Objectives

- Understand principles of operation of flexible-drive systems.
- Determine allowable forces and torques for flexible-drive systems, along with the necessary sprockets or sheaves.
- Describe basic features of belt-drive systems.
- Describe basic features of chain-drive systems.
- Understand principles of operation of different chain drives.
- Specify types and sizes of chain drives and their associated sprockets for different applications.

Introduction

- **Consequence of failure**: Belts will not break because of overload.
- **Versatility in shaft connection**: Belts are more versatile with many geometries as well as large center distances.
- **Effect on shaft bearing life**: Belts increase bearing load because of the initial tension required.
- **Speed ratio**: Belts will not provide exact speed ratio because of the slippage.

**Table 9.1: Common Applications of Belts and Chains**

<table>
<thead>
<tr>
<th>Belts</th>
<th>Chains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressors</td>
<td>Bicycles</td>
</tr>
<tr>
<td>Sewing machines</td>
<td>Motorcycles</td>
</tr>
<tr>
<td>Textile machines</td>
<td>Power lawn mowers</td>
</tr>
<tr>
<td>Automotive devices</td>
<td>Chain saws</td>
</tr>
<tr>
<td>water pumps</td>
<td>Cranes</td>
</tr>
<tr>
<td>alternators</td>
<td>Hoists</td>
</tr>
<tr>
<td>fans</td>
<td>Paper-mill machinery</td>
</tr>
<tr>
<td>Mixing machines</td>
<td>Conveyors</td>
</tr>
<tr>
<td>Washing machines</td>
<td>Textile machinery</td>
</tr>
<tr>
<td>Printing machinery</td>
<td>All terrain vehicles</td>
</tr>
<tr>
<td>Pumps</td>
<td></td>
</tr>
<tr>
<td>Machine tools</td>
<td></td>
</tr>
<tr>
<td>Crushing machinery</td>
<td></td>
</tr>
</tbody>
</table>
Flat Belts

- Rectangular in cross section mounted on pulleys
- Crowning on the pulley to prevent the belt from running off the pulley

Fig. 14.1 Flat belts – Open belt

Belt Drives

- Driving force, \( F_d = F_t - F_b \)
- Torque, \( T = (F_t - F_b) \cdot r = F_d \cdot r \)
- Ratio of belt drive is similar to gears
  \[ m_m = \frac{D_2}{D_1} \]
- Surface velocity, \( V_m = \frac{\pi D_m n}{12} \text{ ft/min} \)

Example Problem 14-1: Belt Drives

- A flat-belt system has small pulley with 6-inch diameter and large pulley with 10-inch diameter. Small pulley transmits 2 hp at 2450 rpm, and back force of 10 pounds in belt is required for frictional purposes.
- Determine front force, net driving force, and force on shafts.
- Find belt surface speed and output speed.

\[
\begin{align*}
T &= \frac{6000 \text{ hp} \cdot 2450 \text{ rpm}}{33,000 \text{ ft/min}} \\
T &= 51.4 \text{ in-lb} \\
F_d &= T \cdot \frac{r}{r} \\
F_t &= \frac{F_d}{r} \\
F_b &= 10 \text{ lb} \\
F_c &= 17 \text{ lb}
\end{align*}
\]
Then, the front force would be:

\[ F_d = F_f - F_b \]

\[ F_f = F_d + F_b \]

\[ F_f = 17 \text{ lb} + 10 \text{ lb} \]

\[ F_f = 27 \text{ lb} \]

The force pulling the shafts together would be:

\[ F_t = F_f + F_b \]

\[ F_t = 27 \text{ lb} + 10 \text{ lb} \]

\[ F_t = 37 \text{ lb} \]

Find the surface speed:

\[ V_m = \frac{\pi D n}{12} \]

\[ V_m = \frac{\pi \times 6 \text{ in} \times 2450 \text{ rpm}}{12} \]

\[ V_m = 3848 \text{ ft/min} \]

Example Problem 14-1: Belt Drives (cont'd.)

\[ mw = \frac{D_2}{D_1} \]

\[ mw = 10 \div 6 \]

\[ mw = 1.67 \]

Output speed is:

\[ n = \frac{2400 \text{ rpm}}{1.67} \]

\[ n = 1467 \text{ rpm} \]

This is approximate as minor slippage may occur.

