# ME 222: Kinematics of Machines and Mechanisms

[L8] MEMS, Compliant Linakge and Practical Consideration

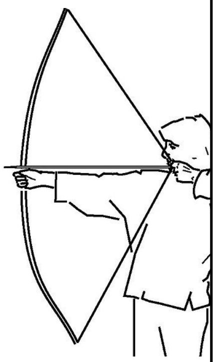


## Outline

- Compliant linkage
- Micro Electro-Mechanical Systems (MEMS)
- Some practical considerations

## Compliant Mechanisms

- Compliance is the opposite of stiffness.
- An ancient example: bow and arrow
- Provide similar motions with fewer parts joints.



In purest form a compliant mechanism has single link designed to provide areas of flexibility that serve as pseudo joints.

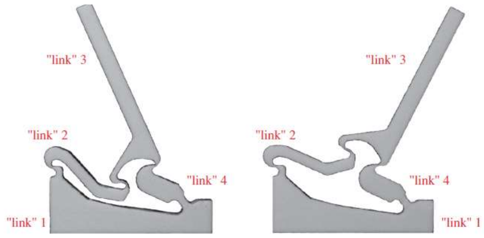


## Compliant Mechanisms

- A common example: plastic tackle box
- Two-link mechanism with a thin section connecting the two.
- Certain thermoplastics allow thin sections to be flexed repeatedly without failure for millions times

# Compliant Toggle Switch

- A fourbar linkage made in one piece of plastic.
- It moves between the on and off positions
- Flexure of the thin hinge sections serve as pseudo joints.

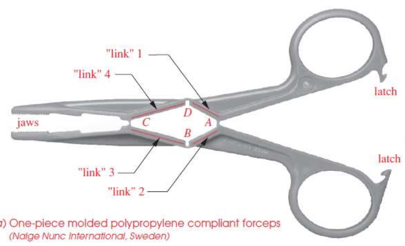



(a) Switch on (b) Switch off



# Compliant Forceps

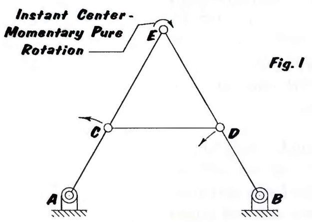
- Designed as a one-piece compliant mechanism.
- There is a fourbar linkage 1, 2, 3, 4 at the center
- Small cross sections designed to serve as pseudo joints.
- Built-in spring effect to hold it open in the rest state



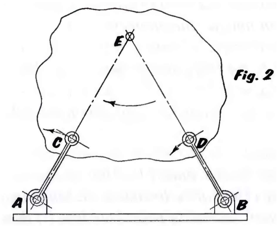

(a) One-piece molded polypropylene compliant forceps
(Nalge Nunc International, Sweden)

# Homework 1: Case Study

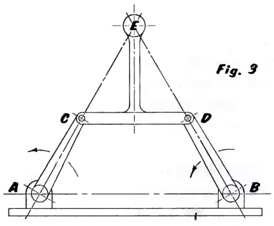
- Rotational adjustment for the oscillating mirror of an optical galvanometer.
- Development Stages




The Theory




The Development

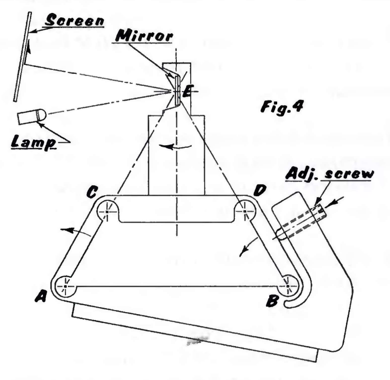



The Mechanism



# Homework 1: Case Study

- Final Design




The Final Product of Keivan Towfigh

## Compliant Mechanisms

Evolved in the late 20th century due the availability of new materials and modern manufacturing processes.

Advantages:
- Reduction of number of parts
- Elimination of joint clearances
- Inherent spring loading
- Reductions in cost, weight, wear, and maintenance

Disadvantages:
- Difficult to design and analyze
- Preclude the use of conventional small-deflection theory.



## Micro Electro-Mechanical Systems (MEMS)

- Advances in the manufacture of microcircuitry (chips) have led to a new form of mechanism known as

**Micro Electro-Mechanical Systems or MEMS**

- Have features measured in micrometers
- Made from the same silicon wafer material

# Microgears

Silicon microgears of only a few micrometers in diameter.

