Sheikh Hasina University, Netrokona

Department of Computer Science and Engineering

CSE-2205: Introduction to Mechatronics

Lec-14: Mechanical Actuation System

Md. Ariful Islam

Assistant Professor

Dept. of Robotics and Mechatronics Engineering

University of Dhaka

&

Adjunct Faculty

Sheikh Hasina University, Netrokona

Department of Computer Science and Engineering

Contents

Mechanical Actuation System

A mechanical actuation system refers to a set of mechanisms and devices designed to convert one form of motion into another in order to achieve a specific action or function. These systems play a crucial role in various mechanical applications where controlled and precise movements are required. The primary purpose of a mechanical actuation system is to transmit motion from a source to an output in a desired manner.

Key components and mechanisms within a mechanical actuation system include:

1. **Linkages:** Linkages consist of interconnected rigid components that transmit motion. They are often used to create specific movements or trajectories by connecting various parts of a system.

2. **Cams:** Cams are rotating or sliding elements with specially shaped profiles that control the motion of other components (followers) in a predetermined way. They are used to convert rotary motion into linear or oscillatory motion.

3. **Gears:** Gears are toothed wheels that mesh together to transmit motion between parallel or intersecting shafts. Different types of gears, such as spur gears, bevel gears, and rack-and-pinion systems, can be employed in a mechanical actuation system.

4. **Rack-and-pinion:** This mechanism converts rotational motion into linear motion and is commonly used in applications where linear movement is required.

5. **Chains and Belt Drives:** Chains and belts are used to transmit motion between shafts that are not in direct contact. They can transfer rotational motion from one component to another.

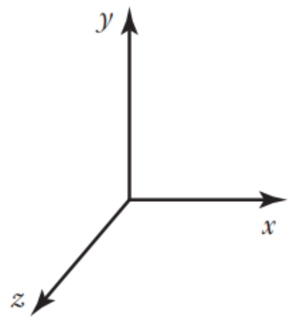
6. **Mechanical Actuators:** Devices like pistons, cylinders, and levers are often used to produce mechanical movement or force in response to an input signal.

Mechanical actuation systems find application in various fields, including machinery, automotive engineering, robotics, and manufacturing. While these traditional mechanical systems have been widely used, as mentioned in the text, modern approaches in mechatronics often incorporate microprocessor systems to achieve more sophisticated control and automation. These integrated systems combine mechanical components with electronics and computer control for improved precision, efficiency, and flexibility.

Types of Motion

1. **Translational Motion:**

Translational motion involves the movement of an object in a straight line along a particular direction. It is characterized by a change in the object's position without any change in its orientation.

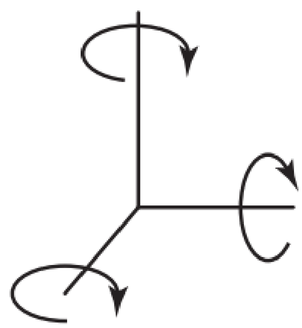


Linear Motion: A car moving along a straight road is an example of translational motion. The motion of an elevator moving up or down is also translational.

Vertical Motion: The rise and fall of a hot air balloon in the vertical direction represent translational motion.

2. **Rotational Motion:**

Rotational motion involves the movement of an object in a circular or rotational path around a fixed point or axis. It is characterized by a change in the object's orientation without any change in its position.



Rotary Motion: The rotation of a bicycle wheel is an example of rotational motion. The spinning of a record on a turntable is also rotational.

Planetary Motion: The rotation of Earth on its axis is a large-scale example of rotational motion.

3. **Complex Motion:**

Complex motion involves a combination of translational and rotational motions. Objects undergoing complex motion may experience both linear movement and rotation simultaneously.

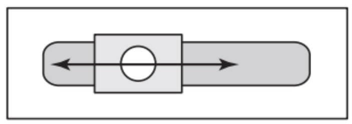
Picking up a Pencil: As mentioned in the text, the motion required to pick up a pencil involves a combination of translational and rotational motions. Your hand may move towards the table (translational), rotate to align with the pencil (rotational), and then fingers open and close (translational and rotational). This complexity can be broken down into components for analysis and programming, especially in the context of instructing a robot to perform the task.

