TA202A - Manufacturing Processes II

Mechanisms

Lecture 2

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Design of mechanical systems

The design of any mechanical system needs proper understanding of:

i. The geometrical aspects of motion (kinematics), and

ii. The various forces involved in motion (kinetics and dynamics, i.e., mechanics)

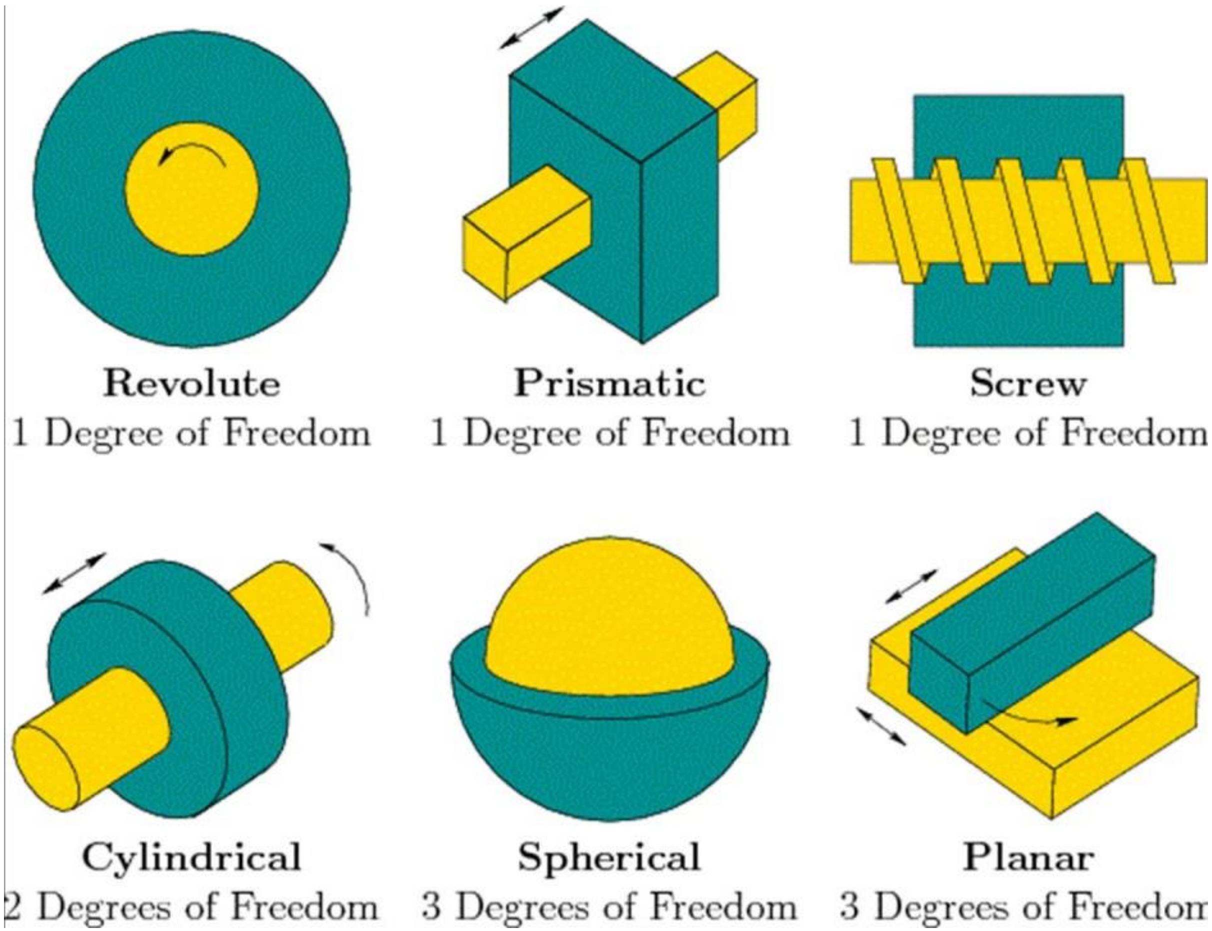
Mechanism and machines

- Mechanism: is a combination of rigid or restraining bodies so shaped that they can move upon each other with a definite relative motion
- Machine: is a mechanism or a collection of mechanisms which performs useful mechanical work
- Every machine is a mechanism, but not vice versa

Structure of this lecture

- What is a mechanism?
  - Building blocks of mechanisms
- Mechanisms of interest to us
  - Cams
  - Belt-pulley, chain-sprocket
  - Gears
    - Spur, Bevel, Worm, Trains
  - Quick return
  - Indexing
- How different components of mechanisms are made

Building blocks of mechanisms – kinematic pairs

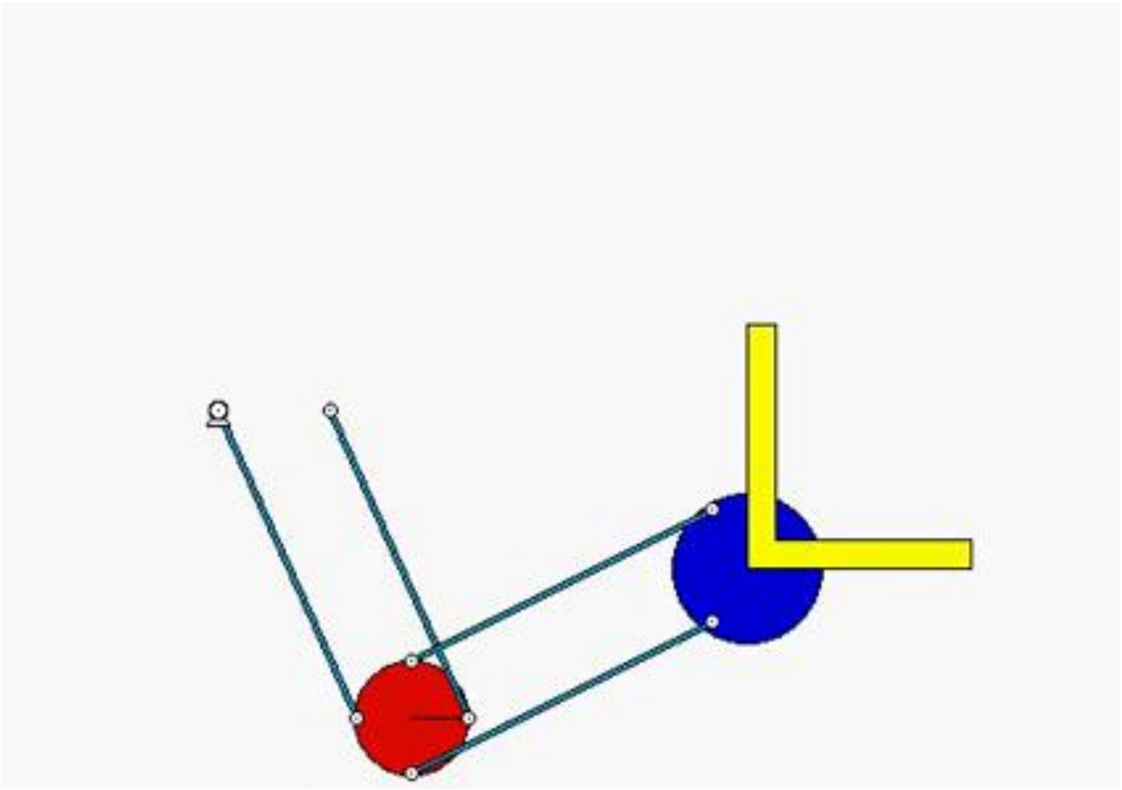


Degree of freedom of a kinematic pair is given by the number of independent coordinates required to specify the relative movement

Source: http://planning.cs.uiuc.edu/node109.html

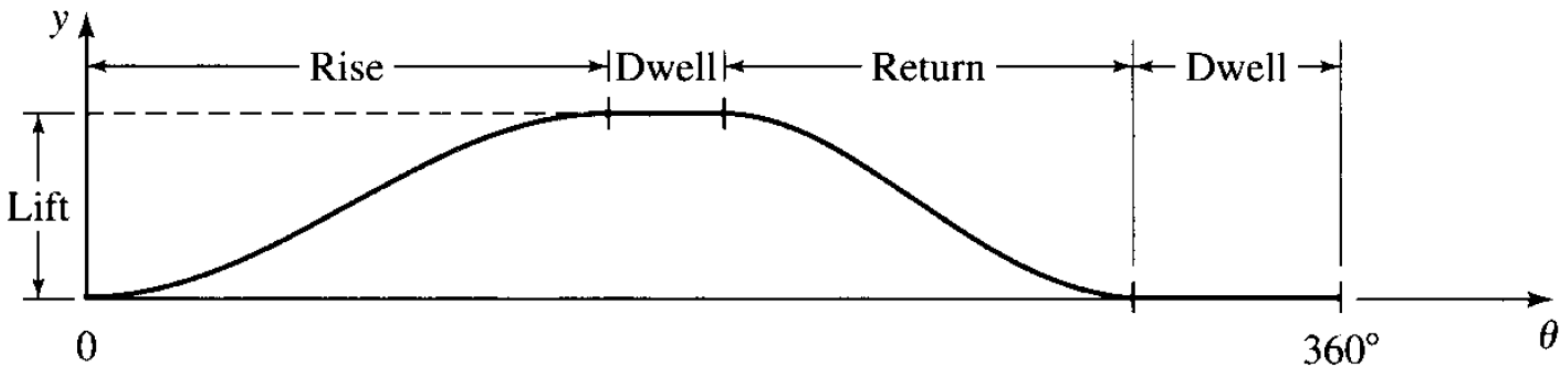
Mechanisms you are familiar with

https://www.isomars.com/p/drawing-table-scholar-with-drafter/



https://www.youtube.com/watch?v=nb1pPOSAgnQ

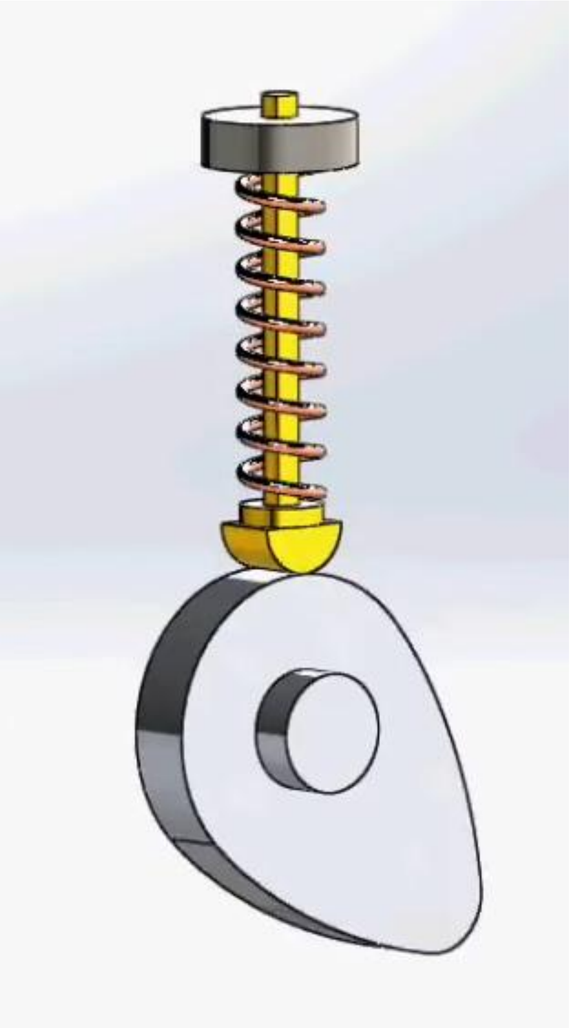
Desired motion

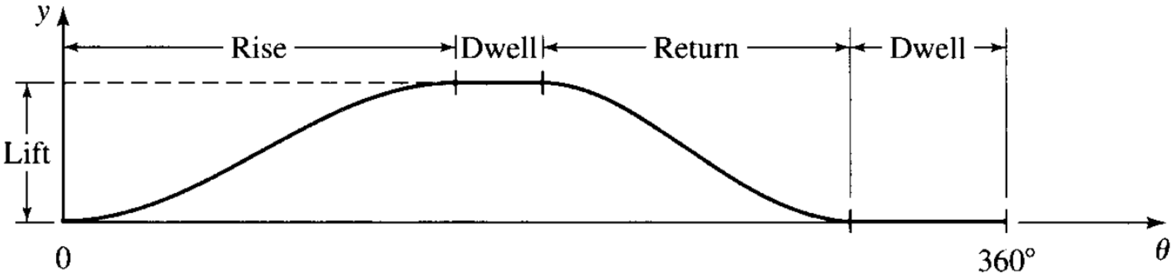


What kind of mechanism will provide me this motion?

