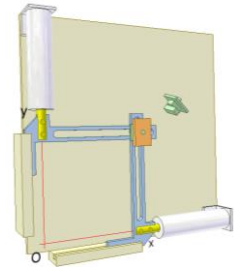
$$x = t$$

$$y = s$$

$x$  and  $t$  are measured along  $Ox$  axis.

Large distance from point  $A$  to the runways is a disadvantage so ball bearing sliders should be used.

Angular position of the object is unstable and needs a control device (not shown).



#### Planar motion control 1b

<http://youtu.be/7OX351jGXeM>

Pink object has 3 degrees of freedom in its planar motion: two linear and one angular displacements.

This pantograph can deal with two linear ones.

Relations between coordinates of the object center  $A(X,Y)$  and coordinates of pistons ends  $B(t,0)$  and  $C(0,s)$ :

$$x = (t+s \cdot \cos\alpha)/2$$

$$y = (s+t \cdot \cos\alpha)/2$$

$\alpha$  is angle between  $Ox$  and  $Oy$

$x$  and  $t$  are measured along  $Ox$  axis.

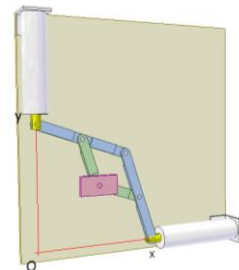
If  $\alpha = 90$  deg.

$$x = t/2$$

$$y = s/2$$

Angular position of the object is unstable and needs a control device (not shown).

Advantage of pantograph: no prismatic joints.



#### Planar motion control 1c

<http://youtu.be/c49hlov2C2l>

Orange object has 3 degrees of freedom in its planar motion: two linear and one angular displacements.

This mechanism can deal with two linear ones.

For object center  $A(x,y)$ :

Left motor controls  $x$  value via screw-nut drive.

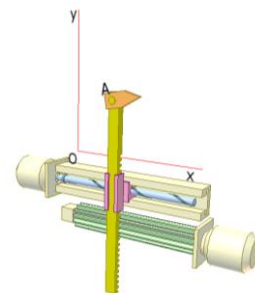
Right motor controls  $y$  value via rack-pinion drive.

Angular position of the object is unstable and needs a control device (not shown).

For angular control devices refer to:

<http://youtu.be/cMA1BmS-Ptk>

<http://youtu.be/GMVuvjjDMPs>



### Planar motion control 1d

<http://youtu.be/wQz2YepAH4k>

Orange object has 3 degrees of freedom in its planar motion: two linear and one angular displacements.

This mechanism can deal with two linear ones  $x, y$ .

They are controlled based on the polar coordinate system

The object center  $A$  is determined by distance  $r$  from a fixed point  $O$  and angle  $\varphi$  from fixed direction  $Ox$ .

$$x = r \cdot \cos\varphi$$

$$y = r \cdot \sin\varphi$$

The video shows how the mechanism moves the object to get distance  $r$  and then angle  $\varphi$ .

Lower motor controls  $r$  value.

Upper motor controls  $\varphi$  value.

There is a helical joint between pink slider and blue shaft.

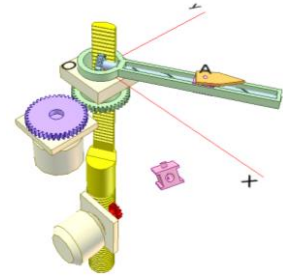
Round rack on lower half of the yellow shaft allows independent operation of the motors.

Angular position of the object is unstable and needs a control device (not shown).

For angular control devices refer to:

<http://youtu.be/cMA1BmS-Ptk>

<http://youtu.be/GMVuvjjDMPs>



### Controlling two linear motions of an object 1a

<https://youtu.be/lkM2K7CsiHo>

This is called as Hbot mechanism.

Hbot = H-shaped robot.

Linear motions of orange object along  $X$  and  $Y$  axes are controlled by pink and green driving pulleys.

One branch of the black timing belt is fixed to the orange block, the other branch goes through it.

When pink and green pulleys rotate in opposite directions at the same velocity, the object moves along  $X$  axis.

When pink and green pulleys rotate in the same direction at the same velocity, the object moves along  $Y$  axis.

The green line is trajectory of a point on the object.

The mechanism can be used for 3D printers.

When the pink pulley turns  $P$  deg. clockwise (the green one is immobile) the orange object displacements are:

$$\text{Along } X \text{ axis: } \Delta X_p = - \text{Pi} \cdot D \cdot P / 720$$

$$\text{Along } Y \text{ axis: } \Delta Y_p = - \text{Pi} \cdot D \cdot P / 360$$

When the green pulley turns  $G$  deg. clockwise (the pink one is immobile) the orange object displacements are:

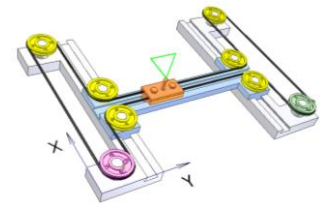
$$\text{Along } X \text{ axis: } \Delta X_g = \text{Pi} \cdot D \cdot G / 720$$

$$\text{Along } Y \text{ axis: } \Delta Y_g = - \text{Pi} \cdot D \cdot G / 360$$

$$\text{Pi} = 3.1416$$

$D$ : pulley diameter.

Programming driving pulley motion to get desired trajectory of the orange object is not easy.



### Controlling two linear motions of an object 1b

<https://youtu.be/nzxGOKhHSY>

Linear motions of violet slider along X and Y axes are controlled by orange and green driving pulleys.

The black timing belt is fixed to the violet slider.

When orange and green pulleys rotate in opposite directions at the same velocity, the slider moves along Y axis.

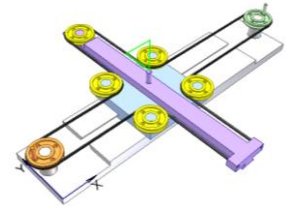
When orange and green pulleys rotate in the same direction at the same velocity, the slider moves along X axis.

When only one driving pulley rotates, the violet slider moves obliquely.

The green line is trajectory of a point on the slider.

The mechanism can be used for 3D printers.

Disadvantage: the violet slider mass is large.



### Controlling two linear motions of an object 3

<https://youtu.be/fW7jzLN-w>

This is called as CoreXY mechanism.

Linear motions of violet object along X and Y axes are controlled by red and orange driving pulleys.

The black timing belt is fixed to the violet object. It connects the red driving pulley with pink pulleys.

The red timing belt is fixed to the violet object. It connects the orange driving pulley with yellow pulleys.

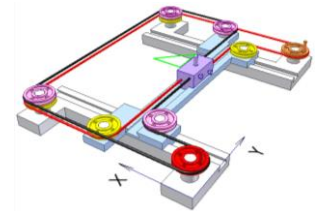
When red and orange pulleys rotate in opposite directions at the same velocity, the object moves along X axis.

When red and orange pulleys rotate in the same direction at the same velocity, the object moves along Y axis.

When only one driving pulley rotates, the violet object moves obliquely.

The green line is trajectory of a point on the object.

The mechanism can be used for 3D printers.



### Controlling two linear motions of an object 2

<https://youtu.be/XJ23ld2GE8w>

Linear motions of violet object along X and Y axes are controlled by pink and orange driving pulleys.

The black timing belt is fixed to blue slider at two points. It connects the pink driving pulley with brown pulleys.

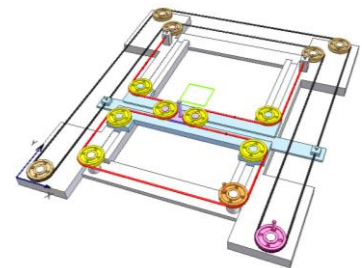
The red timing belt is fixed to the base at two points. It connects the orange driving pulley with yellow pulleys.

The orange pulley controls motion of the object along X axis.

The pink pulley controls motion of the object along Y axis.

The green line is trajectory of a point on the object.

The mechanism can be used for 3D printers.



#### Controlling two linear motions of an object 4

<https://youtu.be/hOXxcvLxli8>

It is the mechanism in “Etch A Sketch”, a drawing toy.

Two ends of the green rail are fixed to black and blue belts.

Two ends of the blue rail are fixed to red and orange belts.

Pink stylus has prismatic joints with the green and blue rails.

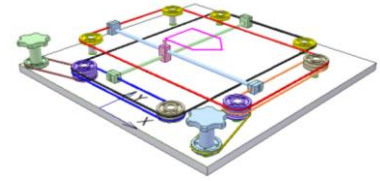
Violet pulleys have 3 belt grooves.

Brown pulleys have 2 belt grooves.

Turn the green knob to move the green rail along X axis (via brown, blue and black belts).

Turn the blue knob to move the blue rail along Y axis (via yellow, orange and red belts).

The pink line is trajectory of the pink stylus.



#### Controlling two linear motions of an object 5

<https://youtu.be/1Gv2FKfgvBo>

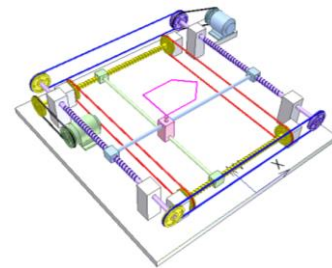
Green motor moves the green rail along X axis (via belt and yellow screw-nut drives).

Blue motor moves the blue rail along Y axis (via belt and violet screw-nut drives).

Pink stylus has prismatic joints with the green and blue rails.

The pink line is trajectory of the stylus.

The mechanism can be used for 3D printers.



#### Controlling two linear motions of an object 6

<https://youtu.be/khU1YqOIRZU>

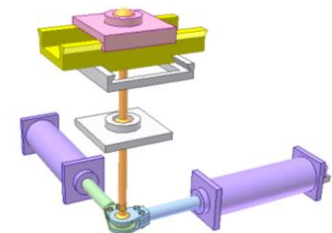
The motion of pink object along two perpendicular horizontal axes is controlled by two grounded violet actuators.

Orange vertical bar has spherical joints with blue and green pistons, point on line (sphere in cylindrical hole) joints with the white base and the pink object.

For the orange vertical bar, the middle sphere is at the bar center (distances between two adjacent spheres are the same).

Position of the pink object in the horizontal plane is determined by the displacements of two pistons.

Approximately, the displacement of the blue piston is equal to the one of the pink object along the yellow slider. The displacement of the green piston is equal to the one of the yellow slider along the base white runway.



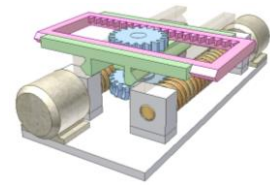
### Controlling 2 linear motions of an object 1

<https://youtu.be/roD6pfjI8cA>

The motion of pink frame along two perpendicular horizontal axes is controlled by two grounded brown motors. This mechanism is developed from the one shown at:

<https://youtu.be/gU0wqocH7tQ>

When the motors rotate in the same direction, the frame moves along longitudinal axis. When the motors rotate in different directions, the frame moves along transversal axis.



### Eccentric rotations of two objects

<https://youtu.be/n8E0ulM8cNo>

Yellow disk and lower brown disk rotate eccentrically from only a motion source (pink bevel pinion).

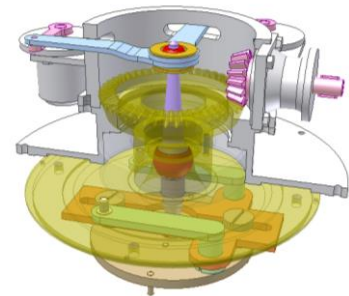
Their eccentricity (value and direction) can be adjusted thanks to two step motors via pink cranks, blue conrods and violet bar.

The latter has central spherical joint with the yellow disk, cylindrical joints with two red spheres at its ends. Two green cranks and orange cross create a parallelogram mechanism. The brown disk has two pins that slide in a slot of the orange cross.

This mechanism is used for ship vertical propellers.

This video was made based on:

<http://observethebanana.com/wp-content/uploads/2008/06/modelvsp.pdf>



### Controlling linear and rotary motions of an object 1

<https://youtu.be/gU0wqocH7tQ>

Linear motion of pink object along longitudinal axis and its rotary motion around vertical axis are controlled by two grounded blue motors. Two worms are identical.

When the motors rotate in the same direction at the same velocity, the object moves linearly only.

When the motors rotate in different directions at the same velocity the object rotates only.

Linear displacement  $L = S \cdot (n_1 + n_2) / 2$

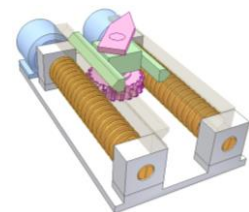
Angular displacement in degrees:  $A = 180 \cdot k \cdot (n_1 - n_2) / Z$

S: lead of the worms of k starts

$n_1, n_2$ : worms revolutions. They are of same sign (+ or -) if the worms rotate in the same direction and vice versa.

Z: tooth number of the pink gear.

Advantage: self-locking feature. So after getting desired position of the pink object there is no need to supply the motors further with the electricity.

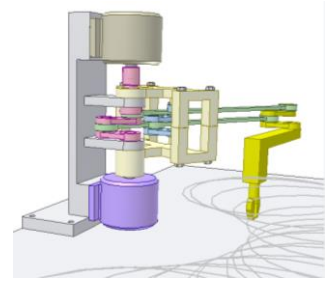




### Mechanism of 2 DoF for robots

<https://youtu.be/kxnLXuNtM7s>

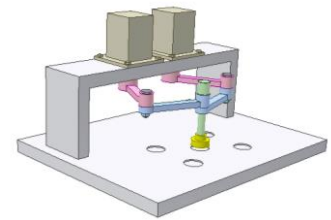
Violet motor controls the rotation of popcorn frame.  
Brown motor controls the rotation of yellow head via pink crank shaft of a double parallelogram mechanism.  
Both motors are installed on the base (grounded).  
Robot working area is shown by grey curves.  
Blue curves show two ways of the motion of yellow gripper between two positions.



### Five-bar parallel robot 1

<https://youtu.be/cPmnAHVEEYM>

The robot has 2 degrees of freedom.  
Input: pink cranks, motions of which are programmed to get desired positions or trajectories of the green tool.  
The video was made based on:  
<https://youtu.be/jYHawaGL90o>



### Five-bar parallel robot 2

[https://youtu.be/dvi\\_3OcbScl](https://youtu.be/dvi_3OcbScl)

The robot has 2 degrees of freedom.  
Input: pink and violet cranks, the motions of which are programmed to get desired positions or trajectories of the green tool.

Here the stationary bar (the base) is a special bar, in which the distance between its two revolution joints is zero. So it is an embodiment of “Five-bar parallel robot 1” shown at:

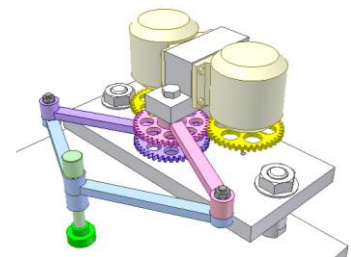
<https://youtu.be/cPmnAHVEEYM>

The video last scene shows:

- When the pink and violet cranks rotate at the same speed but in opposite directions, the green tool traces a radial straight line.
- When the pink and violet cranks rotate at the same speed and in the same direction, the green tool traces a circle.

The video was made based on:

<https://youtu.be/zJleRVHyuiA->



### Controlling linear and rotary motions of an object 2

<https://youtu.be/pe19F4LaWog>

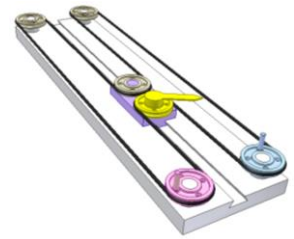
Linear motion of yellow object along longitudinal axis and its rotary motion around vertical axis are controlled by two grounded cranks (in blue and pink). Six pulleys are identical. They are connected together by a closed cable.

Instead of pulleys and cable a chain drive of six sprockets is possible.

When only one crank rotate, the object performs two motions: rotation and translation.

When two cranks rotate in the same direction at the same velocity, the object moves linearly only.

When two cranks rotate in different directions at the same velocity, the object rotates only.



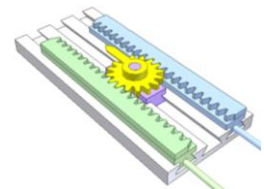
### Controlling linear and rotary motions of an object 3

[https://youtu.be/LxqMH\\_2DcBI](https://youtu.be/LxqMH_2DcBI)

Linear motion of yellow object along longitudinal axis and its rotary motion around vertical axis are controlled by two racks (in blue and green).

When two racks move in the same direction at the same velocity, the object moves linearly only.

When two racks move in opposite directions at the same velocity, the object rotates only. Each rack is connected to a cylinder (not shown).



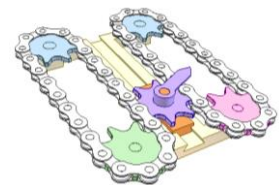
### Controlling linear and rotary motions of an object 4

<https://youtu.be/KBRDFzGqd6k>

Linear motion of violet object along longitudinal axis and its rotary motion around vertical axis are controlled by two chain drives. Their driving sprockets are in pink and green.

When two driving sprockets rotate in the same direction at the same velocity, the object rotates only.

When two driving sprockets rotate in opposite directions at the same velocity, the object moves linearly only.



### Controlling 2 DoF of a series of objects

[https://youtu.be/Wb\\_ymWviVKI](https://youtu.be/Wb_ymWviVKI)

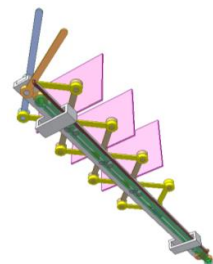
Blue crank controls linear motions of pink plates via a scissor mechanism.

Orange crank controls their 90 deg. rotation via a parallelogram mechanism. The rotation can be performed at any position of the plates.

Each plate has a pin that moves in long groove of green bar.

Long brown rod helps the parallelogram mechanism overcome dead positions.

It can be used for louver or deployable curtain wall (for indoor light control).



### Planar motion control 2a

<http://youtu.be/cMA1BmS-Ptk>

Pink object has 3 degrees of freedom in its planar motion: two linear and one angular displacements.

Two white actuators deal with two linear ones. See:

“Planar motion control 1a”

<http://youtu.be/tZj6O5biJ0M>

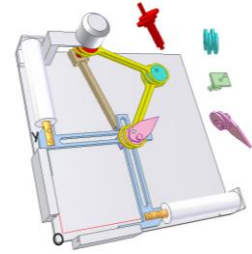
Servo motor turns red shaft and controls angular displacement via a double parallelogram drive. Each of red and pink shafts has 2 eccentrics for overcoming dead positions of the parallelogram mechanisms. So the cyan shaft has 4 eccentrics. Transmission ratio between the red and pink shafts is 1/1. The pink shaft and the object are fixed together.

If the red shaft is immobile, the object **does not** rotate when moving along Ox and Oy axes.

The video shows how the pink object moves along Ox axis, along Oy axis and then rotates.

The parallelogram drive can be applied for “Planar motion control 1b”

<http://youtu.be/7OX351jGXeM> to control the pink object.



### Planar motion control 2b

<http://youtu.be/GMVuvjjDMPs>

Pink object has 3 degrees of freedom in its planar motion: two linear and one angular displacements.

Two white actuators deal with two linear ones via a pantograph (two violet and two blue bars). For more about pantograph see:

“Planar motion control 1b”

<http://youtu.be/7OX351jGXeM>

Servo motor turns red gear and controls angular displacement via 4 bevel gear drive.

Four gears have the same tooth number.

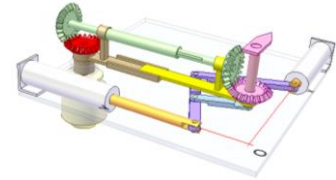
Transmission ratio between the red and pink gear is 1/1.

If the red gear is immobile, the object does not rotate when moving along Ox and Oy axes.

The video shows how the pink object moves along Ox axis, along Oy axis and then rotates.

The 4 bevel gear drive can be applied for “Planar motion control 1a”

<http://youtu.be/tZj6O5biJ0M> to control the orange object.



### Planar motion control 2c

<http://youtu.be/6jppg8GXdgc>

Red object has 3 degrees of freedom in its planar motion: two linear x, y and one angular displacements.

Left motor controls x motion via screw-nut drive.

Right motor controls y motion via rack-pinion drive.

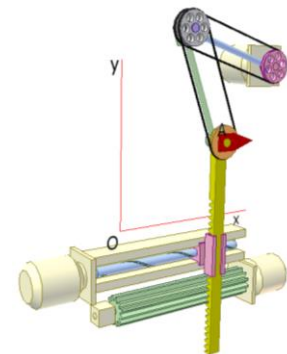
Upper motor turns pink pulley and controls angular displacement via two toothed belt drives (chain drives are possible).

Four pulleys have same diameter (same tooth number).

Transmission ratio between the pink and orange pulleys is 1/1.

If the pink pulley is immobile, the object does not rotate when moving along Ox and Oy axes.

The video shows how the red object moves along Ox axis, along Oy axis and then rotates.



## 21.2. Controlling two spherical DoF

### 2 DoF spherical connection control 1

<https://youtu.be/BwMVrxxZPt8>

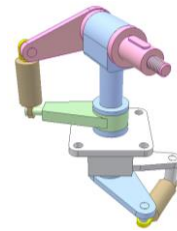
This mechanism is a replacement for spherical joint with a pin (2 degrees of freedom).

Input: two brown actuators.

Output: pink shaft of 2 degrees of freedom (rotations).

Disadvantage: only one actuator is base grounded.

The mechanism is applied for manipulators.



### 2 DoF spherical connection control 2

<https://youtu.be/p5qInBFmQc0>

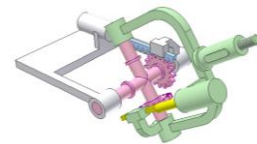
This mechanism is a replacement for spherical joint with a pin (2 degrees of freedom).

Input: two actuators, grey and green.

Output: green shaft of 2 degrees of freedom (rotations).

Disadvantage: only one actuator is base grounded.

The mechanism is applied for manipulators.



### 2 DoF spherical connection control 3

<https://youtu.be/Ja4k5ilYK-g>

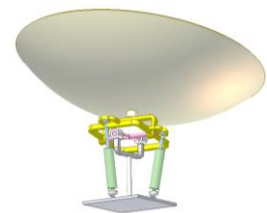
This mechanism is a replacement for spherical joint with a pin (2 degrees of freedom).

Yellow output frame has 2 degrees of freedom (rotations).

When the yellow frame is horizontal, centers of spherical joints between blue pistons and the yellow frame must lay on axis of pink cross shaft to get motion independence of two pistons.

Advantage: two actuators (green cylinders) are base-grounded.

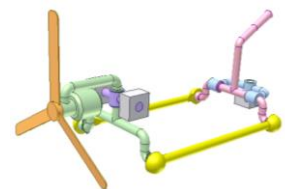
The mechanism can be applied for moving antennas.



### 2 DoF spherical connection control 4

<https://youtu.be/oEOzNl5zQ>

The left 2 DoF spherical joint is controlled from a distance thanks to pink lever of the right 2 DoF spherical joint and two yellow conrods of sphericals joints at their ends.



## 2 DoF spherical connection control 5

<https://youtu.be/WYhf-KRjzhQ>

Blue and orange parts are connected by a spherical joint with a pin (in red). It can be replaced with a Hook joint to get larger rotary angles.

Blue and green parts are connected by a planar joint.

Inputs: orange and green parts.

Output: blue part of 2 degrees of freedom (rotations).

Advantage: motors (not shown) are base grounded.

The combination of input velocities or turning angles gives various output motions or positions.



## Controlling rotation around a point 1b

[https://youtu.be/R-6Uo\\_zinaQ](https://youtu.be/R-6Uo_zinaQ)

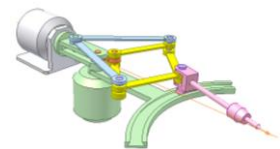
Inputs: green shaft driven by grey motor and orange crank driven by green motor.

Blue and yellow bars create a variant of Peaucelier linkage. See:

<https://youtu.be/1VzRxG1Bq04>

Pink bar moves around a point at various angles.

This mechanism is used for moving the welding head.



## Controlling rotation around a point 1c

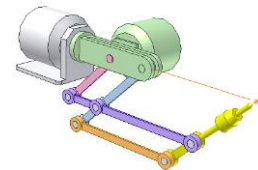
<https://youtu.be/tXufyE5kcl>

Inputs: green shaft driven by grey motor and pink crank driven by green motor.

It is a combination of two parallelogram mechanisms.

Yellow bar moves around a point at various angles.

This mechanism is used for moving the welding head.



## Controlling rotation around a point 1d

<https://youtu.be/PH3NogbMGmM>

Inputs: green shaft driven by grey motor and pink crank driven by green motor.

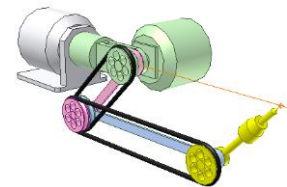
Pulleys of each timing belt (or chain) drive are of equal diameter.

Pink pulley is fixed to pink bar.

Blue pulley is fixed to blue bar.

Yellow bar moves around a point at various angles.

This mechanism is used for moving the welding head.



### Controlling 2 rotations of an object 7

<https://youtu.be/BC4EhwPEa1w>

The rotations of blue gun around two intersecting vertical and horizontal axes are controlled by grounded brown motor and violet linear actuators.

Brown motor makes pink shaft and the gun rotate around vertical axis. Violet linear actuators make yellow bush of inner circular groove move up down thus control the gun rotation around horizontal axis (via sine mechanism).



### Security camera of 2 rotational DOF

<https://youtu.be/Cm-Ae0F1ZbE>

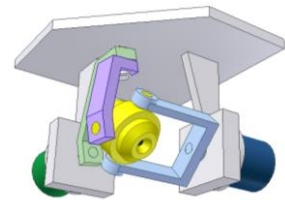
Yellow security camera is controlled by two step motors (grounded) via a spherical mechanism (axes of all five revolution joints are concurrent).

Green and violet bars are connected together by a revolution joint.

See a real mechanism:

<https://www.youtube.com/watch?v=191Wmn9h-GI>

This mechanism can be used for a joystick where the camera plays role of a joystick to control blue and green shafts.



### Robot head of 2 rotation DoF 1

<https://youtu.be/-q6lVE32CuY>

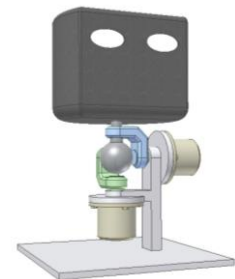
Black head fixed to grey angular part has two degrees of freedom:

- Rotation around vertical axis.
- Rotation around horizontal axis.

Each motion is controlled by a grounded step motor.

It's a spherical mechanism (axes of all five revolution joints are concurrent).

Video scenario: Observation.



### Robot head of 2 rotation DoF 2

<https://youtu.be/7r7VDzcBofE>

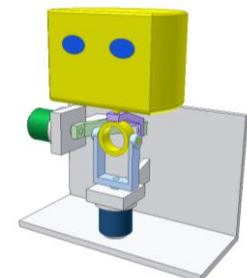
Yellow head fixed to yellow ring has two degrees of freedom:

- Rotation around vertical axis.
- Rotation around horizontal axis.

Each motion is controlled by a grounded step motor. It's a spherical mechanism (axes of all five revolution joints are concurrent).

Green and violet bars are connected together by a revolution joint.

Video scenario: Greeting.



### Robot head of 2 rotation DoF 3

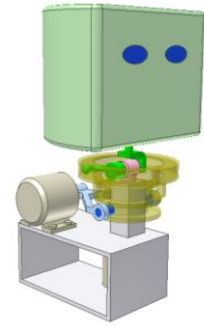
<https://youtu.be/T-Gs3eYWikI>

Green head fixed to green part has two degrees of freedom:

- Rotation around vertical axis (controlled by the vertical step motor via pink vertical shaft).
- Rotation around horizontal axis (controlled by the horizontal step motor).

Both motors are grounded.

Video scenario: Observation.



### Controlling Hooke's joint 2

<https://youtu.be/Ngkn5EIN6qE>

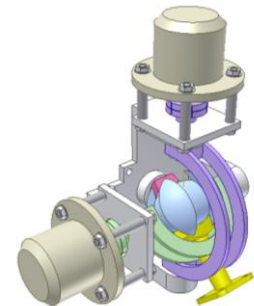
Pink, blue and yellow parts create a Hooke's joint.

