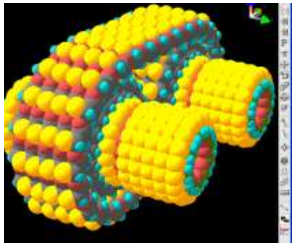
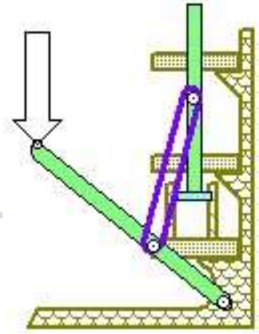
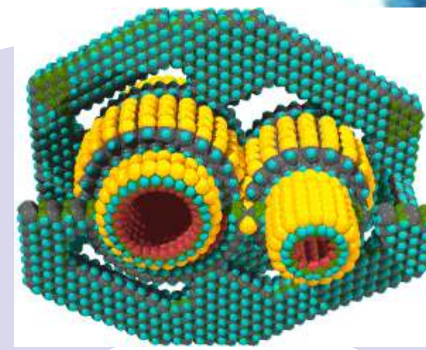


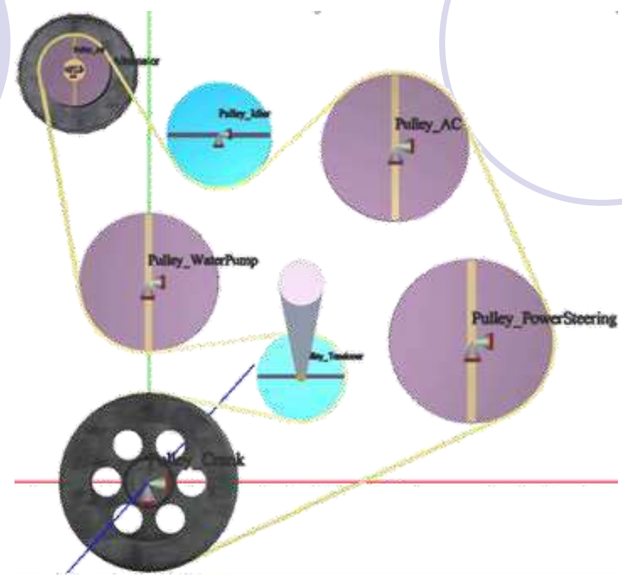




Mechanical Design II

(Chapter 17 Shigley)

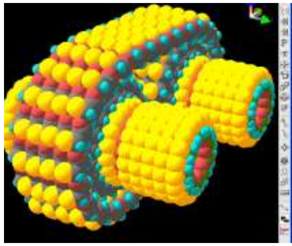
By S.G.Khan



Power Transmission Elements, Flexible Mechanical Elements

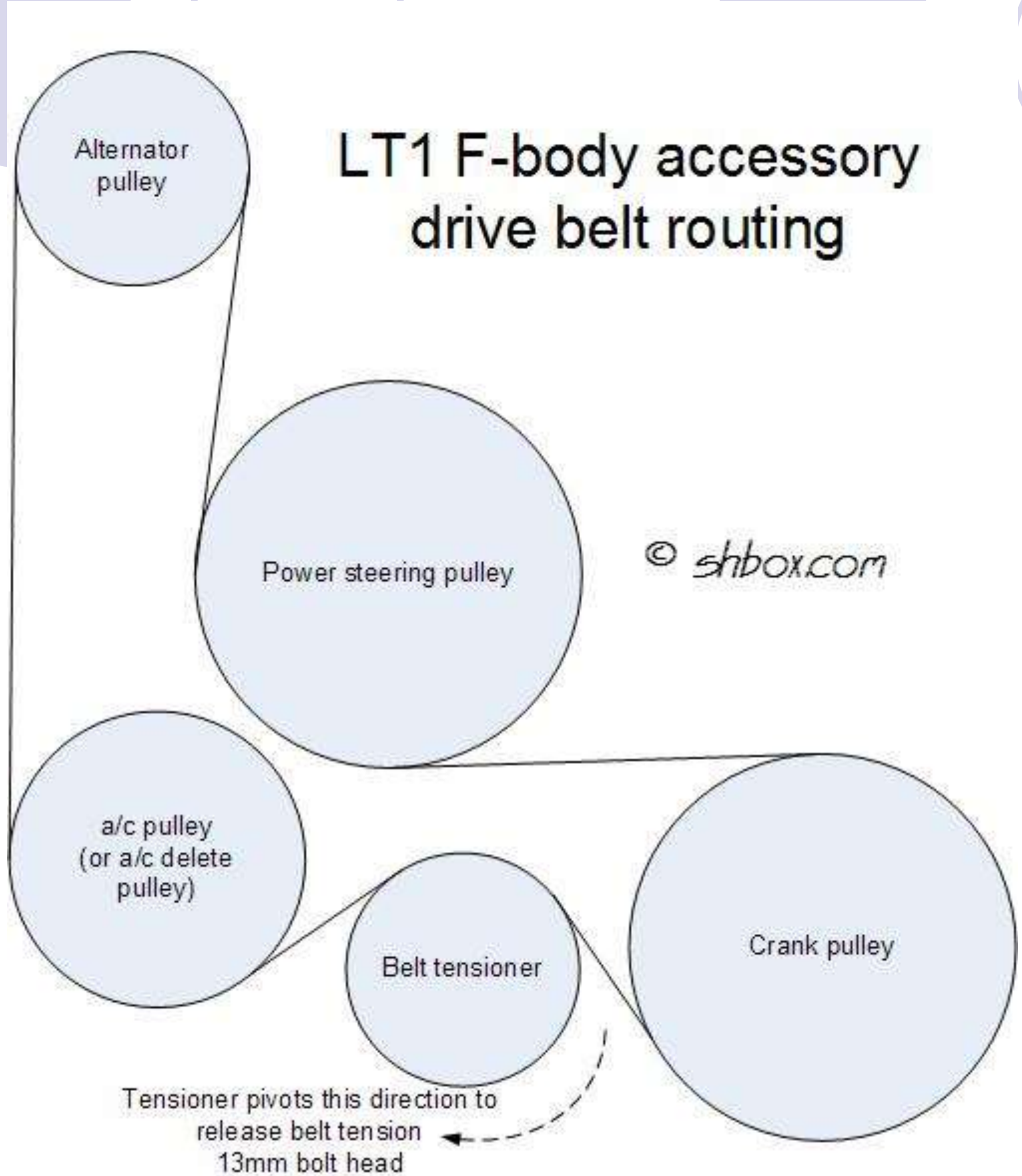
SHAFTS,BELT/ROPE/chain DRIVES

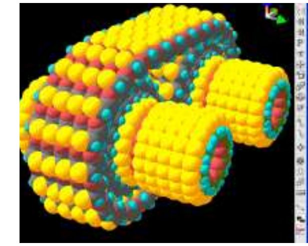
Flexible Mechanical Elements

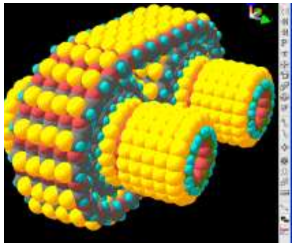


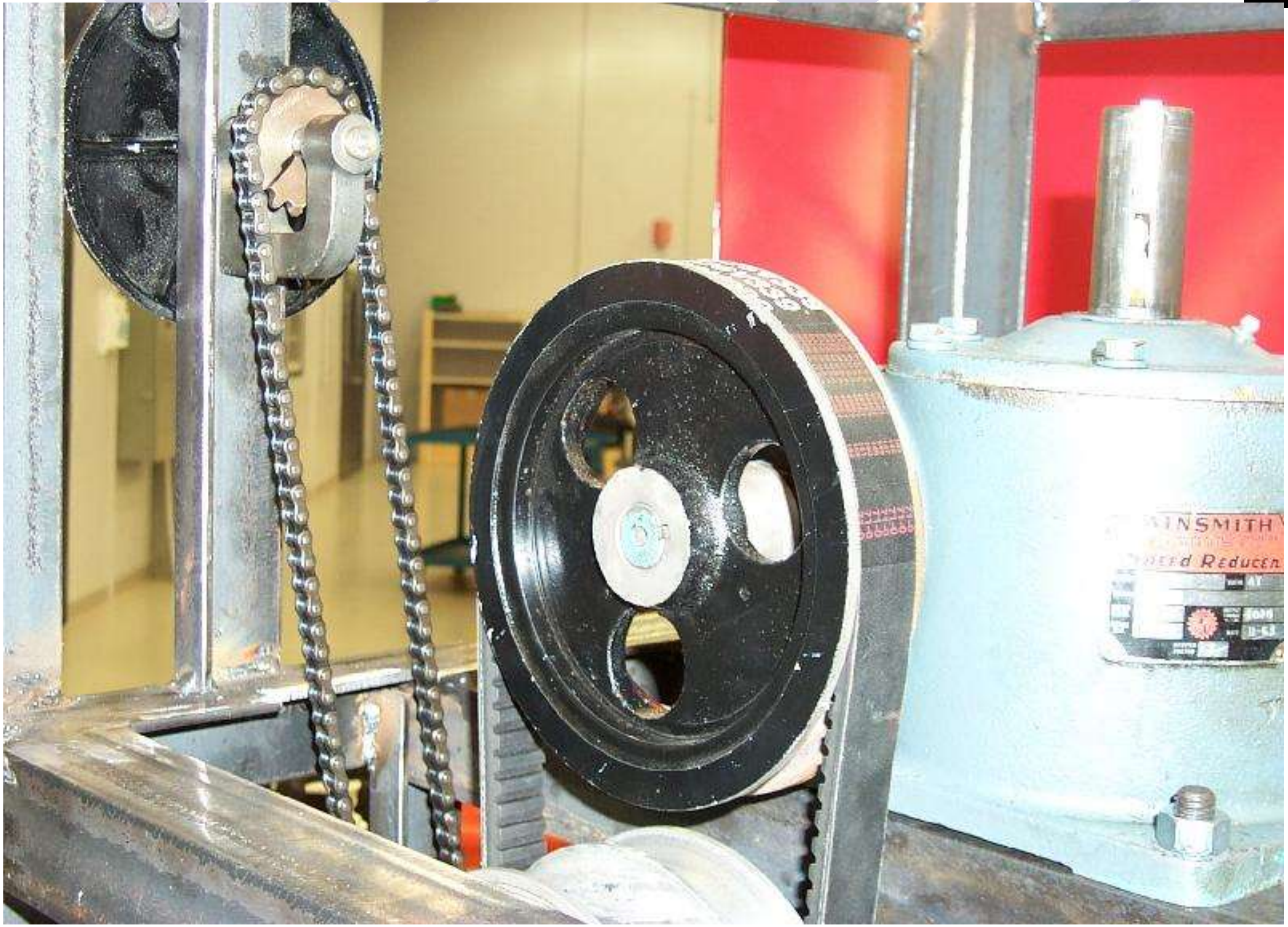
Belts, ropes, chains, and other similar elastic or flexible machine elements are used in conveying systems and in the transmission of power over comparatively long distances. It often happens that these elements can be used as a replacement for gears, shafts, bearings, and other relatively rigid power-transmission devices. In many cases their use simplifies the design of a machine and substantially reduces the cost.

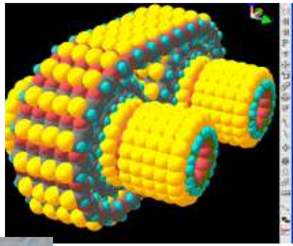
In addition, since these elements are elastic and usually quite long, they play an important part in absorbing shock loads and in damping out and isolating the effects of vibration. This is an important advantage as far as machine life is concerned.

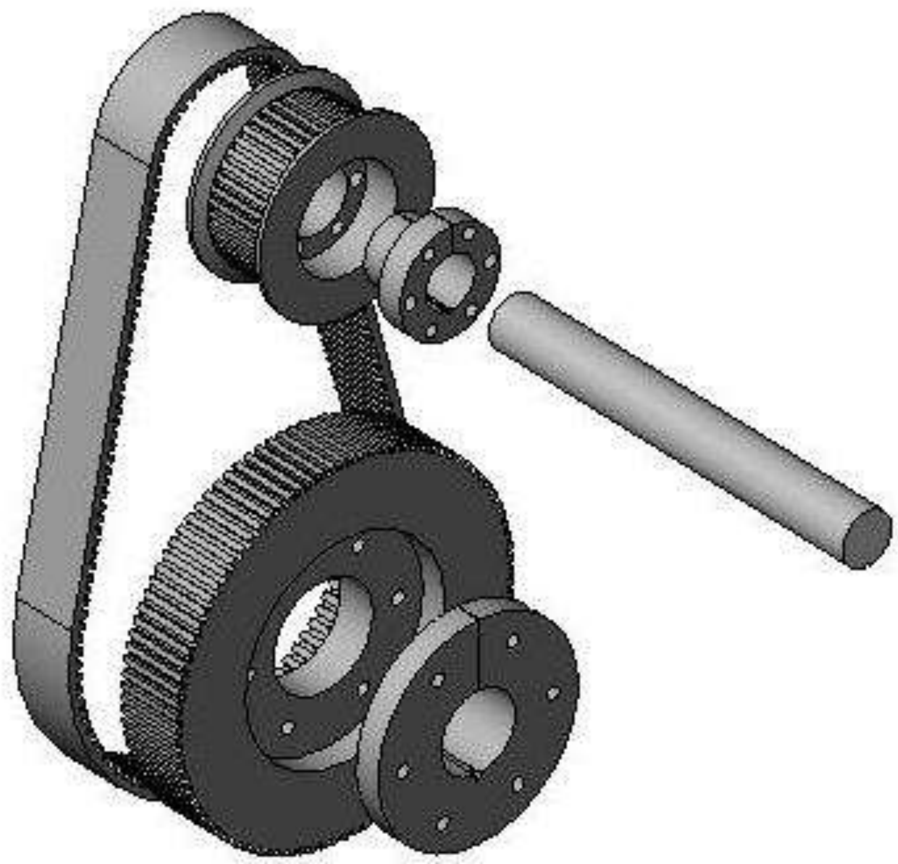

LT1 F-body accessory drive belt routing
Alternator pulley
Power steering pulley
© shbox.com
a/c pulley (or a/c delete pulley)
Belt tensioner
Crank pulley
Tensioner pivots this direction to release belt tension
13mm bolt head