Manufacturing process

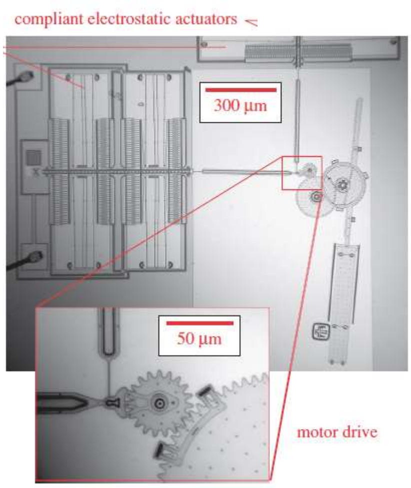
- Shape of the desired device is computer generated at large scale.
- Then photographically reduced and projected onto the silicon wafer.
- An etching process then removes the silicon material.
- What remains is a tiny reproduction of the original geometric pattern in silicon.

(a) Microgears



# Micromotor and gear train

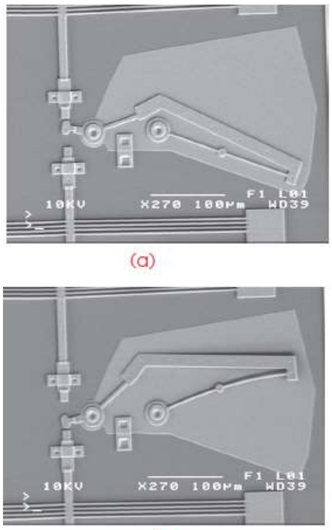
- Uses gears smaller than a few millimeters overall.
- Series of compliant linkages oscillated by an electrostatic field to drive the crank
- Provides continuous speeds of 360 000 rpm.




(b) Micromotor and gear train

# A compliant bistable mechanism

- It has two stable positions .
- Thermal actuators amplify thermal expansion to snap the device between its two positions.
- It can be used as a micro-switch or a micro-relay.
- Being so small, it can be actuated in a few hundred microseconds.



(a)
(b)



# Some more applications

Applications for these micro devices are just beginning to be found.

- MEMS Microsensors are currently used in automobile airbag to detect sudden deceleration and fire the airbag inflator.
- MEMS blood pressure monitors that can be placed in a blood vessel have been made.
- MEMS pressure sensors are being fitted to automobile tires to continuously monitor tire pressure.
- Many other applications are being and will be developed to utilize this technology in the future.

## Some practical considerations

- Pin Joints versus Sliders and Half Joints
- Cantilever or Straddle Mount?
- Short Links
- Bearing Ratio
- Commercial Slides
- Linkages versus Cams
- Selection of Motors and Drivers

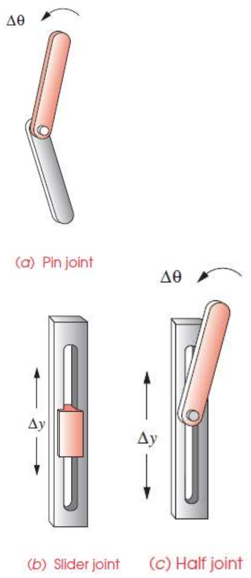


## Practical considerations

- Many factors need to be considered to create good-quality designs
- Not all of them are contained within the applicable theories
- A great deal of art based on experience is involved in design as well.

# Pin Joints versus Sliders and Half Joints

- At joint two materials rub together
- Such a rubbing interface is called a **bearing**.
- Proper material and good lubrication are the key to long life of joint.
- Choice of joint type affects ability to provide good clean lubrication

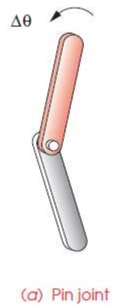


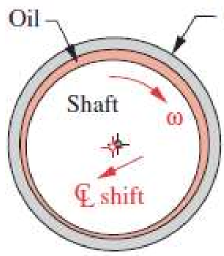



# Revolute (Pin) Joints

**Simple revolute joint is the clear winner for several reasons**

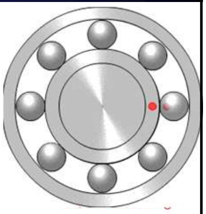
- Easy and inexpensive to design and to build a good quality pin joint
- In its pure form—also called **sleeve** or **journal** bearing
- Geometry of pin-in-hole traps a lubricant film within its interface
- Promotes a condition called *hydrodynamic lubrication* in which the parts are separated by a thin film of lubricant
- Replacement lubricant can be done through radial holes
- Seals can easily be provided at the ends of the hole

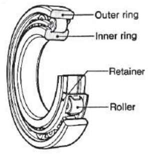


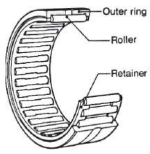
# Ball and roller bearing

- Available in large variety of sizes for revolute joints
- Relatively inexpensive
- Available pre-lubricated and with end seals.
- Good ability to trap lubricant within the roll cage
- Relatively high rolling speed of the balls or rollers
- Promotes long life






(b) Roller bearing




(c) Needle bearing



# Spherical Rod End Bearings

- This has a spherical, sleeve-type bearing
- *Self-aligns* to an out of parallel shaft
- Its body threads onto the link, allowing links to be made from round stock with threaded ends
- Allow adjustment of link length.

