Power Transmission

Learning Outcome
When you complete this module you will be able to:
Discuss the major types of power transmission systems.

Learning Objectives
Here is what you will be able to do when you complete each objective:

1. Describe belt systems and calculate pulley speeds, transmitted power, and efficiency.

2. Describe gearing systems and calculate gear speeds.
INTRODUCTION

Mechanical power may be transmitted by belts, chains, or gears. Linear motion is motion that takes place in a straight line. For example, a piston moving in a cylinder is moving with linear motion. Circular motion is motion that takes place by rotation about a fixed center. For example, consider a point on the wheel of a vehicle, or the crankpin of an engine.

BELT DRIVES

A belt drive moves a pulley (called the follower or driven pulley) from another pulley (called the driver) by means of a friction force between the surface of the belt and the pulleys.

If there is no slippage between the belt and the pulleys, the linear speed of a point on each pulley will be the same, and equal to the linear speed of the belt. If the pulleys are the same diameter, the rotational speeds (r/min) of the pulleys will be equal. If the driver pulley is smaller in diameter than the follower, the follower will rotate at a lower number of r/min than the driver, and vice versa. Consider a belt driven pulley as shown in Fig. 1.

A belt drive should also be arranged so that the tension (force $F_1$) in the bottom belt is always greater than the tension (force $F_2$) in the top belt. This increases the angle of contact of the belts with the pulleys and reduces slippage, with a resulting increase in power transmission from the driver to the follower. Belt drives are used to transmit power, or to change rotational speeds, or both.
Rotational Speed of Pulleys

If the belts do not slip (i.e., efficiency = 100%), then any point on the rim of each pulley will travel at the same linear speed (m/s) as the belt itself, although the rotational speed (r/min) of the pulleys will vary if they are different diameters. This is illustrated in Fig. 2.

![Belt Drive Diagram](image)

*Figure 2*

*Belt Drive*

If there is no belt slippage, a point on the rim of the driver would travel a distance equal to the circumference of the driver for each revolution.

For one revolution of the driver, the linear distance moved by the belt

\[ = \pi D \text{ (or } 2\pi R) \]

\[ = \pi \times 1 \]

\[ = 3.142 \text{ m} \]

This would be the distance traveled by a point on the belt and also by a point on the rim of the follower.

For one revolution of the follower, the circumference

\[ = \pi D \text{ (or } 2\pi R) \]

\[ = \pi \times 0.5 \]

\[ = 1.571 \text{ m} \]

But for one revolution of the driver, a point on the rim of the follower moves 3.142 m. That is, the follower rotates:

\[ \frac{3.142}{1.571} = 2 \text{ times for each revolution of the driver} \]
Since $\pi$ is a constant, the revolutions of the pulleys are inversely proportional to the diameters. In the last case:

Driver diameter $= 1 \text{ m}$

Follower diameter $= 0.5 \text{ m}$

Revolutions of follower $= \frac{1 \text{ m}}{0.5 \text{ m}} = 2 \times$ revolution of driver

Summary:

If $D_1$ = diameter of pulley 1

$N_1$ = r/min of pulley 1

$D_2$ = diameter of pulley 2

$N_2$ = r/min of pulley 2

then $D_1N_1 = D_2N_2$

$$\frac{N_1}{N_2} = \frac{D_2}{D_1}$$

Also, the linear velocity of a belt being driven without slippage by a rotating drive wheel of radius $R$ (in m) is:

Linear Velocity (in m/s) $= \frac{r \text{ / min } \times 2\pi R}{60}$

Example 1:

A pulley with a diameter of 1 m is driven at (a) 200 r/min, (b) 150 r/min, (c) 120 r/min. What will be the linear speed in m/s of a point on the rim of the pulley for each rotational speed?

Solution:

(a) Linear Velocity $= \frac{r\text{ / min } \times 2\pi R}{60}$

$= \frac{200 \times 2\pi (0.5) \text{ m/s}}{60}$

$= 10.47 \text{ m/s} \text{ (Ans.)}$
(b) Linear Velocity = \( \frac{r/\text{min} \times 2 \pi R}{60} \)

\[ = \frac{150 \times 2 \pi (0.5)}{60} \text{ m/s} \]

\[ = 7.855 \text{ m/s} \text{ (Ans.)} \]

(c) Linear Velocity = \( \frac{r/\text{min} \times 2 \pi R}{60} \)

\[ = \frac{120 \times 2 \pi (0.5)}{60} \text{ m/s} \]

\[ = 6.284 \text{ m/s} \text{ (Ans.)} \]

Example 2:

A pulley with a diameter of 1.5 m is driven at 50 r/min by a belt drive from a pulley of 0.5 m diameter. What will be the r/min of the driving pulley?