Source: Shigley and Uicker, Theory of Machines and Mechanisms

Cam



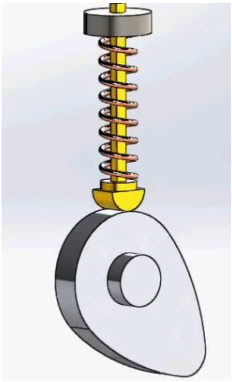


- Follower motion, y is the ordinate, and the cam motion , θ is on the abscissa.
- In general: $y = y(\theta)$
- 1st derivative is the measure of steepness: $y'(\theta) = \frac{dy}{d\theta}$
- 2nd derivative is a measure of the radius of curvature:

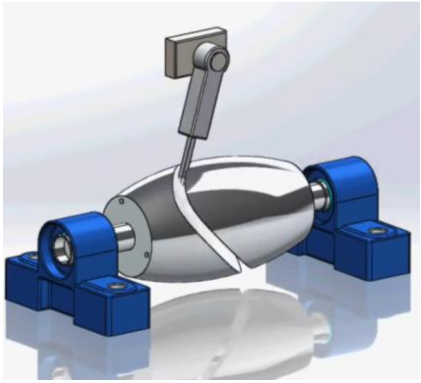
$$y''(\theta) = \frac{d^2y}{d\theta^2}$$

Types of Cams

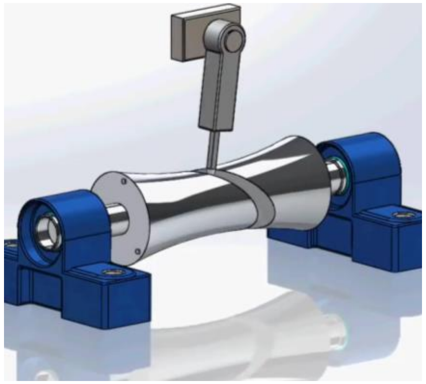
Radial cam



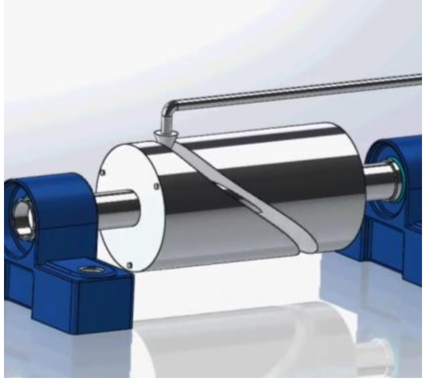
Convex cam



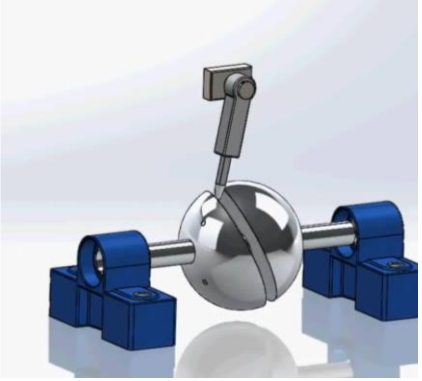
Concave cam



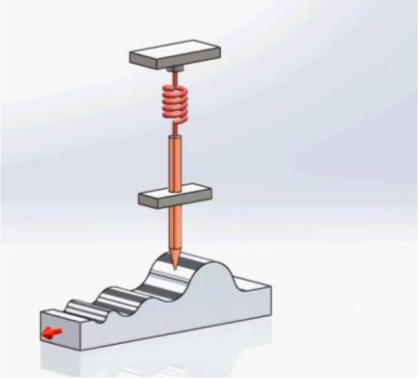
Cylindrical cam



Spherical cam

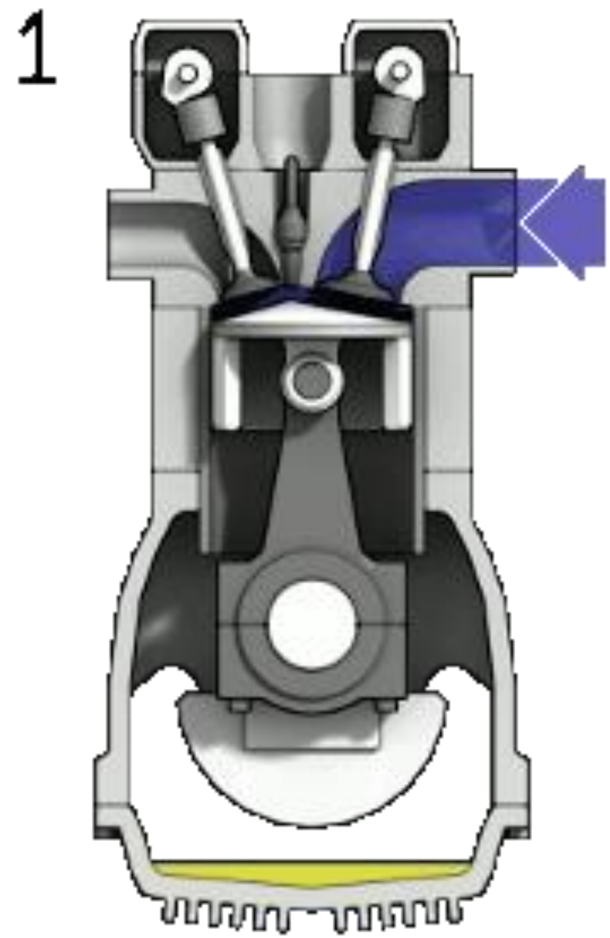


Flat/wedge cam



https://www.youtube.com/watch?v=GYVgGSQjX2U

A common example of the use of a cam

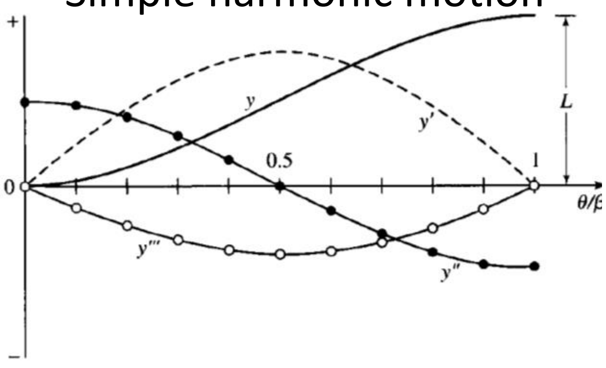


https://en.wikipedia.org/wiki/Four-stroke_engine

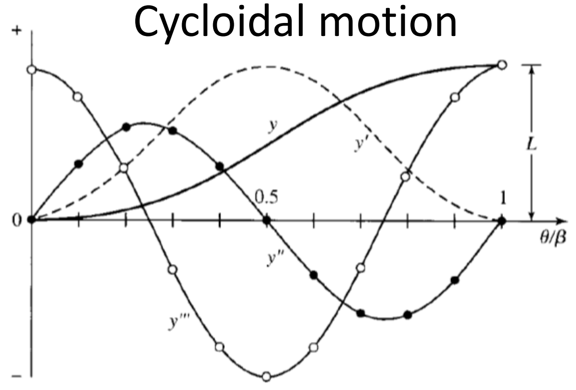
How are Cams designed?

- Usually, the total lift, dwell, and return cycles depend on application, and are predetermined.
- However, there are many possible choices of follower motion that can achieve the desired lift/return and dwell
- The key step is cam design is hence the right choice for these motions
- We would preferably like smooth velocity, acceleration and jerk profiles
- Matching derivatives of displacement diagrams with the desired motion profile

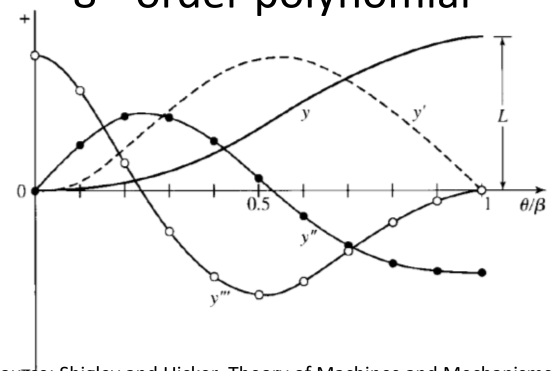
Simple harmonic motion



Cycloidal motion

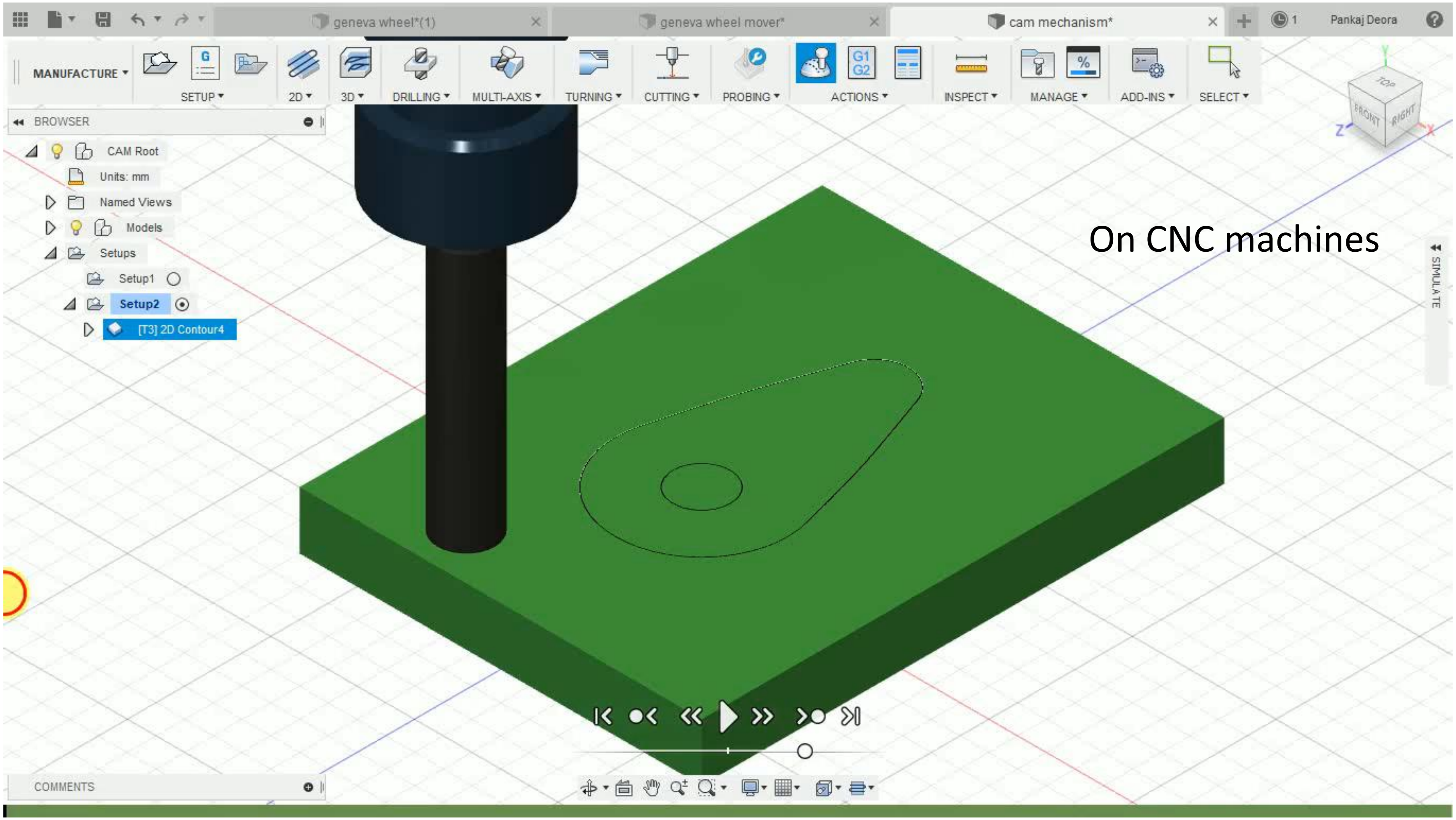


8^{th} order polynomial



Source: Shigley and Uicker, Theory of Machines and Mechanisms

How are cams manufactured?