Freedom and constraints

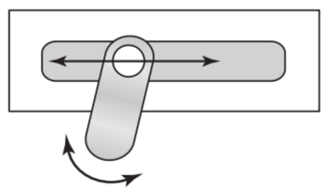
Consider a simple joint that allows translational motion along a single axis. In this case, we have a constraint applied to limit the motion to only one direction.

Freedom Analysis:

A body that is free in space has six degrees of freedom (3 translational and 3 rotational). If a joint is constrained to move along a line (translation along one axis), its translational degrees of freedom are reduced to one.



If a joint is constrained to move on a plane, then it has two translational degrees of freedom.



Freedom and Constraints Relationship:

Without any constraints a body would have six degrees of freedom. A constraint is needed for each degree of freedom that is to be prevented from occurring. Provided we have no redundant constraints, the number of degrees of freedom would be six minus the number of constraints. The number of degrees of freedom for a constrained body can be determined using the formula:

$$6 - number\ of\ constraints = number\ of\ degrees\ of\ freedom - number\ of\ redundancies$$

If a body is required to be fixed (zero degrees of freedom), then the number of constraints needed is six (without redundancies).

Kinematic chains

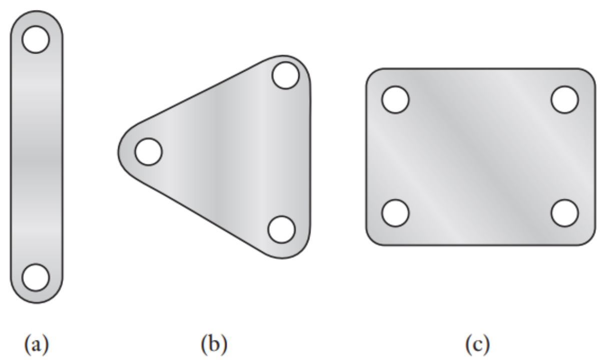
Links

Each part of a mechanism capable of motion relative to some other part is termed a link. A link is a resistant body capable of transmitting required forces with negligible deformation.

Representation: Links are often represented by rigid bodies with two or more points of attachment to other links, known as nodes.

Examples: In the context of a motor car engine mechanism:

- Link 1: Crankshaft
- Link 2: Connecting rod
- Link 3: Fixed frame
- Link 4: Slider (piston)



Links: (a) with two nodes, (b) with three nodes, (c) with four nodes.

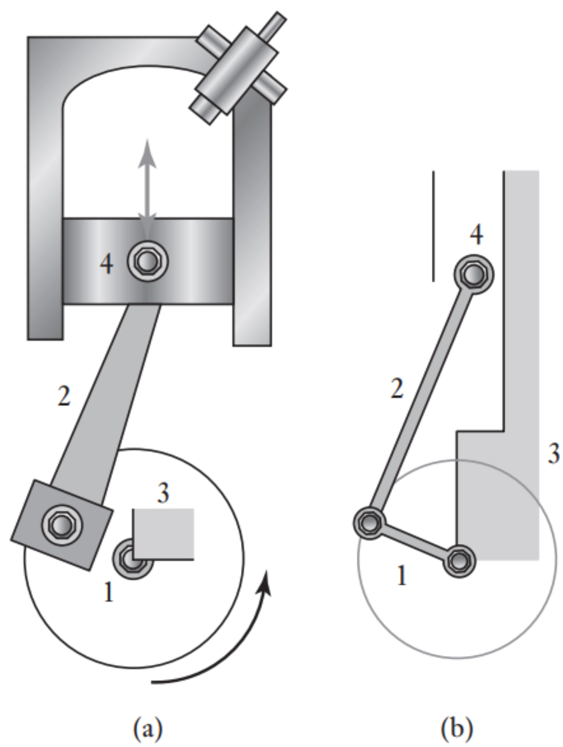
Joints

A joint is a connection between two or more links at their nodes, allowing some motion between the connected links.

