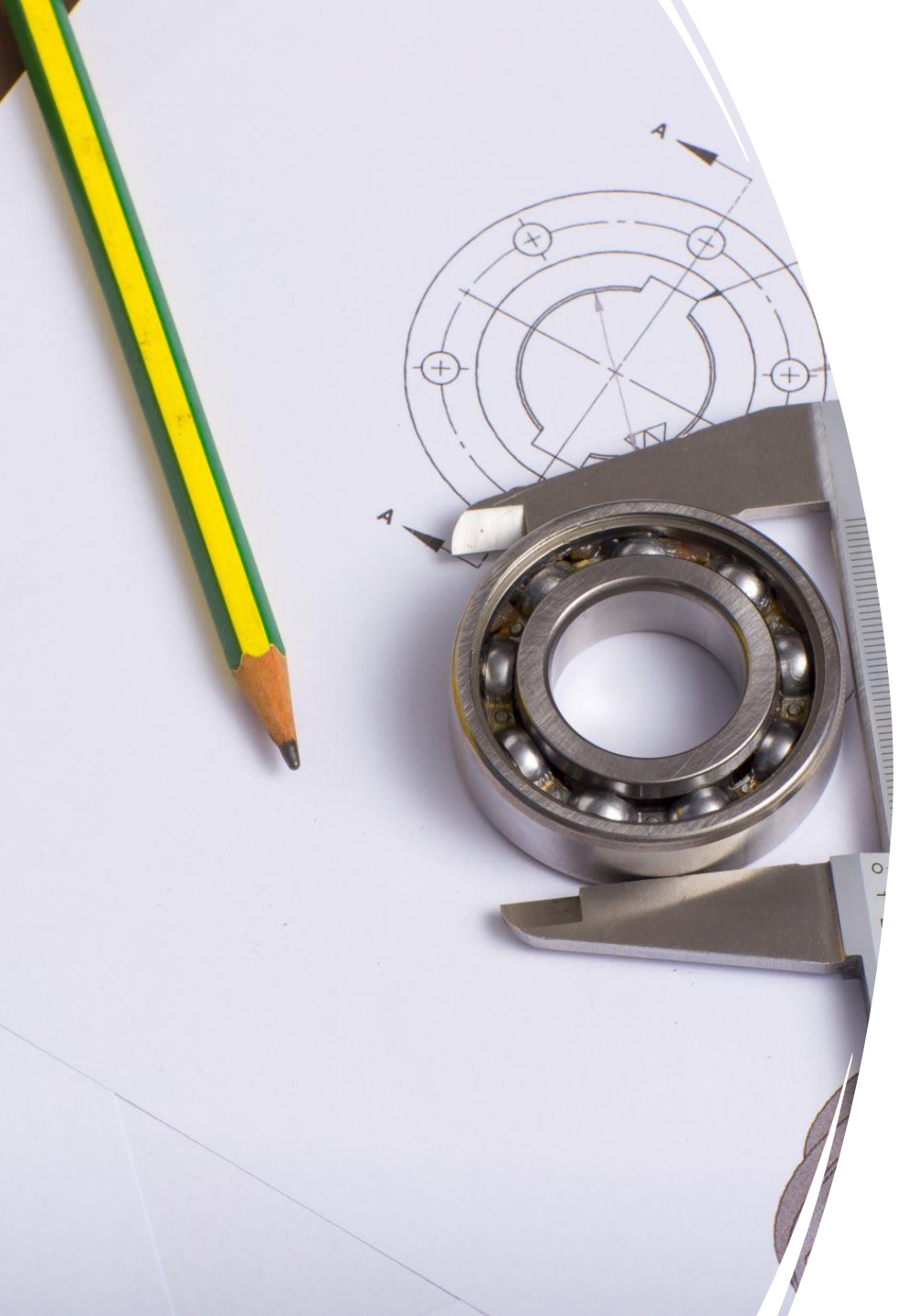
KINEMATICS FUNDAMENTALS

Mechanism Inversion



Learning Outcomes

- In this section, we will focus on the mechanism inversion configuration of a closed kinematic chain.