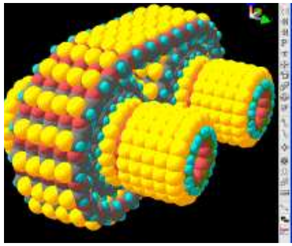


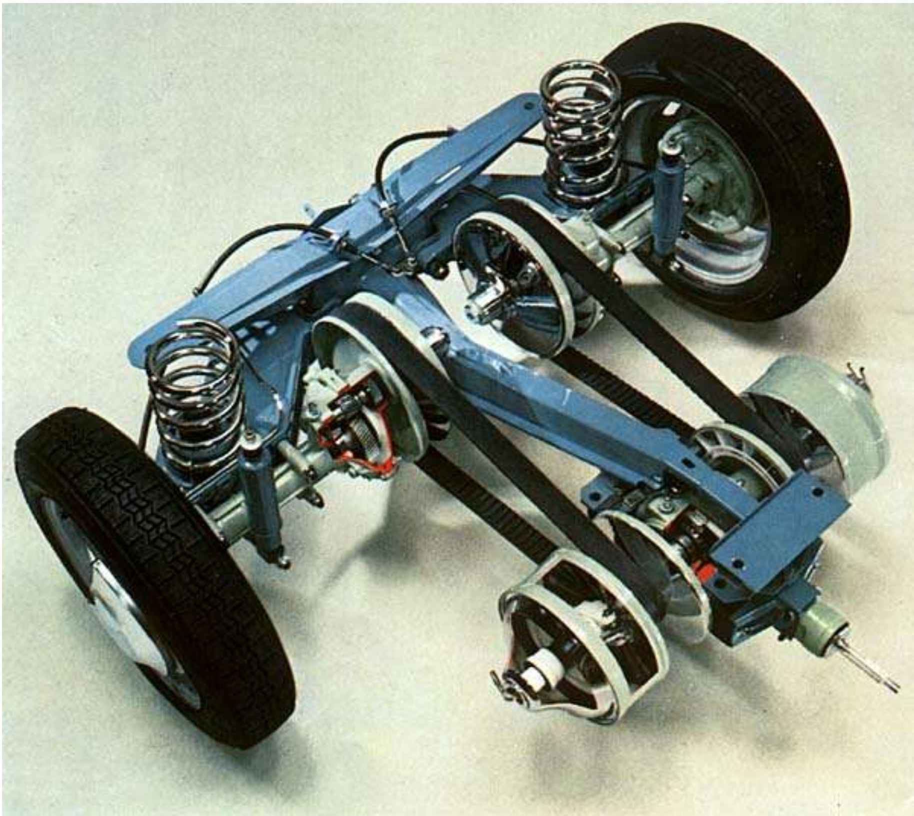




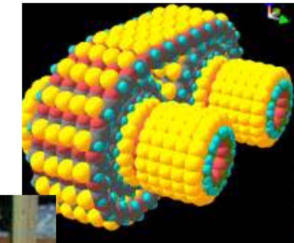


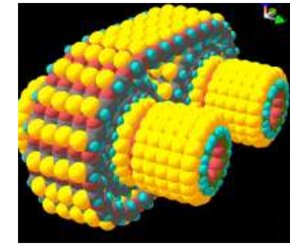


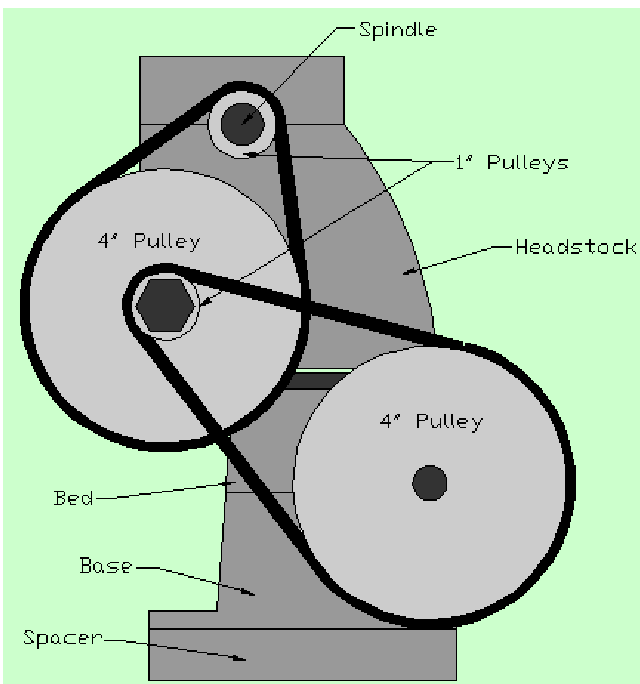




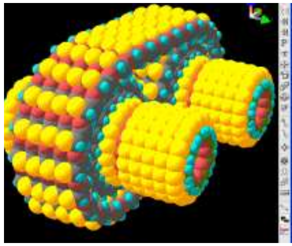


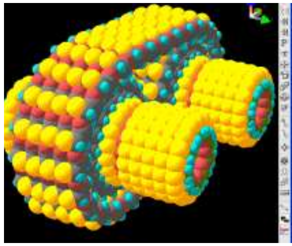





Spindle
1" Pulleys
4" Pulley
Headstock
4" Pulley
Bed
Base
Spacer

Flexible shafts





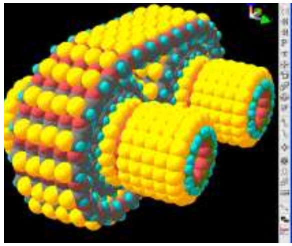
OBJECTIVE

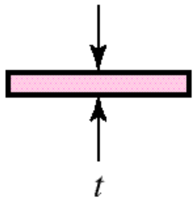
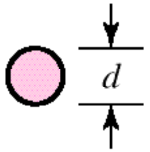
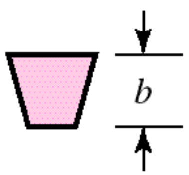
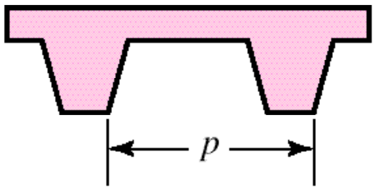
- Transmission of Power over relatively large distances.
- Replacement of Shafts, Gears and other relatively rigid machine elements.

IMPOTANT FEATURES

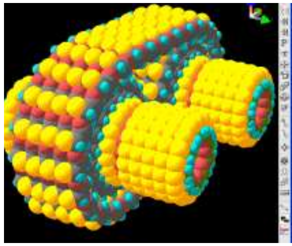
- Being elastic and usually long they:
  1. Absorb Shock Load
  2. Damp and isolate the effect of vibration
- Life is relatively short and need to check wear, aging and loss of elasticity.
- Except Timing belt, there is some slip and creep.

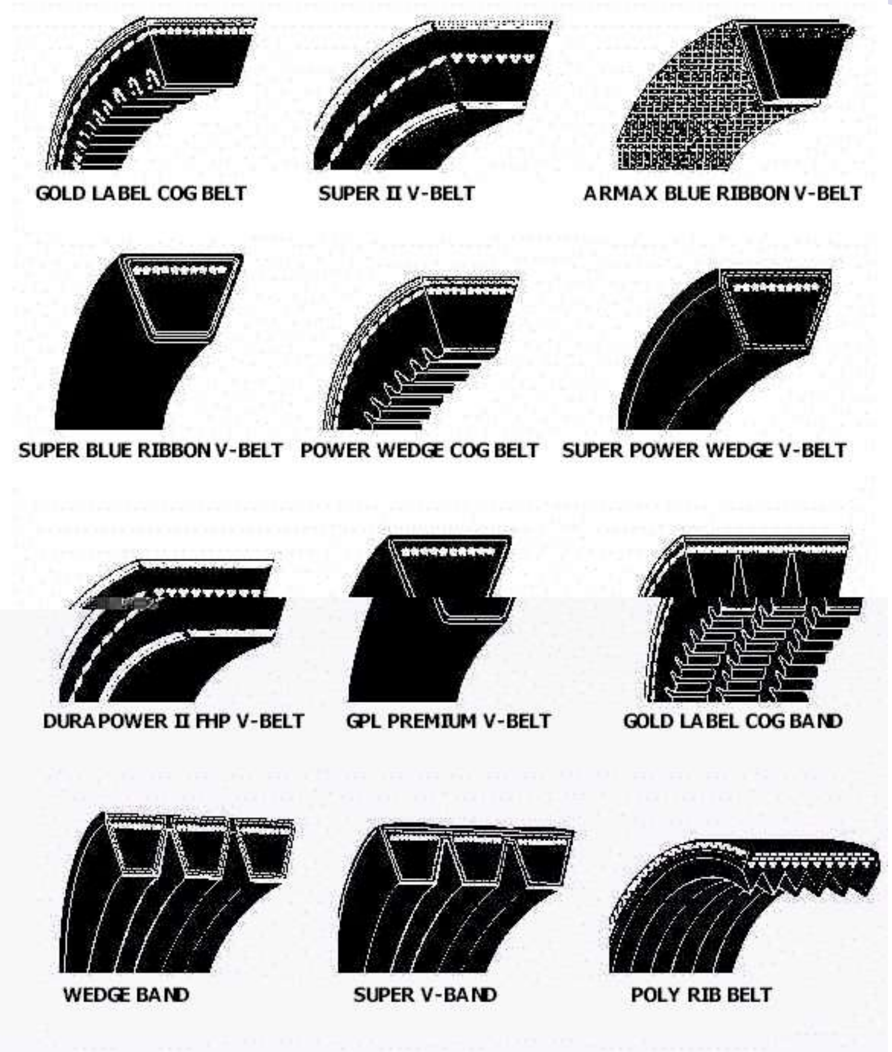
CHARACTERISTICS OF SOME COMMON BELTS



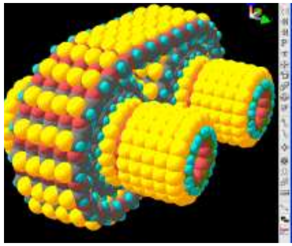
Belt Type	Figure	Joint	Size Range	Center Distance
Flat		Yes	$t = \begin{cases} 0.03 \text{ to } 0.20 \text{ in} \\ 0.75 \text{ to } 5 \text{ mm} \end{cases}$	No upper limit
Round		Yes	$d = \frac{1}{8}$ to $\frac{3}{4}$ in	No upper limit
V		None	$b = \begin{cases} 0.31 \text{ to } 0.91 \text{ in} \\ 8 \text{ to } 19 \text{ mm} \end{cases}$	Limited
Timing		None	$p = 2$ mm and up	Limited

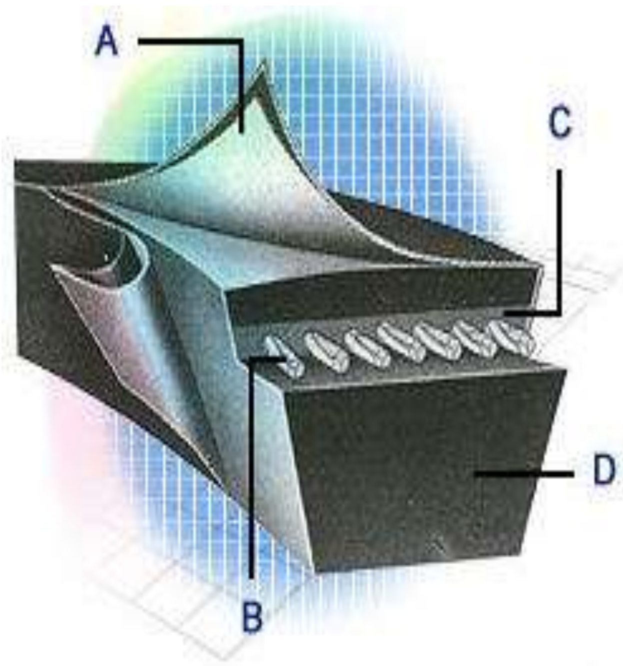
Some More Belt types





Belt Construction





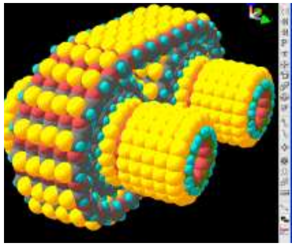
(A) PROTECTIVE COVER
It is a tough and elastic duck with specially rubber impregnating so that it gives the best slip resistant and least worn-out.

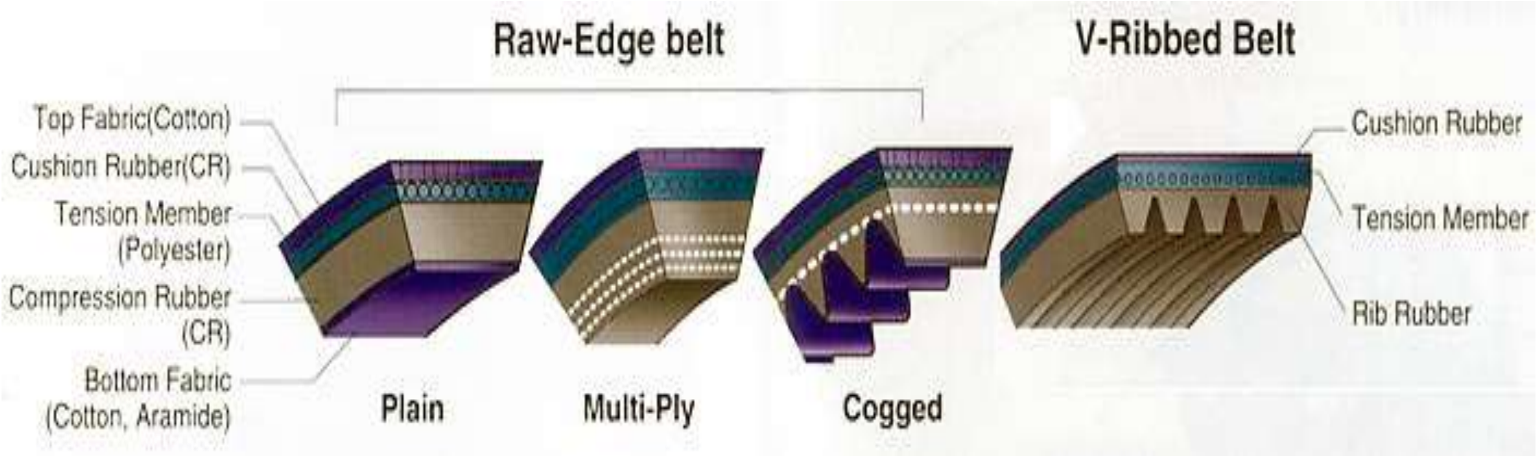
(B) TENSION MEMBERS
Pre-stretched polyester cords provide high tensile strength and minimum stretch

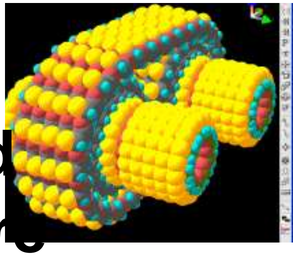
(C) CUSHION COMPOUND
It bonds the cords right in their position and mininmizes the heat build-up so as to extend service life.

(D) COMPRESSION RUBBER
The tough compound keeps the belt in the pulley at the right position without any distortion of contour.

Belt Construction…





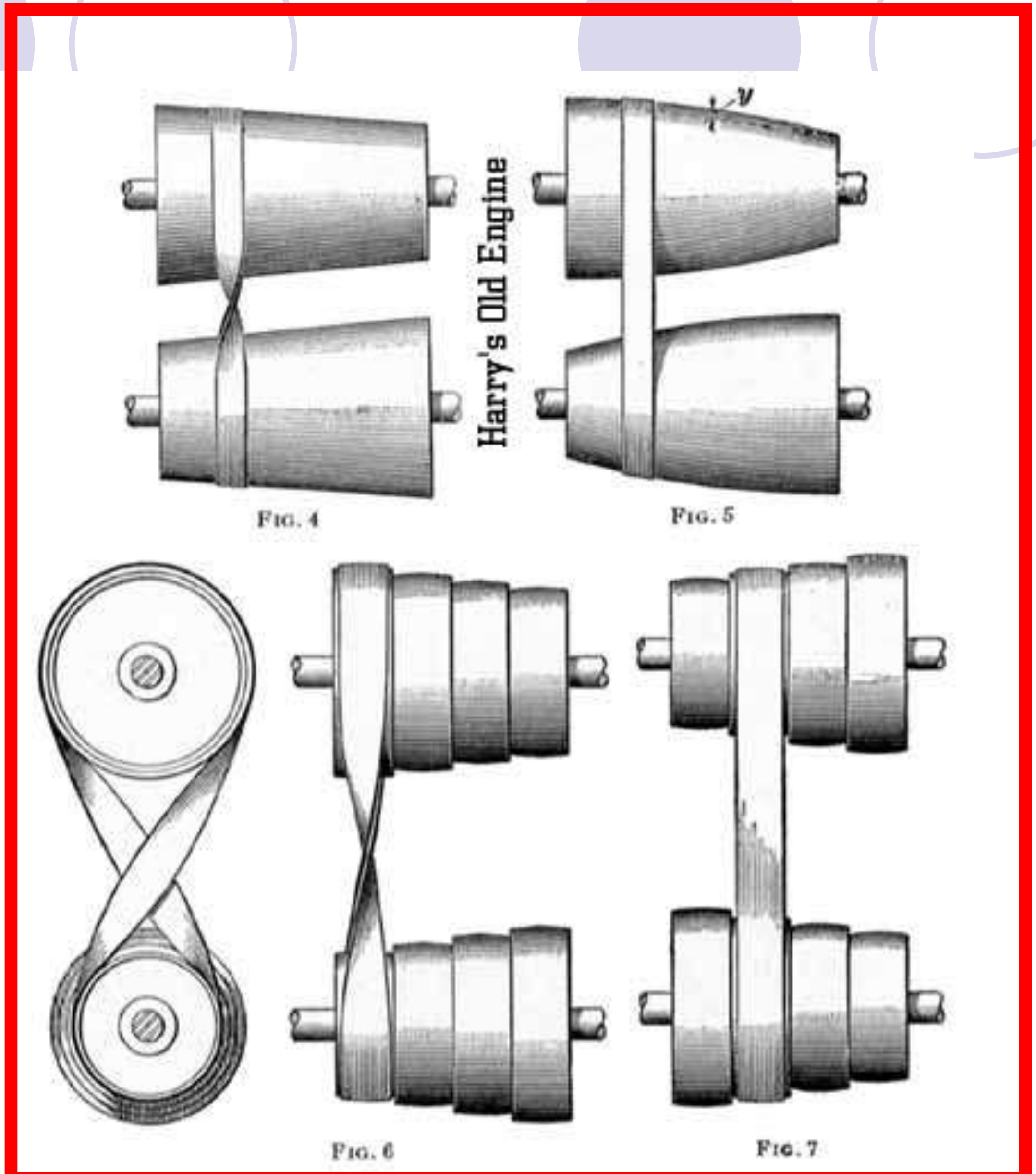


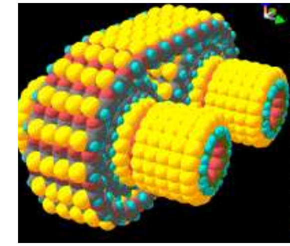
Belt: A band of flexible material that is looped around two or more fixed pulleys to transmit motion. Belts are made of various materials and come in different types, such as flat belts, round belts, and V-belts.

