Belts

Belts and belt drives are flexible mechanical elements widely used for power transmission, conveyor systems, and elevator services. They have been essential components in industrial systems due to their cost-effectiveness, simplicity, and flexibility in design. Belts are made from a flexible material and are looped over pulleys to transmit power between shafts.

Flexible belts are extensively used in industrial power transmission due to their ability to connect shafts over considerable distances and accommodate slight misalignments. These belts are particularly advantageous when the driver and driven shafts must be spaced apart. Benefits include smooth power transfer, reduced need for lubrication, lower maintenance, and enhanced safety due to minimal backlash. Belts also offer effective shock absorption and noise damping, which make them suitable for a range of machinery. Additionally, V-belts and toothed belts enable positive engagement and non-slip power transmission in specific applications.

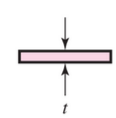
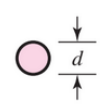
CLASSIFICATION AND APPLICATIONS

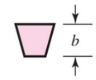
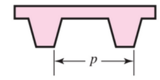
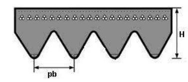
Belt applications are generally divided into three categories:

- **Power Transmission Belts**: Used to transmit power from one shaft to another, historically competing with rope and now electric drives.
- **Conveyor Belts**: Designed for material handling and transportation within a facility.
- **Elevator Belts**: Used in lifting applications; their usage is expanding with technology.

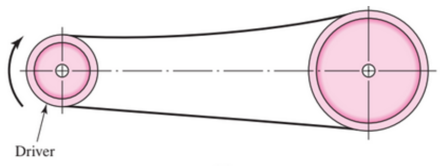
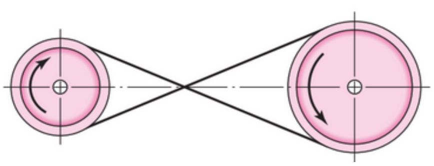
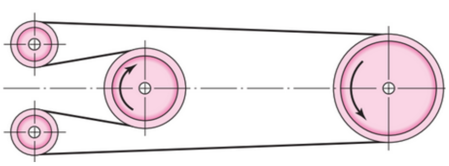
Advantages	**Disadvantages**
Absorb shocks and vibrations Lubrication free Suitable for large center distances Quite Long-life when properly maintained Some misalignment is tolerable	Subjected to belt-slip and stretch Heat could build up Speed and power is limited Belt tensioner is necessary to compensate wear

TYPES OF BELTS AND DRIVES

Flat Belts	Efficient and used over long distances; affected by flexing fatigue	
Round Belts	Work with grooved pulleys, compact, and suitable for multiple drives	

V-Belts	Simple, suited for low-power or light-duty applications.	
Timing Belts	Have teeth for positive drive without slipping.	
Ribbed Belts	Have multiple longitudinal ribs that provide high grip and power transmission in compact, multi-pulley systems	

Nonreversing and Reversing Belt Drives

	The **open belt drive** represents a common setup where the driver and driven pulleys rotate in the same direction. The belt runs parallel without crossing, providing nonreversing motion. This is the simplest belt drive arrangement and is typically used where space is not a constraint and where the direction of rotation must be maintained. However, open belts may suffer from less grip, especially under heavy loads, and the belt tension must be adjusted carefully to prevent slippage.
	A **crossed belt drive** is shown. In this configuration, the belt crosses itself between the driver and driven pulleys, resulting in the two pulleys rotating in opposite directions. This setup is used when a reversal in the direction of rotation is required. However, the belt experiences more wear due to the increased bending and possible rubbing where the belt crosses. For high-friction materials like rubber, the belt sections must be separated using guide rollers or spaced pulleys to prevent contact and overheating.
	The figure shows a **complex reversing open-belt drive** with multiple pulleys. In this system, the direction of rotation of the final driven pulley can be reversed depending on which idler pulley is engaged with the driver. By controlling the contact between the belt and specific pulleys (via tensioners or mechanical linkages), the motion can be selectively reversed without physically repositioning the belts. This type of system is often used in applications like textile machinery, packaging equipment, and industrial automation systems where selectable reversing motion is necessary.

FLAT BELTS

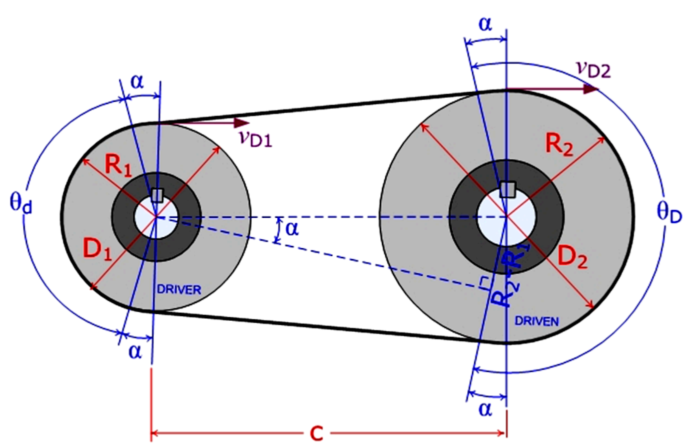
Flat belts are used to transmit high-speed motion rather than power. Flat belts have minimal noise and offer high efficiency (~98%). V-belts offer 70–96% efficiency. Timing belts allow synchronous transmission and are not stretch-prone.

Flat belting was originally crafted from leather due to its durability and adaptability, making it ideal for early mechanical systems. These belts could be easily cut, joined, and used with cylindrical or crowned pulleys to transmit torque across long distances. Historically, they played a vital role in driving factory machinery and equipment like steam engines, where power needed to be transferred over considerable spans. With advances in materials and manufacturing, leather belts have largely been replaced by belts made of synthetic polymers and textiles reinforced with high-strength fibers. Modern flat belts are often constructed from rubber or thermoplastic materials, sometimes layered with polyurethane or elastomers, providing enhanced flexibility, durability, and resistance to heat, oil, and solvents. High-performance flat belts can now sustain tensile strengths up to 40,000 psi (276 MPa), with Shore hardness typically between 85 and 95.

One of the distinguishing features of flat belts is their ability to operate efficiently without lubrication while maintaining high transmission capacity and excellent rotational accuracy. Flat belts are quiet, produce less vibration, and generate minimal heat during operation. They can tolerate minor misalignment, which makes them suitable for precision applications such as in high-speed V-belts and industrial machinery. Their thin cross-sections allow them to run at very high surface speeds—up to 20,000 ft/min (102 m/s) in some cases—and their low bending resistance makes them suitable for compact and high-speed systems.

OPEN BELT INSTALLATION

In an open belt drive, the belt connects two pulleys such that both rotate in the same direction.



Angle of wrap or Arc of contact

The wrap angle—the amount of belt in contact with the pulley surface—is crucial in maintaining sufficient friction. For positive drive belts, the arc of contact should be no less than 120°; for friction drives, 180° is ideal. Wrap angles are optimized by adjusting the center distance or by incorporating idler pulleys. Minimum center distances and tensioning procedures should ensure belts are properly engaged without excessive slack or misalignment. In multi-pulley systems, the wrap angle and contact lengths influence load distribution and belt life. For complex arrangements, such as a belt traversing three pulleys, geometric formulas involving center distances and angles (in radians) are used to calculate total belt length.