Inversion Configuration of a Closed Kinematic Chain - Mechanisms

- The term "inversion" refers to different arrangements of links in a kinematic chain while maintaining the same overall function.
- In the fourbar linkage, the inversion includes the crank, coupler (connecting rod), the rocker, and the ground link.
- In the slider-crank linkage, the inversion includes the crank, coupler, slider, and ground link.

Inversion Configuration of a Closed Kinematic Chain - Mechanisms

- A mechanism is created when one of the kinematic chain's links is fixed. So, fixing different links of the same kinematic chain can provide different mechanisms.
- The number of mechanisms obtained by modifying the fixed link is equal to the number of linkages.
- In the design and analysis of mechanisms for different engineering purposes, the inversions are widely employed for motion transmission and modification of motion.

Inversions of Fourbar Chain:

- The fourbar linkage as shown Figure #1 is one of the most useful and frequent systems.

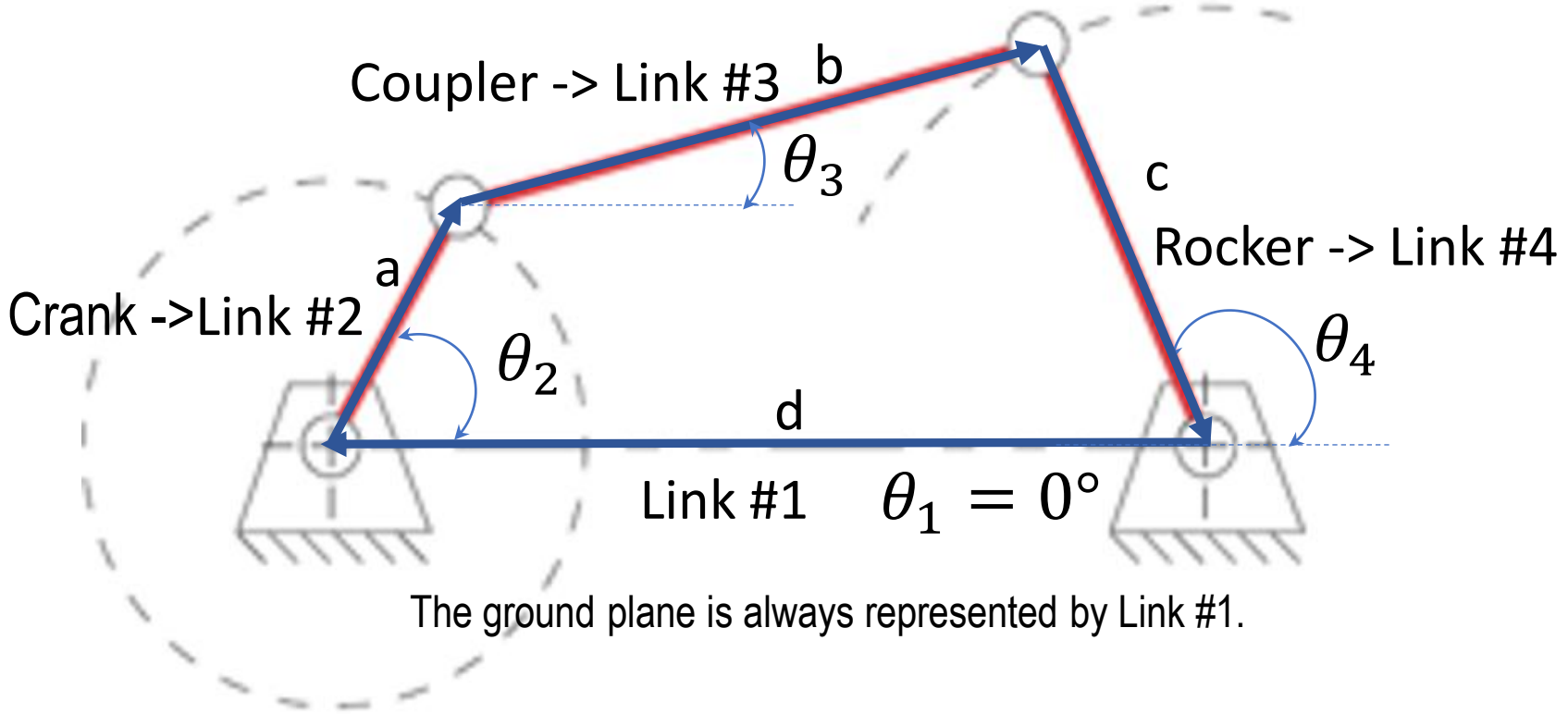