Solution:

\[ D_1 = 1.5 \text{ m} \]

\[ N_1 = 50 \text{ r/min} \]

\[ D_2 = 0.5 \text{ m} \]

\[ \frac{N_1}{N_2} = \frac{D_2}{D_1} \]

\[ N_2 = \frac{N_1 D_1}{D_2} \]

\[ = \frac{50 \text{ r/min} \times 1.5 \text{ m}}{0.5 \text{ m}} \]

\[ = 150 \text{ r/min} \text{ (Ans.)} \]
Power Transmitted By Belts

Power transmitted (watts) = \((F_1 - F_2) \times \text{speed of belt}\)

where

- \(F_1\) = Tension on tight side (N)
- \(F_2\) = Tension on slack side (N)

Speed of belt = speed in m/s

Example 3:

The tensions in the tight and slack side of a belt drive system are 2000 N and 500 N, respectively. If the belt speed is 5 m/s, what power will be transmitted if there is no belt slippage?

Solution:

\[
\text{Power} = (F_1 - F_2) \times \text{belt speed} \\
= (2000 \text{N} - 500 \text{N}) \times 5 \text{ m/s} \\
= 1500 \text{ N} \times 5 \text{ m/s} \\
= 7500 \text{ Nm/s} \\
= 7500 \text{ J/s} \\
= 7500 \text{ watts or 7.5 kW (Ans.)}
\]

Belt Slippage

In practice, belts slip on pulley drives and there is a resulting loss of energy or power transmitted, so that the efficiency is less than 100%.

\[
\% \text{ efficiency} = \frac{\text{Power output}}{\text{Power input}} \times 100\%
\]

Example 4:

In a belt drive system, the input to the driver pulley is 75 kW and the output from the follower is 70 kW. What is the % efficiency of the drive?

Solution:

\[
\% \text{ efficiency} = \frac{\text{Output}}{\text{Input}} \times 100\% \\
= \frac{70}{75} \times 100\% \\
= 93.33\% \ (\text{Ans.})
\]
Pulley Trains

A series of pulleys, connected by belts, is called a pulley train. Pulley trains are used to change speeds and/or to transmit power at varying speeds to different shops or machines. When considering pulley trains, the principles for simple pulley arrangements can be applied.

Example 5:

Find the r/min of the 2 m diameter pulley in the train shown in Fig. 3 if (a) there is no belt slippage, (b) there is overall belt slippage of 10%.

![Figure 3: Pulley Train](image)

Solution:

(a) If \( N_1 \) = 100 r/min then

\[
N_2 = N_1 \times \frac{D_1}{D_2} = 100 \times \frac{0.5}{1.5} = 33.33 \text{ r/min}
\]

If pulley #2 rotates at 33.33 r/min, then pulley #3 must also rotate at 33.33 r/min, since it is on the same shaft. Thus \( N_3 = N_2 = 33.33 \text{ r/min} \).

\[
N_4 = N_3 \times \frac{D_3}{D_4} = 33.33 \times \frac{0.5}{2} = 8.33 \text{ r/min} \text{ (Ans.)}
\]
(b) Assuming 10% belt slippage overall,

\[ N_4 \text{ (with belt slippage)} = 8.33 \text{ r/min} - 10\% \text{ of } 8.33 \text{ r/min} \]

\[ = (8.33 - 0.83) \text{ r/min} \]

\[ = 7.50 \text{ r/min} \text{ (Ans.)} \]

**NOTE:** With belt drives, the pulleys all rotate in the same direction.

**Gear Drives**

In gear drives, teeth cut into each gear wheel mesh together to transmit the power. For single gears meshing together, the direction of rotation becomes reversed. The ratio of rotational speeds of the gears depends upon the number of teeth on each gear, Fig. 4.

![Gear Drive Diagram](https://via.placeholder.com/150)

\[ \frac{r/min \ A}{r/min \ B} = \frac{\text{number of teeth on } B}{\text{number of teeth on } A} \]

*Figure 4
Gear Drive*

**Example 6:**

A gear wheel having 20 teeth and rotating at 200 r/min drives a gear having 40 teeth. What will be the r/min of the driven gear?