At the larger pulley:

$$\theta_{D_2} = \pi + 2\alpha$$

$$\sin\alpha = \frac{R_2 - R_1}{c}$$

$$\alpha = \sin^{-1}\left(\frac{R_2 - R_1}{c}\right)$$

$$\theta_{D_2} = \pi + 2\sin^{-1}\left(\frac{R_2 - R_1}{c}\right)$$

$$2\sin^{-1}\left(\frac{R_2 - R_1}{c}\right) \approx \frac{D_2 - D_1}{c}$$

$$\theta_{D_2} = \pi + \frac{D_2 - D_1}{c} \quad ; \quad \text{rad}$$

At the smaller pulley:

$$\theta_{D_1} = \pi - 2\alpha$$

Hence;

$$\theta = \pi \pm \frac{D_2 - D_1}{c} \quad ; \quad \text{rad}$$

Where:
+ for larger pulley
- for smaller pulley
c = center distance between pulleys

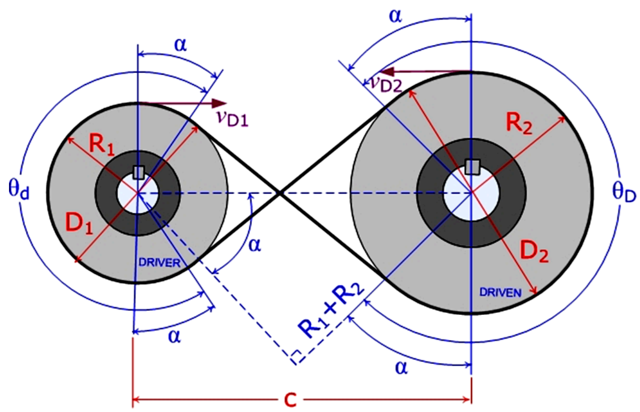
Length of the belt

$$L = \frac{\pi}{2}\left(D_2 + D_1\right) + 2c + \frac{\left(D_2 - D_1\right)^2}{4c}$$

The effective length of a belt corresponds to the contact arc over the sheave. This is determined by wrapping the belt around two or more sheaves and calculating the angle of wrap. Specific guidelines from manufacturers or standards organizations are used to establish the allowable tension and corresponding service life. As the belt rotates, the total tension is the sum of the internal stresses caused by rotation, flexure, and centrifugal effects.

CROSSED BELT INSTALLATION

In a crossed belt drive, the belt is twisted so the pulleys rotate in opposite directions.



Angle of wrap or Arc of contact

$$\theta = \pi + \frac{D_2 + D_1}{c} \qquad ; \qquad \text{rad}$$

$$\theta_D = \theta_d$$

Length of the belt

$$L = \frac{\pi}{2}\left(D_2 + D_1\right) + 2c + \frac{\left(D_2 + D_1\right)^2}{4c}$$

Pulley Diameter and Speed Relation

$$D_1 N_1 = D_2 N_2$$

Velocity Ratio, VR

$$VR = \frac{N_1}{N_2}$$

Comparison between Open and Crossed Belt Drive

	Open Belt Drive	**Crossed Belt Drive**
Pulley Rotation Direction	Same	Opposite
Contact Angle	Less than 180°	More than 180°
Slipping Tendency	Higher	Lower
Power Transmission	Moderate	Better due to increased grip
Belt Wear Rate	Lower	Higher (due to rubbing and twist)
Installation Complexity	Simple	More complex
Safety	Safer	Needs enclosure due to crossover hazard

Belt Speed

% Slip not mentioned:

For smaller pulley: $v_{D_1} = \frac{\pi D_1 N_1}{60}$

For larger pulley: $v_{D_2} = \frac{\pi D_2 N_2}{60}$

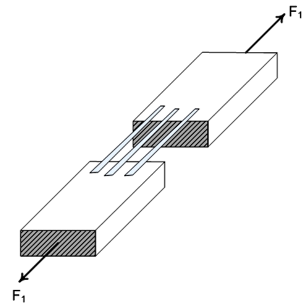
% Slip mentioned:

For smaller pulley: $v_{D_1} = \frac{\pi D_1 N_1 (1 - \%Slip)}{60}$

For larger pulley: $v_{D_2} = \frac{\pi D_2 N_2 (1 - \%Slip)}{60}$

Note: $v = v_{D_1} = v_{D_2}$ with or without slip

Maximum Induced Tensile Fiber Stress



$$S_t = S_d = \frac{F_1}{A} = \frac{F_1}{bt}$$

Where: $S_d = S_t$ = design stress
b = belt width
t = belt thickness

Force on the Tight Side of the Belt, F_1

$$F_1 = S_t(bt) = S_d(bt)$$

Allowing for weakening of the belt strength due to joints

$$S_d = \frac{S_u}{FS} * JF$$

Where: S_u = ultimate design stress
JF = joint factor
FS = Factor of Safety
FS = 10 for leather belts
FS = 6 - 8 for rubber belts

Mass Density of Belts, ρ

$$\rho = \frac{m}{V}$$

$$\rho = \frac{m}{btL}$$

For leather belt: $\rho = 0.035\frac{lb}{in^3} = 965\frac{kg}{m^3}$

For rubber belt: $\rho = 0.045\frac{lb}{in^3} = 1,244\frac{kg}{m^3}$

For standard leather belt thickness and belt speed, use Table 17.1 of Design of Machine Elements by Faires page 450.

Transmitted Shaft Power, P

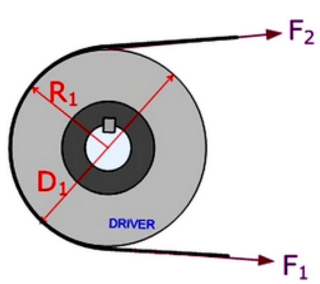
$$P = \frac{2\pi TN}{60}$$

Where: P = power transmitted, kW
T = torque or torsional moment
N = speed (rpm)

Power is transmitted by the difference in tension between the tight side and the slack side of the belt. This tension difference produces the effective driving force. Net horsepower transmitted through a belt is calculated using the relation:

$$P = (F_1 - F_2)v$$

Torque Developed or Brake Torque, T

	$T = (F_1 - F_2)\frac{D_1}{2}$ Where: F_1= force at the tight side of the belt F_2 = force at the slack side of the belt For flat belt drives, the tight side, F_1 is generally at the bottom and the slack side, F_2 at the top because gravity helps manage slack and ensures better pulley contact. The tight side at the top is only used in special layouts where pulley positions demand it.

Centrifugal Force, F_C

$$F_C = \rho\frac{btv^2}{g_c}$$

Belt-tension Ratio (Centrifugal force, F_c included)

When a belt runs over pulleys at high speed, each small segment of the belt experiences centrifugal force due to its mass and velocity. This outward force, denoted as F_C, acts uniformly on both the tight side and the slack side of the belt.

$$\frac{F_1 - F_C}{F_2 - F_C} = e^{f\theta}$$

Higher belt speed increases centrifugal force rapidly, while longer belts increase the total load. Designers must balance both to avoid excessive stress and loss of efficiency.

Belt-tension Ratio (Centrifugal force, F_c not included)

$$\frac{F_1}{F_2} = e^{f\theta}$$

Net-belt Pull or tension

$$F_1 - F_2 = \left(F_1 - F_C\right)\left[\frac{e^{f\theta} - 1}{e^{f\theta}}\right]$$

$$F_1 - F_2 = bt\left[S_d - \rho\frac{v^2}{g_c}\right]\left[\frac{e^{f\theta} - 1}{e^{f\theta}}\right]$$

Conditions:

If pulleys are made of same material, compare θ_d and θ_D, use which has smaller value.