On CNC machines

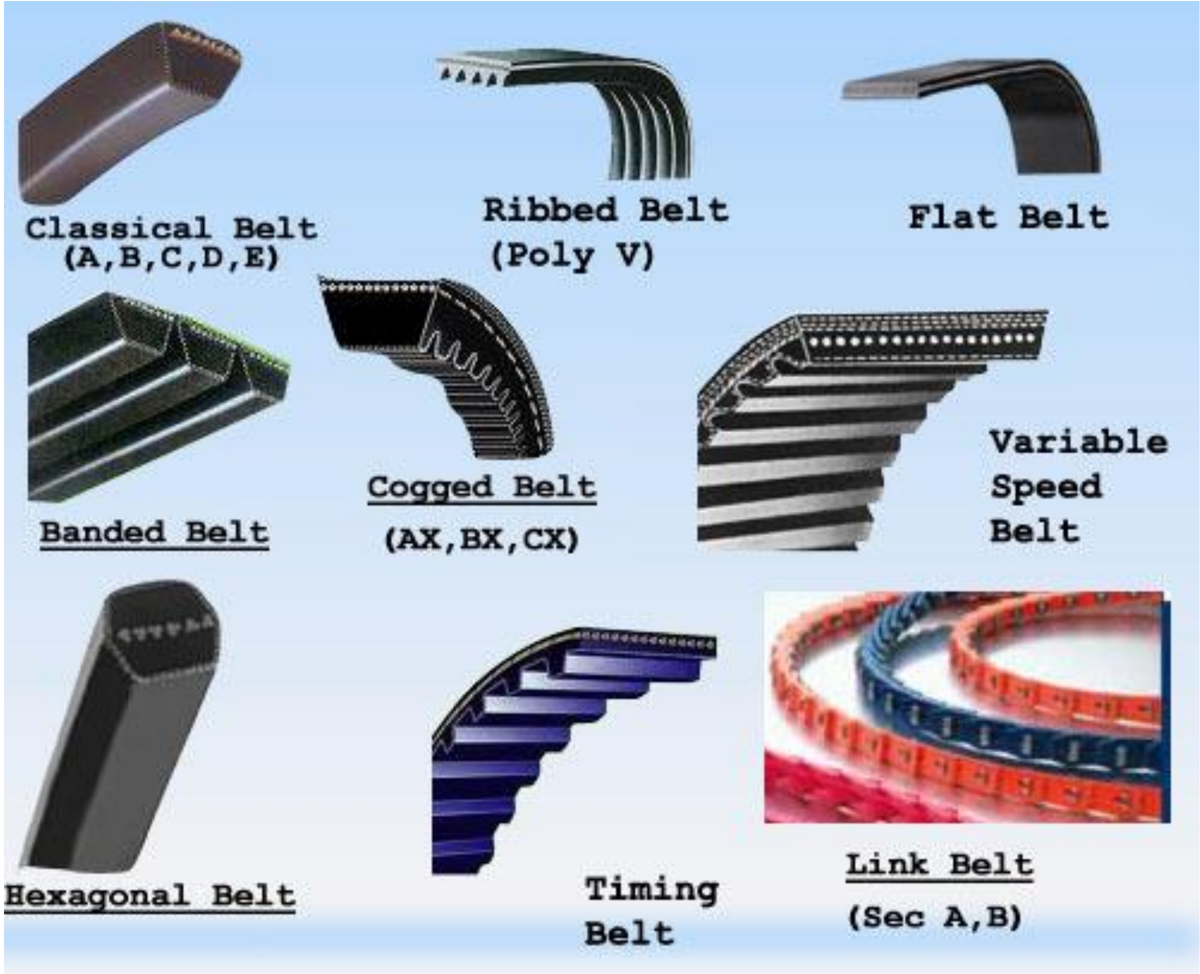
Belt + pulley drive

https://www.youtube.com/watch?v=hkIyGrLDy3A

Line-shafts with flat belts

Source: https://en.wikipedia.org/wiki/Line_shaft

Other types of belts



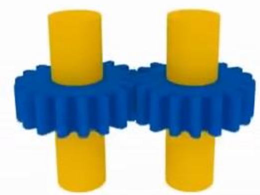
http://www.learneasy.info/MDME/MEMmods/MEM30009A/shaft_drives/shaft_drives.html

Chain + sprocket drives

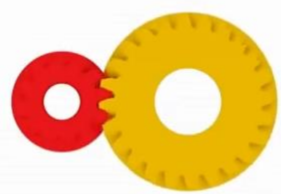
https://www.youtube.com/watch?v=tXVE5O_jJi8

Gears

Gears are a positive drive, i.e., no slipping, i.e., angular velocity of gear 1 is the same as angular velocity of gear 2



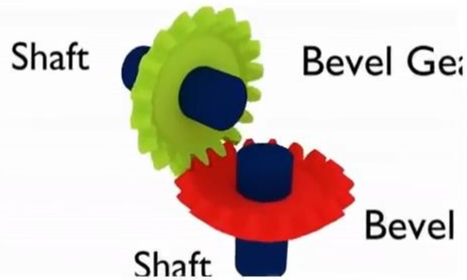
1. Spur gear



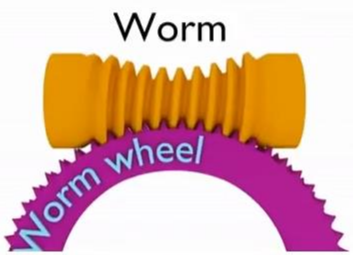
2. Helical gear

3. Herringbone gear

4. Rack and pinion



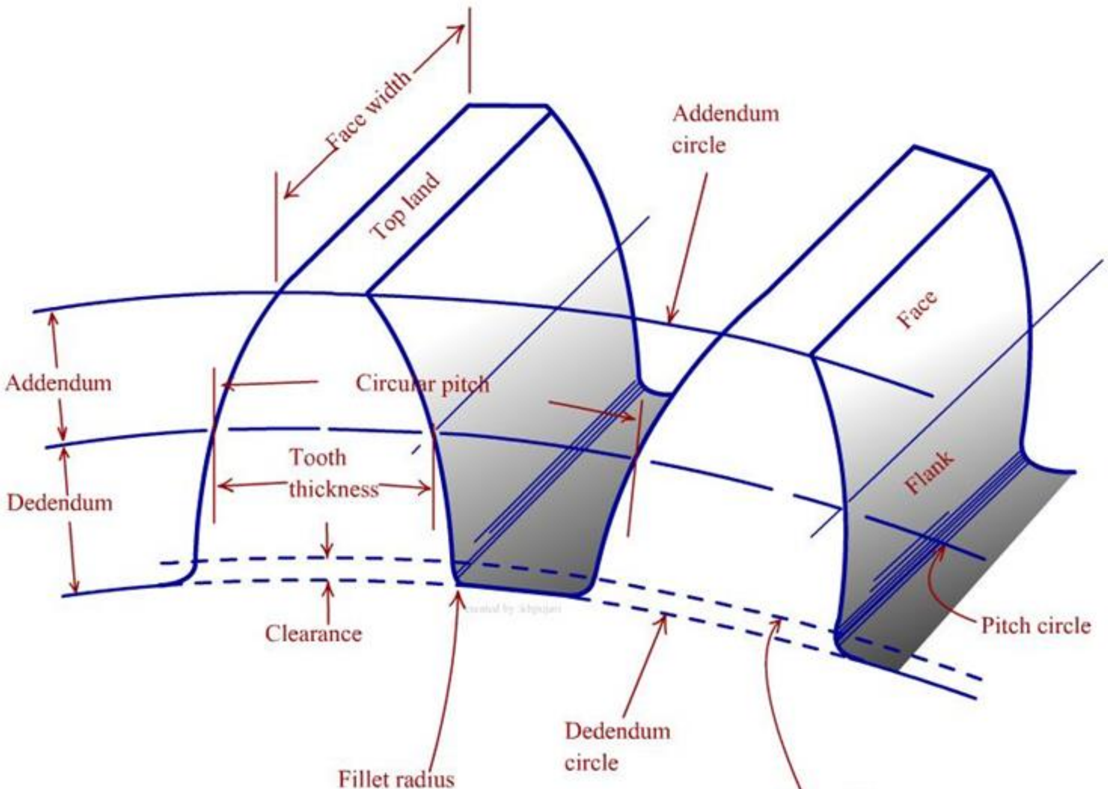
5. Bevel gear



6. Worm and worm wheel

https://www.youtube.com/watch?v=P4rNX0gCm3E

Spur gear nomenclature



Diametrical pitch: $\boxed{P = \frac{N}{d}}$

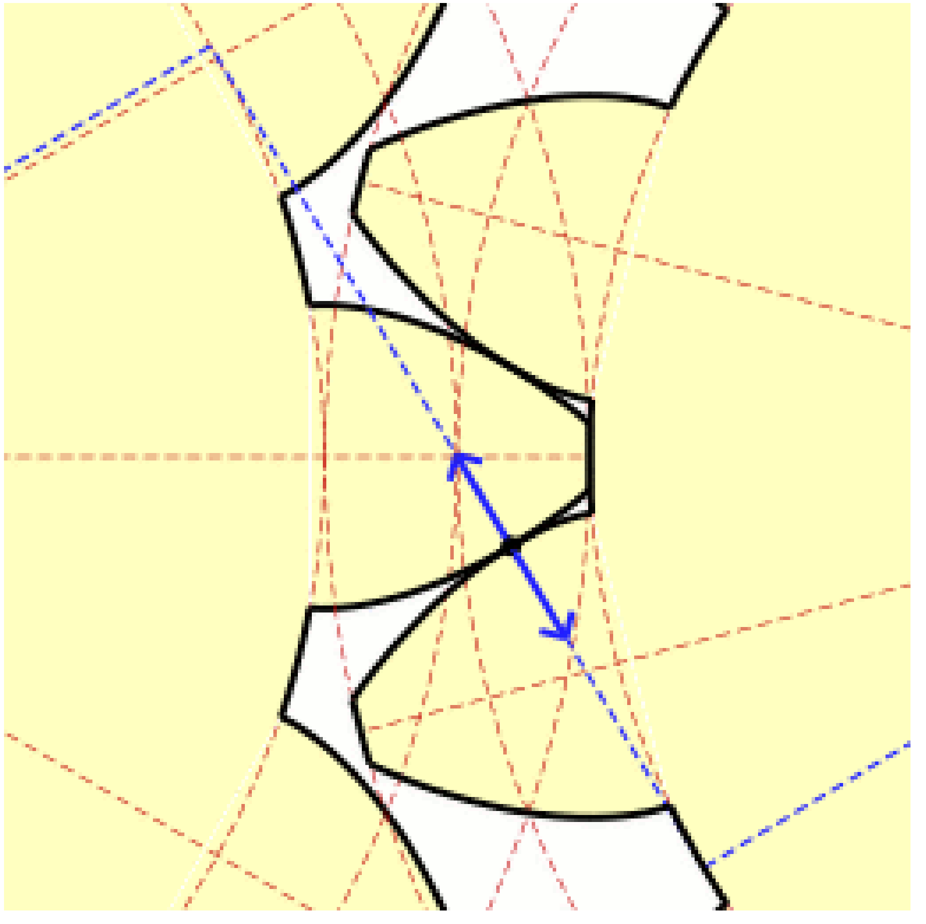
Module of the gear: $\boxed{m = \frac{d}{N}}$