Two grounded motors control angular positions of yellow part around 2 perpendicular to each other axes.

Pink part is fixed to the base.

As for the Hooke's joint see:

<https://youtu.be/95bZU6yIEzw>



### 2 DoF spherical connection control 6

<https://youtu.be/EvALwzHBIUQ>

Violet frame pivots around grey base.

Pink gear to which an antenna is fixed, pivots around the violet frame.

Inputs: green and blue gears.

Output: pink gear.

Three small gears are of the same tooth number.

Four yellow gears are identical.

The video shows alternately:

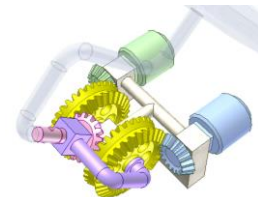
1. When green and blue gears rotate in the same direction and with the same speed, the violet frame is immobile, the pink gear pivots around its own axis.

2. When green and blue gears rotate in opposite directions and with the same speed, the violet frame pivots on its revolute joint with the base, the pink gear does not pivot around its own axis.

Thus the pink gear has 2 degrees of freedom (rotations).

Advantage: motors are base grounded.

The combination of input velocities or turning angles gives various output motions or positions.



## 2 DoF spherical connection control 7

<https://youtu.be/TKoZp0MiN8w>

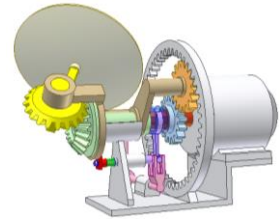
Yellow antenna can turn around two perpendicular axes. Only one motor (in grey) drives it. The mechanism is controlled by pink lever and violet sliding shifter.

The video shows:

1. Clutch (in blue transparent) moves to the right to connect transmission between red motor shaft and blue gear. The clutch has key sliding joint with the motor shaft.
2. Motor starts, red shaft rotates. Brown carrier gets motion through gear satellite drive (blue, orange and grey gears) and the antenna turns around longitudinal axis. Green gear is not kept immobile so its turns together with yellow gear.
3. Motor stops when the antenna reaches needed position.
4. The clutch moves to the left to connect transmission between the motor shaft and green gear and to brake the brown carrier (red brake pad and green spring).
5. Motor starts, red shaft rotates. The antenna turns around traversal axis thanks to bevel gear drive.
6. Motor stops when the antenna reaches needed position.
7. The clutch moves to neutral position.

Advantage: motor is base grounded.

Disadvantage: the antenna can not turn around two axes at the same time.



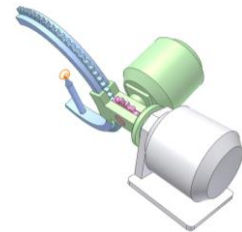
## Controlling rotation around a point 1a

[https://youtu.be/Xf\\_Vik8cCHw](https://youtu.be/Xf_Vik8cCHw)

Inputs: green shaft driven by grey motor and yellow shaft driven by green motor.

Cylindrical bar fixed to blue gear moves around a point at various angles. The bar point moves on a sphere.

This mechanism is used for moving the welding head.



## Controlling 2 rotations of an object 5

<https://youtu.be/EmdYFiPCO2A>

The rotations of blue object of a bevel gear (around two perpendicular axes XX and YY) are controlled by two grounded motors.

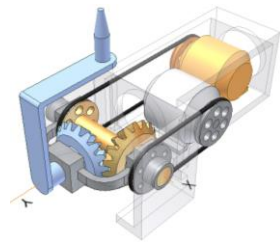
Grey motor makes grey frame rotate around axis XX thus controls the object rotation around axis XX.

Orange motor makes orange gear shaft rotate around axis XX thus controls the object rotation around axis YY.

Motion of the grey motor also affects the object rotation around axis YY. First part of the video shows this phenomenon.

To keep the object do not rotate around axis YY while adjusting the object position around axis XX, the orange motor must rotate together with the grey one. Second part of the video shows this correction.

Motion of the orange motor does not affect the object rotation around axis XX (see third part of the video).





## Controlling 2 rotations of an object 6

[https://youtu.be/ztrsc\\_MPFWQ](https://youtu.be/ztrsc_MPFWQ)

The rotations of blue antenna of a worm gear (around two perpendicular axes XX and YY) are controlled by two grounded motors.

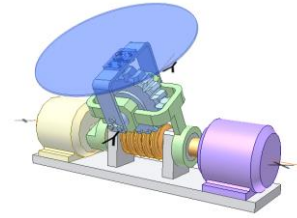
Yellow motor makes green frame rotate around axis XX thus controls the object rotation around axis XX.

Violet motor makes orange worm shaft rotate around axis YY thus controls the object rotation around axis YY.

Motion of the yellow motor also makes the object turn around axis YY a small value that is not easy to be realized. First part of the video shows this phenomenon.

To keep the object do not turn around axis YY while adjusting the object position around axis XX, the violet motor must rotate together with the yellow one (with different speed subject to transmission ratio of the worm drive). Second part of the video shows this correction.

Motion of the violet motor does not affect the object rotation around axis XX (see third part of the video).



## Robot head of 2 rotation DoF 4

<https://youtu.be/UfEwmsozGXE>

Black head fixed to vertical bevel gear has two degrees of freedom:

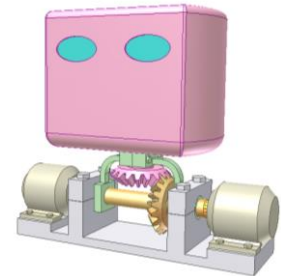
- Rotation around vertical axis (controlled by the right step motor).
- Rotation around horizontal axis (controlled by both step motors).

Their directions and speeds must be identical.

It's a spherical mechanism (axes of all five revolution joints are concurrent).

Both motors are grounded.

Video scenario: Yes/No.



## 2 DoF spherical connection control 8

[https://youtu.be/H\\_xllHoNJ8o](https://youtu.be/H_xllHoNJ8o)

Two bevel gears have the same tooth number.

Two worm gears have the same tooth number.

Two worms are identical.

Inputs:

1. Yellow fork receiving rotation from yellow motor via a worm-gear drive.
2. Blue vertical shaft receiving rotation from blue motor via a worm-gear drive.

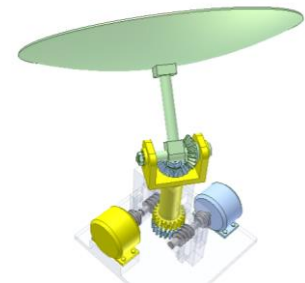
Output: green antenna of 2 degrees of freedom (rotations).

Its elevation angle is controlled by the blue motor (when the yellow motor stops and the blue motor rotates, the green shaft rotates).

Its azimuth angle is controlled by both motors that rotate at the same time to ensure that the yellow fork and the blue vertical shaft turn the same angle in the same direction (the green shaft does not rotate).

Advantages:

- Self-locking feature thanks to the worm-gear drives. So after getting desired position of the antenna, there is no need to supply the motors further with the electricity.
- Both motors are grounded.



## 2 DoF spherical connection control 9

[https://youtu.be/MXfYYSvCO\\_k](https://youtu.be/MXfYYSvCO_k)

Inputs:

1. Orange shaft receiving rotation from orange motor via a worm drive.
2. Popcorn disk receiving rotation from popcorn motor via a worm drive.

Output: brown antenna of 2 degrees of freedom (rotations).

Its azimuth angle is controlled by the popcorn motor.

Its elevation angle is controlled by the orange motor.

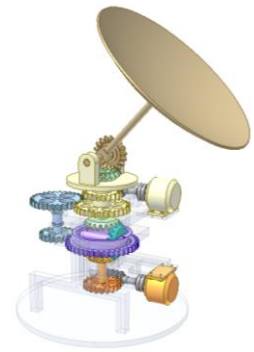
When orange shaft is kept immobile, rotation of the popcorn disk does not make brown bevel gear rotate thus the antenna elevation angle is not changed.

That is ensured by:

1. Bevel gear differential of violet carrier.
2. Spur gear train from yellow gear to violet one. Its transmission ratio is 2.  
Tooth numbers of bevel gears are the same.

Advantages:

- Motions for controlling azimuth and elevation angles are independent of each other and can be carried out at the same time. So the calculation of controlling parameters is simple.
- Self-locking feature thanks to the worm drives. So after getting desired position of the antenna, there is no need to supply the motors further with the electricity.
- Both motors are grounded.



## 21.3. Controlling three spherical DoF

### Spherical connection control 1

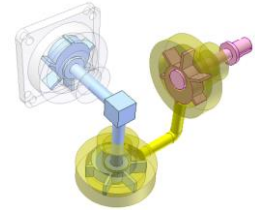
<https://youtu.be/xKKQVEb0pk4>

This is “Spherical connection of large turning angle  $2\alpha$ ” equipped with drives.

Transparent parts represent hydraulic motors.

Disadvantage: only one motor is base grounded.

The mechanism is applied for manipulators.



### Remote control of three rotations

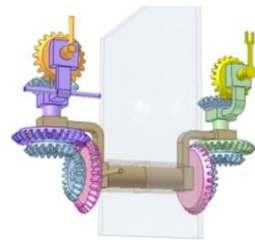
<https://youtu.be/qrOsJi5Gmqg>

The rotations of yellow object around 3 axes perpendicular to each other are controlled from a distance by turning in turn orange, violet and brown levers.

Small gears have the same tooth number.

So do the large gears.

To avoid incidental rotations there must be enough braking friction forces in the revolution joints between orange gear and violet bracket, violet bracket and brown bracket, brown bracket and the base.



### Spherical connection control 2

<https://youtu.be/BgOkUOfRlvs>

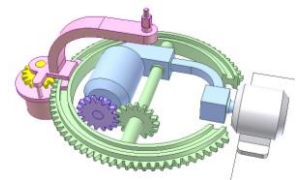
This is “Spherical connection of large turning angle  $2\alpha$ ” equipped with drives.

Joint center is the intersecting point of three rotary axes (blue, green and pink parts).

The video shows the motion caused by grey, blue and pink motors alternately.

Disadvantage: only one motor is base grounded.

The mechanism is applied for manipulators.



### Geared spherical wrist mechanism

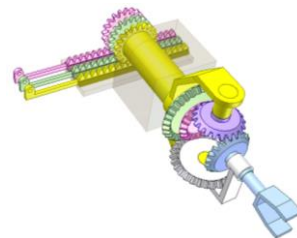
<https://youtu.be/z9kE4TkCGEE>

It is a 3 DoF mechanism.

Inputs: 3 racks in pink, green and yellow.

Output: blue end-effector that can rotate about 3 perpendicular intersecting joint axes.

The combination of 3 input displacements determines the end-effector angular position in space.



### Controlling a disk of 3 rotational DOF

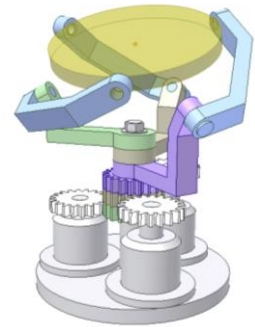
<https://youtu.be/QvzNVPXgNfw>

Yellow disk is controlled by three step motors (grounded) via gear drives and a spherical mechanism (axes of all nine revolution joints are concurrent).

By combination of positions of green, beige and violet bars the disk can reach any angular position in 3D space. However, the calculation is not simple.

See a real mechanism:

<https://www.youtube.com/watch?v=soWiX1eqZq0>



### Controlling Hooke's joint 1

<https://youtu.be/wyVD9Y35dGg>

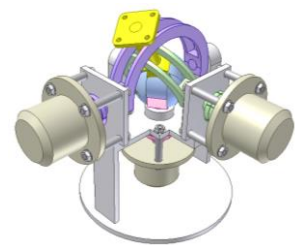
Pink, blue and yellow parts create a Hooke's joint.

Three grounded motors control angular positions of yellow part around 3 perpendicular to each other axes.

The yellow part does not rotate regularly except the position when the yellow and pink parts are in line.

As for the Hooke's joint see:

<https://youtu.be/95bZU6yIEzw>



## 21.4. Controlling three spatial linear DoF

### Tripteron 1

<https://youtu.be/sx0gS7iqg8w>

Pink plate is controlled by three step motors via blue timing belt drives, green sliders, violet and yellow bars.

Each slider is fixed to front branch of its belt.

Axes of three revolution joints of the plate are perpendicular to each other.

The plate is kept always horizontal and can move without rotation in three directions of a Cartesian coordinate system XYZ. Its displacement in X, Y or Z direction is equal to the one of the slider that moves in X, Y or Z direction respectively.

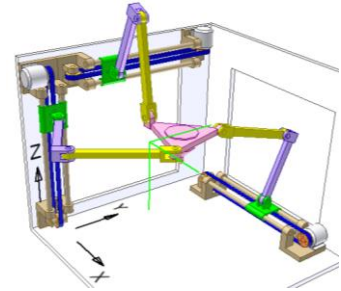
It can be used for 3D printers, pick and place devices.

See a real tripteron:

<https://www.youtube.com/watch?v=beuY401hfh8>

For more see:

<https://reprap.org/wiki/Tripteron>



### Tripteron 2

<https://youtu.be/6aoK7nCJOhM>

Yellow plate is controlled by three step motors via ball screw drives, blue sliders and green bars.

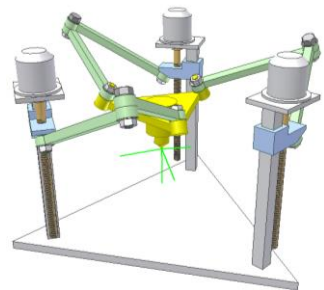
Oblique angles of axes of three revolution joints on the plate are the same.

The video shows the plate motion when the sliders move with the same displacement, first one after another and then at the same time.

The plate is kept always horizontal and moves without rotation. By combination of positions of the sliders the plate can reach any position in 3D space. However, the calculation is not simple.

See a real tripteron:

<https://www.youtube.com/watch?v=gPnnYZwSM38>



## Quadruperon 1

[https://youtu.be/U\\_1fFDmaVrw](https://youtu.be/U_1fFDmaVrw)

Pink plate of 4 DOF is controlled by four step motors via blue timing belt drives, sliders, violet and yellow bars.

Each slider is fixed to front branch of its belt.

Three red parts have revolution joints with the plate and yellow bars.

Blue slider motion makes the plate go along Z axis.

Orange slider motion makes the plate go along X axis.

The motions of two green sliders make the plate go in XY plane and rotate around Z axis.

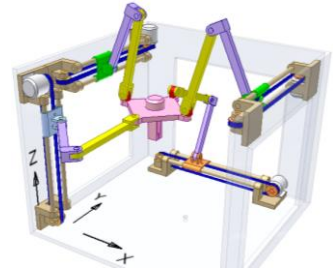
In case the blue and orange sliders are immobile:

- If green sliders move in the same direction and with the same speed, the plate moves along X axis only.

- If green sliders move in opposite directions and with the same speed, the plate moves along Y axis and rotates around Z axis.

See a real mechanism:

<https://www.youtube.com/watch?v=CNeH8c8RvZM>



## Delta robot 1

<https://youtu.be/HiBn9V2ZRKY>

Yellow head is controlled by three step motors via spatial linkage.

Green and pink bars create 3 parallelogram mechanisms. In some designs the revolution joints between them are replaced with spherical ones.

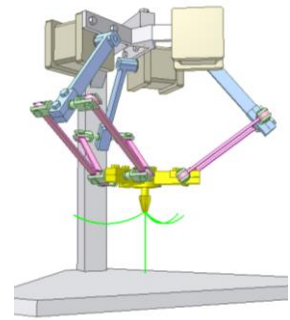
The video shows the head motion from central position when three blue input cranks turn with the same angle, first one after another and then at the same time.

The head is kept always horizontal and moves without rotation. By combination of positions of the input cranks the head can reach any position in 3D space. However, the calculation is not simple.

It can be used for 3D printers, pick and place devices.

See a real mechanism:

<https://www.youtube.com/watch?v=Gv5B63HeF1E>



## Delta robot 2

<https://youtu.be/Z4LTDS7ejFA>

Yellow head is controlled by three step motors via screw drives and spatial linkages. Green and pink bars create 3 parallelogram mechanisms. In some designs the revolution joints between them are replaced with spherical ones.

The video shows the head motion from central position when three blue input sliders move with the same displacement, first one after another and then at the same time.

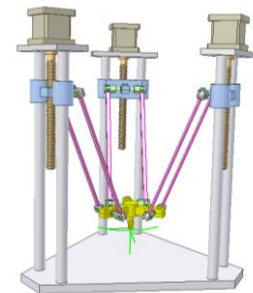
The head is kept always horizontal and moves without rotation. By combination of positions of the input sliders the head can reach any position in 3D space.

However, the calculation is not simple.

It can be used for 3D printers, pick and place devices.

See a real mechanism:

[https://www.youtube.com/watch?v=AYs6jASd\\_Ww](https://www.youtube.com/watch?v=AYs6jASd_Ww)



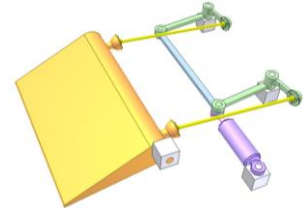
## 21.5. Controlling other cases

### Mechanism for spoiler control

<https://youtu.be/HkWqFFrAZu8>

Input: violet cylinder, piston of which moves blue conrod of a parallelogram mechanism of two green crank.

Output: orange spoiler that rocks thanks to two yellow conrods of spherical joints at their ends.



### Bowden mechanism for robot control 1

<https://youtu.be/mcANMG9A-MA>

In this video the Bowden mechanism is used for motion transmission to a shaft, position of which is variable in relation with the base. It is for 2 DoF robot.

Both motors are grounded.

Brown motor controls blue arm rotation.

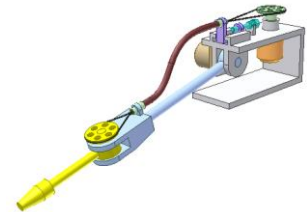
Orange motor controls yellow arm rotation via a Bowden mechanism that consists of green and yellow pulleys, black cable and brown flexible tube.

Ways to avoid cable sliding on the pulleys:

- Tension screw as shown in this video (cyan screw).
- Spring placed between the base and violet slider.
- Fixing the cable to the pulleys at a point, if the pulley rotation is small.
- Wrapping the cable more than one revolution around the pulleys if the pulley rotation is small.

Transmission ratio can differ from 1 if the pulley diameters are different.

For a robot of more DoF, several similar Bowden mechanisms can be used. Advantage: they operate independently from each other.



### Robot head of 2 DoF (up-down and turn) 1

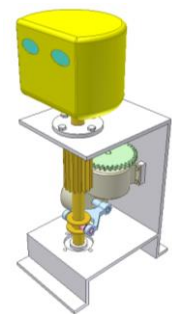
<https://youtu.be/hPa5AVrxpbq>

Yellow head has two degrees of freedom:

- Rotation around vertical axis.
- Translation along vertical axis.

Each motion is controlled by a step motor.

The teeth of yellow pinion slide on the teeth of green gear when moving up-down.



### Robot head of 2 DoF (up-down and turn) 2

[https://youtu.be/Q\\_1Xf2VrYXg](https://youtu.be/Q_1Xf2VrYXg)

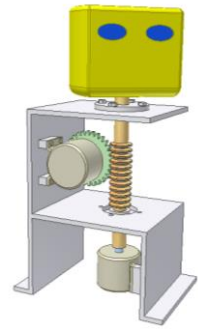
Yellow head fixed to orange shaft has two degrees of freedom:

- Rotation around vertical axis.
- Translation along vertical axis.

Each motion is controlled by a step motor.

Circular teeth of the shaft maintains the gear-rack mesh while the shaft rotates.

Blue motor shaft has prismatic joint with the orange shaft (sliding keys).



### Robot head of 2 DoF (up-down and turn) 3

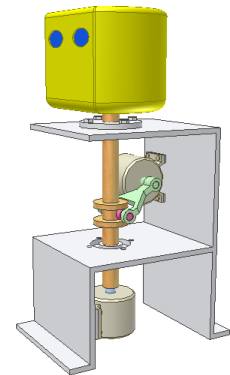
[https://youtu.be/2Pdug\\_g-2s](https://youtu.be/2Pdug_g-2s)

Yellow head fixed to orange shaft has two degrees of freedom:

- Rotation around vertical axis.
- Translation along vertical axis.

Each motion is controlled by a step motor.

Blue motor shaft has prismatic joint with the orange shaft (sliding keys).



### Spatial motion control 1

<http://youtu.be/iNa6y4aXG3g>

It is a design of Goddard Space Flight Center, USA.

The position and orientation of the orange platform is governed uniquely, in all six degrees of freedom, by the positions of the drivers on the base plate.

The lower ends of the violet limbs are connected via universal joints (2 DoF) to the drivers.

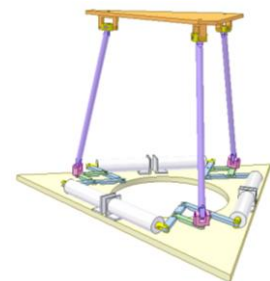
The upper ends of the violet limbs are connected via universal joints (2 DoF) to the platform.

In this video the drivers are pantographs of two degrees of freedom (2 DoF). See:

<http://youtu.be/7OX351jGXeM>

Other types of drivers of 2 DoF are possible.

This mechanism is used for a minimanipulator producing small, precise motions and high mechanical advantage.



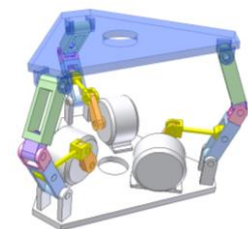
### Canfield joint 1

<https://youtu.be/g3CmLAj1YzY>

It was invented by Dr. Stephen Canfield and is used for spacecraft thrusters and solar panels.

Grey motor controls blue platform via orange crank, yellow conrod, blue arm, pink and violet hinge, green arm. All the joints are revolute. Orange crank, yellow conrod and blue arm create a parallelogram mechanism.

The platform can be directed toward a point moving in the upper hemisphere by programming motions of three orange cranks mounted on the motors.





## Stewart platform

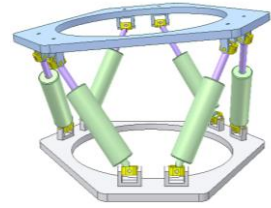
<https://youtu.be/A0JeDvGckXc>

Six cylinders are connected to grey base and blue platform by Cardan joints. Joints between the cylinders and their pistons are cylindrical (not prismatic). Six degrees of freedom of the platform are controlled by programming relative positions between pistons and cylinders.

The kinematic calculation is very complicated:

<http://www.techfak.uni-bielefeld.de/~fszufnar/publications/Szufnarowski2013.pdf>

Stewart platforms have applications in flight simulators, machine tool technology, crane technology, underwater research, air-to-sea rescue, satellite dish positioning, telescopes and orthopedic surgery.



## 22. Mechanisms having self-controlled direction links

### 22.1. Mechanisms having linearly translating link

#### Tchebicheff's four-bar linkage 3B

<http://www.youtube.com/watch?v=xPVcL0fMBck>

Length of the crank:  $a = 30$  mm

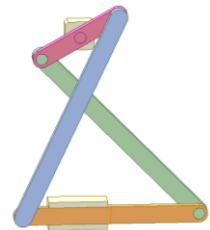
Length of the two connecting rods:  $2.6a = 78$  mm

Length of the translating bar:  $2a = 60$  mm

The mechanism can work if the crank oscillates  $\pm 30$  degrees around the horizontal direction and gap between the runway and the translating bar more than 0.044 mm.

The mechanism is deduced from the one of Tchebicheff's four-bar linkage 3

<http://www.youtube.com/watch?v=IDDPW6NR5TE>



#### Double parallelogram mechanism 1

<http://www.youtube.com/watch?v=u5XA2-E9ZDk>

A combination of two parallelogram mechanisms.

The yellow bar has straight-line motion.

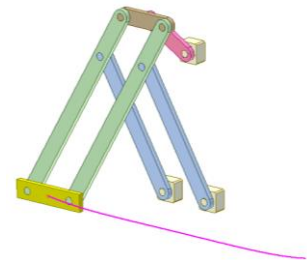
Lengths of the links:

Three shortest links: 8

Two blue links: 22

Two green links:  $27 + 8 = 35$

Height of the upper fixed bearing to the two lower ones: 22.



#### Kite mechanism 3

<http://youtu.be/EQ0DLpqnN-g>

A modification of Peaucellier linkage proposed in 1877 by A. B. Kempe, London.

Length of blue bar:  $a$

Length of green bar of 3 joints:  $0.5a + 0.5a$

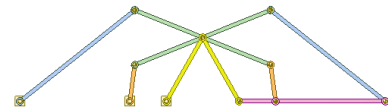
Length of pink bar of 3 joints:  $0.25a + 0.75a$

Length of yellow bars:  $0.5a$

Length of orange bars:  $0.25a$

Axle distance between the three fixed revolution joints  $0.75a + 0.25a$

The pink bar moves along an absolutely straight line.



#### Kite mechanism 4

<http://youtu.be/oKmy7CMYASA>

A modification of Peaucellier linkage proposed in 1877 by A. B. Kempe, London.

Length of blue bar:  $a$

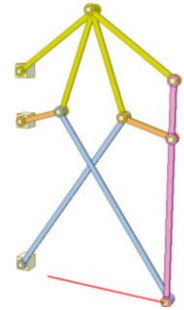
Length of pink bar of 3 joints:  $0.25a + 0.75a$

Length of yellow bars:  $0.5a$

Length of orange bars:  $0.25a$

Axle distance between the three fixed revolution joints  $0.25a + 0.75a$

The pink bar moves along an absolutely straight line.



#### Kite mechanism 5a

<http://youtu.be/ShmKYOnMuw4>

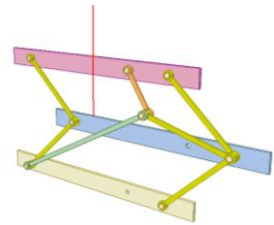
A modification of Peaucellier linkage proposed in 1877 by A. B. Kempe, London.

Length of green bars:  $a$

Length of yellow bars:  $0.5a$

Length of orange bars:  $0.25a$

The pink plate moves along an absolutely straight line.



#### Kite mechanism 5b

[http://youtu.be/oBgOfMio\\_LA](http://youtu.be/oBgOfMio_LA)

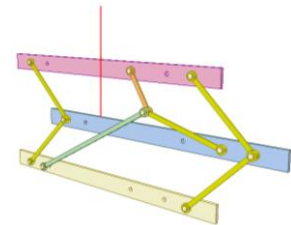
A modification of “Kite and spear-head mechanism 5a” proposed in 1877 by A. B. Kempe, London.

Length of green bars:  $a$

Length of yellow bars:  $0.5a$

Length of orange bars:  $0.25a$

The pink plate moves along an absolutely straight line.



#### 4 V-shaped arm mechanism

[http://youtu.be/-FPMdta-Y\\_A](http://youtu.be/-FPMdta-Y_A)

This linkage was proposed in 1877 by A. B. Kempe, London.

It is a development of “Inverse parallelogram mechanism 11”.

Revolution joint centers of the yellow (or blue) V-shaped arm create a isosceles right triangle.

Axle distance between the revolution joints of the green table, axle distance between the ground revolution joints and length of the pink bar are equal.

The green table moves along an absolutely straight line.

Pay attention to the red variable rectangular and two variable parallelograms.



### Tchebicheff stool 1

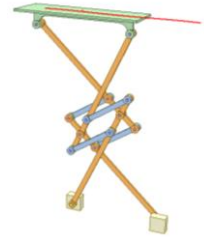
<http://youtu.be/k0XrKv1B7h0>

This is a development of "Tchebicheff's four-bar linkage 3".

Bars of identical colour are of equal length.

Axle distance between the revolution joints of the green seat, axle distance between the ground revolution joints are equal.

The green seat has horizontal motion (not strictly rectilinear).



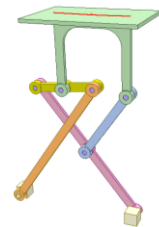
### Tchebicheff stool 2

[http://youtu.be/gV0xl\\_lbdDs](http://youtu.be/gV0xl_lbdDs)

This is a development of "Tchebicheff's four-bar linkage 3".