If pulleys are not made of the same material, compare $e^{f\theta_d}$ and $e^{f\theta_D}$, use which has smaller value.

Coefficient of Friction, f

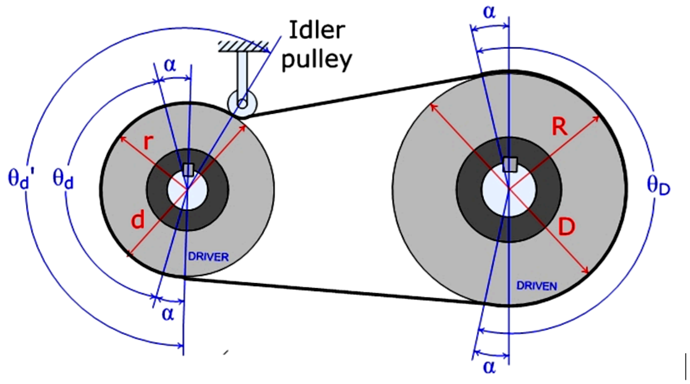
The coefficient of friction in belt drives plays a critical role in determining how effectively power is transmitted between the belt and the pulley. However, friction is not constant—it varies depending on the belt material, pulley material, surface conditions, and the presence of load. In practice, this means that machine designers cannot always rely on the maximum theoretical coefficient of friction. Instead, they use conservative values to ensure safe and reliable operation over time.

In belt drives, two important phenomena affect friction: creep and slip. *Creep* is caused by unequal stretching of the belt as it moves around the driver and driven pulleys—the driving pulley delivers a slightly longer section of belt than the driven pulley receives. This is due to elastic deformation rather than actual sliding. *Slip*, on the other hand, happens when the belt truly slides over the pulley surface because the available friction is not enough to hold it in place. Both creep and slip reduce the efficiency of power transmission, with slip being more serious since it can lead to overheating, wear, and even squealing noises.

As the load on the belt increases, the contact pressure between the belt and pulley also increases, which in turn raises the effective coefficient of friction. Designers typically allow for a small percentage of slip, around 2%, as acceptable in flat belt drives. Beyond this, efficiency losses and wear become significant. For practical design values, the coefficient of friction is usually taken as 0.3 for leather belts on steel or iron pulleys, and 0.5 for leather belts on paper pulleys.

Installation of idler pulley

Open belt drives with significantly unequal pulley sizes may suffer from a reduced wrap angle on the smaller pulley, which can cause slippage or reduced power transmission efficiency. To mitigate this, idler pulleys may be introduced on one or both sides to increase the angle of wrap and ensure better belt engagement. In conclusion, while flat belting systems may seem simple, their successful implementation requires careful attention to materials, pulley design, tensioning methods, and operating conditions to ensure reliable and efficient power transmission.



1. When the idler pulley is placed on the slack side of the belt, the tight side is unaffected by the set-up.

$$\left[F_1\right]_{w/o\ idler} = \left[F_2\right]_{w\ idler}$$

2. If pulleys and belts are not changed, the belt speed and the coefficient of friction remains the same.

$$[v]_{w/o\ idler} = [v]_{w\ idler}$$

$$[f]_{w/o\ idler} = [f]_{w\ idler}$$

$$\left[F_1 - F_C\right]_{w/o\ idler} = \left[F_1 - F_C\right]_{w\ idler}$$

3. With the presence of an idler pulley in the slack side, the angle of wrap or arc of contact increases, hence the transmission capacity also increases.

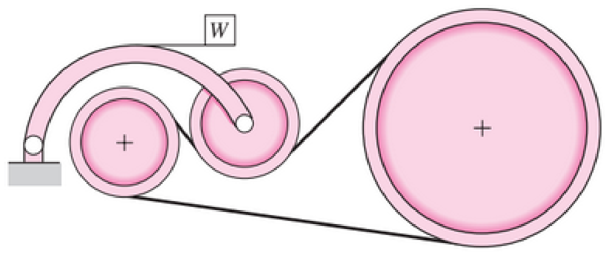
$$[P]_{w\ idler} = [P]_{w/o\ idler} + \ \%\ increase\ [P]_{w/o\ idler}$$

$$\frac{\left[F_1 - F_C\right]_{w\ idler}}{\left[F_1 - F_C\right]_{w/o\ idler}} = \frac{\left[\frac{e^{f\theta} - 1}{e^{f\theta}}\right]_{w\ idler}}{\left[\frac{e^{f\theta} - 1}{e^{f\theta}}\right]_{w/o\ idler}} = (1 + \%\ increase)$$

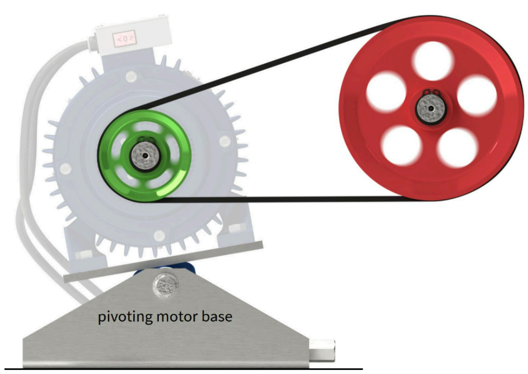
Belt-Tensioning Schemes

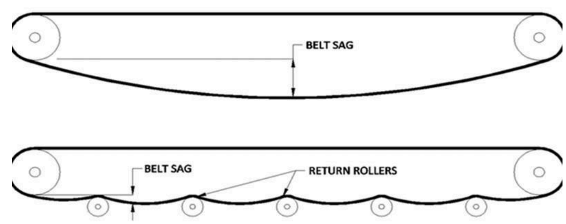
Three common belt-tensioning schemes used in mechanical systems to maintain adequate tension in belt drives: (a) weighted idler pulley, (b) pivoted motor mount, and (c) catenary-induced tension. Proper belt tension is critical for maintaining friction between the belt and pulley surfaces, preventing slippage, and ensuring efficient power transmission.

The **weighted idler pulley** system uses a pulley with an attached weight to apply tension to the slack side of the belt. This system provides automatic tension adjustment since the weight maintains a constant downward force, accommodating small changes in belt length due to stretching or thermal expansion. This method is effective for systems with fluctuating loads or moderate misalignments, and it simplifies maintenance since tension remains fairly constant over time.



A **pivoted motor mount setup**, where the motor is mounted on a pivoted base with a weight or spring applying force. As the belt transmits power, the tight side pulls against the motor, which swings slightly but is resisted by the counterweight. This setup balances the belt tension between the tight and slack sides (F_1 and F_2), making it ideal for installations where belt slack varies due to starting loads or shock. It is commonly used in industrial drives and conveyor systems.



<table>
<tr>
<td>The belt tension can be generated by catenary-induced sag, where the belt naturally dips between two pulleys due to its own weight. The sag or "dip" introduces a natural tension component. While this is the simplest of the methods, it is limited to lightweight belts and low-power transmission scenarios where minor tension is sufficient. It may also be used in synchronous belts or timing belts where pre-tensioning is minimal.</td>
<td>
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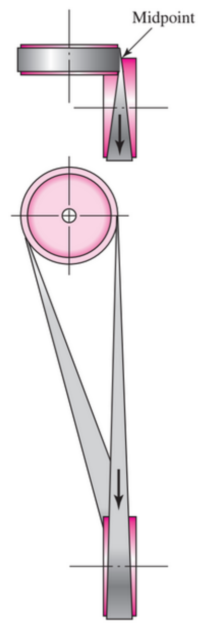
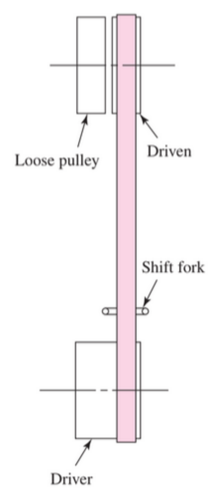
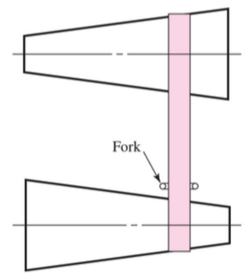
A belt tensioner pulley can also be considered a type of idler pulley, but it performs a more specific and active role in the system. An idler pulley is generally fixed in position and its main purpose is to guide the belt, maintain alignment, and often increase the wrap angle on the driver pulley to improve power transmission. It does not actively alter the belt tension; instead, it simply redirects the belt path.

On the other hand, a belt tensioner pulley is designed to maintain or apply the proper belt tension automatically. It is usually spring-loaded or adjustable so that it can compensate for belt elongation, wear, or thermal expansion during operation. By doing this, the tensioner ensures that the belt remains tight enough to prevent slippage while also avoiding excessive stress that could damage the belt or bearings.

Other Belt Configurations

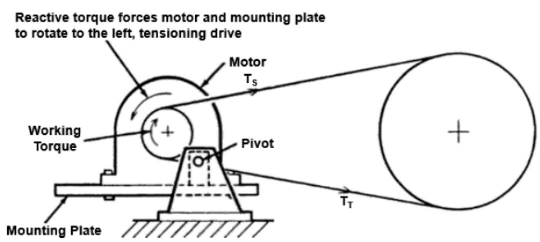
Quarter-twist belt drive configuration, where the pulleys are mounted at 90° angles, typically on non-parallel, intersecting shafts. In this arrangement, the belt is twisted a quarter turn to accommodate the shaft orientation, allowing motion to be transmitted between two perpendicular axes. This setup is especially useful in tight or misaligned machinery layouts, where traditional belt alignments are not feasible. However, if bidirectional rotation (motion in both directions) is required, an idler pulley must be added to maintain proper belt contact and tracking. While the quarter-twist drive is practical in constrained spaces, the twisting action increases stress on the belt, potentially leading to reduced belt life due to added wear and flexural fatigue.	
Clutching flat belt drive system. In this setup, a belt can be shifted laterally between a loose pulley and a tight (driving) pulley using a mechanical shift fork. This configuration enables the operator to engage or disengage the driven machine without needing to stop the motor. When the belt is moved onto the tight pulley, the system transmits motion—effectively engaging the drive. Conversely, when shifted to the loose pulley, the motion is interrupted, and the driven component stops. This system acts as a mechanical clutch, offering a simple yet effective means of controlling machine operation, especially in early mechanical systems that lacked electrical controls.	

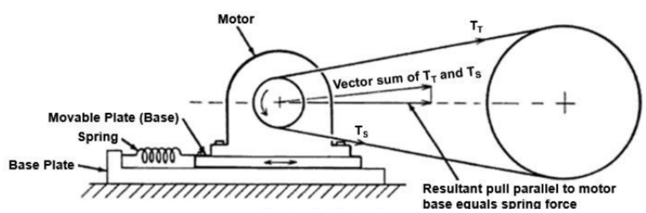
Variable-speed drives

Flat belt runs across a cone-shaped pulley, allowing adjustment of the effective diameter on the drive or driven side. By sliding the belt along the cone, the pulley ratio changes, which in turn alters the output speed. This setup is used exclusively for flat belt drives and provides a continuous range of speed control without the need for gears.	

A similar principle is applied using V-belts or round belts in combination with grooved pulleys. The belt is moved between different grooves of varying diameters, resulting in changes to the output speed. This method allows for stepwise speed control and is commonly used in more modern industrial


One method to add belt tension is where the motor is mounted on a **pivoting frame**. When power is transmitted, the motor frame reacts with torque opposite to the rotor's direction, causing the frame to rotate slightly and apply tension to the belt. The greater the torque demand, the more the frame shifts and tightens the belt automatically. This provides self-regulating tension under varying loads, although it may not be perfectly constant.

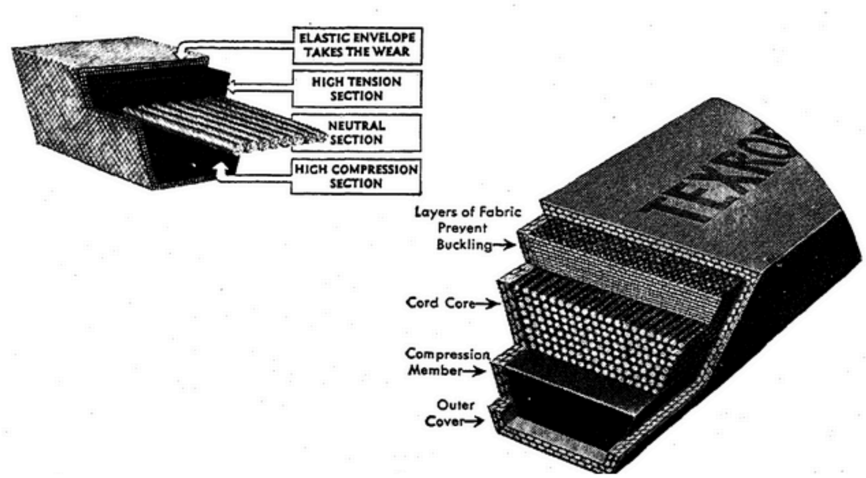




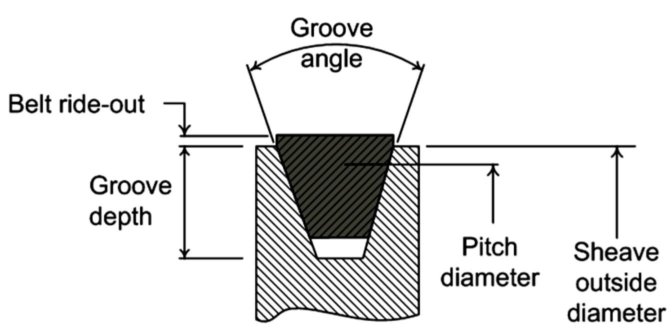
The **spring-loaded motor base** is one of the two primary types of motor mounting systems used to automatically maintain belt tension in belt-driven machinery. In this configuration, the motor is mounted on a movable base plate that is connected to a spring mechanism. As the belt transmits power, it exerts a pull on the motor in the direction of the resultant belt force, which is the vector sum of the tight side tension (T□) and the slack side tension (T□). The spring is designed to apply a force that opposes this resultant belt pull, thereby keeping the belt properly tensioned.

V-belts

V-belts or also commonly known as “fan belts” are tapered cross-sectional shaped which wedge in a pulley with a V-shaped groove so that the driving action occurs at the sides of the belt rather than the bottom. V-belts transmit higher torque at a smaller width than the flat belt.



V-belts are widely used in industrial and automotive applications due to their compact design and effective power transmission. These belts are constructed with high-tensile members made from cords or fabric to withstand stress, and a rubber body that serves as a cushioning material. The wedge-shaped cross-section allows the belt to sit firmly in the sheave grooves, enhancing the normal force between the belt and the pulley through the wedging action. This results in increased friction and greater torque transmission capability.



V-belts operate on grooved pulleys known as sheaves, and because of the wedging effect, they are highly efficient on short center distances without needing frequent retensioning. Sheave dimensions (groove width, angle, and outside diameter) must match the belt profile precisely for optimal performance.

Length of the belt

$$L = \frac{\pi}{2}\left(D_2 + D_1\right) + 2c + \frac{\left(D_2 - D_1\right)^2}{4c}$$

Where: $D_1 = pitch\ diameter\ of\ smaller\ sheave$

$D_2 = pitch\ diameter\ of\ larger\ sheave$

To solve for the center distance, we have;

$$c = \frac{b + \sqrt{b^2 - 32\left(D_2 - D_1\right)^2}}{16}$$

Where: $b = 4L - 6.28\left(D_2 + D_1\right)$

To choose a minimum center distance, we use:

$$c = \frac{\left(D_2 + D_1\right)}{2} + D_1 \quad \text{or} \quad c = D_2$$

Choose whichever is larger.

Number of Belts

$$Number\ of\ belts = \frac{Design\ HP}{Adjusted\ Rated\ \frac{HP}{belt}}$$

$$Design\ HP = N_{sf}(Transmitted\ HP)$$

$$Adjusted\ Rated\ HP = K_{\theta}K_L(Rated\ HP)$$

$$Rated\ HP = \left[a\left(\frac{10^3}{v_D}\right)^{0.09} - \frac{c}{K_d D_1} - e\frac{v_D^{\ 2}}{10^6}\right]\frac{v_D}{10^3}$$

Where: a, c, e = rated Hp Constants. Table 17.3

N_{sf} = service factor. Table 17.7

K_{θ} = correction factor for an arc of contact other than 180°. Table 17.5

K_L = correction factor for belt length. Table 17.6

K_d = small-diameter factor. Table 17.4

D_1 = pitch diameter of smaller sheaves, in inches

v_D = belt speed, in ft/min

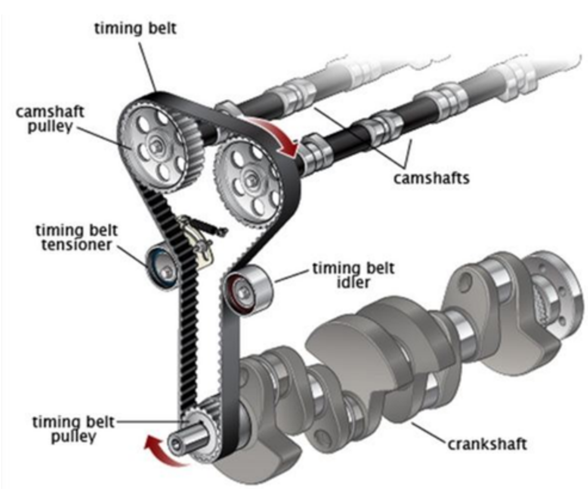
For one belt with B section, a = 4.737, c = 13.962 and e = 0.0234:

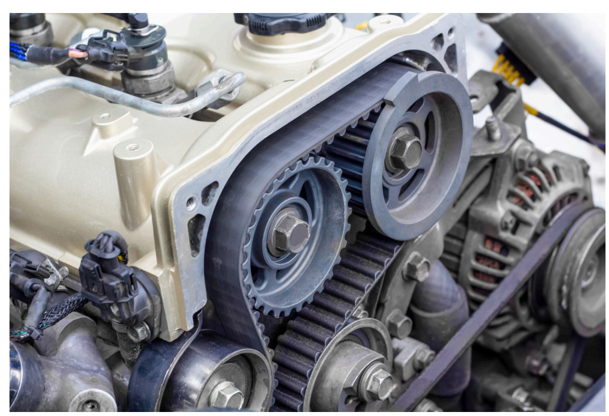
$$Rated\ HP = \left[4.737\left(\frac{10^3}{v_D}\right)^{0.09} - \frac{13.962}{K_d D_1} - 0.0234\frac{v_D^{\ 2}}{10^6}\right]\frac{v_D}{10^3}$$

TIMING BELTS

Synchronous belts, commonly referred to as timing belts or positive-drive belts, are used in applications where precise synchronization between the driver and driven shafts is required. Unlike conventional friction belts, synchronous belts have evenly spaced teeth on their inner surfaces that mesh with toothed pulleys or sprockets, ensuring no-slip power transmission. These belts eliminate issues such as slip and stretch, which are common in V-belt systems, making them ideal for timing-sensitive applications such as automation, robotics, and engine camshaft systems.

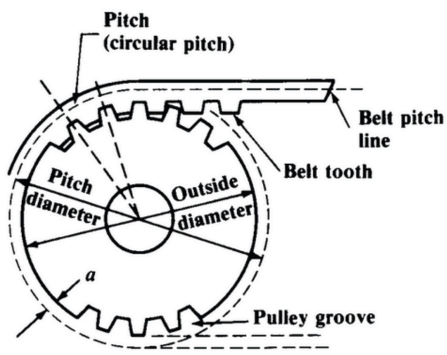
Timing belts are specialized belts made of rubberized fabric reinforced with nylon and steel wire, designed to deliver positive, non-slip transmission of power. Unlike flat or V-belts, timing belts have teeth that fit into corresponding grooves on the pulleys, ensuring a constant angular velocity ratio and no slippage or stretching during operation. This makes them ideal for applications requiring high precision and synchronized movement, such as in automotive engines or robotics. They also require no lubrication, operate quietly, and offer high efficiency—typically between 97% to 99%.





The internal steel wire in the belt provides tensile strength and is aligned along the belt pitch line, which is the reference diameter for pulley sizing. The pitch length of the belt remains constant regardless of the thickness of the belt material.

When selecting a synchronous belt, the service factor—which accounts for the nature of the load and the operating hours—must be considered. Belt selection also involves checking the tooth pitch, belt width, and number of teeth in mesh, all of which influence the belt's load capacity and durability.

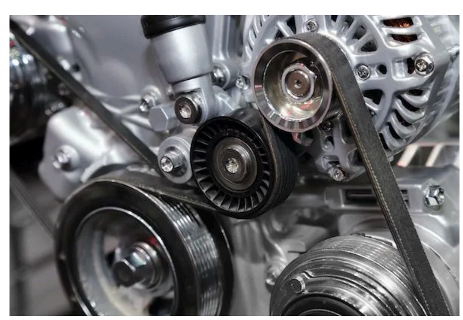


a = Pitch line differential *a*

The diagram illustrates the geometry of a synchronous belt and pulley system, emphasizing the relationship between the belt tooth and pulley groove. The pitch diameter is the effective circle where power is transmitted, while the outside diameter refers to the outer edge of the pulley. The belt pitch line aligns with the pitch circle and ensures proper engagement. The pitch line differential (denoted as "a") represents the radial distance between the pitch and outside diameters. Accurate meshing of belt teeth with pulley grooves ensures precise, slip-free power transmission, making synchronous belts ideal for timing-critical applications such as robotics and engines.