Figure #1. Fourbar Mechanism.

Inversions of Single Fourbar Chain:

- The inversions of a fourbar chain involve rearranging and fixing the *links* to achieve different functionalities. These are some common inversions:
    1. Rail or Locomotive Double-Crank Mechanism
    2. Beam Engine Mechanism
    3. Watt's Indicator Mechanism

Inversions of Fourbar Chain – Double-Crank Mechanism

- By fixing link #1 of the fourbar chain produces the mechanism known as *rail or locomotive* as shown in the Figure #2. The links AD and BC having equal length act as cranks transmitting rotary motion from one wheel to the other wheel.
- The link CD acts as a coupling rod and the link AB is fixed in order to maintain a fixed center-to-center distance between them.

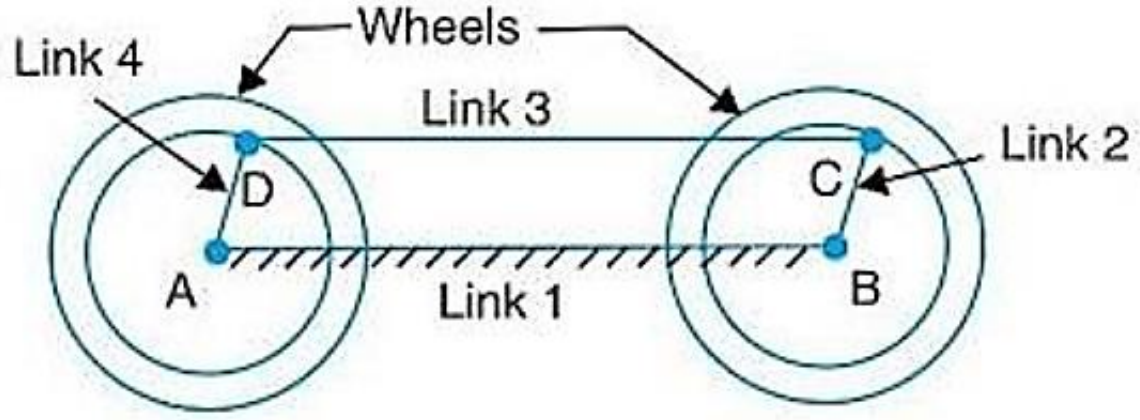


Figure #2. Rail or Locomotive Double-Crank Mechanism.

Inversions of Fourbar Chain - Beam Engine Mechanism

- The *Beam Engine Mechanism* is also known as crank-lever mechanism which consists of four links; when the crank rotates about fixed-point A, the lever oscillates about a fixed-point D.