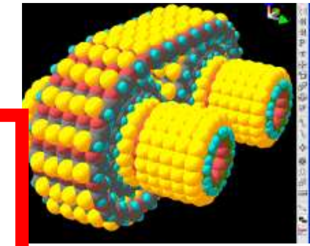
- **What is the definition of creep?**

A condition that occurs in flat belt drives that causes the belt to move forward slightly on the driving pulley, which causes the driven pulley to rotate at a slower speed.

- **Slip: A condition that occurs in flat belt drives when the load causes the belt to slide out of proper position on the pulley.**


Harry's Old Engine
v
FIG. 4
FIG. 5
FIG. 6
FIG. 7





Harry's Old Engine Line Shaft Page

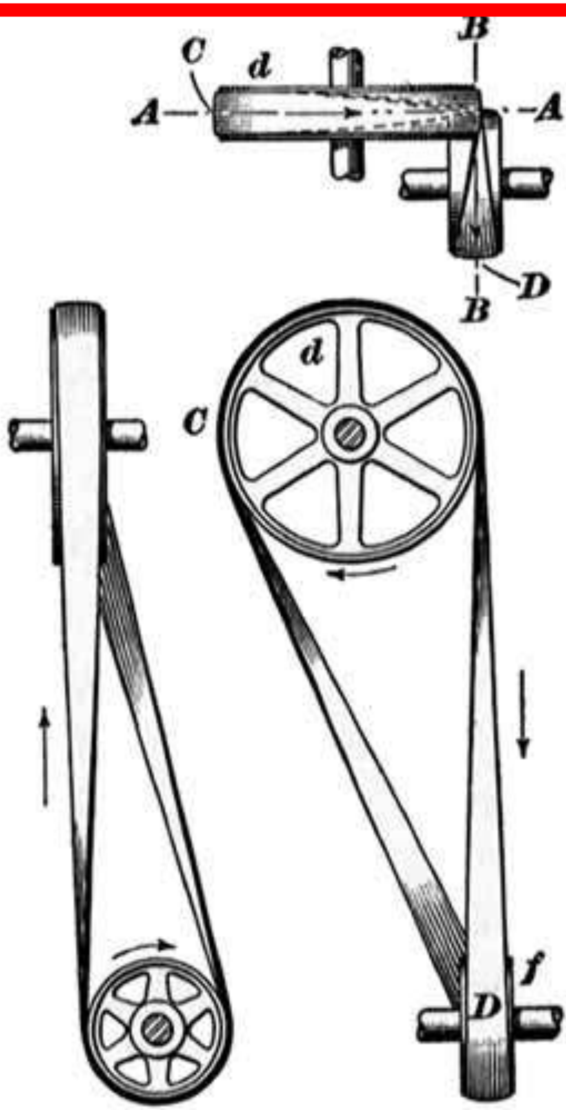


FIG. 18

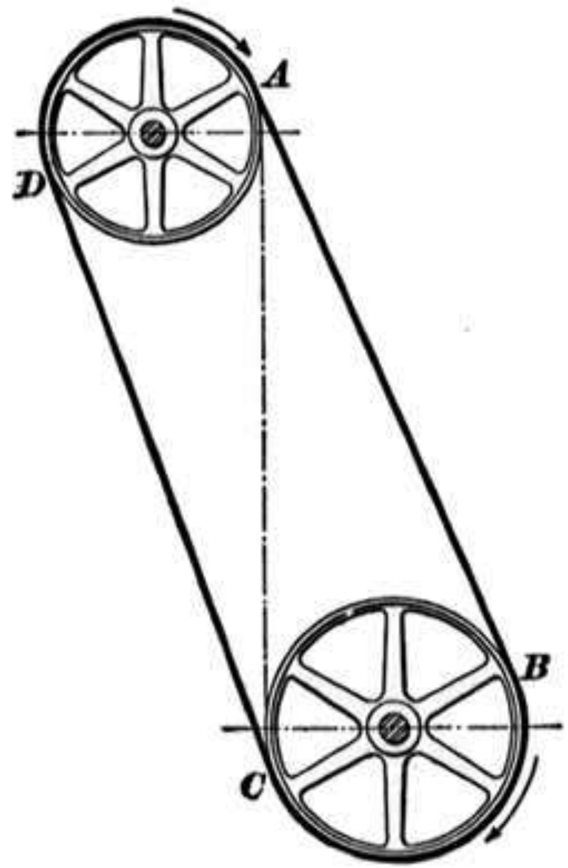
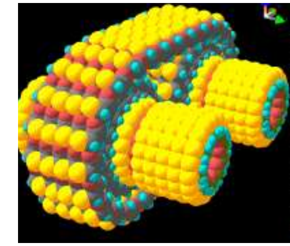
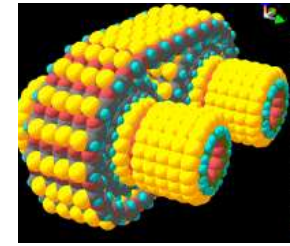


FIG. 19

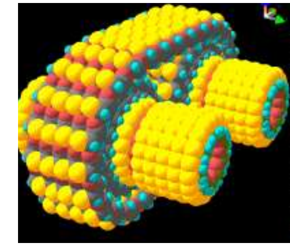
Timing Belts

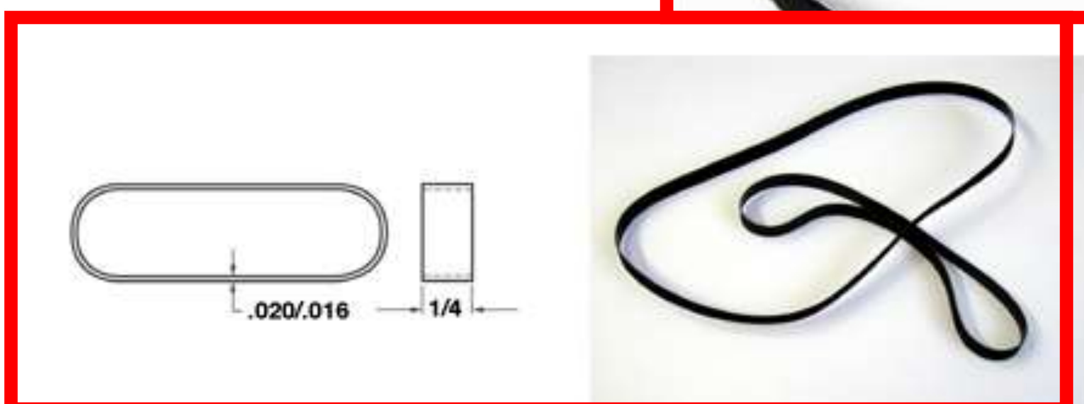


Round Belts

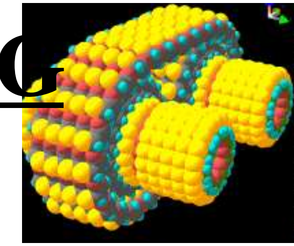


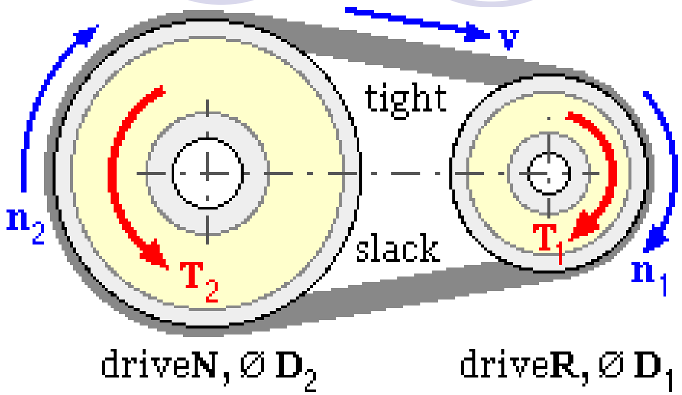
Flat and V belts

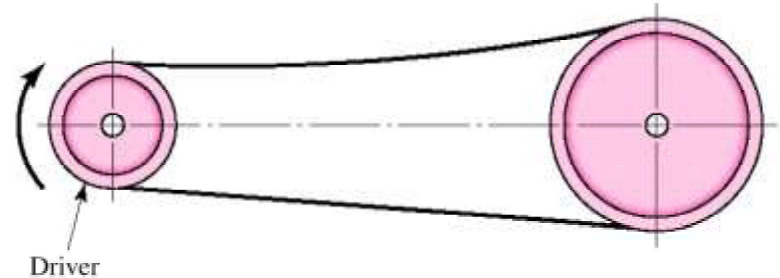




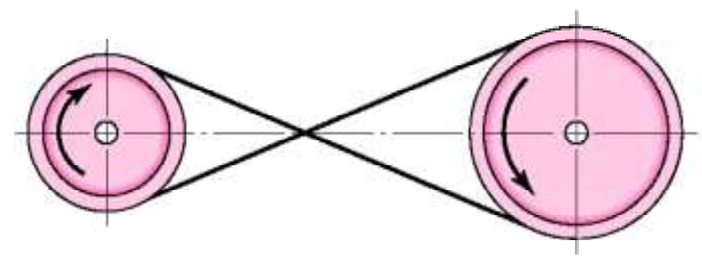
REVERSING & NON-REVERSING



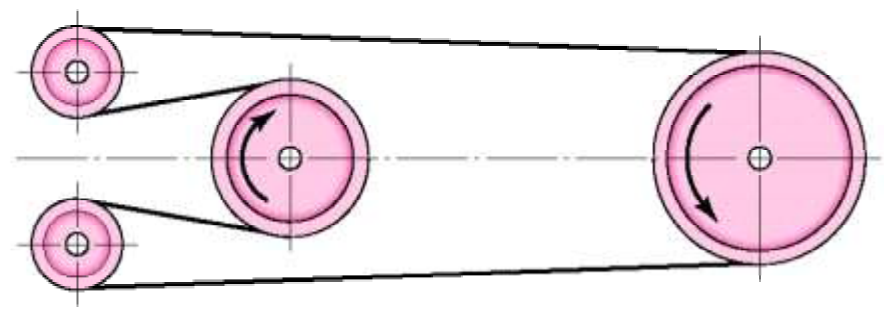




(a)

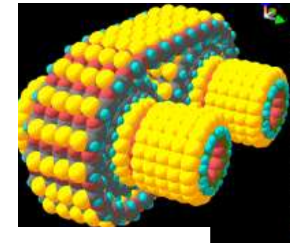


(b)



(c)

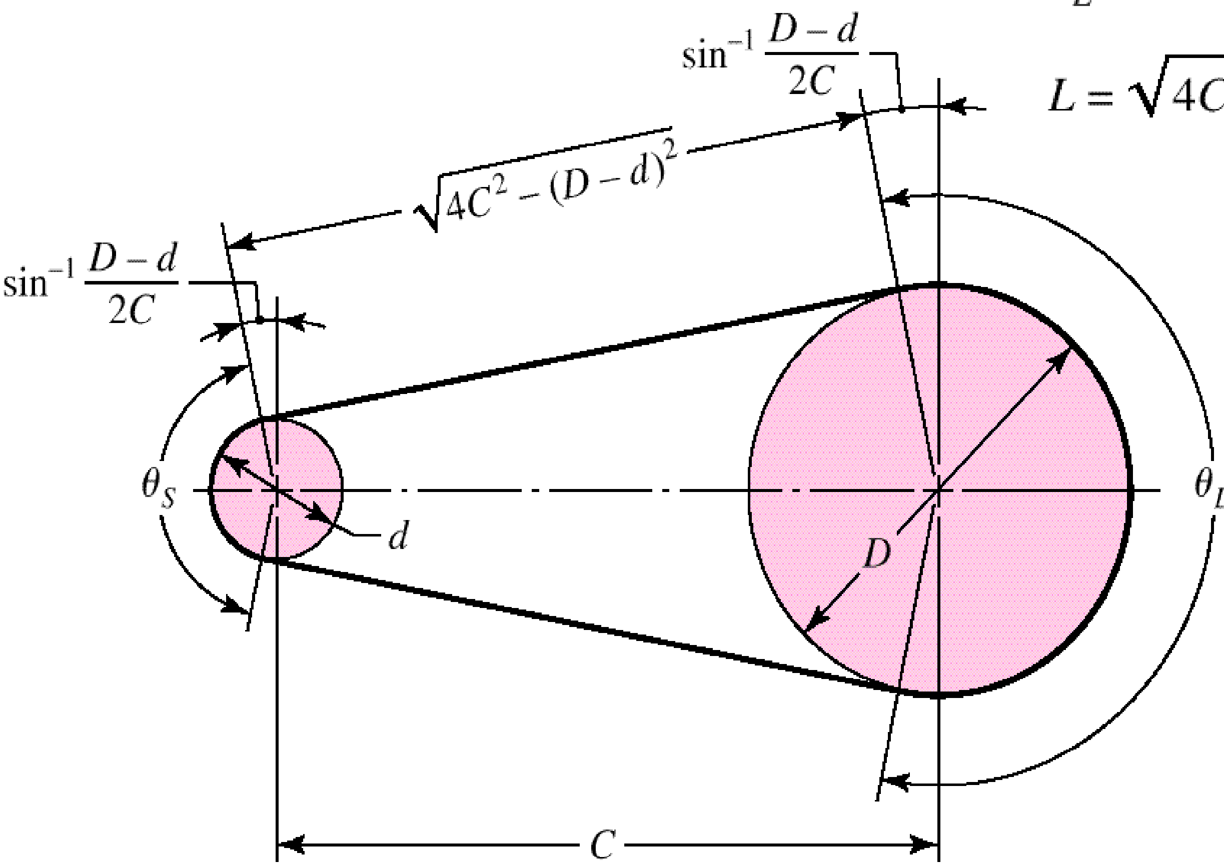
BELT LENGTH OF OPEN BELT



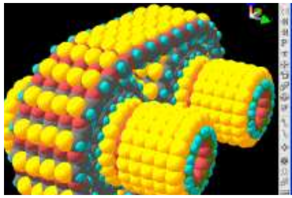
$$\theta_S = \pi - 2\sin^{-1}\frac{D-d}{2C}$$

