# Introduction to Belt drives

## Instructional Objectives:

At the end of this lesson, the students should be able to understand:

- Uses and advantages of belt drives
- Types of belt drives and their nomenclature
- Relationship between belt tensions
- Some commonly used design parameters

## 13.1.1 Flexible Machine Elements

Belt drives are called flexible machine elements. Flexible machine elements are used for a large number of industrial applications, some of them are as follows.

1. Used in conveying systems
   *Transportation of coal, mineral ores etc. over a long distance*

2. Used for transmission of power.
   *Mainly used for running of various industrial appliances using prime movers like electric motors, I.C. Engine etc.*

3. Replacement of rigid type power transmission system.
   *A gear drive may be replaced by a belt transmission system*

Flexible machine elements has got an inherent advantage that, it can absorb a good amount of shock and vibration. It can take care of some degree of misalignment between the driven and the driver machines and long distance power transmission, in comparison to other transmission systems, is possible. For all the above reasons flexible machine elements are widely used in industrial application.

Although we have some other flexible drives like rope drive, roller chain drives etc. we will only discuss about belt drives.

## 13.1.2 Typical belt drives

Two types of belt drives, an open belt drive, (Fig. 13.1.1) and a crossed belt drive (Fig. 13.1.2) are shown. In both the drives, a belt is wrapped around the pulleys. Let us consider the smaller pulley to be the driving pulley. This pulley will transmit motion to the belt and the motion of the belt in turn will give a rotation to the larger driven pulley. In open belt drive system the rotation of both the pulleys is in the same direction, whereas, for crossed belt drive system, opposite direction of rotation is observed.

## 13.1.3 Nomenclature of Open Belt Drive

**$d_L$** - Diameter of the larger pulley

**$d_S$** – Diameter of the smaller pulley

**$\alpha_L$**- Angle of wrap of the larger pulley

**$\alpha_S$** – Angle of wrap of the smaller pulley

**C**- Center distance between the two pulleys

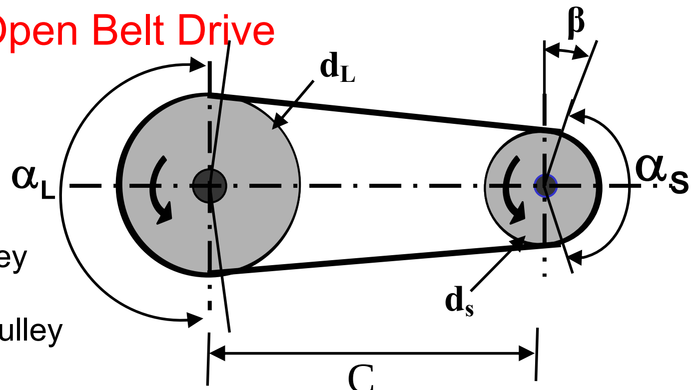


**Fig.13.1.1 Open belt drive**

**Basic Formulae**

$\alpha_L = 180^o + 2\boldsymbol{\beta}$

$\alpha_S = 180^o - 2\boldsymbol{\beta}$

Where angle β is,

$$\beta = \sin^{-1}\left(\frac{d_L - d_S}{2C}\right)$$

**$L_0$** = Length of open belt

$$L_o = \frac{\pi}{2}(d_L + d_S) + 2C + \frac{1}{4C}(d_L - d_S)^2$$

This formulae may be verified by simple geometry.

