Sheikh Hasina University, Netrokona

Department of Computer Science and Engineering

CSE-2205: Introduction to Mechatronics

Lec-15: Mechanical Actuation System

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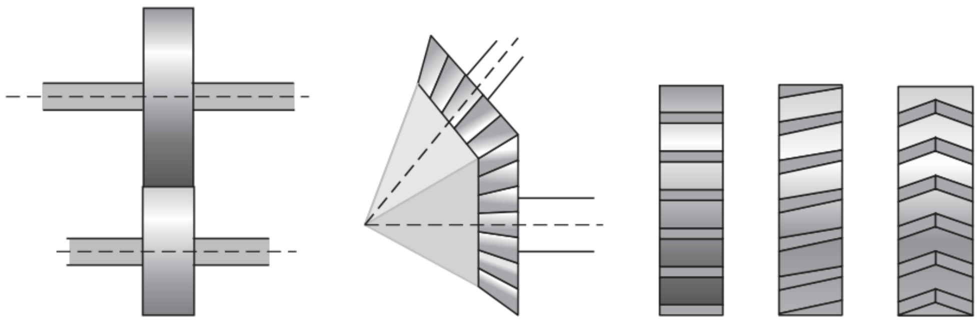
Gear Trains

Gear trains are mechanisms widely used to transfer and transform rotational motion. They are employed when a change in speed or torque of a rotating device is needed.

Application Example: The car gearbox is an example of a gear train, enabling the driver to match the speed and torque requirements of the terrain with the available engine power.

Types of Gears



(a) (b) (c) (d) (e)

1. **Parallel Shaft Gears (Figure (a)):**

Gears used for the transmission of rotary motion between parallel shafts.

Example: Spur gears (teeth cut along axial lines parallel to the shaft axis).

2. **Bevel Gears (Figure (b)):**

Gears used for shafts with axes inclined to one another, where the lines of the shafts intersect.

Example: When two gears are in mesh, the larger gear wheel is often called the spur or crown wheel, and the smaller one is called the pinion.

3. **Helical Gears (Figure (d)):**

Gears with teeth cut on a helix, resulting in a gradual engagement of individual teeth.

Advantages: Smoother drive and generally prolonged life of the gears.

Consideration: The inclination of teeth introduces an axial force component on the shaft bearing.

4. **Double Helical Gears (Figure (e)):**

Helical gears with double teeth that help overcome the axial force component on the shaft bearing.

Advantage: Reduction of axial forces compared to single helical gears.

Spur Gears vs. Helical Gears

- **Spur Gears (Figure (c)):**

Axial teeth with teeth cut along axial lines parallel to the axis of the shaft.

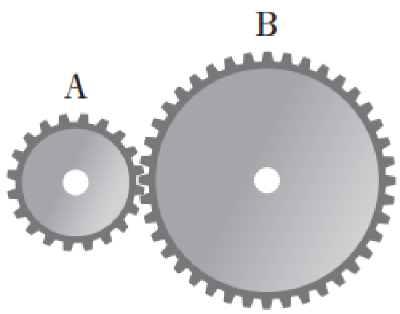
Simple and widely used but may generate more noise than helical gears.

- **Helical Gears:**

Teeth cut on a helix for smoother engagement and reduced noise.

Introduces an axial force component on the shaft bearing, which can be mitigated by using double helical gears.

Consider two meshed gear wheels A and B (Figure). If there are 40 teeth on wheel A and 80 teeth on wheel B, then wheel A must rotate through two revolutions in the same time as wheel B rotates through one.



Thus the angular velocity ω_A of wheel A must be twice the ω_B of wheel B, i.e.

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

Since the number of teeth on a wheel is proportional to its diameter, we can write

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

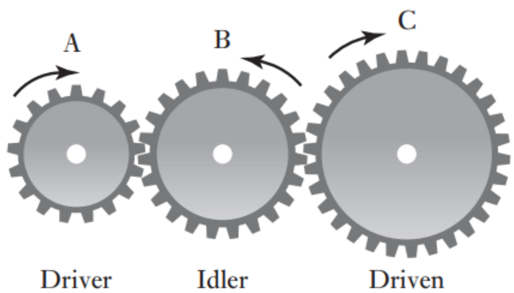
Gear Train

A gear train refers to a series of intermeshed gear wheels that transmit motion and power between rotating shafts.