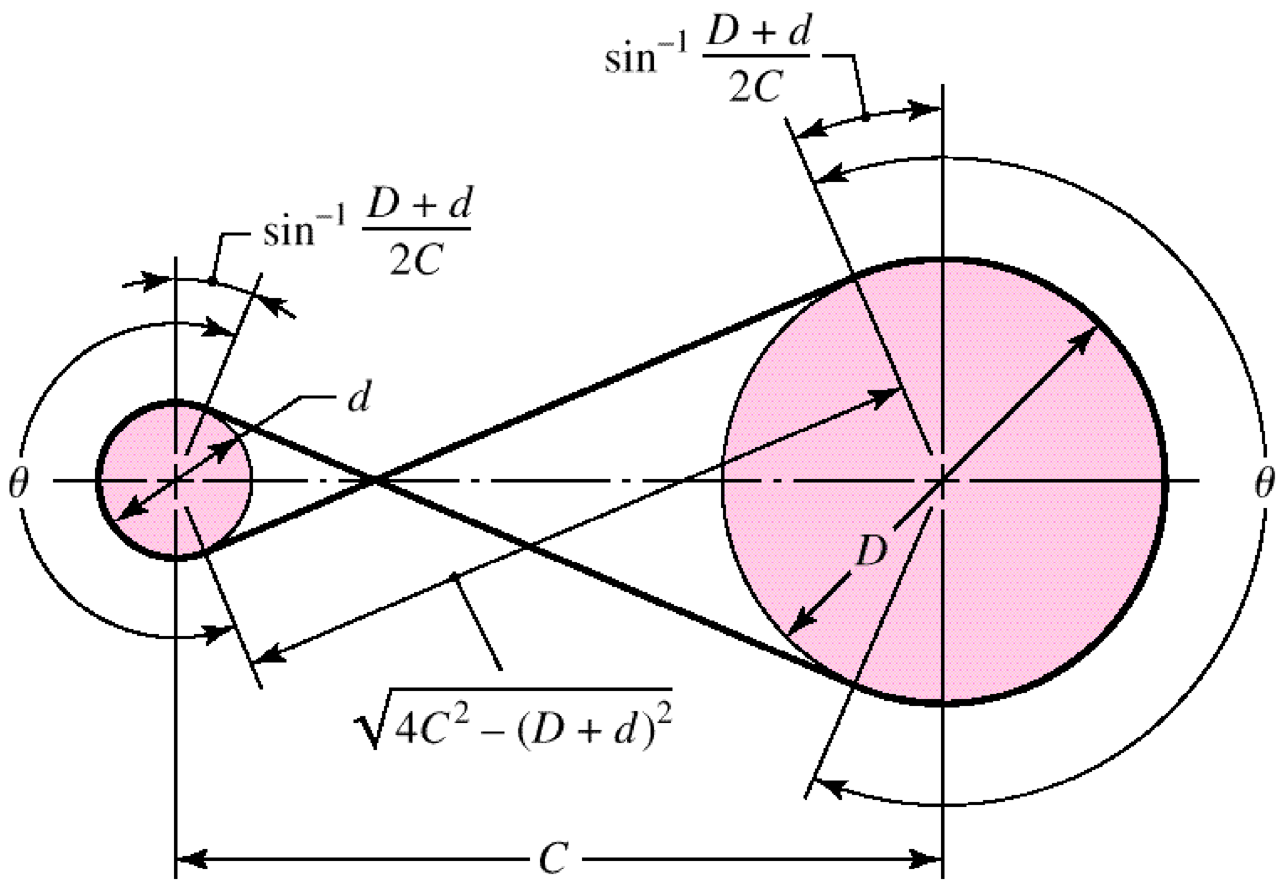
$$\theta_L = \pi + 2\sin^{-1}\frac{D-d}{2C}$$

$$L = \sqrt{4C^2 - (D-d)^2} + \frac{1}{2}(D\theta_L + d\theta_S)$$



BELT LENGTH OF CROSSED BELT

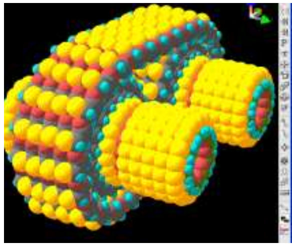




$$\theta = \pi + 2\sin^{-1}\frac{D+d}{2C}$$

$$L = \sqrt{4C^2-(D+d)^2} + \frac{\theta}{2}(D+d)$$

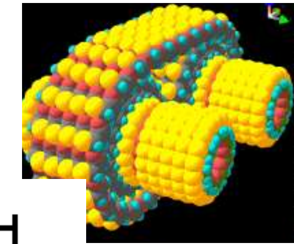
Belt Drive Theory

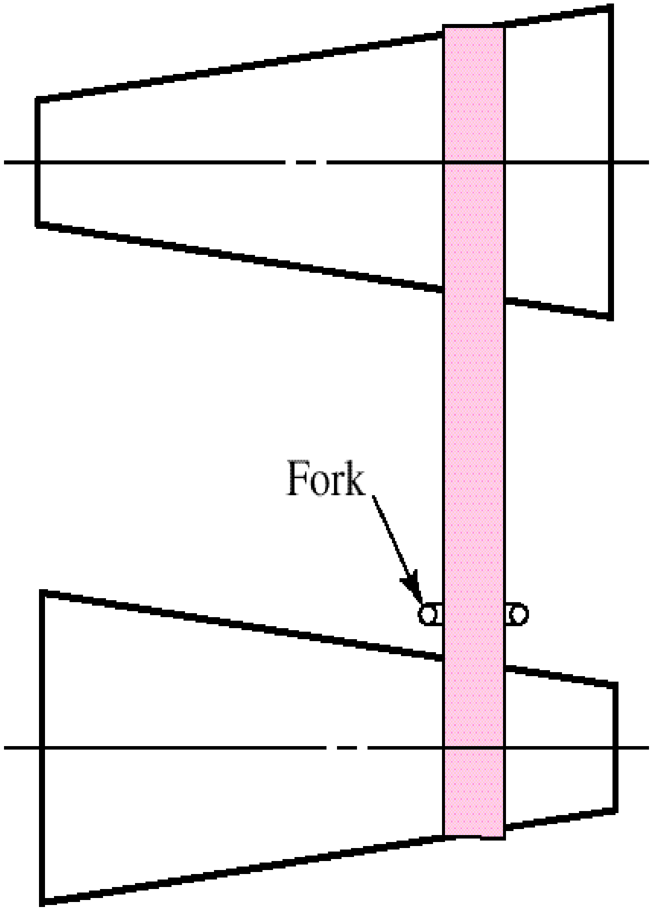


Firbank[2] explains flat-belt-drive theory in the following way. A change in belt tension due to friction forces between the belt and pulley will cause the belt to elongate or contract and move relative to the surface of the pulley. This motion is caused by *elastic creep* and is associated with sliding friction as opposed to static friction. The action at the driving pulley, through that portion of the angle of contact that is actually transmitting power, is such that the belt moves more slowly than the surface speed of the pulley because of the elastic creep. The angle of contact is made up of the *effective arc*, through which

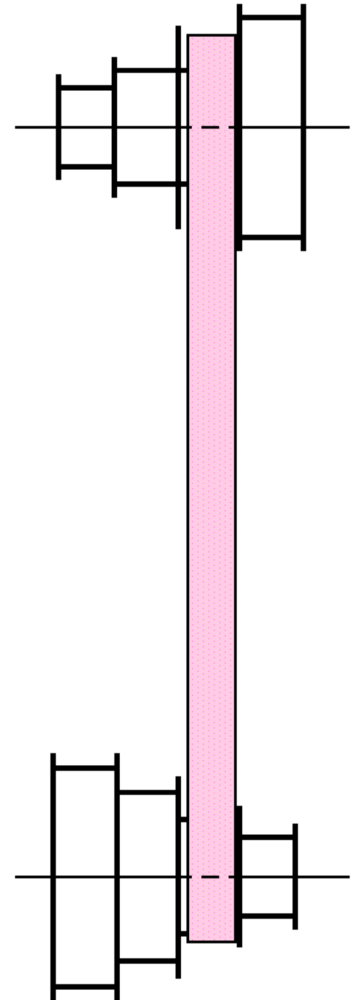
power is transmitted, and the *idle arc*. For the driving pulley the belt first contacts the pulley with a *tight-side tension* F_1 and a velocity V_1, which is the same as the surface velocity of the pulley. The belt then passes through the idle arc with no change in F_1 or V_1. Then creep or sliding contact begins, and the belt tension changes in accordance with the friction forces. At the end of the effective arc the belt leaves the pulley with a *loose-side tension* F_2 and a reduced speed V_2.

VARIABLE SPEED BELT



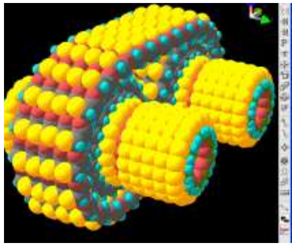


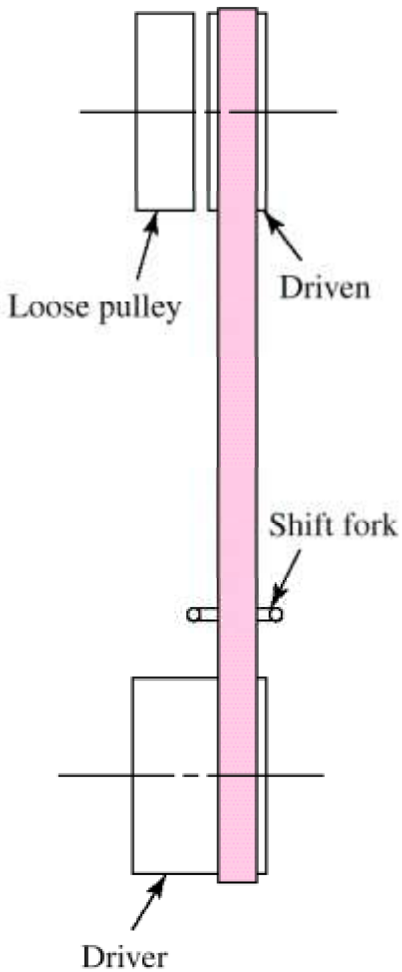
Cone Pulley



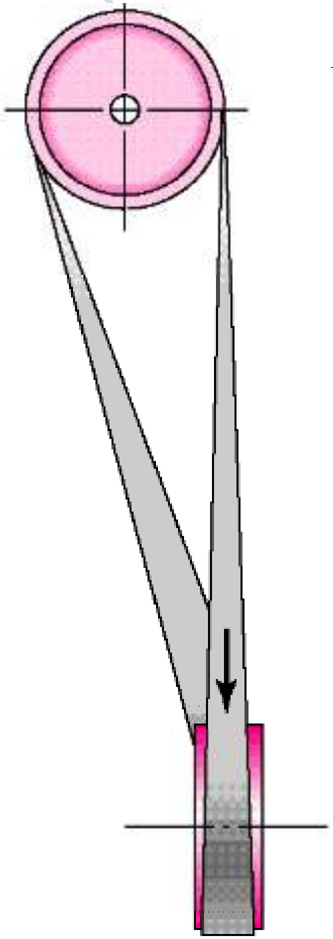
Step Cone Pulley

SPECIAL FUNCTIONS

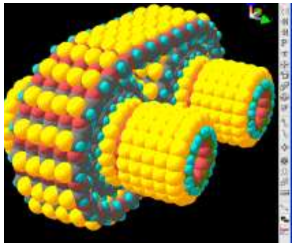




To Eliminate Clutch

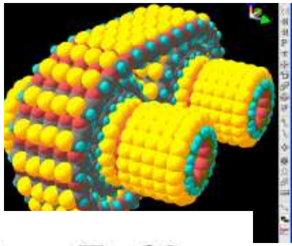


To Change Axis Rotation

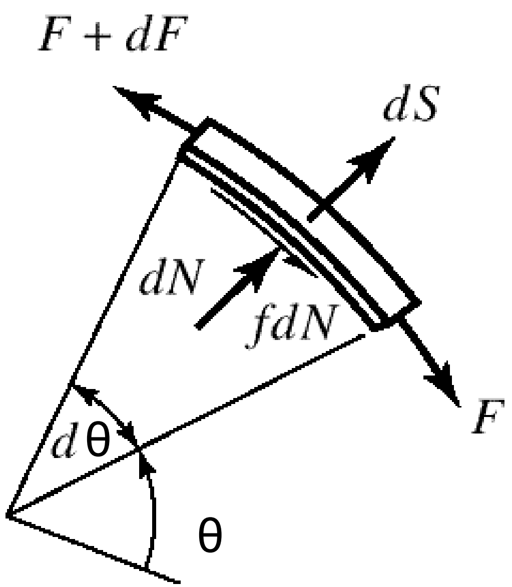


Our model will assume that the friction force on the belt is proportional to the normal pressure along the arc of contact. We seek first a relationship between the tight side tension and slack side tension, similar to that of band brakes but incorporating the consequences of movement, that is, centrifugal tension in the belt. In Fig. 17–6 we see a free body of a small segment of the belt. The differential force dS is due to centrifugal force, dN is the normal force between the belt and pulley, and $f\,dN$ is the shearing traction due to friction at the point of slip. The belt width is b and the thickness is t. The belt mass m is expressed per unit length. The centrifugal force dS can be expressed as

TORQUE TRANSMITTED



m is the belt mass per unit length



$$dS = (mr\,d\theta)r\omega^2 = mr^2\omega^2 d\theta = mV^2 d\theta = F_c\,d\theta$$

where V is the belt speed. Summing forces radially giv

$$\sum F_r = (F + dF)\frac{d\theta}{2} + F\frac{d\theta}{2} - dN - dS = 0$$

from which

$$dN = f\,d\theta - dS$$

Summing forces tangentially gives

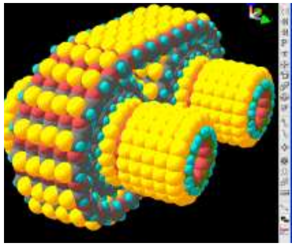
$$\sum F_t = -f\,dN - F + (F + dF) = 0$$

from which, incorporating Eq. (b), we obtain

$$dF = f\,dN = fF\,d\theta - dS = fF\,d\theta - fmr^2\omega^2\,d\theta$$

or

$$\frac{dF}{d\theta} - fF = -fmr^2\omega^2$$



$$\frac{dF}{d\theta} - fF = -fmr^2\omega^2 \qquad \text{(c)}$$

The solution to this nonhomogeneous first-order linear differential equation is

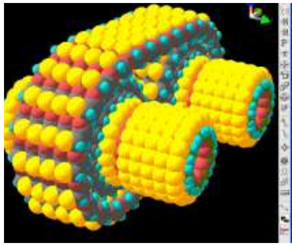
$$F = A\ \exp(f\theta) + mr^2\omega^2 \qquad \text{(d)}$$

where A is an arbitrary constant. The boundary condition that F at $\theta = 0$ equals F_2 gives $A = F_2 - mr^2\omega^2$. The solution is

$$F = (F_2 - mr^2\omega^2)\exp(f\theta) + mr^2\omega^2 \qquad \text{(17–5)}$$

At the end of the angle of wrap ϕ

$$F|_{\theta=\phi} = F_1 = (F_2 - mr^2\omega^2)\exp(f\phi) - mr^2\omega^2 \qquad \text{(17–6)}$$



$$F_1 - F_2 = (F_1 - F_c)\frac{\exp(f\phi) - 1}{\exp(f\phi)} \qquad (17\text{–}8)$$

Belting Equation

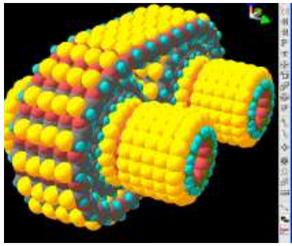
Now F_c is found as follows:

$$V = \pi\, dn/12 \text{ ft/min}$$

The weight w of a foot of belt is given in terms of the weight density γ in lbf/in^3 as $w = 12\gamma bt$ lbf/ft and F_c is written as

$$F_c = \frac{w}{g}\left(\frac{V}{60}\right)^2 = \frac{w}{32.2}\left(\frac{V}{60}\right)^2 \qquad (e)$$

The weight w of a foot of belt is given in terms of the weight density γ in lbf/in^3 as $w = 12\gamma bt$ lbf/ft and F_c is written as



$$F_c = \frac{w}{g}\left(\frac{V}{60}\right)^2 = \frac{w}{32.2}\left(\frac{V}{60}\right)^2 \quad (e)$$

Figure 17–7 shows a free body of a pulley and part of the belt. The tight side tension F_1 and the loose side tension F_2 have the following additive components:

$$F_1 = F_i + F_c + \Delta F' = F_i + F_c + T/D \quad (f)$$

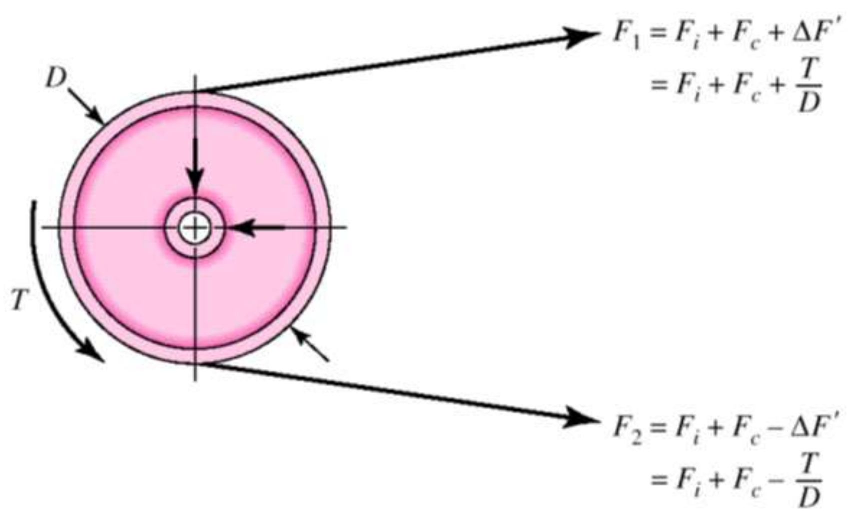
$$F_2 = F_i + F_c - \Delta F' = F_i + F_c - T/D \quad (g)$$

where $F_i =$ initial tension

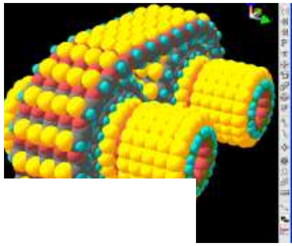
$F_c =$ hoop tension due to centrifugal force

$\Delta F' =$ tension due to the transmitted torque T

$D =$ diameter of the pulley



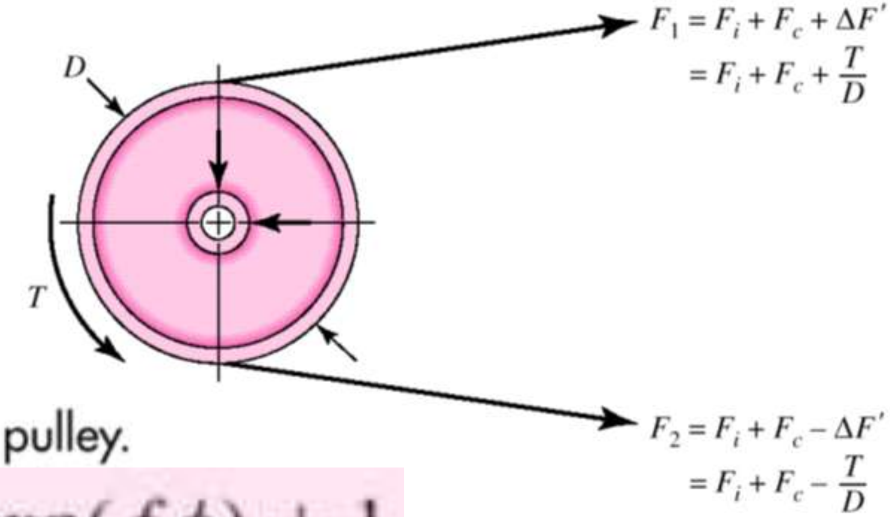
The difference between F_1 and F_2 is related to the pulley torque. Subtracting Eq. from Eq. (f) gives



$$F_1 - F_2 = \frac{2T}{D} = \frac{T}{D/2}$$

Adding Eqs. (f) and (g) gives

$$F_1 + F_2 = 2F_i + 2F_c$$



Forces and torques on a pulley.

$$F_i = \frac{T}{D}\,\frac{\exp(f\phi)+1}{\exp(f\phi)-1}$$

Equation (17–9) give us a fundamental insight into flat belting. If F_i equals zero, then T equals zero: no initial tension, no torque transmitted. The torque is in proportion to the initial tension. This means that if there is to be a satisfactory flat-belt drive, the initial tension must be (1) provided, (2) sustained, (3) in the proper amount, and (4) maintained by routine inspection.