Axle distance between the revolution joints of the green seat, axle distance between the ground revolution joints are equal.

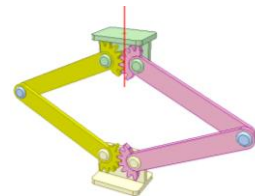
The green seat has horizontal motion (not strictly rectilinear).



### Gear and linkage mechanism 3a

<http://youtu.be/3FNWwFqunNU>

Combination of linkage and gear drive. The green part translates along an absolutely straight line.



### Gear and linkage mechanism 3

<https://youtu.be/cSg8g83QanU>

Linear motion without prismatic joint.

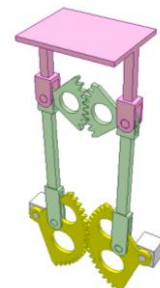
Input: one among two yellow gears.

Green gear is fixed to green bar.

The yellow gears have the same tooth number.

The green gears have the same tooth number.

Pink table translates along an absolutely straight line (vertical).



### Gear and linkage mechanism 17

<https://youtu.be/ybR4tRKMkho>

The bars create parallelograms.

Yellow parts are fixed together.

Blue parts are fixed together.

Input: green bar.

Z1: tooth number of the small gear.

Z2: tooth number of the large gear.

$Z2 = 2 \cdot Z1$

L2: length of blue and green bars.

L1: length of yellow and orange bars.

If  $L1 / L2 = 0.267$

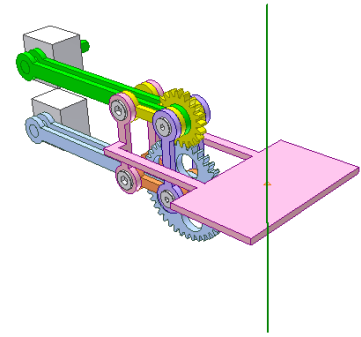
The pink table translates along almost straight line (in green) (without a runway).

Length of the straight line is around  $1.5 \times L2$  (the input turn  $\pm 30$  deg.).

The video last scene is for case when the pink table moves in horizontal plane.

This video was made based on:

<https://www.youtube.com/watch?v=9Du6h4pHYGs>



### Translation table of changing direction possibility

<https://youtu.be/-u6hbG1TRJo>

It is an application of mechanism shown at

<https://youtu.be/Z2uncDpQXU>

The two mechanisms are connected by yellow table.

Inputs: pink cranks that are connected together by red chain.

The table performs linear translation without runway. Motion

direction of the table is changed when turning large green

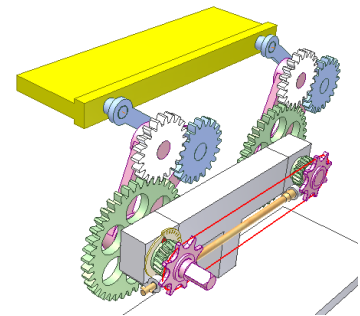
gears via orange worm drives.

The video shows how to change vertical translation to

horizontal one. Red arrow points out the translation direction on yellow scale plate.

The process can be performed without stopping the mechanism.

This concept can be used for playground equipments.



## 22.2. Mechanisms having unchanged direction link

### Keeping direction unchanged during rotation 1

<http://www.youtube.com/watch?v=jMCBm9bG4EY>

The direction of the red object is unchanged.

Using spur gears.

The end gears have the same number of teeth.

The number of intermediate gears must be odd.



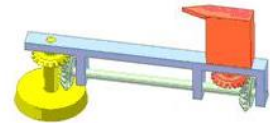
### Keeping direction unchanged during rotation 2

[http://www.youtube.com/watch?v=5Oa\\_7k1GMi0](http://www.youtube.com/watch?v=5Oa_7k1GMi0)

The direction of the red object is unchanged.

Using bevel gears.

The gears have the same number of teeth.



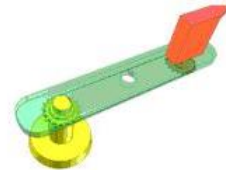
### Keeping direction unchanged during rotation 3

<http://www.youtube.com/watch?v=BkZswBBbvD8>

The direction of the red object is unchanged.

Using chain (or tooth belt) drive.

The sprockets have the same number of teeth.



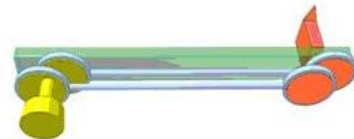
### Keeping direction unchanged during rotation 4

<http://www.youtube.com/watch?v=N8jE8gLbHR4>

The direction of the red object is unchanged.

Using parallelogram mechanism.

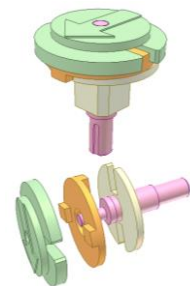
Overcoming dead point by adding second parallelogram mechanism



### Keeping direction unchanged during rotation 5

<http://youtu.be/-XsHSvDqG8s>

The green disk receives motion from a pink eccentric shaft. Due to a Oldham mechanism that consists of three disks, the orientation of the green disk does not change during motion.



### Keeping direction unchanged during rotation 6

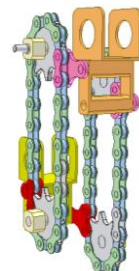
<http://youtu.be/D1IPLLELEBuA>

Two chain drives are arranged with a large non-coaxiality A.

The yellow link connects two drives by two red chain pivot links. Center distance between two revolution joints of the yellow link is equal to A.

The direction of the yellow link is kept unchanged during motion. More of the connecting links and the pivot links is possible.

This mechanism can be applied for continuous lift.



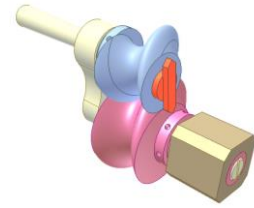
### Pin coupling 6

<http://www.youtube.com/watch?v=zfXDfoOAnrY>

A planetary mechanism from Pin Coupling 5.

<http://www.youtube.com/watch?v=QfiJSTRDASs>

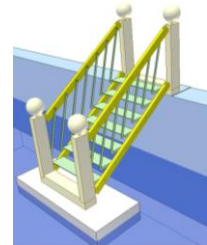
The direction of the red bar attached to the blue shaft is unchanged during the motion.



### Application of parallelogram mechanism 6

<http://www.youtube.com/watch?v=PJQEkv4UESw>

Self-adjusting step ladder for wharfs. The steps remain horizontal whatever the water level rises or falls.

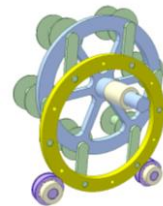


### Application of parallelogram mechanism 7

[http://www.youtube.com/watch?v=nn\\_v\\_DIZ6tY](http://www.youtube.com/watch?v=nn_v_DIZ6tY)

Cable winding machine.

The bobbins rotate about the machine main shaft axle but not their own ones.

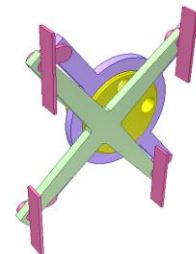


### Application of parallelogram mechanism 8

<http://www.youtube.com/watch?v=hWNt1ZhnSnk>

Vertical blade paddle wheel.

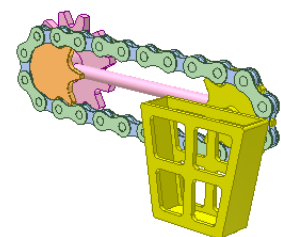
The blades are kept always upright giving the most propulsion effectiveness.



### Chain drive 5A

<http://youtu.be/DI6DdKPXctY>

The orange sprocket is fixed. The orange and yellow sprockets have the same tooth number. The pink crank and gear is driving. The yellow basket, which is fixed with the yellow sprocket, stays vertically during rotation.



### Gear and linkage mechanism 8a

[https://www.youtube.com/watch?v=iGYtz\\_uVKTY](https://www.youtube.com/watch?v=iGYtz_uVKTY)

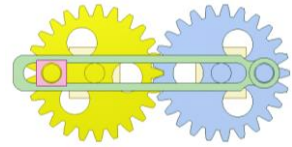
The green bar has unchanged direction during rotation.

The gears have the same tooth number and the same distance of their pins to their rotation axes.

Assembly requirement: there is mechanism position where pin axes and gear rotation axes are on a plane and both pins are in the middle (or outside) of the gear center distance.

If not the green bar has complicated motion as in:

<https://www.youtube.com/watch?v=wTG1Ai2S9I8>



### Keeping direction unchanged during rotation 7

<http://youtu.be/VcLRHZAFc9o>

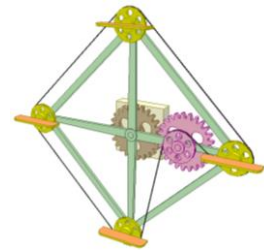
The gears have same tooth number.

Five pulleys have same pitch diameter.

Input: green carrier rotating regularly.

The yellow pulleys have unchanged direction during rotation.

Instead of belt drive using chain one is better.



### Keeping direction unchanged during rotation 8

<http://youtu.be/W5tLTJraf84>

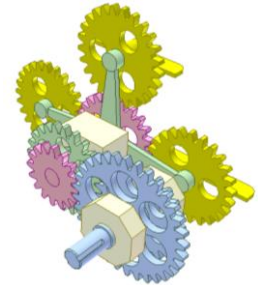
Pink gear, four yellow satellite gears and green carrier create a differential planetary drive.

Four yellow satellite gears and the big pink gear have same tooth number.

Input is the blue shaft having two gears.

Receiving rotation from the input shaft, the pink gears and the green carrier rotate in the same direction. The pink gears rotate twice faster than the green carrier.

The yellow gears have unchanged direction during rotation.



### Keeping direction unchanged during rotation 9a

<http://youtu.be/q8HKd938yp0>

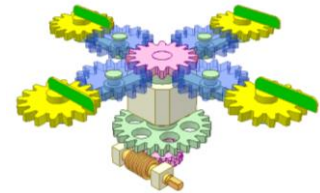
Pink gear, four yellow satellite gears, four blue gears and green carrier create a differential planetary drive.

The gears (except the green one) have same tooth number.

Input: green carrier rotating regularly.

The yellow gears have unchanged direction during rotation while the pink gear is immobile.

Use the orange worm to rotate the pink gear for adjusting the direction. The video shows 90 deg. adjustment.





### Keeping direction unchanged during rotation 9b

<http://youtu.be/APdnbZI20S0>

Pink gear, four yellow satellite gears, two blue gears and green carrier create a differential planetary drive.

The yellow gears and the pink spur gear have same tooth number.

The blue gears have same tooth number.

Input: green carrier rotating regularly.

The yellow gears have unchanged direction during rotation while the pink gear is immobile.

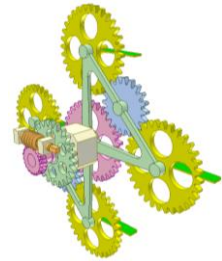
Use the orange worm to rotate the pink gear for adjusting the direction.

The video shows 45 deg. adjustment.

This mechanism is similar to the one in video:

<http://youtu.be/q8HKd938yp0>

but uses less gears.



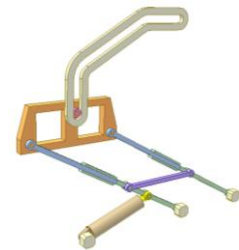
### Keeping direction unchanged during motion 10

[http://youtu.be/xAYL\\_MtkEgM](http://youtu.be/xAYL_MtkEgM)

Orange plate performs planar motion without rotation. Its upper edges are kept always horizontal thanks to a parallelogram mechanism driven by brown cylinder. Distance between two revolute joints on the orange plate is equal to length of the violet conrod.

Change of popcorn fixed cam profile gives various trajectories of a point on the orange plate.

The mechanism has an unstable position when violet conrod is perpendicular to the rockers. So avoid it or use measures to overcome it.



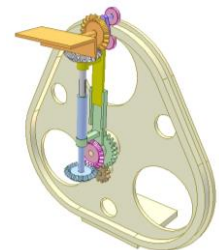
### Keeping direction unchanged during motion 11

<http://youtu.be/iIYesahDn38>

Orange plate performs planar motion without rotation. Its upper surface is kept always horizontal thanks to 4 bevel gear drive of equal tooth numbers driven by brown spur gear. Sliding joints between green and yellow bars and between blue and grey shafts allow radial displacements of the orange plate. Pink gear is fixed.

Change of popcorn fixed cam profile gives various trajectories of a point on the orange plate.

4 bevel gear drive can be replaced by 4 screw gear drive in another embodiment of this mechanism.



### Keeping direction unchanged during motion 12

<http://youtu.be/4xGNB2jlcV/k>

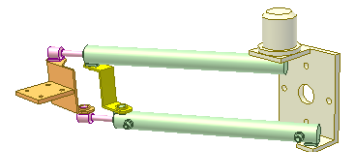
Orange plate performs planar motion without rotation.

The plate direction is kept unchanged thanks to a parallelogram mechanism driven by a motor. Distances between two revolute joints on the yellow conrod and between two revolute joints of the orange plate are equal.

Motion of the orange plate along sliding joint between green bar and pink bar is controlled by two green cylinders.

This mechanism can be applied for manipulator of polar coordinate system.

Disadvantage: the cylinders are not base-mounted.



### Keeping direction unchanged during motion 13

<http://youtu.be/485OGPdp13g>

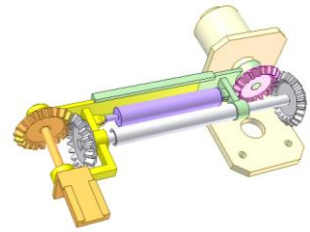
Orange plate performs planar motion without rotation. Its upper surface is kept always horizontal thanks to 4 bevel gear drive of equal tooth numbers driven by a motor. Pink gear is fixed.

Sliding joints between green and yellow bars and between grey shafts allow radial displacements of the orange plate that are controlled by violet actuator.

4 bevel gear drive can be replaced by 4 screw gear drive in another embodiment of this mechanism.

This mechanism can be applied for manipulator of polar coordinate system.

Disadvantage: the actuator is not base-mounted.



### Keeping direction unchanged during motion 14

<http://youtu.be/q2Foisj9re0>

Orange slider performs planar motion without rotation.

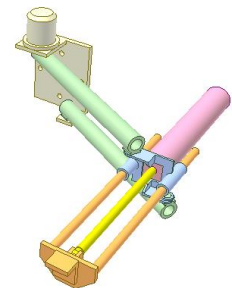
Its upper surface is kept always horizontal thanks to a parallelogram mechanism driven by a motor. Distances between two revolute joints on the blue conrod and between two revolute joints of the base are equal.

Motion of the orange slider along sliding joint on the blue conrod is controlled by pink actuator.

Disadvantages:

The actuator is not base-mounted.

The calculation of trajectory of a point on the orange slider can not be based on polar coordinate system.



### Keeping direction unchanged during motion 15

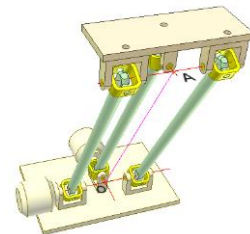
<http://youtu.be/iQ5TkU04Xdc>

Green bars are connected to lower and upper plates by universal joints of two degrees of freedom. The mechanism has two degrees of freedom based on computer test so two motors are used for controlling.

Upper plate is kept always horizontal during motion.

A point of the upper plate moves on a spherical surface.

Angle between motor rotary axes can differ from 90 deg.



### Keeping direction unchanged during motion 16

<http://youtu.be/4smmgMNyrv>

Blue upper table is kept always horizontal when moving in 3D space.

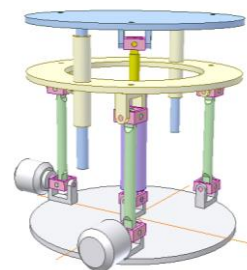
Motion of the popcorn disk is controlled by two base-mounted motors.

Motion of the blue table along sliding joint on the popcorn disk is controlled by violet actuator.

Disadvantages:

The actuator is not base-mounted.

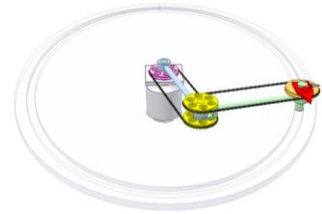
The calculation of trajectory of a point on the blue table can not be based on spherical coordinate system.



### Keeping direction unchanged during motion 17

<http://youtu.be/inr1H2-mKS8>

Red plate performs planar motion without rotation thanks to two toothed belt drives. Tooth numbers of four pulleys are equal. Pink pulley is immobile. Two yellow pulleys are fixed together. Change of glass fixed cam profile gives various trajectories (an ellipse in this video) of the red plate. The belt drives can be replaced by chain ones.



### Keeping direction unchanged during motion 18

<http://youtu.be/6NayQfZpSWY>

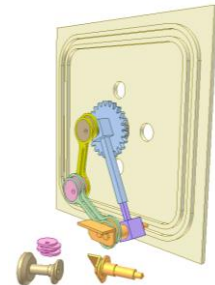
Pink and yellow plates perform planar motion without rotation thanks to gear drives. Tooth numbers of 5 gears are equal. Grey gear is immobile. Four other gears idly rotate on their bearings. Change of glass fixed cam profile gives various trajectories (a hexagon in this video) of the pink plate.



### Keeping direction unchanged during motion 19

<http://youtu.be/M3qFSIEA1Rg>

Orange plate performs planar motion without rotation. Its upper surface is kept always horizontal thanks to a double parallelogram mechanism driven by blue gear. Each of brown and orange shafts has 2 eccentrics for overcoming dead positions of the parallelogram mechanisms. So the pink shaft has 4 eccentrics. Change of popcorn fixed cam profile gives various trajectories of the orange plate.



### Keeping direction unchanged during rotation 20

<http://youtu.be/P-BaJiRCg68>

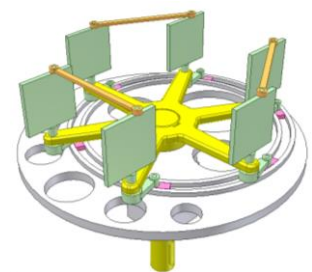
Grey cam of eccentric circular groove is immobile. Its eccentricity and length of green cranks are equal. Radius of center circle of the cam groove and radius of yellow crank are equal.

When yellow shaft rotates, the direction of the green cranks is unchanged during rotation.

In fact it is a combination of 6 parallelogram mechanisms.

Orange conrods help in overcoming unstable positions when the green and yellow cranks are in line.

Turn cam to adjust the direction.



### Keeping direction unchanged during rotation 21

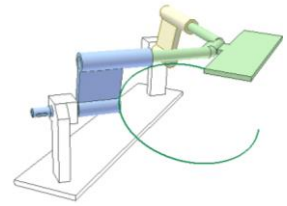
<https://youtu.be/fNuWRsr17mY>

It is an application of Hobson's joint so it can be called as Hobson's platform.

Input: blue crank.

Green plate moves along an ellipse and is kept always horizontal.

The mechanism has unstable positions when the planes created by axes of two joints of each crank are vertical.



### Keeping direction unchanged during spatial motion 1

<http://youtu.be/Cu8oJTe8zrk>

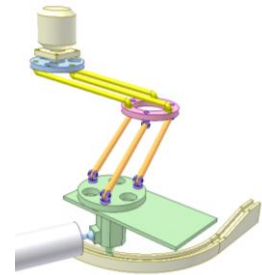
The green disk lower end moves along a 3D curve. When blue disk is immobile, green plate (fixed to green disk) performs spatial motion without rotation around all three coordinate axes thanks to yellow planar and orange spatial parallelogram mechanisms.

The grey cylinder is connected to the base via a spherical joint (not shown). The blue piston is connected to the green disk via a spherical joint.

Pay attention to violet universal joints (2 DoF).

Angular position of the green plate in horizontal plane can be adjusted by turning the blue disk. The video shows such adjustment occurring after first double strokes of the piston.

Gravity maintains contact between the green disk lower end and the groove bottom of the popcorn runway.



## 22.3. Other mechanisms

### Planetary drive 1a

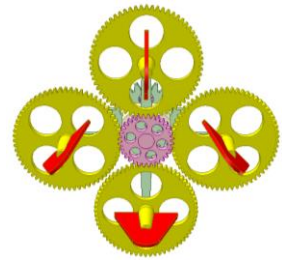
<http://youtu.be/k6ap5Yxmk7M>

Pink fixed gear, four yellow satellite gears and green carrier create a differential planetary drive. Tooth number of the yellow gears is double to the one of the pink gear.

Input: green carrier rotating regularly.

When the yellow gears reach highest position, their red plates are vertical. When the yellow gears reach lowest position their red plates are horizontal.

Use the orange worm for adjusting the direction of the plates.



### Planetary drive 1b

<http://youtu.be/sLknrW47hzc>

Pink fixed pulley, yellow satellite big pulley and green carrier create a belt differential planetary drive. Diameter of the yellow big pulley is double to the one of the pink pulley.

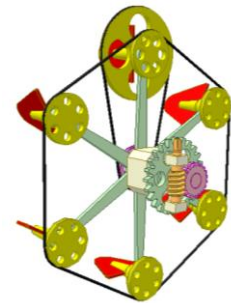
Six yellow small pulleys have same diameter. They are connected together by the black belt.

Using chain drive instead of belt one is better.

Input: green carrier rotating regularly.

When the yellow small pulleys reach highest position, their red plates are vertical. When the yellow small pulleys reach lowest position their red plates are horizontal.

The video also shows that after using the worm drive for adjusting the direction of the plates the situation is reversed.



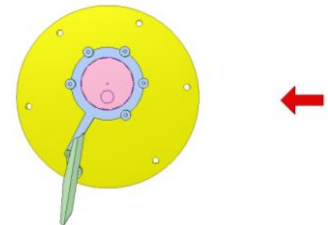
### Wind-mill 1a

<http://youtu.be/7pN7hFZuUw>

Plan view. It is a 4-bar linkage consisting of two cranks (blue bar, yellow disk) and a connecting rod (green sail). Blue bar rotates on the eccentric of a pink fixed shaft.

Such arrangement makes the green sail present its edge in returning toward the wind, but present its face to the action of the wind, the direction of which is supposed to be as indicated by red arrow.

Output motion (clockwise rotation) is taken from the yellow disk.



### Wind-mill 1b

<http://youtu.be/Y1X2b-dU7mU>

Plan view. Green sails are so pivoted as to present their edges in returning toward the wind, but to present their faces to the action of the wind, the direction of which is supposed to be as indicated by red arrow.

Blue bar rotates on the eccentric of a pink fixed shaft.

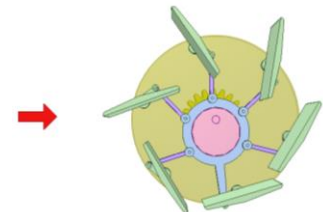
Output motion (clockwise rotation) is taken from a gear fixed to the yellow disk.

The mechanism can be applied for simple water turbines (no need of flow guide).

This mechanism is developed from "Wind-mill 1a":

<http://youtu.be/7pN7hFZuUw>

by adding more sails.



## Wind mill 2

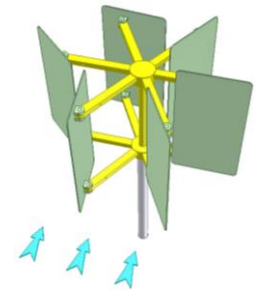
<https://youtu.be/zheugW77FWs>

The sails are so pivoted as to present their edges in returning toward the wind, but to present their faces to the action of the wind when they are on other side. The arrows show the wind direction.

The sails are automatically flipped under the wind action.

This mechanism is numbered as 486 in the book "507 mechanical movements", 1868.

Mass center of each sail must lay on its rotary axis by adding counter weight to eliminate the influence of centrifugal forces.



## Controlling direction during planetary rotation of plates

<https://youtu.be/44DksgBBONg>

Input: belt wheel (in popcorn or transparent)

Yellow tooth-uncompleted gear is stationary.

Its number of remained teeth: 9

Its number of teeth (teeth-completed): 20

Its number of cut-off teeth: 11

Tooth number of green gears that are in mesh with yellow gear: 20.

The gear drives for pink plates has transmission ratio of 1.

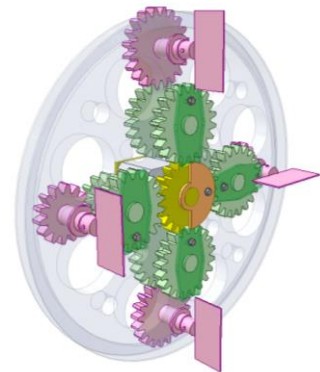
The pink plates rotate around center axis of the whole system.

When they are on the right side of the system, they do not rotate around their own axes, the pink plates point towards the system center.

When they are on the left side of the system, the pink plates are kept vertical.

For easy understanding last scene of the video shows the transmission for only one pink plate.

In  $\frac{1}{2}$  rev. of the input wheel, green satellite gear rotates 180 deg. around its own axis then stops for the remaining  $\frac{1}{2}$  rev. Orange and green disks keep green gear do not rotate.



## Wind vane

<https://youtu.be/dEklmjFX234>

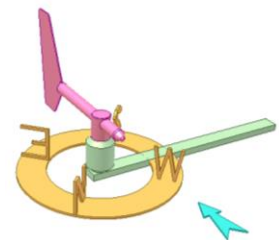
Wind vanes are designed to rotate freely on the vertical axis so they can respond to small changes in wind direction (shown by blue arrow). The weight on either side of the vertical axis is equal, but the surface area is much larger on one side. That side will catch the wind if the pointer is not pointing directly in line with the wind. The vane tends to get stable equilibrium so the pointer always points the direction from which the wind blows.

The letters indicate the points of the compass.

Disadvantage: when no wind it still shows the recent wind direction. So an anemometer should be added. See:

<http://www.whenwasitinvented.org/when-was-anemometer-invented/>

In modern designs wind vanes can send the wind direction to a data logger using a potentiometer; as the vane rotates, the resistance of a potentiometer changes.



### Planetary rotation 1

<https://youtu.be/gUGJZED-7FY>

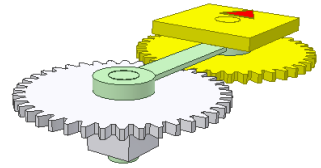
Input: green crank.

Output: yellow square, velocity of which is double of the input one.

The video shows that 90 deg. input oscillation gives 180 deg. output oscillation.

The square is fixed to yellow gear.

The same function can be got by replacing the spur gear drive with any drive of transmission ratio of -1, for example, crossed belt drive.



### Planetary rotation 2

<https://youtu.be/9T1HfRinoYc>

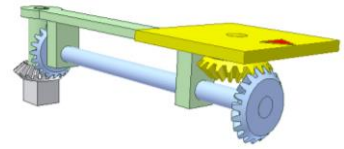
Input: green crank.

Output: yellow square, velocity of which is double of the input one.

The video shows that 90 deg. input oscillation gives 180 deg. output oscillation.

The square is fixed to yellow gear.

It is used when the green crank is long.



### Planetary rotation 4

<https://youtu.be/MmJCbsQHS6k>

Input: green crank.

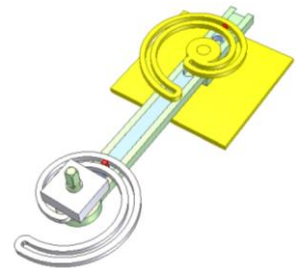
Output: yellow square, velocity of which is double of the input one.

The video shows that 90 deg. input oscillation gives 180 deg. output oscillation.

The wheels have Archimedean grooves of the same radial distance between successive turnings and of opposite spiral directions. Distance between two red pins of blue slider is equal to the one between two revolution joints of the green crank. The square is fixed to the yellow wheel.

It is developed from the mechanism shown at:

<https://youtu.be/aNLLu7VUKVk>

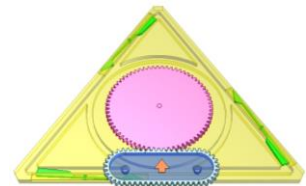


### Oval gear 3a

<http://youtu.be/jedbQnuuiy0>

An input pink gear, rotating around fixed axis, engages with blue gear of oval shape. The latter has two pins that slide in grooves of the base. In one cycle of motion the blue gear performs two revolutions around rotary axis of the pink gear and changes its direction twice.

Green arms that always turn clockwise due to springs (not shown) in coordination with the front pin of the blue gear allow the front pin follow the straight grooves and direct the rear pin follow the circular groove.