For such a gear train, the overall gear ratio is the ratio of the angular velocities at the input and output shafts and is thus ω_A/ω_B, i.e.

$$G = \frac{\omega_A}{\omega_C}$$

Consider a simple gear train consisting of wheels A, B and C, as in Figure, with A having 9 teeth and C having 27 teeth. Then, as the angular velocity of a wheel is inversely proportional to the number of teeth on the wheel, the gear ratio is 27/9 = 3. The effect of wheel B is purely to change the direction of rotation of the output wheel compared with what it would have been with just the two wheels A and C intermeshed. The intermediate wheel, B, is termed the idler wheel.

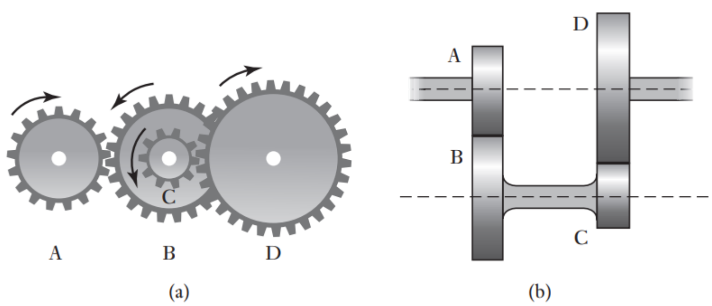


We can rewrite the equation for the overall gear ratio G as

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

But ω_A/ω_B is the gear ratio for the first pair of gears and ω_B/ω_C the gear ratio for the second pair of gears. Thus the overall gear ratio for a simple gear train is the product of the gear ratios for each successive pair of gears.

The term compound gear train is used to describe a gear train when two wheels are mounted on a common shaft. Figure (a) and (b) shows two examples of such a compound gear train. The gear train in Figure (b) enables the input and output shafts to be in line.



When two gear wheels are mounted on the same shaft they have the same angular velocity. Thus, for both of the compound gear trains in Figure, ω_A=ω_B. The overall gear ratio G is thus

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

For the arrangement shown in Figure (b), for the input and output shafts to be in line we must also have for the radii of the gears

$$r_A + r_B = r_D + r_C$$

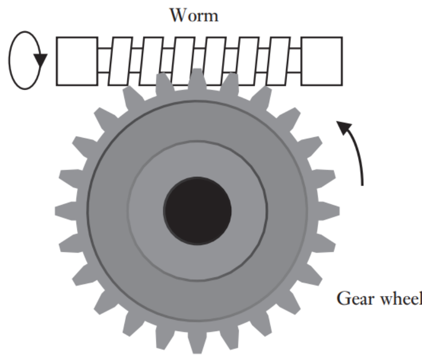
Consider a compound gear train of the form shown in Figure (a), with A, the first driver, having 15 teeth, B 30 teeth, C 18 teeth and D, the final driven wheel, 36 teeth. Since the angular velocity of a wheel is inversely proportional to the number of teeth on the wheel, the overall gear ratio is

$$G = \frac{30}{15} \times \frac{36}{18} = 4$$

Worm Gear

A worm gear is a gear arrangement in which a gear, shaped like a screw and known as the worm, meshes with a gear wheel whose axis is perpendicular to that of the worm.

Illustration: Figure provides a visual representation of a worm gear arrangement.



Characteristics:

- The worm (screw-shaped gear) meshes with the gear wheel, and the motion is not reversible.
- For each complete turn of the worm shaft, the gear shaft advances only one tooth of the gear wheel.
- The reduction ratio is determined by the number of teeth on the gear wheel and the number of distinct threads (starts) on the worm.