If F_i=0 then Toque transmitted will be zero

The transmitted horsepower is given by

$$H = \frac{(F_1 - F_2)V}{33\,000} \tag{j}$$

Manufacturers provide specifications for their belts which include allowable tension F_a (or stress σ_{all}), the tension being expressed in units of force per unit width. Belt life is usually several years. The severity of flexing at the pulley and its effect on life is reflected in a pulley correction factor C_p. Speeds in excess of 600 ft/min and their effect on life is reflected in a velocity correction factor C_v. For polyamide and urethane belts use $C_v = 1$. For leather belts see Fig. 17–9. A service factor K_s is used for excursions of load from nominal, applied to the nominal power as $H_d = H_{nom} K_s n_d$, the design factor for exigencies. These effects are incorporated as follows:

$$(F_1)_a = bF_aC_pC_v \tag{17–12}$$

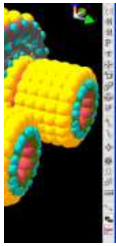
where $(F_1)_a$ = allowable largest tension, lbf

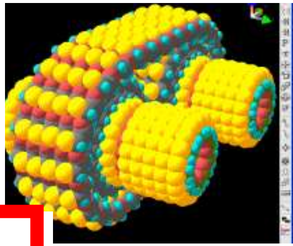
b = belt width, in

F_a = manufacturer's allowed tension, lbf/in

C_p = pulley correction factor

C_v = velocity correction factor





The steps in analyzing a flat-belt drive can include

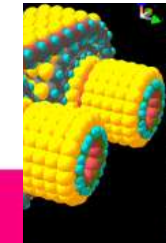
1. Find $\exp(f\phi)$ from belt-drive geometry and friction
2. From belt geometry and speed find F_c
3. From $T = 63\,025 H_{\text{nom}} K_s n_d / n$ find necessary torque
4. From torque T find the necessary $(F_1)_a - F_2 = 2T/D$
5. Find F_2 from $(F_1)_a - [(F_1)_a - F_2]$
6. From Eq. (i) find the necessary initial tension F_i
7. Check the friction development, $f' < f$. Use Eq. (17–7) solved for f':

$$f' = \frac{1}{\phi} \ln \frac{(F_1)_a - F_c}{F_2 - F_c}$$

8. Find the factor of safety from fos $= H_a/(H_{\text{nom}} K_s)$

Table 17–2

Properties of Some Flat- and Round-Belt Materials. (Diameter = d, thickness = t, width = w)



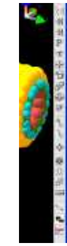
Material	Specification	Size, in	Minimum Pulley Diameter, in	Allowable Tension per Unit Width at 600 ft/min, lb/in	Specific Weight, lb/in^3	Coefficient of Friction
Leather	1 ply	$t = \frac{11}{64}$	3	30	0.035–0.045	0.4
		$t = \frac{13}{64}$	$3\frac{1}{2}$	33	0.035–0.045	0.4
	2 ply	$t = \frac{18}{64}$	$4\frac{1}{2}$	41	0.035–0.045	0.4
		$t = \frac{20}{64}$	6[a]	50	0.035–0.045	0.4
		$t = \frac{23}{64}$	9[a]	60	0.035–0.045	0.4
Polyamide[b]	F–0[c]	$t = 0.03$	0.60	10	0.035	0.5
	F–1[c]	$t = 0.05$	1.0	35	0.035	0.5
	F–2[c]	$t = 0.07$	2.4	60	0.051	0.5
	A–2[c]	$t = 0.11$	2.4	60	0.037	0.8
	A–3[c]	$t = 0.13$	4.3	100	0.042	0.8
	A–4[c]	$t = 0.20$	9.5	175	0.039	0.8
	A–5[c]	$t = 0.25$	13.5	275	0.039	0.8
Urethane[d]	$w = 0.50$	$t = 0.062$	See	5.2[e]	0.038–0.045	0.7
	$w = 0.75$	$t = 0.078$	Table	9.8[e]	0.038–0.045	0.7
	$w = 1.25$	$t = 0.090$	17–3	18.9[e]	0.038–0.045	0.7
	Round	$d = \frac{1}{4}$	See	8.3[e]	0.038–0.045	0.7
		$d = \frac{3}{8}$	Table	18.6[e]	0.038–0.045	0.7
		$d = \frac{1}{2}$	17–3	33.0[e]	0.038–0.045	0.7
		$d = \frac{3}{4}$		74.3[e]	0.038–0.045	0.7

[a] Add 2 in to pulley size for belts 8 in wide or more.

[b] *Source: Habasit Engineering Manual,* Habasit Belting, Inc., Chamblee (Atlanta), Ga.

Table 17–4

Pulley Correction Factor C_P for Flat Belts*



Material	Small-Pulley Diameter, in					
	1.6 to 4	4.5 to 8	9 to 12.5	14, 16	18 to 31.5	Over 31.5
Leather	0.5	0.6	0.7	0.8	0.9	1.0
Polyamide, F–0	0.95	1.0	1.0	1.0	1.0	1.0
F–1	0.70	0.92	0.95	1.0	1.0	1.0
F–2	0.73	0.86	0.96	1.0	1.0	1.0
A–2	0.73	0.86	0.96	1.0	1.0	1.0
A–3	—	0.70	0.87	0.94	0.96	1.0
A–4	—	—	0.71	0.80	0.85	0.92
A–5	—	—	—	0.72	0.77	0.91

*Average values of C_P for the given ranges were approximated from curves in the *Habasit Engineering Manual*, Habasit Belting, Inc., Chamblee (Atlanta), Ga.

Useful formulas:

$$\theta_d = \pi - 2\sin^{-1}\frac{D-d}{2C}$$

$$\theta_D = \pi + 2\sin^{-1}\frac{D-d}{2C}$$

$$L = [4C^2 - (D-d)^2]^{1/2} + \frac{1}{2}(D\theta_D + d\theta_d)$$

$$F_1 - F_2 = \frac{2T}{D} = \frac{T}{D/2}$$

$$(F_1)_a = bF_aC_pC_v$$

$$F_i = \frac{F_1 + F_2}{2} - F_c$$

$$F_1 - F_2 = (F_1 - F_c)\frac{\exp(f\phi) - 1}{\exp(f\phi)}$$

Now F_c is found as follows:

$V = \pi dn/12$ ft/min

The weight w of a foot of belt is given in terms of the weight density γ in lbf/in^3 as $w = 12\gamma bt$ lbf/ft and F_c is written as

$$F_c = \frac{w}{g}\left(\frac{V}{60}\right)^2 = \frac{w}{32.2}\left(\frac{V}{60}\right)^2 \qquad \text{(e)}$$

$$F_i = \frac{T}{D}\frac{\exp(f\phi) + 1}{\exp(f\phi) - 1}$$

$$H_d = H_{nom}K_s n_d,$$

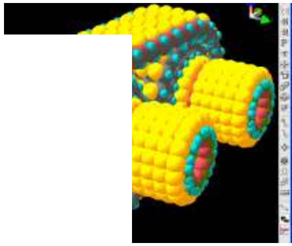
$$f' = \frac{1}{\phi}\ln\frac{(F_1)_a - F_c}{F_2 - F_c}$$

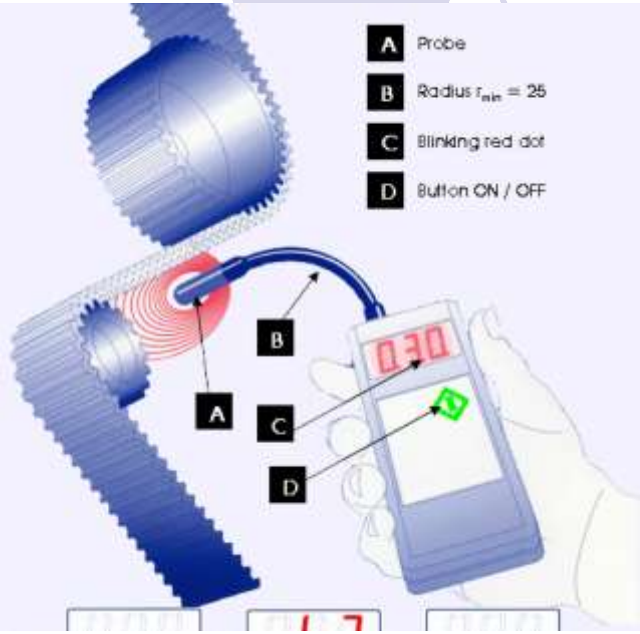
$$H = \frac{(F_1 - F_2)V}{33\,000}$$

$$F_1 = F_c + F_i\frac{2\exp(f\phi)}{\exp(f\phi) + 1}$$

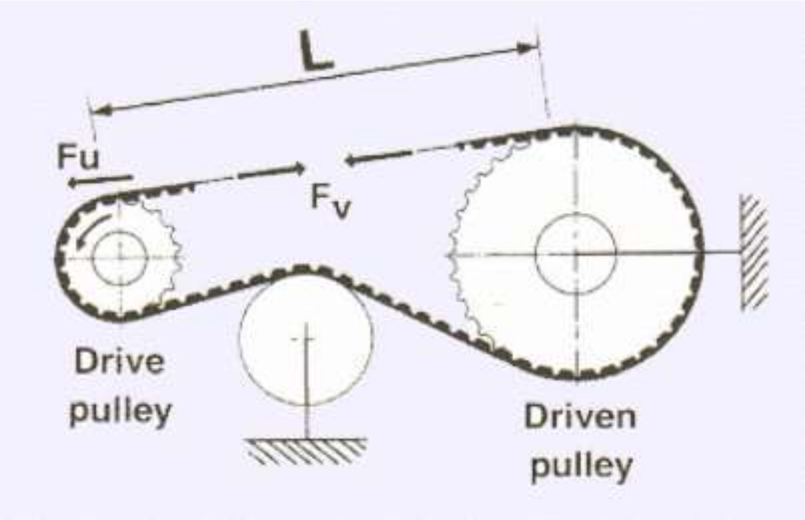
$$F_2 = F_c + F_i\frac{2}{\exp(f\phi) + 1}$$

Pretension in belts





Tension meter



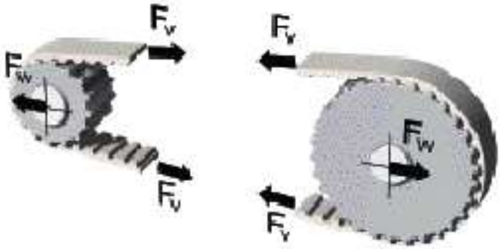
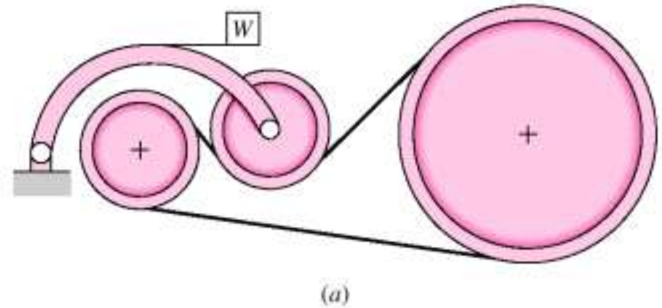
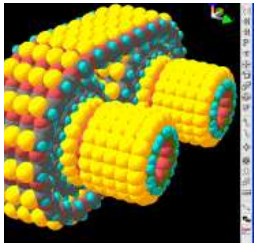


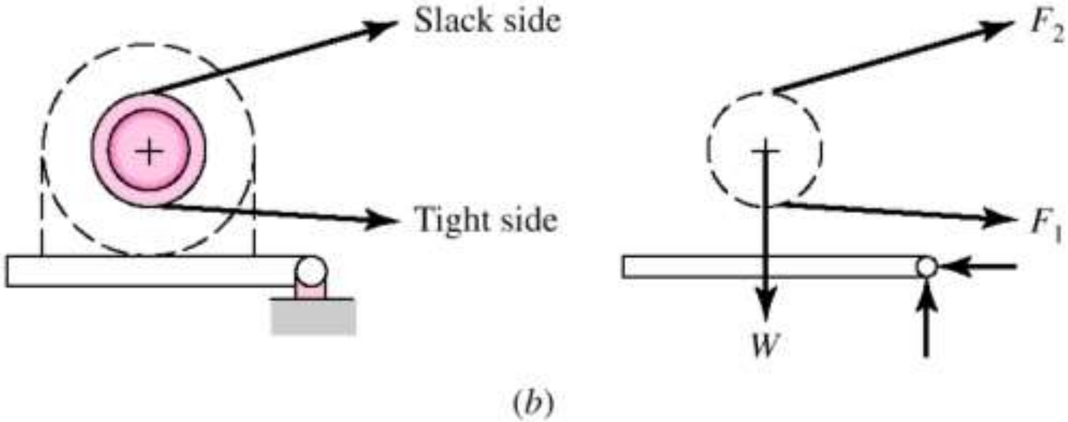
Figure 17–11

Belt-tensioning schemes.
(*a*) Weighted idler pulley.
(*b*) Pivoted motor mount.