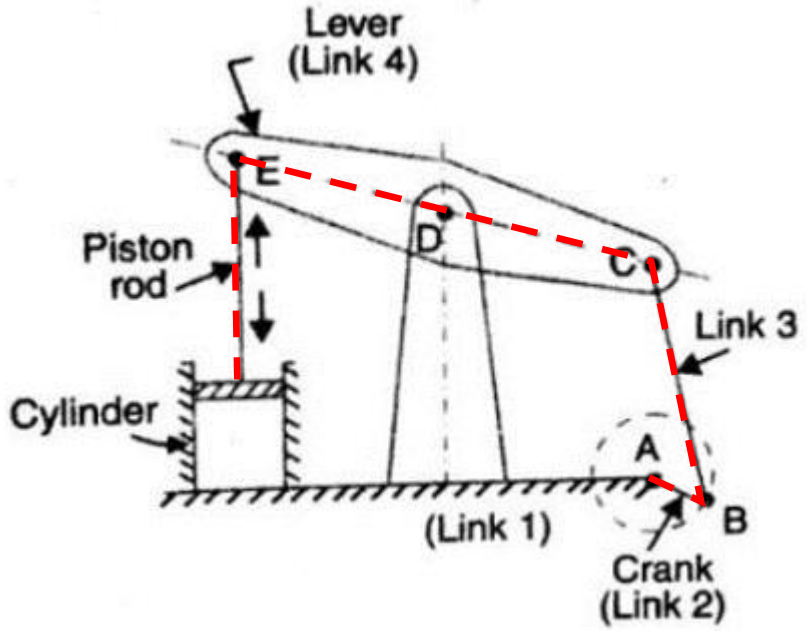


Figure #3. Beam Engine or Crank and Lever Mechanism.

Inversions of Fourbar Chain - Watt's Indicator Mechanism

- A *Watt's Indicator Mechanism* is also known as double-lever mechanism that consists of four links, is shown in Figure #4.
- The four links are: link 1 (fixed), link AC, link CE and link BFD. Notice that BF and FD form one link because these two parts have no relative motion among them.

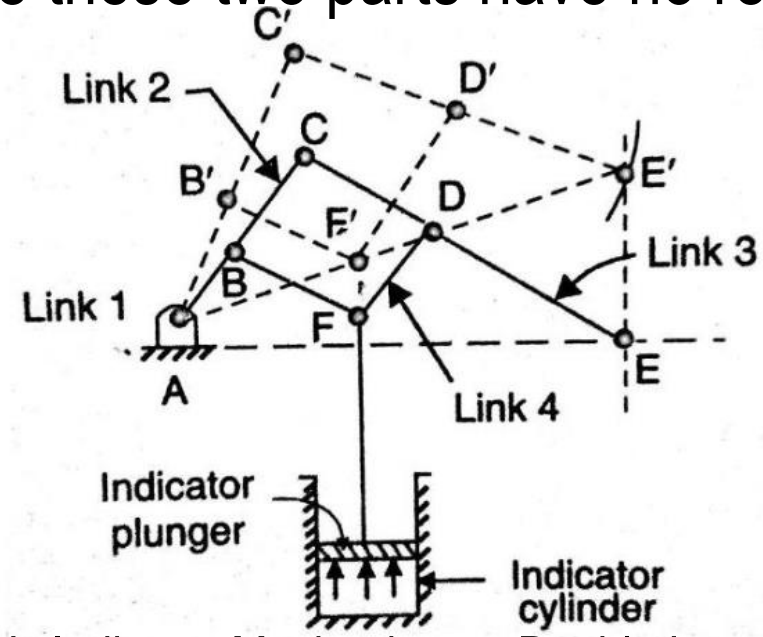


Figure #4. Watt's Indicator Mechanism or Double Lever Mechanism.

Inversions of Fourbar Chain - Watt's Indicator Mechanism

- The links CE and BFD act as *lever*. The displacement vector of the link BFD is directly proportional to the pressure (e.g., fluid or gas) that acts on the indicator plunger as shown in Figure #4.
- ***Note:*** For small displacement of the mechanism, the tracing point of E at end of link CE trace out approximately straight line.

