Mechatronics System Design

EC4.404 - S2023

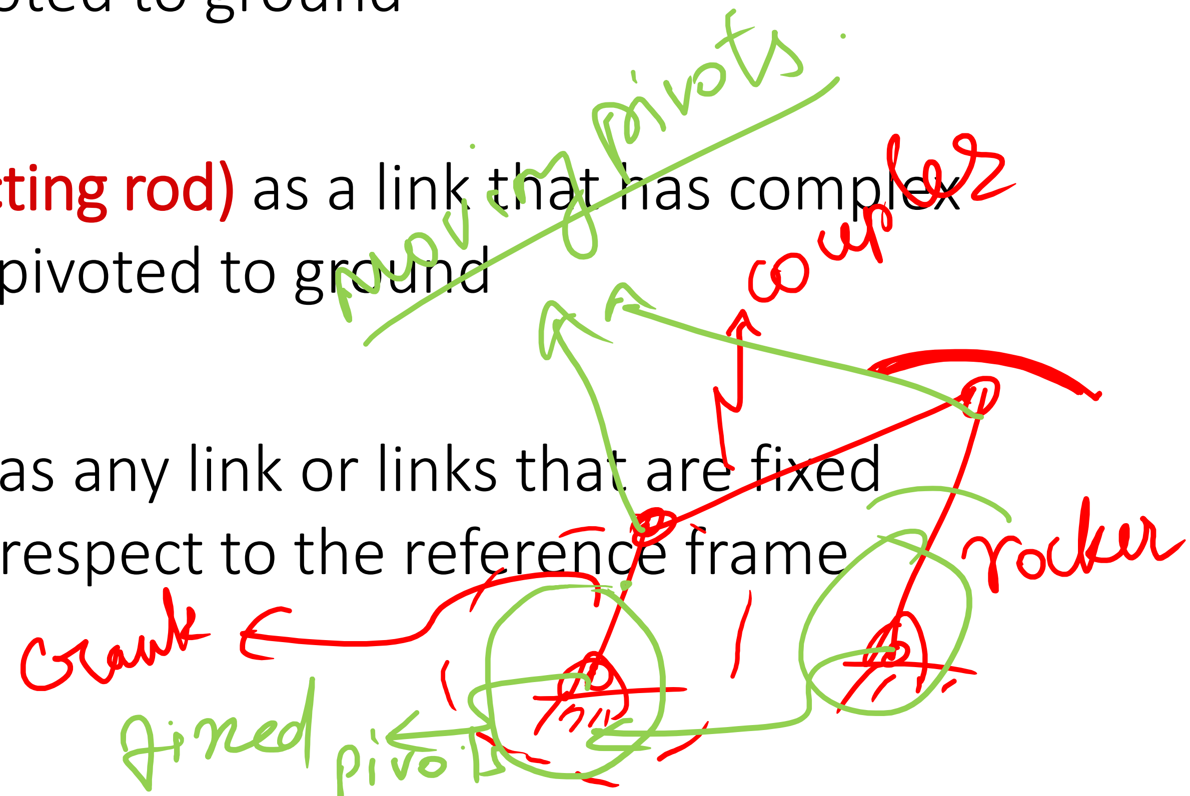
Lecture 10

Nagamanikandan Govindan

Robotics Research Center, IIIT Hyderabad.
nagamanikandan.g@iiit.ac.in

Fourbar Mechanism

- **crank** as a link that makes a complete revolution and is pivoted to ground
- **rocker** as a link that has oscillatory (back and forth) rotation and is pivoted to ground
- **coupler (or connecting rod)** as a link that has complex motion and is not pivoted to ground
- **Ground** is defined as any link or links that are fixed (nonmoving) with respect to the reference frame

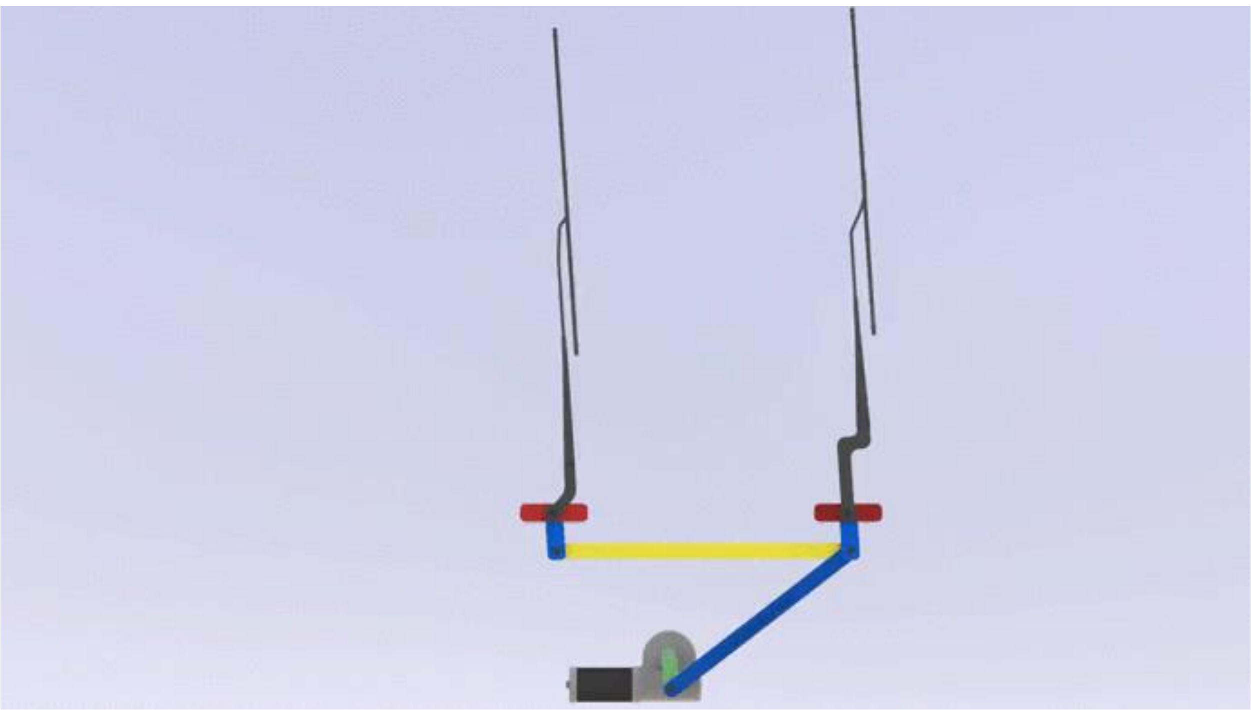


Grubler DoF

Grashof =

Complete Rotatability of a link

- In many applications, the mechanisms are driven by rotary motor. Therefore, one of the links must rotate continuously in order to connect it with the motor.



Fourbar Mechanism

Simplest possible pin-jointed mechanism for single-degree-of-freedom controlled motion

Grashof condition:

Predicts the rotation behavior or rotatability of a fourbar linkage's inversions based only on the link lengths.

At least one of link (Shortest) is capable of making a full revolution

$$\text{If } \boldsymbol{S} + \boldsymbol{L} \leq \boldsymbol{P} + \boldsymbol{Q}$$

S = length of the shortest link

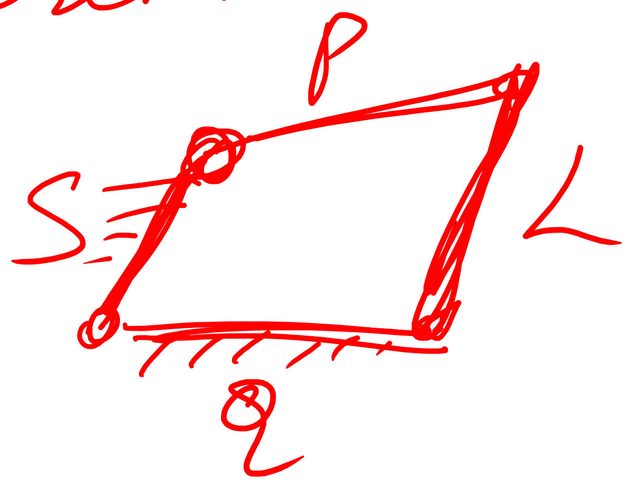
L = length of the longest link

P and Q = lengths of other two links

Inversion :-

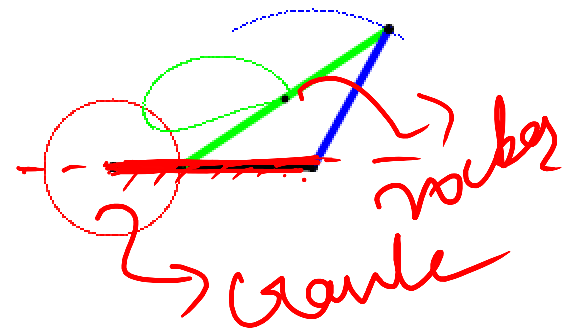
If you join different links

$\Rightarrow$ different motions characteristics



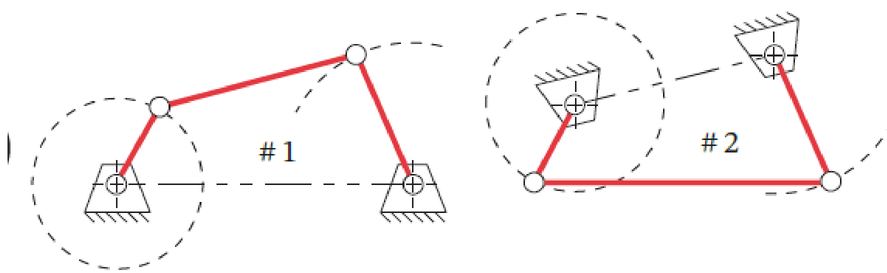
- For Class I case: $S + L < P + Q$: is called **Grashof chain**

1. Ground either link adjacent to the shortest to get crank-rocker.
    - Rocker cannot cross the line of frame



Concept of Assembly mode

Given the link lengths, the rocker rocks above or below the line of frame.