**Solution:**

\[ \text{Speed of driven gear} = 200 \times \frac{20}{40} \]

\[ = 100 \text{ r/min} \text{ (Ans.)} \]
Intermediate Gears

Intermediate gears, or idler gears, are used to transmit power between gears that are a distance apart. Intermediate gears do not affect the speed of the driven gear, since the same number of teeth mesh with both the driven and driver.

If two intermediate gears were used, then the rotation of the driver and driven gears would be in opposite directions. The intermediate gears do not affect the speed ratio.

Example 7:

An idler gear is used as shown in Fig. 5. The driver rotates at 200 r/min and has 20 teeth. If the driven gear has 30 teeth and the idler gear has 40 teeth, what will be the r/min of the driven gear?

Solution:

\[
\text{r/min } B = \frac{\text{r/min } A \times \text{ teeth on } A}{\text{teeth on } B}
\]

\[
= \frac{200 \times 20}{40}
\]

\[
= 100 \text{ r/min}
\]

\[
\text{r/min } C = \frac{\text{r/min } B \times \text{ teeth on } B}{\text{teeth on } C}
\]

\[
= \frac{100 \times 40}{30}
\]

\[
= 133.33 \text{ (Ans.)}
\]
If there were no intermediate gear:

\[
\frac{r}{\text{min } C} = \frac{r}{\text{min } A \times \text{ teeth on } A}{\text{ teeth on } C}
\]

\[
= 200 \times \frac{20}{30}
\]

\[
= 133.33 \text{ as before}
\]

The idler gear does not reverse the direction of rotation of \( C \), which rotates in the same direction as \( A \). An advantage of gear drives over belt drives is that there is no slippage. However, badly meshing or poorly lubricated gears result in excessive friction and low efficiency. Gears are able to transmit more power than belt systems of comparable size.

**CHAIN DRIVES**

Chain drives use special gears called sprockets, which are driven by chains. An advantage of chain drives is that the gears do not have to mesh together and a positive drive can be obtained over a longer distance. The speeds, etc., of chain drives are calculated in the same way as for gear drives.

**Gear Trains**

A number of gears may mesh together in a train, to produce variations in shaft speeds and directions of rotation.

Gear trains are considered in a similar manner to pulley trains.

**Backlash**

Because clearance is necessary between teeth that have to mesh, gears can be moved slightly when not driving. This movement is called backlash and if excessive can cause extreme forces on the teeth during starting or reversing.
Self Test

After completion of the self-test, check your answers against the answer guide that follows.

1. A driver gear rotates at 200 r/min in an anticlockwise direction and has 20 teeth. The driver gear meshes with the first intermediate gear having 40 teeth which meshes with the second intermediate gear having 20 teeth. The second intermediate gear meshes with the driven gear, which has 30 teeth. Find the speed of rotation of the intermediate gears and the driven gear and the direction of rotation of each gear.

2. A belt pulley has a diameter of 0.855 m and is driven at 305 r/min. What is the linear speed in m/s of a point on the rim of the pulley? If the pulley hub is 200 mm in diameter, what is the linear speed of a point on the hub?

3. The tension in the tight side of a belt is 2500 N and in the slack side is 475 N. The driver pulley is 0.9 m in diameter and runs at 150 r/min. If the efficiency of the drive is 95%, what is the power input and power output?

4. The gear train shown has a driver speed of 150 r/min in a clockwise direction. Find the speed of the driven shaft and its direction of rotation.

5. A chain drive has a driver sprocket of 300 mm dia. and a driven sprocket of 1000 mm dia. What is the speed of the driven shaft if the driver shaft turns at 890 r/min?
Self Test Answers

1. First intermediate gear rotates at 100 r/min clockwise.
   Second intermediate gear rotates at 200 r/min anticlockwise.
   Driven gear rotates at 133.33 r/min clockwise.

2. Linear speed of a point on the rim is 13.65 m/s.
   Linear speed of a point on the hub is 3.19 m/s.

3. Power output is 14 314 watts or 14.3 kW.
   Power input is 15 067 watts or 15.1 kW.

4. 50 r/min clockwise.

5. 267 r/min.

References and Reference Material

For more information on this topic, the following is recommended: