Chain Drives

1. Introduction

In Belt and Rope drives slipping may occur. In order to avoid slipping, steel chains are used. The chains are made up of a number of rigid links which are hinged together by pin joints in order to provide the necessary flexibility for wrapping round the driving and driven wheels. These wheels have projecting teeth of special profile and fit into the corresponding recesses in the links of the chain as shown in Fig. 1. The toothed wheels are known as sprocket wheels or simply sprockets. The sprockets and the chain are thus constrained to move together without slipping and ensures perfect velocity ratio.

![Fig. 1. Sprockets and chain.](image)

The chains are mostly used to transmit motion and power from one shaft to another, when the centre distance between the shafts is short such as in bicycles, motorcycles, agricultural machinery, conveyors, rolling mills, road rollers etc. The chains may also be used for long centre distance of up to 8 metres. The chains are used for velocities up to 25 m/s and for power up to 110 kW. In some cases, higher power transmission is also possible.

2. Advantages and Disadvantages of Chain Drive over Belt or Rope Drive

Advantages

1. As no slip takes place during chain drive, hence perfect velocity ratio is obtained
2. Since the chains are made of metal, therefore they occupy less space in width than a belt or rope drive
3. It may be used for both long as well as short distances
4. It gives high transmission efficiency (up to 98 percent)
5. It gives less load on the shafts
6. It has the ability to transmit motion to several shafts by one chain only

7. It transmits more power than belts

8. It permits high speed ratio of 8 to 10 in one step

9. It can be operated under adverse temperature and atmospheric conditions

**Disadvantages**

1. The production cost of chains is relatively high

2. The chain drive needs accurate mounting and careful maintenance, particularly lubrication and slack adjustment

3. The chain drive has velocity fluctuations especially when unduly stretched

**3. Terms Used in Chain Drive**

1. **Pitch of chain**: It is the distance between the hinge centre of a link and the corresponding hinge centre of the adjacent link, as shown in Fig. 2. It is usually denoted by $p$.

2. **Pitch circle diameter of chain sprocket**: It is the diameter of the circle on which the hinge centres of the chain lie, when the chain is wrapped round a sprocket as shown in Fig. 2. The points A, B,
C, and D are the hinge centres of the chain and the circle drawn through these centres is called pitch circle and its diameter (D) is known as pitch circle diameter.

4. Relation between Pitch and Pitch Circle Diameter

A chain wrapped round the sprocket is shown in Fig. 2. Since the links of the chain are rigid, therefore pitch of the chain does not lie on the arc of the pitch circle. The pitch length becomes a chord. Consider one pitch length AB of the chain subtending an angle θ at the centre of sprocket (or pitch circle),

Let

\[ D = \text{Diameter of the pitch circle, and} \]
\[ T = \text{Number of teeth on the sprocket.} \]

From Fig. 21.2, we find that pitch of the chain,

\[ p = AB = 2AO \sin \left( \frac{\theta}{2} \right) = 2 \times \left( \frac{D}{2} \right) \sin \left( \frac{\theta}{2} \right) = D \sin \left( \frac{\theta}{2} \right) \]

We know that

\[ \theta = \frac{360^\circ}{T} \]

\[ \therefore \quad p = D \sin \left( \frac{360^\circ}{2T} \right) = D \sin \left( \frac{180^\circ}{T} \right) \]

or

\[ D = p \cosec \left( \frac{180^\circ}{T} \right) \]

The sprocket outside diameter \( (D_o) \), for satisfactory operation is given by

\[ D_o = D + 0.8d_1 \]

where

\[ d_1 = \text{Diameter of the chain roller.} \]

Note: The angle θ/2 through which the link swings as it enters contact is called angle of articulation.

5. Velocity Ratio of Chain Drives

The velocity ratio of a chain drive is given by

\[ V.R. = \frac{N_1}{N_2} = \frac{T_2}{T_1} \]

where

\[ N_1 = \text{Speed of rotation of smaller sprocket in r.p.m.,} \]
\[ N_2 = \text{Speed of rotation of larger sprocket in r.p.m.,} \]
\[ T_1 = \text{Number of teeth on the smaller sprocket, and} \]
\[ T_2 = \text{Number of teeth on the larger sprocket.} \]

The average velocity of the chain is given by

\[ v = \frac{\pi D N}{60} = \frac{T p N}{60} \]

where

\[ D = \text{Pitch circle diameter of the sprocket in metres, and} \]
\[ p = \text{Pitch of the chain in metres.} \]
6. Length of Chain and Centre Distance

An open chain drive system connecting the two sprockets is shown in Fig. 3.