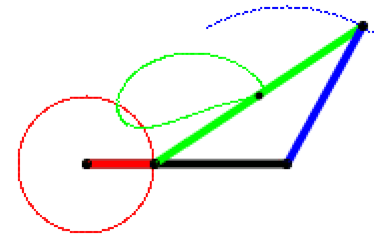


(*a*) Two nondistinct crank-rocker inversions (GCRR)

Cannot move from one assembly mode to another.

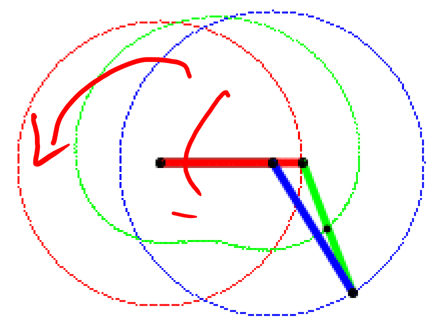
Grashof chain

- For Class I case: $\boldsymbol{S} + \boldsymbol{L} < \boldsymbol{P} + \boldsymbol{Q}$: is called **Grashof chain**

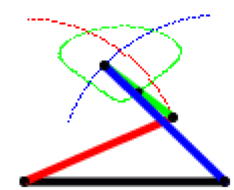


1. Ground either link adjacent to the shortest to get **crank-rocker.**

   -Rocker cannot cross the line of frame

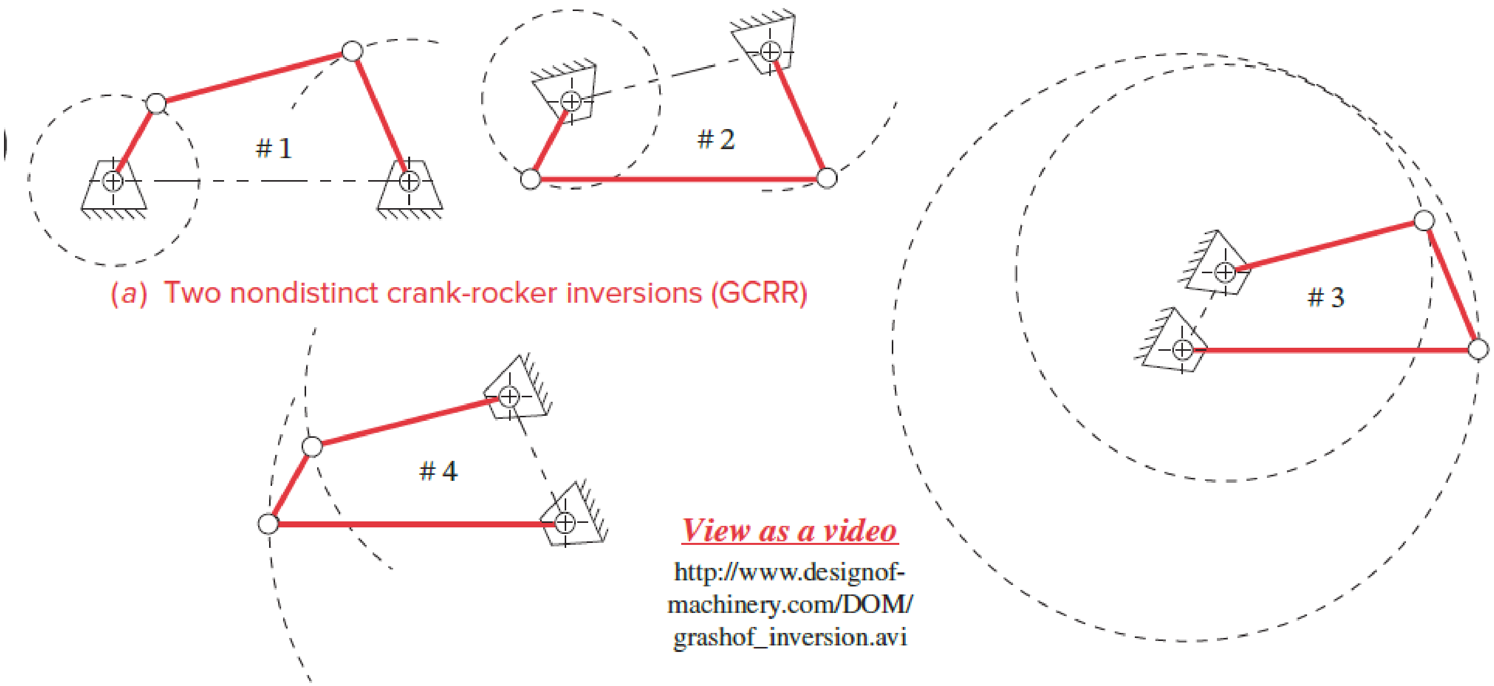


2. Ground the shortest link to get a double-crank. **All links rotate completely.**



3. Ground the link opposite the shortest and you will get a Grashof double-rocker

All inversions of the Grashof fourbar linkage



(a) Two nondistinct crank-rocker inversions (GCRR)

(c) Double-rocker inversion (GRCR)
(coupler rotates)

(b) Double-crank inversion (GCCC)
(drag link mechanism)

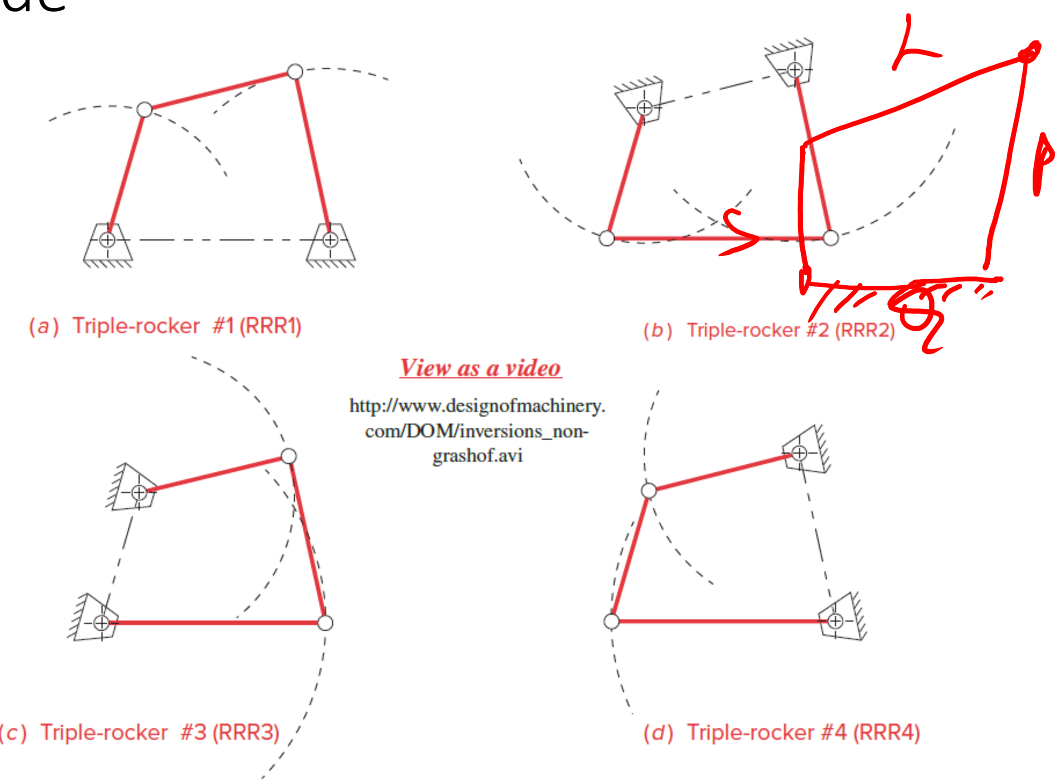
View as a video

http://www.designof-machinery.com/DOM/grashof_inversion.avi

Non-Grashof chain

- **For Class II case: $S + L > P + Q$** : is called **non-Grashof chain**

1. All inversions will be triple-rockers in which no link can fully rotate.
2. Rockers cross the line of reference; therefore, only one assembly mode



(a) Triple-rocker #1 (RRR1)

(b) Triple-rocker #2 (RRR2)

(c) Triple-rocker #3 (RRR3)

(d) Triple-rocker #4 (RRR4)