Circular pitch: $\boxed{p = \frac{\pi d}{N} = \pi m}$

N – number of teeth;
d – pitch circle diameter

Source: Shigley and Uicker, Theory of Machines and Mechanisms

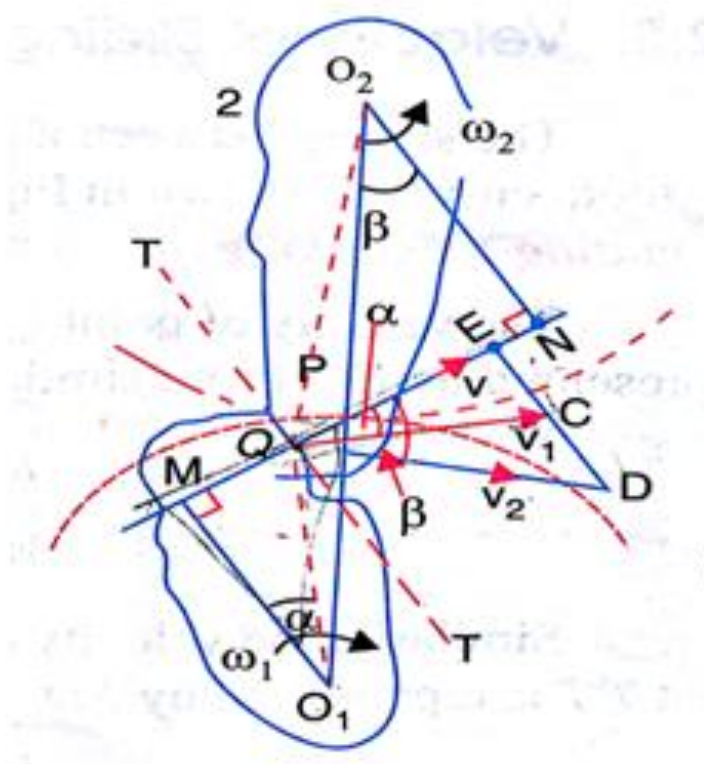
The involute gear



https://en.wikipedia.org/wiki/Involute_gear

Law of gearing

- the angular velocity ratio of all gears of a meshed gear system must remain constant,
- also the common normal at the point of contact must pass through the pitch point.
- Let v_1 and v_2 be the velocities of the point Q on the wheels 1 and 2 respectively. If the teeth are to remain in contact, then the components of these velocities along the common normal MN must be equal, i.e.,



$$v_1 \cos\alpha = v_2 \cos\beta \rightarrow (\omega_1 \times O_1Q)\cos\alpha = (\omega_2 \times O_2Q)\cos\beta \rightarrow \frac{\omega_1}{\omega_2} = \frac{O_2N}{O_1M} = \frac{O_2P}{O_1P}$$

https://www.ques10.com/p/24423/state-explain-law-of-gearing/

Spur gears

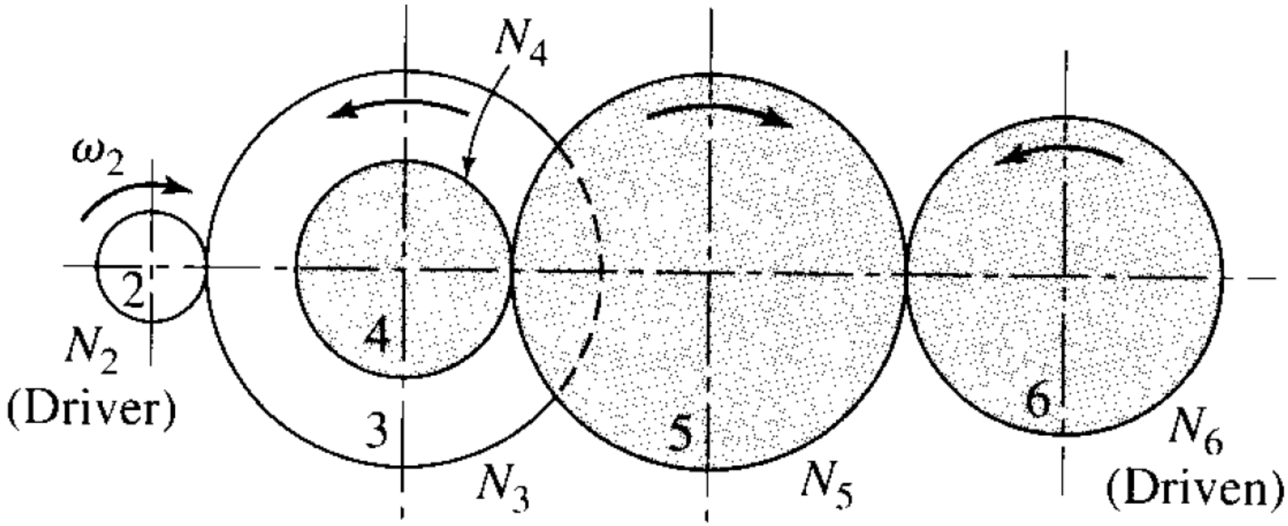
Spur gears are used to transmit rotary motion between parallel shafts

$$v = r_A\omega_A = r_B\omega_B \rightarrow \frac{\omega_A}{\omega_B} = \frac{r_B}{r_A} = \frac{N_B}{N_A}$$

https://www.youtube.com/watch?v=49IOAHJ-V4I

Spur gear train

What is the speed of the driven gear?

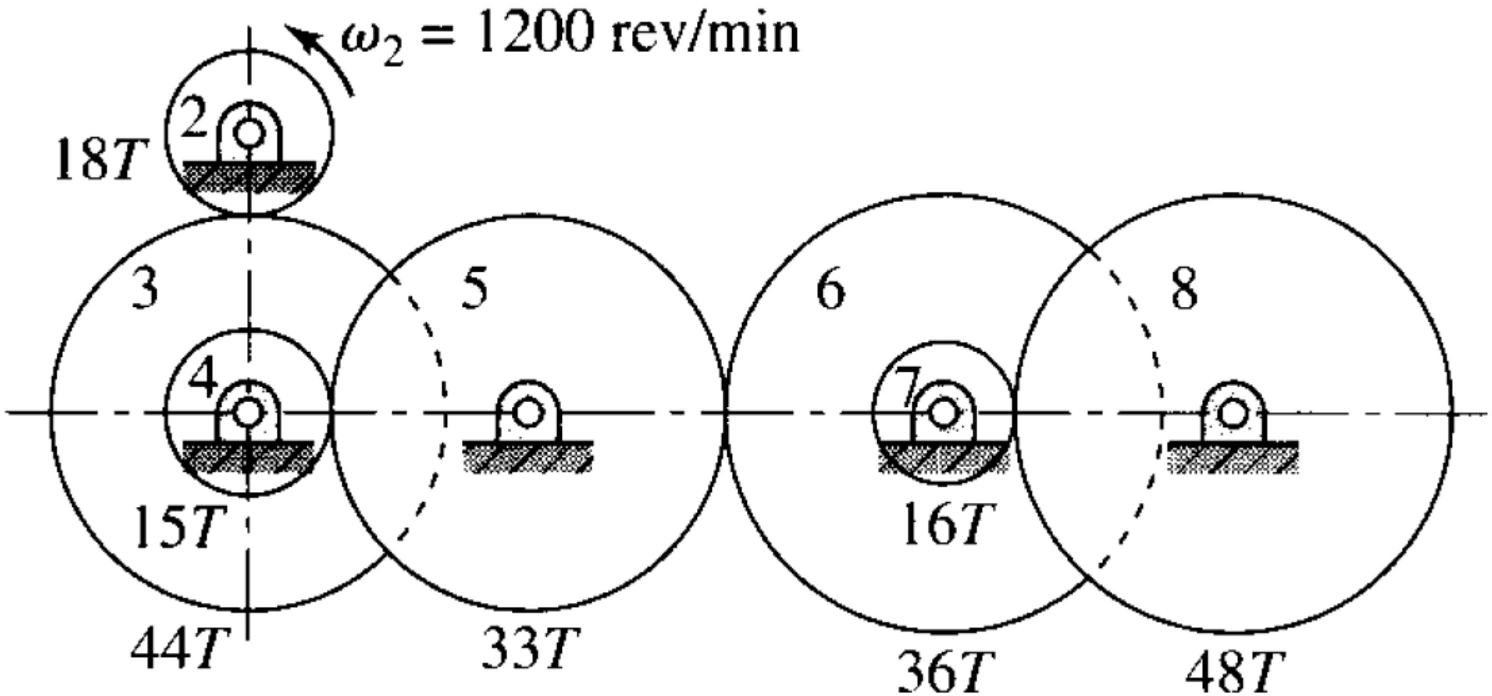


$$\omega_6 = \frac{N_2}{N_3}\frac{N_4}{N_5}\frac{N_5}{N_6}\omega_2$$

Source: Shigley and Uicker, Theory of Machines and Mechanisms

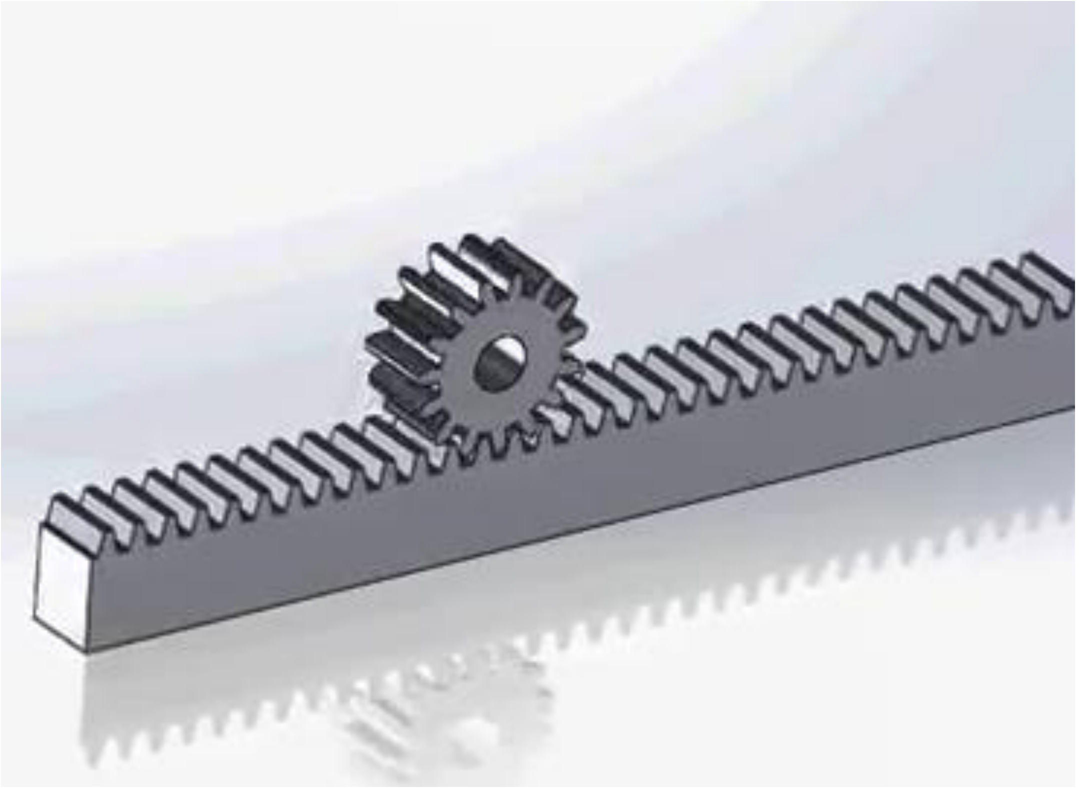
Gear trains

What is the speed of the driven gear, gear # 8?