RIBBED BELTS

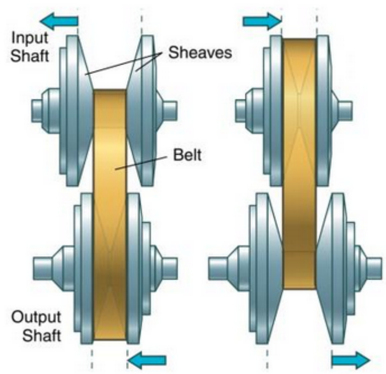
V-ribbed belts are a hybrid between flat belts and V-belts. They consist of a flat backing with multiple V-shaped ribs on the underside, which fit into matching grooved sheaves (pulleys). These ribs help guide the belt and improve grip and stability, making V-ribbed belts more efficient and compact than traditional flat belts.



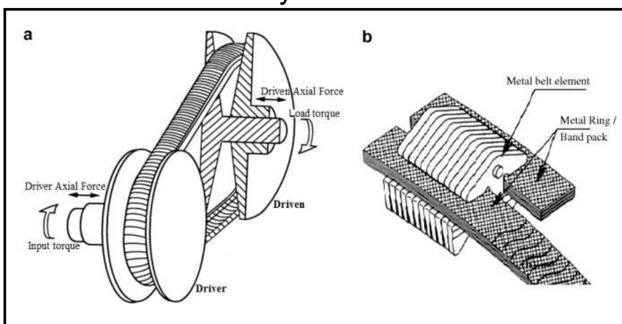
Unlike standard V-belts, V-ribbed belts do not rely on the wedging action for torque transmission. As a result, they can operate at higher tensions and are especially well-suited for high-speed, high-efficiency, and serpentine belt drive systems—like those found in automotive engines and compact industrial applications. They are also preferred for use with small diameter pulleys due to their flexibility and thinner cross-section.

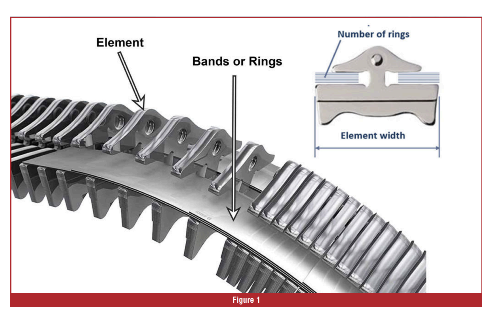
CVT Belts

Continuously Variable Transmissions (CVTs) are a unique type of transmission system that differ from conventional gearboxes because they have no fixed gear ratios. Instead, a CVT allows the engine to smoothly and continuously adjust the gear ratio within its operating range. This provides a seamless transition between speed and torque, optimizing the engine's performance for fuel efficiency, smooth acceleration, or power depending on driving conditions.



Metal belts used in Continuously Variable Transmissions (CVTs) are highly specialized components designed to handle the smooth and efficient transfer of power between the engine and the wheels. Unlike conventional gear systems, CVTs rely on a belt-and-pulley mechanism to provide an infinite range of gear ratios. The steel belt is composed of hundreds of small, transversely mounted steel elements held together by high-strength steel bands running longitudinally. These steel plates grip the pulley surfaces by compression rather than tension, which prevents stretching and ensures long-term durability. The bands act like flexible rings that keep the plates tightly compressed, transmitting power efficiently as the pulley sheaves adjust their diameters to vary the ratio.





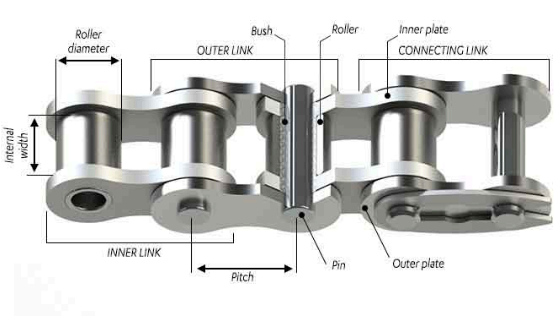
The plates and bands work together to provide strength and flexibility. The plates carry the compressive forces, while the bands guide the plates and keep them aligned. When the primary pulley contracts, the belt elements are pushed outward, transferring torque to the secondary pulley. This arrangement prevents slippage and reduces surface pressures on each plate, allowing high torque transmission even under demanding loads. To reduce friction and wear, the steel belt is lubricated with transmission fluid sprayed directly into the belt at high pressure, ensuring smooth operation and cooling. At the same time, the belt allows minimal clearance between plates, which enables oil to penetrate between them and maintain lubrication.

Maintenance of CVT belts requires strict adherence to manufacturer specifications, especially in terms of transmission fluid type and service intervals. Specialized CVT fluids are used because they contain additives to handle the unique sliding and compressive forces of the belt system. Some CVTs also incorporate oil heaters to ensure the fluid reaches proper operating temperature in cold conditions.

CHAINS AND SPROCKETS

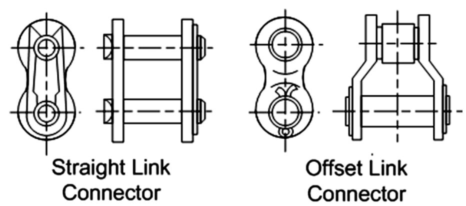
Transmission chains are widely used in mechanical systems for transmitting power, motion, or timing between rotating shafts. They come in several types, including detachable chains, cast roller chains, and pintle chains—each designed for specific operational needs. The most common type is the roller chain, which consists of alternating inner and outer links, rollers, pins, and bushings. These chains are available in single-strand and multi-strand designs, the latter being suitable for higher loads by combining multiple chains side by side. Chains are standardized under ANSI/ASME B29.1M-1993 for dimensions, strength ratings, and applications.

Roller chain drives are one of the most commonly used types of chain power-transmission systems in mechanical design. They consist of a series of interconnected links with rollers that engage with the sprockets to transmit power efficiently and widely used to transmit power on bicycles, motorcycles and other machinery.

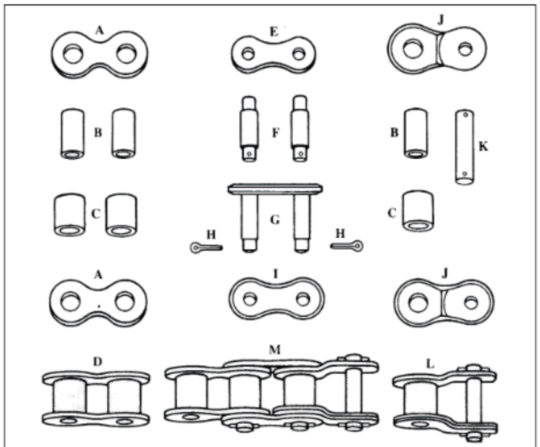


Straight link connectors and offset link connectors are two types of roller chain link configurations used to connect sections of chain or to adjust chain length. A **straight link connector**, also known as an even-pitch or standard connector, consists of two identical outer plates connected by pins and bushings, with rollers in between. It maintains the uniform pitch of the chain and is typically used when the chain has an even number of links.

An **offset link connector** is used when an odd number of pitches is needed. It consists of one inner and one outer plate that are asymmetrical, resulting in a single-pitch extension. This design allows the chain length to be increased or decreased by one pitch, which is helpful during installation or maintenance. However, offset links are generally less strong than straight links due to their asymmetrical structure and are not recommended for high-load applications unless necessary.