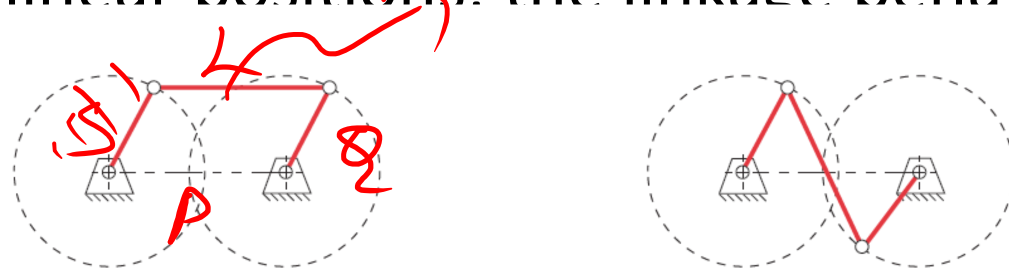
View as a video

http://www.designofmachinery.com/DOM/inversions_non-grashof.avi

All inversions of the non-Grashof fourbar linkage are triple rockers

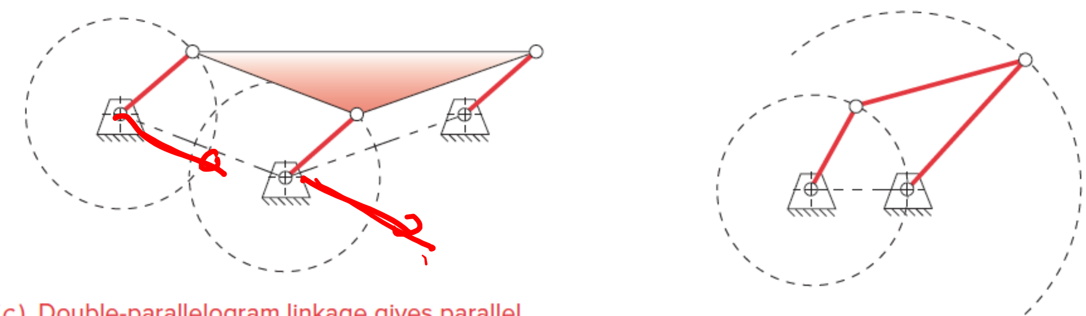
Special-Grashof chain

- For Class III case: $S + L = P + Q$: is called **Special Grashof chain**
- all inversions will be either double-cranks or crank-rockers
- At these colinear positions, the linkage behavior is unpredi configu



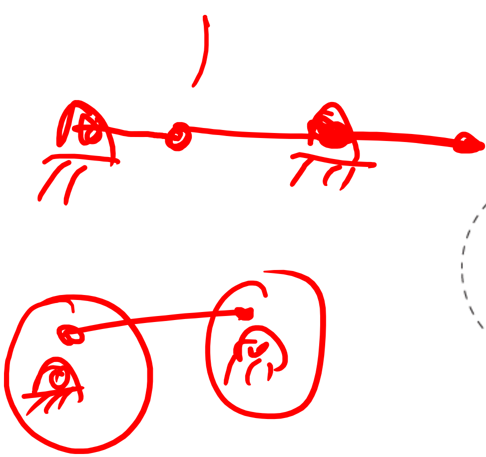
(a) Parallelogram form

(b) Antiparallelogram form



(c) Double-parallelogram linkage gives parallel motion (pure curvilinear translation) to coupler and also carries through the change points

(d) Deltoid or kite form



Some forms of the special-case Grashof linkage

Check the Grashof Condition

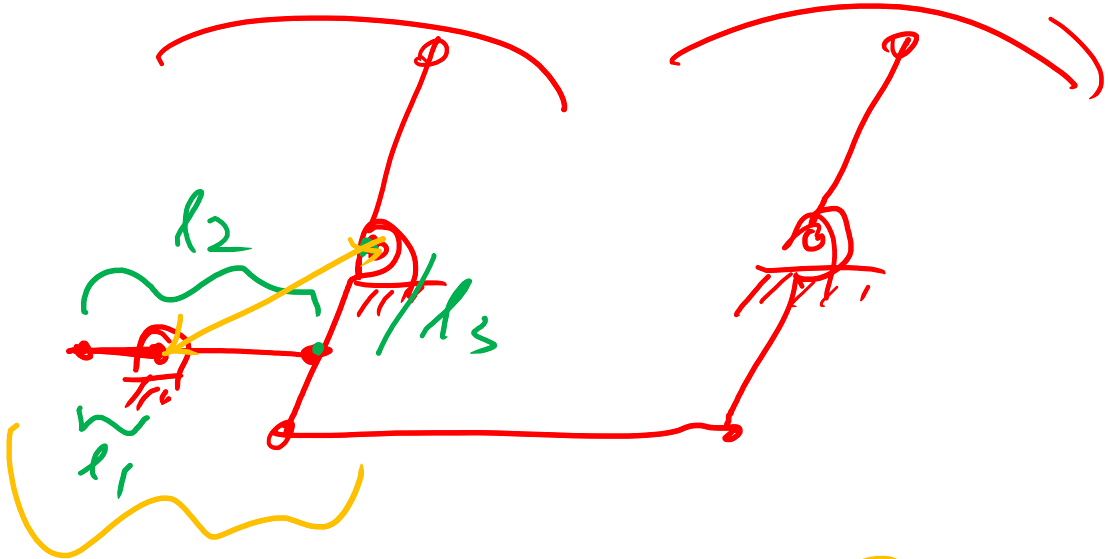
- A Fourbar Chain with the following Link Proportions: 30mm, 70mm, 90mm, and 120mm.

S = 30 mm, L = 120 mm, P = 70 mm, and, Q = 90 mm

S+L = 150 < P+Q = 160 thus the Linkage is a Grashof Four bar:

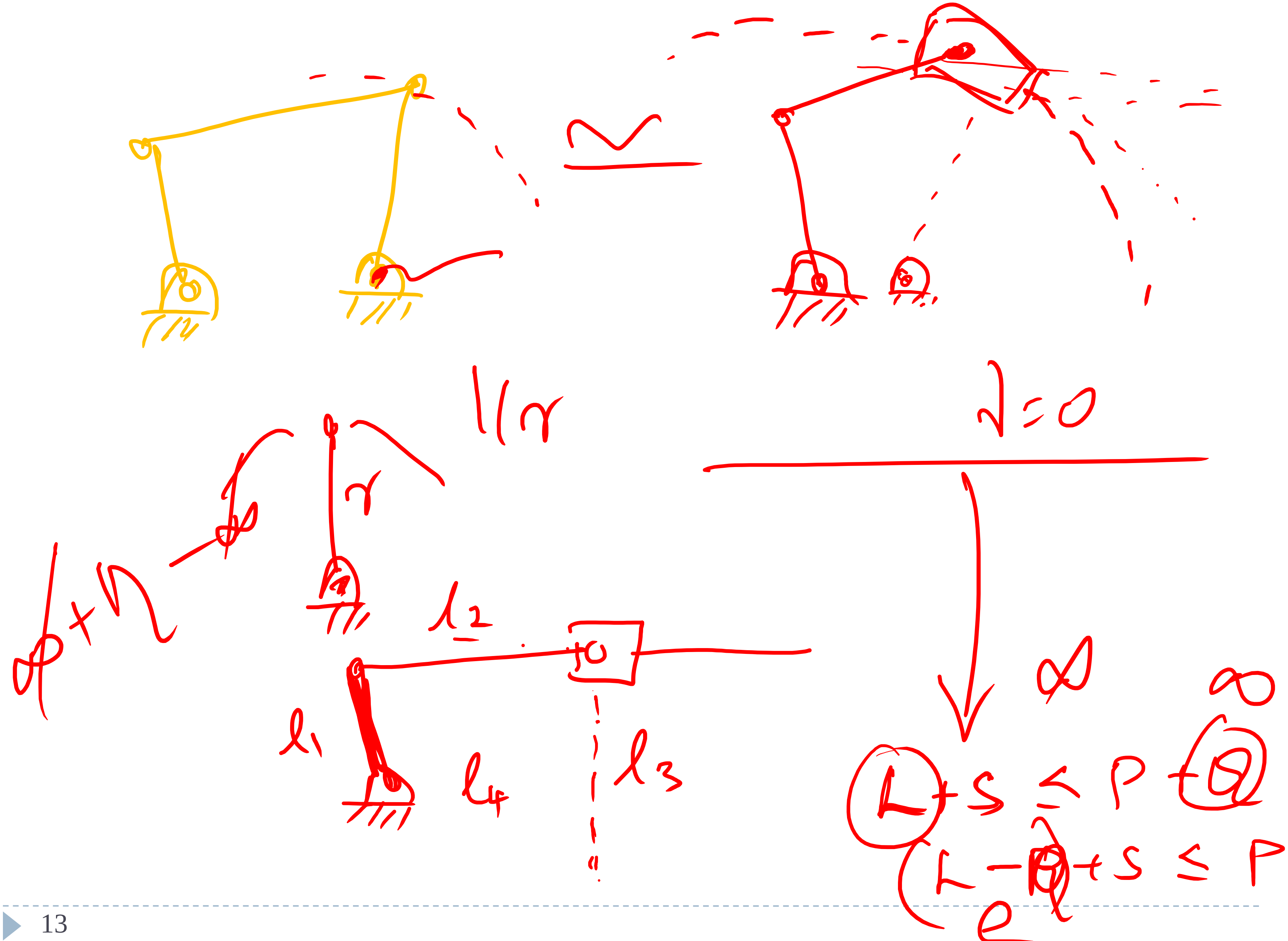
1. If ground is the shortest → crank-crank-crank
2. If the input is the shortest → crank-rocker-rocker
3. If the coupler is the shortest → rocker-crank-rocker
4. Output is the shortest → rocker-rocker-crank

How to design a double wind-shield wiper mechanism

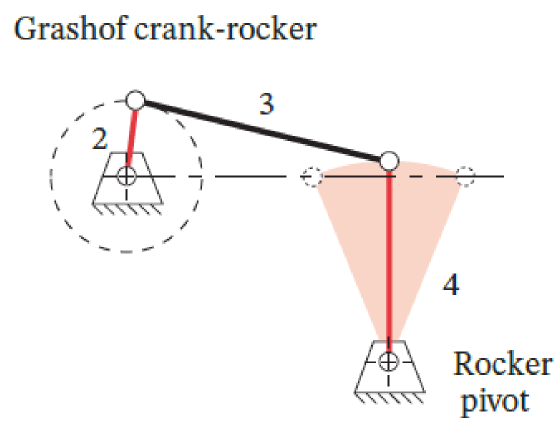


$L+S < P+Q$

Extending Grashof criterion for 3R-1P.