Example Problem 14-1: Belt Drives (cont'd.)

Belt Drive - formulae

- Length of belt, \( L = \frac{2C + 1.57(D_s + D_i) + (D_s - D_i)^2}{4 \times C} \)

- Centerline distance, \( C = \frac{B + \sqrt{B^2 - 32(D_s - D_i)^2}}{16} \)

- Where, \( B = 4L - 6.28(D_s + D_i) \)

- Wrap angle, \( \theta = 80^\circ \pm 2 \sin^{-1} \left( \frac{D_s - D_i}{2C} \right) \)

- + for larger pulley

Fig. 14.2 Serpentine Belt System

- Mate 4-inch-diameter sheave with 6-inch-diameter sheave. Their centerlines can range from 18 to 20 inches apart. Select length of belt and determine actual centerline distance. If small sheave rotates 1800 rpm, determine ratio and surface speed. Find the angle of contact for the small sheave.

Belt Drives

- Greater angle of contact is better
- Idler pulley is used for the purpose
- Idler is used to increase the angle of contact which should not be less than 160 deg.

Example Problem 14-2: Belt Drives
Example Problem 14-2: Belt Drives

For determining the length of belt, try centerline spacing of 19 inches.

\[ L = 2C + 1.57(D_1 + D_2) + \frac{(D_2 - D_1)^2}{4C} \]

\[ L = 2(19) + 1.57(4 + 6) + \frac{(6 - 4)^2}{4(19)} \]

\[ L = 53.75 \text{ inches} \]

Assuming a 54-inch belt is available.

Example Problem 14-2: Belt Drives

\[ C = \frac{\pi}{2} \sqrt{\frac{B^2 - 3(D_2 - D_1)^2}{8}} \]

\[ B = 4L - 6.28(D_2 + D_1) \]

\[ B = 4(54) - 6.28(6 + 4) \]

\[ B = 153.2 \]

\[ C = \frac{151.2 + \sqrt{151.2^2 - 3(6 - 4)^2}}{8} \]

\[ C = 19.12 \text{ inches} \]

\[ \omega = \frac{D_2}{D_1} = \frac{6}{4} = 1.5 \]

Example Problem 14-2: Belt Drives (cont’d.)

-- Find the centerline distance:

-- Find the ratio:

Flat belts

- Materials
  - Leather
  - Rubber
  - Canvas

Layers
- Single-ply
- Double-ply
- Triple-ply

Example Problem 14-2: Belt Drives (cont’d.)

-- Find the angle of contact:

\[ \alpha = 180^\circ - 2\sin^{-1}\left(\frac{D_2 - D_1}{2C}\right) \]

\[ \alpha = 180^\circ - 2\sin^{-1}\left(\frac{6 - 4}{2(19.12)}\right) \]

\[ \alpha = 174^\circ \]

Angle of contact

- Is the angle over which the belt makes contact with a pulley
  - Open belt < 180 deg
  - Cross belt > 180 deg

- The amount of horsepower that a pulley can transmit decreases as the angle of contact decreases.

V-belts

- Most popular.
- V belt is designed to ride inside the groove of the pulley or sheave.
- Typical sizes are shown in Fig. 14.4
Fig. 14.3 Cross-section of V-belt in sheave groove

Fig. 14.4 Standard V-belt sizes

V-belts
- Higher friction
- Less back force
- Short shaft sizes

Fig. 14.5 Power Ratings
Example Problem 14-3: V-Belts

- From Figure 14-5, determine power rating for 5 VF Aramide cord belt for input speed of 1800 rpm, output speed of 900 rpm, with input sheave OD of 8 inches and service factor of 1.5.
- Determine standard belt length if input and output shafts need to be about 20 inches apart.

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Example Problem 14-3: V-Belts (cont'd.)

- Output sheave would need to have 16-inch diameter to obtain 900 rpm speed.
- Find approximate length of belt needed:

\[ L = \frac{2C + 1.57(D_1 + D_2) + (D_2 - D_1)^2}{4C} \]

\[ L = \frac{2(20) + 1.57(8 + 16) + (16 - 8)^2}{4(20)} \]

\[ L = 78.5 \text{ inches} \]

- Use an 80-inch belt.