# Revolute joints pivoted to ground

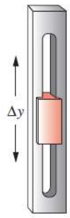
- **Pillow blocks** and **flange-mount bearings**
- Fitted with rolling or sleeve-type journal bearings.
- **Pillow block**: mounting to a surface parallel to the pin axis
- **Flange mount**: fasten to surfaces perpendicular to the pin axis.

(a) Pillow-block bearing

(b) Flange-mount bearing



# Prismatic (Slider) Joints

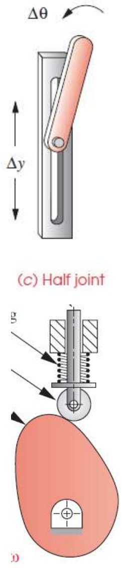



(b) Slider joint

- Require a carefully machined and straight slot or rod
- Bearings often must be custom made
- Lubrication is difficult to maintain as not geometrically captured
- Lubrication is resupplied either by running the joint in an oil bath by periodic manual regreasing.
- An open slot tends to accumulate airborne dirt
- This can act as a grinding compound when trapped in the lubricant and accelerate wear.

# Higher (Half) Joints

- Suffer even more acutely from the slider's lubrication problems
- Two oppositely curved surfaces in line contact, tend to squeeze any lubricant out of the joint.
- Joint needs to be run in an oil bath for long life.
- Requires housing the assembly in an expensive oil-tight box with seals



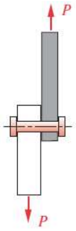



# An example

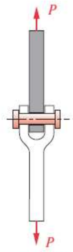
- These joints are used extensively in machinery with great success.
- Some common examples can be found in an automobile.
  - The windshield wiper mechanism is a pin-jointed linkage.
  - The pistons in the engine cylinders sliders and bathed in oil.
  - The valves are operated by cam-follower and drowned in oil.
- You probably change your engine oil fairly frequently.
- When was the last time you lubricated your windshield wiper?
- Has this linkage (not the motor) ever failed?

# Cantilever or Straddle Mount?

- A cantilevered joint has the pin (journal) supported only.
- It is necessary when a crank must pass over the coupler.
- Cantilever beam is weaker than a straddle-mounted beam.
- Straddle mounting can avoid applying a bending moment to the links by keeping the forces in the same plane.
- Straddle-mounted pin is in double shear a cantilevered pin is in single shear.
- **It is good practice to use straddle-mounted joints wherever possible.**



(a) Cantilever mount —single shear

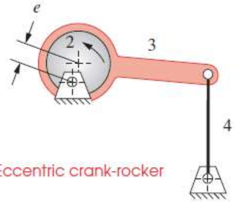


(b) Straddle mount —double shear

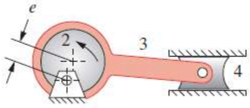


# Short Links

- If crank is short it is not possible to provide suitably sized pins or bearings at each of its pivots.
- The solution is to design the link as an **eccentric crank**
- The fixed pivot is placed a distance *e* from the center of this circle equal to the required crank length.
- Lubricating large-diameter journal can be difficult.



(a) Eccentric crank-rocker



(b) Eccentric slider-crank

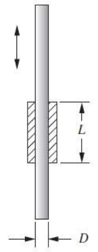
# Bearing ratio

- Need for straight-line motion requires extensive use of linear sliding joints.
- There is a very basic geometrical relationship called ***bearing ratio***, which if ignored leads to several problems.
- The **bearing ratio** (*BR*) is defined as *the effective length of the slider over the effective diameter of the bearing*:

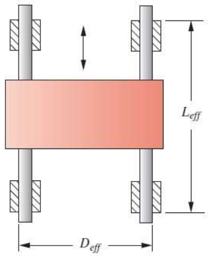
$$BR = L / D.$$



- **Effective length is** *the distance over which the moving slider contacts the stationary guide*
- **Effective diameter** is *the largest distance across the stationary guides* in a plane perpendicular to motion
- A common example of a device with a poor bearing ratio is a drawer in an inexpensive piece of furniture
- You have probably experienced the sticking and jamming that occurs with such a drawer
- For smooth operation this ratio should be **greater than 1.5**, and **never less than 1**




(a) Single rod in bushing




(b) Platform on two rods

# Thank you

Next Class: Dimensional Synthesis