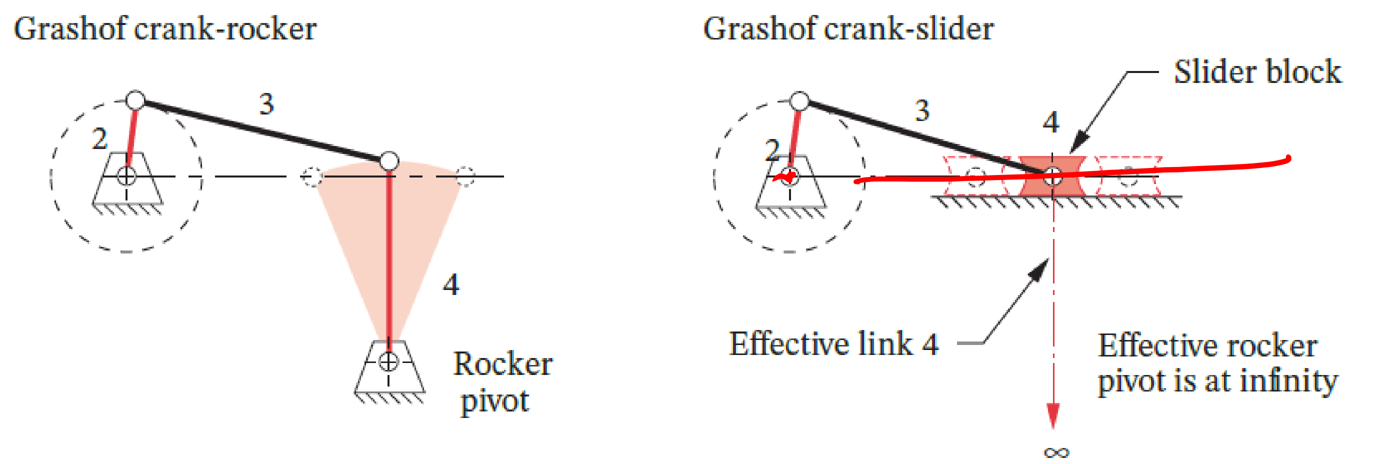
Extending Grashof criterion for Crank-Slider.



(*a*) Transforming a fourbar crank-rocker to a crank-slider

Transformation from a rocking output link to a slider output link is equivalent to increasing the length (radius) of rocker link 4 until its arc motion at the joint between links 3 and 4 becomes a straight line. Thus the slider block is equivalent to an infinitely long rocker link 4, which is pivoted at infinity along a line perpendicular to the slider axis

Extending Grashof criterion for Crank-Slider (RRRP).



(*a*) Transforming a fourbar crank-rocker to a crank-slider

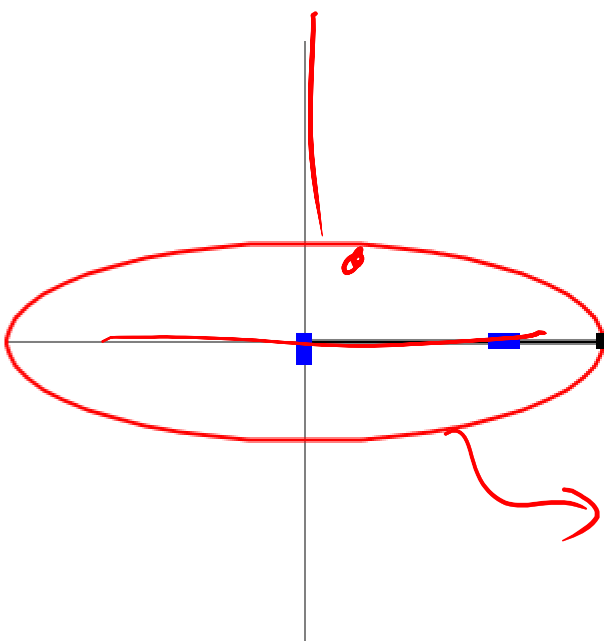
$$\boldsymbol{S + L \leq P + Q}$$

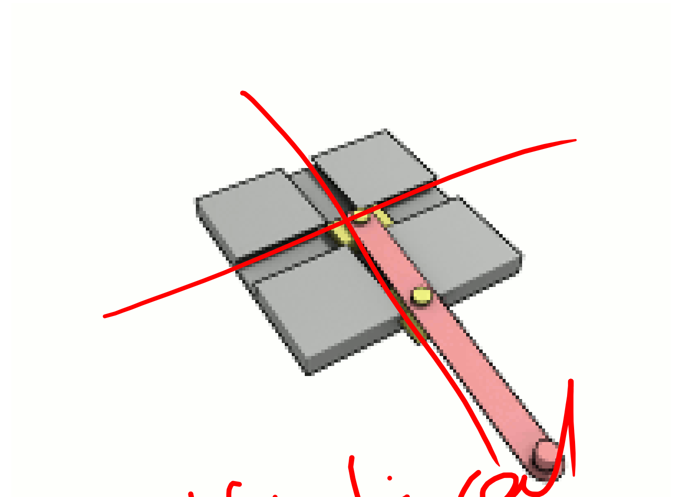
$$\boldsymbol{S + L \leq P + Q}$$

$$\boxed{\boldsymbol{S + e \leq P}}$$

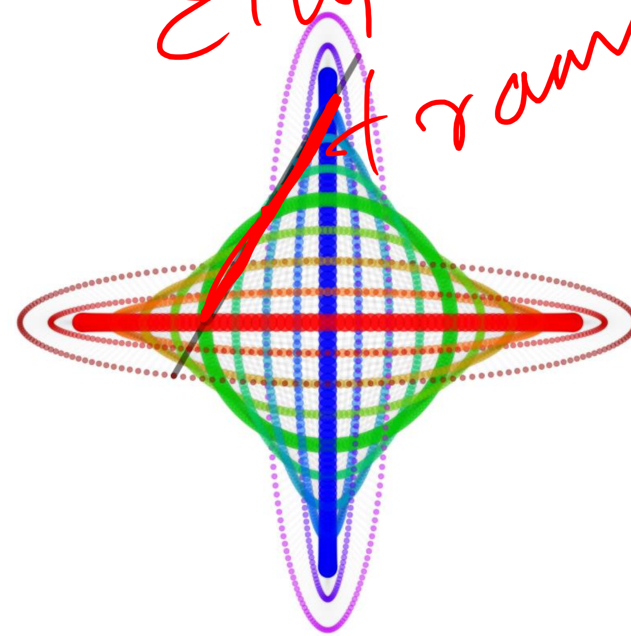
Two link lengths become infinity

Extending Grashof criterion for RRPP.