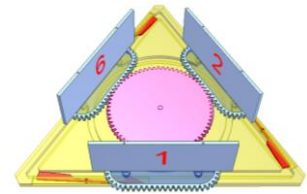
### Oval gear 3b

<http://youtu.be/9kjUcsqieRg>

An input pink gear, rotating around fixed axis, engages with blue gears of oval shape. The latter have two pins that slide in grooves of the base. In one cycle of motion the blue gears performs two revolutions around rotary axis of the pink gear and changes its direction twice.

Red arms that always turn clockwise due to springs (not shown) in coordination with the front pin of the blue gear allow the front pin follow the straight grooves and direct the rear pin follow the circular groove.

On each side of the triangular base numbers 1, 2, ..., 6 appear one after another.

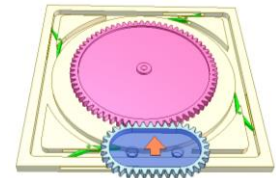


### Oval gear 3c

<http://youtu.be/dPif6o4yf18>

An input pink gear, rotating around fixed axis, engages with blue gear of oval shape. The latter has two pins that slide in grooves of the base. In one cycle of motion the blue gear performs four times of straight motion and four times of rotation alternately.

Green arms that always turn anticlockwise due to springs (not shown) in coordination with the front pin of the blue gear direct the front pin follow the straight grooves and the rear pin follow the circular groove.



### Controlling plates pivoted on chain axes

<https://youtu.be/80UIVse4x0>

Pay attention to directions of orange plates that are pivoted on chain link axes. The plates on one chain branch are always perpendicular to the ones on the other branch.

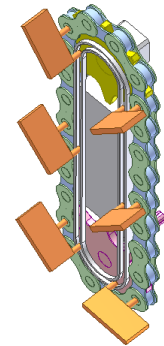
Let call locus of the chain link axes as A.

Each orange plate has a pin that slides in a closed groove G. Circular portions of the groove G are coaxial with the chain sprockets. There the distance between G and A is equal to distance between two pins of the orange plate. So at two ends of the chain drive the plate direction may change. The cut-off places on the groove wall help the plates turn 90 deg. at upper end and 270 deg at lower end of the chain drive.

If G and A are equidistant the orange plates turns 180 deg. at both ends of the chain drive.

See:

<https://youtu.be/rDNHDcdSgZg>



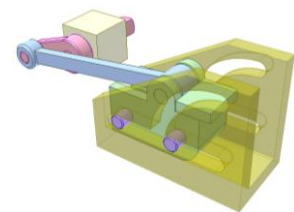
### Turnable slider 1

<https://youtu.be/6c5ow2ped3Y>

Input: pink crank.

The green slider reciprocates and turns 90 deg. at its right stroke end.

Slider crank mechanism is converted into four-bar linkage and vice versa in one working cycle.





### Planetary rotation 3

<https://youtu.be/eEfZKIC8AAM>

Input: pink crank.

Output: yellow square, velocity of which is double of the input one.

The video shows that 90 deg. input oscillation gives 180 deg. output oscillation.

The mechanism has the same function of mechanisms shown at:

<https://youtu.be/gUGJZED-7FY>

<https://youtu.be/9T1HfRinoYc>

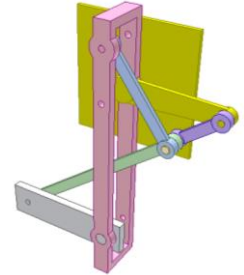
but consists only of bars and revolution joints (no gears).

The square is fixed to yellow crank.

It is developed from the mechanism shown at:

<http://youtu.be/dqDHfOBE8EQ>

where the part dimensions can be got.



### Gear-rack drive for linear motion and interrupted 180 deg. turn

<https://youtu.be/i5VoNWBuC7s>

Input: pink slider linearly reciprocating.

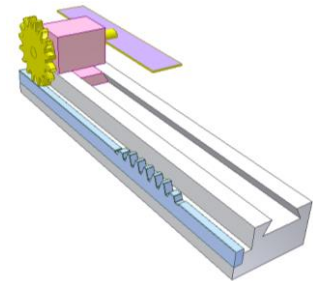
Output: yellow shaft.

When the shaft moves to the right, it rotates 180 deg. at the end of its stroke thanks to the gear-rack drive.

When moving to the left at first the shaft rotates 180 deg. then moves to the initial position without rotation.

The flat portions of the rack prevent the shaft from rotation.

Tops of two end teeth of the rack are cut off for easy meshing start.



### Linear reciprocation with one way interrupted 180 deg. rotation 1

<https://youtu.be/twMg0D5i3JM>

Input: pink slider linearly reciprocating.

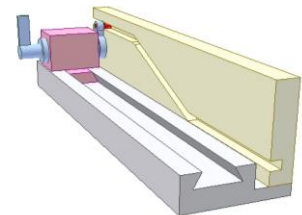
Output: blue shaft.

When the shaft moves to the right, it rotates 180 deg. at the center of its stroke thanks to the cam mechanism.

When it moves to the left it rotates 180 deg. at the center of its stroke in the same direction.

So in one double stroke the output rotates totally 360 deg.

To ease the output rotation the cam slanting angle must not large (20 deg. in this video).

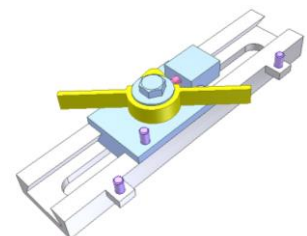


### Automatic 90 deg. switch 1

<https://youtu.be/U9bd7oERi0o>

Input: blue slider performing linear reciprocating motion.

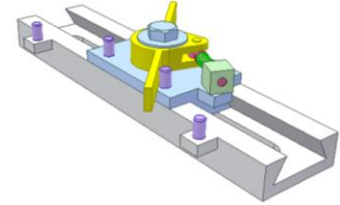
Yellow cam pivoted on the slider turns 90 deg. at both ends of the slider stroke thanks to spring pin (in pink) and violet pins by snap motion.



### Automatic 90 deg. switch 2

<https://youtu.be/f5m6APM9Y9w>

Input: blue slider performing linear reciprocating motion.  
Yellow crank pivoted on the slider turns 90 deg. at both ends of the slider stroke thanks to sliding conrod (in pink), green swivel part, green spring and violet pins by snap motion.



### Linear reciprocation with one way interrupted 180 deg. rotation 1

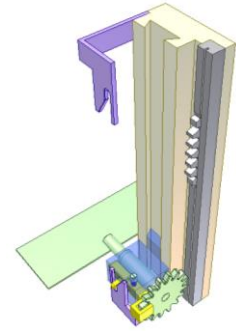
<https://youtu.be/KosONar7WzA>

Input: blue slider linearly reciprocating.  
Output: green shaft.

When the slider moves up, at upper end of its stroke the shaft rotates 180 deg. thanks to gear-rack drive and then the shaft moves to the right by interaction of the pin on yellow shifter and violet upper cam. When the slider moves down, the shaft does not rotate at all because the gear and the rack are not in merge. At lower end of the slider stroke the shaft moves to the left by interaction of the pin on yellow shifter and violet lower cam.

Red spring pin is for positioning the yellow shifter and the shaft.  
This mechanism is developed from the mechanism shown at:

<https://youtu.be/i5VoNWBuC7s>



### Linear reciprocation with one way interrupted 180 deg. rotation 2

<https://youtu.be/47GoltUb3pw>

Input: glass slider linearly reciprocating.  
Output: blue shaft.

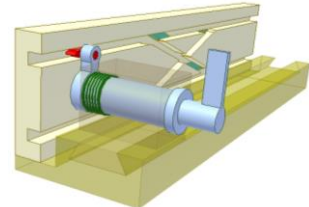
When the shaft moves to the right, it rotates 180 deg. at the center of its stroke thanks to the cam mechanism.

When it moves to the left it does not rotate at all.

So in one double stroke the output rotates only 180 deg.

Key factors: shape of the red pin and variable depth of the cam grooves (the cyan portions are slant)

Green spring always forces the blue shaft towards the yellow cam.



### Linear reciprocation with one way interrupted 180 deg. rotation 3

<https://youtu.be/2yWE15zedxE>

Input: pink slider linearly reciprocating.  
Output: grey shaft.

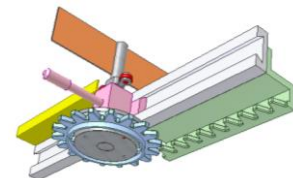
When the shaft moves to the right, it rotates 180 deg. at the end of its stroke thanks to the gear-rack drive.

When it moves to the left it does not rotate at all because of the ratchet mechanism of red pawl (one way overrunning clutch,

[http://youtu.be/bAL\\_nWjuhOI](http://youtu.be/bAL_nWjuhOI))

The grey arm of two red rollers and the yellow runway ensure that after one double stroke the shaft rotates exactly 180 deg.

Disadvantage: possible jam when the blue gear starts to mesh with the rack so their teeth should be rounded as much as possible.



### Linear reciprocation with one way interrupted 180 deg. rotation 4

<https://youtu.be/xSbUKu9sFi0>

Input: blue slider linearly reciprocating.

Output: grey shaft.

When the shaft moves up, it rotates 180 deg. at the upper end of its stroke thanks to orange pins, green movable stopper and red spring.

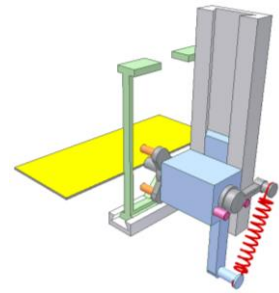
When moving down the shaft does not rotate at all.

At the lower end of the shaft stroke the orange pins move the stopper horizontally to prepare the stopper for the back 180 deg. rotation of the shaft.

The device for positioning the green stopper (for example spring pin) is not shown.

The orange pins can turn the shaft a little more than 90 deg. only but the red spring helps to get 180 deg. rotation.

Pink pins ensure that the shaft turns 180 deg exactly.



### Automatic 90 deg. switch 3

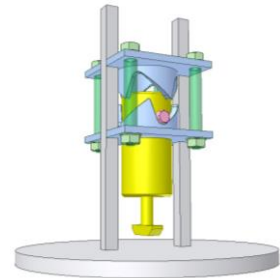
<https://youtu.be/IRFDwZR3VzU>

Input: blue cam-slider performing linear reciprocating motion.

Yellow cylinder having cylindrical joint with the blue cam-slider turns 90 deg., after its end contacts the base.

This mechanism may be used in following drum lifter:

<https://www.youtube.com/watch?v=QfwsfT-cldl>



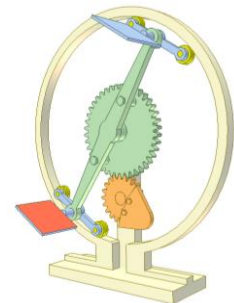
### Cam and gear mechanism 2

<http://youtu.be/-zOdLhISU1M>

Input is the green gear to which a long arm is fixed.

Two short arms (each carries two rollers) are connected to both ends of the long arm by revolution joints. Due to the orange gear cam and a slot in the base, the short arms change their directions after every revolution of the long arm.

Transmission ratio of the gear drive is 2.



### Slider carrying automatic flipping plate 1

<https://youtu.be/DV0h1Gn7ifw>

Input: pink crank rotating counterclockwise.

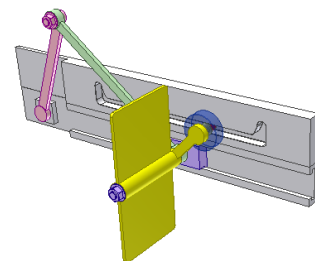
Yellow plate is pivoted on violet slider.

Red pin (fixed to the plate) moves in U-shaped of the base.

The plate is 90 deg. flipped at the ends of the slider stroke.

When the slider moves forwards, the plate is parallel to the moving direction. When the slider moves backwards, the plate is perpendicular to the moving direction.

Inertia of blue weight (fixed to the plate) ensures that the flipping process is stable.



### Slider carrying automatic flipping plate 2

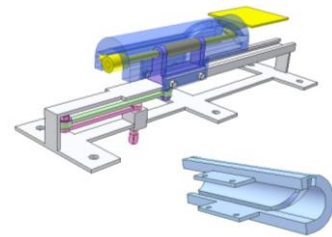
<https://youtu.be/Wd8Cp0XXHeM>

Input: pink crank.

Yellow plate is pivoted on violet slider.

Spherical head pin (fixed to the plate) moves in groove of blue stationary barrel cam.

The plate performs 180 deg. forth and back turn at the far end of the slider stroke.



### +/- 90 deg. flipping 1

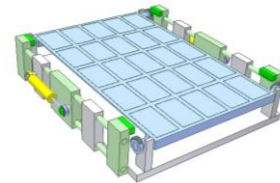
<https://youtu.be/9MIFBM8kfVw>

Green sliders move back and forth thanks to yellow cylinders. The gear-rack drives flip blue plate 90 deg. in two directions alternately around two sides of the plate. The rotation speed of the plate is regular theoretically, if violet pistons move regularly.

Weaknesses:

- Large forces in gear-rack drives.
- Inevitable pauses of the plate at its horizontal positions.

This mechanism may be used for solar pannels that slowly rotate for orientation to the sun.



### +/- 90 deg. flipping 2

<https://youtu.be/bNCHyTSfzXA>

It is an improved design for “+/- 90 deg. flipping 1” in:

<https://youtu.be/9MIFBM8kfVw>

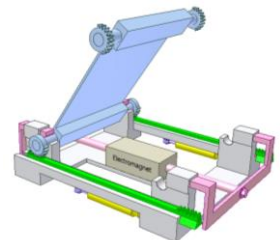
in an effort to reduce the pause time of the blue plate.

Green rack-sliders move back and forth thanks to yellow cylinders.

The gear-rack drives flip blue plate 90 deg. in two directions alternately around two sides of the plate. The temporary rotary axes of the plate depend on the positions of the pink stoppers that are controlled by the electromagnet.

Motions of the stoppers and violet pistons are programmed to get right coordination.

The rotation speed of the plate is regular theoretically, if violet pistons move regularly.



### +/- 90 deg. flipping 3

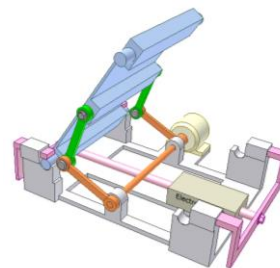
<https://youtu.be/YxyChzoDeDw>

Orange crank-shaft gets motion from the yellow servo motor.

The blue plate flips +/- 90 deg. in two directions alternately around two its sides. The temporary rotary axes of the plate depend on the positions of the pink stoppers that are controlled by the electromagnet. Orange crank-shaft, green bars and blue plate create a four-bar linkage.

Motions of the stoppers and violet pistons are programmed to get right coordination.

If the orange shaft rotates regularly, the plate doesn't.



### +/- 90 deg. flipping 4

<https://youtu.be/w0zN6fXqEbA>

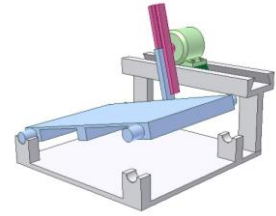
Pink shaft gets motion from the green motor.

The blue plate flips +/- 90 deg. in two directions alternately around two its sides.

If the pink shaft rotates regularly, the plate so does.

At +/- 90 deg. positions the mechanism motion is not stable so in this animation the motor turns +/- 88 deg.

Weakness: the motor is not grounded.



### +/- 90 deg. flipping 5

[https://youtu.be/VHzZ\\_j8Y8mA](https://youtu.be/VHzZ_j8Y8mA)

Input: pink crank.

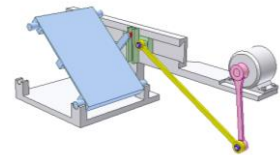
The crank, yellow conrod and green slider create a slider crank mechanism.

Red pin on the blue plate moves in a groove of the green slider.

The plate flips +/- 90 deg. in two directions alternately around two its sides.

If the pink crank rotates regularly, the plate doesn't.

If the crank rotates too fast, the blue plate may jump off from the base.



### 90 deg. flip to 4 directions 1

[https://youtu.be/wq-ROU\\_CG28](https://youtu.be/wq-ROU_CG28)

The green plate can be flipped to 4 directions around its four bars.

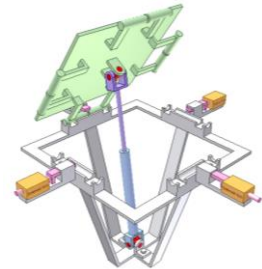
The temporary rotary axes of the plate depend on the positions of the pink stoppers that are controlled by 4 solenoid locks of 3 positions (in orange). The stoppers also prevent axial displacements of the bars thanks to circular grooves on the bars.

The blue cylinder and violet piston raise the plate to flip.

They are connected to the plate and the base via Hook's joints (spherical joints are possible).

Motions of the stoppers and violet pistons are programmed to get right coordination.

Weakness: the cylinder occupies too much room. Using telescopic cylinder is a good solution.



### 90 deg. flip to 4 directions 2

<https://youtu.be/XSPvoRs17s4>

The green plate can be flipped to 4 directions around its four bars.

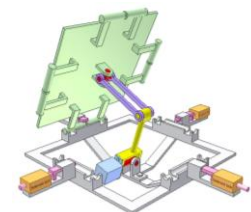
The temporary rotary axes of the plate depend on the positions of the pink stoppers that are controlled by 4 solenoid locks of 3 positions (in orange). The stoppers also prevent axial displacements of the bars thanks to circular grooves on the bars.

The blue motor, yellow and violet bars raise the plate to flip.

They are connected to the plate and the base via Hook's joints. The motor is fixed to the yellow bar and the motor shaft to the red cross.

Motions of the stoppers and violet pistons are programmed to get right coordination.

Weakness: the motor is not grounded.

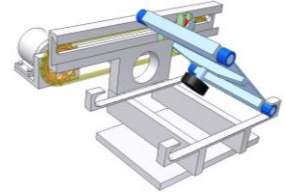


### **+/- 90 deg. flipping 6**

<https://youtu.be/snPRzaRZu7Y>

Input: orange sprockets receiving rotation from the motor.  
Green slider is fixed to the upper side of the yellow chain.  
Red pin on the blue plate moves in a groove of the green slider.  
The plate flips +/- 90 deg. in two directions alternately around two its sides.

At max flip angle the plate motion may be unstable. The black weight helps to reduce this weakness.



### **Controlling rotation and translation of an object**

<https://youtu.be/s7rny2alwlw>

Input: yellow slider that has linear reciprocating motion.  
Output: blue part that moves forwards, turns 180 deg., moves backwards and turns back 180 deg.

Orange pin fixed to the slider moves along helical groove of the blue part. This helical joint can be replaced with a screw-nut drive (the yellow part: nut; the blue part: screw).

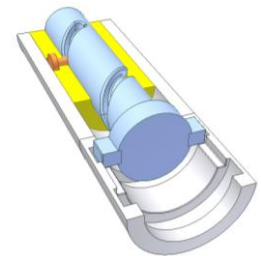
The friction preventing the blue part from rotation must be set larger than the friction preventing the yellow part from translation to ensure that the blue part rotates only when it can not translate.

Grey outer pipe and the yellow slider are cut off half for easy understanding.

This video was made based on the following video:

<https://www.youtube.com/watch?v=N70Vy7hgDTk>

The mechanism is aimed at moving needle in a medical instrument.



### **Control of Cardan joint 1**

<https://youtu.be/ELc28X25ZUM>

Green output frame is connected to the base (in glass) via a Cardano joint. Output motion is controlled by linearly moving pink slider.

The green output frame can rotate around vertical axis thanks to yellow conrod and around horizontal axis thanks to orange conrod.

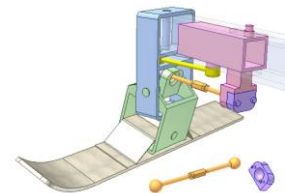
Relation between rotation angles of blue and green frames depends on ratio  $R_b/R_g$ .

$R_b$ : center distance of two vertical revolute joints of the blue frame.

$R_g$ : center distance of revolute and spherical joints of the green frame.

The mechanism can be applied for ice boat of four skis. The ski (in brown) is fixed to green frame. The skis are tilted when the boat turns.

This mechanism was made on request of Jason Brown, a student from Concordia University in Montreal, Canada.



### Oar of 2 DoF 1

<https://youtu.be/kMuxyhFrPYU>

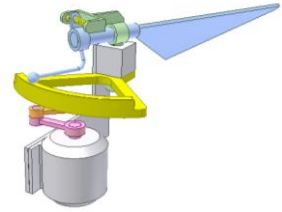
Blue oar moves with different oblique angles  $A$ .

$A = 45$  deg. when going forward.

$A = 0$  deg. when going backward.

$A$  is changed at the ends of the oar stroke thanks to the interaction of blue ball and yellow face cam. Yellow springs tend to press the ball on upper surface of the cam.

Grey motor makes the oar turn around vertical axis via 4-bar mechanism.



### Oar of 2 DoF 2

<https://youtu.be/gSd6uFLe7zw>

Yellow oar moves with different oblique angles  $A$ .

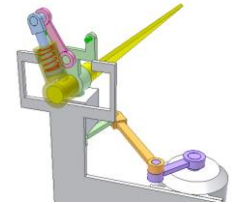
$A = 45$  deg. when going forward.

$A = 0$  deg. when going backward.

$A$  is changed at the ends of the oar stroke thanks to spring toggle mechanism shown at:

<http://youtu.be/u4oW1ZiiRGA>

Grey motor makes the oar turn around vertical axis via 4-bar mechanism.



### Nut of two motions

<https://youtu.be/uYUSwiRqH1Q>

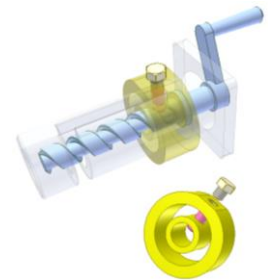
Turn blue screw counterclockwise to move yellow nut linearly and then to turn it.

Turn back to return it to initial position.

Pink pin moves along helical groove of the screw and along L-shaped slot of the base (in glass).

See its application in tea rolling machine:

<https://youtu.be/7AExAoGK1lc>



### Open/Closed plate

<https://youtu.be/lAfcE8jOKsc>

Violet crank, green conrod and red slider create a slider-crank mechanism, where the conrod is shorter than the crank.

Thanks to chain drive (orange, grey sprockets and yellow chain) the mechanism is driven by white motor.

Driving force is applied to green sprocket fixed to the conrod.

Force applied to red slider is not workable due to facing dead positions.

Force applied to violet crank is not workable due to facing 90 deg. pressure angle.

The Open/Closed plate occupies the same place after flipping. The flipping happens only in front space of the plate.

If the motor must be distant from the plate, it's possible to use Bowden cable driver to transmit torque to the green gear.

This mechanism may be applied for License Plate Flipper - Like James Bond:

<https://www.youtube.com/watch?v=ZFrze9eY9o0>

<https://www.youtube.com/watch?v=uanNZieRys8>

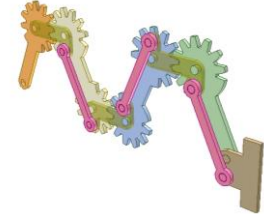


## 23. Mechanisms for folding, contracting or stretching

### Stretch and contraction mechanism 1

<http://www.youtube.com/watch?v=4UpjmxQ3900>

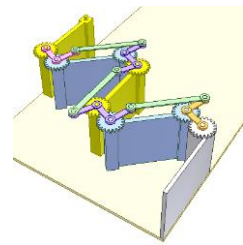
A combination of parallelogram mechanisms and gears.  
Loci of various points on the bars are shown. They can be ellipse, circle or straight line.  
By similar connecting of bars the stretch can be very long.



### Stretch and contraction mechanism 2

[https://youtu.be/L\\_ScRCOM2y0](https://youtu.be/L_ScRCOM2y0)

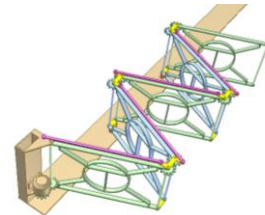
A combination of parallelogram mechanisms and gears.  
Input: orange angular lever. Its cylinder is not shown.  
By similar connecting of bars the stretch can be very long.  
At contraction position the mechanism does not occupy any portion of the passage.



### Penta-folding gate

<http://www.youtube.com/watch?v=6jSwpmr4k5I>

A combination of parallelogram mechanisms and gears.  
There is no need of railway.  
If the construction is not heavy, the wheels can be removed.  
It is an application of mechanism shown in:  
<http://www.youtube.com/watch?v=QNkODQMZfwc>



### Bi-folding gate 1

<http://youtu.be/LG2-y4iVDB4>

Orange conrod, green and upper yellow cranks create a parallelogram mechanism.

R1: pitch radius of green gear

R2: pitch radius of blue gear

$i = R1 / R2 = 40 / 19$ . This ratio is needed to meet requirement when green gate rotates  $\alpha = 58$  deg., blue gate rotates 90 deg. in relation with the green gate.

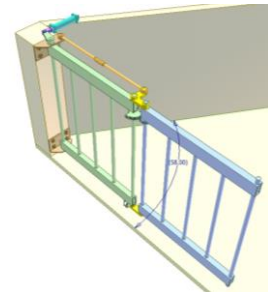
$i$  changes when  $\alpha$  has different values.  $i = 1$  if  $\alpha = 90$  deg.

If necessary a supporting swivel wheel for the blue gate is mounted at its lower right corner.

This video was made on request of Mr. JC Lo from Malaysia.

The two gears can be replaced by a bar to get similar effect. See:

<http://www.youtube.com/watch?v=LF8kSTCZlxw>



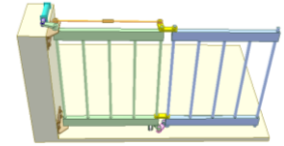


### Bi-folding gate 2

<https://youtu.be/ysdMluJH5tl>

Orange conrod, green and upper yellow cranks create a parallelogram mechanism. There is a 4-bar linkage of the pink conrod that connect green and blue panels. See another solution:

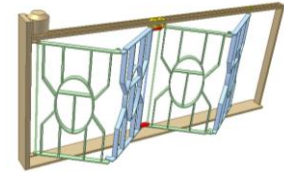
[https://www.youtube.com/watch?v=yeL\\_tcLv1do](https://www.youtube.com/watch?v=yeL_tcLv1do)



### Tetra-folding gate

<http://www.youtube.com/watch?v=II88I0AP6-Q>

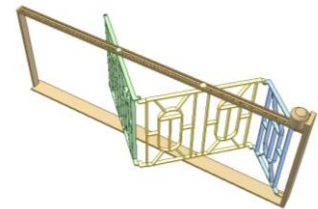
A combination of slider-crank mechanisms and gears. The gears are fixed with the two center gate panels.



### Tri-folding gate

<http://www.youtube.com/watch?v=SoL0uq5K6fq>

A combination of slider-crank mechanisms.



### Festooning cable system

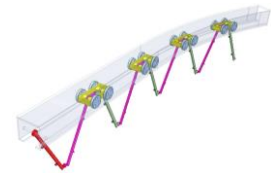
<https://youtu.be/Rft0SUmYoA>

Pink lever and green lever on each car are connected together via gear sectors.

Pink lever and green lever on adjacent cars are connected together by a spherical joint.

So the cars can move along curved runway and distances between two adjacent cars are always equal.

The power cable (in zigzag shape) is attached to the small rings on red, pink and green levers.



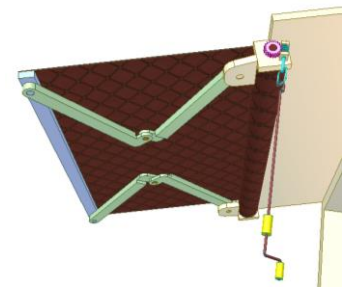
### Contractible eave

<http://www.youtube.com/watch?v=YmcJmXpR7XM>

It is an application of the slider-crank mechanism.

Manual rotation of the detachable brown crank rolls the roof through a worm drive.

The roof has some slope so it keeps even during stretching.



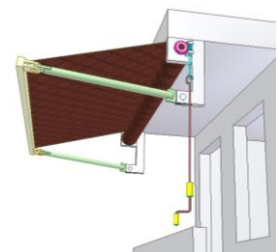
### Movable eave for balcony

<https://youtu.be/ETc-dLC18s>

Turn the brown detachable crank to roll or unroll the roof through a worm drive thus uncover or cover the balcony.