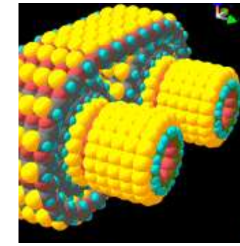




$$F_i = \frac{T}{D}\frac{\exp(f\phi)+1}{\exp(f\phi)-1}$$



From catenary theory the dip is
related to the initial tension by



$$d = \frac{12L^2 w}{8F_i} = \frac{3L^2 w}{2F_i}$$

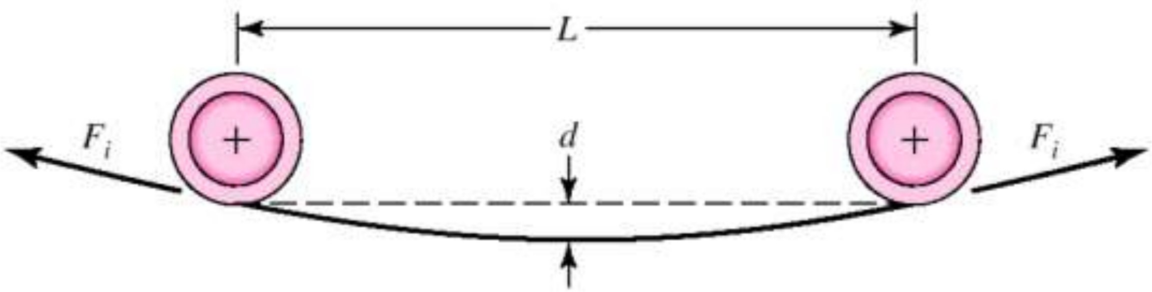
where d = dip, in

L = center-to-center distance, ft

w = weight per foot of the belt, lbf/ft

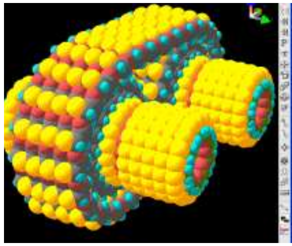
F_i = initial tension, lbf

(b)



(c)

EXAMPLE 1

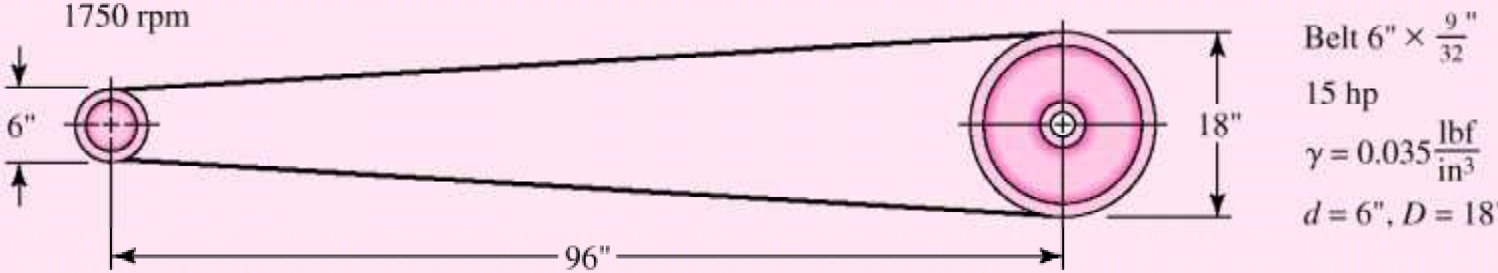


A polyamide A-3 flat belt 6 in wide is used to transmit 15 hp under light shock conditions where $K_s = 1.25$, and a factor of safety equal to or greater than 1.1 is appropriate. The pulley rotational axes are parallel and in the horizontal plane. The shafts are 8 ft apart. The 6-in driving pulley rotates at 1750 r/min in such a way that the loose side is on top. The driven pulley is 18 in in diameter. See Fig. 17–10. The factor of safety is for unquantifiable exigencies.

(a) Estimate the centrifugal tension F_c and the torque T.

(b) Estimate the allowable F_1, F_2 and allowable power H_a.

(c) Estimate the factor of safety. Is it satisfactory?



Solution (*a*) Eq. (17–1) $\theta_d = \pi - 2\sin^{-1}\left[\frac{18-6}{2(8)12}\right] = 3.0165$ rad

$$\exp(f\phi) = \exp[0.8(3.0165)] = 11.17$$

$$V = \pi(6)1750/12 = 2749 \text{ ft/min}$$

Table 17–2 $w = 12\gamma bt = 12(0.042)6(0.13) = 0.393$ lb/ft

Answer Eq. (*e*) $F_c = \frac{wV^2}{g} = \frac{0.393}{32.174}\left(\frac{2749}{60}\right)^2 = 25.6$ lb

$$T = \frac{63\,025\,H_{\text{nom}}K_s n_d}{n} = \frac{63\,025(15)1.25(1.1)}{1750}$$

Answer $= 742.8 \text{ in} \cdot \text{lb}$

(*b*) The necessary $(F_1)_a - F_2$ to transmit the torque T is

$$(F_1)_a - F_2 = \frac{2T}{d} = \frac{2(742.8)}{6} = 247.6 \text{ lb}$$

From Eq. (17–12) the allowable largest belt tension $(F_1)_a$ is

Answer $(F_1)_a = bF_aC_pC_v = 6(100)0.70(1) = 420$ lb

then

Answer $F_2 = (F_1)_a - [(F_1)_a - F_2] = 420 - 247.6 = 172.4$ lb

and from Eq. (i)

$$F_i = \frac{420 + 172.4}{2} - 25.6 = 270.6 \text{ lb}$$

Answer The combination $(F_1)_a$, F_2, and F_i will transmit the design power of $15(1.25)(1.1) = 20.6$ hp and protect the belt. We check the friction development by solving Eq. (17–7) for f':

$$f' = \frac{1}{\phi} \ln \frac{(F_1)_a - F_c}{F_2 - F_c} = \frac{1}{3.0165} \ln \frac{420 - 25.6}{172.4 - 25.6} = 0.33$$

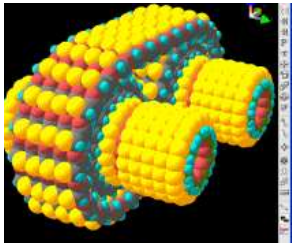
Since $f' < f$, that is, $0.33 < 0.80$, there is no danger of slipping.

(c)

Answer
$$\text{fos} = \frac{H}{H_{\text{nom}} K_s} = \frac{20.6}{15(1.25)} = 1.1 \qquad \text{(as expected)}$$

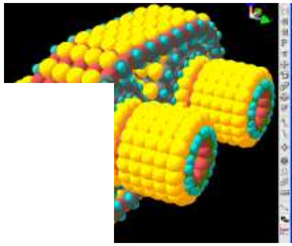
Answer The belt is satisfactory and the maximum allowable belt tension exists. If the initial tension is maintained, the capacity is the design power of 20.6 hp.

------Tutorial-1 Flat Belt------



Problem 17-1

- A 6-in-wide polyamide F-1 flat belt is used to connect a 2-in-diameter pulley to drive a larger pulley with an angular velocity ratio of 0.5. The center-to-center distance is 9 ft. The angular speed of the small pulley is 1750 rev/min as it delivers 2 hp. The service is such that a service factor K_s of 1.25 is appropriate.
- (*a*) Find F_c, F_i, F_{1a}, and F_2.
- (*b*) Find H_a, n_{fs}, and belt length.
- (*c*) Find the dip.



Given: F-1 Polyamide, $b = 6$ in, $d = 2$ in @ 1750 rev/min

$C = 9(12) = 108$ in, vel. ratio 0.5, $H_{\text{nom}} = 2$ hp, $K_s = 1.25$, $n_d = 1$

Table 17-2: $t = 0.05$ in, $d_{\min} = 1.0$ in, $F_a = 35$ lbf/in,

$\gamma = 0.035\ \text{lbf/in}^3$, $f = 0.5$

Table 17-4: $C_p = 0.70$

$$w = 12\gamma bt = 12(0.035)(6)(0.05) = 0.126\ \text{lbf/ft}$$

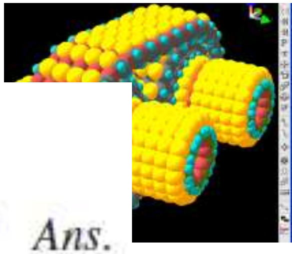
$$\theta_d = 3.123\ \text{rad}, \quad \exp(f\theta) = 4.766 \quad \text{(perhaps)}$$

$$V = \frac{\pi dn}{12} = \frac{\pi(2)(1750)}{12} = 916.3\ \text{ft/min}$$

(a) Eq. (*e*), p. 865: $F_c = \dfrac{w}{32.17}\left(\dfrac{V}{60}\right)^2 = \dfrac{0.126}{32.17}\left(\dfrac{916.3}{60}\right)^2 = 0.913\ \text{lbf}$ *Ans.*

$$T = \frac{63\,025 H_{\text{nom}} K_s n_d}{n} = \frac{63\,025(2)(1.25)(1)}{1750} = 90.0\ \text{lbf}\cdot\text{in}$$

$$\Delta F = \frac{2T}{d} = \frac{2(90)}{2} = 90\ \text{lbf}$$



Do not use Eq. (17-9) because we do not yet know f'.

Eq. (i), p. 866: $$F_i = \frac{F_{1a} + F_2}{2} - F_c = \frac{147 + 57}{2} - 0.913 = 101.1 \text{ lbf} \quad Ans.$$

Eq. (17-7): $$f' = \frac{1}{\theta_d} \ln\left[\frac{(F_1)_a - F_c}{F_2 - F_c}\right] = \frac{1}{3.123} \ln\left(\frac{147 - 0.913}{57 - 0.913}\right) = 0.307$$

The friction is thus undeveloped.

(b) The transmitted horsepower is,

$$H = \frac{(\Delta F)V}{33\,000} = \frac{90(916.3)}{33\,000} = 2.5 \text{ hp} \quad Ans.$$

$$n_{fs} = \frac{H}{H_{\text{nom}} K_s} = \frac{2.5}{2(1.25)} = 1$$

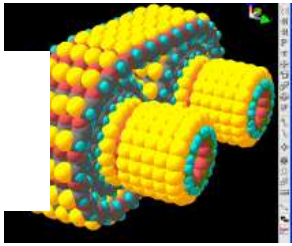
From Eq. (17-2), $$L = 225.3 \text{ in} \quad Ans.$$

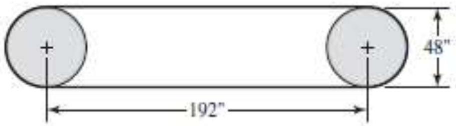
(c) From Eq. (17-13), $$\text{dip} = \frac{3C^2 w}{2F_i}$$

where C is the center-to-center distance in feet.

$$\text{dip} = \frac{3(108/12)^2(0.126)}{2(101.1)} = 0.151 \text{ in} \quad Ans.$$

17-3 A flat-belt drive is to consist of two 4-ft-diameter cast-iron pulleys spaced 16 ft apart. Select a belt type to transmit 60 hp at a pulley speed of 380 rev/min. Use a service factor of 1.1 and a design factor of 1.0.





As a design task, the decision set on p. 873 is useful.

A priori decisions:

- Function: $H_{nom} = 60$ hp, $n = 380$ rev/min, $C = 192$ in, $K_s = 1.1$
- Design factor: $n_d = 1$
- Initial tension: Catenary
- Belt material: Polyamide A-3, $F_a = 100$ lbf/in, $\gamma = 0.042$ lbf/in^3, $f = 0.8$
- Drive geometry: $d = D = 48$ in
- Belt thickness: $t = 0.13$ in

Design variable: Belt width of 6 in

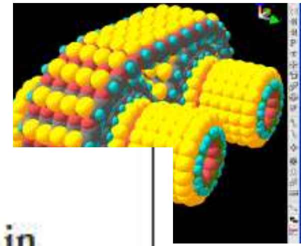
Use a method of trials. Initially choose $b = 6$ in

$$V = \frac{\pi d n}{12} = \frac{\pi(48)(380)}{12} = 4775 \text{ ft/min}$$

$$w = 12\gamma bt = 12(0.042)(6)(0.13) = 0.393 \text{ lbf/ft}$$

$$F_c = \frac{wV^2}{g} = \frac{0.393(4775/60)^2}{32.174} = 77.4 \text{ lbf}$$

$$T = \frac{63\,025 H_{nom} K_s n_d}{n} = \frac{63\,025(60)(1.1)(1)}{380} = 10\,946 \text{ lbf} \cdot \text{in}$$



$$T = \frac{63\,025 H_{nom} K_s n_d}{n} = \frac{63\,025(60)(1.1)(1)}{380} = 10\,946 \text{ lbf} \cdot \text{in}$$

$$\Delta F = \frac{2T}{d} = \frac{2(10\,946)}{48} = 456.1 \text{ lbf}$$

$$F_1 = (F_1)_a = bF_a C_p C_v = 6(100)(1)(1) = 600 \text{ lbf}$$

$$F_2 = F_1 - \Delta F = 600 - 456.1 = 143.9 \text{ lbf}$$

Transmitted power H

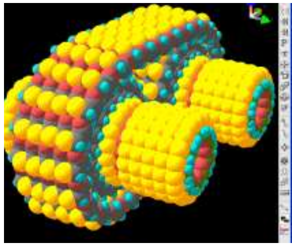
$$H = \frac{\Delta F(V)}{33\,000} = \frac{456.1(4775)}{33\,000} = 66 \text{ hp}$$

$$F_i = \frac{F_1 + F_2}{2} - F_c = \frac{600 + 143.9}{2} - 77.4 = 294.6 \text{ lbf}$$

$$f' = \frac{1}{\theta_d} \ln\left(\frac{F_1 - F_c}{F_2 - F_c}\right) = \frac{1}{\pi} \ln\left(\frac{600 - 77.4}{143.9 - 77.4}\right) = 0.656$$

Eq. (17-2): $L = [4(192)^2 - (48 - 48)^2]^{1/2} + 0.5[48(\pi) + 48(\pi)] = 534.8 \text{ in}$

Friction is not fully developed, so b_{min} is just a little smaller than 6 in (5.7 in). Not having a figure of merit, we choose the most narrow belt available (6 in). We can improve the



design by reducing the initial tension, which reduces F_1 and F_2, thereby increasing belt life. This will bring f' to 0.80

$$F_1 = \frac{(\Delta F + F_c)\exp(f\theta) - F_c}{\exp(f\theta) - 1}$$

$$\exp(f\theta) = \exp(0.80\pi) = 12.345$$

Therefore

$$F_1 = \frac{(456.1 + 77.4)(12.345) - 77.4}{12.345 - 1} = 573.7 \text{ lbf}$$

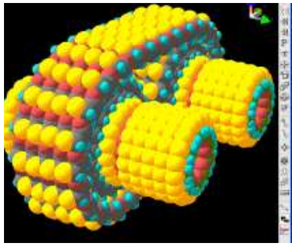
$$F_2 = F_1 - \Delta F = 573.7 - 456.1 = 117.6 \text{ lbf}$$

$$F_i = \frac{F_1 + F_2}{2} - F_c = \frac{573.7 + 117.6}{2} - 77.4 = 268.3 \text{ lbf}$$

These are small reductions since f' is close to f, but improvements nevertheless.

$$\text{dip} = \frac{3C^2w}{2F_i} = \frac{3(192/12)^2(0.393)}{2(268.3)} = 0.562 \text{ in}$$

decision set for belt

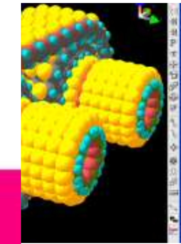


- Design factor: n_d
- Initial tension maintenance
- Belt material
- Drive geometry, d, D
- Belt thickness: t
- Belt width: b

Depending on the problem, some or all of the last four could be design variables. Belt cross-sectional area is really the design decision, but available belt thicknesses and widths are discrete choices. Available dimensions are found in suppliers' catalogs.

Table 17–2

Properties of Some Flat- and Round-Belt Materials. (Diameter = d, thickness = t, width = w)



Material	Specification	Size, in	Minimum Pulley Diameter, in	Allowable Tension per Unit Width at 600 ft/min, lb/in	Specific Weight, lb/in³	Coefficient of Friction
Leather	1 ply	$t = \frac{11}{64}$	3	30	0.035–0.045	0.4
		$t = \frac{13}{64}$	$3\frac{1}{2}$	33	0.035–0.045	0.4
	2 ply	$t = \frac{18}{64}$	$4\frac{1}{2}$	41	0.035–0.045	0.4
		$t = \frac{20}{64}$	6[a]	50	0.035–0.045	0.4
		$t = \frac{23}{64}$	9[a]	60	0.035–0.045	0.4
Polyamide[b]	F–0[c]	$t = 0.03$	0.60	10	0.035	0.5
	F–1[c]	$t = 0.05$	1.0	35	0.035	0.5
	F–2[c]	$t = 0.07$	2.4	60	0.051	0.5
	A–2[c]	$t = 0.11$	2.4	60	0.037	0.8
	A–3[c]	$t = 0.13$	4.3	100	0.042	0.8
	A–4[c]	$t = 0.20$	9.5	175	0.039	0.8
	A–5[c]	$t = 0.25$	13.5	275	0.039	0.8
Urethane[d]	$w = 0.50$	$t = 0.062$	See	5.2[e]	0.038–0.045	0.7
	$w = 0.75$	$t = 0.078$	Table	9.8[e]	0.038–0.045	0.7
	$w = 1.25$	$t = 0.090$	17–3	18.9[e]	0.038–0.045	0.7
	Round	$d = \frac{1}{4}$	See	8.3[e]	0.038–0.045	0.7
		$d = \frac{3}{8}$	Table	18.6[e]	0.038–0.045	0.7
		$d = \frac{1}{2}$	17–3	33.0[e]	0.038–0.045	0.7
		$d = \frac{3}{4}$		74.3[e]	0.038–0.045	0.7

[a] Add 2 in to pulley size for belts 8 in wide or more.

[b] *Source: Habasit Engineering Manual,* Habasit Belting, Inc., Chamblee (Atlanta), Ga.

