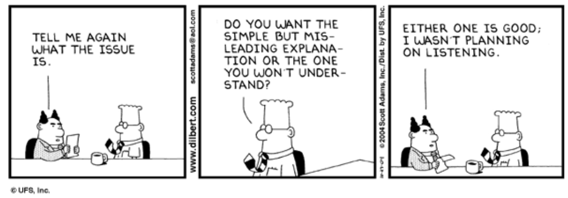
14. Belt and Chain Drives



Objectives

- Understand principles of operation of flexible-drive systems.
- Determine allowable forces and torques for flexible-drive systems, along with the necessary sprockets or sheaves.
- Describe basic features of belt-drive systems.
- Describe basic features of chain-drive systems.
- Understand principles of operation of different chain drives.
- Specify types and sizes of chain drives and their associated sprockets for different applications.

Introduction

- **Consequence of failure:** Belts will not break because of overload.
- **Versatility in shaft connection:** Belts are more versatile with many geometries as well as large center distances.
- **Effect on shaft bearing life:** Belts increase bearing load because of the initial tension required.
- **Speed ratio:** Belts will not provide exact speed ratio because of the slippage.

Introduction

- **Cost:** Belts are least expensive.
- **Noise and vibration:** Belt drives produce least amount of noise and vibration.
- **Speed and power:** Gears can operate at higher speeds and transmit more power than chains or belts.
- **Maintenance:** Chains and belts require periodic adjustment from wear and stretch, respectively.

TABLE 9.1 Common Applications of Belts and Chains

Common Applications	
Belts	Chains
Compressors	Bicycles
Sewing machines	Motorcycles
Textile machines	Power lawn mowers
Automotive devices	Chain saws
water pumps	Cranes
alternators	Hoists
fans	Paper-mill machinery
Mixing machines	Conveyers
Washing machines	Textile machinery
Printing machinery	All terrain vehicles
Pumps	
Machine tools	
Crushing machinery	

Flat Belts

- Rectangular in cross section mounted on pulleys
- Crowning on the pulley to prevent the belt from running off the pulley

Flat belt pulley

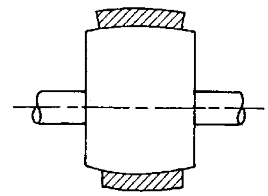
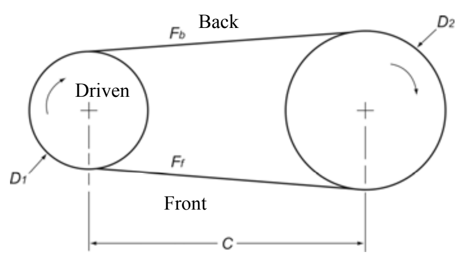


FIGURE 9.1 Flat belt and crowned pulley

Fig. 14.1 Flat belts – Open belt



Belt Drives

- Driving force, $F_d = F_f - F_b$
- Torque, $T = (F_f - F_b)\ r = F_d\ r$
- Ratio of belt drive is similar to gears

$$m_w = \frac{D_2}{D_1}$$

- Surface velocity, $V_m = \dfrac{\pi\ D_p\ n}{12}$ ft/min

Example Problem 14-1: Belt Drives

- A flat-belt system has small pulley with 6-inch diameter and large pulley with 10-inch diameter. Small pulley transmits 2 hp at 2450 rpm, and back force of 10 pounds in belt is required for frictional purposes.
- Determine front force, net driving force, and force on shafts.
- Find belt surface speed and output speed.

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• Determine front force, net driving force, and force on shafts.
• Find belt surface speed and output speed.

– Find torque on small pulley:

$$T = \frac{63{,}000\ hp}{n} \quad (2\text{-}6)$$

$$T = \frac{63{,}000\ (2)}{2450}$$

$$T = 51.4\ in\text{-}lb$$

– If:

$$T = F_d\ r \quad (14\text{-}3)$$

$$F_d = \frac{T}{r}$$

$$F_d = \frac{51.4\ in\text{-}lb}{\frac{6\ in}{2}}$$

$$F_d = 17\ lb$$

Example Problem 14-1: Belt Drives (cont'd.)