---

V-belts

![V-belts](image)

- Multiple-groove sheave with four ribbed belts (Courtesy of the Gates Rubber Co. Denver, Colorado)

---

Roller chains

- Can connect two parallel shafts
- Similar to gears
- Suitable for very long and short distances
- More compact
- Power transmission efficiency is 98 to 99%
Roller chains

- Regular lubrication is required.
- Better at lower speed because of the inertia
- No back force is required like belts, but a slack is normally used.

Roller chains

- Roller links
  - Two inner end plates, two rollers, and two bushings
- Pin links

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**Figure 14.7 Number 40 Roller chain HP ratings**

<table>
<thead>
<tr>
<th>HP Ratings</th>
<th>Number of Links</th>
<th>Pitch Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 hp</td>
<td>40</td>
<td>0.075 in</td>
</tr>
<tr>
<td>0.2 hp</td>
<td>50</td>
<td>0.090 in</td>
</tr>
<tr>
<td>0.3 hp</td>
<td>60</td>
<td>0.100 in</td>
</tr>
<tr>
<td>0.5 hp</td>
<td>80</td>
<td>0.125 in</td>
</tr>
<tr>
<td>1.0 hp</td>
<td>120</td>
<td>0.150 in</td>
</tr>
<tr>
<td>2.0 hp</td>
<td>180</td>
<td>0.200 in</td>
</tr>
<tr>
<td>5.0 hp</td>
<td>360</td>
<td>0.400 in</td>
</tr>
</tbody>
</table>

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**Example Problem 14-4: Chain Drives**

- From Figure 14-7, determine horsepower rating for number 40 roller chain if input is through 12-tooth sprocket turning at 1800 rpm and output turns at 900 rpm:
  1. \( P = 5.31 \text{ hp} \).
  2. Select output sprocket for this application:
Example Problem 14-4: Chain Drives

• From Figure 14-7, determine horsepower rating for number 40 roller chain if input is through 12-tooth sprocket turning at 1800 rpm and output turns at 900 rpm:
  
  1. \( P = 5.31 \) hp.
  
  2. Select output sprocket for this application:

\[
\text{12 tooth } \frac{1800}{900} = 24 \text{ teeth}
\]

Example Problem 14-4: Chain Drives (cont’d.)

3. Determine surface speed for this application:

\[
F_v = \frac{2 \pi D_n}{12}
\]

\[
F_v = \frac{\pi}{12} (1.91 \times 1800)
\]

\[
F_v = 900 \text{ ft/min}
\]

3. What type of lubrication is recommended for this application?
(Bath or disc lubrication from the bottom of Figure 14-7.)

Example Problem 14-4: Chain Drives (cont’d.)

5. If sprocket centerlines are to be 10 inches apart, how long a chain will be needed in full links?

- Find large sprocket diameter:

\[
D = \frac{P c}{N t} \pi
\]

\[
D = \frac{24}{12} \times 3.82 \text{ inches}
\]

\[
D = 3.82 \text{ inches}
\]

- Use 29- or 30-inch chain.
- This formula is only approximate for chains.

Example Problem 14-4: Chain Drives (cont’d.)

6. What is the force in the chain if the power transmitted is 5.31 hp?

\[
lbin F = \frac{P}{T} \neq \frac{0.31}{1900} \text{ lb/ft}
\]

\[
lbin F = 0.000,63\text{ lb/ft}
\]

7. How does this force compare to the ultimate strength?

\[
F = \frac{2 F}{lbin F} = \frac{186}{0.000,63} = 293.1\text{ lb}
\]

8. Compare the result to the ultimate strength of 3700 pounds (not a valid comparison because of speed, etc.).

Roller chain – Life

- Number of teeth on sprocket: The smaller the number of teeth, the greater the shock loading.
- Chain speed: The greater the chain speed, the greater the shock loading.
- Lubrication: Poor lubrication will shorten the life of a roller due to wear.
- Environment: Dirty or dusty conditions tend to have an adverse affect on roller chain life.

Conclusions

- Belts and chains are used for power transmission.
- These are cheap and accommodate large center distances.
- Angle of contact is very important.
- Flat belts are made from leather, as well as rubber or canvas.
- V-belts are suitable for large torque transmission.
- A number of other types of belts are also used.
- Roller chains provide positive drive. Shock loading on the chain increases if the number of sprocket teeth are reduced or if the speed is increased.