Let
\[ T_1 = \text{Number of teeth on the smaller sprocket}, \]
\[ T_2 = \text{Number of teeth on the larger sprocket}, \]
\[ p = \text{Pitch of the chain, and} \]
\[ x = \text{Centre distance}. \]

The length of the chain \( L \) must be equal to the product of the number of chain links \( K \) and the pitch of the chain \( p \). Mathematically,
\[ L = Kp \]

The number of chain links may be obtained from the following expression, \textit{i.e.}
\[ K = \frac{T_1 + T_2}{2} + \frac{2x}{p} + \left( \frac{T_2 - T_1}{2\pi} \right)^2 \cdot \frac{p}{x} \]

The value of \( K \) as obtained from the above expression must be approximated to the nearest even number.

The centre distance is given by
\[ x = \frac{p}{4} \left[ K - \frac{T_1 + T_2}{2} + \sqrt{\left( K - \frac{T_1 + T_2}{2} \right)^2 - 8 \left( \frac{T_2 - T_1}{2\pi} \right)^2} \right] \]

In order to accommodate initial sag in the chain, the value of the centre distance obtained from the above equation should be decreased by 2 to 5 mm.

\textbf{Notes:} 1. The minimum centre distance for the velocity transmission ratio of 3, may be taken as
\[ x_{\text{min}} = \frac{d_1 + d_2}{2} + 30 \text{ to } 50 \text{ mm} \]

where \( d_1 \) and \( d_2 \) are the diameters of the pitch circles of the smaller and larger sprockets.

2. For best results, the minimum centre distance should be 30 to 50 times the pitch.

3. The minimum centre distance is selected depending upon the velocity ratio so that the arc of contact of the chain on the smaller sprocket is not less than 120°. It may be noted that larger angle of arc of contact ensures a more uniform distribution of load on the sprocket teeth and better conditions of engagement.
7. Classification of Chains

The chains, on the basis of their use, are classified into the following three groups:

1. Hoisting and hauling (or crane) chains,
2. Conveyor (or tractive) chains, and
3. Power transmitting (or driving) chains.

8. Hoisting and Hauling Chains

These chains are used for **hoisting and hauling purposes** and operate at a maximum velocity of 0.25 m/s. The hoisting and hauling chains are of the following two types:

1. **Chain with oval links.** The links of this type of chain are of oval shape, as shown in Fig. 4 (a). Such type of chains are used only at low speeds such as in chain **hoists** and in **anchors** for marine works.

2. **Chain with square links.** The links of this type of chain are of square shape, as shown in Fig. 4 (b). Such types of chains are used in **hoists, cranes, dredges.**

9. Conveyor Chains

These chains are used for elevating and conveying the materials continuously at a speed up to 2 m/s. The conveyor chains are of the following two types:

1. Detachable or hook joint type chain, Fig. 5 (a), and 2. Closed joint type chain, Fig. 5 (b)
Conveyor chains are usually made of malleable cast iron and run at slow speeds of about 0.8 to 3 m/s.

10. Power Transmitting Chains

These chains are used for transmission of power, when the distance between the centres of shafts is short. These chains have provision for efficient lubrication. The power transmitting chains are of the following three types.

1. **Block or Bush Chain.** A block or bush chain is shown in Fig. 6. This type of chain was used in the early stages of development in the power transmission.

   ![Fig. 6. Block or bush chain.](image)

   It produces noise when approaching or leaving the teeth of the sprocket because of rubbing between the teeth and the links. Such type of chains is used to some extent as conveyor chain at small speed.

2. **Bush Roller Chain.** A bush roller chain as shown in Fig. 7 consists of outer plates or pin link plates, inner plates or roller link plates, pins, bushes and rollers. A pin passes through the bush which is secured in the holes of the roller between the two sides of the chain. The rollers are free to rotate in the bush protect the sprocket wheel teeth against wear. The pins, bushes and rollers are made of alloy steel.
The roller chains are standardized and manufactured on the basis of pitch. These chains are available in single-row or multi-row roller chains such as simple, duplex or triplex strands, as shown in Fig 8.

3. Silent chain. A silent chain (also known as inverted tooth chain) is shown in Fig 9.

It is designed to eliminate the evil effects caused by stretching and to produce noiseless running. When the chain stretches and the pitch of the chain increases, the links ride on the teeth of the sprocket wheel at a slightly increased radius. This automatically corrects the small change in the pitch. There is no relative sliding between the teeth of the inverted tooth chain and the sprocket wheel teeth. When properly lubricated, this chain gives durable service and runs very smoothly and quietly.