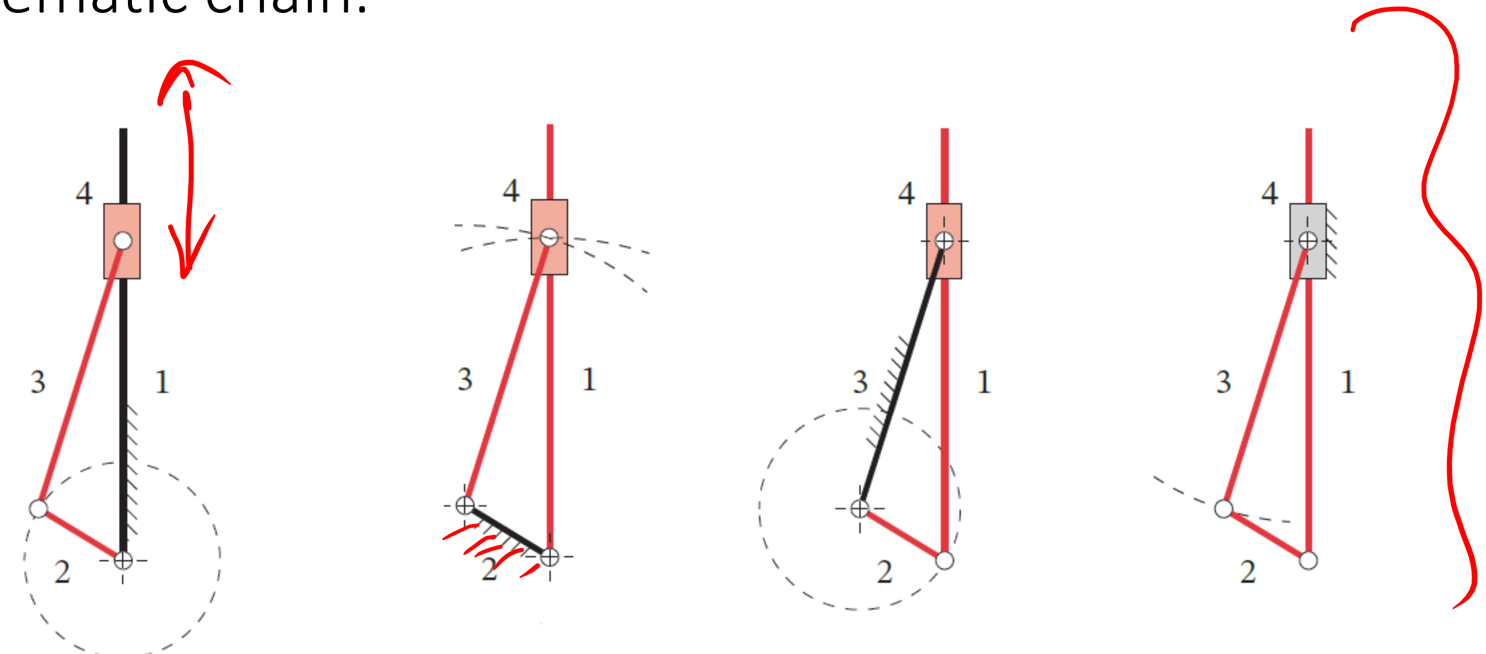


Elliptical trammel



Inversions: Crank – Slider

- An inversion is created by grounding a different link in the kinematic chain.



http://www.designofmachinery.com/DOM/slider_inversion.avi

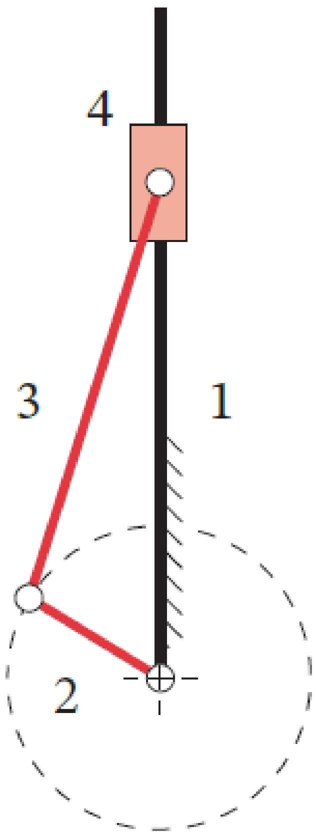
(*a*) Inversion #1 slider block translates

(*b*) Inversion #2 slider block has complex motion

(*c*) Inversion #3 slider block rotates

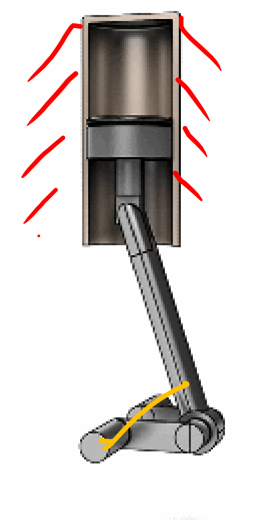
(*d*) Inversion #4 slider block is stationary

Inversion 1

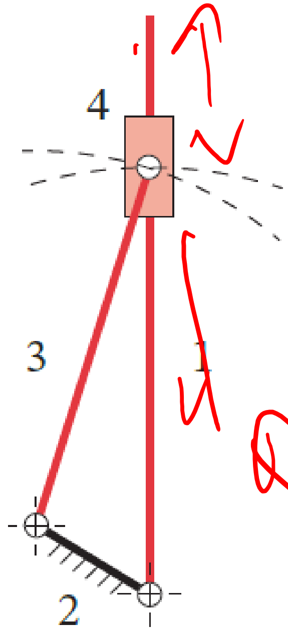


(a) Inversion #1 slider block translates

with link 1 as ground and its slider block in pure translation, is the most commonly seen and is used for **piston engines** and **piston pumps**.

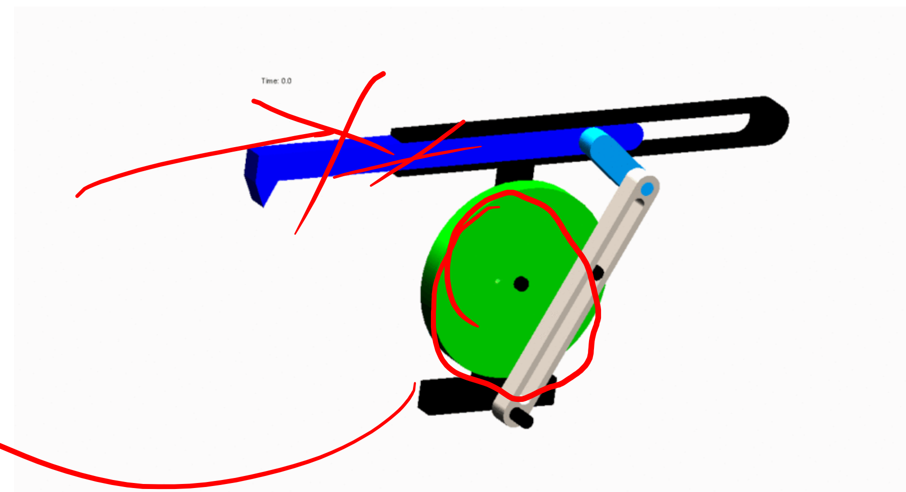


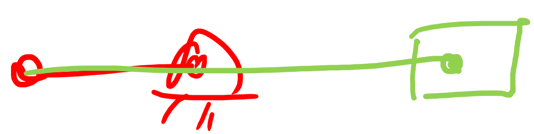
Inversion 2



(b) Inversion #2
slider block has
complex motion

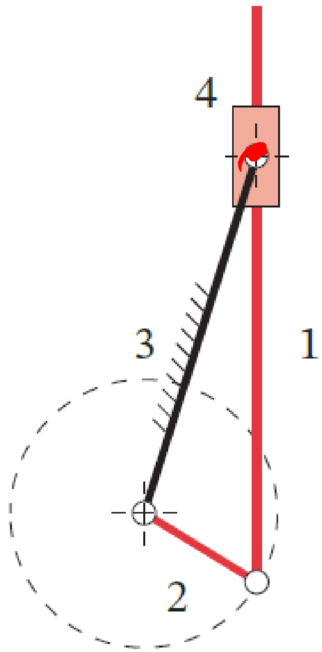
grounding link 2 and gives the **Whitworth** or **crank-shaper** quick-return mechanism, in which the slider block has complex motion.



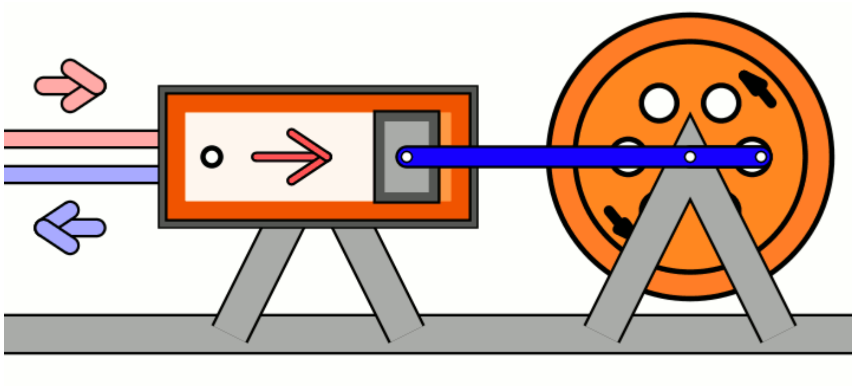


Inversion 3

Inversion #3 is obtained by grounding link 3 and gives the slider block pure rotation.