### 13.1.4 Nomenclature of Cross Belt Drive

**$d_L$** - Diameter of the larger pulley

**$d_S$** – Diameter of the smaller pulley

**$\alpha_L$**- Angle of wrap of the larger pulley

**$\alpha_S$** – Angle of wrap of the smaller pulley

**C**- Center distance between the two pulleys

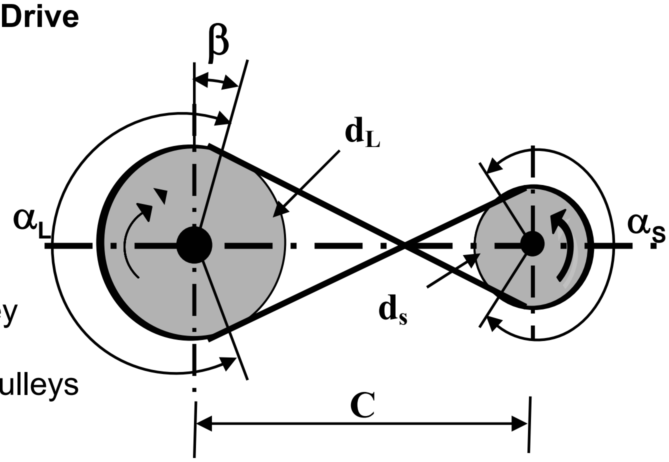


**Fig. 13.1.2 Cross belt drive**

**Basic Formulae**

$\alpha_L = \alpha_S = 180^o + 2\beta$

Where angle β is,

$$\beta = \sin^{-1}\left(\frac{d_L - d_S}{2C}\right)$$

Length of cross belt

$$L_c = \frac{\pi}{2}(d_L + d_S) + 2C + \frac{1}{4C}(d_L + d_S)^2$$

## 13.1.5 Belt tensions

The belt drives primarily operate on the friction principle. i.e. the friction between the belt and the pulley is responsible for transmitting power from one pulley to the other. In other words the driving pulley will give a motion to the belt and the motion of the belt will be transmitted to the driven pulley. Due to the presence of friction between the pulley and the belt surfaces, tensions on both the sides of the belt are not equal. So it is important that one has to identify the higher tension side and the lower tension side, which is shown in Fig. 13.1.3.

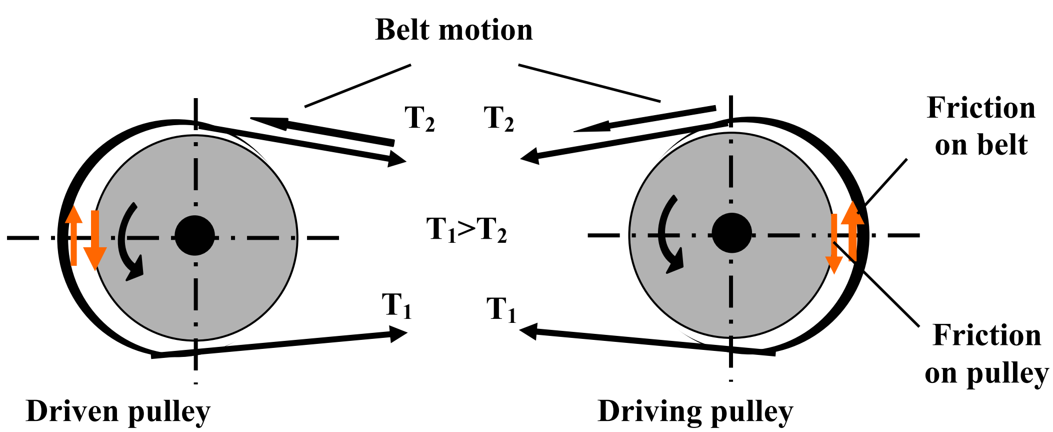


**Fig.13.1.3 Belt tensions**

When the driving pulley rotates (in this case, anti-clock wise), from the fundamental concept of friction, we know that the belt will oppose the motion of the pulley. Thereby, the friction, **f** on the belt will be opposite to the motion of the pulley. Friction in the belt acts in the direction, as shown in Fig. 13.1.3, and will impart a motion on the belt in the same direction. The friction **f** acts in the same direction as $T_2$. Equilibrium of the belt segment suggests that $T_1$ is higher than $T_2$. Here, we will refer $T_1$ as the tight side and $T_2$ as the slack side, ie, $T_1$ is higher tension side and $T_2$ is lower tension side.