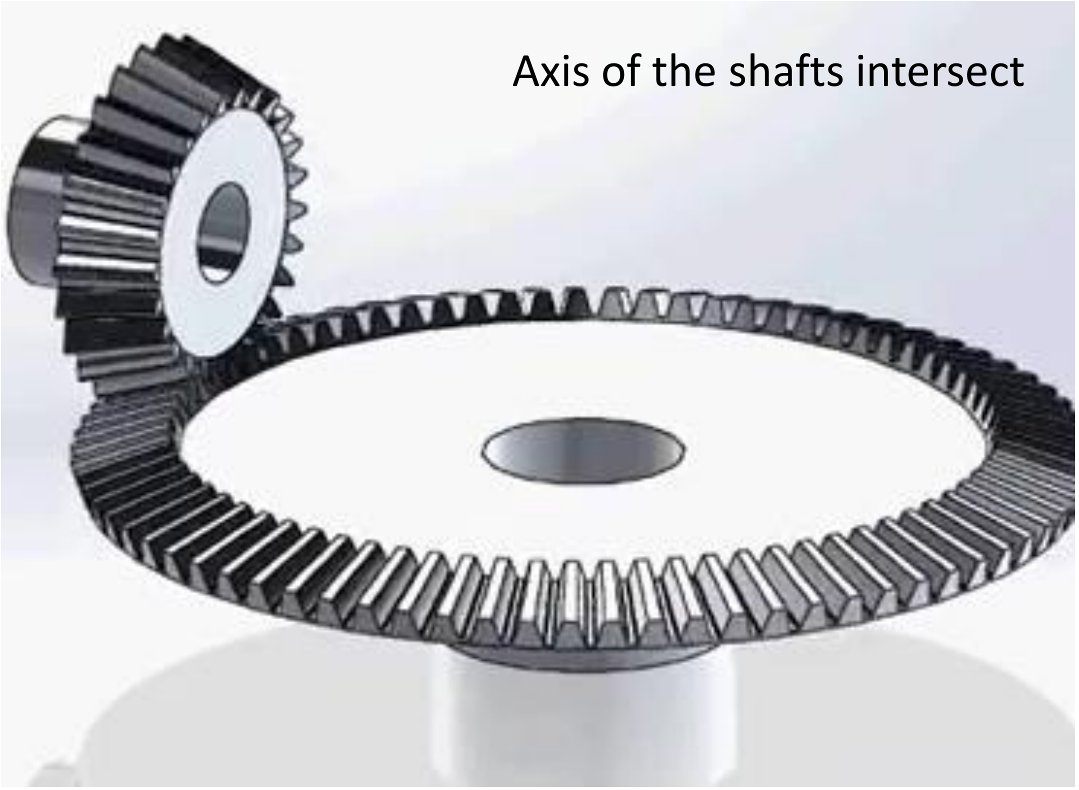
Source: Shigley and Uicker, Theory of Machines and Mechanisms

Rack and pinion (spur gears)



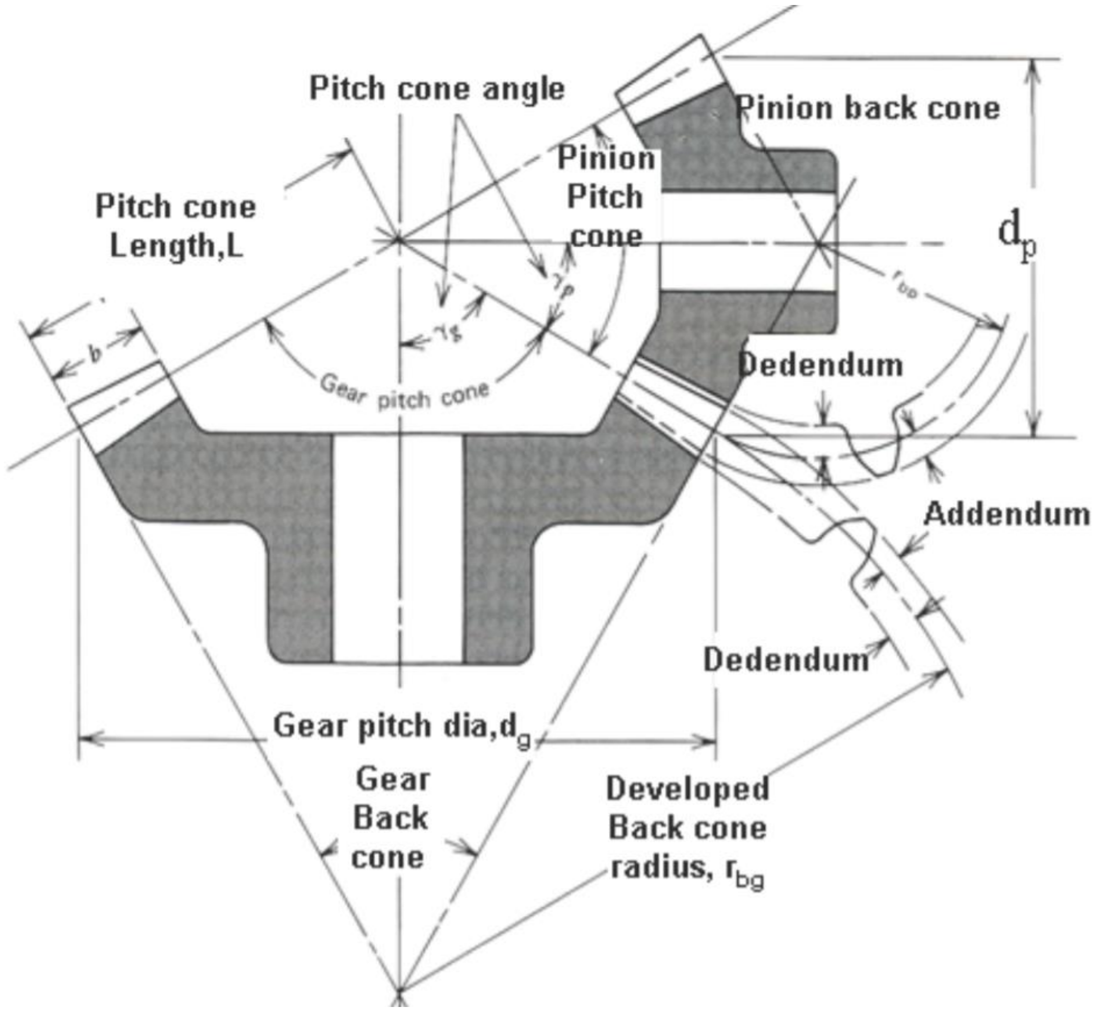
https://www.youtube.com/watch?v=49IOAHJ-V4I

Bevel gears



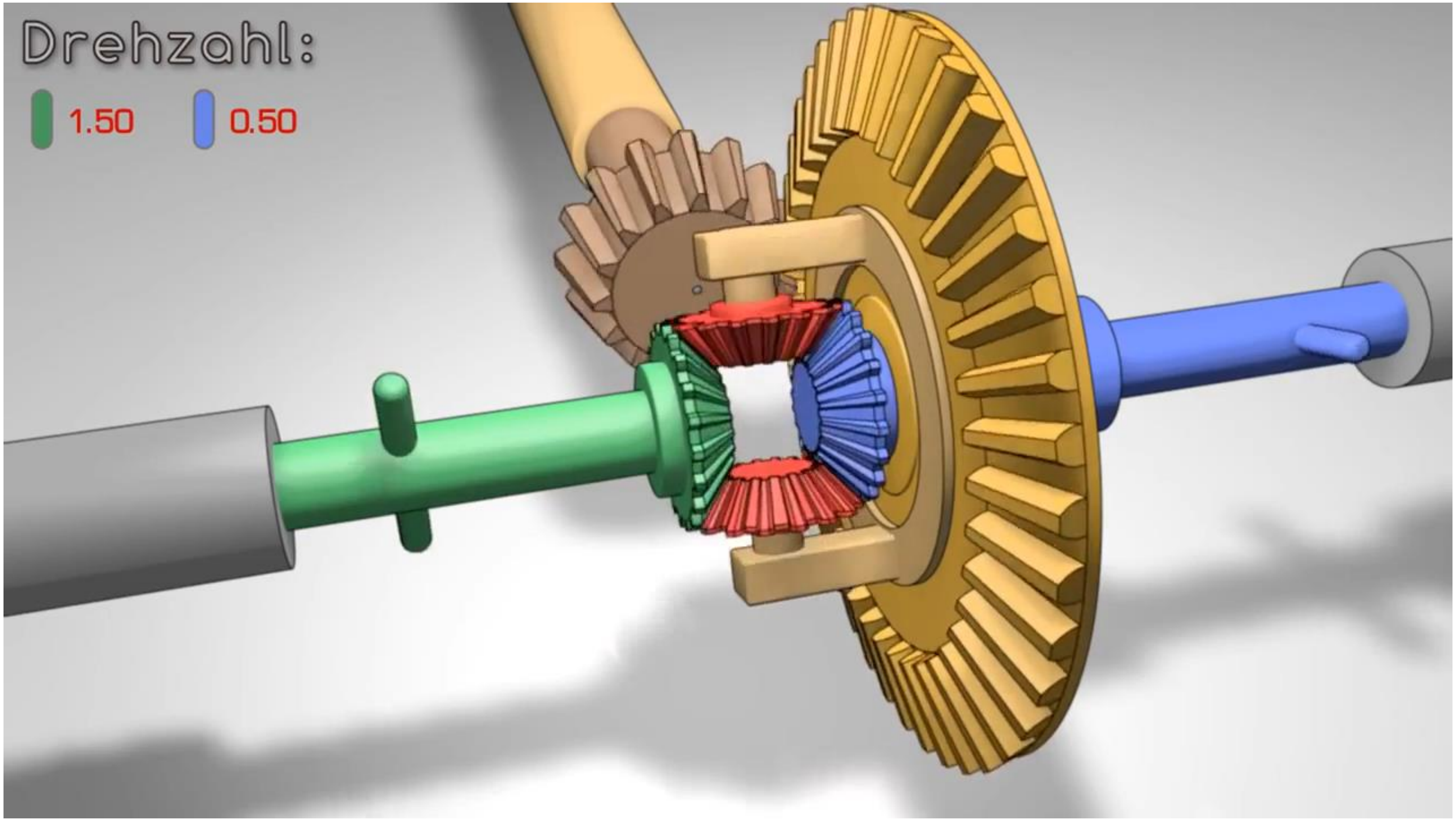
https://www.youtube.com/watch?v=49IOAHJ-V4I

Bevel gears



Pitch cone angle
Pinion back cone
Pinion
Pitch
cone
Pitch cone
Length,L
d_p
r_{bp}
b
γ_p
γ_g
Gear pitch cone
Dedendum
Addendum
Dedendum
Gear pitch dia,d_g
Gear
Back
cone
Developed
Back cone
radius, r_{bg}

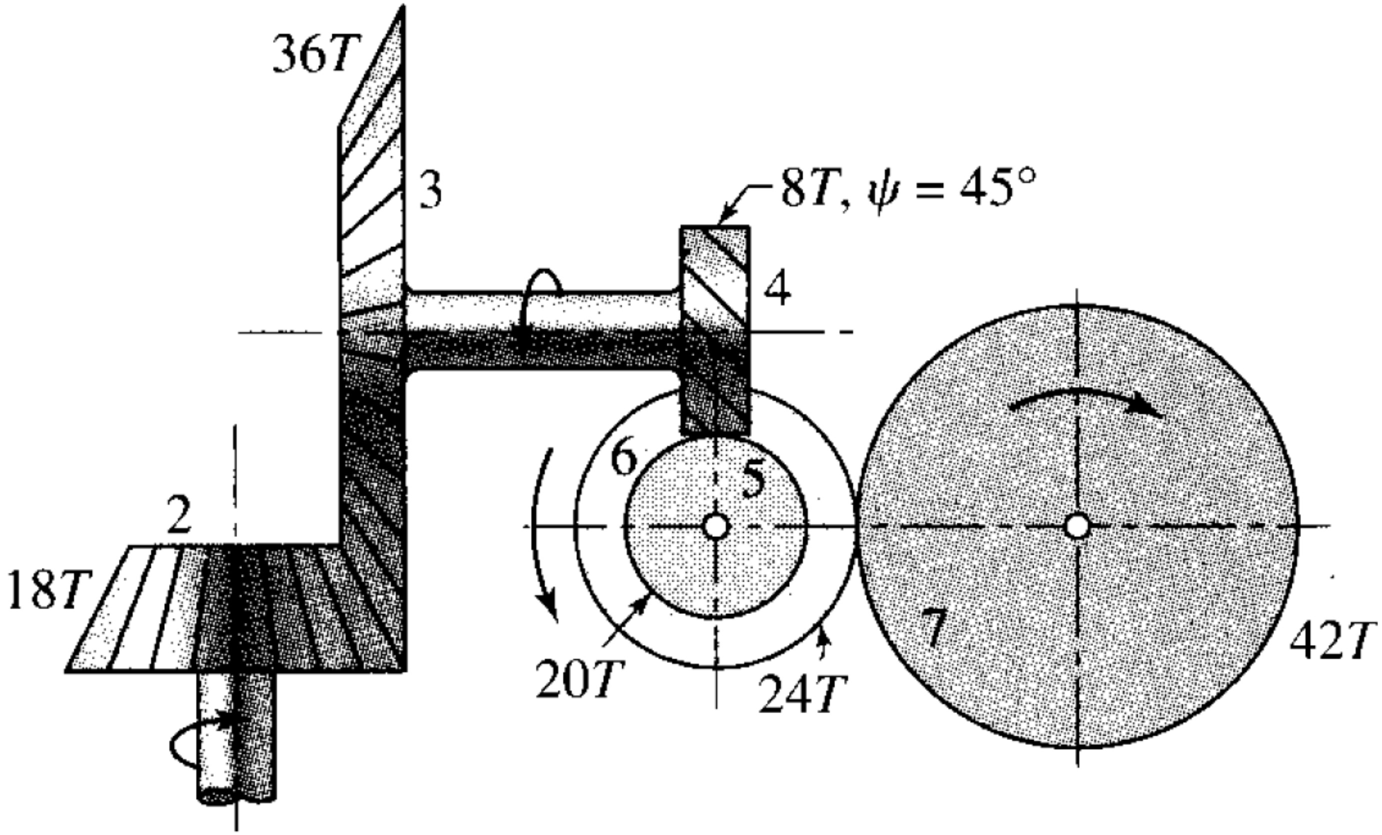
Where are bevel gears used?



https://www.youtube.com/watch?v=eef7MutOVME

Gear trains

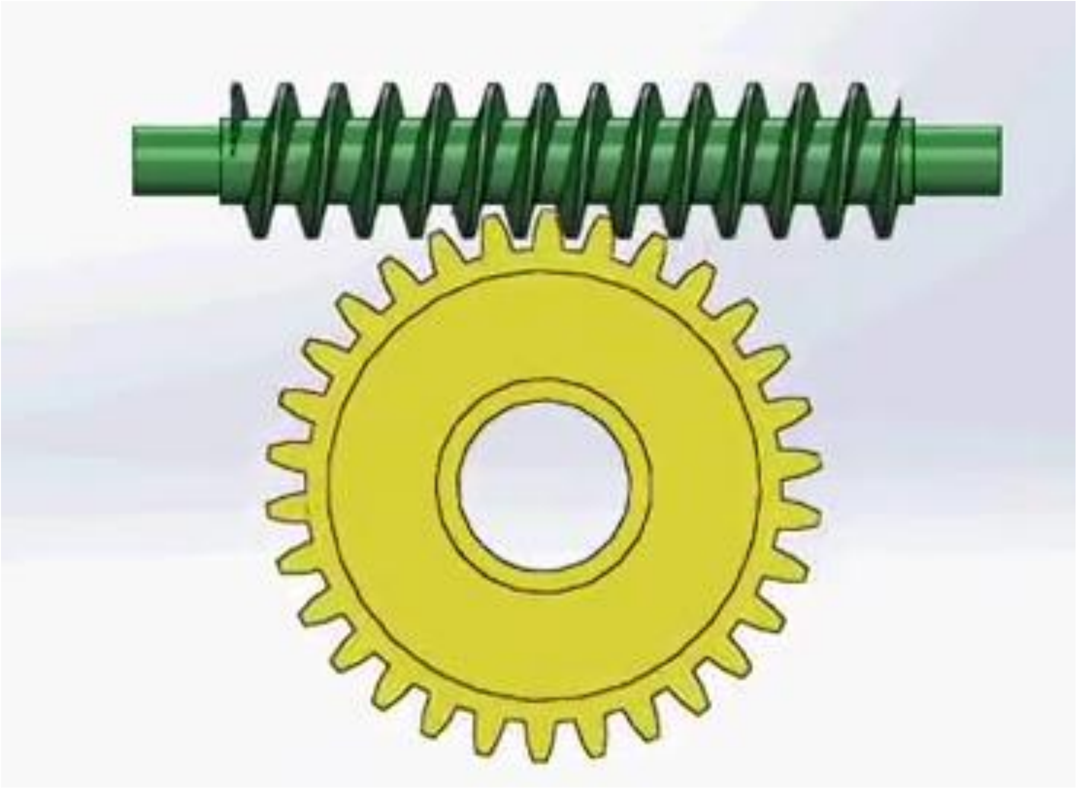
Given the speed of gear 2, what will be the speed of gear 7?



Source: Shigley and Uicker, Theory of Machines and Mechanisms

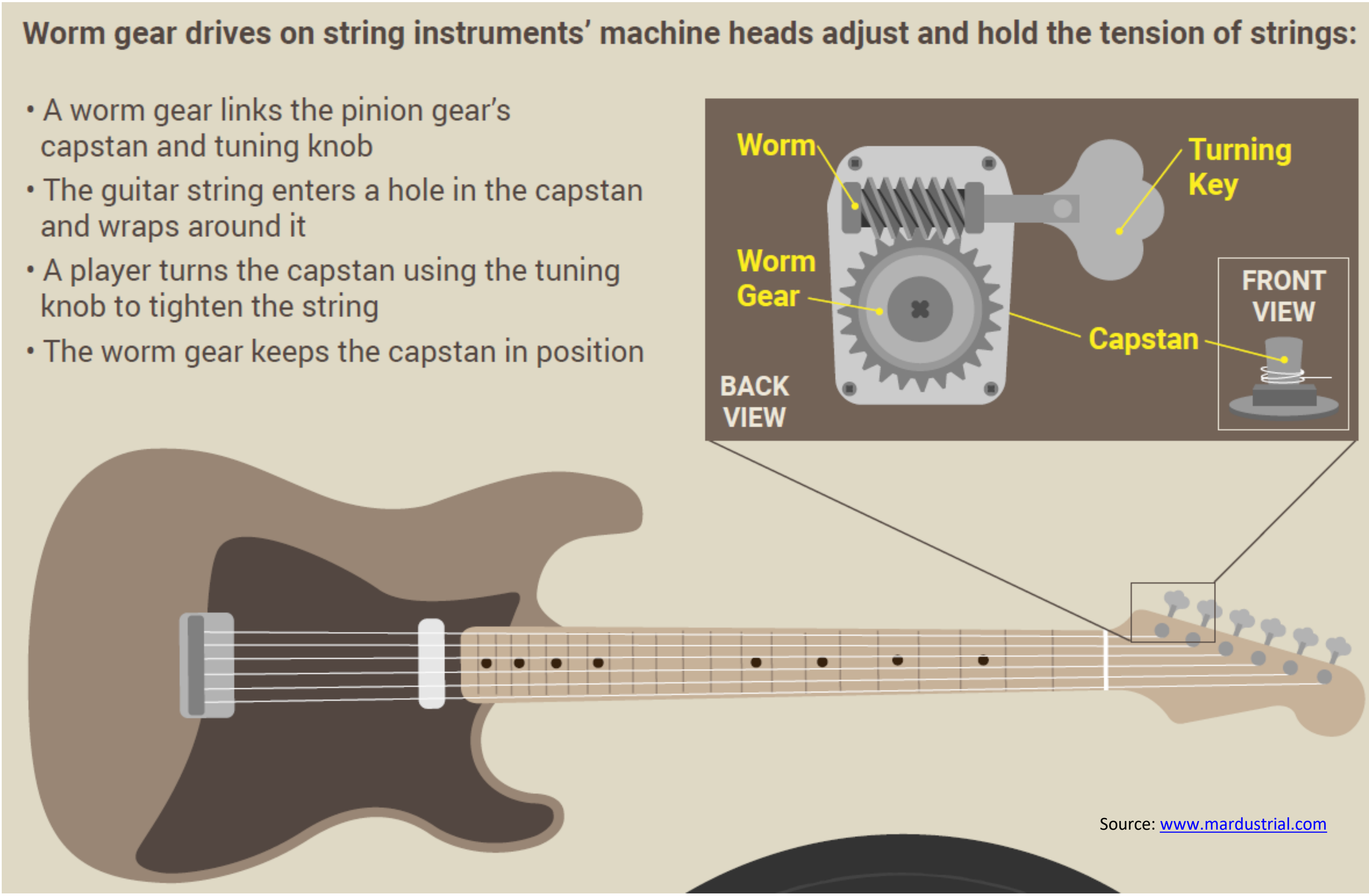
Worm gears

Normally used with nonintersecting shafts which are usually at a shaft angle of 90°



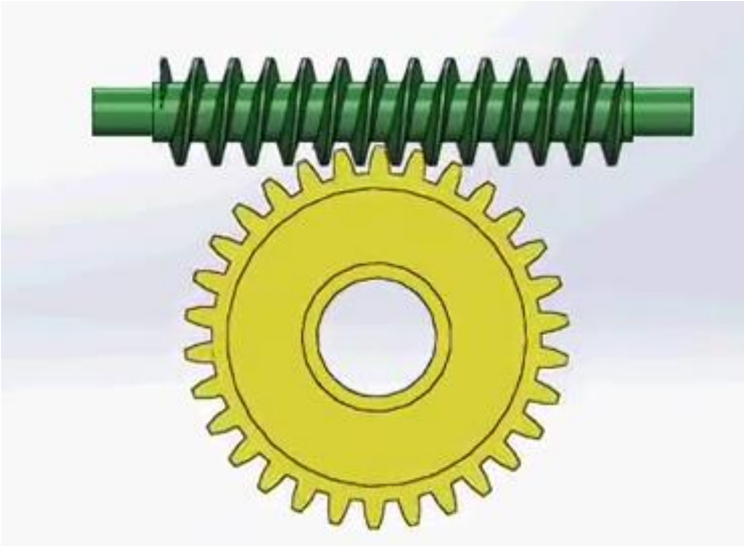
https://www.youtube.com/watch?v=49IOAHJ-V4I

Everyday example of use of worm gears

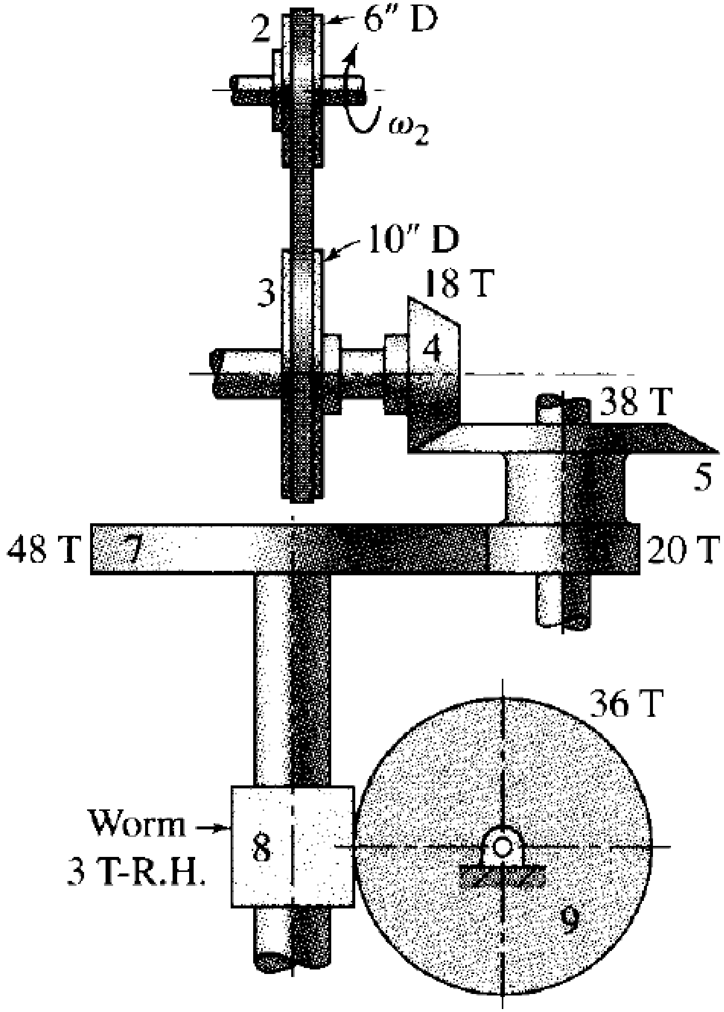


Worm gears

- One rotation of the worm moves one tooth on the worm wheel (gear)
- Very high gear ratios
- For example, if you have
  - 8 teeth, ratio is 1/8
  - 24 teeth, ratio is 1/24
  - …
- These are one directional, and hence 'self-locking'



Gear trains



Given the speed of gear 2, what will be the speed of gear 9?