Table 17–4

Pulley Correction Factor C_P for Flat Belts*

Material	Small-Pulley Diameter, in					
	1.6 to 4	4.5 to 8	9 to 12.5	14, 16	18 to 31.5	Over 31.5
Leather	0.5	0.6	0.7	0.8	0.9	1.0
Polyamide, F–0	0.95	1.0	1.0	1.0	1.0	1.0
F–1	0.70	0.92	0.95	1.0	1.0	1.0
F–2	0.73	0.86	0.96	1.0	1.0	1.0
A–2	0.73	0.86	0.96	1.0	1.0	1.0
A–3	—	0.70	0.87	0.94	0.96	1.0
A–4	—	—	0.71	0.80	0.85	0.92
A–5	—	—	—	0.72	0.77	0.91

*Average values of C_P for the given ranges were approximated from curves in the *Habasit Engineering Manual*, Habasit Belting, Inc., Chamblee (Atlanta), Ga.

Useful formulas:

$$\theta_d = \pi - 2\sin^{-1}\frac{D-d}{2C}$$

$$\theta_D = \pi + 2\sin^{-1}\frac{D-d}{2C}$$

$$L = [4C^2 - (D-d)^2]^{1/2} + \frac{1}{2}(D\theta_D + d\theta_d)$$

$$F_1 - F_2 = \frac{2T}{D} = \frac{T}{D/2}$$

$$(F_1)_a = bF_aC_pC_v$$

$$F_i = \frac{F_1 + F_2}{2} - F_c$$

$$F_1 - F_2 = (F_1 - F_c)\frac{\exp(f\phi) - 1}{\exp(f\phi)}$$

Now F_c is found as follows:

$V = \pi\, dn/12$ ft/min

The weight w of a foot of belt is given in terms of the weight density γ in lbf/in^3 as $w = 12\gamma bt$ lbf/ft and F_c is written as

$$F_c = \frac{w}{g}\left(\frac{V}{60}\right)^2 = \frac{w}{32.2}\left(\frac{V}{60}\right)^2 \qquad \text{(e)}$$

$$F_i = \frac{T}{D}\,\frac{\exp(f\phi) + 1}{\exp(f\phi) - 1}$$

$$H_d = H_{nom}K_s n_d,$$

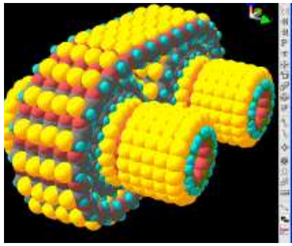
$$f' = \frac{1}{\phi}\ln\frac{(F_1)_a - F_c}{F_2 - F_c}$$

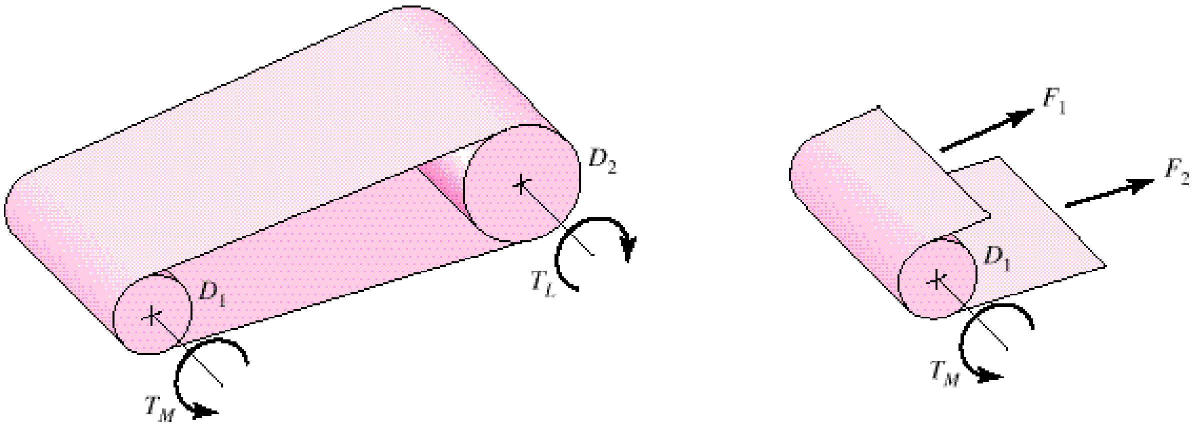
$$H = \frac{(F_1 - F_2)V}{33\,000}$$

$$F_1 = F_c + F_i\frac{2\exp(f\phi)}{\exp(f\phi) + 1}$$

$$F_2 = F_c + F_i\frac{2}{\exp(f\phi) + 1}$$

FLAT METAL BELTS

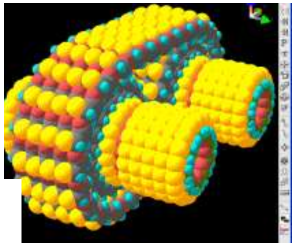




Thick as 0.002 in and narrow as 0.026 in.

- High strength-to-weight ratio
- Dimensional stability
- Accurate timing
- Usefulness to temperatures up to 700°F
- Good electrical and thermal conduction properties

FLAT METAL BELTS …….



Bending Tensile Stress

$$\sigma_b = \frac{Et}{(1-\nu^2)D} = \frac{E}{(1-\nu^2)(D/t)}$$

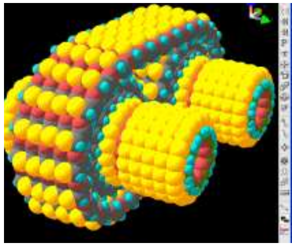
Tensile stresses

$$(\sigma)_1 = F_1/(bt) \quad \text{and} \quad (\sigma)_2 = F_2/(bt)$$

Belt Life

$\frac{D}{t}$	Belt Passes
625	$\geq 10^6$
400	$0.500 \cdot 10^6$
333	$0.165 \cdot 10^6$
200	$0.085 \cdot 10^6$

FLAT METAL BELTS ....



1 Find exp $f\phi$ from geometry and friction

2 Find endurance strength

$$S_f = 14.17(10^6)N_p^{-0.407} \qquad \text{301, 302 stainless}$$

$$S_f = S_y/3 \qquad \text{others}$$

3 Allowable tension

$$F_{1a} = \left[S_f - \frac{Et}{(1-\nu^2)D}\right] tb = ab$$

4 $\Delta F = 2T/D$

5 $F_2 = F_{1a} - \Delta F = ab - \Delta F$

6 $F_i = \dfrac{F_{1a} + F_2}{2} = \dfrac{ab + ab - \Delta F}{2} = ab - \dfrac{\Delta F}{2}$

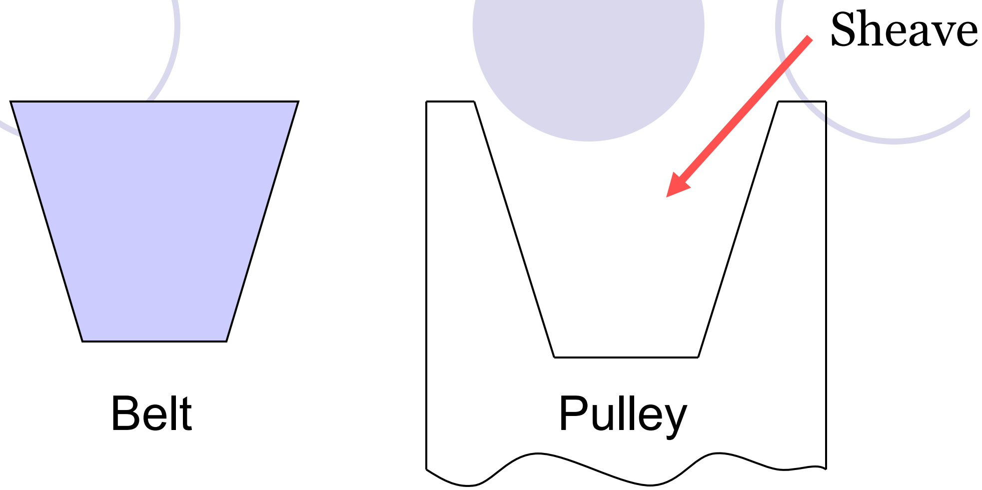
7 $b_{\min} = \dfrac{\Delta F}{a} \dfrac{\exp f\phi}{\exp f\phi - 1}$

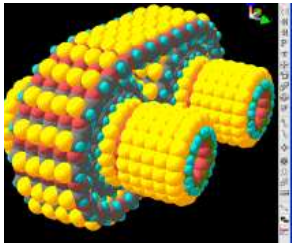
8 Choose $b > b_{\min}$, $F_1 = ab$, $F_2 = ab - \Delta F$, $F_i = ab - \Delta F/2$, $T = \Delta F D/2$

9 Check frictional development f':

$$f' = \frac{1}{\phi}\ln\frac{F_1}{F_2} \qquad f' < f$$

V- BELTS



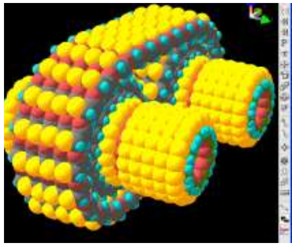


- Used for relatively large torque over small distances
- In custom size which can not be more than 19 mm
- Size of Sheave is kept slightly smaller than X-Section of Belt
- For greater torque more than one belts are used on the same pulley

Pitch Length $L_p = 2C + 1.57(D+d) + (D-d)^2/(4C)$

Center to Center Dist $C = 0.25\left\{\left[\frac{\pi}{2}(D+d) - L_p\right] + \sqrt{\left[\frac{\pi}{2}(D+d) - L_p\right]^2 - 2(D-d)^2}\right\}$

V- BELTS (Some Relations)



$$H_a = K_1 K_2 H_{\text{tab}}$$

where H_a = allowable power, per belt, Table 17–12

K_1 = angle-of-wrap correction factor, Table 17–13

K_2 = belt length correction factor, Table 17–14

effective coefficient of friction f' is $f/\sin\phi/2$

$$\frac{F_1 - F_c}{F_2 - F_c} = \exp(0.5123\phi)$$

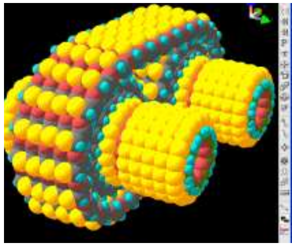
$$F_c = K_c \left(\frac{V}{1000}\right)^2$$

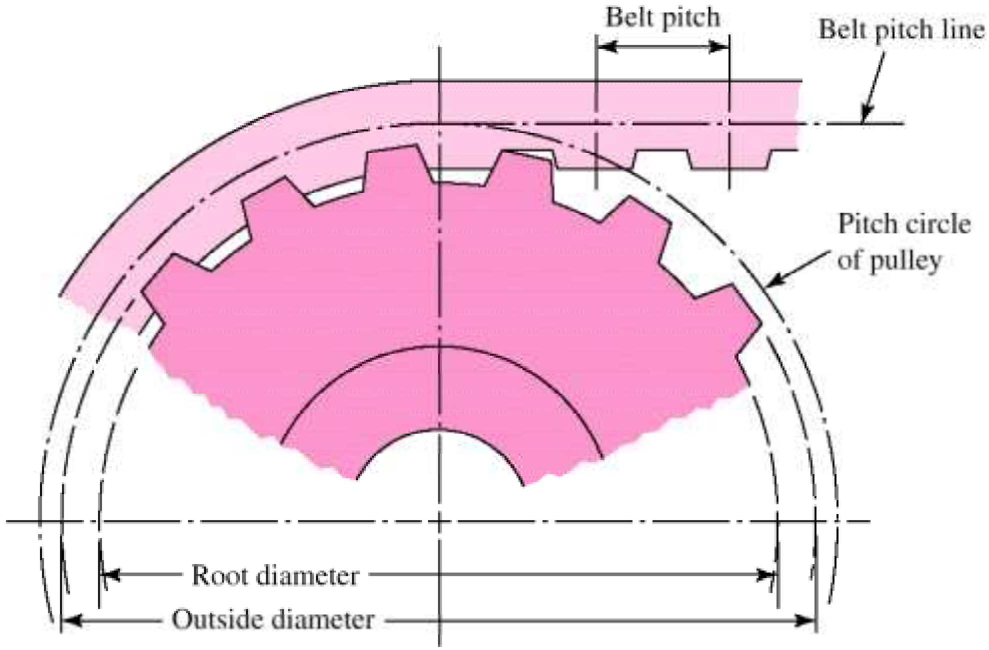
$$H_d = H_{\text{nom}} K_s n_d$$

No. of Belts = H_d / H_a.

$$\text{fos} = \frac{H_a N_b}{H_{\text{nom}} K_s}$$

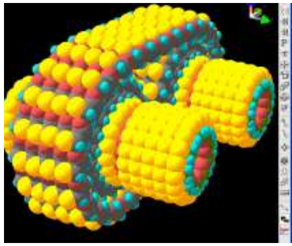
TIMING BELTS

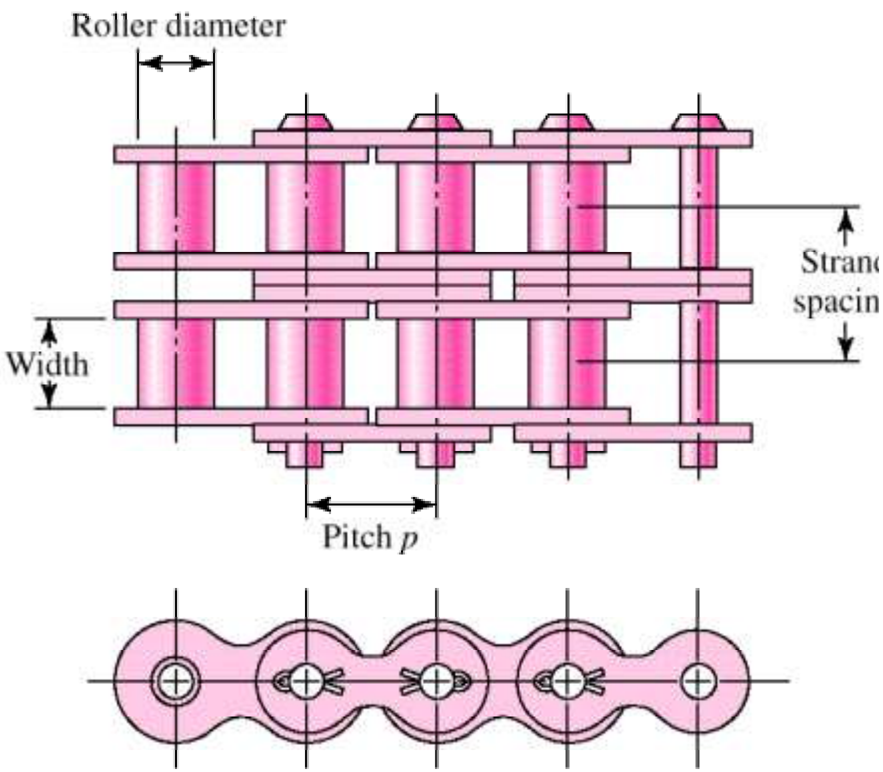


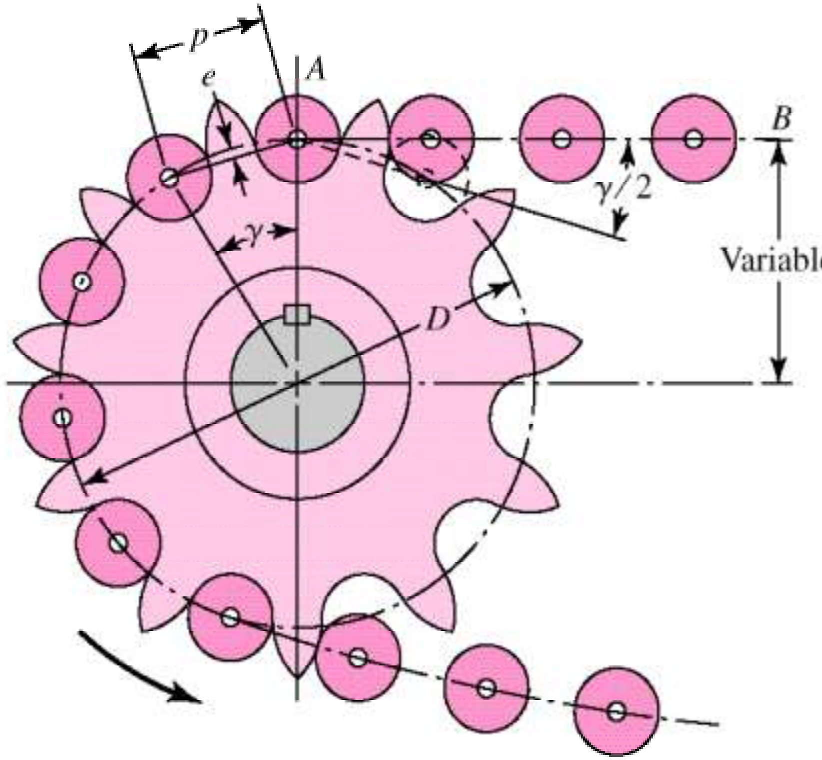


Service	Designation	Pitch p, in
Extra light	XL	$\frac{1}{5}$
Light	L	$\frac{3}{8}$
Heavy	H	$\frac{1}{2}$
Extra heavy	XH	$\frac{7}{8}$
Double extra heavy	XXH	$1\frac{1}{4}$