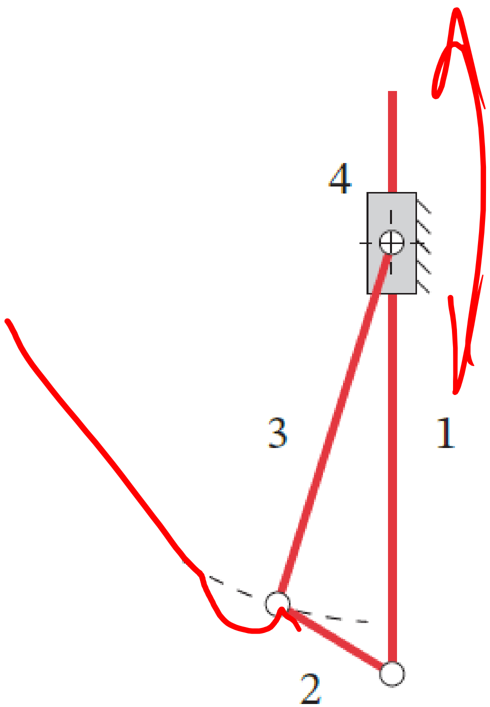


(c) Inversion #3 slider block rotates



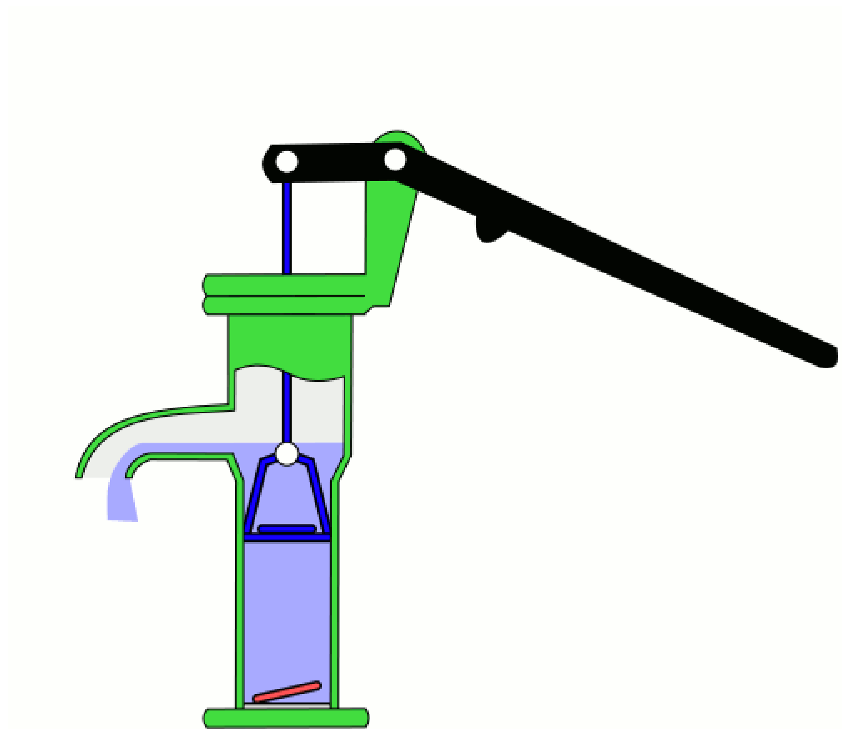
Oscillating cylinder steam engine

Inversion 4



(d) Inversion #4
slider block
is stationary

Inversion #4 is obtained by grounding the slider link 4 and is used in hand-operated, **well pump** mechanisms

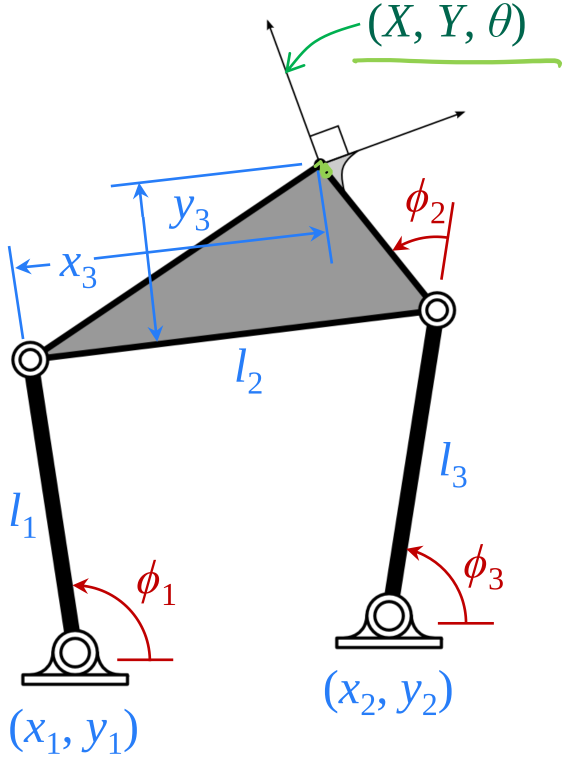


Problems in Kinematics

Dimensions

Joint Parameters

End Effector Coordinates

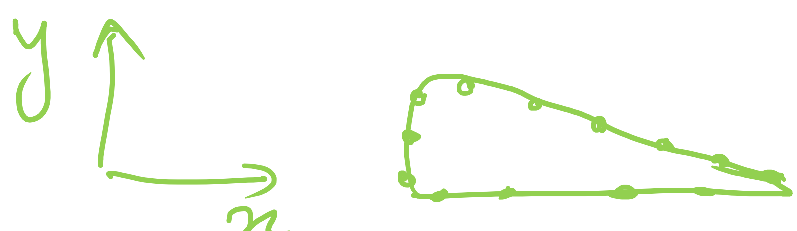


Analysis

Forward Kinematics
Known: Dimensions, Joint Parameters
Solve for: End Effector Coordinates

Inverse Kinematics
Known: Dimensions, End Effector Coordinates
Solve for: Joint Parameters

Synthesis
Known: End Effector Coordinates
Solve for: Dimensions, Joint Parameters



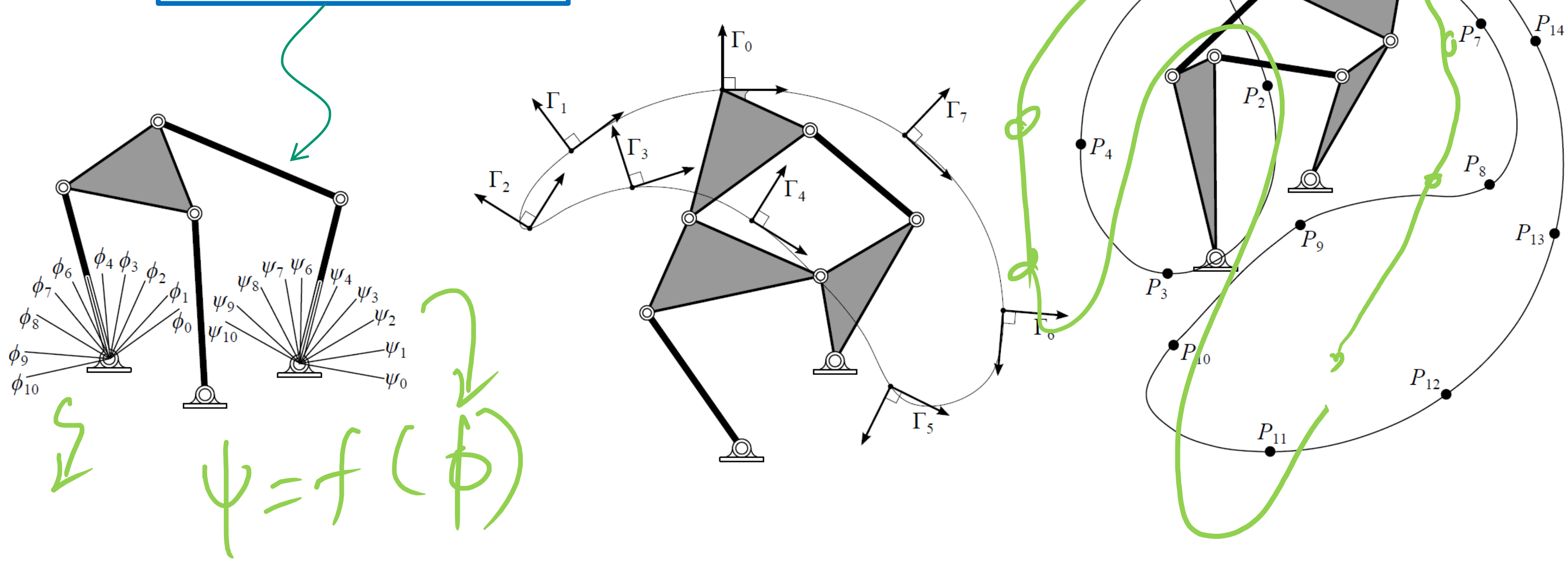
Types of Synthesis Problems

a) Function generation: set of input angles and output angles;

b) Motion generation: set of positions and orientations of a workpiece;

c) Path generation: set of points along a trajectory in the workpiece.

Gives control of mechanical advantage



Above are examples of function, motion, and path generation for planar six-bar linkages. Analogous problems exist for spherical and spatial linkages of all bars.

Desired Tasks for Synthesis - **Function generation**

- To design a linkage to correlate the input and the output motion $y = f(x)$ for the range $x_0 \le x \le x_{n+1}$

- The values of the independent parameter $x_0, x_1, \dots x_n$ correspond to prescribed precision points $P_1, P_2, \dots P_n$ on the function $y = f(x)$ in a range of x between x_0 *and* x_{n+1}

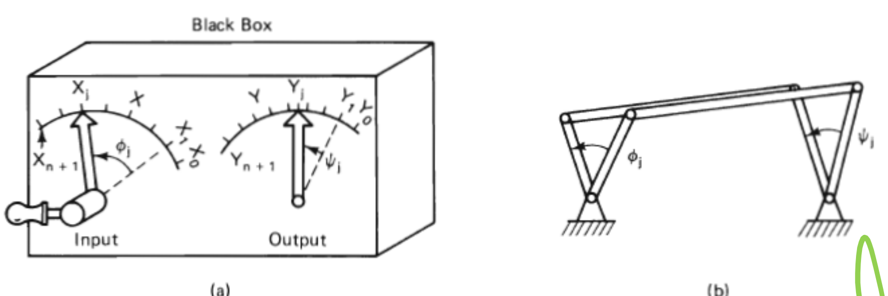


Figure Function-generator mechanism; (a) exterior view; (b) schematic of the mechanism inside.