Reduction Ratio:

For one revolution of the gear wheel, the worm must rotate by

$$\frac{\text{number of teeth on the wheel}}{\text{number of distinct threads on the worm}}$$

The reduction ratio in a worm gear can be substantial due to the screw-like nature of the worm, offering an efficient means of decreasing speed and increasing power.

Non-Reversibility:

- Unlike ordinary gears, the motion in a worm gear system is not reversible.
- A worm can drive a gear wheel to reduce speed, but a gear wheel cannot effectively drive a worm.

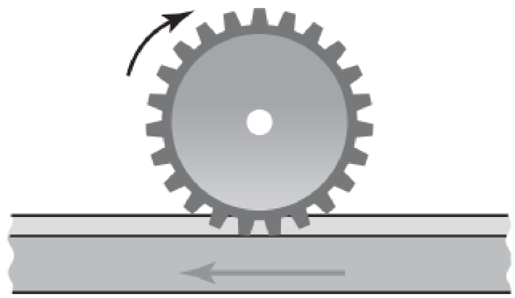
Applications:

- **Compact and Efficient:** Worm gears are compact and efficient, making them suitable for applications where a significant reduction in speed and an increase in power are required.

- **Electric Motors:** They find applications with small electric motors, providing a way to transmit power effectively in a compact space.

Rack-and-Pinion

The rack-and-pinion is a gear mechanism where one gear has a base circle of infinite radius, essentially forming two intermeshed gears.



Transformation: It can be used to transform either linear motion to rotational motion or rotational motion to linear motion.

Screw and Nut System:

- **Description:** The screw and nut system is a method for converting rotary motion to translational motion.
- **Conventional Form:** In the conventional form, the nut is rotated and moves along the stationary screw.
- **Lead Screw:** If the screw is rotated, a nut attached to the driven part moves along the screw thread. This arrangement is called a lead screw.
  - **Lead (L):** The distance moved parallel to the screw axis when the nut is given one turn. For a single thread, the lead is equal to the pitch.

Linear Velocity in Lead Screw System:

- The linear velocity (v) parallel to the screw axis is given by $v=nL/t$, where n is the number of revolutions, L is the lead, and t is the time.

Challenges and Solutions:

- **High Friction:** Direct sliding contact between the screw and the nut can lead to high friction forces.
- **Lack of Rigidity:** The system might lack rigidity.

Ball Screw:

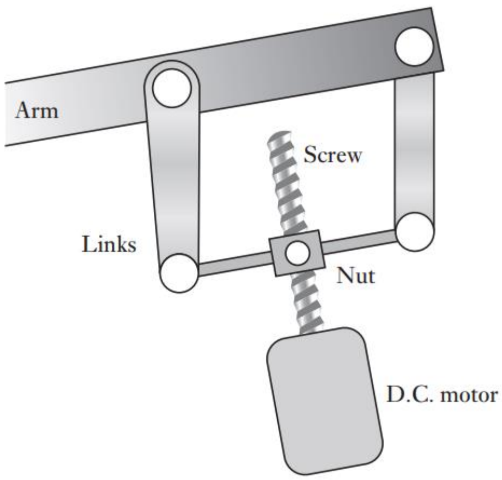
- **Solution:** A ball screw is similar to a lead screw, but ball bearings are located in the thread of the nut. This reduces friction and increases efficiency.

Advantages:

- Reduced friction forces.
- Improved efficiency.
- Enhanced rigidity.

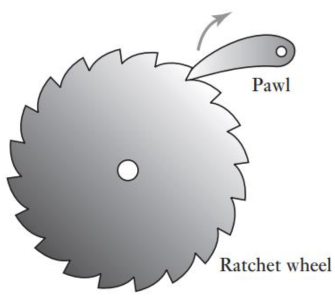
Application Example:

- **Robotic Arm:** Ball screws are used in robotic systems, where a geared d.c. motor rotates the screw, moving the nut along its thread. The movement is then conveyed to the robotic arm via a linkage.



Ratchets and Pawls

Ratchets and pawls are mechanisms designed to lock a mechanism when it is holding a load, preventing undesired motion.



Components:

- **Ratchet:** A wheel with saw-shaped teeth.
- **Pawl:** An arm that engages with the teeth of the ratchet.