Continuing the discussion on belt tension, the figures though they are continuous, are represented as two figures for the purpose of explanation. The driven pulley in the initial stages is not rotating. The basic nature of friction again suggests that the driven pulley opposes the motion of the belt. The directions of friction on the belt and the driven pulley are shown the figure. The frictional force on the driven pulley will create a motion in the direction shown in the figure. Equilibrium of the belt segment for driven pulley again suggests that $T_1$ is higher than $T_2$.

It is observed that the slack side of the belt is in the upper side and the tight side of the belt is in the lower side. The slack side of the belt, due to self weight, will not be in a straight line but will sag and the angle of contact will increase. However, the tight side will not sag to that extent. Hence, the net effect will be an increase of the angle of contact or angle of wrap. It will be shown later that due to the increase in angle of contact, the power transmission capacity of the drive system will increase. On the other hand, if it is other way round, that is, if the slack side is on the lower side and the tight side is on the upper side, for the same reason as above, the angle of wrap will decrease and the power transmission capacity will also decrease. Hence, in case of horizontal drive system the tight side is on the lower side and the slack side is always on the upper side.

## 13.1.6 Derivation of relationship between belt tensions

The Fig.13.1.4 shows the free body diagram of a belt segment.

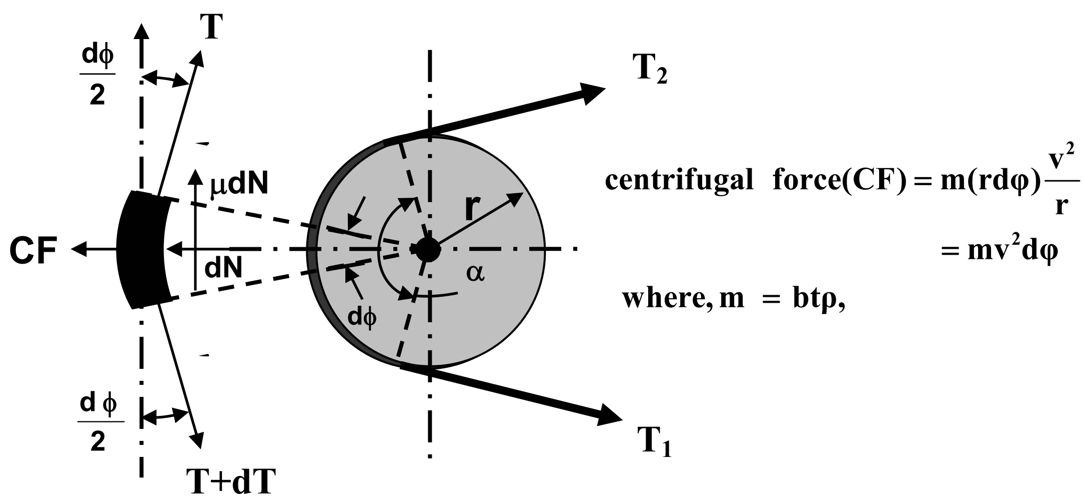


Fig.13.1.4

The belt segment subtends an angle **dφ** at the center. Hence, the length of the belt segment,

$$dl = r\, d\varphi \qquad (13.1.1)$$

At the impending condition, ie., when the belt is in just in motion with respect to the pulley, the forces acting on the belt segment are shown in Fig.13.1.4. This belt segment is subjected to a normal force acting from the pulley on the belt segment and due to the impending motion the frictional force will be acting in the direction as shown in the figure.

$$f = \mu dl \qquad (13.1.2)$$

where **μ** is the coefficient of friction between the belt and the pulley.