– Then, the front force would be:

$$F_d = F_f - F_b \qquad (14\text{-}1)$$

$$F_f = F_d + F_b$$

$$F_f = 17\ lb + 10\ lb$$

$$F_f = 27\ lb$$

– The force pulling the shafts together would be:

$$F_t = F_f + F_b$$

$$F_t = 27\ lb + 10\ lb$$

$$F_t = 37\ lb$$

– Find the surface speed:

$$V_m = \frac{\pi D n}{12} \qquad (14\text{-}5)$$

$$V_m = \frac{\pi\ 6\ in\ \ 2450\ rpm}{12}$$

$$V_m = 3848\ ft/min$$

Example Problem 14-1: Belt Drives (cont'd.)

– Find ratio:

$$m_w = \frac{D_2}{D_1} \qquad (14\text{-}4)$$

$$m_w = \frac{10}{6} = \frac{1.67}{1}$$

– Output speed is:

$$n = \frac{2450\ rpm}{\frac{1.67}{1}} = 1467\ rpm$$

This is approximate as minor slippage may occur.

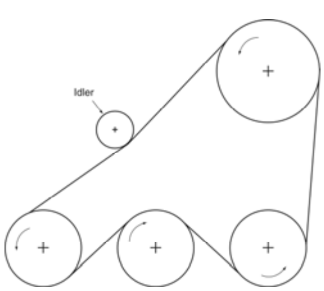
Belt Drive - formulae

- Length of belt, L = $2C + 1.57(D_1 + D_2) + \frac{(D_2 - D_1)^2}{4\ C}$
- Centerline distance, C = $\frac{B + \sqrt{B^2 - 32(D_2 - D_1)^2}}{16}$
- Where, $B = 4\ L - 6.28\ (D_2 + D_1)$
- Wrap angle, θ = $180^o \pm 2 \sin^{-1}\left(\frac{D_2 - D_1}{2\ C}\right)$
- + for larger pulley

Belt Drives

- Greater angle of contact is better
- Idler pulley is used for the purpose
- Idler is used to increase the angle of contact which should not be less than 160 deg.

Fig. 14.2 Serpentine Belt System



Example Problem 14-2: Belt Drives

- Mate 4-inch-diameter sheave with 6-inch-diameter sheave. Their centerlines can range from 18 to 20 inches apart. Select length of belt and determine actual centerline distance. If small sheave rotates 1800 rpm, determine ratio and surface speed. Find the angle of contact for the small sheave.

Example Problem 14-2: Belt Drives

•For determining the length of belt, try centerline spacing of 19 inches.

$$L = 2C + 1.57(D_1 + D_2) + \frac{(D_2 - D_1)^2}{4C} \quad (14\text{-}6)$$

$$L = 2(19) + 1.57(4 + 6) + \frac{(6 - 4)^2}{4(19)}$$

$$L = 53.75 \text{ inches}$$

Assuming a 54-inch belt is available.

Example Problem 14-2: Belt Drives (cont'd.)

– Find the centerline distance:

$$C = \frac{B + \sqrt{B^2 - 32(D_2 - D_1)^2}}{16} \quad (14\text{-}7)$$

$$B = 4L - 6.28(D_2 + D_1) \quad (14\text{-}8)$$

$$B = 4(54) - 6.28(6 + 4)$$

$$B = 153.2$$

$$C = \frac{153.2 + \sqrt{153.2^2 - 32(6 - 4)^2}}{16}$$

$$C = 19.12 \text{ inches}$$

– Find the ratio:

$$m_w = \frac{D_2}{D_1} = \frac{6}{4} = 1.5 \quad (14\text{-}4)$$

Example Problem 14-2: Belt Drives (cont'd.)