Examples: In the motor car engine mechanism:

- Joints connect the crankshaft to the connecting rod, the connecting rod to the fixed frame, and the fixed frame to the slider (piston).

Link 1 is the crankshaft, link 2 the connecting rod, link 3 the fixed frame and link 4 the slider, i.e. piston, which moves relative to the fixed frame



Kinematic Chain

A kinematic chain is a sequence of joints and links that allows motion. For a kinematic chain to transmit motion, one link must be fixed.

- **Illustration:** In the motor car engine mechanism, the kinematic chain involves the crankshaft, connecting rod, fixed frame, and slider (piston). If the fixed frame is anchored, the reciprocating motion of the piston can be transformed into the rotational motion of the crankshaft.

Basic Kinematic Chain Forms:

- **Four-Bar Chain:** This is a common type of kinematic chain with four links connected by revolute joints.
- **Slider–Crank Chain:** Another common form where a slider (linearly moving link) is connected to a crank (rotating link).

Four-Bar Chain

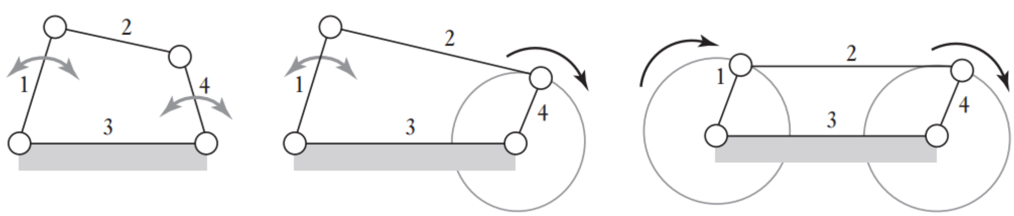
The four-bar chain is a type of kinematic chain composed of four links connected by revolute joints, resulting in four joints where turning can occur.

- **Components:** The four links are typically labeled as link 1, link 2, link 3, and link 4.
- **Joints:** There are four joints (revolute joints) connecting the links.

Grashof Condition:

The Grashof condition is a criterion that determines whether a four-bar mechanism can achieve a complete revolution. The condition states that if the sum of the shortest and longest links is less than or equal to the sum of the other two links, at least one link can make a full revolution.

Forms of the Four-Bar Chain: Figure illustrates different forms of the four-bar chain by altering the relative lengths of the links:



(a) (b) (c)

1. **Double-Lever Mechanism (Figure (a)):**
    - Link 3 is fixed, and the relative lengths of links 1 and 4 are such that links 1 and 4 can oscillate but not rotate.
    - This results in a mechanism where both links 1 and 4 act as levers, creating a double-lever mechanism.
2. **Lever–Crank Mechanism (Figure (b)):**

- By shortening link 4 relative to link 1, link 4 can rotate while link 1 oscillates.
- This configuration is termed a lever–crank mechanism.

3. **Double-Crank Mechanism (Figure (c)):**

- When links 1 and 4 are of the same length and both are capable of rotating, it forms a double-crank mechanism.

Variations:

- By altering which link is fixed and adjusting the relative lengths, various other forms of mechanisms can be produced within the four-bar chain framework.

The slider–crank mechanism

Slider–Crank Mechanism:

- **Components:**
    - **Crank (Link 1):** The crank is the rotating link that provides the input motion. It is usually connected to a source of rotational motion.
    - **Connecting Rod (Link 2):** The connecting rod connects the crank to the slider. It translates the rotational motion of the crank into linear motion.
    - **Slider (Link 4):** The slider moves back and forth along a straight path. In the context of an engine mechanism, the slider is often associated with the piston.

Functionality:

- The slider–crank mechanism is designed to transform an input of back-and-forth motion into rotational motion.
- In the context of an engine mechanism, link 3 (the fixed link) is typically the housing in which the piston (slider) moves. The rotation of the crank (link 1) forces the piston to move backward and forward.