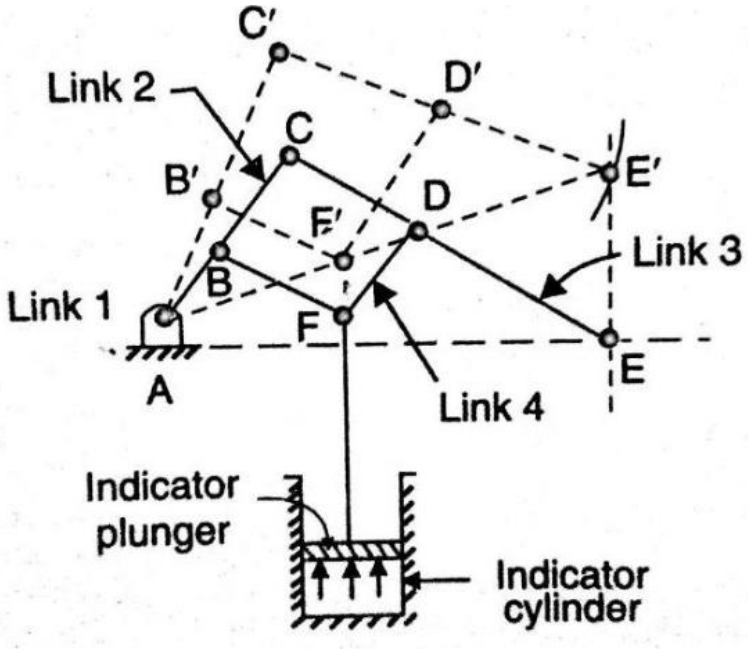


Figure #4 (repeated). Watt's Indicator Mechanism or Double Lever Mechanism.

Inversions of Single Slider-Crank Chain:

- Again, the inversions of a single slider-crank chain involve rearranging and fixing the links to achieve different functionalities. These are some common inversions:
    1. Reciprocating Engine Mechanism
    2. Oscillating Cylinder Engine Mechanism
    3. Whitworth Quick-return Motion Mechanism
    4. Elliptical Trammel Mechanism
    5. Scotch Yoke Mechanism

Inversions of Single Slider-Crank Chain:

- *Reciprocating Engine Mechanism (1st inversion):* As Figure #5 shows, link #1 is fixed, link #2 works as crank, link #4 works as a slider and link #3 connects link #2 with #4 (coupler or connecting rod).

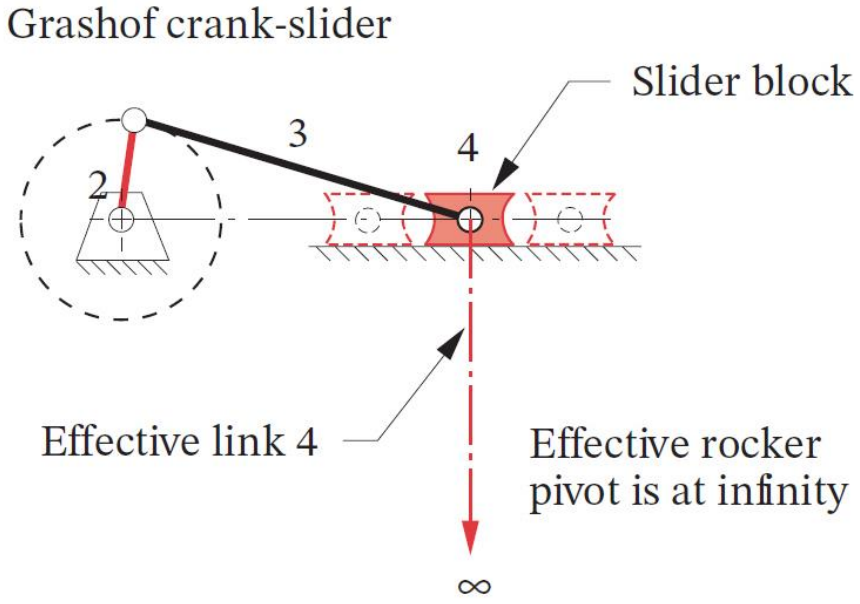


Figure #5. Reciprocating Engine Mechanism. Source: Design of Machinery by Robert L. Norton Textbook.

Inversions of Single Slider-Crank Chain:

- This mechanism is also known as *slider-crank chain or reciprocating engine mechanism*. It is commonly used in reciprocating pumps as it converts rotary motion into reciprocating motion and vice-versa.