– Find the surface speed:

$$V_m = \frac{\pi D n}{12} \quad (14\text{-}5)$$

$$V_m = \frac{\pi \, 4\,in \;\; 1800\,rpm}{12}$$

$$V_m = 1885 \; ft/\min$$

– Find the angle of contact:

$$\theta = 180^\circ - 2\sin^{-1}\left(\frac{D_2 - D_1}{2C}\right) \quad (14\text{-}9)$$

$$\theta = 180^\circ - 2\sin^{-1}\left(\frac{6 - 4}{2(19.12)}\right)$$

$$\theta = 174^\circ$$

Flat belts

- Materials
  - Leather
  - Rubber
  - Canvas
- Layers
  - Single-ply
  - Double-ply
  - Triple-ply

Angle of contact

- Is the angle over which the belt makes contact with a pulley
  - Open belt < 180 deg
  - Cross belt > 180 deg
- The amount of horsepower that a pulley can transmit decreases as the angle of contact decreases.

V-belts

- Most popular.
- V belt is designed to ride inside the groove of the pulley or sheave.
- Typical sizes are shown in Fig. 14.4

Fig. 14.3 Cross-section of V-belt in sheave groove

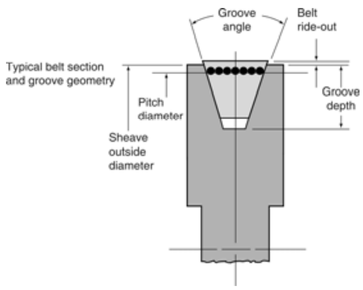


Fig. 14.4 Standard V-belt sizes

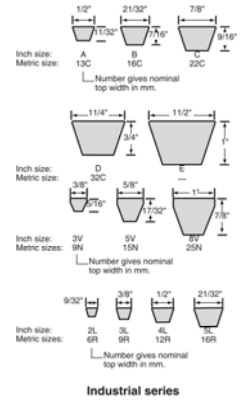
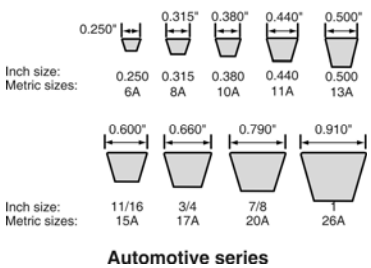


Fig. 14.4 Standard V-belt sizes



V-belts

- Higher friction
- Less back force
- Short shaft sizes

Fig. 14.5 Power Ratings

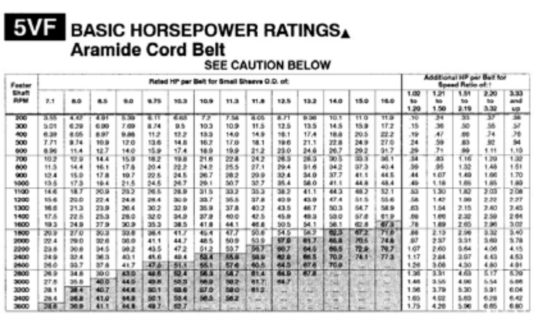
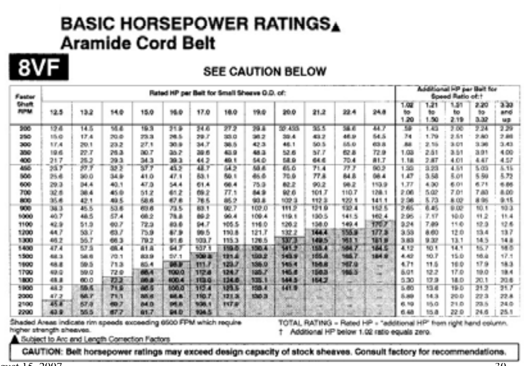


Fig. 14.5 Power Ratings



Example Problem 14-3: V-Belts

- From Figure 14-5, determine power rating for 5 VF Aramide cord belt for input speed of 1800 rpm, output speed of 900 rpm, with input sheave OD of 8 inches and service factor of 1.5.
- Determine standard belt length if input and output shafts need to be about 20 inches apart.