The various types of joints used in a silent chain are shown in Fig 10.
12. Factor of Safety for Chain Drives

The factor of safety for chain drives is defined as the ratio of the breaking strength \( (W) \) of the chain to the total load on the driving side of the chain \( (W) \). Mathematically,
Factor of safety \( \frac{W_B}{W} \) 

The breaking strength of the chain may be obtained by the following empirical relations, i.e. 
\[ W_B = 106 \, p^2 \text{ (in newtons) for roller chains} \]
\[ = 106 \, p \text{ (in newtons) per mm width of chain for silent chains.} \]

where \( p \) is the pitch in mm.

The total load (or total tension) on the driving side of the chain is the sum of the tangential driving force \( F_T \), centrifugal tension in the chain \( F_C \) and the tension in the chain due to sagging \( F_S \).

We know that the tangential driving force acting on the chain,
\[ F_T = \frac{\text{Power transmitted (in watts)}}{\text{Speed of chain in m/s}} = \frac{P}{v} \text{ (in newtons)} \]

Centrifugal tension in the chain,
\[ F_C = m.v^2 \text{ (in newtons)} \]

and tension in the chain due to sagging,
\[ F_S = k.mg.x \text{ (in newtons)} \]

where
\[ m = \text{Mass of the chain in kg per metre length,} \]
\[ x = \text{Centre distance in metres, and} \]
\[ k = \text{Constant which takes into account the arrangement of chain drive} \]
\[ = 2 \text{ to } 6, \text{ when the centre line of the chain is inclined to the horizontal at an angle less than } 40^\circ \]
\[ = 1 \text{ to } 1.5, \text{ when the centre line of the chain is inclined to the horizontal at an angle greater than } 40^\circ \]

The following table shows the factor of safety for the bush roller and silent chains depending upon the speed of the sprocket pinion in r.p.m. and pitch of the chains.

<table>
<thead>
<tr>
<th>Type of chain</th>
<th>Pitch of chain (mm)</th>
<th>Speed of the sprocket pinion in r.p.m.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50</td>
<td>200</td>
</tr>
<tr>
<td>Bush roller chain</td>
<td>12 – 15</td>
<td>7</td>
</tr>
<tr>
<td>20–25</td>
<td>7</td>
<td>8.2</td>
</tr>
<tr>
<td>30–35</td>
<td>7</td>
<td>8.55</td>
</tr>
<tr>
<td>Silent chain</td>
<td>12.7 – 15.87</td>
<td>20</td>
</tr>
<tr>
<td>19.05 – 25.4</td>
<td>20</td>
<td>23.4</td>
</tr>
</tbody>
</table>
13. Permissible Speed of Smaller Sprocket

<table>
<thead>
<tr>
<th>Type of Chain</th>
<th>Number of teeth on sprocket pinion</th>
<th>Pitch of chain (p) in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>Bush roller</td>
<td>15</td>
<td>2300</td>
</tr>
<tr>
<td>chain</td>
<td>19</td>
<td>2400</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>2500</td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>2550</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>2600</td>
</tr>
<tr>
<td>Silent chain</td>
<td>17 – 35</td>
<td>3300</td>
</tr>
</tbody>
</table>

Note: The chain velocity for the roller chains may be as high as 20 ms⁻¹, if the chains are properly lubricated and enclosed, whereas the silent chain may be operated up to 40 ms⁻¹.

14. Power Transmitted by Chains

The power transmitted by the chain on the basis of breaking load is given by,

\[ P = \frac{W_b \times v}{n \times K_s} \text{ (in watts)} \]

where

- \( W_b \) = Breaking load in newtons,
- \( v \) = Velocity of chain in m/s
- \( n \) = Factor of safety, and
- \( K_s \) = Service factor = \( K_1 \times K_2 \times K_3 \)