Note that there are spur gears, bevel gears, and a worm and worm wheel in this gear train

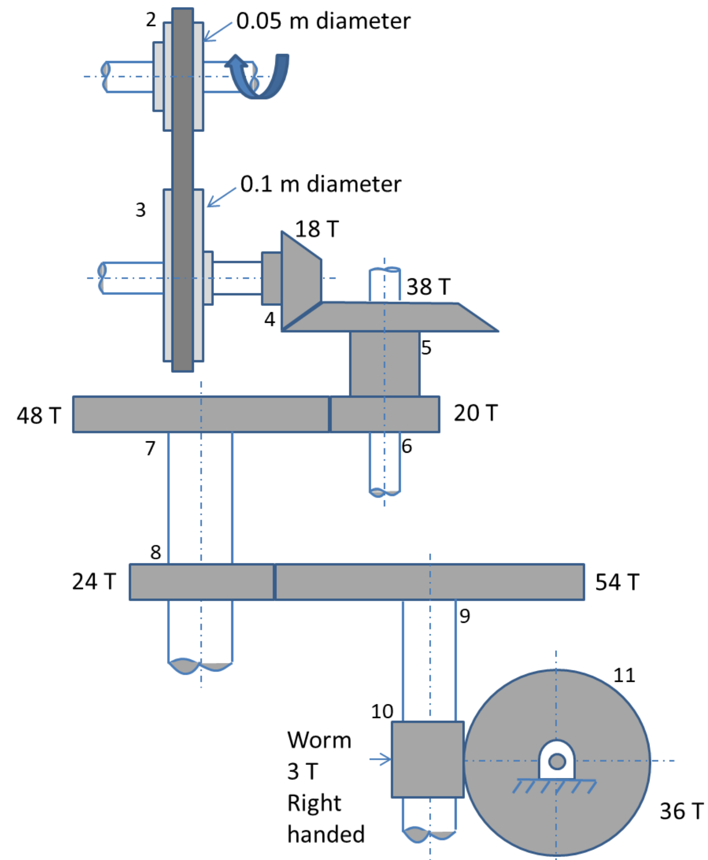
Source: Shigley and Uicker, Theory of Machines and Mechanisms

Exam question from 2019 - 2020 - I

Question 1 [1]

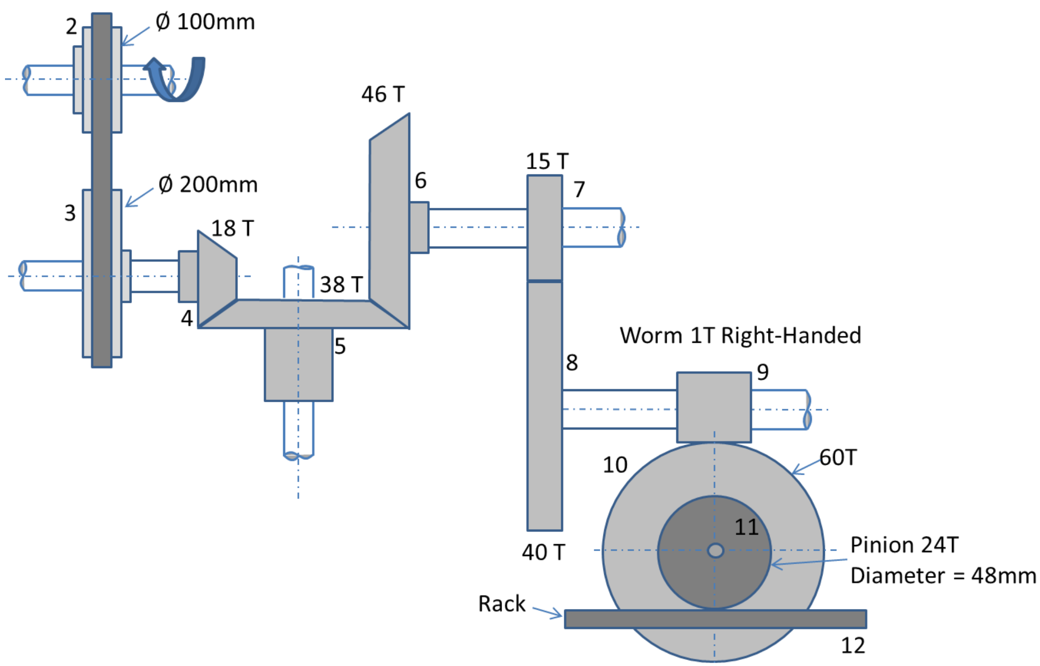
A gear train is shown on the right. It includes a pulley drive, a set of bevel gears, two sets of spur gears, and a worm and worm wheel pair. The number of teeth (T) on each gear is as shown. If the input speed of the driving pulley (# 2 in the figure) is 30 RPM, what is the output speed of the worm wheel? Also, if the required output torque at the worm wheel is 10 Nm, what should be the torque supplied by the motor driving the pulley # 2? Keep in mind that if the input gear rotates faster than the output gear, then the gear train amplifies the input torque.

Show all steps in your calculations for a full grade.



Exam question from 2019 - 2020 - II

A gear train is shown below. It includes two pulleys, bevel gears, spur gears, a worm and worm wheel pair, and a rack and a pinion. The number of teeth (T) on each gear is as shown. If the input speed of the driving pulley (# 2 in the figure) is 30 RPM, and if the required output torque at gear # 11 is ~817 Nm, what should be the torque supplied by the motor driving the pulley # 2? Also, if the driving pulley rotates in the clockwise direction, what is the direction of translation of the rack, i.e., does it move right or left? Also, what will be the linear speed (in m/s) of the rack? Show detailed calculations for a full grade.



How are gears made?