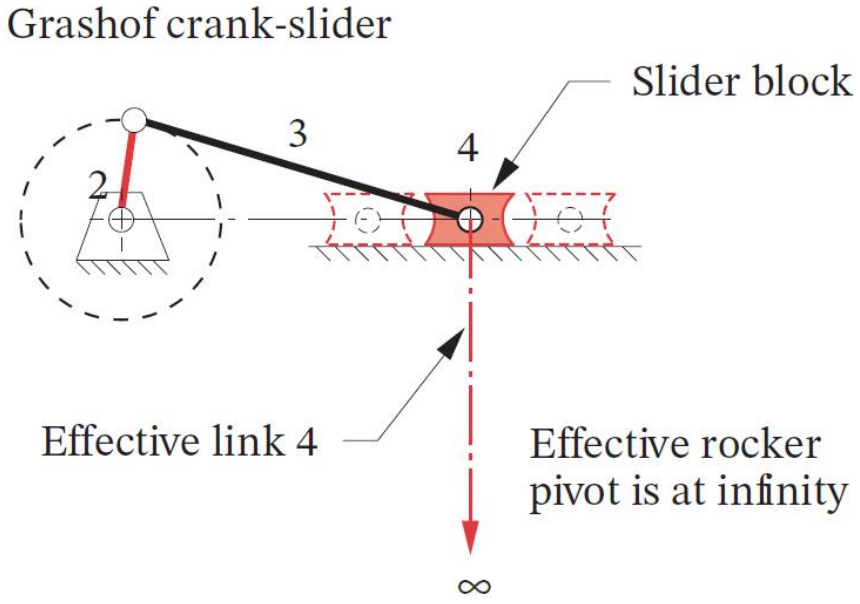


Figure #5. Reciprocating Engine Mechanism. Source: Design of Machinery by Robert L. Norton Textbook.

Inversions of Single Slider-Crank Chain:

- *Oscillating Cylinder Engine Mechanism (2nd inversion):* It is used to convert reciprocating motion into rotary motion as shown in Figure #6. The link #3 is fixed and corresponds to the connecting rod of a reciprocating engine mechanism.
- When the crank (link #2) rotates, the piston attached to piston rod (link #1) reciprocates and the cylinder (link #4) oscillates about a pin pivoted to the fixed link at point A.

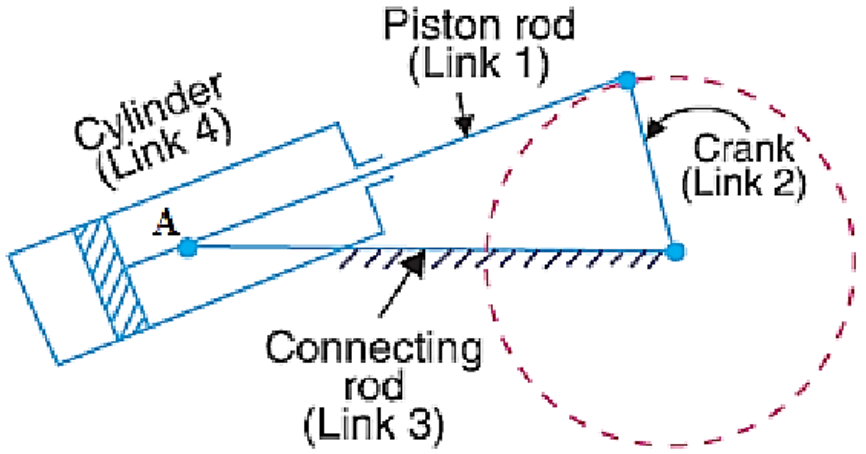


Figure #6. Oscillating Cylinder Engine Mechanism.

Inversions of Single Slider-Crank Chain:

- *Whitworth Quick-Return Motion Mechanism (3rd inversion):* It is mostly used in shaping and slotting machines; the link CD (link #2, fixed) corresponds to a crank in a reciprocating engine as shown in Figure #7.
- The driving crank CA (link #3) rotates at a uniform angular speed. The slider (link 4) attached to the crank pin at A slides along the slotted bar PA (link 1) which oscillates at a pivoted point D. The connecting rod PR carries the ram at R to which a cutting tool is fixed. The motion of the tool is constrained along the line RD produced, i.e., along a line passing through D and perpendicular to CD.