The power transmitted by the chain on the basis of bearing stress is given by

\[ P = \frac{\sigma_b \times A \times v}{K_s} \]

where

- \( \sigma_b \) = Allowable bearing stress in MPa or N/mm²,
- \( A \) = Projected bearing area in mm²,
- \( v \) = Velocity of chain in m/s, and
- \( K_s \) = Service factor.
Consider an arrangement of a chain drive in which the smaller or driving sprocket has only four teeth, as shown in Fig. 11 (a). Let the sprocket rotates anticlockwise at a constant speed of N r.p.m. The chain link AB is at a distance of $d/2$ from the centre of the sprocket and its linear speed is given by,

$$v = \frac{N \times d}{2 \times \cos \theta}$$

### Table 4. Power rating (in kW) of simple roller chain.

<table>
<thead>
<tr>
<th>Speed of smaller sprocket or pinion (r.p.m.)</th>
<th>Power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>06 B</td>
<td>0.25</td>
</tr>
<tr>
<td>08 B</td>
<td>0.64</td>
</tr>
<tr>
<td>10 B</td>
<td>1.18</td>
</tr>
<tr>
<td>12 B</td>
<td>2.01</td>
</tr>
<tr>
<td>16 B</td>
<td>4.83</td>
</tr>
<tr>
<td>200</td>
<td>0.47</td>
</tr>
<tr>
<td>200</td>
<td>1.18</td>
</tr>
<tr>
<td>300</td>
<td>0.61</td>
</tr>
<tr>
<td>300</td>
<td>1.70</td>
</tr>
<tr>
<td>500</td>
<td>1.09</td>
</tr>
<tr>
<td>500</td>
<td>2.72</td>
</tr>
<tr>
<td>700</td>
<td>1.48</td>
</tr>
<tr>
<td>700</td>
<td>3.66</td>
</tr>
<tr>
<td>1000</td>
<td>2.03</td>
</tr>
<tr>
<td>1000</td>
<td>5.09</td>
</tr>
<tr>
<td>1400</td>
<td>2.73</td>
</tr>
<tr>
<td>1400</td>
<td>6.81</td>
</tr>
<tr>
<td>1800</td>
<td>3.44</td>
</tr>
<tr>
<td>1800</td>
<td>8.10</td>
</tr>
<tr>
<td>2000</td>
<td>3.80</td>
</tr>
<tr>
<td>2000</td>
<td>8.67</td>
</tr>
</tbody>
</table>

The service factor $(K_s)$ is the product of various factors, such as load factor $(K_1)$, lubrication factor $(K_2)$ and rating factor $(K_3)$. The values of these factors are taken as follows:

1. Load factor $(K_1)$
   - $= 1$, for constant load
   - $= 1.25$, for variable load with mild shock
   - $= 1.5$, for heavy shock loads

2. Lubrication factor $(K_2)$ $= 0.8$, for continuous lubrication
   - $= 1$, for drop lubrication
   - $= 1.5$, for periodic lubrication

3. Rating factor $(K_3)$
   - $= 1$, for 8 hours per day
   - $= 1.25$, for 16 hours per day
   - $= 1.5$, for continuous service

### 15. Number of Teeth on the Smaller or Driving Sprocket or Pinion

Consider an arrangement of a chain drive in which the smaller or driving sprocket has only four teeth, as shown in Fig. 11 (a). Let the sprocket rotates anticlockwise at a constant speed of N r.p.m. The chain link AB is at a distance of $d/2$ from the centre of the sprocket and its linear speed is given by,
The maximum allowable speed for the roller and silent chains, depending upon the number of teeth on the smaller sprocket or pinion and the chain pitch is shown in the following table.

### Table 5. Number of teeth on the smaller sprocket.

<table>
<thead>
<tr>
<th>Type of chain</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roller</td>
<td>31</td>
<td>27</td>
<td>25</td>
<td>23</td>
<td>21</td>
<td>17</td>
</tr>
<tr>
<td>Silent</td>
<td>40</td>
<td>35</td>
<td>31</td>
<td>27</td>
<td>23</td>
<td>19</td>
</tr>
</tbody>
</table>

**Note:** The number of teeth on the smaller sprocket plays an important role in deciding the performance of a chain drive. A small number of teeth tends to make the drive noisy. A large number of teeth makes chain pitch smaller which is favourable for keeping the drive silent and reducing shock, centrifugal force and friction force.

### 16. Maximum Speed for Chains

The maximum allowable speed for the roller and silent chains, depending upon the number of teeth on the smaller sprocket or pinion and the chain pitch is shown in the following table.

### Table 6. Maximum allowable speed for chains in r.p.m.

<table>
<thead>
<tr>
<th>Type of chain</th>
<th>Number of teeth on the smaller sprocket (T)</th>
<th>Chain pitch (p) in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>Roller chain</td>
<td></td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
</tr>
<tr>
<td>Silent chain</td>
<td></td>
<td>17–35</td>
</tr>
</tbody>
</table>

**Note:** The r.p.m. of the sprocket reduces as the chain pitch increases for a given number of teeth.