सत्यं शिवं सुन्दरम्

DEPARTMENT OF MECHANICAL ENGINEERING

The Maharaja Sayajirao University of Baroda

Vadodara

Chapter-1

1.1 Introduction:

The power is transmitted from driver shaft to the driven shaft by means of various elements depending on the distance between them. The belts and ropes are flexible members preferably used when the distance between the two shafts is large while the chain drive is preferred when the distance is intermediate. The gear drive is used when the shafts are very close with each other and the no slip characteristic of the drive makes it a positive drive. If the distance is slightly larger, chain drive can be used for making it a positive drive. Belts and ropes transmit power due to the friction between the belt or rope and the pulley and as there is a possibility of slip and creep, this drive is not a positive drive.

1.1.1 Problems to be encountered & studied with Belt Drive System during Power Transmission:

Belts, along with electrical motors, shafts, and pulleys, are the critical components of power transmission in belt drive systems. While belts require very little maintenance, improper belt tension, misalignment of pulleys, mishandling of belts and environmental factors are common problems that can shorten the life of the belts and bring the power drive system to a halt.

1.1.2 The Project aims for experimental study and analysis with an intension:

(1) To understand the concept of circumferential force (effective force) and the forces on the tight side and slack side of the belt in a belt drive system,
(2) To study & verify the theoretical equation with experimental results for analysing the relationship between the belt tension ratio and coefficient of friction,
(3) To understand the concept of maximum circumferential force acting in the given belt drive system,
(4) To determine the maximum circumferential force transmitted under given working conditions,
(5) To understand the effect of wrap angle and coefficient of friction on transmission capacity of the belt,
(6) To understand the concept of pre-tensioning of the belt and to determine the minimum pre-tensioned force, and
(7) To study the causes and effects of different problems to be faced with belt as power drive system.

1.1.3 Scope of the Work and contribution of the students:

The experimental study covers the measurement of tight side and slack side tensions of the belt with salient wrap angles i.e. 90˚, 180˚, 270˚ and 360˚. The work content involves the graphical presentation and comparative study of the tensions as well as tension ratio with different wrap angles. It also involves the comparison of theoretical and experimental results related to coefficient of friction based on graphical presentation.

The group of students initialised with their ideas and thoughts focusing on various theoretical aspects of the project entitled as "**Experimental Study of Belt Tension Measurement with salient wrap angles**". The work content has been laid down in consultation with the guide **Prof Kalpesh m Bhavsar** and each an individual student has been assigned appropriate responsibility to carry out the project so as to get it completed within the timeline set by the authority. The details of the work responsibility assigned to accomplish the project are briefly described below:

Sr. No.	**Full Name of the Student**	**PRN Number**	**Work/ Activity description (until December,2020)**	**Work Status with remark**
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4.	Somaiya Devkumar Hareshbhai devbro38@gmail.com	2018033800138005	Physical research & Contact, Derivations	
5.	Varia Dhruv Prafulbhai dhruvvaria1101@gmail.com	2018033800138992	Documentation, Formating, Images	

Chapter-2

Comparative Study

2.1 Power Transmission

It is the movement of energy from its place of generation to a location where it is applied to perform useful work.

Power is defined formally as units of energy per unit time. In SI units:

$$\text{watt} = \frac{\text{joule}}{\text{second}} = \frac{\text{newton} \times \text{meter}}{\text{second}}$$

We are transmitting many forms of power, like

1. Electrical Power
2. Mechanical Power
3. Thermal Power
4. Chemical & Fuels

2.1.1 Mechanical Power Transmission

Mechanical power transmission is the transfer of energy from where it's generated to a place where it is used to perform work using simple machines, linkages and mechanical power transmission elements.

Nearly all machines have some kind of power and motion transmission from an input source. This is usually an electric motor or an internal combustion engine which typically provides rotary driving torque via an input shaft – coupling combination.

2.1.2 Why do we need Mechanical Power Transmission?

There are many ways to generate power but sometimes it's impossible to generate power where it's needed.

Mechanical power transmission and its elements are used for the following reasons:

1. Generated power or energy can be converted into a useful form.
2. Physical lack of limit of the power generation at the place where its used hence it can be transferred from source to a place where it is needed.
3. It can be used to change direction and magnitude such as speed or torque.
4. It can be used to change the type of energy i.e. rotational to linear and vice versa.

2.1.3 Types of Mechanical Power Transmission Elements

1. Shafts ad Couplings -

Shafts and Couplings are an integral part of the power transmission for modern age engineering product designs such as machinery. Since power transmission shafts are widely used in almost all types of mechanical equipment design, the design is critical for the safe and long life of the machines.

2. Power Screws -

A Power screw also known as Leadscrew (or lead screw) and translation screw, is a screw used as a power transmission linkage element in an engineering product such as machine to translate rotational motion into linear motion. The large area of sliding contact between the male and female part of the screw threads provides large mechanical advantage via the small wedge angle.

3. Gears and Gear Trains -

Gear trains are multiple sets of gears that transmit power. A gear train is a mechanical power transmission system where gears are installed on shafts so the teeth of the mating gears engage and each roll on each other on its pitch circle diameter.

4. Brakes and Clutches –

A brake function in a similar manner, except that one of the elements, is fixed, so when actuated the common angular velocity is zero.

Although brakes and clutches are known for its automotive application, it’s also widely used in winches, mowers, hoists, washing machines, tractors, mills, elevators and excavators.

5. Chains and Sprockets -

Chains are used for lower speed applications where distance between the shafts are too far apart to use gear trains and belts are going to support the torque that needs transmitting. They are also a good way of transmitting power when exact speed ratios are needed.

6. Belts, Ropes and Pulleys

Belts and pulleys are used when the distance between the shafts too far apart to use gears.

2.1.4 Various kind of Power Drives System

Belts and pulleys are used when the distance between the shafts too far apart to use gears.

1. Gear Transmission –

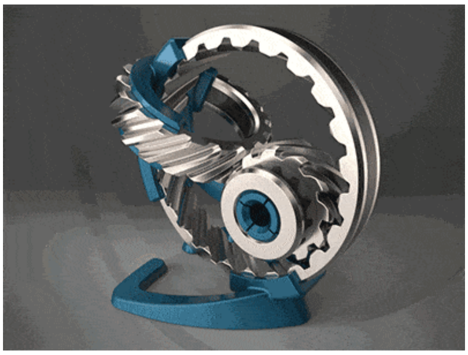


Fig. 2.1

Gear transmission is the most widely used form of transmission in mechanical transmission. Its transmission is more accurate, high efficiency, compact structure, reliable operation and long service life. Gear drives can be divided into many different types according to different standards.

	PROS		CONS
1.	Compact structure, suitable for short distance transmission.	1.	High manufacturing and installation accuracy and high cost
2.	Wide range of applicable peripheral speeds and powers.	2.	Not suitable for transmission between two axes at a long distance.
3.	The transmission ratio is accurate, stable and efficient, High reliability and long life.	3.	No overload protection.
4.	It can realize the transmission between the parallel axis, the intersecting axis of any angle and the staggered axis of any angle.		

Table No.2.1

2. Turbo Vortex Drive –

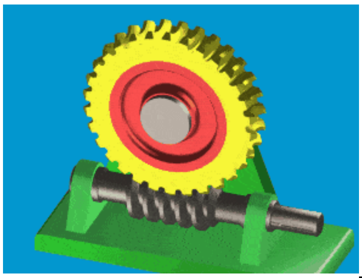


Fig. 2.2

Suitable for motion and power between two axis's with vertical and non-intersecting spaces.

	PROS		**CONS**
1.	Large transmission ratio.	1.	Large axial force Easy to heat.
2.	The structure is compact.	2.	Low efficiency Only one-way transmission.

Table No.2.2

3. Belt Drives –

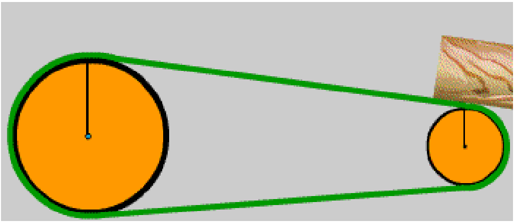


Fig. 2.3

A belt drive is a mechanical transmission that utilizes a flexible belt that is tensioned on a pulley for motion or power transmission. The belt drive usually consists of a drive wheel, a driven wheel and an endless belt that is tensioned on the two wheels.

	PROS		**CONS**
1.	Applicable to the transmission with a large centre distance between the two shafts, the belt has good flexibility, can mitigate the impact and absorb vibration	1.	The outer dimensions of the transmission are large.
2.	Slip during overload to prevent damage to other parts.	2.	The tensioning device is required.
3.	Simple structure and low cost.	3.	Due to slippage, a fixed gear ratio cannot be guaranteed.
		4.	The belt has a short life span & The transmission efficiency is low

Table no. 2.3

4. Chain Drive

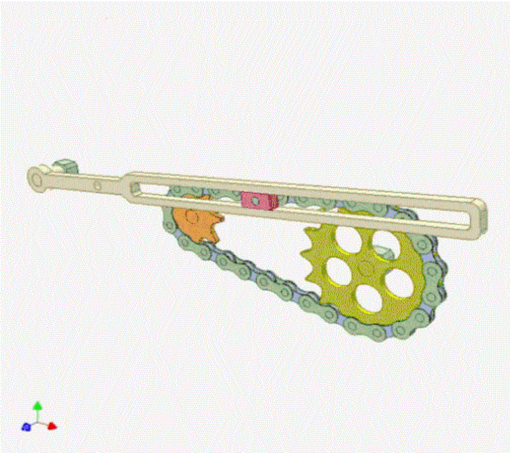


Fig. 2.4,

The chain drive is a transmission method in which the movement and power of a drive sprocket having a special tooth shape are transmitted to a driven sprocket having a special tooth shape through a chain. Including: 1) active chain driven chain 2) circular chain.