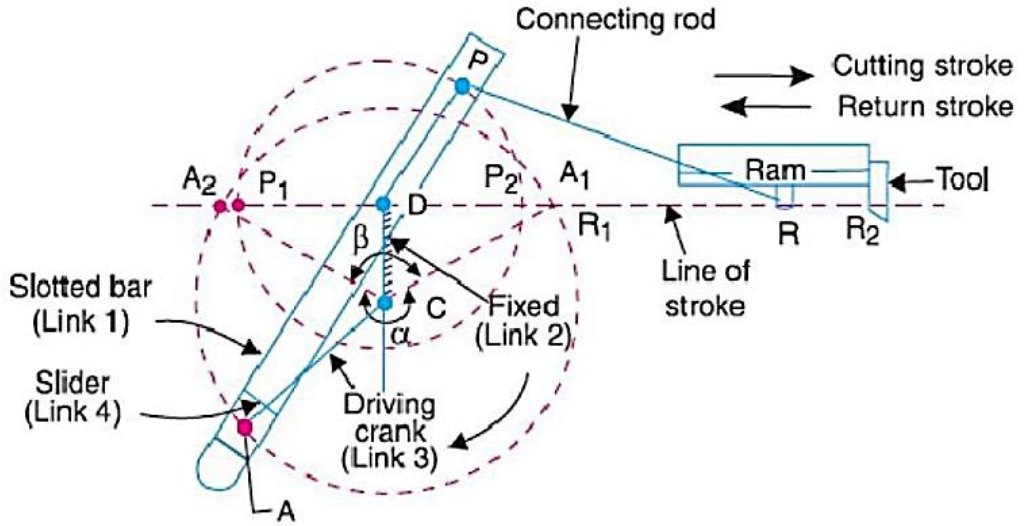


Figure #7. Oscillating Cylinder Engine Mechanism.

Inversions of Single Slider-Crank Chain:

- *Whitworth Quick-Return Motion Mechanism (3rd inversion) – cont.:* The quick-return equations are (more details later):

$$\frac{Time\ of\ cutting\ stroke}{Time\ of\ return\ stroke} = \frac{\alpha}{\beta}$$

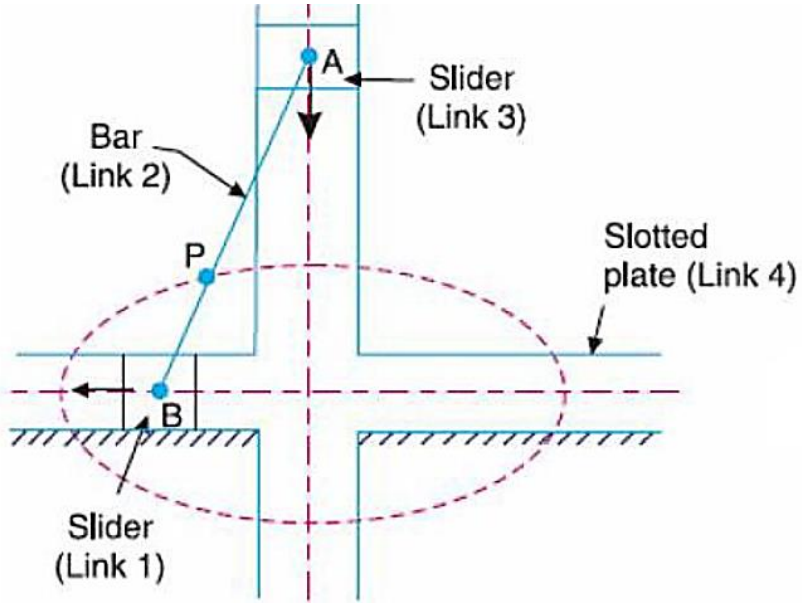
$$= \frac{\alpha}{360° - \alpha}$$

Or

$$= \frac{360° - \beta}{\beta}$$

Inversions of Double Slider-Crank Chain

- *Elliptical Trammels:* This is inversion of double slider-crank chain. This is obtained by fixing the slotted plate (link #4). The fixed plate or link #4 has two straight grooves cut in it at right angles to each other. The link #1 and link #3 are known as sliders and form sliding pairs with link #4 as shown in Figure #8. The link AB (link #2) is a bar which forms turning pair with links #1 and #3.