The centrifugal force due to the motion of the belt acting on the belt segment is denoted as CF and its magnitude is,

$$CF = [m(rd\varphi)x\ v^2]/r = mv^2 d\varphi \qquad (13.1.3)$$

Where, **v** is the peripheral velocity of the pulley **m** is the mass of the belt of unit length,

$$m = bt\rho \qquad (13.1.4)$$

where, **b** is the width, **t** is the thickness and **ρ** is the density of the belt material.

From the equation of equilibrium in the tangential and normal direction,

$\sum F_t = 0$

$$T\cos\frac{d\phi}{2} - (T + dT)\cos\frac{d\phi}{2} + \mu dN = 0 \qquad (13.1.5)$$

$\sum F_n = 0$

$$mv^2 d\phi + dN + T\sin\frac{d\phi}{2} - (T + dT)\left(\sin\frac{d\phi}{2}\right) = 0 \qquad (13.1.6)$$

For small angle, dφ,

$$\cos\frac{d\phi}{2} \approx 1 \quad \text{and} \quad \sin\frac{d\phi}{2} \approx \frac{d\phi}{2}$$

Therefore, simplified form of (13.1.5) is,

$$dN = \frac{dT}{\mu}$$

(13.1.7)

From (13.1.6) and using (13.1.7),

$$mv^2 d\phi + \frac{dT}{\mu} - Td\phi = 0$$

or, $$\frac{dT}{T - mv^2} = \mu d\phi$$

(13.1.8)

Considering entire angle of wrap,

$$\int_{T_1}^{T_2} \frac{dT}{T - mv^2} = \int_0^{\alpha} \mu d\phi$$

(13.1.9)

The final equation for determination of relationship between belt tensions is,

$$\frac{T_1 - mv^2}{T_2 - mv^2} = e^{\mu\alpha}$$

(13.1.10)

It is important to realize that the pulley, driven or driver, for which the product, **$\mu\alpha$** of (13.1.10) is the least, should be considered to determine the tension ratio. Here, **$\alpha$** should be expressed in radians.

## 13.1.7 Elastic Creep and Initial Tension

Presence of friction between pulley and belt causes differential tension in the belt. This differential tension causes the belt to elongate or contract and create a relative motion between the belt and the pulley surface. This relative motion between the belt and the pulley surface is created due to the phenomena known as elastic creep.

The belt always has an initial tension when installed over the pulleys. This initial tension is same throughout the belt length when there is no motion. During rotation of the drive, tight side tension is higher than the initial tension and slack side tension is lower than the initial tension. When the belt enters the driving pulley it is elongated and while it leaves the pulley it contracts. Hence, the driving pulley receives a larger length of belt than it delivers. The average belt velocity on the driving pulley is slightly lower than the speed of the pulley surface. On the other hand, driven pulley receives a shorter belt length than it delivers. The average belt velocity on the driven pulley is slightly higher than the speed of the pulley surface.

Let us determine the magnitude of the initial tension in the belt.

Tight side elongation $\propto$ $(\mathbf{T_1 - T_i})$

Slack side contraction $\propto$ $(\mathbf{T_i - T_2})$

Where, $\mathbf{T_i}$ is the initial belt tension .

Since, belt length remains the same, ie, the elongation is same as the contraction,

$$\mathbf{T_i = \frac{T_1 + T_2}{2}} \tag{13.1.11}$$

It is to be noted that with the increase in initial tension power transmission can be increased. If initial tension is gradually increased then $\mathbf{T_1}$ will also increase and at the same time $\mathbf{T_2}$ will decrease. Thus, if it happens that $\mathbf{T_2}$ is equal to zero, then $\mathbf{T_1 = 2T_i}$ and one can achieve maximum power transmission.

## 13.1.8 Velocity ratio of belt drive

Velocity ratio of belt drive is defined as,

$$\mathbf{\frac{N_L}{N_S} = \frac{d_S + t}{d_L + t}(1 - s)} \tag{13.1.12}$$

where,

$\mathbf{N_L}$ and $\mathbf{N_S}$ are the rotational speeds of the large and the small pulley respectively, **s** is the belt slip and **t** is the belt thickness.