Example Problem 14-3: V-Belts

– (From Figure 14-5, basic rating from 1800-rpm row and 8-inch column is 27 hp.)

– In addition, add the horsepower for 2 : 1 ratio of 2.98:

$$P = 27 + 2.98 = 29.98\ hp$$

– Add service factor:

$$P = \frac{29.98}{1.5} = 20\ hp$$

Example Problem 14-3: V-Belts (cont'd.)

- Output sheave would need to have 16-inch diameter to obtain 900 rpm speed.
  – Find approximate length of belt needed:

$$L = 2C + 1.57\,(D_1 + D_2) + \frac{(D_2 - D_1)^2}{4C} \qquad (14\text{-}6)$$

$$L = 2(20) + 1.57\,(8 + 16) + \frac{(16 - 8)^2}{4(20)}$$

$$L = 78.5\ inches$$

(Table 14-1)

– Use an 80-inch belt.

V-belts

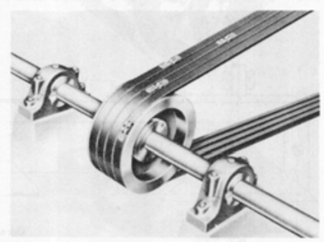
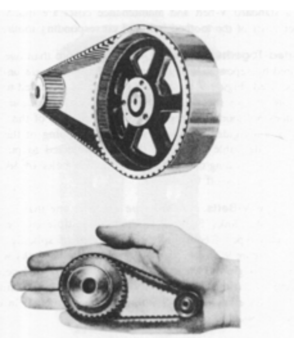


FIGURE 9.11 Multiple-groove sheave with four spliced belts *(Courtesy of the Gates Rubber Co. Denver, Colorado)*

Timing belts



RE 9.14 Fractional-hp and 600 hp positive-drive belting systems *(Courtesy of Maurey Manufacturing Corp., Chicago, Illinois)*

Roller chains

- Can connect two parallel shafts
- Similar to gears
- Suitable for very long and short distances
- More compact
- Power transmission efficiency is 98 to 99%

Roller chains

- Regular lubrication is required.
- Better at lower speed because of the inertia
- No back force is required like belts, but a slack is normally used.

Roller chains

- Roller links
  - Two inner end plates, two rollers, and two bushings
- Pin links