	PROS		CONS
1.	Chain drives have many advantages, compared to belt drives, In elastic sliding and slipping phenomenon, accurate average transmission ratio, reliable operation and high efficiency.	1.	Can only be used for transmission between two parallel shafts High Cost Easy to wear, easy to stretch, poor transmission stability.
2.	The transmission power is large, the overload capability is strong, and the transmission size under the same working condition is small.	2.	Additional dynamic loads, vibration, shock and noise are generated during operation. It should not be used in a fast reverse drive.
3.	The required tension is small, and the pressure acting on the shaft is small.		
4.	It can work in harsh environments such as high temperatures, humidity, dust, and pollution temperatures, humidity, dust, and pollution. Compared with gear transmission, chain drive featured.		
5.	The instantaneous chain speed and instantaneous gear ratio are not constant, and the transmission is less stable.		

Table No.2.4

5. Wheel Train

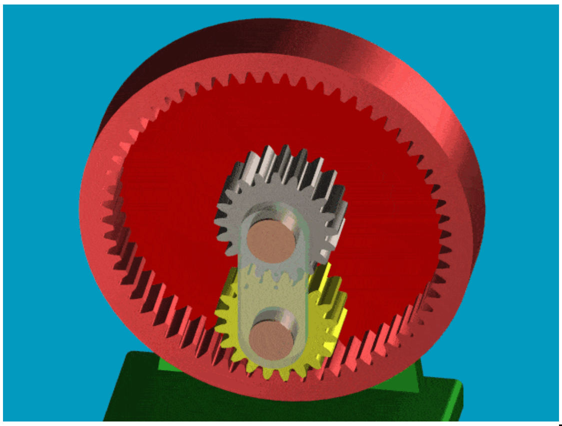


Fig. 2.5

A transmission consisting of more than two gears is called wheel train. According to whether there is axis movement in the wheel train, the gear transmission can be divided into ordinary gear transmission and planetary gear transmission A gear that has an axis motion in a wheel train is called a planetary gear.

There are two types of Wheel Train –

1. Fixed Axle Train
2. Epi Cyclic Train

2.2 Belt Drives – Introduction

Belt Drives are a type of frictional drives used for transmitting powers from one shaft to another by means of pulleys which rotate at the same speed or at the different speed. The belts or ropes are used to transmit power.

Power transmission belting has been used for more than 200 years. The first belts were flat and ran on flat pulleys. Later, cotton or hemp rope was used with V-groove pulleys to reduce belt tension. This led to the development of the vulcanized rubber V-belt in 1917. The need to eliminate speed variations led to the development of synchronous or toothed belts about 1950 and the later development of fabric-reinforced elastomer materials.

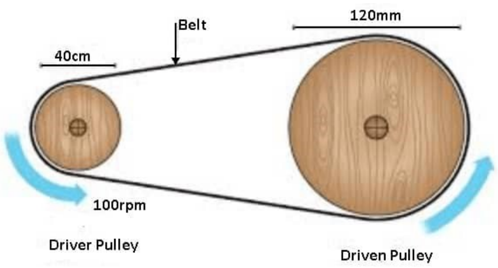


Fig. 2.6

A belt drive is shown in the figure. It consists of two pulleys over which an endless belt it passed over them. The mechanical power or rotary motion is transmitted from the driving pulley to the driven pulley because of the frictional grip that exists between the belt and the pulley surface.

The portion of the belt which is having less tension is called **slack side** and the one which has **higher tension** is called **tight side**. The effective pulling power of the belt that causes the rotation of the driven pulley is the difference in tension on the slack and tight side.

The tensions in the tight and slack sides of the belt depend on the angle of contact, the belt drives have to be arranged such that the slack side comes above and the tight side comes below the pulleys.

2.2.1 The amount of power transmitted depends upon the following factors:

1. The velocity of the belt.
2. The tension under which the belt is placed on the pulleys.
3. The arc of contact between the belt and the smaller pulley.
4. The conditions under which the belt is used.

It may be noted that

I. The shafts should be properly in line to insure uniform tension across the belt section.
II. The pulleys should not be too close together, in order that the arc of contact on the smaller pulley may be as large as possible.

III. The pulleys should not be so far apart as to cause the belt to weigh heavily on the shafts, thus increasing the friction load on the bearings.

IV. A long belt tends to swing from side to side, causing the belt to run out of the pulleys, which in turn develops crooked spots in the belt.

V. The tight side of the belt should be at the bottom, so that whatever sag is present on the loose side will increase the arc of contact at the pulleys.

VI. In order to obtain good results with flat belts, the maximum distance between the shafts should not exceed 10 metres and the minimum should not be less than 3.5 times the diameter of the larger pulley.

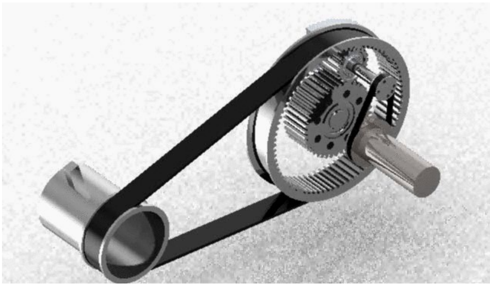


Fig 2.7

This arrangement increases the angled contact of the belt on the driven side. Sometimes in a belt-drive, there is always a possibility of some slipping taking place between the belt and the pulleys which cause the driven pulley to rotate at a lesser speed, consequently reduces the power transmission. Hence belt drives are said to be not a Positive type of power transmission system.

2.2.3 Selection of Belt Drive

The selection of belt drive depends on several factors. Some of them I am listed out here:

- It requires a positive drive.
- The centre distance between the shaft and pulley.
- The speed of the driver and driven pulley.
- Power transmitted between the system.

2.2.4 Advantages

1. It can easily install and easily remove
2. The price of the belt drive is low.
3. Simple in construction.
4. The maintenance cost is low.
5. It can transfer power vertical, horizontal and inclined too.
6. Power consumption is low.

7. Cleanliness
8. Lubrication-free
9. Absorbs shock loads
10. Wide selection of speed ratios
11. Can provide variable speeds
12. Quiet operation
13. Efficiency over 95%
14. Transmits power between widely spaced shafts
15. Visual warning of failure

2.2.5 Disadvantages

1. Power loss due to slip and creep.
2. Not used for a very short distance.
3. And speed is limited to some extent.
4. Chances of breaking are more.
5. The operation temperature is limited between -35 to 85 degrees Celsius. If it exceeds temperature, then it causes wear.
6. Angular velocity ratio is not necessarily constant or equal to the ratio of pulley's diameter because of slipping.
7. Longer life is not possible.
8. Need to retention periodically
9. Deterioration from exposure to lubricants or chemicals
10. Cannot be repaired, must be replaced.

2.2.6 Applications

Belt-drives are used in various places like:

- A belt drive is used to transfer power.
- The belt drive is used in the Mill industry.
- The belt drive is used in Conveyor.

2.2.7 Types of Belt Drives

The belt drives are usually classified into the following three groups:

1. Light drives: These are used to transmit small powers at belt speeds up to about 10 m/s as in agricultural machines and small machine tools.

2. Medium drives: These are used to transmit medium powers at belt speeds over 10 m/s but up to 22 m/s, as in machine tools.

3. Heavy drives: These are used to transmit large powers at belt speeds above 22 m/s as in compressors and generators.

2.2.8 Types of Flat Belt Drives

The power from one pulley to another may be transmitted by any of the following types of belt drives.

1. Open belt drive -

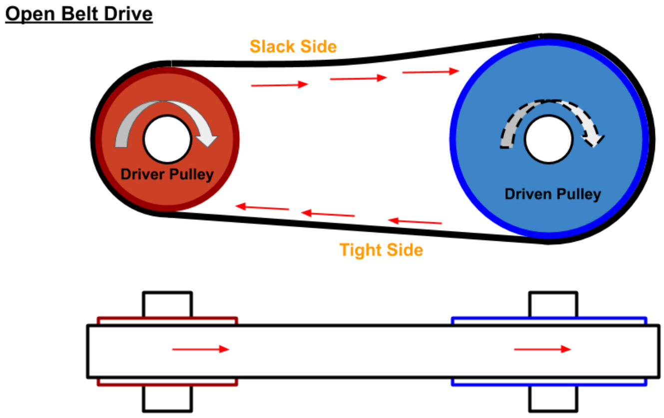


Fig. 2.8

The open belt drive, as shown in Fig.is used with shafts arranged parallel and rotating in the same direction. In this case, the driver A pulls the belt from one side (i.e. lower side RQ) and delivers it to the other side (i.e. upper side LM). Thus the tension in the lower side belt will be more than that in the upper side belt. The lower side belt (because of more tension) is known as tight side whereas the upper side belt (because of less tension) is known as slack side, as shown in Fig.

2. Crossed or twist belt drive –

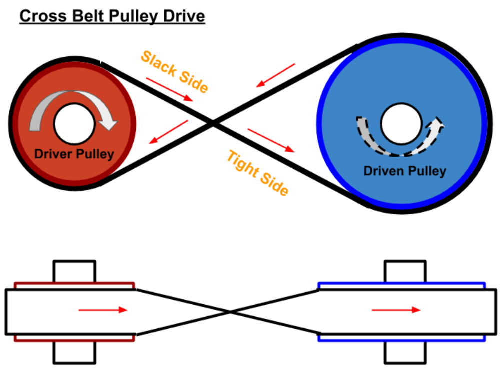
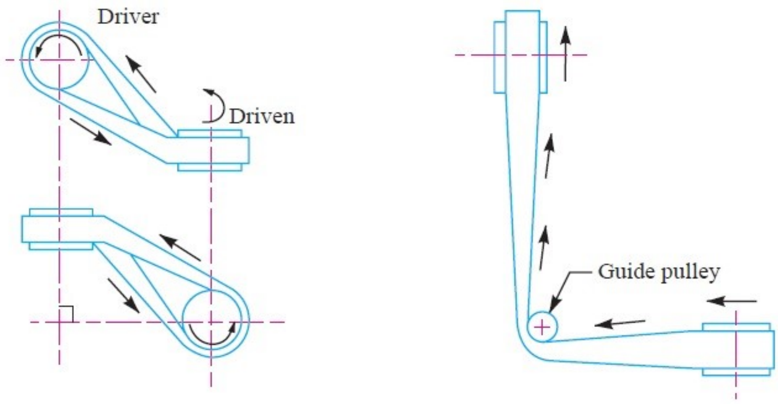


Fig. 2.9

The crossed or twist belt drive, as shown in Fig., is used with shafts arranged parallel and rotating in the opposite directions. In this case, the driver pulls the belt from one side (i.e. RQ) and delivers it to the other side (i.e. LM). Thus, the tension in the belt RQ will be more than that in the belt LM. The belt RQ (because of more tension) is known as tight side,

whereas the belt LM (because of less tension) is known as slack side, as shown in Fig. A little consideration will show that at a point where the belt crosses, it rubs against each other and there will be excessive wear and tear. In order to avoid this, the shafts should be placed at a maximum distance of 20 b, where b is the width of belt and the speed of the belt should be less than 15 m/s.

3. Quarter turn belt drive -



(*a*) Quarter turn belt drive. (*b*) Quarter turn belt drive with guide pulley. **Fig. 2.10**

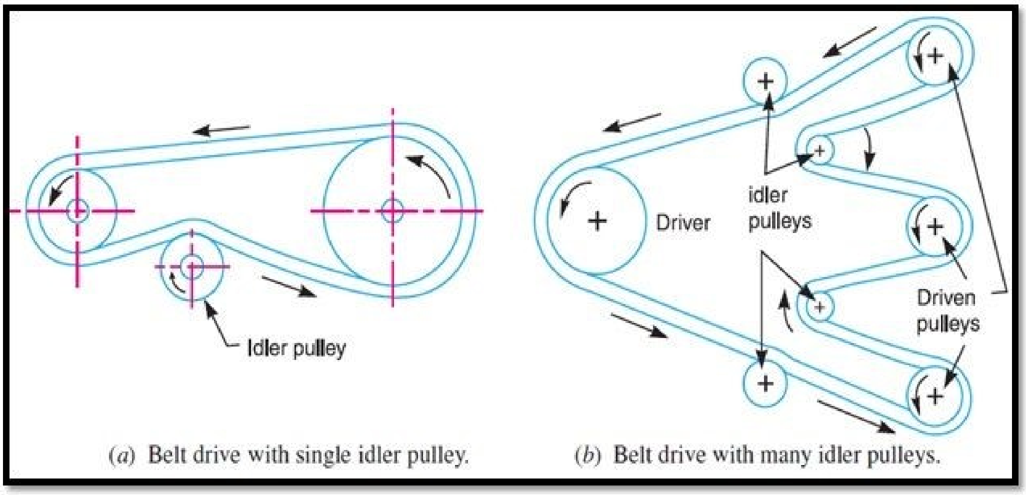
The quarter turn belt drive (also known as right angle belt drive) as shown in Fig. is used with shafts arranged at right angles and rotating in one definite direction.

In order to prevent the belt from leaving the pulley, the width of the face of the pulley should be greater or equal to 1.4 b, where b is width of belt.

In case the pulleys cannot be arranged as shown in Fig. or when the reversible motion is desired, then a quarter turn belt drive with a guide pulley, as shown in Fig., may be used.

4. Belt drive with idler pulleys –

A belt drive with an idler pulley (also known as jockey pulley drive) as shown in Fig, is used with shafts arranged parallel and when an open belt drive cannot be used due to small angle of contact on the smaller pulley. This type of drive is provided to obtain high velocity ratio and when the required belt tension cannot be obtained by other means.



(a) Belt drive with single idler pulley. (b) Belt drive with many idler pulleys.

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Fig 2.11

A belt drive with an idler pulley (also known as jockey pulley drive) as shown in Fig, is used with shafts arranged parallel and when an open belt drive cannot be used due to small angle of contact on the smaller pulley. This type of drive is provided to obtain high velocity ratio and when the required belt tension cannot be obtained by other means.
When it is desired to transmit motion from one shaft to several shafts, all arranged in parallel, a belt drive with many idler pulleys, as shown in Fig. employed.

5. Compound belt drive -

A compound belt drive as shown in Fig , is used when power is transmitted from one shaft to another through a number of pulleys. Compound belt drive.

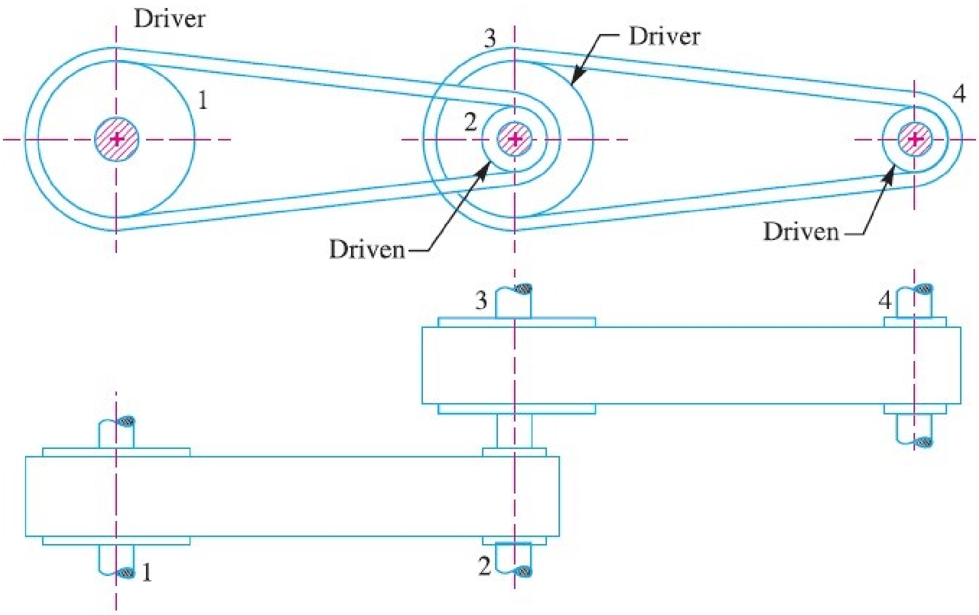


Fig. 2.12

6. Stepped or cone pulley drive -

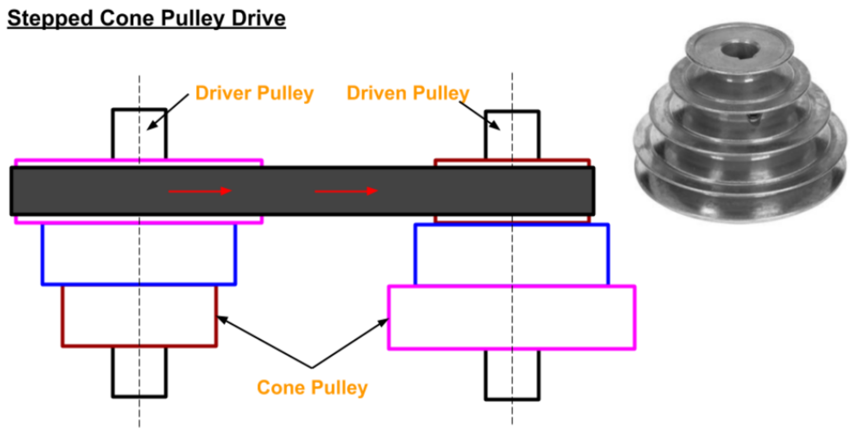


Fig. 2.13

A stepped or cone pulley drive, is used for changing the speed of the driven shaft while the main or driving shaft runs at constant speed. This is accomplished by shifting the belt from one part of the steps to the other.

7. Fast and loose pulley drive -

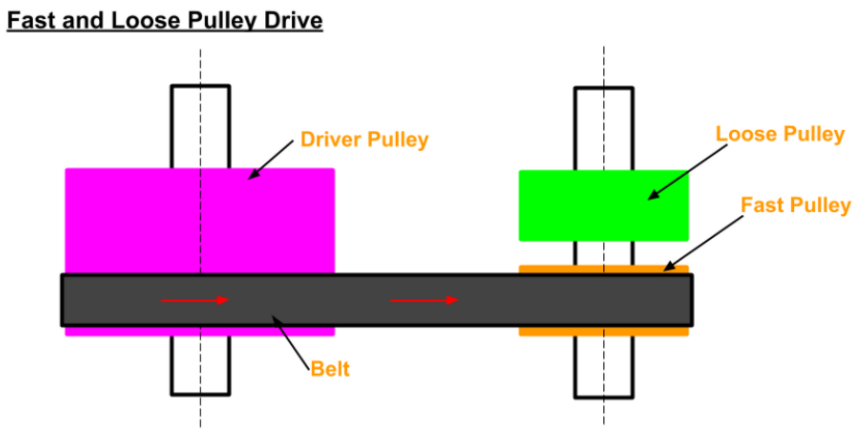


Fig. 2.14

A fast and loose pulley drive, as shown in Fig., It is used when the driven or machine shaft is to be started or stopped whenever desired without interfering with the driving shaft. A pulley which is keyed to the machine shaft is called fast pulley and runs at the same speed as that of machine shaft. A loose pulley runs freely over the machine shaft and is incapable of transmitting any power. When the driven shaft is required to be stopped, the belt is pushed on to the loose pulley by means of sliding bar having belt forks.

2.3 Terms Related to Belt Drive –

2.3.1 Law of Belting -

The centre line of the belt as it approaches the pulley must lie in a plane perpendicular to the axis of the pulley, or must lie in the plane of pulley, otherwise the belt will run of the pulley.