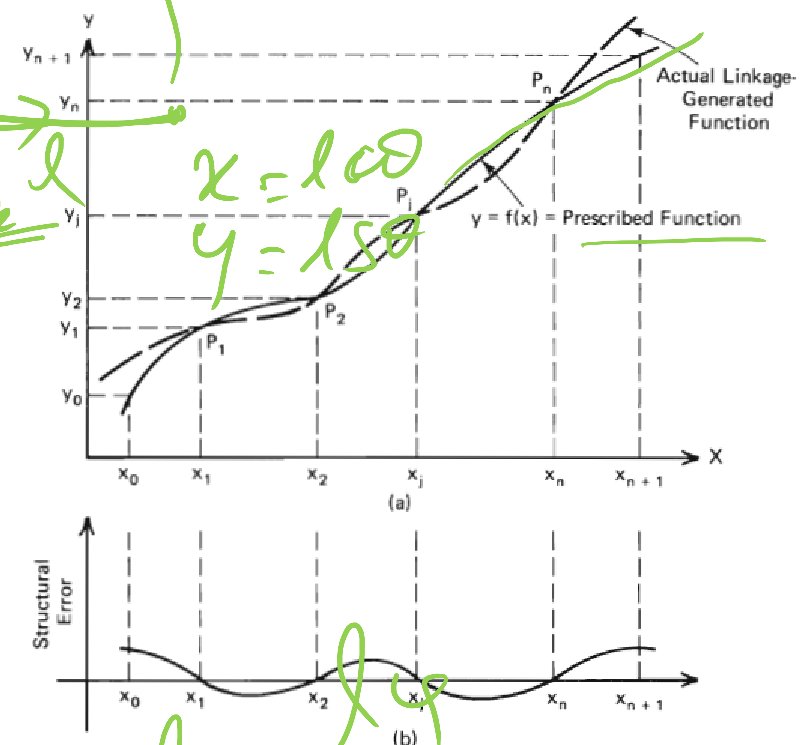


Figure 2.4 Function-generation synthesis; (a) ideal function and generated function (b) structural error.

l_1, l_2, l_3, l_4

- Structural error:
  - Difference between the generated function and the prescribed function
  - the precision points must be spaced over the range of the function in such a way as to minimize the structural error.

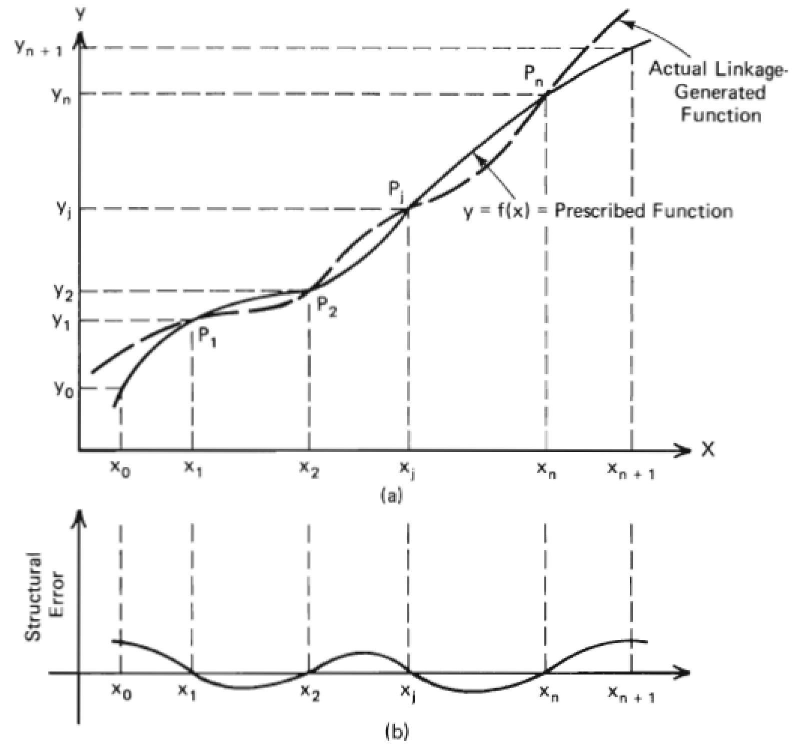


Figure 2.4 Function-generation synthesis; (a) ideal function and generated function (b) structural error.

Desired Tasks for Synthesis - **Function generation**

- Fourbar is not capable of error-free generation of an arbitrary function. It can match only at a limited number of precision points.

- **The no. of precision points for fourbar is generally 2 to 5 if closed-form methods are utilised.** Freudenstein and Sandor produced closed form solutions for up to 4 precision points

- **Up to 7 precision points are possible but require numerical methods.**

Desired Tasks for Synthesis - **Path Generation**

- A point on a floating link is to trace a path defined with respect to the fixed frame. The path points are generally related to input link position or time.

- A fourbar designed to pitch a ball. In this case, the trajectory of point P would ensure to pick up a ball and deliver the ball along the prescribed path.

- Examples: Thread guiding eye on a sewing mechanism

Desired Tasks for Synthesis - **Path Generation**

Thread guiding eye on a sewing mechanism

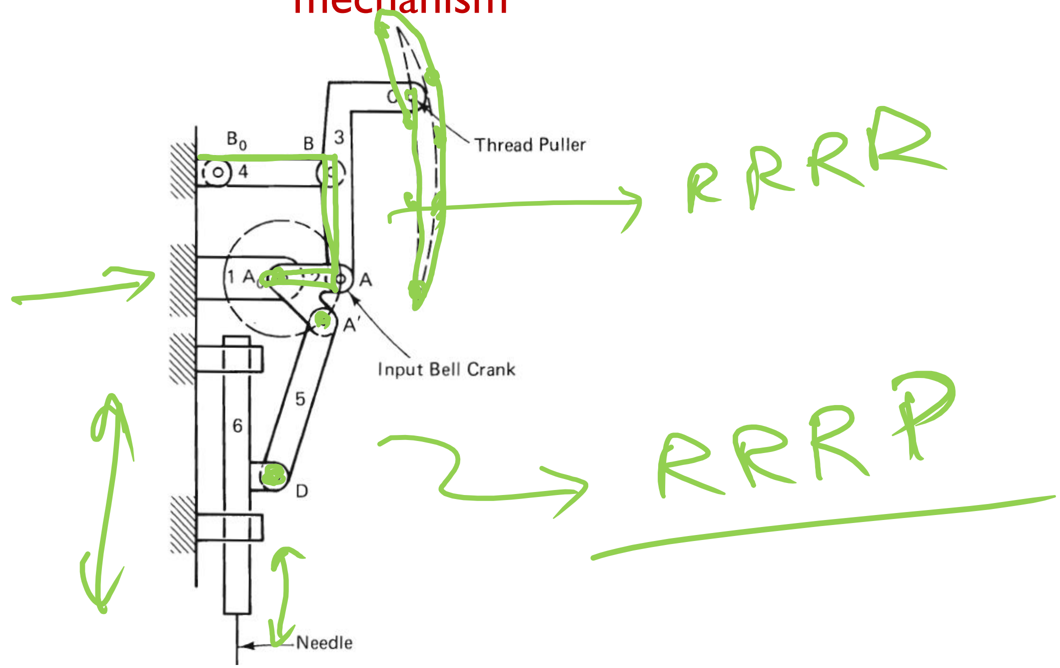
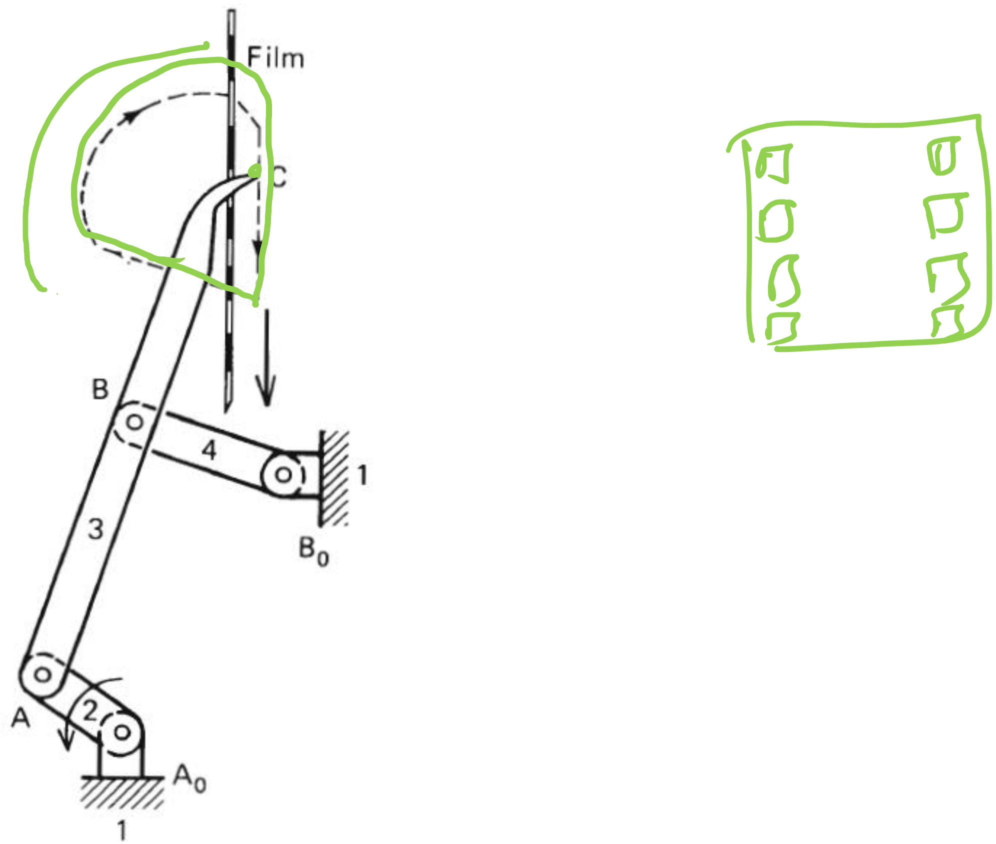


Figure 2.13 In a sewing machine, one input (bell crank 2) drives a path generator (four-bar mechanism 1,2,3,4) and a function generator slidercrank (1,2,5,6). The first generates the path of thread-guide C and the second generates the straight-line motion of the needle, whose position is a function of crank rotation.