Chain pitch, which is the center-to-center distance between adjacent pins, is a critical dimension that determines chain compatibility and performance. Standard roller chains are identified using a numbering system that reflects their pitch and series (standard, heavy, or multiple-strand). The chain's **ultimate tensile strength** depends on its construction, and minimum values are specified based on pitch and the number of strands. Chain parts are standardized and include components like inner plates, rollers, pins, and offset links, as shown below



Roller Link D. — An inside link consisting of two inside plates, two bushings, and two rollers.
Pin Link G and E. — An outside link consisting of two pin-link plates assembled with two pins.
Inside Plate A. — One of the plates forming the tension members of a roller link.
Pin Link Plate E. — One of the plates forming the tension members of a pin link.
Pin F. — A stud articulating within a bushing of an inside link and secured at its ends by the pin-link plates.
Bushing B. — A cylindrical bearing in which the pin turns.
Roller C. — A ring or thimble which turns over a bushing.
Assembled Pins G. — Two pins assembled with one pin-link plate.
Connecting-Link G and I. — A pin link having one side plate detachable.
Connecting-Link Plate I. — The detachable pin-link plate belonging to a connecting link. It is retained by cotter pins or by a one-piece spring clip (not shown).
Connecting Link Assembly M. — A unit designed to connect two roller links.
Offset Link L. — A link consisting of two offset plates assembled with a bushing and roller at one end and an offset link pin at the other.
Offset Plate J. — One of the plates forming the tension members of the offset link.
Offset Link Pin K. — A pin used in offset links.

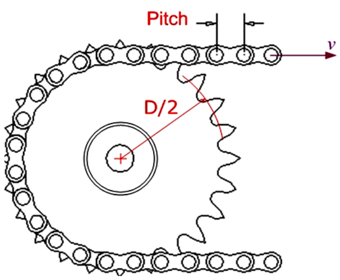
Advantages	Disadvantages
Adaptable for long and short center distances Can be arranged to drive more than one unit No slippage Can operates in hostile environment Long-life when properly maintained	Risk of coming off the sprocket Guide sprockets and spring tensioner may be necessary to maintain chain tension Noisier than belts or gears Flexibility is limited to single plane Limited to low speed applications compared with belts or gears

Chain elongation and wear primarily occur at the pin and bushing articulation points, where repeated motion leads to gradual material loss. The rate of wear is significantly influenced by the number of teeth on the sprocket. In general, sprockets with more teeth result in less wear because they reduce the angle of articulation at each joint. Conversely, smaller sprockets with fewer teeth increase the angle of articulation, causing faster elongation of the chain.

Standard pitches for roller chains

Chain no.	25	35	41	40	50	60	80	100
Pitch	¼”	3/8”	½”	½”	5/8”	¾”	1”	1-1/4”

Chain no.	120	140	160	180	200	240
Pitch	1-1/2”	1-3/4”	2”	2-1/4”	2-½”	3”



Length of chain

From ASME/ANSI B29.1, the length of a roller chain in pitches is given by:

$$L = 2c + \frac{T_2 + T_1}{2} + \frac{(T_2 - T_1)^2}{4\pi^2 c}$$

Where:
L = chain length, in pitches
c = center distance, in pitches
T_1 = number of teeth of smaller sprocket
T_2 = number of teeth of large sprocket

This empirical formula is derived to approximate the exact chain length with excellent accuracy under typical industrial design assumptions.

If center distance is not given, use:

$$c = D_2 + \frac{D_1}{2}$$

General rule:

1. The center distance between sprockets should not be less than 1.50 times the diameter of the larger sprocket
2. The center distance should not be less than 30 times the pitch nor about 50 times the pitch.
3. A center distance of 80 pitches may be considered an approved maximum
4. L, in pitches should be an even number, so that the use of offset connecting link will not be necessary

Center Distance between Sprockets

$$c = \frac{P}{8}\left[2L - T_2 - T_1 + \sqrt{\left(2L - T_2 - T_1\right)^2 - \frac{8}{\pi^2}\left(T_2 - T_1\right)^2}\right]$$

Where: P = pitch of chain, in pitches
L = length of chain, in pitches
c = center distance, in inches

Average chain speed

The speed limits of roller chain drives are mainly determined by the number of teeth on the sprockets, especially the smallest sprocket, and the pitch of the chain. Smaller pitch chains can operate at higher rotational speeds; for instance, a 1/4-inch pitch chain can reach up to 8,800 RPM. Sprockets with fewer than 16 teeth are generally limited to low-speed applications, while sprockets with 18 to 24 teeth are recommended for standard use. If sprockets with fewer than 25 teeth are used at speeds above 500 RPM, they should be heat-treated to achieve a surface hardness of 35 to 45 on the Rockwell C scale for durability.

$$v_1 = \frac{\pi D_1 N_1}{60} = \frac{P_1 T_1 N_1}{60}$$

$$v_2 = \frac{\pi D_2 N_2}{60} = \frac{P_2 T_2 N_2}{60}$$

Where: N_1 = speed of the smaller sprocket, in rpm
N_2 = speed of the larger sprocket, in rpm

Note: $v = v_1 = v_2$

Pitch diameter of sprocket

$$D = \frac{P}{sin\left(\frac{180^o}{T}\right)}$$

P = pitch of chain, in pitches

Maximum pitch

In selecting a pitch, the given empirical may be used:

$$P_{max} = \left(\frac{900}{N_1}\right)^{2/3}$$

Minimum number of teeth calculation

Roller-chain sprocket

$T_{min} = \frac{4D}{P} + 5$ for pitches to 1-inch

$T_{min} = \frac{4D}{P} + 4$ for pitches to 1-¼ inches to 2-½ inches

Silent-chain sprocket

$T_{min} = \frac{4D}{P} + 6$ for pitches to 2-inches

Allowable load of standard roller chain used in tension linkage under steady load

$$Allowable\ Load = 1,900\ P^2$$

For lightweight chain, use 1,000 instead of 1,900

Where: P = pitch of the chain, in inches

Factor of Safety for Roller chains

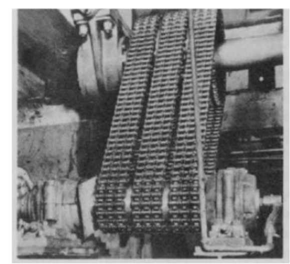
$FS = \frac{F_{Ultimate\ Strength}}{F_{allowable}}$; based on ultimate strength

$FS = \frac{F_{Fatigue\ Strength}}{F_{allowable}}$; based on fatigue strength

Where: $F_{Ultimate\ Strength}$ = From Table 73 Finished steel roller chains; page 352 (Design of Machine Members 2nd Edition by Venton Levy Doughtie and Alex Vallance)

$$F_{Fatigue\ Strength} = \frac{F_{Ultimate\ Strength}}{4}$$

The selection of a chain and sprocket system involves considering factors like horsepower transmission, speed, service factor, and center distance between sprockets. Machine Design Tables provide references for horsepower ratings based on chain pitch, lubrication method, and number of teeth. For high-torque or short-pitch applications, multi-strand chains offer increased capacity. Adjustments to center distance are necessary to maintain proper chain tension and avoid premature wear.

Multiple-strand chains are composed of two or more single-strand chains joined side by side. Pins extend across all strands to maintain alignment and provide increased strength and load distribution.		 Example of Multi-strand chain From page 466 (Design of Machine Elements 4th Edition by Virgil Morning Faires)

Standard Roller Chain Numbers
Roller chains are identified using a standardized numbering system that provides specific information about the chain's pitch, type, and construction.

Each roller chain is identified by a specific **chain number**, which gives information about the chain's pitch, type, and construction.