Behavior:

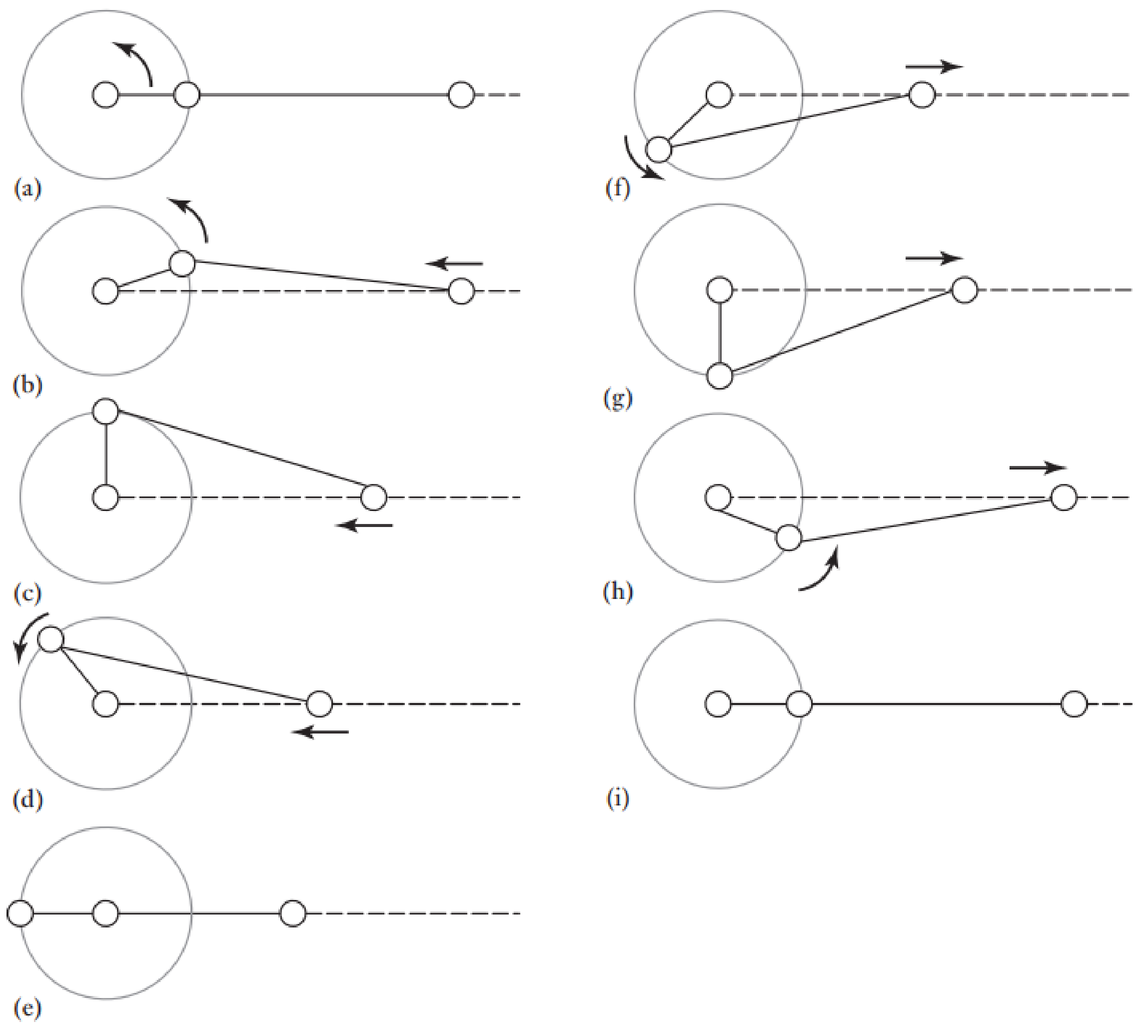
- As the piston (slider, link 4) moves backward and forward, the crank (link 1) is forced to rotate.
- Figure illustrates various stages in this motion, showcasing how the rotation of the crank is related to the linear motion of the piston.