Note: AP and BP are the semi-major axis and semi minor axis of the ellipse, respectively.

Elliptical Trammels are commonly used in instruments for drawing ellipses.

Figure #8. Oscillating Cylinder Engine Mechanism.

Inversions of Double Slider-Crank Chain

- *Scotch Yoke Mechanism:* This mechanism is used for converting rotary motion into a reciprocating motion as illustrated in Figure #9; as the crank (link #3) rotates, the horizontal portion of the link #1 slides in the fixed link #4 (ground frame).
- This mechanism is commonly used for controlling the valve actuators in applications involving high-pressure oil or gas pipelines.

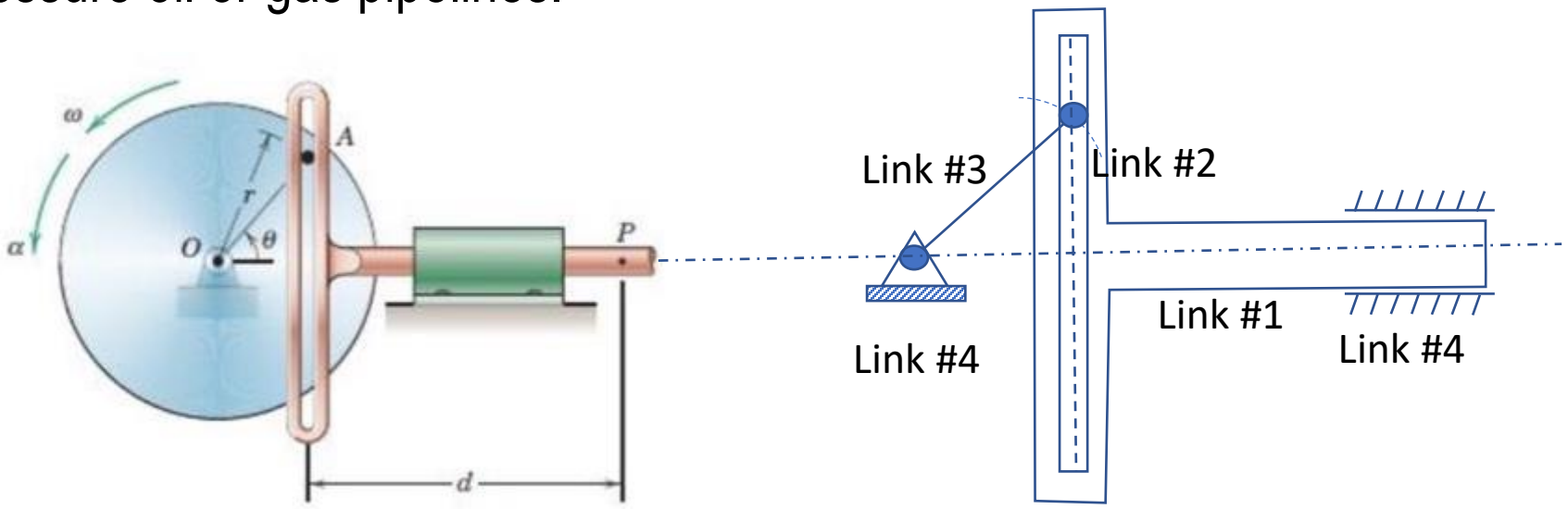


Figure #9. Scotch Yoke Mechanism.

Inversion Configuration of a Closed Kinematic Chain - Remarks

- The inversions allow engineers to adapt the single fourbar chain or slider-crank chain to various applications by changing the roles of the links.
- As discussed, each inversion has its specific advantages and applications based on the desired motion or mechanical function.