1. **Right-hand figure (last digit):**
   0: Standard roller chain (usual proportions)
   1: Lightweight chain
   5: Rollerless bushing chain

2. **Left-hand figures:** These numbers tell you the **pitch** of the chain (the distance between roller centers). The number represents how many **eighths of an inch (⅛")** the pitch is. For example:
   Chain number **80** → 8 × ⅛" = **1 inch pitch**
   Chain number **50** → 5 × ⅛" = **5/8 inch pitch**

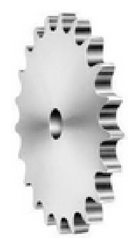
3. **Letter "H" after the number:**
   This indicates a **heavy series** chain. Heavy chains have **thicker link plates** for added strength.
   Example: **80H** means a 1-inch pitch **heavy-duty** chain.

4. **Hyphenated numbers (strand count):**
   If a number like **-2**, **-3**, or **-4** is added, it indicates **multiple strands** of chain joined together:
   - **-2** = Double strand
   - **-3** = Triple strand
   - **-4** = Quadruple strand

In summary, a chain number like **80H-2** means a **1-inch pitch**, **heavy-duty**, **double-strand** roller chain. This numbering system helps identify the chain's physical characteristics and suitability for different applications.

TYPES OF SPROCKETS

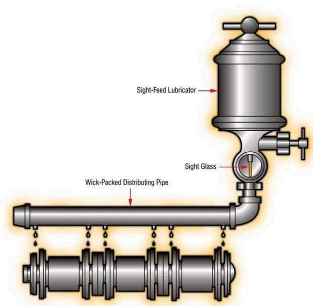
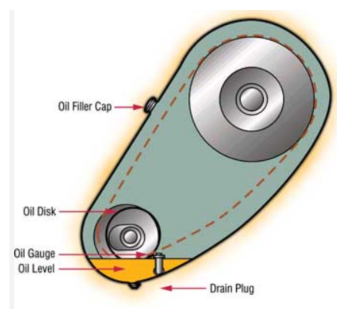
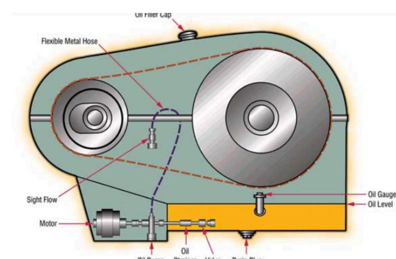
Sprockets are the toothed wheels that engage with the chain, converting rotary motion to linear force or vice versa. They are classified as commercial or precision, based on tolerances and load requirements. Key sprocket dimensions include pitch diameter, outside diameter, bottom diameter, and caliper diameter, all of which are critical for ensuring proper chain engagement. Different sprocket types—such as plain plate, hub, and shear pin types—are selected based on operational safety and maintenance concerns.

The **plain plate sprocket** is the simplest form, consisting of a flat disk with teeth but no hub. It is lightweight and compact, making it ideal for light-duty applications or when space is limited	
The **sprocket with a hub** includes a central hub section that adds strength and allows for more secure mounting to a shaft, typically using a keyway and set screw. This type is commonly used in medium to heavy-duty applications where more torque needs to be transmitted.	
A **double-strand sprocket** is used. This sprocket features two rows of teeth, allowing it to engage with double-strand roller chains, which helps distribute the load and improve durability	

The **taper lock sprocket** is designed with a tapered bore to accommodate a taper lock bushing. This design allows for quick and secure mounting to a shaft without the need for machining keyways. It is especially useful for applications where ease of installation, removal, and alignment is important.	

Lubrication of Chain Drives

Proper lubrication is critical for the performance and longevity of chain drives. In fact, chains are more likely to fail from insufficient lubrication than from long-term service. The primary goal of lubrication is to minimize wear, prevent overheating, and ensure smooth operation of the chain. Light-bodied oil of good quality, suitable for the prevailing operating temperature, is generally recommended. For both high- and low-speed drives, S.A.E. 20 or S.A.E. 30 oil is ideal for shorter pitches, while S.A.E. 40 is suited for heavier chains. In colder climates, winter-grade oils should be used to maintain adequate fluidity.

Type A: Manual or Drip Lubrication	**Type B: Oil Bath or Splash Lubrication Method**	**Type C: Oil Stream Lubrication**
		
Chain speed: up to ~1.5 m/s (≈ 300 ft/min) **Power:** low to moderate loads **Application:** Light-duty, slow-moving machinery where the chain can be lubricated periodically by oil can, brush, or drip system. **Notes:** Not suitable for continuous heavy-duty operation, but economical for small farm or workshop equipment.	**Chain speed:** 1.5 to 8 m/s (≈ 300–1600 ft/min) **Power:** medium to heavy loads **Application:** Agricultural machinery, industrial drives, conveyor systems. The lower strand of the chain runs through an oil bath or oil disk that splashes lubricant. **Notes:** Provides better coverage and cooling. Requires enclosed housing to prevent contamination.	**Chain speed:** greater than 8 m/s (≈ 1600 ft/min) up to ~12–15 m/s **Power:** heavy loads, high torque, or continuous-duty applications (e.g., diesel engines, turbines, high-speed industrial drives). **Application:** Chains under high speed and high temperature. Pressurized oil is pumped and directed onto the chain. **Notes:** Best for minimizing wear and dissipating heat. Requires pump, filter, and piping.

Proper lubrication is essential for the efficient operation and long life of transmission roller chains. A lubricating film must be maintained between the pin and bushing to prevent metal-to-metal contact. Lubricants should match ambient temperatures: for example, SAE 20 oil is suitable for 20–40°F, SAE 30 for 40–100°F, and SAE 40 for 100–120°F. There are three main lubrication methods: **Type A (manual or drip)**, where oil is applied periodically; **Type B (bath or disc)**, where a portion of the chain is submerged in oil or picks up oil from a rotating disc; and **Type C (oil-stream)**, where a pump circulates oil through the chain. Lubrication must be selected based on speed, load, and chain type, and better oil quality than the minimum standard is recommended to extend service life.

Heavy oils and greases are not recommended at normal temperatures because they are too thick to penetrate the narrow clearances between the pins and bushings where lubrication is most needed. Instead, for systems not using splash or bath lubrication methods—which are generally restricted to speeds below 1,500 feet per minute (fpm)—oil should be applied directly to the upper edges of the link plates in the bottom span of the chain. This ensures that oil reaches the critical internal surfaces. Applying oil only to the upper span of the chain or directly onto the rollers is largely ineffective in extending chain life or reducing wear.

Sufficient lubrication must be applied to prevent the overheating and tempering of the hardened bearing surfaces. The exact amount of oil required depends on the operating conditions and should be adjusted accordingly.

Silent chains, also known as inverted-tooth chains, are composed of alternating steel links shaped to form straight tooth edges that engage with the entire length of the sprocket teeth. This design allows for smoother and quieter operation compared to other chain types. Silent chains are suitable for general applications at speeds up to 1,600 feet per minute (fpm), and can operate at even higher speeds—up to 2,500 fpm—if they are enclosed and properly lubricated. The selection process for silent chains is generally similar to that used for roller chains.

Installation and alignment of sprockets are equally critical. Sprockets should meet ANSI standards and be mounted securely, with a recommended center distance of 30 to 50 chain pitches. A minimum wrap angle of 120 degrees should be maintained to ensure engagement and reduce wear. The alignment of shafts and chain tension should be checked regularly.