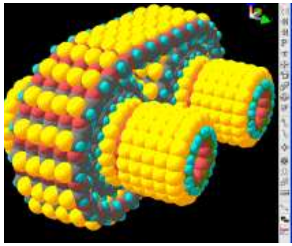
ROLLER CHAIN



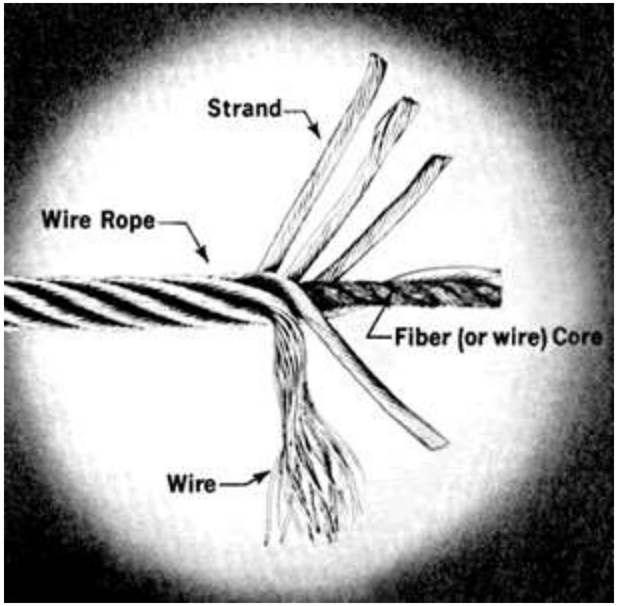




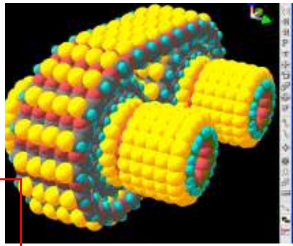
Wire Ropes



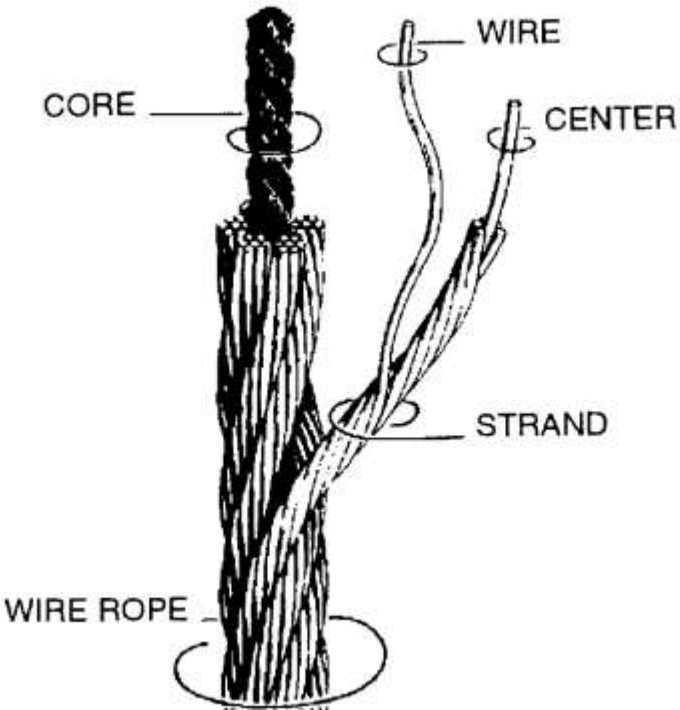
A wire rope is a piece of flexible, multi-wired, stranded machinery made of many precision parts.



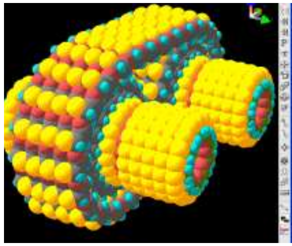
Wire Rope



Wire rope itself is a very complicated and delicate tool. Wire ropes are twisted bundles of wire around a core of natural or occasionally metal fibers. A wire rope is made up of several strands of coiled wires. The wires are wound together in one direction to form a strand. The strands are then laced together in the opposite direction to form a wire rope. The wire rope's core, if made up of natural fibers, is saturated with lubricant at the factory. The outside wires and strands are lubricated with a coating during the processing of the cable. This type of dual lubrication protects the cable during shipment and storage.

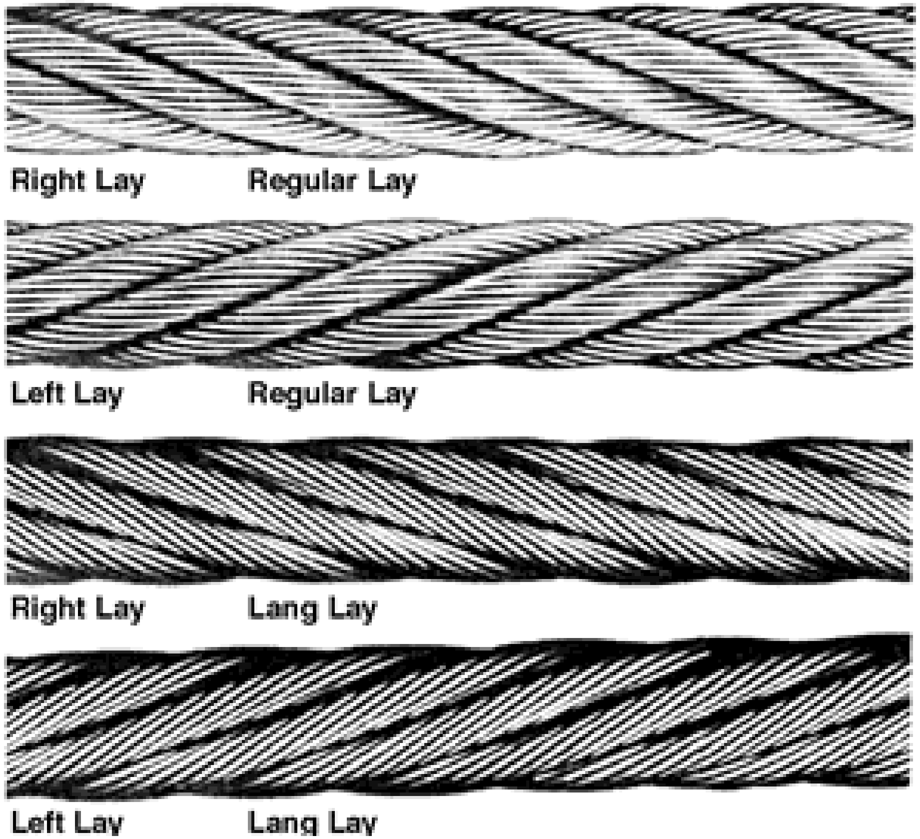


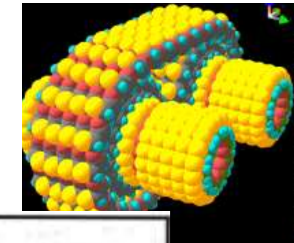
- Regular lay and lang lay describe the way wires are placed within each strand.



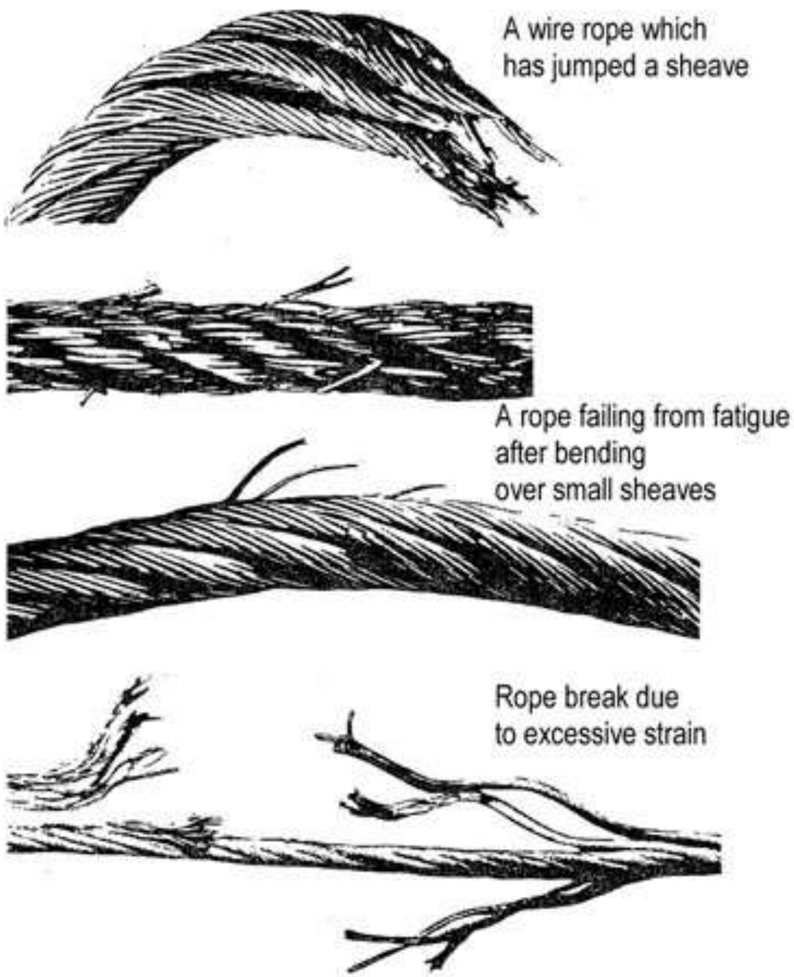
- Regular lay means that wires in the strands are laid opposite in direction to the lay of the strands..

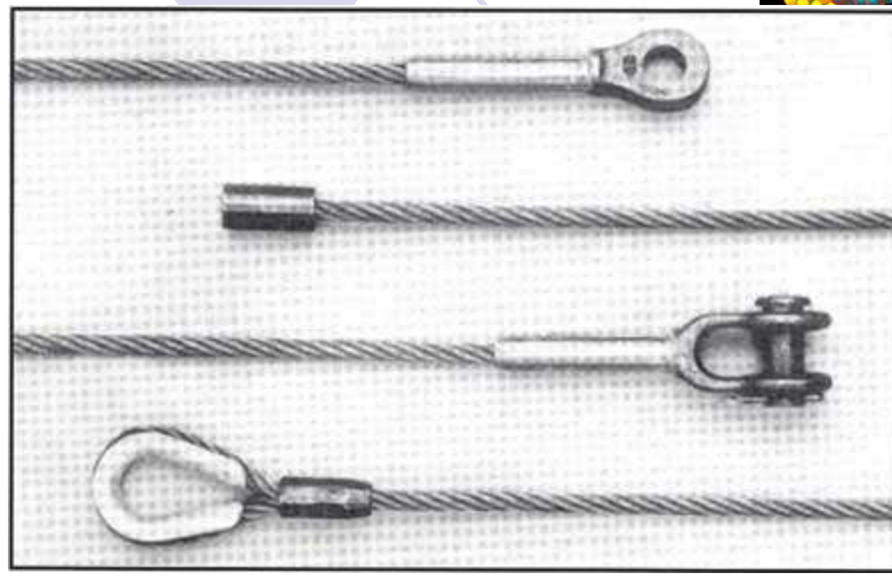
Lang lay means that wires are laid in the same direction as the lay of the strands

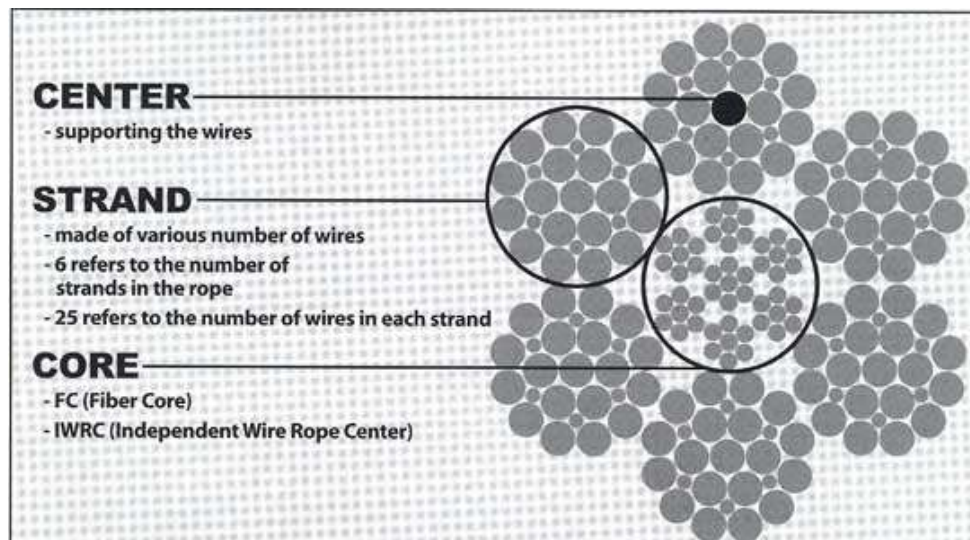




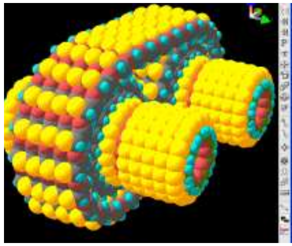
Typical Rope Damage

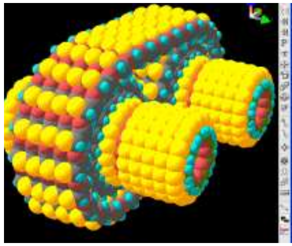






Applications of wire ropes





- **Service Factors**
  When designing belt drives it is normal to apply a service factor to the drive operating load to compensate or allow for different driver type, driven load types and operating periods. Typical Service factor values are included on the linked page

http://www.roymech.co.uk/Useful_Tables/Drive/Service_Factors.html

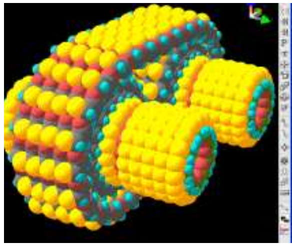


Table 17–5

Crown Height and ISO Pulley Diameters for Flat Belts*

ISO Pulley Diameter, in	Crown Height, in	ISO Pulley Diameter, in	Crown Height, in	
			$w \le 10$ in	$w > 10$ in
1.6, 2, 2.5	0.012	12.5, 14	0.03	0.03
2.8, 3.15	0.012	12.5, 14	0.04	0.04
3.55, 4, 4.5	0.012	22.4, 25, 28	0.05	0.05
5, 5.6	0.016	31.5, 35.5	0.05	0.06
6.3, 7.1	0.020	40	0.05	0.06
8, 9	0.024	45, 50, 56	0.06	0.08
10, 11.2	0.030	63, 71, 80	0.07	0.10

*Crown should be rounded, not angled; maximum roughness is $R_a = \text{AA } 63\ \mu\text{in}$.

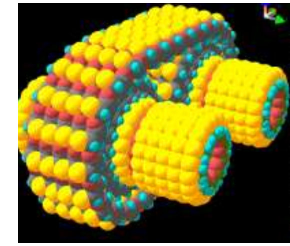
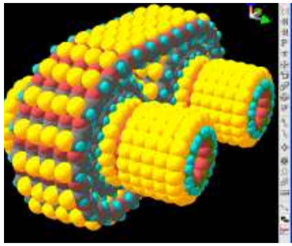


Table 17–3

Minimum Pulley Sizes for Flat and Round Urethane Belts. (Listed are the Pulley Diameters in Inches)

Source: Eagle Belting Co., Des Plaines, Ill.

Belt Style	Belt Size, in	Ratio of Pulley Speed to Belt Length, r/(ft · min)		
		Up to 250	250 to 499	500 to 1000
Flat	0.50 × 0.062	0.38	0.44	0.50
	0.75 × 0.078	0.50	0.63	0.75
	1.25 × 0.090	0.50	0.63	0.75
Round	$\frac{1}{4}$	1.50	1.75	2.00
	$\frac{3}{8}$	2.25	2.62	3.00
	$\frac{1}{2}$	3.00	3.50	4.00
	$\frac{3}{4}$	5.00	6.00	7.00



Thank You