2.3.2 Velocity ratio or Speed ratio of belt drive -

Velocity ratio/Speed ratio is defined as the ratio of speed of the driving pulley (n) to the speed of driven pulley (N). In other terms its the ratio of diameter of the driven pulley (D) to the diameter of driving pulley (d).

$$i = \frac{D}{d} = \frac{n}{N}$$

2.3.3 Tight side and slack side -

When belt is running over pulley, the friction creates grip on pulley which creates tension on one side of belt which makes the driven pulley to run, this side is called tight side. The other side does not experience same tension, that side is called slack side.

2.3.4 Slip and Its effect -

Slip is a type of loss occurring in belt drives. When the friction force between the pulley and belt is less, the belt moves without rotating the pulley or pulley rotates without pulling the belt.

2.3.5 Angle of contact (θ) -

The angle subtended by the belt on the pulley is known as angle of contact or arc of contact. For better performance the angle of contact should be between 90° to 170°. To increase the angle of contact idler pulleys can be used.

2.3.6 Belt creep -

As the belt moves from slack side to tight side the tension increases. That is tension is less in slag side and high in tight side. This results in elongation of belt in tension side resulting in less thickness on tension side. This is called creep.

2.3.7 Belt Wiping -

As the distance between the pulley driven by belt increases, the belt begins to vibrate in the direction perpendicular to the direction of motion of the belt drive. These vibrations of belt drives are called wiping.

2.3.8 Centrifugal tension in belt -

When the belt runs round the pulleys, a centrifugal force is produced on the belt. This force tends to lift the belt from the pulley surface, resulting in more tension on belt.

T_1 - Tension on tight side
T_2 - Tension on slack side
μ - Coefficient of friction
θ - Angle of contact

$$\frac{T_1}{T_2} = e^{\mu\theta}$$

In classic mechanical physics, a pulley is one of the six "simple machines," along with the lever, inclined plane, screw, wheel and axle, and wedge. In the classic description of the renaissance scientists who first defined them, a simple machine is a device that changes the direction or magnitude of a force.

A pulley consists of a rope and a hub or "drum" in which there is a grooved wheel mounted with an axle. The pulley has a wide range of applications in many circumstances and can be used to make a variety of moving and lifting tasks easier. There are three basic types of pulleys, one that changes the direction of the force, one that changes the magnitude, and one that changes both the magnitude and direction.

2.4 Difference between Belt Drive and Chain Drive

	BELT DRIVE		CHAIN DRIVE
1.	Belt drive is used for transferring the power.	1.	The chain drive is also used for transferring power.
2.	The belt drive is powered by only a belt.	2.	The chain drive is powered by a chain loop.
3.	Belt drives are made up of synthetic material. This is not stronger as compared to the belt drive.	3.	Chain drives are made up of metal which is stronger and more durable.
4.	Belt drives are used in mills.	4.	The chain drive is used in bicycles, motorcycles, and many more engines.
5.	In belt drive, little difficulties have when it gets damaged.	5.	It is easier to change or fix when its get damage
6.	In belt drive, little difficulties have when it gets damaged.	6.	Price is high
7.	The belt drive is not the lubricating system	7.	The chain drive is a lubricating system.

Chapter - 3

Components Study

3.1 Pulley

3.1.1 Introduction

A **pulley** is a wheel on an axle or shaft that is designed to support movement and change of direction of a taut cable or belt, or transfer of power between the shaft and cable or belt.

A pulley may have a groove or grooves between flanges around its circumference to locate the cable or belt. The drive element of a pulley system can be a rope, cable, belt, or chain.

3.1.2 Types of Pulleys

1. Fixed or Immovable Pulley –

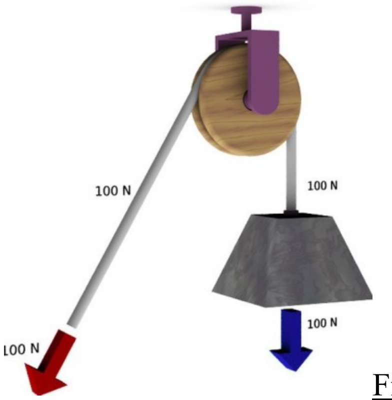


Fig. 3.1

This is the simplest type of pulley system. In this, the wheel is fixed at a particular point like a pivot and works by changing the direction of the force applied. It is advantageous because you don't have to push an object or pull it directly to move it. But it requires a large effort to move the object and this is its turn off when compared with other pulley systems.

2. Movable Pulley -

Fig. 3.2

In this type of pulley, the wheel moves with the object it is displacing. This arrangement allows the pulley to lift the load with much lesser force. Only that much force is applied to the load as much as the force levied on the rope. It usually multiplies the force actually applied to it by the user. Thus, with the application of a small force, the load can be displaced thereby making the task easier.

3. Compound System or Combined Pulley –

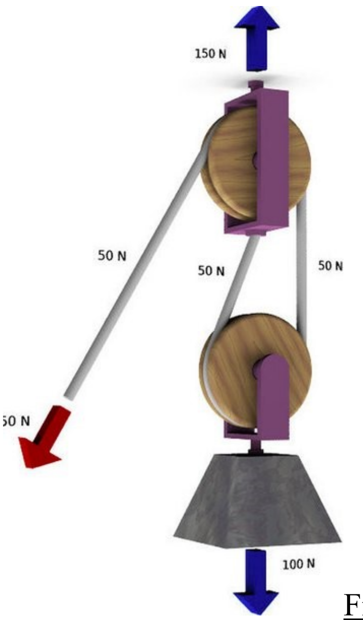


Fig. 3.3

These kinds of pulleys are a combination of both fixed and moveable pulleys. As such, they have the advantage of both of them. The user requires minimal application of force to lift an object without pushing or pulling it.

Other than this conventional classification, there are also various types of pulleys that we never usually think about. These are highly modified and advanced to make a particular task easier.

4. Complex Pulley System –

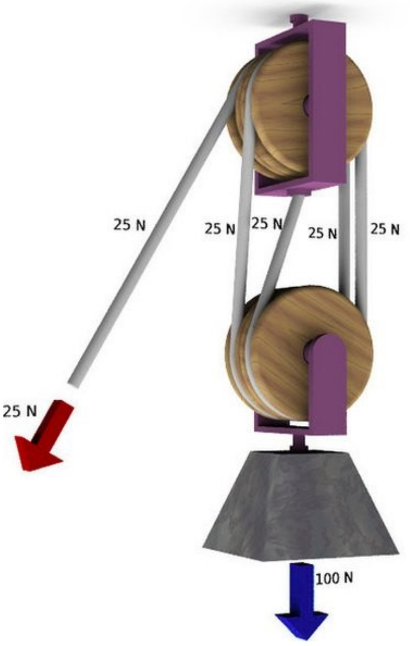


Fig. 3.4

Pulleys can be multiplied in any number of ways to accomplish a variety of tasks. A *block and tackle*, for example, is a pulley configuration that contains two or more individual drums, each containing two or more wheels rotating on the same axle. The rope loops back and forth between the pulley drums, weaving through the individual wheels within those drums.

These configurations can get quite elaborate, as is sometimes seen in large sailboats where a single sailor may need to control sails that are under huge force from strong winds.

Complex pulley systems like this can move enormously heavy loads, provided they are anchored very firmly. But while the *magnitude* of force required is greatly reduced, the *amount* of that reduced magnitude (the amount the rope must travel to accomplish the work) is greatly increased.

3.1.3 Pulley Materials & its Properties

- Pulleys can be made from a variety of materials, including an extensive range of plastics, wood and metals.
- Steels and aluminium alloys are regularly used in industrial pulley manufacture.
- Many pulley designs incorporate multiple materials in order to meet strength with proper resistance characteristics.

1. Aluminium –

- Among the materials here, the most frequently utilized product is aluminium and, the next on our list, steel.
- It's greatly considered because of its lightweight, durable, greater tensile strength, and resistant to high temperature.
- This makes the ideal option for drive systems with high horsepower.
- Compared to other materials, such as plastics or nylon, only aluminium has the sufficient capacity for such horsepower drive systems.

1. Tensile Strength - Its tensile strength capacity makes it an ideal choice if you wish to put heavy materials as its load capacity is high.

2. High – Temperature Resistant – Industry involved working with the high – temperature environment, pick aluminium as a material for your timing belt so that the belt won't fail.

3. Durable – Aluminium is durable and is stable with regards to its dimensions so worry less about getting pulley crooked or deformed with this kind of material.

2. Steel –

- Steel is similar to aluminium when it comes to quality. Due to its availability, it's also a commonly used material for timing pulleys.
- Its qualities meet the standard of several industries, including those with the most rigid requirements.

1. Stable – Materials like steel can withstand harsh environments. So, it doesn't have a tendency to be deformed as time passes by.

2. Higher Load Capacity – Due to its high tensile strength steel, it has a capacity to take greater loads. Pulleys that can take the maximum load while still meeting all industrial standards.

3. Temperature Sensitive – As mentioned Steel is stable material compared to plastics. It has a greater ability to be stable whether in a cold or hot environment.

4. Plastics –

- This might be the least durable among the list, but plastics are actually still preferred and have applications depending on where you'll use it.
- You shouldn't worry about using plastics since only in extreme or cold environment it somehow creeps from its original shape.

1. Light Weight – It is lightest on this list, making it ideal for lighter projects. Being cheapest on this list. And needs less maintenance.
Unlike Aluminium and Steel, Plastics apparently doesn't undergo oxidation.

3.1.4 Following must have qualities for timing pulleys –

- Cheaper operating cost
- Longer timing pulley and belt lifespan
- Lower Maintenance

3.2 Belts

Belts and pulleys are used when the distance between the shafts too far apart to use gears.

Power transmitted between a belt and a pulley is expressed as the product of difference of tension and belt velocity:

$P = (T_1 – T_2)v_1$

where, T_1 and T_2 are tensions in the tight side and slack side of the belt respectively. They are related as

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

where, μ is the coefficient of friction, and α is the angle (in radians) subtended by contact surface at the centre of the pulley.

Fig. 3.5

3.2.1 Pros & Cons -

Belt drives are simple, inexpensive, and do not require axially aligned shafts. They help protect machinery from overload, wet and isolate noise and vibration. Load fluctuations are shock-absorbed (cushioned). They need no lubrication and minimal maintenance. They have high efficiency (90–98%, usually 95%), high tolerance for misalignment, and are of relatively low cost if the shafts are far apart. Clutch action is activated by releasing belt tension. Different speeds can be obtained by stepped or tapered pulleys.

The angular-velocity ratio may not be constant or equal to that of the pulley diameters, due to slip and stretch. However, this problem has been largely solved by the use of toothed belts. Working temperatures range from - 35°C to 85°C. Adjustment of centre distance or addition of an idler pulley is crucial to compensate for wear and stretch.

3.2.2 Types of Belts

There are four commonly used types of belts are:

1. Flat belt
2. V belt
3. Circular

1. Flat belt

This belt has a rectangular cross-section. These belts are capable of transmitting power over long distances between pulley centres. The efficiency of this drive is around 98% and produce little noise.

- Flat belts are usually made of leather, rubber and fabric.
- Belts are made of leather has high coefficient of friction thereby ideal for flat belts.

- To achieve the desired thickness of belt, number of layers of belt material is cemented together To transmit more power.
- Usually the top and bottom layers are made of leather or rubber which has high coefficient of friction and also it acts as a protective layer.
- The inside layers are made of canvas, fabric or other material which transmits the majority of the load handled by belt.
- The material from which belt is made of should have high coefficient of friction.
- To withstand the tensions created, the belt material should have high tensile strength.
- The material should have water resistance.

Fig. 3.6

2. V Belt

v-belts also used with grooved pulleys; V-belts are trapezoidal in cross-section. These belts permit large speed ration and can transmit higher power. Multiple drives are possible.

These are the most commonly used belts for power transmission. At the same level of tension, they transmit higher power than flat belts. They are used, for example, in variable-speed drives. They offer the best combinations of traction, speed, bearing load and service life.

V-belts, with a trapezoidal or V shape, made of rubber, neoprene, and urethane synthetic materials, replaced flat belts.

Now, the increased overall surface material of modern belts adheres to pulley grooves through friction force, to reduce the tension required to transmit torque.

Fig. 3.7

3. Circular Belt

This type of belt has a circular cross-section and is used with the grooved pulleys.

3.2.3 Material of Belts

1) For choosing belt material, the material should follow some properties which are:

- It should be flexible
- It should be reliable and durable
- The material can withstand high tensile stress
- More temperature can be resisted
- Low weight per unit length
- High coefficient of friction between belt and pulley
- It should have excellent resistance to wear and fatigue

2) ***Strength criteria for leather material:-***

- *In our project we have used leather material for both belts because* the tensile strength of leather is the tensile strain of leather until it tears.
- The tensile strength is very different in the longitudinal and transverse direction of the leather skin.
- Leather with higher fat content has higher tear strength. But there are many other parameters that influence the tear strength:

- Since leather is a natural product, every skin behaves differently, and even within the same skin, the properties are very different.

- The tensile strength of cow leather is between 8 – 25 N / mm². The car industry requires at least 200 N per 5 cm.

Materials

- *Leather belt*
- *Rubber belt*
- *Cotton or Fabric belt*
- *Plastic belt*
- *Balata belt*

Let's study these 5 different types of belt material in detail.

1. Leather Belt - This is the most important type of belt. This belt is first found in Egypt. It is more expensive than other belts made of cloth or recycled synthetic material.

To become a Leather belt strong, the one layer of lather is joint to another layer of leather. It increases the thickness of the belt also.

2. Rubber Belt - This Belt is made up of Fabric. This is used in sawmills, paper mills and more.

3. Cotton or Fabric Belt -This type is mostly used In farm machinery and belt conveyor. This is cheaper and best suited for warm climates and a damp atmosphere.

4. Plastic Belt - These types of belt materials are made up of plastic sheets and rubber layers. The main advantages of a plastic belt are that it can design almost any size.

5. Balata Belt - Balata belts are similar to rubber type belts but this is stronger than rubber belt. The balata gum is used here to stick it.

It is a Waterproof type belt and has a high resistance to acidic, alkaline material so this is used for food packaging conveyor.

This is not used for high temperatures because balata becomes sticky gum at a higher temperature.

3.3 Spring Balance or Spring Scale

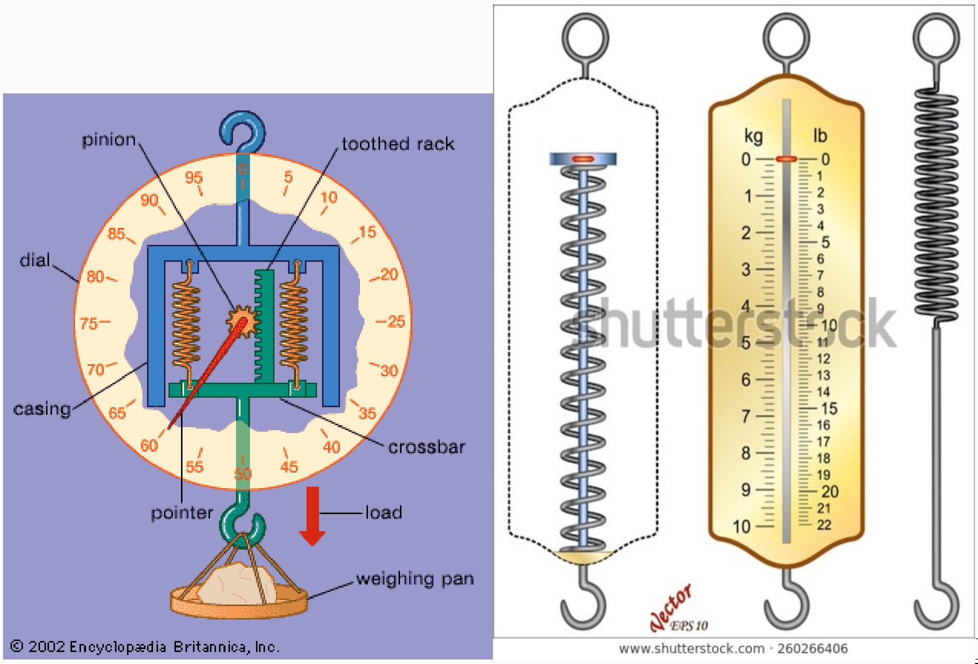


Fig. 3.9

Fig. 3.10

3.3.1 Introduction

A spring scale or spring balance or Newton meter is a type of mechanical force gauge or weighing scale. It consists of a spring fixed at one end with a hook to attach an object at the other.

It works by Hooke's Law, which states that the force needed to extend a spring is proportional to the distance that spring is extended from its rest position.
A spring scale cannot measure mass, only weight.

Modern balance springs are made of special low temperature coefficient alloys like, nivarox to reduce the effects of temperature changes on the rate, and carefully shaped to minimize the effect of changes in drive force as the mainspring runs down.

3.3.2 Materials

The spring scale is manufactured from stainless steel or aluminium.

3.3.3 Aluminium and Stainless Steel Comparison

Aluminium and Stainless Steel might look similar, but they are actually quite different. Keep these 10 differences.

1. Strength to weight ratio –

Aluminium is typically not as strong as steel, but it is also almost one third of the weight. This is the main reason why aircraft are made from Aluminium.

2. Corrosion –

- Stainless steel is made up of iron, chromium, nickel, manganese and copper.
- The chromium is added as an agent to provide corrosion resistance. Also, because it is non-porous the resistance to corrosion is increased.
- Aluminium has a high oxidation and corrosion resistance mainly due to its passivation layer. When aluminium is oxidized, its surface will turns white and will sometimes pit.
- In some extreme acidic or base environments, Aluminium may corrode rapidly with catastrophic results.

3. Thermal Conductivity –

Aluminium has a much better thermal conductivity (conductor of heat) than stainless steel. One of the main reasons it is used for car radiators and air conditioning units.

4. Cost –

Aluminium is typically cheaper than stainless steel.

5. Workability –

- Aluminium is fairly soft and easier to cut and form. Due to its resistance to wear and abrasion, Stainless can be difficult to work with.
- Stainless steels are harder and are especially harder to form than aluminium.

6. Welding –

Stainless is relatively easy to weld, while Aluminium can be difficult.

7. Thermal Properties –

Stainless can be used at much higher temperatures than Aluminium which can become very soft above about 400 degrees.

8. Electrical Conductivity –

- Stainless steel is a really poor conductor compared to most metals.
- Aluminium is a very good conductor of electricity. Due to its high conductance, light weight, and corrosion resistance, high-voltage overhead power lines are generally made of aluminium.

9. Strength –

- Stainless steel is stronger than Aluminium provided weight is not a consideration.

