All mechanical devices containing moving parts are composed of some type of mechanism.

A mechanism is a group of links interacting with each other through joints to complete required motion or force transmission.

There are 5 fundamental questions to be considered when designing a mechanism:

1. How many links are there in the mechanism?
2. How many joints are there in the mechanism? What are the types of the joints?
3. What are the relations between the links and joints?
4. What are the fundamental dimensions of the links to achieved the required motion?
5. What are the actual shape of the mechanism which can provide enough strength and stiffness during the motion?
Links

✓ Conceptually a link is considered as a rigid body that will not deform under the loads during the motion.

✓ A link is not necessarily a “stick-like part”. A link may be composed of several parts assemble together, and move as a rigid body during motion.

✓ How many links are there in a bicycle?
Planar Mechanism

✓ The **planar mechanism** is the most common type of mechanism. The trajectory of one point on the planar mechanism lies on a plane during motion. The trajectory of all points on the planar mechanism lie on planes which are parallel to each other.

✓ For example, a door is a simple planar mechanism that consists of a **moving link** and a **ground link**. This mechanism can be described on a plane.

✓ In a **spatial mechanism**, the motion of the links is not planar. For example, the trajectories of the links in a **spherical mechanism** form concentric spheres.

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Joints in a Planar Mechanism

✓ Links are connected by joints. There are 3 types of joints:

  • **Revolute joint** permits rotational motion with respect to a fixed axis.
  • **Prismatic joint** permits translational motion between of a pair of links.
  • **Direct contact joint** permits both rotation and slide between links.

✓ Both revolute joint and prismatic joint are single-DOF joints. Only one parameter is needed to describe the relative position between two links. The direct contact joint is a 2-DOF joint.
**Joints in a Spatial Mechanism**

- **Helical joint** is a one-DOF joint consists of a screw nut and a bolt.
- **Cylindrical joint** consists of a shaft and a sleeve, and permits two-DOF motion.
- A universal joint is a **spherical joint** which provides three-DOF motion.
- The direct contact joint in a spatial mechanism can have 5 DOF (point contact), 4 DOF (line contact) or 3 DOF (surface contact).
The function of a mechanism in a machine is to convert the input force or motion into desired output.

In a linearly proportional mechanism, the output motion or force is linearly proportional to the input.

In some mechanisms, the relation between output and input is nonlinear. The number, type and connectivity of joints, and the length of links determine the characteristic of the mechanism. Such mechanism is called a linkage.

The purpose of linkage design is to decide the length of the links, the position and type of the joints, and how to assemble the links so that the desired motion can be achieved.
When analyzing a linkage, we often use a “skeleton diagram” to represent the type of joints, distances between joints, and which joints connect which links in the linkage.
Linkage Design (III)

- The close-loop four-bar linkage has only 1 DOF, i.e., only one actuator is needed to drive the linkage. It is the most popular and well-studied linkage.

- 2 bars
- 3 bars
- 4 bars
Four-Bar Linkage

✓ Four-Bar Linkages can be used for non linear motion transmission.

In a four-bar linkage, Grashof’s Law determines whether there is a link that can rotate 360 degree.

• If the sum of length of the longest and shortest links are less than the sum of length of the other two links, there must be a link that can rotate 360 degree.
• If not, no link can rotate 360 degree.

✓ When Grashof’s Law is satisfied, there are 3 possible mechanisms: crank and rocker, double crank, and double rocker.

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Crank and Rocker Mechanism

✓ The shortest link is input crank or output crank. Input crank or output crank rotates 360 degrees.
Double Crank Mechanism

✓ The shortest link is ground link. Both input crank and output crank rotate 360 degrees.
Double Rocker Mechanism

✓ The shortest link is coupler link. The coupler link can rotate 360 degrees.
Example 1. Windshield Wiper Mechanism

- The windshield wiper mechanism can be divided into two 4-bar linkages: (1, 2, 3, 4) and (1, 4, 5, 6).

- Linkage (1, 2, 3, 4) is a crank and rocker mechanism. Link 2 is the input crank which rotates 360 degree to drive other links.

- Linkage (1, 4, 5, 6) is a double rocker mechanism. Link 4 is the input crank, which drives link 6 to rotate with the same direction and angular speed.

- Linkage (1, 4, 5, 6) is called “parallel mechanism”.

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Other Linkages

- **Slider crank** (crank and slider) mechanism has 4 links, 3 revolute joints and 1 prismatic joint. As in the reciprocating engine, this mechanism converts reciprocating motion (piston) into rotational motion (crank).

- **Double slider** mechanism has 4 links, 2 revolute joints and 2 prismatic joints.
Practice 3. Mechanism of Casement Window

1. How many links and joints are there in this mechanism? Which are the input links? Which are the output links? What are their types?

2. Measure the distance between each joint. Draw a skeleton diagram. Be careful with the scale of the links.

3. Make a model of this mechanism using pasteboard and other suitable materials.

4. Operate your model and find out the maximum opening angle of the windows. Can you calculate the result?

5. If you want a larger opening angle, how do you modify the length of links? Make a model again to verify the result. Is there any limit of the angle?
A movable link in a planar mechanism has 2 translational DOF and 1 rotational DOF.

A revolute joint constrains 2 translational DOF. A prismatic joint constrains 1 translational DOF and 1 rotational DOF.

For the casement window mechanism, the number of total degree of freedom is:

- 6 revolute joints, 1 prismatic joint
- 3\times(6-1)-2\times(6+1)=1
- 6 links, 1 ground link

For the windshield wiper mechanism, the number of total degree of freedom is:

- 7 revolute joints
- 3\times(6-1)-2\times7=1
- 6 links, 1 ground link
Many computer simulation software can be used for mechanism analysis.

After the length of the links, the number, type, and connectivity of the joints are decided, force analysis and stress analysis are needed to design the actual size and shape of the links.

A reciprocating force (0N-5N) is exerted on the slider in \(-x\) direction. The period is 0.898 sec.
The analysis results show that, the maximum angular velocity of link 1 (2059.98 deg/s) and the maximum constraint force (42.72 N) of joint 2 occur at the same time $t=0.535$ sec.