Operation: The pawl is pivoted and can move back and forth to engage the teeth of the ratchet. The shape of the teeth allows rotation in only one direction.

- **Unidirectional Rotation:** The mechanism allows rotation of the ratchet wheel only in one direction. Clockwise rotation is prevented by the pawl, and rotation can occur only when the pawl is lifted.
- **Spring Loading:** The pawl is typically spring-loaded to automatically engage with the ratchet teeth.

Application Example:

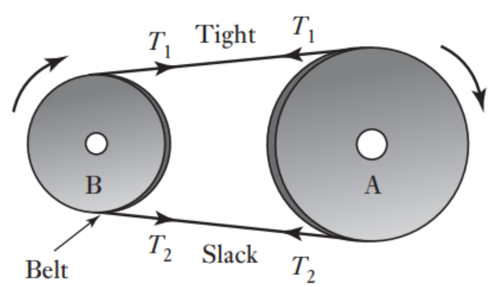
- **Winch with Ratchet and Pawl:**
    - **Scenario:** A winch used to wind up a cable on a drum.
    - **Function:** The ratchet and pawl prevent the cable from unwinding when the handle is released.
    - **Prevention of Unwinding:** When the handle is not actively turning the winch, the pawl engages with the ratchet teeth, preventing the drum from rotating backward and the cable from unwinding.

Benefits of Using Ratchet and Pawl:

- **Load Holding:** Effective in scenarios where it is essential to prevent the mechanism from releasing a load.
- **Automatic Engagement:** The spring-loaded pawl ensures automatic engagement with the ratchet teeth, enhancing reliability.
- **One-Way Motion:** Allows rotation in only one direction, providing control over the movement of the mechanism.

Belt and Chain Drives

Belt drives consist of a pair of rolling cylinders where the motion of one cylinder is transferred to the other by a belt (Figure). Chain drives operate on a similar principle but use a chain instead of a belt.



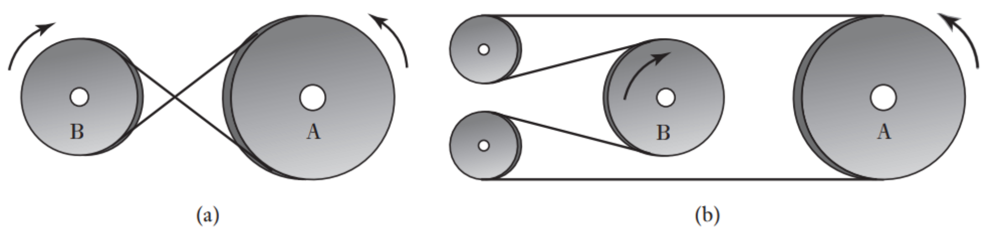
- **Transmission Principle:** Belt drives use friction between the pulleys and the belt to transmit torque. Slip can occur due to the reliance on frictional forces.
- **Tension and Torque Relationship:**
    - Torque on Pulley A: Torque on A=$(T1-T2)\cdot r_A$ where r_A is the radius of pulley A.
    - Torque on Pulley B: Torque on B=$(T1-T2)\cdot r_B$ where r_B is the radius of pulley B.

- The transmitted power is: Power=$(T1-T2)\cdot v$ where v is the belt speed.

- **Advantages of Belt Drives:**
  - Adjustable Length: The length of the belt can be easily adjusted to suit different shaft-to-shaft distances.
  - Overload Protection: The system is automatically protected against overload because slipping occurs if the loading exceeds the maximum tension sustainable by frictional forces.

- **Shaft-to-Shaft Distance Considerations:**
  - Large Distances: Belt drives are more suitable than gears for large distances between shafts.
  - Small Distances: Gears are preferred over short distances.

- **Gearing Effect with Pulleys:**
  - Different-size pulleys can be used to achieve a gearing effect.
  - Gear ratio is limited to about 3 due to the need to maintain an adequate arc of contact between the belt and the pulleys.



Reversed belt drives: (a) crossed belt, (b) open belt.