3.4 Derivations –

3.4.1 Power transmitted by a Belt -

Fig. 11.14 shows the driving pulley (or driver) A and the driven pulley (or follower) B. We have already discussed that the driving pulley pulls the belt from one side and delivers the same to the other side. It is thus obvious that the tension on the former side (i.e. tight side) will be greater than the latter side (i.e. slack side) as shown in Fig. 11.40

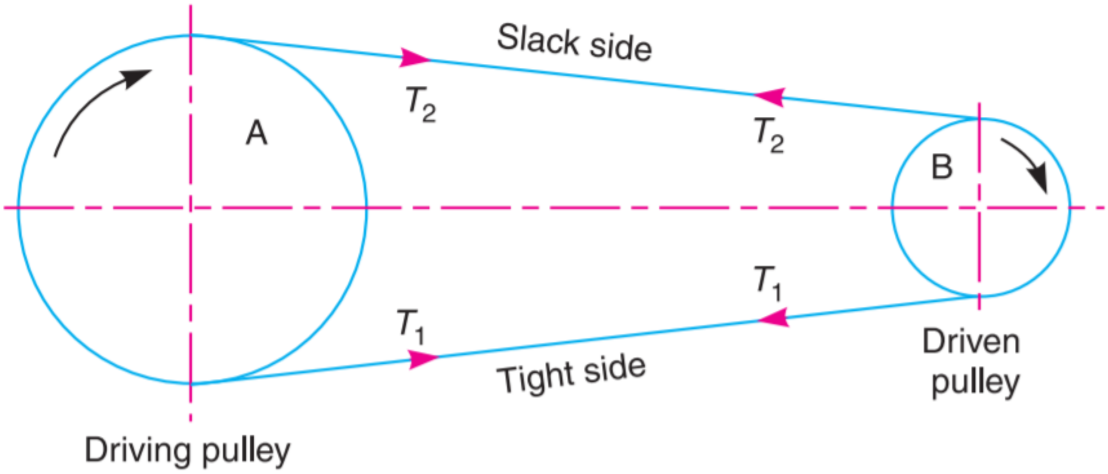


Fig. 11.14. Power transmitted by a belt.

Let,

$T1$ and $T2$ = Tensions in the tight and slack side of the belt respectively in newtons,

$r1$ and $r2$ = Radius of the driver and follower respectively, and v = Velocity of the belt in m/s.

The effective turning (driving) force at the circumference of the follower is the difference between the two tensions (i.e. $T1 – T2$).

∴ Work done per second = $(T1 – T2)\, v$ N-m/s

and power transmitted, $P = (T1 – T2)\, v$ W ...(∵ 1 N-m/s = 1 W) A little consideration will show that the torque exerted on the driving pulley is $(T1 – T2)\, r1$. Similarly, the torque exerted on the driven pulley i.e. follower is $(T1 – T2)\, r2$.

3.4.2 Determination of Angle of Contact -

When the two pulleys of different diameters are connected by means of an open belt as shown in Fig. 11.16 (a), then the angle of contact or lap (θ) at the smaller pulley must be taken into consideration.

Let

$r1$ = Radius of larger pulley,

$r2$ = Radius of smaller pulley, and

x = Distance between centres of two pulleys (i.e. O1 O2).

From Fig. 11.16 (a),

$$\sin \alpha = \frac{O1\,M}{O1\,O2} = \frac{O1\,E - ME}{O1\,O2} = \frac{r1 - r2}{x} \qquad \text{....}(\because ME = O2\,F = r2)$$

∴ Angle of contact or lap,

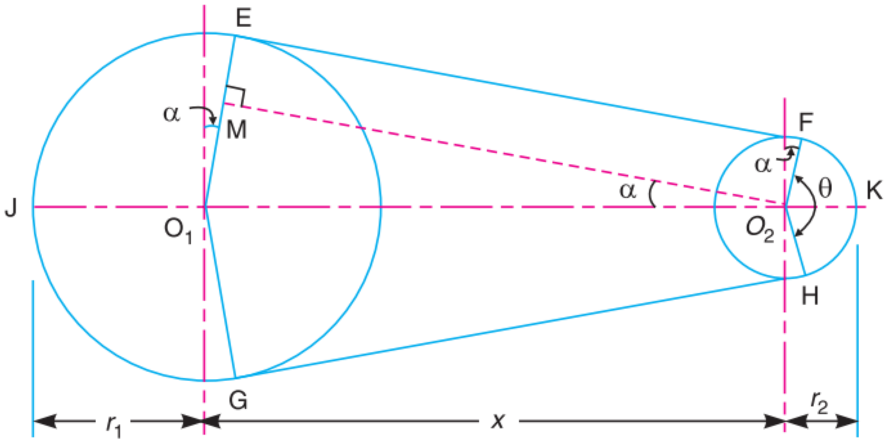
$$\Theta = (180 - 2\alpha)\,\frac{\pi}{180}\ \text{rad}$$

A little consideration will show that when the two pulleys are connected by means of a crossed belt as shown in Fig. 11.16 (b), then the angle of contact or lap (θ) on both the pulleys is same. From Fig. 11.16 (b),

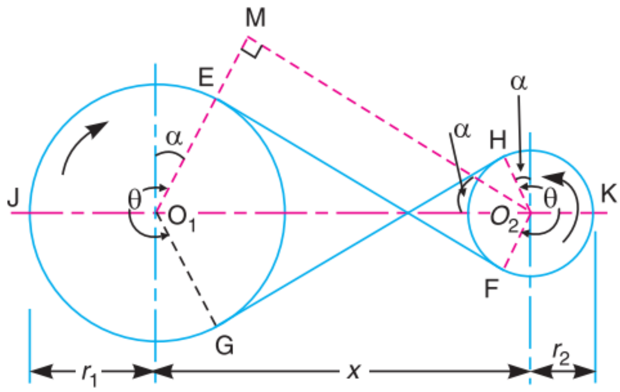
$$\sin \alpha = \frac{O1\,M}{O1\,O2} = \frac{O1\,E + ME}{O1\,O2} = \frac{r1 + r2}{x}$$

∴ Angle of contact or lap,

$$\Theta = (180 + 2\alpha)\,\frac{\pi}{180}\ \text{rad}$$



(a) Open belt drive.



(b) Crossed belt drive.

3.4.3 Ratio of Driving Tensions For Flat Belt Drive -

Consider a driven pulley rotating in the clockwise direction as shown in Fig. 11.15.

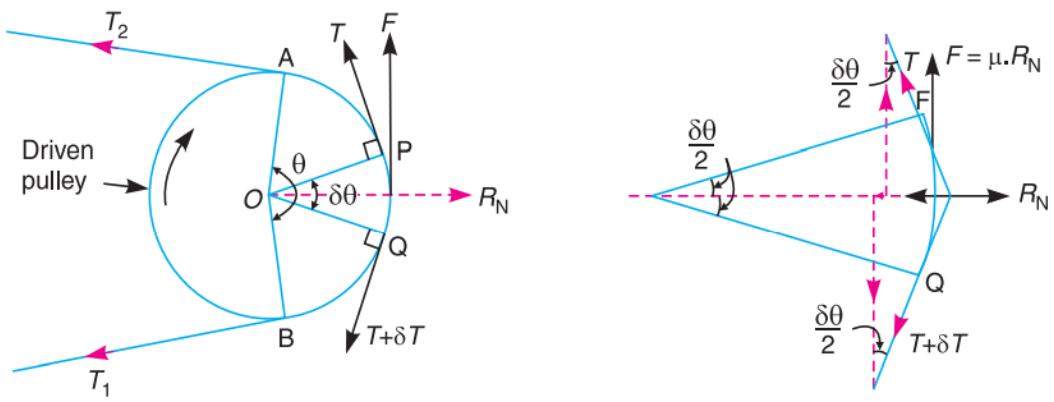


Fig. 11.15. Ratio of driving tensions for flat belt.

Let

T1 = Tension in the belt on the tight side,

T2 = Tension in the belt on the slack side, and

θ = Angle of contact in radians (i.e. angle subtended by the arc A B, along which the belt touches the pulley at the centre).

Now consider a small portion of the belt PQ, subtending an angle δθ at the centre of the pulley as shown in Fig. 11.15. The belt PQ is in equilibrium under the following forces :

1. Tension T in the belt at P,

2. Tension (T + δ T) in the belt at Q,

3. Normal reaction RN, and

4. Frictional force, F = μ × RN , where μ is the coefficient of friction between the belt and pulley.

Resolving all the forces horizontally and equating the same,

$$R_N = (T + \delta T)\, sin\frac{\delta\theta}{2} + T\, sin\frac{\delta\theta}{2} \quad ...(i)$$

Since the angle δθ is very small, therefore putting sin δ θ / 2 = δθ / 2 in equation (i),

$$R_N = (T + \delta T)\, sin\frac{\delta\theta}{2} + T * \frac{\delta\theta}{2} = \frac{T*\delta\theta}{2} + \frac{\delta T*\delta\theta}{2} + \frac{T*\delta\theta}{2} = T.\delta\theta \quad ...(ii)$$

$$......................\left(Neglecting\ \frac{\delta T*\delta\theta}{2}\right)$$

Now resolving the forces vertically, we have

$$\mu * R_N = (T + \delta T)^*\, cos\frac{\delta\theta}{2} - T\, cos\frac{\delta\theta}{2}$$

Since the angle δ θ is very small, therefore putting cos δ θ / 2 = 1 in equation (iii),

$$\mu * R_N = T + \delta T - T = \delta T \qquad \textit{or} \qquad R_N = \frac{\delta T}{\mu}$$

Equating the values of RN from equations (ii) and (iv),

$$T * \delta\theta = \frac{\delta T}{\mu} \qquad \textit{or} \qquad \frac{\delta T}{T} = \mu * \delta\theta$$

Integrating both sides between the limits T2 and T1 and from 0 to θ respectively,

i.e $\int_{T2}^{T1} \frac{\delta T}{T} = \mu \int_{\theta}^{\theta} \delta\theta \qquad \textit{or} \qquad log\left(\frac{T_1}{T_2}\right) = \mu * \theta \qquad \textit{or} \qquad \frac{T_1}{T_2} = e^{\mu\theta}$

Equation (v) can be expressed in terms of corresponding logarithm to the base 10, i.e.

$$2.3\, log\left(\frac{T_1}{T_2}\right) = \mu * \theta$$

The above expression gives the relation between the tight side and slack side tensions, in terms of coefficient of friction and the angle of contact.