The gravity maintains the roof tension.

No relative motion between yellow bar and two green bars. The revolution joints between them are for easy assembling only.



### Folding plug 1

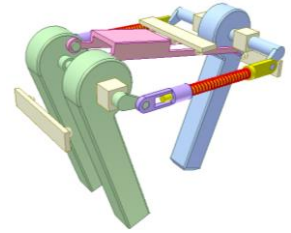
<https://youtu.be/21ULLBnoWu8>

Two green and one blue prongs (rockers) are connected by pink double bar (conrod) to create a 4-bar linkage.

They are also connected by two spring - bar assemblies, the purpose of which is keeping the prongs firmly at closing or opening positions.

Three popcorn bars play role of stoppers for the prongs.

The plug base and cover are not shown.



### Automatic folding leg

<https://youtu.be/VTdJQZMbU5I>

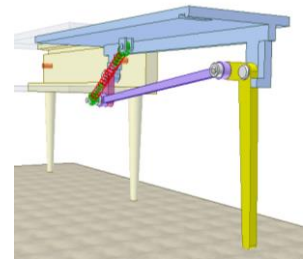
Yellow leg is automatically folded out when pulling out blue desk thanks to the compression spring (in red).

When pushing back the desk, pink rocker turns 90 deg. to fold away the leg.

Pink rocker, yellow leg and violet coupler create a four-bar linkage.

Orange pins are for limiting linear motion of the blue desk.

The video shows only half of the whole table.



### Folding hood frame for a cyclo

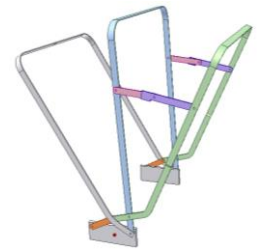
<https://youtu.be/-G95Mv38rPc>

It consists of four-bar linkage (orange, blue and green bars) and a bar lock (pink and violet bars).

The lock keeps the frame firmly at its open position against any outside force applied to the green and blue bars.

To open the frame first pull the green bar, then push up the lock.

To fold the frame first push down the lock then push the green bar.



### Rolling bridge

<https://youtu.be/2yNamCnxdw4>

It is an animation of the Paddington bridge, London.

The bridge consists of 8 spans of isosceles trapezoid shape.

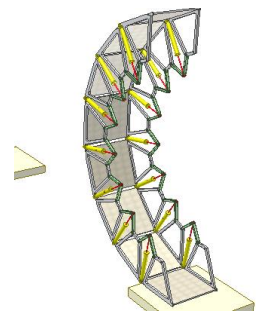
A revolution joint (A) connects two adjacent spans.

Besides they are connected by two green conrods which are linked together by a revolution joint (B).

Yellow cylinder and red piston connect A and B.

7 pairs of hydraulic cylinders moving at the same speed roll and straighten the bridge.

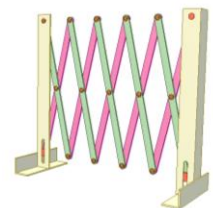
At curled up position the bridge looks like a sculpture of octagonal shape on one side of the bank.



### Folding scissor fence

<http://www.youtube.com/watch?v=Do1DwSqkZoM>

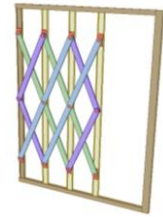
Combination of slider crank mechanism and parallelogram mechanism.



### Folding scissor gate 1

<http://www.youtube.com/watch?v=opSblgV2pSE>

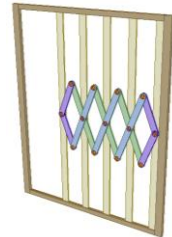
A combination of slider crank mechanisms and parallelogram mechanisms.



### Folding scissor gate 2

<http://www.youtube.com/watch?v=GvjFwcl9rro>

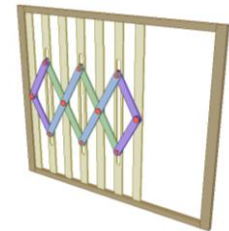
A combination of slider crank mechanisms and parallelogram mechanisms.



### Folding scissor gate 3

[http://www.youtube.com/watch?v=tb4H7Tr\\_W1s](http://www.youtube.com/watch?v=tb4H7Tr_W1s)

A combination of slider crank mechanisms and parallelogram mechanisms.



### Folding scissor gate 4

<http://www.youtube.com/watch?v=GApddnCKz4>

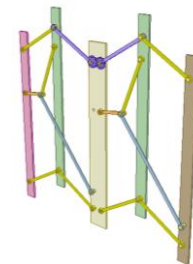
A combination of slider crank mechanisms and parallelogram mechanisms.



### Kite mechanism 5c

[http://youtu.be/AD\\_0MACi44M](http://youtu.be/AD_0MACi44M)

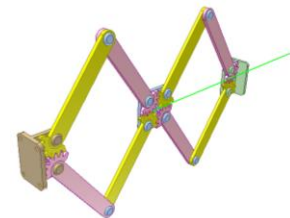
A way to connect two (or more) “Kite and spear-head mechanism 5b” by adding gear drive (in violet). Thus very long rectilinear motion of the end bar (in pink) can be obtained. This mechanism may be applied for retractable gates.



### Gear and linkage mechanism 3b

<http://youtu.be/jFVh3nKOVf8>

Combination of linkage and gear drive. It shows the way to connect two (or more) mechanisms of “Gear and linkage mechanism 3a”. The green part translates along an absolutely straight line.



### Lazy tong 1

<http://youtu.be/Zm-4kJLdRcM>

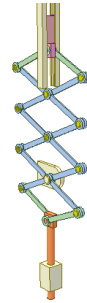
Input: pink slider.

Output: orange link.

Small longitudinal force on the input causes large one on the output (around 3 times in this case). The input and output move in opposite directions.

The mechanism finds application in lazy tong riveter:

<https://www.youtube.com/watch?v=7D7ECCps0h4>



### Lazy tong 2

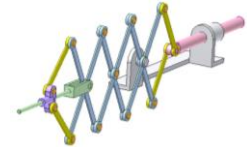
<http://youtu.be/UniRkbt0LOY>

Input: pink slider.

Output: violet link.

Short input motion gives a long output one (around 3 times in this video). The input and output move in opposite directions.

The green link is for keeping the violet link direction unchanged.



### Lazy tong 3

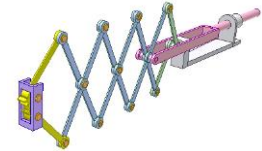
<http://youtu.be/cML0xKSmTPM>

Input: pink slider.

Output: violet link.

Short input motion gives a long output one (around 4 times in this video). The input and output move in the same direction.

The gears on yellow links are for keeping the violet link direction unchanged.



### Scissor mechanism 2

<https://youtu.be/luW-YqVl5nA>

Compare two scissor mechanisms

The right one is an ordinary scissor mechanism of three identical large rhombi.

The left one is a special scissor mechanism of two large rhombi and one small rhombus.

Length of violet bars:  $a$

Length of pink bars:  $a + 2a$

Length of blue bars:  $2a + 2a$

Length of green bars:  $2a$

Red identical cams give orange sliders the same displacement  $S$ .

- Left mechanism: displacement of the brown roller  $L1$ :

$$L1 = S + 2 \cdot n \cdot S$$

$n$ : number of large rhombi created by the bars.

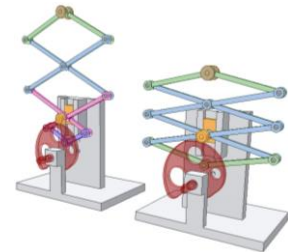
Here  $n = 2$ , so  $L1 = 5 \cdot S$

- Right mechanism: displacement of the brown roller  $L2$ :

$$L2 = n \cdot S$$

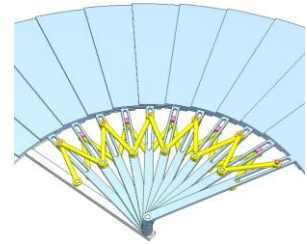
Here  $n = 3$ , so  $L2 = 3 \cdot S$

$L1$  is larger than  $L2$



### Deploying a circle 1

<https://youtu.be/KTIXd9ptlqs>



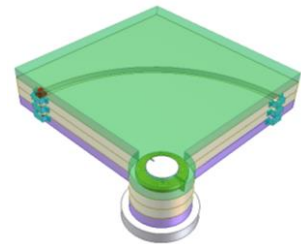
### Deploying a square 1

[https://youtu.be/OG\\_rI8Aau7M](https://youtu.be/OG_rI8Aau7M)

The square of four sectors is deployed thanks to the interaction of red pins and cyan U-shaped parts.

In hubs of movable sectors there are coil springs that tend to turn the sectors counterclockwise.

It can be used for deploying solar panels.



### Deploying a rectangle 1

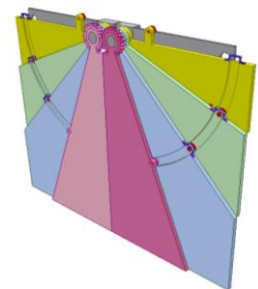
[https://youtu.be/X\\_7VxnnygYE](https://youtu.be/X_7VxnnygYE)

The rectangle is divided into two groups of four sectors.

The interaction of red or pink pins and violet U-shaped parts helps to deploy the rectangle.

Input: one among two pink gears.

It can be used for deploying a partition.



### Eight-bar linkage for translation along straight line

<https://youtu.be/joJUV5Cbr4w>

Input: one of the bars pivoted on the base.

Length of the grey base bar and end bar:  $a$

Length of blue bar:  $a$

Length of green bars:  $0.4a + 0.6a$

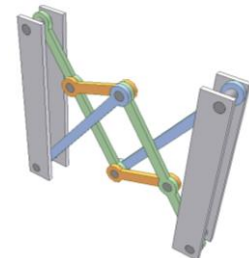
Length of orange bars:  $0.4a$

Output: the grey end bar that translates along an approximately straight line (is kept always parallel to the base).

The gravity tends to keep the mechanism at stretching position.

See a real mechanism:

<https://www.youtube.com/watch?v=E19ht39x7hY>



### Linkage for stretching along straight line

<https://youtu.be/E1u5LdZcEhc>

Input: one of the bars pivoted on the grey base.

Length of the vertical bars (grey, yellow and brown):  $a$

Length of blue bar:  $a$

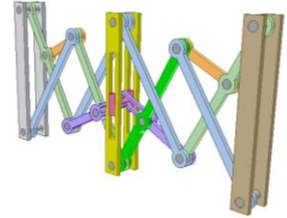
Length of green bars:  $0.4a + 0.6a$

Length of orange bars:  $0.4a$

Distance between two holes of violet bars:  $0.4a$ . They have grooves, in which a pin of the pink slider moves.

Output: the brown end bar that translates along an absolutely straight line and is kept always parallel to the grey base.

The gravity tends to keep the mechanism at a stretching position.



### Eight-bar linkage for stretch and 90 deg turn

<https://youtu.be/gh0xOluJOgY>

Input: one of the bars pivoted on the base.

Length of the grey base bar and yellow end bar:  $a$

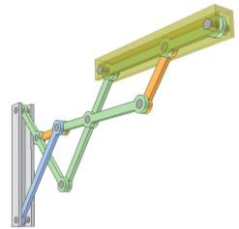
Length of blue bar:  $a$

Length of green bars:  $0.4a + 0.6a$

Length of orange bars:  $0.4a$

Output: the yellow end bar that moves out and gets horizontal position.

The gravity tends to keep the mechanism at folding position.



### Six-bar linkage for stretch and turn

<https://youtu.be/q8tVdjMo22E>

Input: one of the bars pivoted on the base.

Length of the grey base bar and end bar:  $a$

Length of blue bar:  $a$

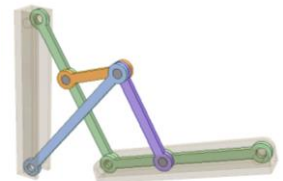
Length of green bars:  $0.4a + 0.6a$

Length of orange bars:  $0.4a$

Length of violet bar:  $0.6a$

Output: the yellow end bar that moves out and gets horizontal position.

The gravity tends to keep the mechanism at stretching position.



### Twelve-bar linkage for stretch and turn

<https://youtu.be/RyO447EkxfI>

Input: one of the bars pivoted on the grey base.

Length of the grey base bar and the yellow end bar:  $a$

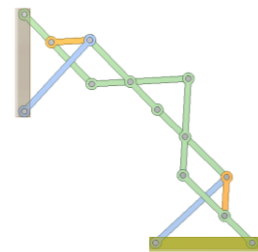
Length of blue bar:  $a$

Length of green bars:  $0.4a + 0.6a$

Length of orange bars:  $0.4a$

Output: the yellow end bar that moves out and gets horizontal position.

The gravity tends to keep the mechanism at stretching position.



### Cable mechanism for controlling window curtains 1

<https://youtu.be/H6Un9TCUDxk>

Pull one or another of cable vertical branches to close or open the curtains that are represented by yellow short bars.

The pulley box (in glass) weight creates the cable tension.



### Cable mechanism for controlling stage curtains 1

[https://youtu.be/DzQp\\_RqS5GU](https://youtu.be/DzQp_RqS5GU)

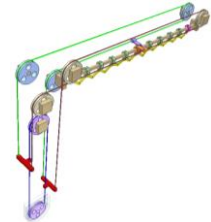
Pull one or another of violet cable branches to close or open the curtains that are represented by yellow short bars.

The pulley box (in glass) weight creates the cable tension.

The ends of green and brown cables are fixed to the red bars, which are fixed to the blue cable

The video was made based on following picture:

[https://www.peroni.com/lang\\_UK/imgschede/TravellerCurtain\\_01aa.jpg](https://www.peroni.com/lang_UK/imgschede/TravellerCurtain_01aa.jpg)



### Cable mechanism for controlling stage curtains 2

<https://youtu.be/DImZ9vU9Sp4>

Pull one or another of red cable branches to lift or lower the curtain that are represented by violet waved bars.

The lower end of each brown cable is fixed to lower side of the curtain. The upper end of each brown cable is fixed to multi-groove pulley. The brown cables pass through button-holes of the curtain.

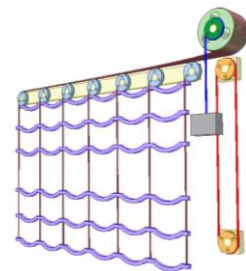
The lower end of blue cable is fixed to the grey contra-weight.

The upper end of blue cable is fixed to the small green pulley.

The contra-weight is fixed to the red cable.

The video was made based on following picture:

[https://www.peroni.com/lang\\_ES/imgschede/VenetianCurtain\\_02aa.jpg](https://www.peroni.com/lang_ES/imgschede/VenetianCurtain_02aa.jpg)



### Cable telescopic sliders 1a

<https://youtu.be/ydkJCE956ko>

Input: motor pulley (in violet).

There are two cables, red and blue.

The red cable is wrapped around the green idle pulley of the base runway.

One end of the red cable is fixed to the violet pulley.

The other end of the red cable is fixed to lower pin of the yellow slider.

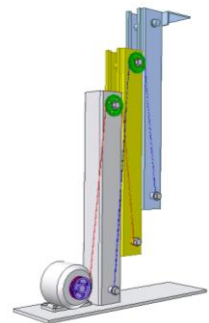
The blue cable is wrapped around the green idle pulley of the yellow slider.

One end of the blue cable is fixed to lower pin of the base runway.

The other end of the blue cable is fixed to lower pin of the blue slider.

The motor pulls the sliders up. The device to keep the sliders at up positions is not shown.

The sliders move down thanks to the gravity.



### Cable telescopic sliders 1b

<https://youtu.be/FJOTa7O4PkQ>

Input: motor pulley (in violet).

There are two cables, red and blue.

The red cable is wrapped around the green idle pulley of the base runway.

One end of the red cable is fixed to the violet pulley.

The other end of the red cable is fixed to lower pin of the yellow slider.

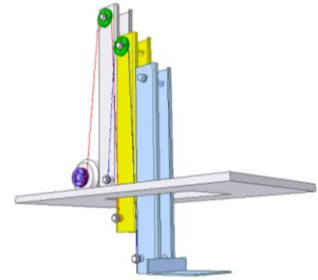
The blue cable is wrapped around the green idle pulley of the yellow slider.

One end of the blue cable is fixed to lower pin of the base runway.

The other end of the blue cable is fixed to lower pin of the blue slider.

The sliders move down thanks to the gravity.

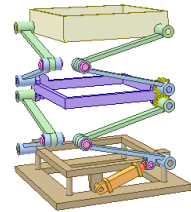
The motor pulls the sliders up. The device to keep the sliders at stop positions is not shown.



### Sarrus linkage 3

<http://youtu.be/FINFAiCQIAk>

A way to connect two (or more) Sarrus linkages by adding gear drive (in yellow). Thus very long up-down rectilinear motion of the top floor can be obtained by just small displacement of a piston (in orange).



### Retractable device for fluid supply

<http://youtu.be/B3khF2IBUyU>

“Sarrus linkage 3” in combination with helical hose.



### Sarrus linkage 4

<https://youtu.be/AWvQ6-pfwFA>

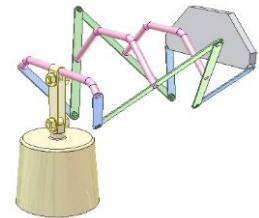
It is an application of Sarrus mechanism for a wall lamp.

The mechanism contains only revolution joints.

Yellow lamp moves along a straight line.

For original Sarrus mechanism see:

<http://youtu.be/pQBJcgJe6t0>



### Sarrus linkage 5

<https://youtu.be/butGEnekwYA>

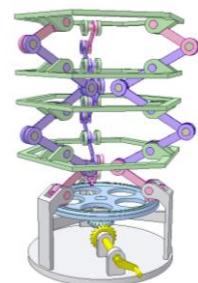
Green frames moves along a vertical straight line.

Self-locking Archimedean gear drive is used for turning three pink gear-cranks at the same time.

The mechanism can be applied for platforms or folding antennas.

For original Sarrus mechanism see:

<http://youtu.be/CPYbD1GUS1A>





### Deployable curtain wall

<https://youtu.be/6UljLg-nD4>

It was made based on the deployable curtain wall for indoor light control, Al Bahr Towers, Abu Dhabi, UAE.

<http://i.imgur.com/5PtvZmV.gifv>

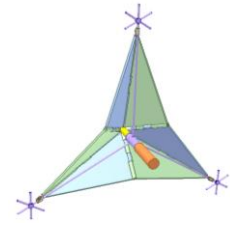
The video shows only an unit of the wall.

The units are assembled on violet stationary frame. Yellow center slider, outside beige slider and pink rod create an ellipse mechanism.

The yellow center slider has 3 revolution joints with 3 pink rods.

Triangular plates have revolution joints with the pink rods and between themselves.

Orange cylinder moves the yellow center slider to deploy the unit.



### Folding a rectangle 1

<https://youtu.be/UNPU7ECOtVA>

The rectangle is divided into 4 parts.

Input: the pink part.

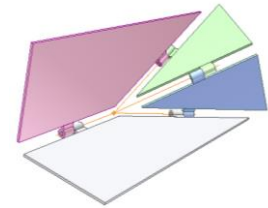
The 4 parts are connecting together by revolute joints, axes of which are concurrent. In fact, it is a spherical 4-bar linkage.

The mechanism has an unstable position when all parts are in a plane.

The mechanism is inspired by paper folding art.

The video was made base on

<https://youtu.be/oLuO-CPJXk>



### Folding a square 1

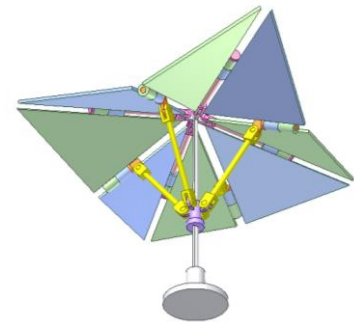
<https://youtu.be/RoRK2kN9Mlk>

The square is divided into 8 sectors.

Input: violet slider.

Two adjoining sectors are connected together by a revolute joint. Yellow conrods connect the violet slider with orange hinge pins by revolute joints. Pink hinge pins are connected to the grey post by revolute joints

The mechanism has an unstable position when all sectors are in a plane.



### Folding a rectangle 2

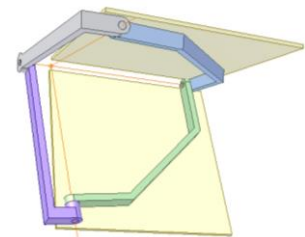
<https://youtu.be/bKgAcnW8R0s>

Input: blue bar.

It is a spherical 4-bar linkage.

Angle A between two axes of revolute joints of the blue (and green) bar is 85 deg.

The simulation shows that if  $A = 90$  deg., the mechanism can't work.



### Folding a circle 1

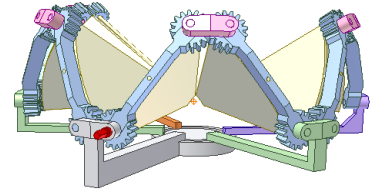
<https://youtu.be/IOVuCLSCclU>

Input: red shaft fixed to one of the blue bars.

The circle is divided into 8 sectors.

It is a spherical mechanism. Axes of all revolute joints are concurrent. Bevel gear drives make all blue bars turn the same angle.

It can be used for deploying solar panels.



### Folding a square frame 1

<https://youtu.be/65gqIGk-5Tc>

The center cross is stationary.

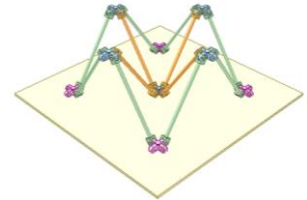
Input: one among the orange bars.

Four pink crosses slide on the ground surface.

The frame can be enlarged by connecting more bars and crosses.

See a real mechanism:

<https://www.youtube.com/watch?v=ayk9PBwpmM>



### Folding a square frame 2a

<https://youtu.be/mil1MH8cTvQ>

Input: orange bar.

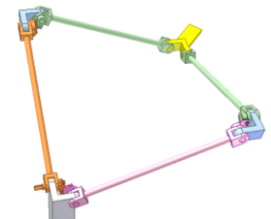
Orange and pink bars are connected together by bevel gears.

Orange and green bars are connected together by bevel gears.

Pink and green bars are connected together by bevel gears.

Yellow part moves in the horizontal plan.

This mechanism can be used for manipulators.



### Folding a square frame 2b

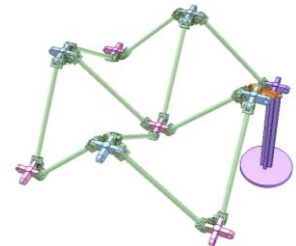
<https://youtu.be/tVkDVS-mGOw>

Input: orange bar.

It is developed from "Folding a square frame 1a":

<https://youtu.be/mil1MH8cTvQ>

by adding more parts.



### Folding a square 2

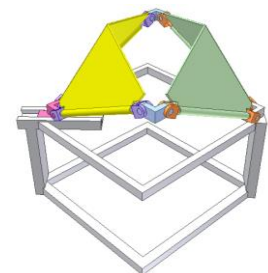
[https://youtu.be/V6\\_sy5B5r5A](https://youtu.be/V6_sy5B5r5A)

Input: one among the orange bars.

Joints between triangular panels and orange or violet bars are cylindrical.

Joints between two yellow (or green) triangular panels are revolute.

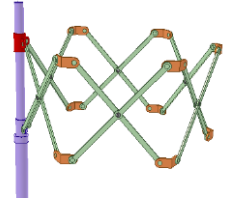
It is an attempt to create a movable roof.



### Folding a hexagon frame 1a

<https://youtu.be/jwzcOYU6XKQ>

It is an application of scissor mechanisms.  
It can be called as the cylindrical scissor mechanism



### Folding a hexagon frame 1b

<https://youtu.be/JPV3Qqulob8>

It is an embodiment of mechanism shown at:

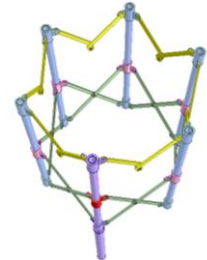
<https://youtu.be/jwzcOYU6XKQ>

Input: red slider.

Adding cylindrical joints of the pink parts with the blue rods as well as the yellow bars does not change motion rule of the whole mechanism.

See a real mechanism:

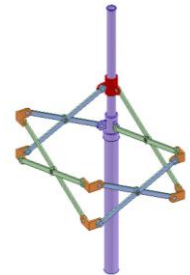
[https://www.youtube.com/watch?v=APSsrPbh\\_X4](https://www.youtube.com/watch?v=APSsrPbh_X4)



### Folding a rectangular frame 1

<https://youtu.be/wXx4iZ1eZBs>

It is an application of scissor mechanisms.



### Folding a rectangular frame 2

<https://youtu.be/VRHqUxAPCD0>

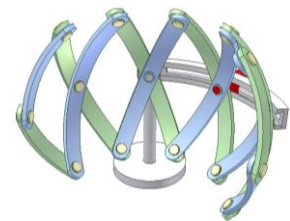
It is an application of scissor mechanisms.  
Length ratio of the rectangle two sides is around  $\frac{1}{2}$ .



### Spherical scissor mechanism 1a

<https://youtu.be/GjqgTo3NjdY>

Input: red circular slider.



### Spatial scissor mechanism

<https://youtu.be/DasxDJJF2hk>

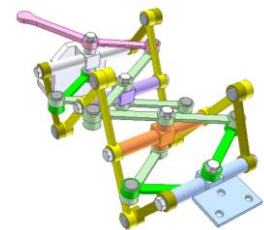
It consists of two scissor mechanisms arranged in two perpendicular planes. Turn the pink handle to move the blue plate along a straight trajectory.

There is no need of prismatic joints like in the planar scissor mechanism.

Two last scenes of the video show a simplifying embodiment where the bar number is reduced by half. The mechanism works the same way with less rigidity.

In fact, it is a Sarrus linkage:

<https://youtu.be/FINFaiCQIAk>



## 24. Mechanisms for opening and closing

### 24.1. Hinges

#### The simplest hinge

<https://youtu.be/qJKEW04r9Y>

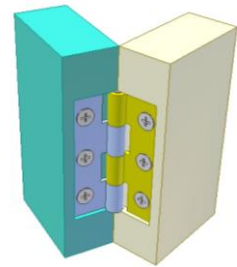
Position of the door can be adjusted thanks to the threads of the pink rings and the blue pins.



#### Butt hinge

<https://youtu.be/JJiUvK-leJo>

The video shows the arrangement of a butt hinge to get zero gap between the door and the frame.



#### Rising butt hinge

<https://youtu.be/m-CBuT-UZi8>

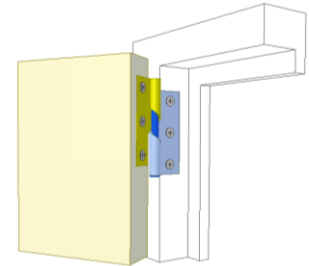
As the door is opened the leaf fitted to the door (in yellow) rides up the spiral knuckle raising the door a few millimetres. The door tends to close itself because of the gravity.

This hinge type is use for cases:

- Thick or uneven door ways
- When an easily removable door is wanted
- Self-closing door

For more about rising butt hinge see:

<https://www.absolutehardware.co.uk/blog/2018/11/01/how-and-when-to-fit-rising-butt-hinge/>



#### Hinge of two DoF

<https://youtu.be/KO1wyOy22BM>

Pull then turn out the blue door to open.

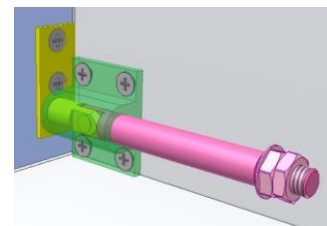
Turn in and push the blue door to close.

The blue door is steadily vertical after the yellow part enters into the hole of the green socket.

Chamfered portion on the yellow part makes the entering process easier.

When the yellow part is in the yellow socket, the hinge has only one degree of freedom (translation).

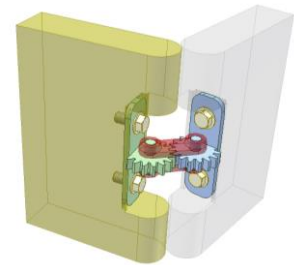
When the yellow part is not in the yellow socket, the hinge has two degrees of freedom (translation and rotation).