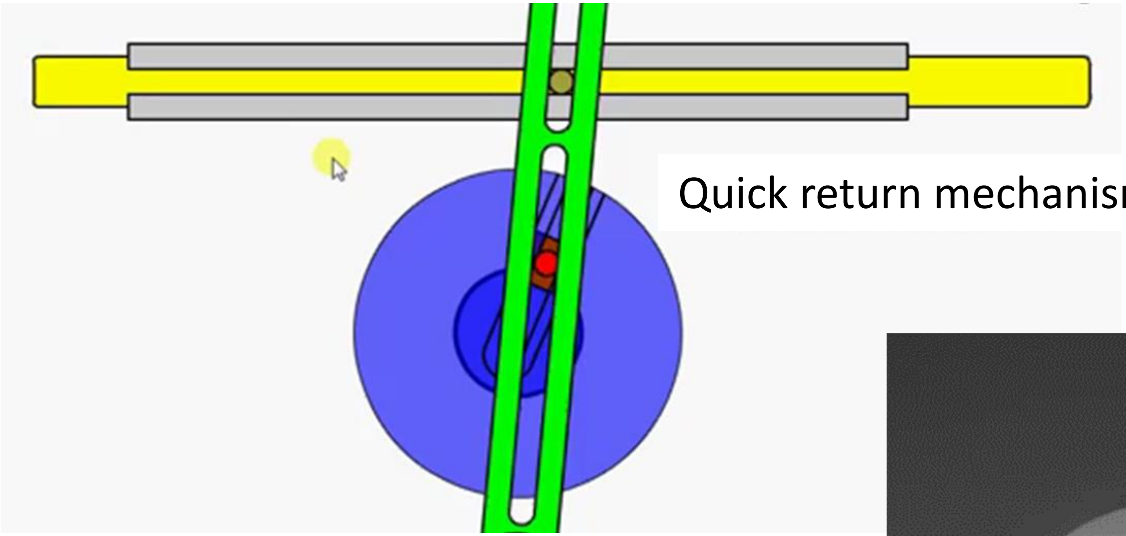
Gear hobbing

https://www.youtube.com/watch?v=0rnTh6c19HM

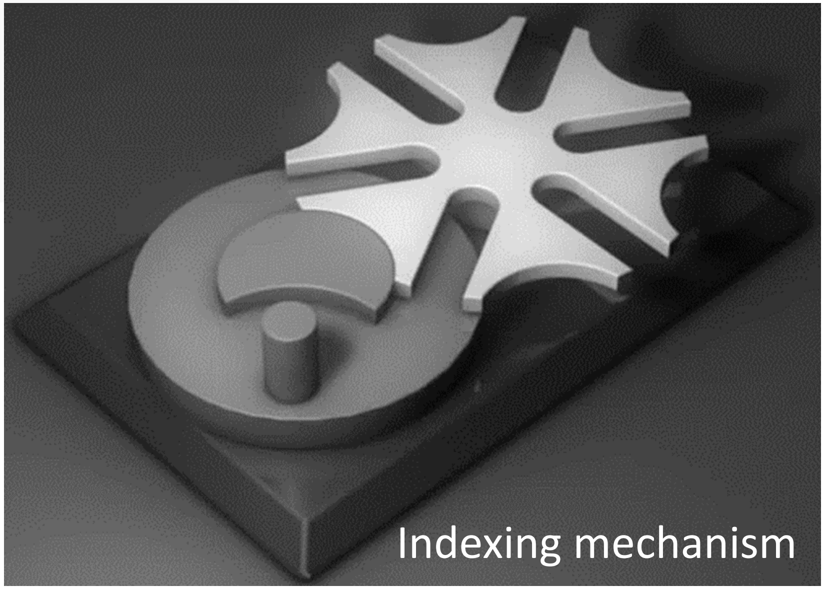
Gear tooth form cutting

https://www.youtube.com/watch?v=8yNj_Ogu0-E

Other interesting and relevant mechanisms

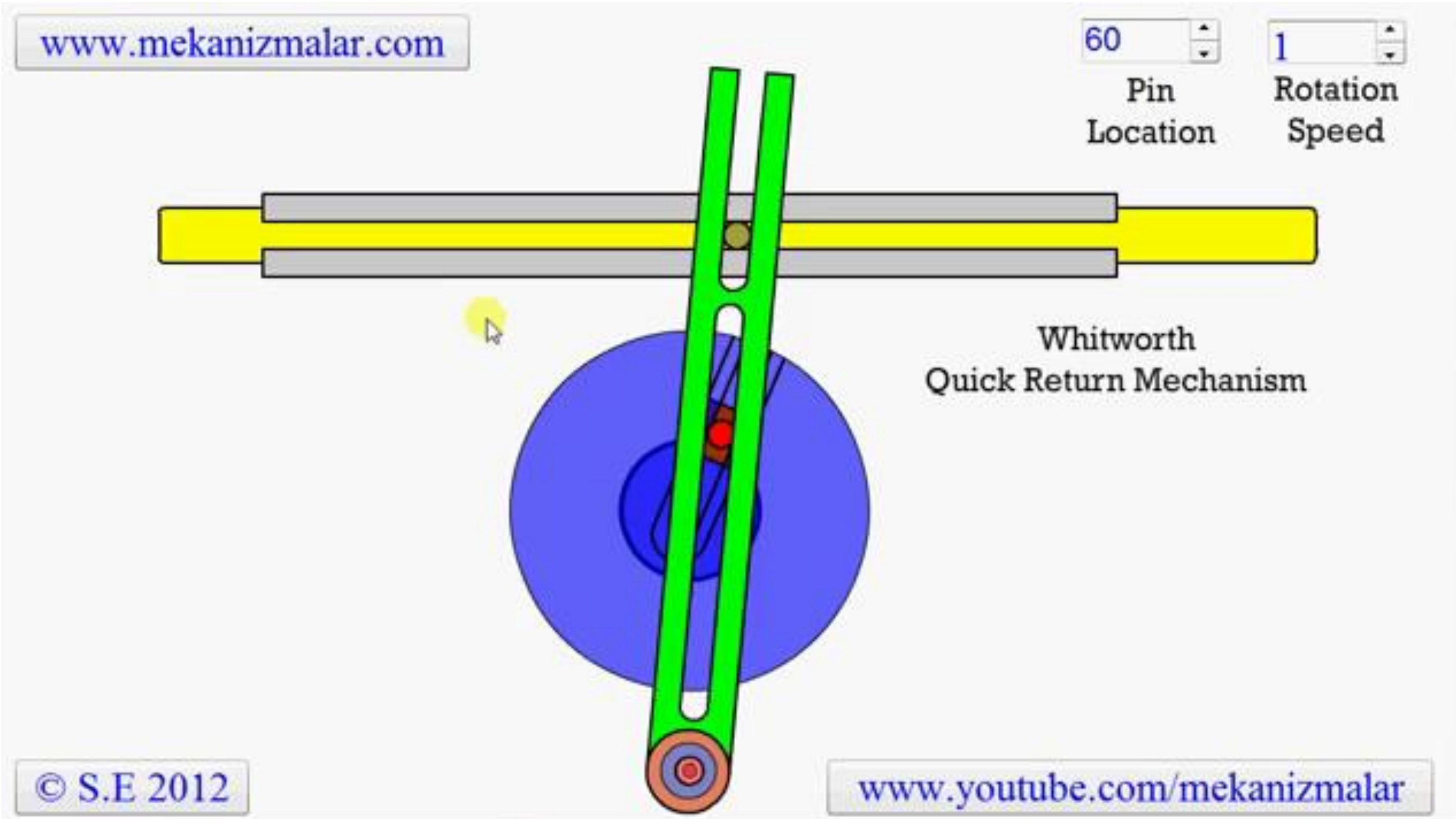


Quick return mechanism

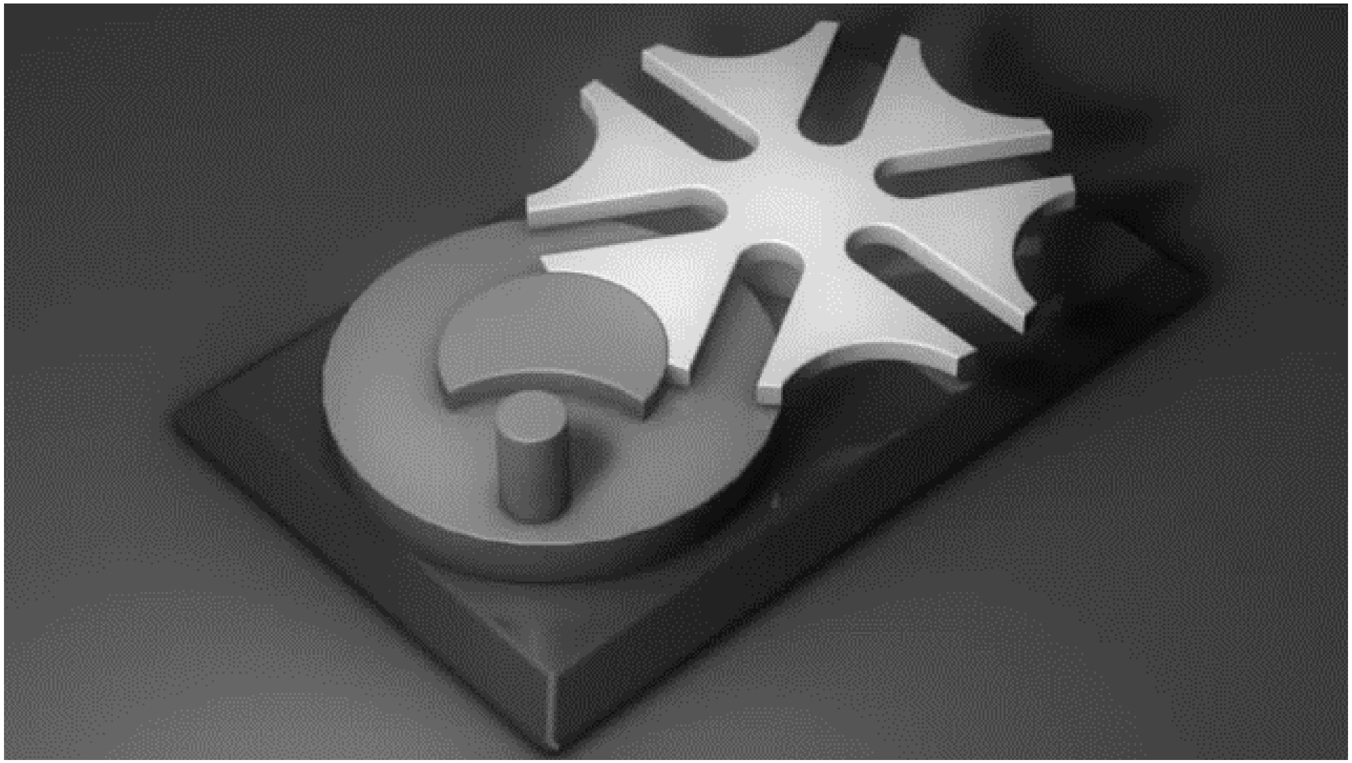


Indexing mechanism

Quick return mechanism

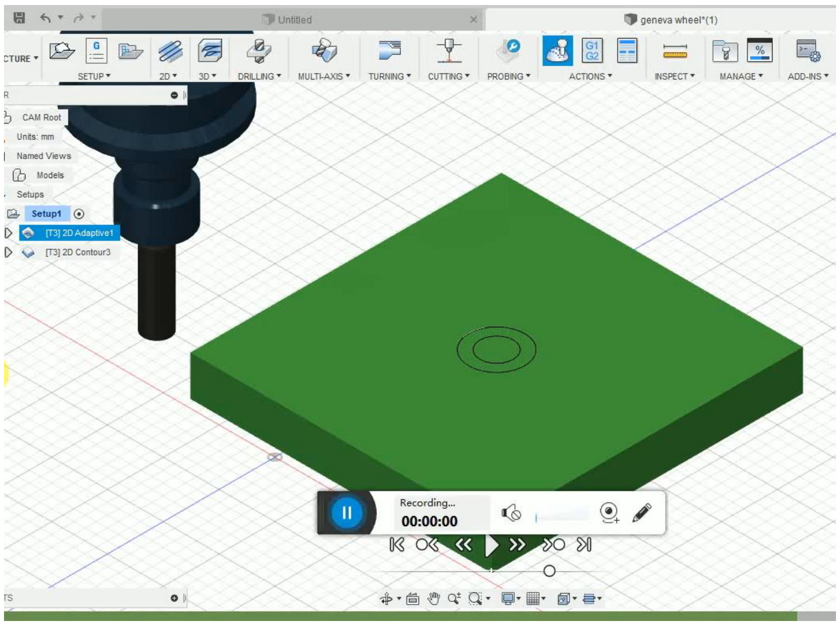


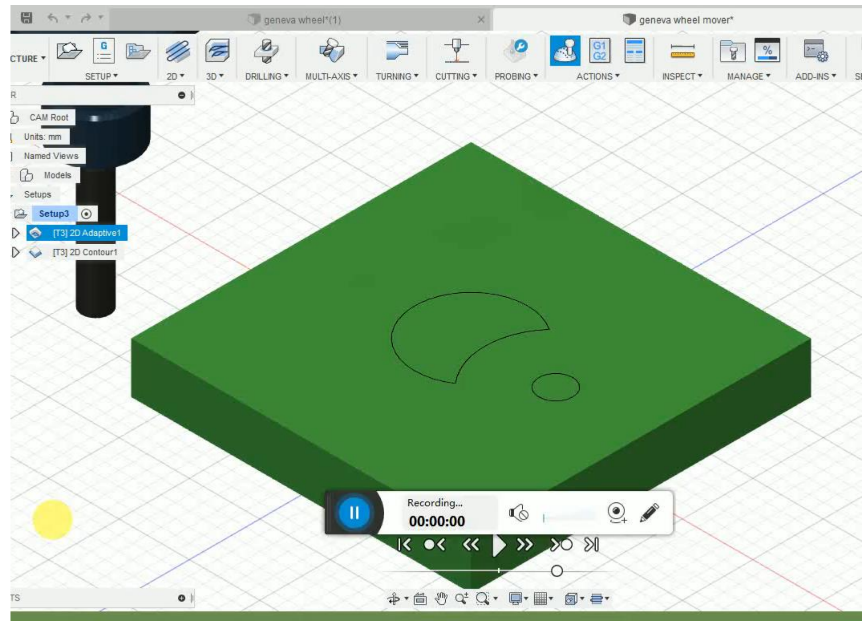
Geneva indexing mechanism



https://www.youtube.com/watch?v=dGxUl36IrB8

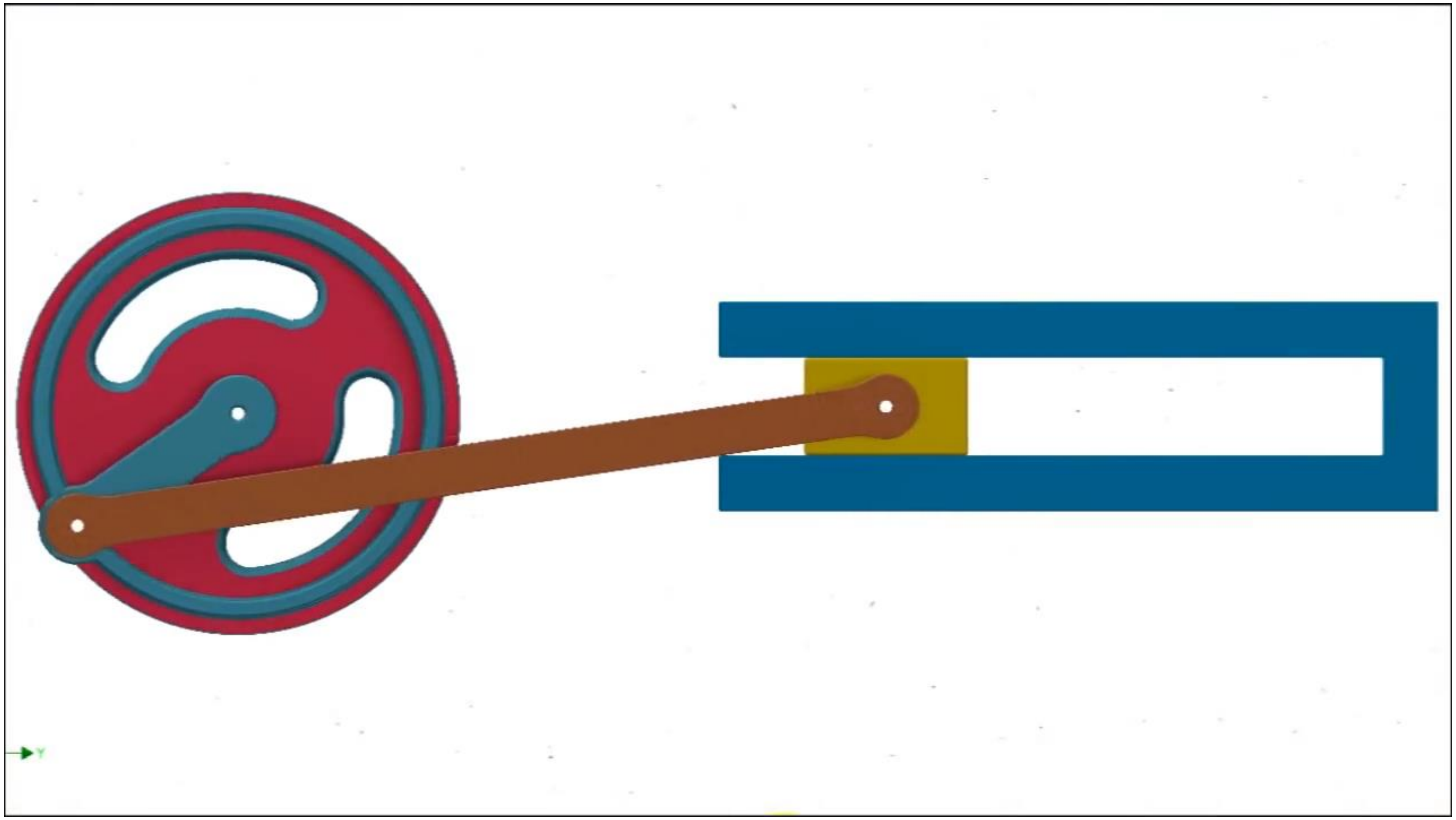
How are Geneva mechanisms made?





On CNC machines

One the most famous mechanisms



https://www.youtube.com/watch?v=ZO8QEG4x0wY

Exam question from 2019 - 2020 - I

Question 2 [1]

Say you have a motor, and you want to use the motor to drive a mechanism that results in translational motion. Sketch any two such mechanisms (other than what is already discussed in Question 4) that can translate rotary motion to linear motion. Please make neat sketches and label all parts for a full grade.

Structure of this lecture

- What is a mechanism?
  - Building blocks of mechanisms
- Mechanisms of interest to us
  - Cams
  - Belt-pulley, chain-sprocket
  - Gears
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  - Quick return
  - Indexing
- How different components of mechanisms are made