Mechanical Actuating Systems

- Mechanisms are devices which can be considered to be motion converters in that they transform motion from one form to other required form.

- Mechanical elements can include:
  - Linkages, cams, gears, rack-and-pinion, chains, belt drives, etc.

- Mechanisms are still used today in many mechatronics applications to provide:
  - Force amplification (levers)
  - Change of speed (gears)
  - Transfer of rotation about one axis to rotation about another (timing belt)
  - Particular types of motion, e.g. that given by a quick-return mechanism

- Kinematics: study of motion without regard to forces …
Types of Motion

The motion of any rigid body can be considered to be a combination of:

- Translational & rotational motions

**Translation motion:** Movement which can be resolved into components along one or more of the 3-axis

**Rotation motion:** A rotation which has components rotating about 1 or more axes

- Breaking down a complex motion into combinations of translational and rotational motions allows us to design mechanisms that can carry out each of these types of motion
Freedom and Constraints

The number of degree of freedom are the number of components of motion that are required in order to generate the motion
A body that is free in space has 6 degree of freedom

- Fig 6.2(a) – 1 degree of freedom
- Fig 6.2 (b) – 2 degrees of freedom

Fig 6.2
Kinematic Chains

Link: a part of a mechanism that has motion relative to some other part

- Links are represented as rigid bodies

Nodes: attachment points between links

Joint: Connection between 2 or more links at their nodes, and which allow some motion between the connected links

Example of links: Levers, cranks, connecting rods and pistons, sliders, pulleys, belts, shafts …
Kinematic chain: a sequence of joints and links

- The kinematic chain can transmit motion if one link is fixed

The design of many mechanisms is based on two basic forms of kinematic chains:
The four-bar chain and the slider-crank chain

The Four-Bar Chain

- Consists of 4 links connected to give 4 joints about which turning can occur. Various forms of the 4-bar chain are produced by altering the relative lengths of the links:
- If $l_s + l_l \leq l_1 + l_2$, then at least one link will be capable of a complete revolution with respect to the fixed link
  (a) double lever mechanism; link 3 is fixed and link1 and link4 can oscillate but not rotate
  (b) lever crank mechanism; link4 can rotate with link1 oscillating
(c) double crank mechanism: link 1 and link 4 same length and both able to rotate

- By altering which link is fixed other forms of mechanisms can be produced

![Fig. 6.6 Examples of four-bar chains](image)
The Slider-Crank Mechanism

This form of mechanism consists of a crank, a connecting rod and a slider

Forms:

- The simple engine mechanism (Fig 6.5)
- Quick-return mechanisms

Fig 6.5
Cams

- A cam is a body which rotates or oscillates and in doing so imparts a reciprocating or oscillatory motion to a second body, called the follower, with which is in contact.
- As the cam rotates so the follower is made to rise, dwell and fall.
- The cam shape required to produce a particular motion of the follower will depend on the shape of the cam and of the type of follower used.
Cam Followers

Roller followers are essentially ball or roller bearings

- Lower friction

Flat faced followers are often used because they are cheaper and can be made smaller than roller followers

Cams can be run dry, but they are often used with lubrication and may be immersed in an oil bath
Fig. 6.12 Cam followers: (a) point, (b) knife, (c) roller, (d) sliding and oscillating, (e) flat, (f) mushroom
Gear Trains

Gear trains are mechanisms used to transfer and transform rotational motion.

Transferring of motion from one shaft to another can be done by:

- Rolling cylinders
  - Possibility of slippage
- Meshed gears
  - (a) parallel; (b) inclined to one another
- Larger gear is called spur or crown gears;
- Smaller gear is called pinion gear

Types of gears:
- (a) spur; (b) helical; (c) double helical
Rack-and-Pinion

- Two intermeshed gears with one having a base circle of infinite radius.
- Can transform rotational/linear motion to linear/rotational motion
Consider two meshed gears with angular velocities $\omega_A$ and $\omega_B$

$$\frac{\omega_A}{\omega_B} = \frac{\text{number of teeth on } B}{\text{number of teeth on } A} = \frac{80}{40} = 2$$

Number of teeth is proportional to diameter

$$\frac{\omega_A}{\omega_B} = \frac{\text{number of teeth on } B}{\text{number of teeth on } A} = \frac{d_B}{d_A}$$
Gear Trains

- A series of intermeshed gear wheels
- **Simple gear train** is used for a system where each shaft carries only one gear wheel
- The overall gear ratio is the ratio of the angular velocities at the input and output shafts:

\[
G = \frac{\omega_A}{\omega_C} = \frac{\omega_A}{\omega_B} \times \frac{\omega_B}{\omega_C}
\]