3.4.4 Ratio of Driving Tensions for V-Belt

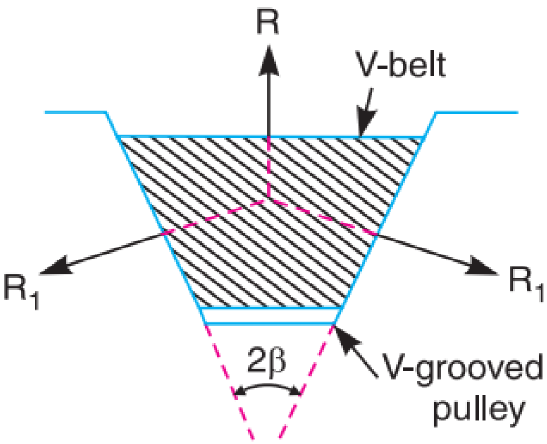


Fig. 11.20.

A V-belt with a grooved pulley is shown in Fig. 11.20.

Let

R1 = Normal reaction between the belt and sides of the groove.

R = Total reaction in the plane of the groove.

2 β = Angle of the groove.

μ = Coefficient of friction between the belt and sides of the groove.

Resolving the reactions vertically to the groove, R = R1 sin β + R1 sin β = 2 R1 sin β

$$R_1 = \frac{R}{2\,sin\,\beta}$$

We know that the frictional force

$$2\mu * R_1 = 2\mu * \frac{R}{2\,sin\,\beta} = \frac{\mu * R}{sin\,\beta} = \mu * R\,cosec\,\beta$$

Consider a small portion of the belt, as in Art. 11.14, subtending an angle δθ at the centre. The tension on one side will be T and on the other side T + δT. Now proceeding as in Art. 11.14, we get the frictional resistance equal to μ. R cosec β instead of μ . R. Thus the relation between T1 and T2 for the V-belt drive will be

$$2.3log = \mu * \theta\,cosec\,\beta$$

Chapter - 4

EXPERIMENTAL STUDY ON BELT TENSION MEASUREMENT

4.1.1 OBJECTIVES -

The objectives of the experiments are:

(1) to investigate the relationship between belt tensions, angle of wrap and coefficient of friction for Flat and V-belts,

(2) to determine the effect of the angle of warp to the power that can be transmitted for belt drive mechanism,

(3) to determine the effect of the belt tensions to the power that can be transmitted for belt drive mechanism, and

(4) to compare the power transmission capability of flat and V-belt.

4.1.2 Theory –

Belt drive machinery makes up significant portions of mechanical system. Belt drive is used in the transmission of power over comparatively long distances. In many cases, the use of belt drive simplifies the design of a machine and substantially reduces the cost. Belt drive employs friction for the transmission of power. Belt drives are considered to be cost effective, easy to use devices designed for power transmission between machines or shafts.

The origins of traction devices can be traced back as far as the Babylonians with flat belts, made of leather, becoming the main source of power transmission in factories during industrial revolution. Although the flat belts are still used in present days, the introduction of Vee belts by John Gates in 1917 revolutionised short distance power transmission, being able to generate more power than a flat belt for a pulley of certain diameters. Modern belt drives are able to transmit power at an efficiency of 90-98%, averaging 95%.

Vee belts provided the opportunity for continuously variable transmission with their ability to work on pulleys of variable diameters, a useful advantage over the other forms of transmission. However, the main disadvantage is the slip between belt & pulley which can limit the efficiency of the drives; the factor contributing to this are the belt profile, the friction & the amount of torque. This project investigates the relationship between the tensions in a stationary flat belt pulley & subsequently the torque & efficiency, comparing experimental results with expected values calculated as described below:

The coefficient of friction for belt drive depends on the type of material used for the belt and the pulley. **Table 1** gives the average coefficient of friction values for various belt and pulley material combinations.

Table 1 Coefficient of friction for belt and pulley materials

Belt material	*Pulley material*						
	Cast iron, steel			*Wood*	*Compressed paper*	*Leather face*	*Rubber face*
	Dry	*Wet*	*Greasy*				
Leather oak tanned	0.25	0.2	0.15	0.3	0.33	0.38	0.40
Leather chrome tanned	0.35	0.32	0.22	0.4	0.45	0.48	0.50
Convass-stitched	0.20	0.15	0.12	0.23	0.25	0.27	0.30
Cotton woven	0.22	0.15	0.12	0.25	0.28	0.27	0.30
Rubber	0.30	0.18	—	0.32	0.35	0.40	0.42
Balata	0.32	0.20	—	0.35	0.38	0.40	0.42

The power (in kW) transmitted by a belt is $power\ transmitted\ in\ kW$ = $(P_1 - P_2)v$ 1000 Where; v is the velocity in meter per second; P_1 is the initial tension on the tight side in Newton; P_2 is the initial tension on the slack side in Newton

Where: μ is the coefficient of friction; α is the angle of wrap in radians measured from the point of tangency of P_1 and P_2; θ is the total angle of groove $(\theta/2) = 90°$ for flat belt, $(\theta/2) = 20°$ for vee belt.

Given the coefficient of friction, v belt angle and angle of contact. The relationship between tight side tension T2 and slack side tension T1 in a slipping pulley, known as belt tension ratio, is given by

$$\frac{T_2}{T_1} = e^{\left(\frac{\mu\beta}{\sin\alpha}\right)}$$

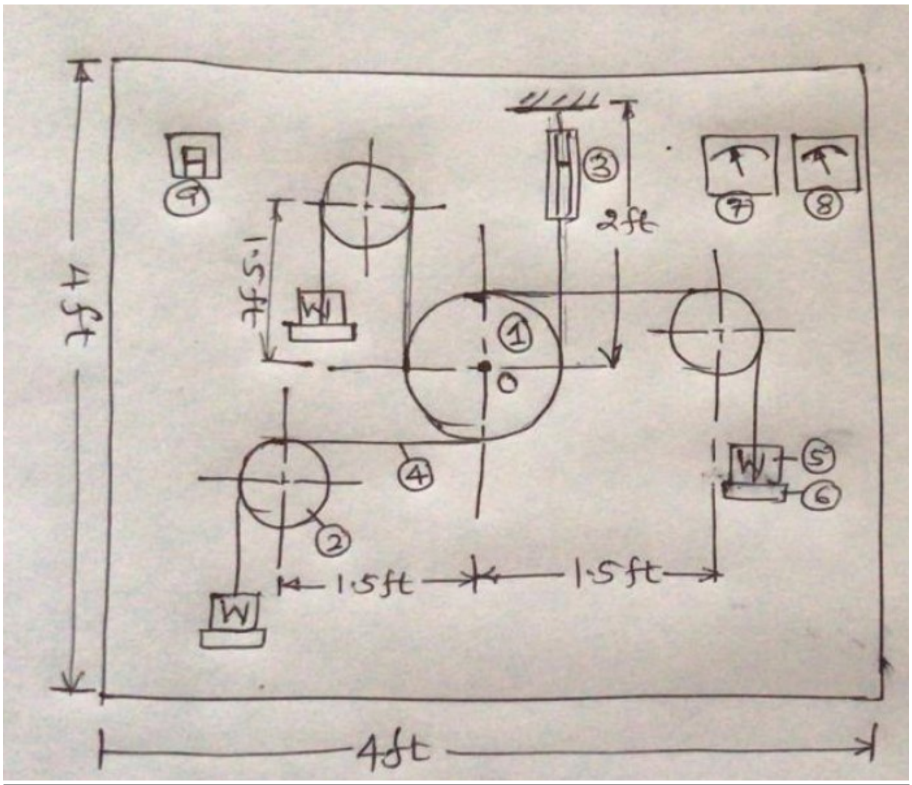
For given flat belt, α=90 & sin α = sin90 = 1,

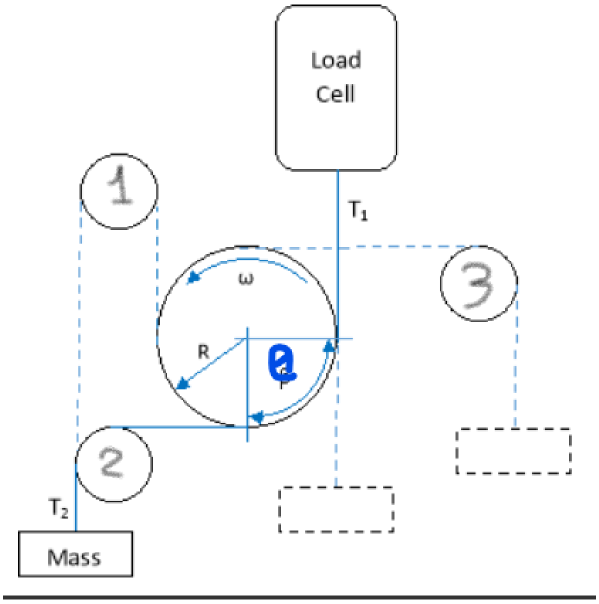
The above equation may be written as,

$$\frac{T_1}{T_2} = e^{\mu_\theta}$$

Using the above equations, we can compare the experimental results with theoretical calculated values to draw some conclusions analysing the relationship between the belt tensions, wrap angles and coefficient of friction.

4.2 Constructional Features of Experimental Set Up –





4.2.1 Experiment Set Up with accessories -

(1) Pulleys: A central Pulley with its diameter as mm and four number of smaller pulley (each of diameter as mm.

(2) Masses: 100 grams - five in numbers 500grams – one in number

(3) Flat Belt with sufficient length, V-belt with sufficient length

(4) Spring Balance (2 Nos.)

(5) Weight hanger

(6) A.C. motor to provide rotational speed to the central pulley with its capacity h.p

(7) Voltage and current measuring instruments/devices with their capacities as V and mA.

(8) Hand operated optical techo - meter capable of measuring rotational speed of the central pulley with its least count as rpm.