### Hinge enabling 360 degree rotation 1

<http://www.youtube.com/watch?v=pl8tq3Z76is>

Ordinary hinges can not rotate 360 degrees because of thickness of moving and grounded parts. The proposed design does not have that limitation. A satellite gear drive is applied here.



### Hinge enabling 360 deg. rotation 2

<http://youtu.be/gltkHiORink>

Ordinary hinges can not rotate 360 degrees because of thickness of moving and grounded parts. The proposed design does not have such limitation.

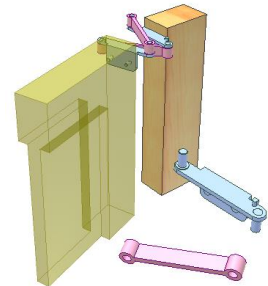
An anti-parallelogram mechanism is used here.

Lengths of blue and pink parts are 80 and 95 respectively.

There is a stopper on the blue part to prevent death positions so the rotation angle is a little less than 360 deg.

STEP files of this video are available at:

<http://www.mediafire.com/download/9t6a7uvkrwi5b8q/360dHinge2STEP.zip>

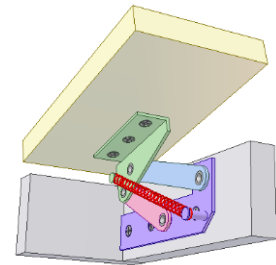


### Bench seat hinge 1

<https://youtu.be/eA4mC4Cf2MM>

It is an application of 4 bar linkage.

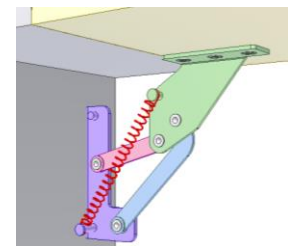
End open positions of the seat is kept firmly thanks to the red spring.



### 90 deg. hinge of 4-bar linkage 1

<https://youtu.be/TLROAYXxkvA>

Yellow movable plate is fixed to green connecting rod of the linkage. Red spring holds the movable plate at stretching or folding positions.



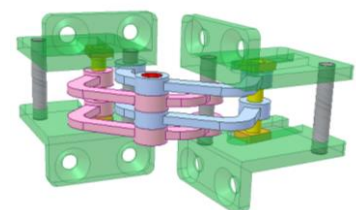
### 180 deg. concealed hinge 2

<https://youtu.be/tSpiNDotdlo>

This 6 bar mechanism enables the hinge to rotate 180 deg.. It contains 5 movable links, 5 revolution joints and 2 prismatic joints.

At close position the hinge is not seen from outside.

It is used for cabinet doors.



### 90 deg. concealed hinge of 4-bar linkage 2

<https://youtu.be/6l-nL4uGSI>

Base link: assembly of gray base plate, brown and green parts.

Rocker 1: orange link.

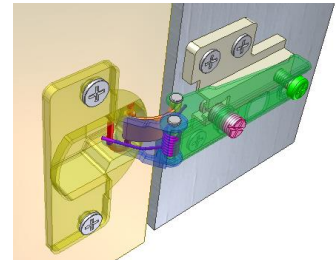
Rocker 2: blue link.

Connecting rod: assembly of popcorn movable plate, yellow part and red U-shaped pin.

Violet spring holds the movable plate at open or closed positions.

It is possible to adjust position of the movable plate in two horizontal directions thanks to slots on the brown and green parts and pink and green screws.

It is a concealed hinge. The hinge is hidden at its closed position.



### 90 deg. concealed hinge 2

[https://youtu.be/kawIO\\_uv0-0](https://youtu.be/kawIO_uv0-0)

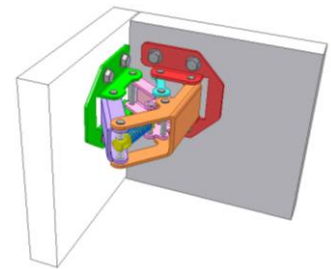
This 6 bar mechanism of all revolution joints enables the hinge to rotate 90 deg.. It contains 5 movable links, 7 revolution joints.

At close position the hinge is not seen from outside.

Blue spring keeps the door stable at open or closed position.

It is used for cabinet doors and is commercialized. See:

<https://www.solmer.co.uk/cabinet-hinges-stays/90-degree-easy-mount-concealed-hinge.html>

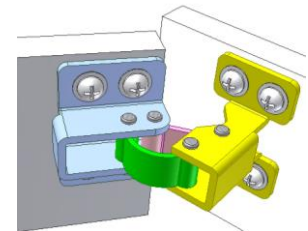


### 90 deg. concealed hinge of 4-bar linkage 3

<https://youtu.be/g3W3q7JqCM8>

This 4-bar mechanism of all revolution joints enables the hinge to rotate a little more than 90 deg..

At close position the hinge is not seen from outside.



### 90 deg. concealed hinge of 4-bar linkage 2b

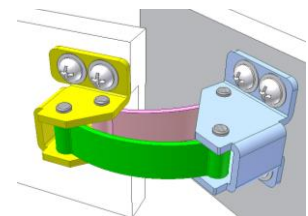
<https://youtu.be/vvqDA52oRXk>

This 4-bar mechanism of all revolution joints enables the hinge to rotate a little more than 90 deg..

At close position the hinge is not seen from outside.

It is a simplified embodiment of the hinge shown at

<https://youtu.be/6l-nL4uGSI>



### Hood hinge

<https://youtu.be/EpXg7bDBe54>

It is a six-bar linkage.

Spring device of blue compression spring plays role of a tension spring keeps the cyan hood stable at its end angular positions.

This mechanism can be used for car hoods.

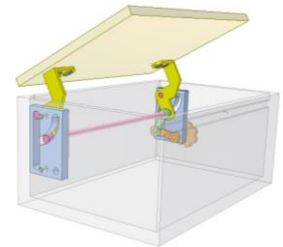


### Concealed hinges 1

<https://youtu.be/kh252HOZrqc>

These concealed hinges allow raising and turning the lid to open.

The opening force may be applied to the orange crank or to the lid directly.



### 180 deg concealed hinge

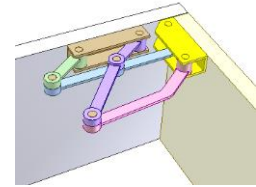
<https://youtu.be/6bMMZq0X29E>

This 6 bar mechanism enables the hinge to rotate 180 deg..

At close position the hinge is not seen from outside.

Green, blue and violet bars create a parallelogram.

It is used for car doors.

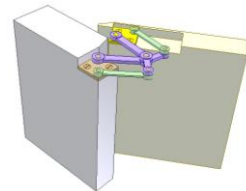


### 90 deg concealed hinge

<https://youtu.be/IE-HTMKPDjQ>

It is 6 bar mechanism of two parallelograms enables the hinge to rotate 90 deg..

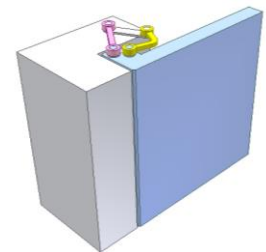
At close position the hinge is not seen from outside.



### Door 1

[https://youtu.be/qYrl\\_t0-U3A](https://youtu.be/qYrl_t0-U3A)

Pink, yellow rockers and blue conrod (door panel) create a 4-bar linkage.



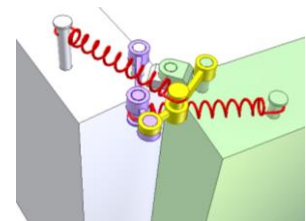
### Door 4

<https://youtu.be/1TmTI4IxiAs>

Violet, green (door panel) rockers and yellow conrod create a 4-bar linkage.

Red springs make the door always closed if no external force.

Advantage: Torques caused by springs applied on the door panel is not too large at door open positions.



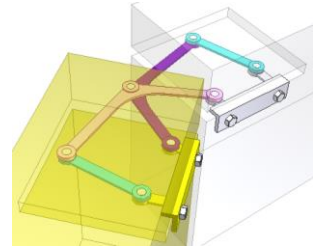
## Door 6

<https://youtu.be/Bi4rNqL2VCI>

It is a 6-bar mechanism consisting of two blue identical bars, two identical V-bars and two white/yellow symmetric bars.

The yellow panel turns 180 deg. around a virtual moving vertical axis.

It is called the hidden hinge because it is not seen when closing.



## Window friction hinge 1

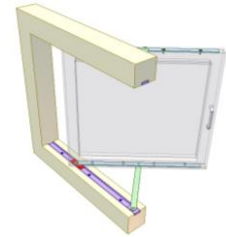
<https://youtu.be/p9Vf0iJaF1s>

The sash is attached to blue conrod of a slider crank mechanism.

Push/pull the sash to open/close the window.

Red slider has friction shoes (not shown) that are pressed towards violet runway thus holds the sash at a desired position against undesired movement by wind or the like.

An advantage of this hinge: the outside of the sash is accessible from the inside for purposes of cleaning.



## Window friction hinge 2

<https://youtu.be/7ylZISiVbXA>

The sash is attached to blue conrod of a 6-bar mechanism. Push/pull the sash to open/close the window.

Red slider has friction shoes (not shown) that are pressed towards violet runway thus holds the sash at a desired position against undesired movement by wind, weight or the like.



## Window of 3 DoF

[https://youtu.be/V\\_XkVWZMfPw](https://youtu.be/V_XkVWZMfPw)

It is 4-bar linkage of 3 movable links (violet rockers, green conrods and blue panel). The panel of only one revolution joint has 3 degrees of freedom so the window works like the one of consealed hinges but the open angle can be very large.

The spring pin (in pink) holds the panel at closed position.

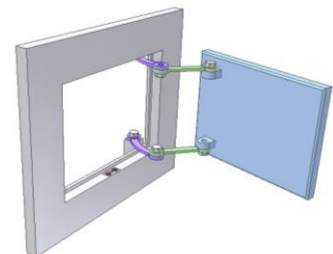
Weakness: the user has to pay attention to “steer” the panel into its closed position.

See a real window where a pus-push lock is applied:

[https://www.reddit.com/r/gifs/comments/9ybblo/this\\_pump\\_access\\_panel/](https://www.reddit.com/r/gifs/comments/9ybblo/this_pump_access_panel/)

As for the push-push lock see:

<https://youtu.be/KaP5Yff94Cc>





### Hinge of 3 DoF

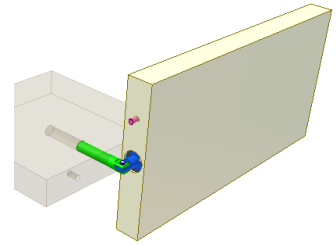
<https://youtu.be/tGkHUY5v3UY>

Steps for folding yellow panel:

Pull out – Turn 90 deg. around horizontal axis – Turn 90 deg. around vertical axis.

This hinge may be used for folding airplane wings:

<https://www.youtube.com/watch?v=pXdMRQikuFg>



### Hinge of 2 DoF

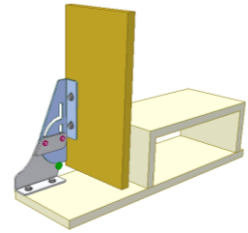
<https://youtu.be/d--gIK0SLKQ>

The hinge allows performing two motions: rotary and straight ones thanks to circular and straight slots on blue part.

Green pin keeps the rotation stable.

This video was made based on:

[http://www.metalmoulding.com/Slide\\_out\\_flip\\_up\\_rotating\\_hinge.html](http://www.metalmoulding.com/Slide_out_flip_up_rotating_hinge.html)

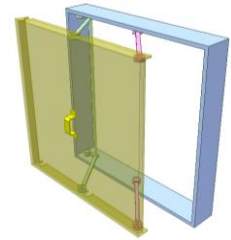


## 24.2. Doors

### Door 2a

<https://youtu.be/8gg9g0fgx94>

Pink, green rockers and yellow conrod (door panel) create parallelogram mechanism that reduces space needed for door opening.

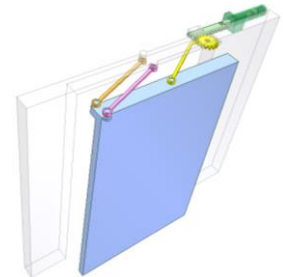


### Door 2b

<https://youtu.be/pTMZ2fbvz-w>

Pink, orange, yellow rockers and blue conrod (door panel) create parallelogram mechanisms that reduce space needed for door opening.

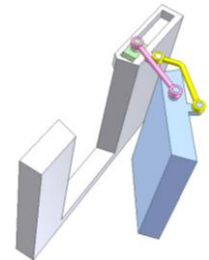
This design can be applied for vehicle doors.



### Door 3

<https://youtu.be/oNzxy69P8Bs>

Pink and yellow rockers, blue conrod (door panel) create a 4-bar linkage. Green slider-pivot can move so the mechanism has two degrees of freedom. By giving two input motions (yellow link and green slider in this video) the blue door panel can be opened to both sides in spite of its wedge section.



### Door and stairs cover

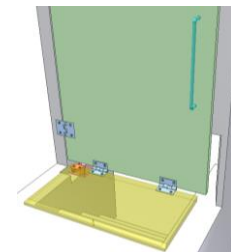
<https://youtu.be/oPsgOePdKU8>

This mechanism enables to open green door and raise yellow cover at the same time.

Motion of the cover is controlled by pink cam and orange follower.

Attention: Axes of vertical and horizontal hinges are skew (not intersecting).

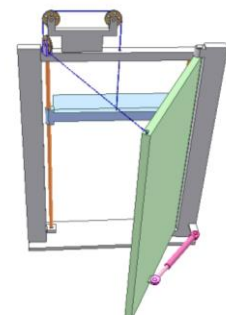
This mechanism was made on request of a YouTube viewer from Arab Saudi for his new house.



### Door pulls up the frame while opened

<https://youtu.be/ExsSjLfcBjs>

While the green door is opened, it pulls up blue frame via cable-pulley system. Pay attention to the violet rotary pulley bearing. Vertical portion of the cable between lower and upper pulleys must be coaxial with rotary axis of the bearing.



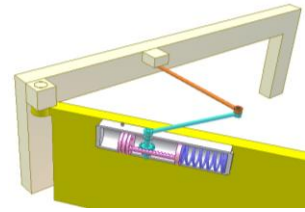
### Door closer 1

<http://youtu.be/vBDIDc9MmI4>

The cyan arm is connected to cyan gear that engages with pink rack-piston. At one end of the rack-piston is violet spring that accumulates energy during door opening and releases it during closing.

The spaces around the rack-piston contain oil. There are oil ways connecting the oil spaces including adjustment valves that regulate opening and closing speeds.

As the door swings closed, connecting link (in orange) comes into toggle with the cyan arm, giving it a large angular velocity, which helps the oil damping be more effective in retarding motion near the closed position.



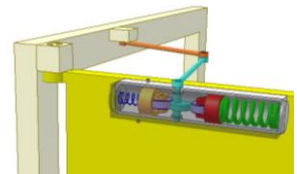
### Door closer 2

<http://youtu.be/ppgPrFq6WXw>

The cyan arm is connected to a cam (eccentric circle profile) that contacts with rollers of two pistons. The red piston has green spring that accumulates energy during door opening (the spring length is reduced) and releases it during closing. The orange piston has a blue spring that ensures its permanent contact with the cam. The cam must be arranged in such a way as to avoid self-locking during closing.

The spaces around the pistons contain oil. There are oil ways connecting the oil spaces including adjustment valves that regulate opening and closing speeds.

As the door swings closed, connecting link (in orange) comes into toggle with the cyan arm, giving it a large angular velocity, which helps the oil damping be more effective in retarding motion near the closed position.



### Cabinet door

<https://youtu.be/JQQEYlvM2GY>

Pull glass door to open or close.

The door slides on its hinge to reduce occupation space at open position.

Red spring holds the door steadily at its opening or closing position.

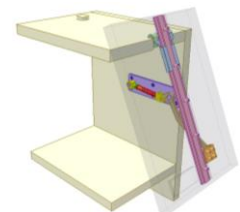
It can be applied for garage doors.

See real mechanism:

<https://www.youtube.com/watch?v=mzEpVIMyrxs&index=9&list=PLRvMm7pRoiKjx7VT9Ds4Wlip5MkXv5n7S>

See a mechanism of the similar function:

[https://youtu.be/f6OKy6Nr\\_4o](https://youtu.be/f6OKy6Nr_4o)

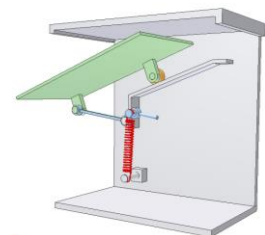


### Door 5

[https://youtu.be/f6OKy6Nr\\_4o](https://youtu.be/f6OKy6Nr_4o)

Blue crank, green conrod (door panel) and orange roller create crank slider mechanism (to some extent, because the roller can be replaced with a slider).

Lower fixed end of red spring is set at position so as to keep the green door panel firmly at its closed or open positions (to create anticlockwise moment on the blue crank at closed position and vice versa).



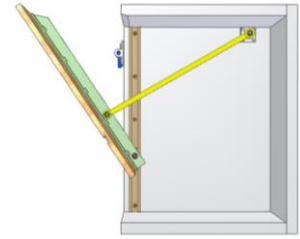
### Cabinet door 2

<https://youtu.be/hKcyeDghVRs>

Yellow crank, green conrod and pink slider create a slider-crank mechanism.

Raise the conrod to open the door.

Use blue pin to prevent the door from falling at its open position.



### Cabinet door 3a

[https://youtu.be/6Un\\_XaJUt58](https://youtu.be/6Un_XaJUt58)

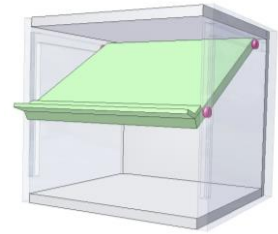
Raise and push green door to open.

Pull and lower the door to close.

Pink rollers roll in grooves of side plates.

At open position, the rollers stay in upper horizontal grooves (a bit slanting), so the door is kept immobile steadily.

Disadvantage: usable inside space is limited because of the door motion.



### Cabinet door 3b

<https://youtu.be/mdwUqLe8ybl>

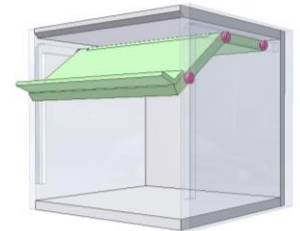
Raise and push green door to open.

Pull and lower the door to close.

The green door is divided into two portions connected together by revolution joints for increasing usable inside space.

Pink rollers roll in grooves of side plates.

At open position, the rollers stay in upper horizontal grooves (a bit slanting), so the door is kept immobile steadily.



### Garage door 1

<https://youtu.be/HYsfBLfHIEI>

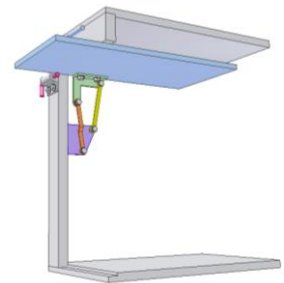
Yellow and orange rockers, green conrod create a 4-bar linkage.

Raise the blue panel (fixed to the conrod) to open the door.

Use pink pin to prevent the panel from falling at its open position.

This video was made based on:

<https://www.youtube.com/watch?v=UPNynnfhqj0>



### Motorized garage door 1

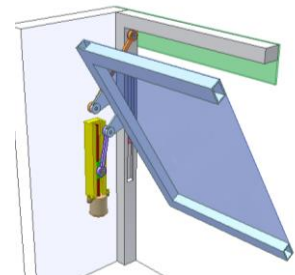
<https://youtu.be/iZkyHB7PL9c>

Input: red screw of brown motor.

Orange rocker (crank), blue frame (conrod) and pink slider create a slider-crank mechanism.

This video was made based on:

<https://youtu.be/INjxktNhP9M>



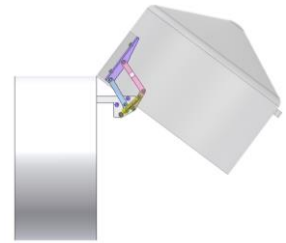
### Tube door

<https://youtu.be/dBFFJyFEu0c>

It is an application of the hinge shown at:

<https://youtu.be/EpXq7bDBe54>

The hinge ensures that at closed position the door covers around outer diameter of the tube.



### Flush sliding door

<https://youtu.be/6lniHdigpmc>

Violet rollers bear the weight of blue door.

Green rollers are for guiding.

The door is connected to the upper sliders via revolute joints.

The 45 deg. corners at the rail ends make the door flush with the wall.

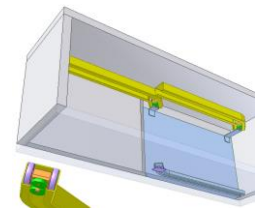
Blue lower rail fixed to the door and violet pin fixed to the ground and moving in the slot of the lower rail keeps the door from swinging.

This video was made on request of a YouTube viewer.

Related sources:

<https://www.youtube.com/watch?v=4RxCRMNvhQ0>

<http://www.sugatsune.com/instructions/mfuinst0115.pdf>



### Motorized flush door

<https://youtu.be/aXe7aYJSyPg>

Violet rollers bear the door weight.

Green rollers are for guiding.

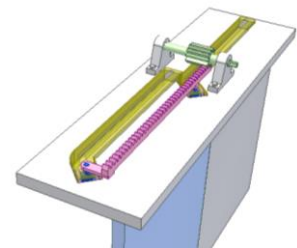
The door is connected to the upper sliders via revolute joints.

The 45 deg. corners at the rail ends make the door flush with the wall.

Input: green gear receiving rotation from a motor (not shown).

Pink rack is fixed to blue flush door.

Gear-rack drive enables motion transmission to the door even in case it moves in two directions perpendicular to each other.



### Lift door 1

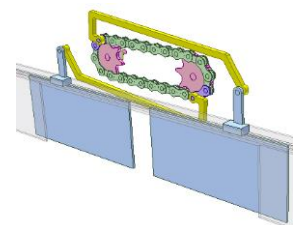
<https://youtu.be/AGXIEqppz1Y>

Stroke length of each door panel =  $A + D$ .

A: center distance of chain drive.

D: pitch diameter of sprockets

The chain drive can be replaced with timing belt one.

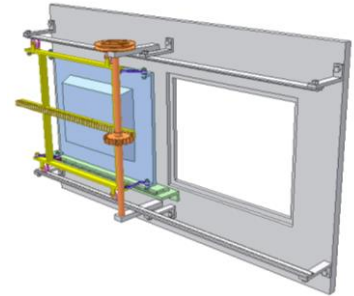


### Industrial sliding door 1a

<https://youtu.be/Uishcbh4-W4>

Input: orange shaft of spur gear that is in mesh with a rack fixed to yellow sliding frame.

Blue door panel and four violet bars create parallelogram mechanisms. Red roller of the panel moves in L-shaped slot of stationary guide way. Therefore, the panel moves along L-shaped trajectory to close the door and force the panel against the wall for sealing.



### Door for limited space 1

[http://youtu.be/iWxtaYE\\_5n0](http://youtu.be/iWxtaYE_5n0)

Each door panel has revolute joints with a slider and a roller. The sliders and rollers move in violet runway.

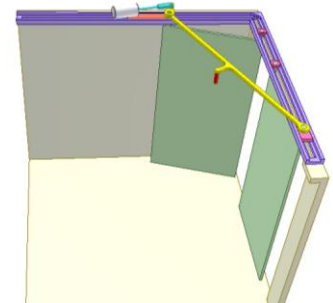
Yellow conrod has revolute joints with the sliders and cyan piston. Grey cylinder has revolute joint with the orange left slider. So driving force from the cylinder is applied to the conrod.

Because of the moving cylinder, its hydraulic hoses must be movable.

In case of power interruption:

- Move red grip of the conrod to open the door.
- The door can not be opened from outside.
- At completely closed or opened positions of the door, force applied to the panels can not move them.

This mechanism can be applied for up & down garage doors.



### Turning and telescopic sliding door 1a

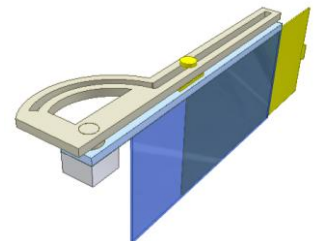
<https://youtu.be/OeniilmaG-s>

Push yellow panel to open, pull it to close the door.

The yellow panel is fixed to yellow slider that moves along blue straight runway, to which blue transparent panel is fixed. The runway is pivoted on the wall.

The yellow slider has a pin that moves along the slot of stationary brown plate. The curve portion of the slot is an Archimedean one.

When the pin enters the curve portion, both panels start their 90 deg. turning.



### Turning and telescopic sliding door 1b

[https://youtu.be/OXc\\_GsdP9k4](https://youtu.be/OXc_GsdP9k4)

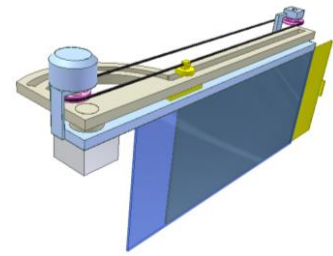
It is a motorized embodiment of  
"Turning and telescopic sliding door 1a"

<https://youtu.be/OeniilmaG-s>

Yellow slider is fixed to the black belt of two pink pulleys. Input: blue motor giving the slider linear reciprocating motion.

The yellow panel is fixed to yellow slider that moves along blue straight runway, to which blue transparent panel is fixed. The runway is pivoted on the wall. The yellow slider has a pin that moves along the slot of stationary brown plate. The curve portion of the slot is an Archimedean one.

When the pin enters the curve portion, both panels start their 90 deg. turning.



### Turning and telescopic sliding door 2a

[https://youtu.be/Wrn0brP2Z\\_A](https://youtu.be/Wrn0brP2Z_A)

Push yellow panel to open, pull it to close the door.

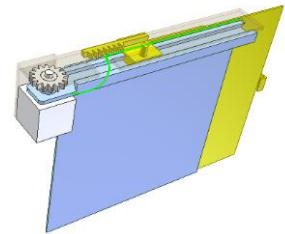
The yellow panel is fixed to yellow slider that moves along blue runway.

The yellow slider has a pin that moves along a slot of stationary plate (in transparent brown).

At left end of the yellow panel stroke the interaction between yellow rack and the stationary grey gear makes the blue runway, to which blue panel is fixed, turn 90 deg.

Green line is the trajectory of the yellow pin center.

For easy motion of the mechanism make the gear as large as possible.



### Turning and telescopic sliding door 2b

<https://youtu.be/LVJ5Ob-JyGI>

It is a motorized embodiment of  
"Turning and telescopic sliding door 2a"

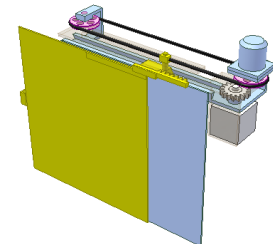
[https://youtu.be/Wrn0brP2Z\\_A](https://youtu.be/Wrn0brP2Z_A)

Yellow slider is fixed to the black belt of two pink pulleys. Input: blue motor giving the slider linear reciprocating motion.

The yellow panel is fixed to yellow slider that moves along blue runway. The yellow slider has a pin that moves along a slot of stationary plate (in transparent brown).

At left end of the yellow panel stroke the interaction between yellow rack and the stationary grey gear makes the blue runway, to which blue panel is fixed, turn 90 deg.

For easy motion of the mechanism make the gear as large as possible.

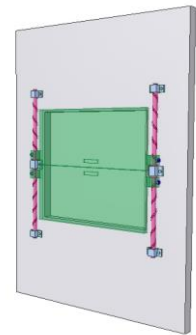


### Vertical bi-parting door 1

<https://youtu.be/TSxt8bcdLKw>

Threads at two sides of pink screws are of opposite hand. Each green panel has red pins that moves in helical groove of the screws. When one panel is driving, the screw is driven but at same time it is driving for the other panel, so reasonable helix angle of the screws is 45 deg. Use ball screws to ease the motion.

The panels are of the same weight so the mechanism is self-balanced.

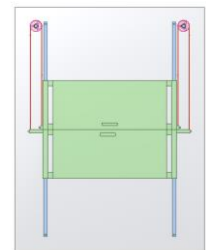


### Vertical bi-parting door 2

<https://youtu.be/lspCWRpYqog>

Upper and lower panels are connected together via red cables wrapping around pink pulleys.