Cardboard Model:

- A useful method to understand and visualize the behavior of a mechanism is to construct a cardboard model to scale.
- By physically moving the links in the model, engineers can observe how changes in link lengths affect the overall behavior of the mechanism.

Design Considerations:

- Engineers often analyze and experiment with different link lengths to optimize the performance and efficiency of the slider–crank mechanism.
- Adjusting the lengths of the crank and connecting rod can influence the stroke length, compression ratio, and overall efficiency of the mechanism.



The position sequence for the links in a slider– crank mechanism.

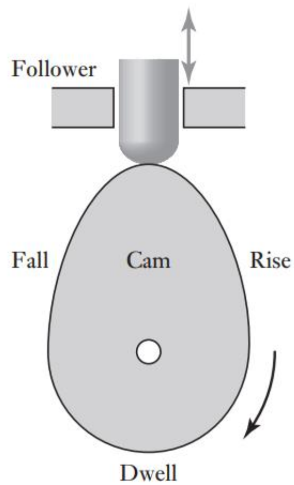
Cam Mechanism

A cam is a rotating or oscillating body that imparts reciprocating or oscillatory motion to a second body, known as the follower, with which it is in contact.

- **Components:**
    - **Cam:** The rotating or oscillating body.
    - **Follower:** The second body that experiences the motion imparted by the cam.

Operation:

- As the cam rotates or oscillates, it drives the follower to rise, dwell, and fall.
- The shape of the cam determines the motion profile of the follower, including the speed and duration of the rise, dwell, and fall sections.



Cam Sections:

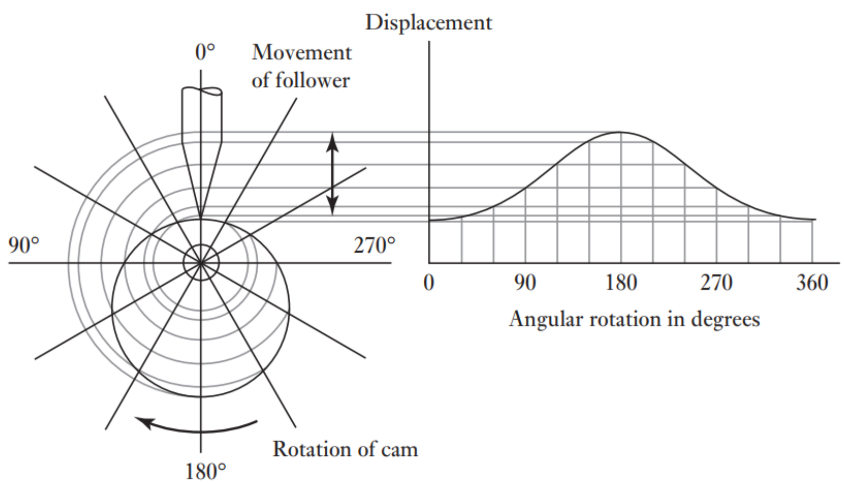
1. **Rise Section:**
    - The part of the cam that drives the follower upwards.
    - The profile of this section determines the speed at which the follower is lifted.
2. **Dwell Section:**
    - The part of the cam that allows the follower to remain at the same level for a significant period.
    - In the dwell section, the cam has a circular shape with a constant radius, and the follower stays stationary.
3. **Fall Section:**
    - The part of the cam that lowers the follower.

- The profile of this section determines the speed at which the follower descends.

Cam Shape and Follower Displacement:

- The shape of the cam required to produce a specific motion of the follower depends on the type of follower and the desired displacement.
- Figure illustrates a displacement diagram produced by an eccentric cam with a point-shaped follower.
    - **Eccentric Cam:** A circular cam with an offset center of rotation.
    - **Follower Displacement:** The radial distance from the axis of rotation to the point of contact with the follower.

The diagram shows how these radial distances, and consequently follower displacements, vary with the angle of rotation of the cam.



Example: Consider a cam mechanism used in a pump system:

- The eccentric cam, in this case, produces simple harmonic motion in the follower.
- The radial distance from the axis of rotation to the point of contact with the follower corresponds to the vertical displacement of the follower.