(9) Small accessories as per requirements.

4.2.2 Procedure –

1) Ensure/Check that the spring balance OR load cell record zero before it is taken in use.
2) Set up the equipment as shown in Figure 1. (Use the flat belt).
3) The free end of the string or belt is placed accordingly to ensure the angle of contact between the belt & the pulley is maintained as 90˚, 180˚, 270˚ & 360˚.
4) The motor supply voltage is set to 10V and it is ensured that the pulley is rotating in correct direction and sense by checking $T_2 > T_1$.
5) The spring balance is set to zero before the minimum load of 100 gram is placed on weight hanger.
6) For each individual mass placed on weight hanger, corresponding spring balance reading is noted as observation and recorded at appropriate place in observation table.
7) The dead weight on hanger creates tight side tension (T_2) in the belt while the spring balance reading is reflecting a slack side tension (T_1).
8) Once the maximum mass is reached, all masses are then removed. Maximum mass is achieved when the motor is about to stop due to frictional resistance but the voltage value is still read as 10V.
9) For each mass load, the current (I) and the speed of rotation is measured using appropriate measuring devices or instruments.
10) 7. The experiment is then repeated for other angle of wrap i.e. 180˚, 270˚ & 360˚.

4.3 Observation Table (Raw Data)

SR.NO	WEIGHT IN (KG)	TIGHT OR HIGHER SIDE TENSION(T_2)= W X 9.81	LOWER OR SLACK SIDE TENSION (T_1)	CURRENT IN AMP.	SPEED OF ROTATION IN RPM (N)
1	0.1				
2	0.2				
3	0.3				
4	0.4				
5	0.5				
6	0.6				
7	0.7				
8	0.8				
9	0.9				
10	1.0				

Note: The tension on the lower side or slack side (T_1) of the belt is reflected by the spring balance and the mass added to the free end of the belt on weight hanger are recorded in a table as raw data. The values of the mass are converted to Newton to give higher side or tight side tension (T_2).

4.4 Calculation –

Experimental determination is based on the experimental values of

both tight and slack side tensions as explained above in NOTE.

While the theoretical determination is based on the values of co-efficient of friction (μ) and angle of wrap

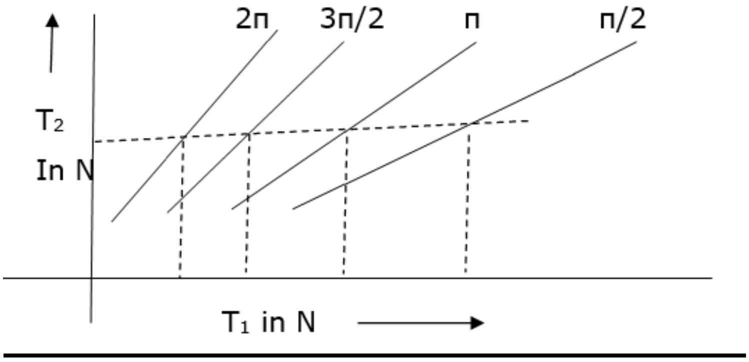
(α) Using the formula $T_2/T_1 = e^{\mu\alpha/\sin(\Theta/2)}$.

Calculating the linear velocity using the equation $v = [\pi \times D \times N/60]$ in m/sec ; calculate the power using the following equation that can be transmitted for different peg angles for both of the belts.

$P = [2\pi NT/60]$; where T= Torque acting on the central pulley at its diameter = $(T_2 - T_1)$ D/2 ; D= diameter of central pulley in meter.

4.5 Graphs –

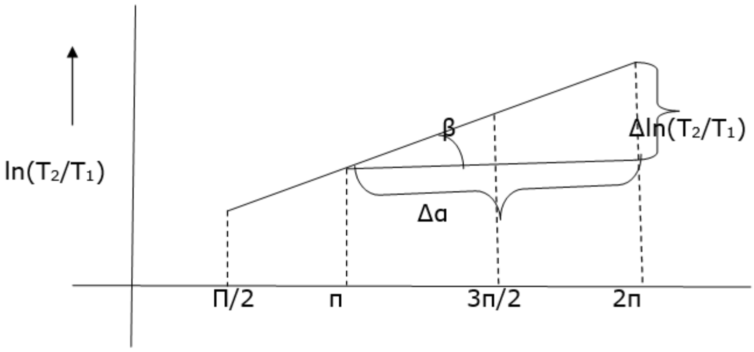
1) Plot the graph of T_2 (Tight side tension)-on Y-axis v/s T_1 (slack side tension) –on X-Axis with suitable scale for all four angle of contacts (wrap angles).



2) Prepare the table as below for the selected value of higher side or tight side tension (T_2).

Wrap angle (Θ) in radian	Tight side tension (T_2)	Slack side tension (T_1)	$\ln(T_2/T_1)$
π/2			
π			
3π/2			
2π			

3) For the above value of T_2 & using the above values from the table, plot the graph of $\ln(T_2/T_1)$ – on Y-axis v/s wrap angle (α) in radian- on X-axis using appropriate scales. The slope of the line is an indication of coefficient of friction (μ).



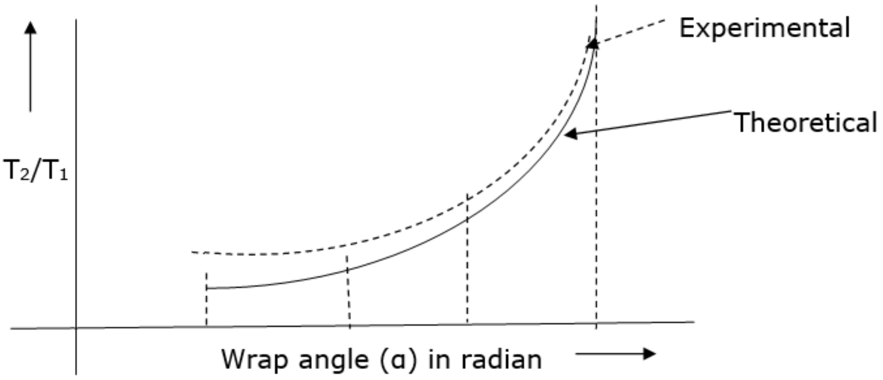
wrap angle (α) in radian

$\tan\beta = \Delta\ln(T_2/T_1)/\Delta\alpha$

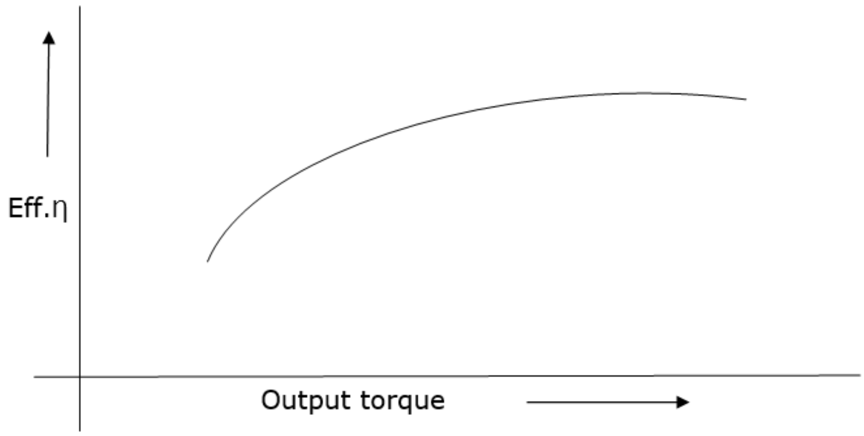
4) Using the value of coefficient of friction as obtained above, prepare the following table and plot the graph of actual (T_2/T_1) & theoretical (T_2/T_1) v/s wrap angle (α) in radian.

Wrap angle (Θ) in radian	**Tight side tension (T_2)**	**Slack side tension (T_1)**	**Actual or Exp. (T_2/T_1)**	**Theoretical (T_2/T_1) = $e^{\mu\alpha/\sin(\Theta/2)}$**
$\pi/2$				
π				
$3\pi/2$				
2π				

5) Plot the graph of (T_2/T_1) against angle of wrap (α), making comparison of actual (experimental) value of (T_2/T_1) & theoretical value of (T_2/T_1).



6) For each angle of contact, the following table is prepared and graph of efficiency against an output torque is to be drawn to understand the effect of angle of contact on output torque and efficiency of transmission.



4.6. Efficiency Table –

T_2	T_1	$F_C=(T_2 - T_1)$	Output Torque $T_o = F_c \times D/2$	Speed N in rpm	$\omega = (2\pi N)/60$ rad/sec	Power Output $P_o = \omega \times T_o$	Voltage V in Volts	Current (I) in Amp.	Power Input P_I	Eff $\eta = P_o/P_I$

4.7 Discussion & Conclusion –

1. Does the experimental T_2 and T_1 relationship agree with theoretical equation?

2. What is the effect of the angle of wrap to the power that can be transmitted for a belt mechanism?

3. What is the effect of the belt tension P_1 and P_2 to the power that can be transmitted for a belt mechanism?

4. Compare the power transmission capability of flat and V- belt.

5. Name two other types of belt commonly used for belt drive

6. Name some application of belt drive mechanism and affix the pics of different kinds of applications.

4.8 Economical Aspect with Bill of Materials:

SR.NO.	NAME OF PART	MATERIAL	QTY.	COST IN RS. PER PC.	REMARKS, IF ANY
1	Mass	brass	8		
2	Flat Belt (l= m)	leather	1		
3	V-Belt	leather	1		
4	Spring balance or load cell		1		
5	Weight Hanger	M.S.	1		
6	Screws/Bolts/Nuts	M.S.			
7	Techo -meter		1		
8	Voltmeter				
9	Ammeter				
10	A.C. Motor				
11	Hard PVC Sheet (4 x 4) sq. ft. Thickness = 8 to 10mm.	PVC	1		