The panels are of the same weight so the mechanism is self-balanced.



### Wire door

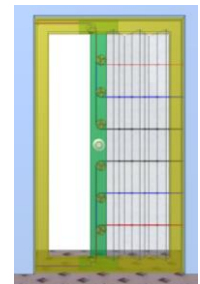
<https://youtu.be/BbljXYQvIJE>

It is used for anti-insect door.

The zigzag net is made of plastic.

There are six wires in red, blue and black. The ends of each wire are fixed to yellow stationary frame. The wires are for guiding and supporting the zigzag net.

In case without the net and the wires diameter is large, it can be used as a normal door.



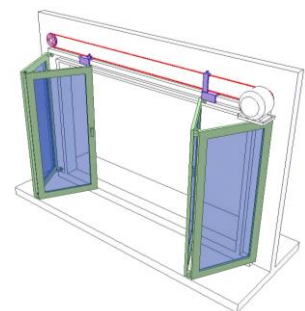
### Folding door controlled by cable

<https://youtu.be/q8lf4YSIhfY>

The door consists of two slider-crank mechanisms.

Driving parts are violet sliders that are brought into motion by a motor via a cable drive of two pink pulleys. Lower branch of the cable is fixed to the left slider. The upper branch is fixed to the right slider.

Thanks to the eccentricity of the slider-crank mechanisms there no dead positions when the door is at its closed position.





### Torggler door 1

<http://youtu.be/ipx3HfH76F8>

The mechanism consists of 4 links (triangular panels) and 5 joints. Blue and orange panels are connected together by a spherical joint. Four remaining joints are revolute.

When the door is completely open or closed (death positions), force applied to the pink or green panels can not move the door. So do the gravity, thus the door is kept rather stable at open or closed positions. No problem for forces applied to the blue or orange panels.

Center of the spherical joint traces half of an ellipse (green curve) so the door occupies less space than ordinary doors in moving.

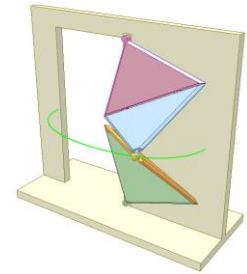
Disadvantages:

- At closed position the panels lay outside the wall thickness.
- Not suitable for partly opening.

It looks like an art work more than an useful door.

The door is named after its designer, Klemens Torggler, an Austrian artist.

Mechanisms of square, pentagon and hexagon panels have been animated but they do not show practice applications.



### Torggler door 2

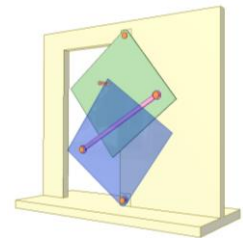
<http://youtu.be/AvLZwzHtHKo>

An application of 4 bar linkage.

Friction in revolute joints must be large enough, otherwise the mechanism will move from open or closed positions due to the gravity.

Adding positioning devices is another solution.

Disadvantage: The two panels are not on the same level.



### Torggler door 3

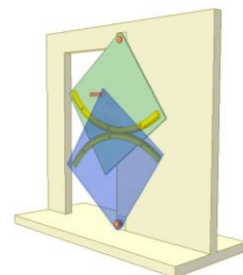
<http://youtu.be/B7y1979IRgk>

An application of gear drive.

Friction in revolute joints must be large enough, otherwise the mechanism will move from open or closed positions due to the gravity.

Adding positioning devices is another solution.

Disadvantage: The two panels are not on the same level.

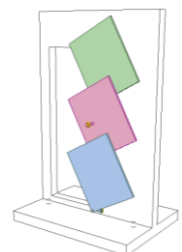


### Torggler door of three leaves 1

<https://youtu.be/mZSSRooaKP0>

It is for the door of height/width ratio of 3/1.

Three leaves are connected together by a double parallelogram mechanism. It needs some free space above the door.



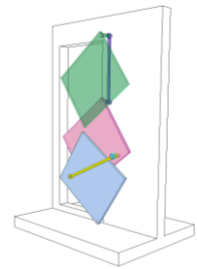
### Torggler door of three leaves 2

<https://youtu.be/OHKay3Jqygk>

It is for the door of height/width ratio of 3/1.

Green, pink leaves and violet conrod create a parallelogram mechanism.

Blue, pink leaves and yellow conrod create a four-bar linkage.

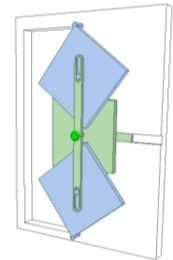


### Torggler door of three leaves 3

[https://youtu.be/L5tork2p\\_BI](https://youtu.be/L5tork2p_BI)

It is for the door of height/width ratio of 3/1.

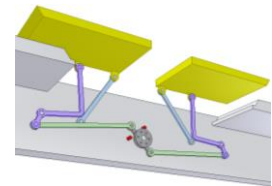
Weakness: prismatic joint between the green leaf and the wall is needed.



### Ceiling window 1

<https://youtu.be/N395Mxotd2M>

Yellow panels, violet and blue rockers create parallelogram mechanisms. Grey crank fixed to a load chain-wheel moves the panels synchronically. The gravity and two red stoppers keep the panels firmly at their end positions.

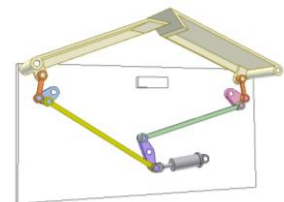


### Ceiling window 2

<https://youtu.be/vfUhv4d3Woo>

The mechanism ensures:

- At beginning of open process the right panel turns faster than the left one.
- At beginning of close process the left panel turns faster than the right one.



### Cover for basement entrance 1a

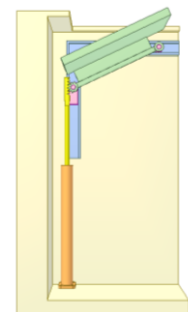
<http://youtu.be/KHyIXFYptfA>

Green cover is a connecting rod of an ellipse mechanism of two pink sliders. Driving force from fixed cylinder is applied to the connecting rod via a pinion rack drive (instead of to pink lower slider) ensures smooth motion of the mechanism even at death position when the connection rod is vertical.

Gap between the floor and the cover is rather small.

The cover occupies rather small space during motion.

The mechanism can be used for a door with ceiling arrangement of the runways.



### Cover for basement entrance 1b

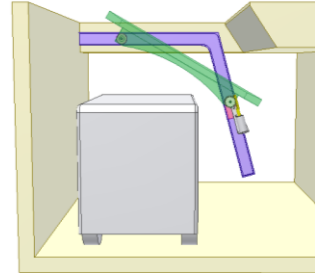
<http://youtu.be/iRH5lwF-1VE>

Green cover is a connecting rod of an ellipse mechanism of two pink sliders. A green pinion is fixed to the cover. A grey actuator of yellow rack is fixed to the right slider. Driving force from the actuator is applied to the connecting rod via the pinion rack drive. That ensures smooth motion of the mechanism.

The obtuse angle of violet runway and the mounting actuator on the slider are measures to overcome limited height of the basement. Moving actuator causes some difficulties for connection with hydraulic or electric source.

The mechanism is cut off half for easy understanding.

The car is moved from the basement to the ground floor by a lift (not shown).

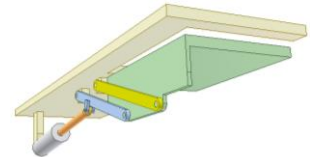


### Cover for basement entrance 2

<http://youtu.be/MeeW9S2qojE>

Green cover is a connecting rod of a four bar linkage.

There must be a considerable gap between floor and the cover at two short sides of the cover. The cover occupies large space during motion.



### Cover for basement entrance 3

<http://youtu.be/VN9ERN1UK1s>

An application of double parallelogram mechanism shown in.

<http://www.youtube.com/watch?v=U-Vn5SoRWCg>

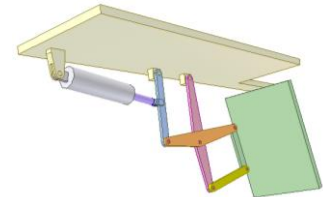
Green cover is a connecting rod of one parallelogram mechanism and rotates around a virtual axis that lies on the upper surface of the floor (or better, within the thickness of the floor).

Gap between the floor and the cover is rather small.

The cover occupies rather large space during motion.

The mechanism is cut off half for easy understanding.

The mechanism of two opposite moving covers is possible.



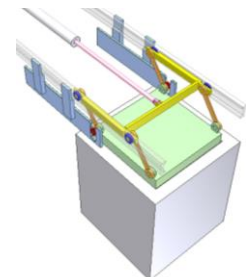
### Cover for furnace 1

<http://youtu.be/bKSJOITi9kE>

Yellow frame reciprocates linearly under action of a cylinder.

Parallelogram mechanism of orange rockers keeps green cover always horizontal in motion.

The cover moves up thanks blue cams and red rollers, goes down due to the gravity.



### Cover for basement entrance 1c

<http://youtu.be/Wnkzo14aA3o>

The cover is divided into green and violet halves in order to reduce its occupied space in moving or to ease the manufacture.

The green half has two pink rollers rolling in blue runway.

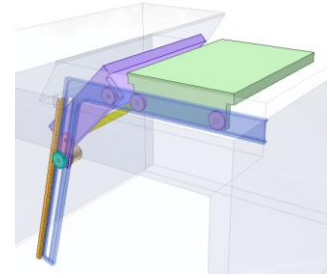
The violet half has a pink roller rolling and a pink slider sliding in the runway.

Yellow conrod has revolute joints with the two halves and the slider. Length of the conrod is reduced to minimum due to the said reason.

Brown motor fixed to the slider has cyan pinion which engages with orange rack fixed to the runway. So driving force from the motor is applied to the slider. The obtuse angle of blue runway is a key factor and it should be as large as possible to ease the motion.

Because of the moving motor, electric cable connected to it must be movable.

The mechanism is cut off half for easy understanding.



### Cover for basement entrance 4

<http://youtu.be/rfnXYbCxlQg>

Yellow frame reciprocates linearly under action of grey cylinder.

Thanks to parallelogram mechanism of two orange rockers, the green cover can raise up to level of the floor.

In motion to the left the cover falls down due to the gravity.

Pay attention to two red pins, pink and brown plates that act as stoppers.

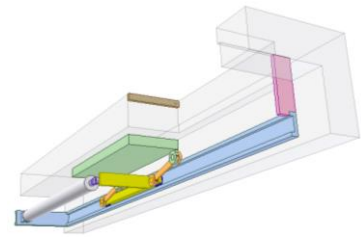
Gap between the floor and the cover is minimum.

The cover occupies small space during motion.

Center of mass of the cover moves up only a little so the mechanism is good in term of saving energy.

The mechanism is cut off half for easy understanding.

The mechanism of two opposite moving covers is possible.



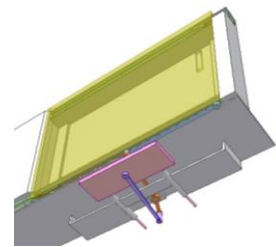
### Car sliding door 1

<https://youtu.be/4FlzoGsCQ1Y>

This ensures synchronic motions of yellow door and pink step.

When the door opens, the step moves out and vice versa.

The mechanism consists of two slider crank mechanisms of a common crank (in orange).



### Car sliding door 2

<https://youtu.be/lonlZH7myA0>

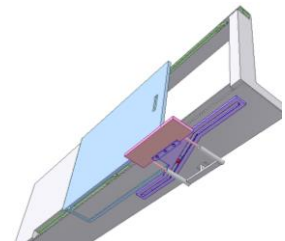
This ensures synchronic motions of blue door and pink step.

When the door opens, the step moves out and vice versa.

Violet translating cam is fixed to the pink step.

Red pin of the door moves in the cam slot and moves the step.

Anti-dust measure for the cam is needed.



### Car sliding door 3

[https://youtu.be/oDW\\_ckSf8s4](https://youtu.be/oDW_ckSf8s4)

This ensures synchronic motions of blue door and yellow step.

When the door opens, the step moves out and vice versa.

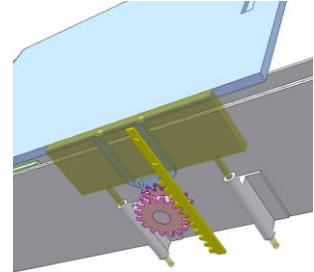
Yellow rack is fixed to the yellow step.

Blue rack is fixed to the blue door.

Both can be in mesh with the pink gear.

Disadvantage: Measure for positioning the step at its two end positions is needed.

Anti-dust measure for the gears is needed.

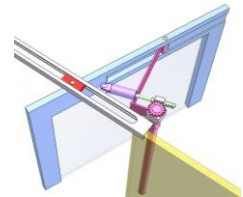


### Bus door 1

<https://youtu.be/6jZc1bNglak>

Pink crank, red slider and blue bus door (in role of a conrod) creates a slider-crank mechanism. Violet cylinder controls door opening.

Door motion occupies very small room for both inside and outside space of the bus.



### Scissor car door

<https://youtu.be/FCPElvdzgmC>

A parallelogram mechanism (yellow and green rockers, blue conrod) makes the pink door panel (fixed to violet bevel gear) always parallel to the car longitudinal vertical plane.

Yellow bevel gear is fixed to yellow rocker.

The violet bevel gear rotates on a bearing fixed to the blue conrod.

Here the two gears have the same tooth number.

The door has two motions at the same time:

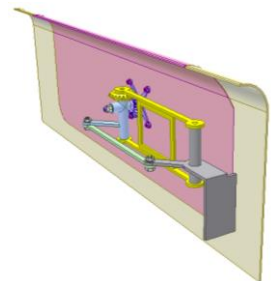
- rotation around a stationary vertical axis.
- rotation around a moving horizontal axis.

Thus, the door is vertical at open position to ease entry/exit.

The chamfer at upper front corner of the panel is needed to avoid its collision with the car body during open/close process.

See a real door:

<https://www.youtube.com/watch?v=zE1R-leKoOg>



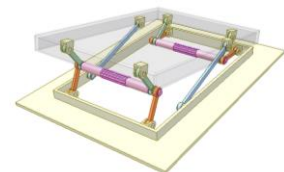
### Car roof window

<http://youtu.be/Url8JhauPYA>

This mechanism (group of 4 bars and 6 revolution joints + two cranks) has 2 degrees of freedom.

Use two pink grips to open the window to the desired direction.

Measure to create friction in the joints is needed for holding the window at adjusted position.

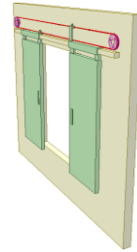


## 24.3. Windows

### Synchronously sliding windows 1

<http://youtu.be/3yodKPhoTsM>

Left pannel is fixed to lower cable branch.  
Right pannel is fixed to upper cable branch.  
Cable tension device is not shown.



### Synchronously sliding windows 2

<http://youtu.be/-8WbMU12oyk>

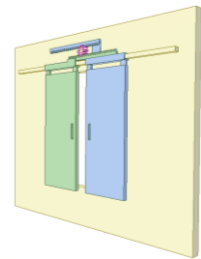
Threads at two sides of blue screw are of opposite hand. Each orange pannel has red pin that moves in helical groove of the screw.  
When one panel is driving, the screw is driven but at same time it is driving for the other panel, so reasonable helix angle of the screw is 45 deg.  
Use ball screw to ease the motion.



### Synchronously sliding windows 3

<http://youtu.be/QHr38WRYuyg>

A pinion and two racks enable window synchronous sliding.



### Synchronously sliding windows 4

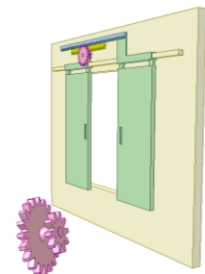
<http://youtu.be/PiHCcPcSsEE>

Yellow rack is stationary and engages with pink small pinion of a block of two ones.

Tooth number of large pinion is twice that of the small one.

This mechanism is not good solution for synchronously sliding windows however it can be applied for other cases where the gears are driving (actuator must be on the left panel).

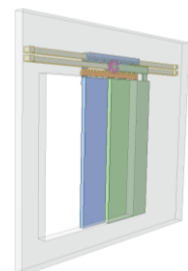
- ▶ In case two pinions are of equal tooth numbers:
  - If the pinion block or left panel are driving, only the left panel moves, the right one is immobile.
  - If right panel is driving, both panels are stuck.



### Telescopic sliding windows 1

<http://youtu.be/kBeLWPvoimU>

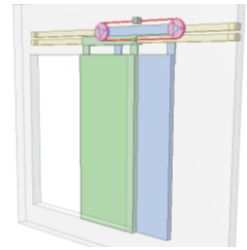
Orange rack is fixed to the wall.  
Pink pinion rotates on a pivot of the green panel.  
Blue rack is fixed to blue panel.  
The blue panel moves twice faster than the green one.  
The video shows back view of the window.  
Disadvantage: The two panels are not on the same level.



### Telescopic sliding windows 2

<http://youtu.be/OuZ9xsp0-LU>

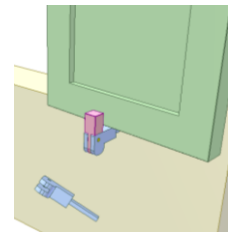
Two pink pulleys rotate on pivots of the blue panel.  
Green panel is fixed to lower cable branch.  
Upper cable branch is fixed to the wall.  
The green panel moves twice faster than the blue one.  
Cable tension device is not shown.  
The video shows back view of the window.  
Disadvantage: The two panels are not on the same level.



### Window stopper

<https://youtu.be/AnbnlvLnplw>

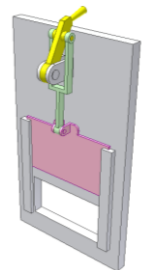
Pink stopper can be set to two positions: up or down.  
When it is down, green window can be opened 180 deg. Then the stopper is set to up position to hold window there. The window can not overcome it because the pink stopper acts as a lever around yellow pivot.  
Set the stopper to down position to close the window.



### Up-down window

<https://youtu.be/YxzauOhqTkU>

It is an application of slider crank mechanism.  
The gravity ensures that the pink window is kept firmly at its open and closed positions.



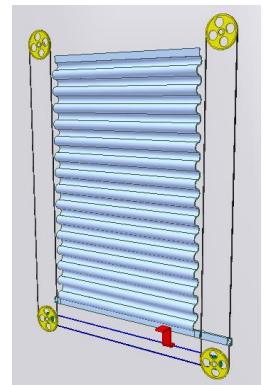
### Cable window

<https://youtu.be/ByMu5bwWBGE>

This video is a guess for inside mechanism of the jet window shown at minute 3:40 of video

[https://www.youtube.com/watch?v=Yz\\_f\\_B8Uoxo&feature=youtu.be](https://www.youtube.com/watch?v=Yz_f_B8Uoxo&feature=youtu.be)

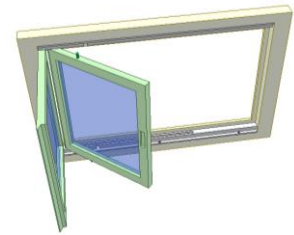
Move red slider to open or close the window.  
Yellow and green pulleys are fixed together.  
Blue panel is fixed to right branches of vertical black belts.  
Instead of cable use timing belts to prevent cable slip.  
Diameter ratio between green and yellow pulleys depends on ratio between width and height of the window.  
The blue panel is waving-shaped to adapt possible curved upper wall.



### Sliding and turning window

<https://youtu.be/IB4Aeya6L44>

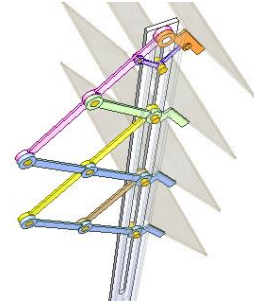
One panel can rotate only.  
The other can slide and rotate.



### Slat window 1

<https://youtu.be/ZCRxmJUbjqM>

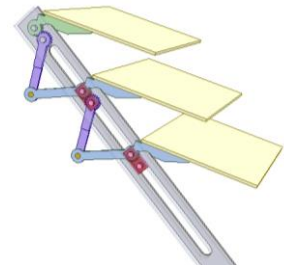
Four slats turn and move up to open.  
It is an application of the scissor mechanism.  
The counterbalance device is not shown.  
Driving force may be applied to any movable part.  
It can be used for the cabinet window shown at:  
[https://www.youtube.com/watch?v=LWUU\\_CYqjE](https://www.youtube.com/watch?v=LWUU_CYqjE)



### Slat window 2

<https://youtu.be/qT1CvAewZzs>

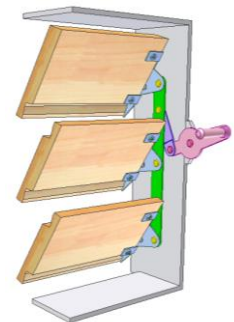
Three slats turn and move up to open.  
It is an application of the slider-crank mechanism in combination  
with gear drives.  
The counterbalance device is not shown.  
Driving force may be applied to any movable part.  
It can be used for the cabinet window shown at:  
[https://www.youtube.com/watch?v=LWUU\\_CYqjE](https://www.youtube.com/watch?v=LWUU_CYqjE)



### Louvre window 1

<https://youtu.be/u5h3l6sFm7g>

Turn pink lever to open or close the window of three shutters.  
Input force is applied to green connecting rod of multi-parallelogram  
mechanism via violet bar.

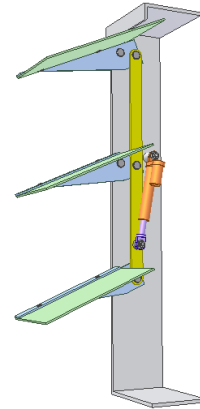




### Louvre window 2

<https://youtu.be/Mmv5gc57RQw>

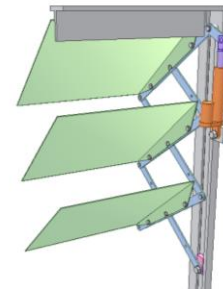
Orange actuator pushes yellow connecting rod of multi-parallelogram mechanism to open the window of three shutters.



### Slat window 3

[https://youtu.be/W-l\\_hMJctD8](https://youtu.be/W-l_hMJctD8)

It is an application of scissor mechanism.  
Green slats are fixed to its bars.  
The window is controlled by orange actuator.



### Controlling 2 DoF of a series of objects

[https://youtu.be/Wb\\_ymWviVKI](https://youtu.be/Wb_ymWviVKI)

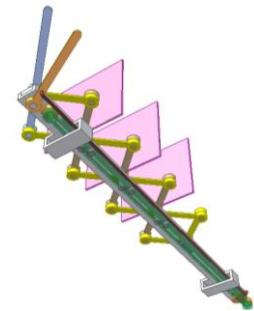
Blue crank controls linear motions of pink plates via a scissor mechanism.

Orange crank controls their 90 deg. rotation via a parallelogram mechanism. The rotation can be performed at any position of the plates.

Each plate has a pin that moves in long groove of green bar.

Long brown rod helps the parallelogram mechanism overcome dead positions.

It can be used for louver or deployable curtain wall (for indoor light control).



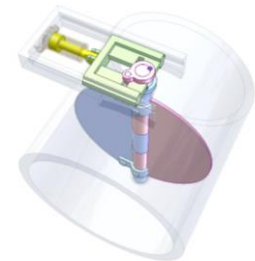
### Butterfly damper 1

<https://youtu.be/scMoPAryXQM>

Pink and blue plates are coaxial.

Each plate has a pin sliding in crosswise slot of green slider. Yellow piston controls motion of the green slider.

The latter makes pink and blue plates turn in opposite directions to close or open the damper.

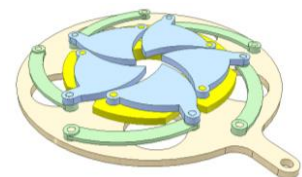


### Diaphragm shutter 1

<http://youtu.be/P1ghKADv78>

Turn outer disk to open or close the aperture of a camera.

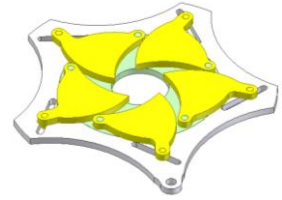
The outer disk, yellow conrod and blue blade create a 4-bar mechanism.



### Diaphragm shutter 2

<http://youtu.be/msWYgarinBs>

Turn outer disk cam to open or close the aperture of a camera.  
Green inner disk is fixed.  
Yellow blades play role of cam followers.



### Diaphragm shutter 3

<http://youtu.be/VUoVnl9PjPU>

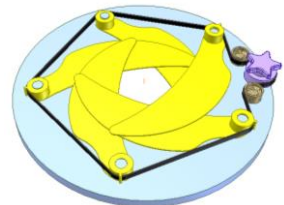
Turn glass outer disk cam to open or close the aperture of a camera.  
Green inner disk is fixed.  
Overlapping curved blades play role of cam followers.  
See real colossal iris:  
<https://www.youtube.com/watch?v=jvEL3KahFsk>



### Diaphragm shutter 4

<http://youtu.be/IW5Wbic1D64>

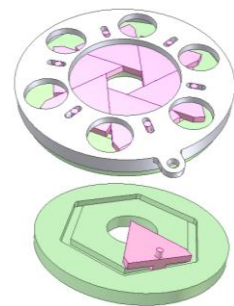
Turn violet knob to open or close the aperture.  
Belt drive forces all yellow blades to rotate synchronously.  
It is possible to replace belt drive with a gear one (internal gear ring and 5 pinions).  
The mechanism can be used for windows:  
<https://www.youtube.com/watch?v=-qlqsCU2NJo>



### Diaphragm shutter 5a

<http://youtu.be/k4m6TRTSzGo>

It is a disk cam mechanism of translation follower.  
Turn grey disk cam to open or close the aperture.  
Fixed green disk has a hexagon slot.  
Each blade (follower) slides along one side of the hexagon.  
Instead of the hexagon 6 symmetrical suitable curves are possible.  
The mechanism can be used for control valves:  
<https://www.youtube.com/watch?v=3w7SSUFHjWE>



### Diaphragm shutter 5b

<http://youtu.be/bWScqsHEvgc>

Turn orange disk of hexagon slot to open or close the aperture.  
Instead of the hexagon 6 symmetrical suitable curves are possible.  
The variable hexagon created by green blades rotates when expanded or contracted.



### Diaphragm shutter 6

[http://youtu.be/RoTgZw\\_nqPM](http://youtu.be/RoTgZw_nqPM)

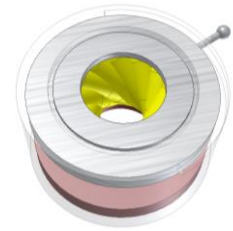
Yellow bars of flexible material are fixed to grey upper and brown lower disks.

Turn upper disk to open or close the aperture.

In practice the yellow bars are replaced with a flexible tube.

The mechanism finds application in valves for handling powder or granule materials. See:

[https://www.youtube.com/watch?v=A-4V\\_V4Hi0g](https://www.youtube.com/watch?v=A-4V_V4Hi0g)

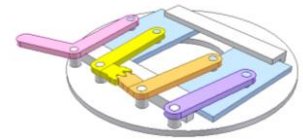


### Diaphragm shutter 7

<https://youtu.be/kytt7QD7mbs>

Input: pink arm.

There are two parallelogram mechanisms connected together by a gear drive. A rectangular slit is created during opening or closing the blue diaphragms that don't move linearly.



### Iris bowl 1

<https://youtu.be/HX1dceXLpo8>

Red pins fixed to pink bowl slide in circular grooves of yellow petals.

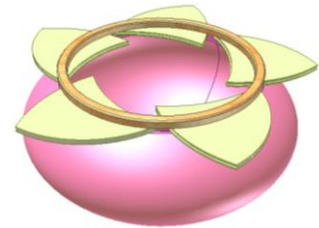
The petals are pivoted on orange ring (white screws).

The screws slide in circular slots made on the bowl and prevent axial displacement of the orange ring.

Turn the ring counter-clockwise to open the bowl.

This video was made in an attempt to explain the transmission of an Iris bowl shown at:

<https://youtu.be/wv6tCFGaZ9w>



### Iris bowl 2

<https://youtu.be/qA5wMXRWkfg>

An internal gear rim (in green) fixed to green bowl is in mesh with a small gear fixed to each blue petal.