- **Compound gear** is used to describe a gear train when two wheels are mounted on a common shaft
• When 2 gear wheels are mounted on the same shaft they have the same angular velocity, in Fig 6.19, $\omega_B = \omega_C$

• The overall gear ratio will be:

$$G = \frac{\omega_A}{\omega_D} = \frac{\omega_A}{\omega_B} \times \frac{\omega_B}{\omega_C} \times \frac{\omega_C}{\omega_D} = \frac{\omega_A}{\omega_B} \times \frac{\omega_C}{\omega_D}$$

• The angular velocity of a wheel is inversely proportional to the number of teeth on the wheel

• Problem 10 of chapter 6 on page no. 159
Ratchet and Pawl

- Ratchets can be used to lock a mechanism when it is holding a load
- The arm (pawl) is pivoted and can move back and forth to engage the wheel
- The shape of the teeth is such that rotation can occur in only one direction
- The pawl is normally spring loaded to ensure that it automatically engages with the ratchet teeth
Belt Drives

• Belts use friction in order to transmit torque

• The transmitted torque is due to the differences in tension that occur in the belt during operation
  □ A tide and a slack side

• Power = (T1 – T2)v

• Advantages of belt drives:
  □ Length of belt can be adjusted to suit the shaft-to-shaft distance
  □ The system is automatically protected against overload because slipping occurs
Fig. 6.21 Belt drive

Torque on A = \((T_1 - T_2)r_A\)

(a) is crossed belt and (b) is open belt
Type of Belts

• Flat:

Has an efficiency of about 98% and produces little noise. Can transmit power over long distances between pulley centers

• Round

The belt has a circular cross section and is used with grooved pulleys

• V

Are less efficient than flat belts but multiple V belts can be used on one pulley

• Timing

Required toothed wheels; does not slip or stretch and consequently transmits power at a constant angular velocity ratio.
Chain drives

- Slip can be prevented by the use of chains which lock into teeth on the rotating cylinders to give the equivalent of a pair of intermeshing gear wheels
- A chain drive has the same relationship for gear ratio as a simple gear train
• The chains are not as quiet as the timing belts but can be used for larger torques

Bearing

• The function of a bearing is to guide with minimum friction and maximum accuracy the movement of one part relative to another

• Of particular importance is to give suitable support to rotating shafts, i.e. support radial loads.

• The term thrust bearing is used for bearing that are designed to withstand forces along the axis of a shaft when relative motion is primarily rotation.

• Commonly used forms of bearings
  □ Plain journal bearings
Plain Journal Bearings

- Journal bearings are used to support rotating shafts which are loaded in a radial direction
  - Dry rubbing bearing
    - Nylon;
  - Lubricated bearing
    - Widely used material is sintered bronze which can be impregnated with oil …
- The lubricant may be:
  - Hydrodynamic; hydrostatic; solid-film; boundary layer
Fig. 6.24  Plain journal bearing

Fig. 6.25  Hydrodynamic journal bearing
Ball and Roller Bearings

- The main load is transferred from the rotating shaft to its support by rolling contact
- Forms of ball bearings
  - (a) Deep-groove
  - (b) Filling-slot
  - (c) Angular contact
  - (d) Double-row
  - (e) Self aligning
  - (f) Thrust, grooved race
Forms of roller bearings
(a) Straight roller
(b) Taper roller
(c) Needle roller
Fig. 6.28  Roller bearings
Mechanical Aspects of Motor Selection; Moments of Inertia

- Consider a system composed of the motor and its load
  - In the absence of gearing => the angular acceleration $\alpha$ and the angular velocity $\omega$ are the same for the load and shaft
  - The power needed to accelerate the system as a whole is:

$$\text{Power} = (I_M + I_L)\alpha \omega$$

- This power is produced by the motor torque

$$T = (I_M + I_L)\alpha$$

- The torque to obtain a given angular acceleration will be minimized when $I_M = I_L$;
• Consider a gear system with the motor shaft rotating at a different angular speed to the shaft rotating the load

\[
\text{Power} = (I_M + G^2 I_L) \alpha_M \omega_M;
\]

\[
\text{Torque; } T = (I_M + G^2 I_L) \alpha_M
\]

• Thus the effect of using the gearing is to give the load an effective moment of inertia of \( G^2 I_L \);

• The torque to give a particular angular acceleration will be minimized when \( I_M = G^2 I_L \);
Mechanical Aspects of Motor Selection; Torque

- The operating curve for a typical motor is shown below.
- For a continuous running the stall torque value should not be exceeded. This is the maximum torque value at which overheating will not occur.
- For intermittent use, greater torques are possible. As the angular speed is increased so the ability of the motor to deliver torque diminishes.
- Thus if higher speeds and torques are required, more powerful motor needs to be selected.

Excerpted from materials prepared by Radu Muresan