## 13.1.9 Power transmission of belt drive

Power transmission of a belt drive is expressed as,

$$\mathbf{P = ( T_1 - T_2 )v} \qquad (13.1.13)$$

where,

**P** is the power transmission in Watt and **v** is the belt velocity in m/s.

**Sample problem**

A pump is driven by an electric motor through a open type flat belt drive. Determine the belt specifications for the following data.

Motor pulley diameter($d_S$) = 300 mm, Pump pulley diameter($d_L$) = 600 mm
Coefficient of friction ($\mu_S$) for motor pulley = 0.25
Coefficient of friction ($\mu_L$) for pump pulley = 0.20
Center distance between the pulleys=1000 mm; Rotational speed of the motor=1440 rpm;
Power transmission = 20kW; density of belt material ($\rho$)= 1000 kg/$m^3$ ; allowable stress for the belt material ($\sigma$) = 2 MPa; thickness of the belt = 5mm.

**Solution**

*Determination of angle of wrap*

$$\beta = \sin^{-1}\left(\frac{d_L - d_s}{2C}\right) = 8.63^0$$

$$\alpha_L = 180 + 2\beta = 197.25^0 = 3.44\ rad$$

$$\alpha_S = 180 - 2\beta = 162.75^0 = 2.84\ rad$$

*Length of open belt*

$$L_o = \frac{\pi}{2}(d_L + d_S) + 2C + \frac{1}{4C}(d_L - d_S)^2$$

$$= \frac{\pi}{2}(600 + 300) + 2000 + \frac{1}{4000}(600 - 300)^2 = 3436\ mm$$

$$v = \frac{\pi \times 300 \times 1440}{60 \times 1000} = 22.62\ m/s$$

$$m = bt\rho = \frac{b}{10^3} \times \frac{5}{10^3} \times 10^3 = 0.005 kg/m$$

$$mv^2 = 2.56 \times b\ N$$

*Now,*

$$\mu_s \alpha_s = 0.25 \times 2.84 = 0.71$$

$$\mu_L \alpha_L = 0.20 \times 3.44 = 0.688$$

$\therefore$ *larger pulley governs the design*

$$\frac{T_1 - 2.56b}{T_2 - 2.56b} = e^{0.688} = 1.99 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

*power equation*

$$P = (T_1 - T_2) \times v$$

$\therefore$ *putting data,*

$$(T_1 - T_2) = 884.17 N \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$again, T_1 = 2 \times b \times 5 N$$

$$= 10bN \ \ (\text{from permissible stress}) \ldots\ldots\ldots\ldots\ldots (3)$$

*From (1), (2) and (3), solving for b,*

$$b \approx 240\ mm$$

*Hence, the required belt dimensions are,*

*Length = 3436 mm; breadth = 240 mm and thickness = 5 mm*

## Questions and answers

Q1. What are the advantages of a belt drive?

A1. The advantages of a belt drive are that, it can absorb a good amount of shock and vibration. It can take care of some degree of misalignment between the driven and the driver machines and long distance power transmission, in comparison to other transmission systems, is possible.

Q2. Why the slack side of the belt of a horizontal belt drive is preferable to place on the top side?

A2. The slack side of the belt is preferably placed on the top side because, the slack side of the belt, due to its self weight, will sag. For this reason the angle of contact between the belt and the pulleys will increase. However, the tight side will not sag to that extent. Hence, the net effect will be an increase in the angle of contact or angle of wrap. Thus, due to the increase in angle of contact, the power transmission capacity of the drive system will increase.

Q3. Which one should be the governing pulley to calculate tension ratio?

A3. The pulley, driven or driver, for which the product, $\mu\alpha$ of equation for belt tension is the least, should be considered to determine the tension ratio.

## References


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