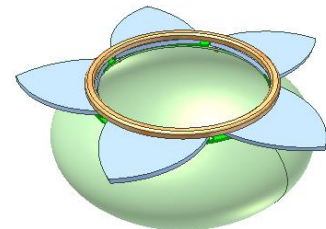
The blue petals are pivoted on orange ring (orange screws).

The screws slide in circular slots made on the bowl and prevent axial displacement of the orange ring.

Turn the ring clockwise to open the bowl.

This video was made in an attempt to explain the transmission of an Iris bowl shown at:

<https://youtu.be/wv6tCFGaZ9w>



### Box with five compartments opened synchronously

<https://youtu.be/4-LkBTy-mh8>

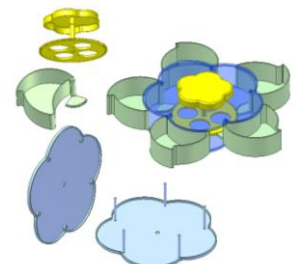
Turn the yellow knob to open or close five green compartments.

The large yellow gear is fixed to the knob.

A green gear sector is fixed to each compartment.

This video was made based on:

<https://youtu.be/nK4G97qUWY0>



### Tool box 1

<https://youtu.be/WsgnkpT1Kpg>

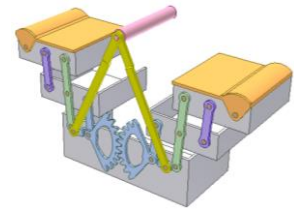
Push down the pink grip to open the box.

Thanks to blue gear sectors the pink grip is always in longitudinal symmetrical plane of the box and the compartments move to opposite directions synchronously.

If no blue gear sectors, the compartments of each side can move independently with the ones of the other side.

Orange covers can be opened thanks to revolution joints.

For simplicity the tool box is cut off a half.



### Plastic wind vent for bus

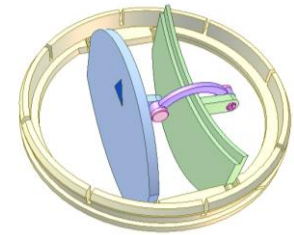
<https://youtu.be/69rX55Y5Wso>

Push blue plate to open.

It uses a parallelogram mechanism consisting of two rockers (in blue and green) and violet conrod. The design ensures that at open position the mechanism does not get into unstable position. Slots for inserting axles of blue and green plates are a little smaller than their diameters.

It can be applied for the commercialized product:

<https://sc02.alicdn.com/kf/HTB1IC7wJVXXXXcFXFXq6xXFXXC/adjustable-auto-bus-air-conditioner-plastic-wind.jpg>



## 24.4. Gates

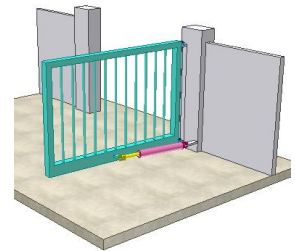
### Motorized gate

<https://youtu.be/2SnwGDlvYgs>

It's an application of rotary cylinder mechanism.

See a real gate:

<https://youtu.be/-XzXT42YxfU>



### Barrier of reasonable speed 1

<https://youtu.be/sQXi6Xc90-l>

Input pink crank of yellow constant speed motor.

Here the 4-bar linkage ensures that the orange bar has low speed at the starts and the ends of its opening and closing strokes.

Last scene of the video shows speed graph of the orange bar.

This video was made on request from an YouTube viewer.



### Barrier of reasonable speed 2

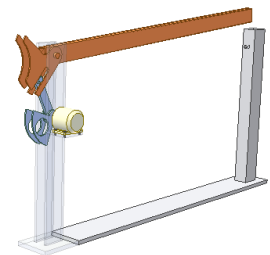
<https://youtu.be/g5zULWAmL6k>

Input blue crank of yellow constant speed motor.

Here the Geneva drive ensures that the orange bar has low speed at the starts and the ends of its opening and closing strokes.

However, max speed is too large.

Last scene of the video shows speed graph of the orange bar.

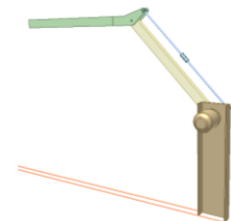


### Folding barrier 1

<http://www.youtube.com/watch?v=bq0iiqCSTFg>

An application of parallelogram mechanism.

Folding barrier is used for height limited place.

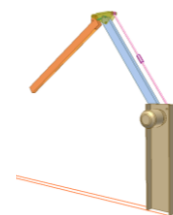


### Folding barrier 2

<http://www.youtube.com/watch?v=LF8kSTCZIxw>

A combination of parallelogram mechanism and 4-bar linkage.

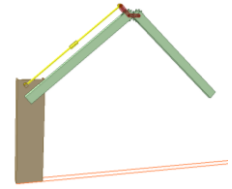
Folding barrier is used for height limited place.



### Folding barrier 3

<https://www.youtube.com/watch?v=j3RNoijvcD4>

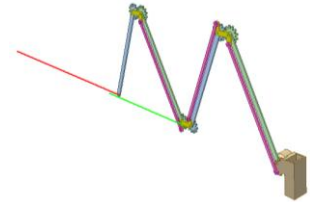
A combination of a parallelogram mechanism and gears.  
The gears are fixed to the bars.  
Folding barrier is used for height limited place.



### Folding barrier 4 (Straight line drawing mechanism)

<http://www.youtube.com/watch?v=QNkODQMZfwc>

A combination of parallelogram mechanisms and gears.  
The gears are fixed with the bars.  
It can be applied for folding barriers, gates, eaves or lamps.  
By similar connecting of bars the barrier can be very long.



### Open up gate 1a

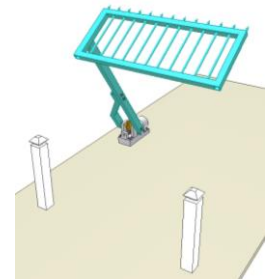
<https://youtu.be/qxSlwIGkvBQ>

This video was made based on:

<https://www.youtube.com/watch?v=a4WvkJYbWTY>

(1:47 - 2:22 minute)

In case of electric interruption, turn the gray worm with a crank (not shown).



### Slide folding gate

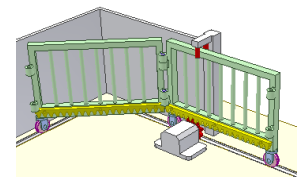
<https://youtu.be/21eDdRSMuA0>

Red pinion of grey motor can engage with two yellow racks and push the gate of two panels.

See a real gate of 4 panels:

<https://www.youtube.com/watch?v=AN8C7m8cYY4>

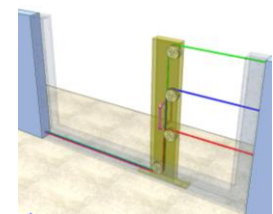
Using lengths of chain instead of the racks is possible. Then the pinion axis is vertical.



### Wire door for fences

<https://youtu.be/TxLCK7GWyY>

There are three wires in red, blue and green. The ends of each wire are fixed to glass stationary frame.



### Mechanical automatic gate

<https://youtu.be/yCR9yyydrw>

This automatic gate without the use of electric power allows to open the barriers only for vehicles and to close for big animals. The red rods connect parallelogram mechanisms of yellow bars with blue bridges pivoted with the base.

The blue bridges are connected together by sliding joints (red pins and blue slotted plates).

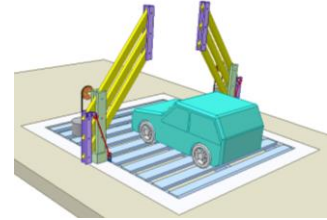
Grey cylindrical weights are for keeping the gate closed thanks to cable drives of orange pulleys.

This video aims to explain the working principle of the gate shown at

<https://www.youtube.com/watch?v=wzzkonJsWnM>

Related videos:

<https://www.youtube.com/watch?v=NlpCFwvJKAY>



### Mechanical automatic gate 2

<https://youtu.be/V2lQfV-BrfY>

This automatic gate without the use of electric power allows to open the barrier only for vehicles and to close for the cattle.

Green traverses act as OPEN buttons.

Red traverses act as CLOSE buttons.

When a car enters the gate, its front wheels press down front green traverse and raise the barrier via pink shaft and red bar. The barrier is kept at raising position and both green traverses are kept at down positions thanks to slotted disk fixed to the pink shaft and yellow sliding pawl.

When the front wheels press down the second red traverse, orange face cam pulls green rod, pushes up the yellow pawl and releases the pink slotted disk. Then the barrier turns down due to the gravity to close the gate.

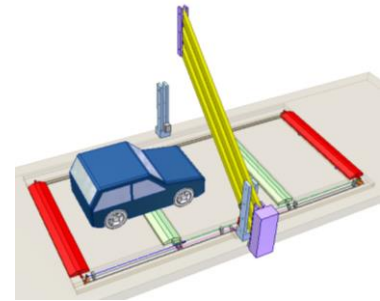
When the gate is at close position, the down motion of the red traverses does not affect the barrier at all. It only raises the yellow pawl a little innocuously.

For a car going in reverse direction the process will happen in the same way.

It's possible to lock the gate by adding a locking device (not shown). The device sliders will move to space under the green traverses to prevent them from going down, when the lock is needed.

This video aims to give an alternative design for the gate shown at

<https://youtu.be/yCR9yyydrw>



### Gate to open inward uphill 1

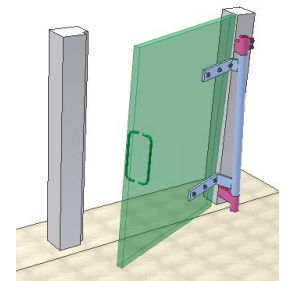
<https://youtu.be/UHOIfmHJaxI>

The gate hinge axis is perpendicular to the ground uphill surface, thus the panel does not collide with the ground.

The gravity tends to close the gate, if the open angle is less than 90 deg.

See a real gate:

<https://www.youtube.com/watch?v=11D54zdl1JI>

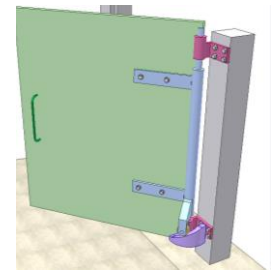


### Gate to open inward uphill 2

<https://youtu.be/J8Lf3N9v3NQ>

Thanks to violet face cam the gate panel is raised when open, thus it does not collide with the uphill ground.

This mechanism is suitable for case when the gate is not too wide and the ground is not too uphill (for easy raising the gate panel).



### Gate to open inward uphill 3

<https://youtu.be/P32pBR-HRa0>

The gate panel includes a lower portion (in blue) that is folded when open thanks to a bevel gear drive. Thus, the panel does not collide with the uphill ground.

Transmission ratio of the bevel gear drive is 2.

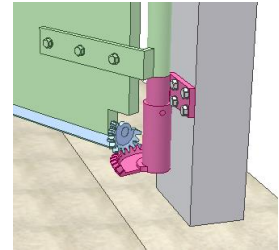
For more uphill ground the height of the lower portion is larger.

For larger opening angle (more than 90 deg.) use teeth-uncompleted bevel gear drive shown at:

<https://youtu.be/0JMF5Op6984>

See an embodiment of this mechanism where the bevel gear drive is replaced with a cable drive:

<https://www.youtube.com/watch?v=UKh6v30d7hl>



### Gate to open inward uphill 2b

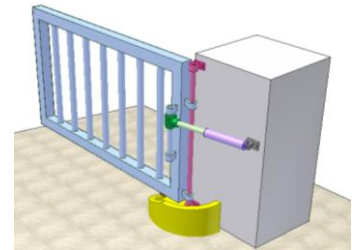
<https://youtu.be/Zaxw-yIXj5g>

This is the motorized embodiment for design shown at:

<https://youtu.be/J8Lf3N9v3NQ>

Violet actuator controls gate motion.

The gate panel and the actuator are connected together by a cylindrical joint that allows their relative vertical linear motion.



### Gate to open inward uphill 2c

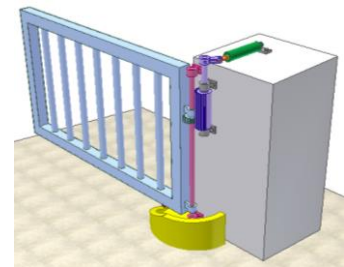
<https://youtu.be/rT5YW1qsZjA>

This is the motorized embodiment for design shown at:

<https://youtu.be/J8Lf3N9v3NQ>

Green actuator controls gate motion via violet lever and spur gear drive of blue gear fixed to the gate and violet long gear.

The blue gear slides along the violet gear (in vertical direction) during open/close process.



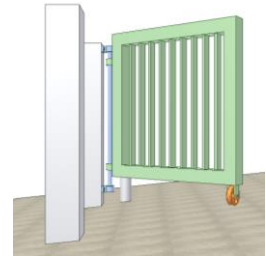


### Gate to open inward uphill 4

<https://youtu.be/hAVxQFUdcxk>

This can work only when the gate is not too wide and the joint between green panel and blue pivot is of small friction type (linear ball bearings for example).

The cylindrical stopper keeps the panel immobile at its open position when open angle is larger than 90 deg.



### Gate to open inward uphill 5

<https://youtu.be/myrfNpOLLuE>

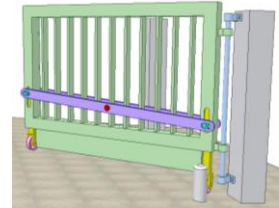
This is an embodiment of the design shown at:

<https://youtu.be/hAVxQFUdcxk>

for case when the gate is rather wide.

The green panel weight is borne by pink wheels pivoted on yellow vertical sliders. Each slider has pins moving in slots at two ends of violet levers. The latter is pivoted on the panel at red screws. Such arrangement ensures that the two wheels always contact the ground and eliminates bending torque applied to the cylindrical joints between the panel and the gate post. The cylindrical stopper keeps the panel immobile at its open position when open angle is larger than 90 deg.

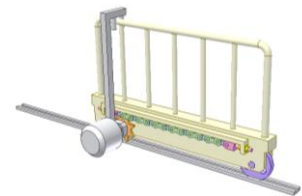
This design can be used for gates on horizontal ground of uneven surface.



### Chain drive 1D

[http://youtu.be/D70s\\_01VTGo](http://youtu.be/D70s_01VTGo)

Using chain rack instead of ordinary one reduces production costs.



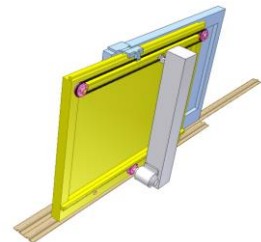
### Telescopic sliding gate

<http://www.youtube.com/watch?v=ASAxH51ify8>

A roller cable mechanism is used.

A point on lower part of the cable is fixed with the grounded post.

A point on upper part of the cable is fixed with the blue panel 2 that moves twice faster than the yellow panel 1.



### Gate of hand fan style

<https://youtu.be/K1ayFZqs0ZU>

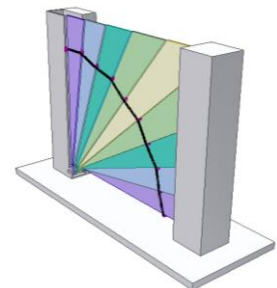
The gate consists of several sectors.

Raise the lowest sector (in violet) to open the gate. The pin (in pink) fixed to the lower sector moves the upper adjacent sector to open position. The measure to keep all sectors at the open position is not shown. It may be a hook for example.

The gate is closed thanks the gravity. The chains (represented by black lines) that pivot on two adjacent pink pins hold the sectors at the close position.

See the gate in real life:

<https://dantricdn.com/2017/anh-dong-hai-huoc-8-1489341515727.gif>



## 25. Hydraulic and pneumatic mechanisms

### Swinging cylinder

<http://youtu.be/Hlq3ZeaeoGU>

A way to connect fluid to a swinging cylinder.

Fluid enters and leaves the swinging cylinder through its stationary pivot so flexible pipes are not needed.

All pink parts are stationary. The arrows show fluid flows.



### Rotary cylinder

<http://youtu.be/ytR2ku1wBgA>

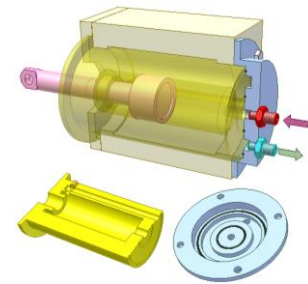
A way to connect fluid to a rotary cylinder.

The red fitting is connected to the rear cylinder space through rear center hole of the cylinder.

The cyan fitting is connected to the front cylinder space through circular groove on the inner face of the blue connector and long eccentric hole of the cylinder.

It is possible to arrange the groove on cylindrical surface.

The cylinder and the piston rotate together with an operational device (not shown). The arrows show fluid flows.



### Hydraulic cylinder with fixed piston

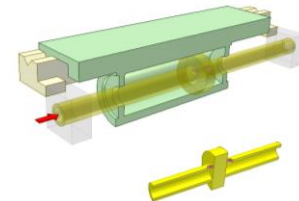
[https://www.youtube.com/watch?v=yX\\_rCTcAPi4](https://www.youtube.com/watch?v=yX_rCTcAPi4)

Green cylinder with machine table reciprocates.

Pressure fluid is conducted into cylinder via holes on fixed piston rod. The hoses can be stationary.

In case using holes on the cylinder the hoses have to move with the cylinder.

The arrows show flows of pressure fluid.



### Floating cylinder 1

<https://youtu.be/B7BGs7T-7Ys>

Green cylinder is pivoted on yellow slider.

Violet piston is pivoted on cyan slider.

When the cylinder stretches, the sliders get their farthest positions to each other when contact with the pink outside stopper.

When the cylinder contracts, the sliders get their nearest positions to each other when contact with the pink inside stoppers.

Two stoppers on the left are for setting length and position of the yellow slider stroke.

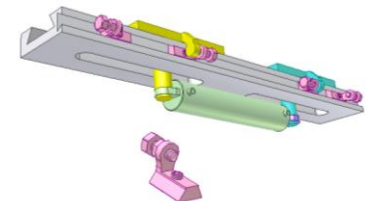
Two stoppers on the right are for setting length and position of the cyan slider stroke.

Applications of floating cylinders:

<https://youtu.be/vSEGVGXqV7A>

<http://youtu.be/U9fi2DJrIZY>

<http://youtu.be/fzz7-g6Qr1o>



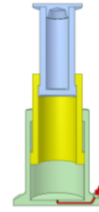
### Hydraulic telescopic cylinder 1

<http://youtu.be/icaqvAtccY>

Red arrow shows pressure flow.

It is single acting cylinder.

The gravity brings pistons to their lowest positions.

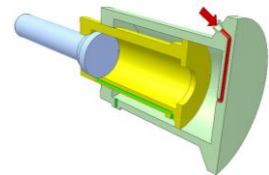


### Hydraulic telescopic cylinder 2

<https://youtu.be/GsZfb3vtof4>

Red and green arrows show pressure flows that control both forward and backward strokes of blue piston.

It is double acting cylinder.



### Hydraulic cylinder with three piston positions

[http://youtu.be/sPD62mJ\\_ViM](http://youtu.be/sPD62mJ_ViM)

By alternately conducting pressure fluid into cylinder through its three holes the pink piston can reach one of its three stable positions: center, left and right.

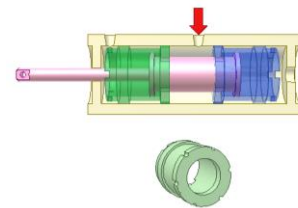
Green and blue floating pistons are identical.

The arrows show flows of pressure fluid.

When pressure fluid enter through the medium hole, green and blue pistons are pushed apart from each other, pink piston gets center position.

When pressure fluid enter through the left hole, pink and blue pistons are pushed to the right, pink piston gets right position.

When pressure fluid enter through the right hole, pink and green pistons are pushed to the left, pink piston gets left position.



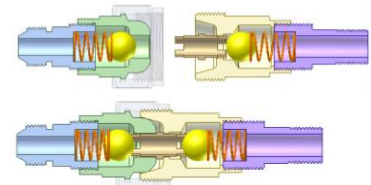
### Pipe connection 1

<http://youtu.be/Nn4P3z589B4>

In disconnected state the fluid can not flow out due to the contact of yellow balls with green and popcorn parts under spring forces.

In connected state brown part pushes the balls, thus prevent the above mentioned contact and the fluid flows through holes on the brown part.

Most parts are cut off half for easy understanding.

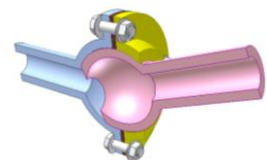


### Pipe movable connection 1

<http://youtu.be/DwrIPPTBrPA>

Spherical joint, arranged for tubing.

The brown gasket is for sealing.

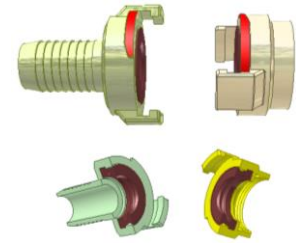


### Geka connector

<https://youtu.be/D6X7TcXXYRA>

Push and twist the connector ends to connect water hoses.  
The red circular wedges force them together.

Brown elastic washers ensure the connection tightness.



### Round adjustable duct elbow 1

<https://youtu.be/VYI7mGtac1o>

The duct elbow consists of two parts.

Angle between oblique face and longitudinal axis of each part is B.

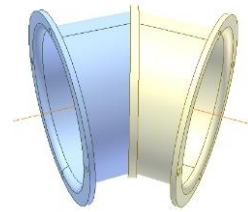
Angle A between axes of two parts is adjustable.

Turn the right part 180 deg. to get max  $A = 2B$ .

The more angle B is, the more duct shape differs from cylinder shape.

So the elbow with more parts (3, 4, ...) is recommended to reduce B.

At two connection planes (not parallel) the duct sections are round. The duct is created by connecting (lofting) those sections. So the duct middle sections are of complicated shape.



### Round adjustable duct elbow 2

<https://youtu.be/se65u1xmmlQ>

The duct elbow consists of four parts.

Angle between oblique face and longitudinal axis of each part is  $B = 15$  deg.

Angle A between axes of two end parts is adjustable.

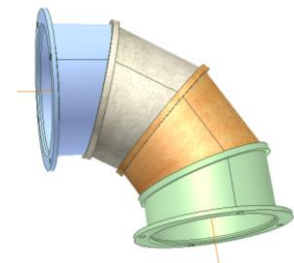
Turn the brown part 180 deg. to get A of 30 deg.

Then turn orange part 180 deg. to get A of 60 deg.

Then turn green part 180 deg. to get max A of 90 deg.

In general: max  $A = k \cdot 2 \cdot B$

Where k is number of movable parts.



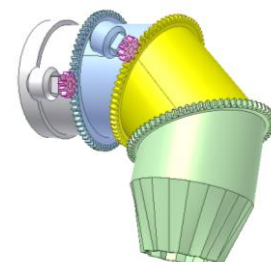
### F-35 Swivel Nozzle

<https://youtu.be/Po--2PoHGI8>

Three motors control gas flow direction.

It is an application of the mechanism shown at:

<https://youtu.be/se65u1xmmlQ>

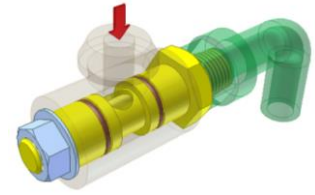


### Rotary connector for fluid 1

<https://youtu.be/H-ucbzaXg0I>

Brown transparent part is stationary and connected to fluid source (red arrow). The fluid is transmitted to rotary part (in green) via circular groove and cross hole on yellow part.

Brown seals are for preventing fluid leakage.



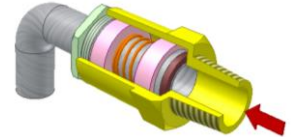
### Rotary connector for fluid 2

<https://youtu.be/CVvECYK8bPA>

Yellow part is stationary and connected to fluid source (red arrow). The fluid is transmitted to rotary part (in grey).

Pink parts represent ball bearings.

Brown seal is for preventing fluid leakage.



### Rotary connector for fluid 3

<https://youtu.be/YMHKGJY4-Zc>

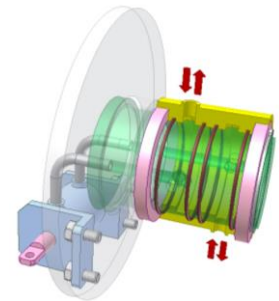
Yellow part is stationary and connected to fluid source (red arrow). The fluid is transmitted to blue rotary cylinder via inner circular grooves of the yellow part, cross and longitudinal holes of green shaft and grey hoses.

Pink parts represent ball bearings.

Brown seal is for preventing fluid leakage.

This working principle can be seen in electric slip rings:

<http://www.uea-inc.com/products/slip-rings>



### Water tank automatic valve

<https://youtu.be/TTad0HzrQt8>

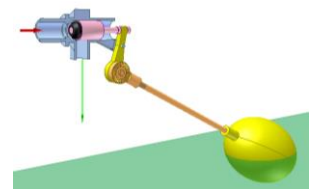
Blue valve body is fixed to the tank. It is cut off haft for easy understanding.

Red arrow represents the water supply.

Green arrow shows water flow controlled by the valve.

Angle between yellow arm and orange lever is adjustable to set the

highest water level in the tank when the black cone completely closes the valve.



### Hydraulic lift 1

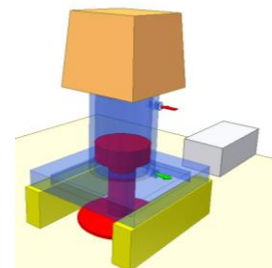
<https://www.youtube.com/watch?v=ITnEJLjQsAk>

This is a way to lift an object (in orange) to large height using cylinder of small stroke by alternately conducting pressure fluid into upper and lower spaces of the piston.

Yellow cushions support blue cylinder.

Grey cushions support red piston.

Arrows show fluid flows. Red arrow is for pressure flow.



### Liquid dispenser 1

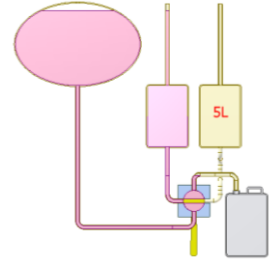
<http://youtu.be/4fbcr1ISroU>

Liquid from the oval tank flows to two meter containers and then to the grey bottle alternately subject to handle positions of the blue four port valve.

The principle of communicating vessels is applied here.

No electricity is required.

Volume error depends on the oscillation of liquid level in the oval tank and the inside diameter (should be minimum) of the air pipes of the meter containers.



### Liquid dispenser 2

<http://youtu.be/4E1AnCBeeQ4>

The upper surface of yellow cup at its lowest position is lower than the liquid surface in the tank. So the cup is filled fully with the liquid.

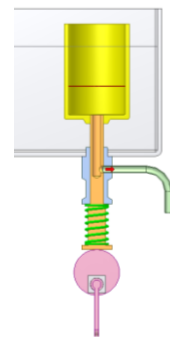
Turn pink cam to raise the cup to its highest position to get:

1. The coincidence of cross holes on the orange bar and on the blue support.
2. The upper surface of yellow cup is higher than the liquid surface in the tank.

Then the liquid amount contained in the cup flows out through green pipe (red arrow). The red line shows liquid surface in the cup.

For dispenser of large liquid amount see "Liquid dispenser 1":

<http://youtu.be/4fbcr1ISroU>



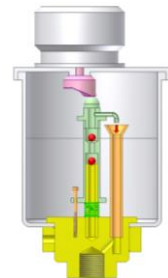
### Liquid dispenser 3

[http://youtu.be/m\\_8wjkpjYLY](http://youtu.be/m_8wjkpjYLY)

Pink continuously rotating cam moves green cylinder to pump out a determined liquid amount during each revolution.

Ball valves are operated automatically thanks to fluid pressure and their own weights. Orange screw is for adjusting liquid amount to be pumped.

Red arrow shows time when the liquid flows out.



### Home floodgate

<https://youtu.be/tqpQ8BZBsq8>

The gate cover (in green) is made of flexible material.

Turn the violet RH and LH screw clockwise to expand the cover in horizontal direction to contact the soft seal (in brown) stuck on the gate.

Turn 4 screws (in gray) to expand the cover to contact the bottom seal.

This video was made based on:

<https://youtu.be/7bNTKbrqjMI>