Desired Tasks for Synthesis - **Path Generation**

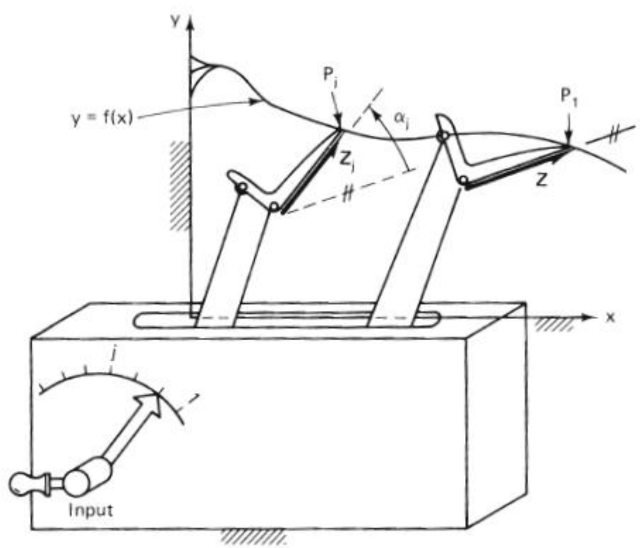


Film advance mechanism of a movie camera.

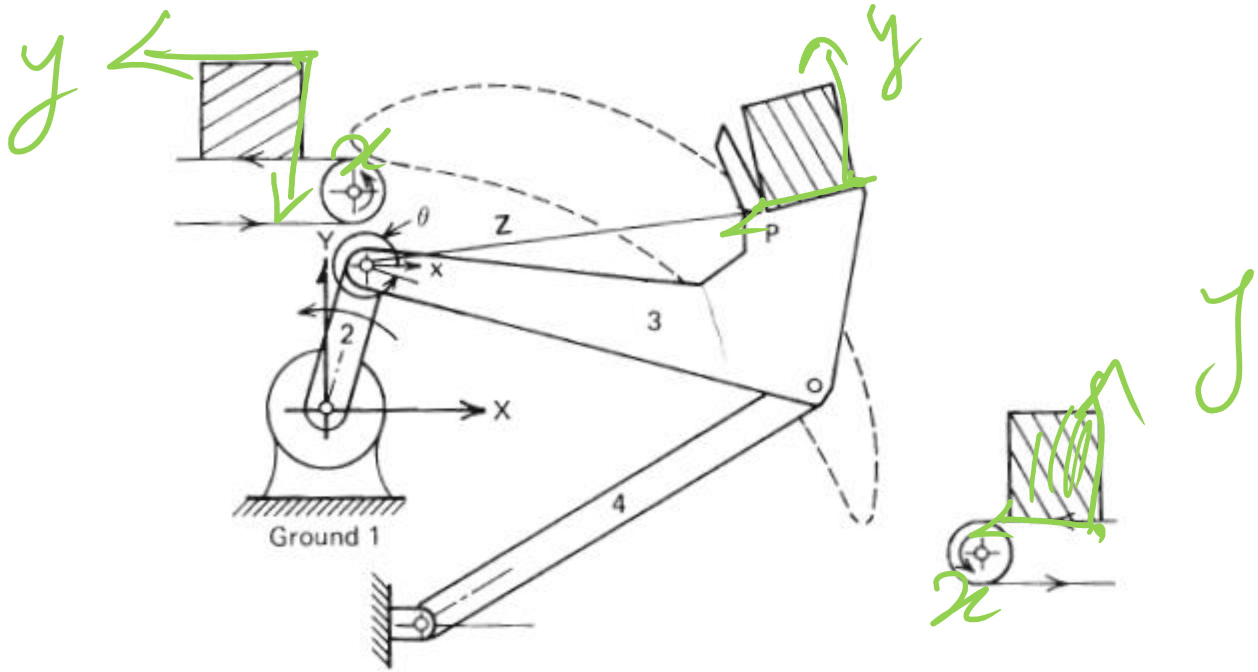
Motion Generation

The entire rigid body to be guided through a prescribed motion sequence.

Not only the path is prescribed, but also the rotation α_j of a vector $\boldsymbol{Z}$ embedded in a moving body.



Desired Tasks for Synthesis - **Motion Generation**



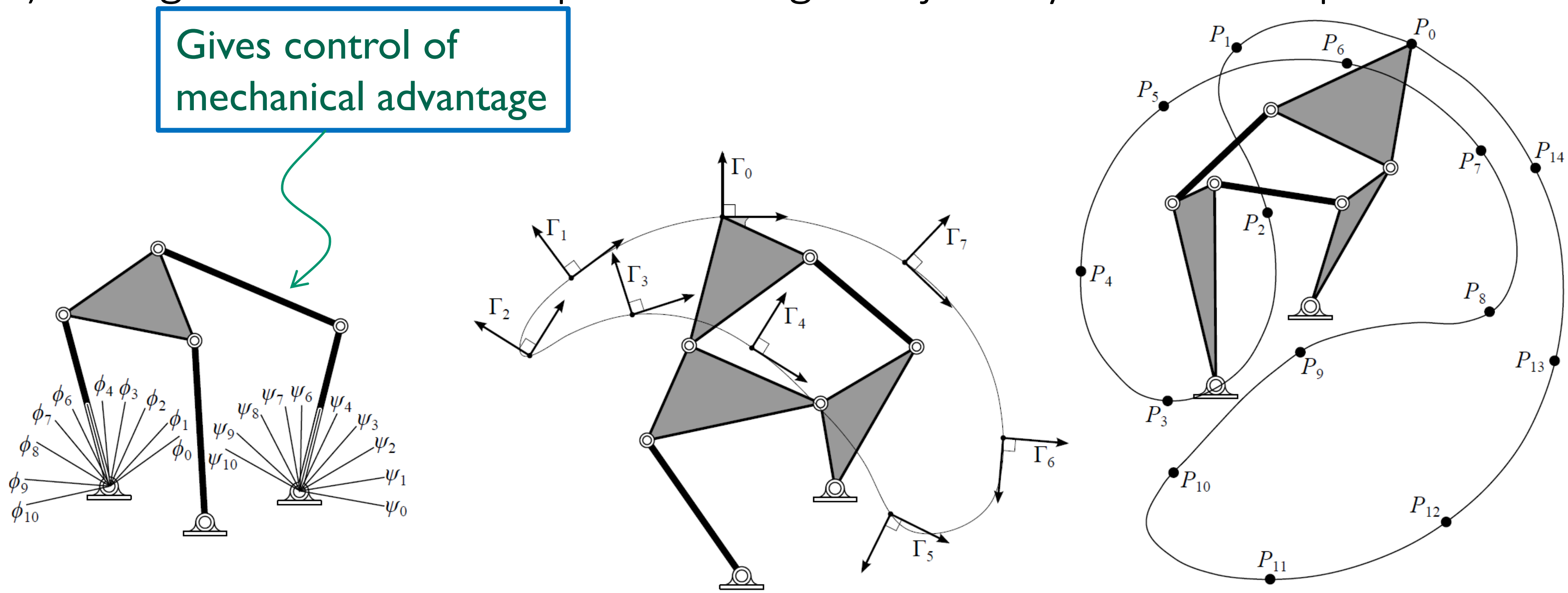
Carrier mechanism in an assembly machine: including lifting and dumping

Types of Synthesis Problems

a) Function generation: set of input angles and output angles;

b) Motion generation: set of positions and orientations of a workpiece;

c) Path generation: set of points along a trajectory in the workpiece.



Above are examples of function, motion, and path generation for planar six-bar linkages. Analogous problems exist for spherical and spatial linkages of all bars.

Dimensional Synthesis

- Geometric
  - Have limitations of accuracy
  - Not suitable for computer simulation
  - Parameters are not easily manipulated to create new solutions
- Analytical
  - Graphical techniques are essential at the initial phases of kinematic synthesis.
  - Suitable for computer simulation