Roller chain

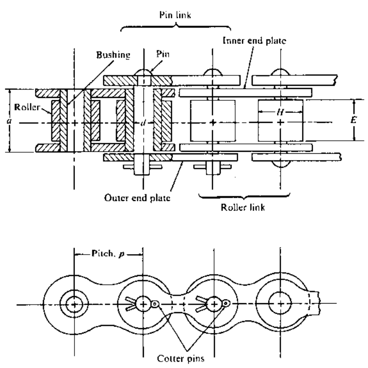


FIGURE 9.19 Construction of typical roller chain

Fig. 14.7 Number 40 Roller chain HP ratings

HP RATINGS—STANDARD SINGLE * STRAND ROLLER CHAIN—NO. 40-1/2" PITCH

Small Sprocket Teeth	P.D.	RPM → 10	20	30	50	75	100	125	150	200	250	300	400	500	600	900	1200	1500	1800	2400	3000
11	1.77	.054	.10	.15	.23	.33	.43	.53	.62	.80	.98	1.16	1.50	1.84	2.16	3.11	4.03	4.93	4.66	3.03	2.17
13	2.09	.065	.12	.17	.28	.40	.52	.63	.74	.96	1.18	1.39	1.80	2.20	2.59	3.73	4.83	5.91	5.99	3.89	2.79
15	2.40	.076	.14	.20	.32	.46	.60	.74	.87	1.12	1.37	1.62	2.10	2.56	3.02	4.35	5.64	6.89	7.43	4.82	3.45
17	2.72	.087	.16	.23	.37	.53	.69	.84	.99	1.29	1.57	1.85	2.40	2.94	3.45	4.98	6.45	7.89	8.96	5.82	4.17
19	3.04	.098	.18	.26	.42	.60	.78	.95	1.12	1.45	1.77	2.09	2.71	3.31	3.90	5.62	7.27	8.89	10.5	6.88	4.92
21	3.35	.109	.20	.29	.46	.67	.87	1.06	1.25	1.62	1.98	2.33	3.02	3.69	4.34	6.26	8.11	9.91	11.7	7.99	5.72
23	3.67	.120	.22	.32	.51	.74	.96	1.17	1.38	1.78	2.18	2.57	3.33	4.07	4.79	6.90	8.94	10.9	12.9	9.16	6.55
25	3.99	.132	.25	.35	.56	.81	1.05	1.28	1.51	1.95	2.38	2.81	3.64	4.45	5.24	7.55	9.78	12.0	14.1	10.4	7.43
Lubrication #		Type I								Type II						Type III		Type IV			

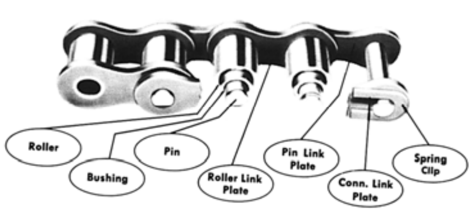
TYPE I—MANUAL LUBRICATION
Manual lubrication is accomplished by applying oil with a brush or spout can to the inside of the chain at the edges of the side plates. Volume and frequency should be determined by periodic inspection.

TYPE II—DRIP LUBRICATION
Oil is directed between link plate edges to a drip lubricator. Only enough oil to keep the chain moist is necessary and a light metal splash guard will keep the floor and surroundings clean.

TYPE III—BATH OR DISC LUBRICATION
With bath lubrication, the lower strand of the chain runs through a sump of oil. The oil level should reach the pitch line of the chain at its lowest point while operating. With disc lubrication, the chain operates above the oil level. The disc picks up oil from the sump and deposits it on the chain, usually by means of a trough. The disc diameter should be such as to produce rim speeds from 600 minimum to 8000 maximum FPM. This type of lubrication requires that the drive be enclosed in an oil tight chain case.

TYPE IV—OIL STREAM LUBRICATION
The lubricant is usually supplied by a circulating pump capable of supplying the chain drive with a continuous stream of oil. The oil should be applied inside the chain loop evenly across the chain width, and directed at the lower strand. This type of lubrication requires that the drive be enclosed in an oil tight chain case.

Fig. 14.8 Cutaway view of Roller chain



Example Problem 14-4: Chain Drives

- From Figure 14-7, determine horsepower rating for number 40 roller chain if input is through 12-tooth sprocket turning at 1800 rpm and output turns at 900 rpm:
  1. P = 5.31 hp.
  2. Select output sprocket for this application:

Example Problem 14-4: Chain Drives

• From Figure 14-7, determine horsepower rating for number 40 roller chain if input is through 12-tooth sprocket turning at 1800 rpm and output turns at 900 rpm:

1. P = 5.31 hp.
2. Select output sprocket for this application:

$$12\ tooth\ \frac{1800}{900} = 24\ teeth$$

Example Problem 14-4: Chain Drives (cont'd.)

3. Determine surface speed for this application:

$$D = \frac{P_c\ N_t}{\pi} \qquad (11\text{-}3)$$
$$D = \frac{.5\ (12)}{\pi} \approx 1.91\ inch$$

– On small sprockets, this is approximate.

$$V_m = \frac{\pi\ D\ n}{12} \qquad (14\text{-}5)$$
$$V_m = \frac{\pi\ 1.91\ \ 1800}{12}$$
$$Vm = 900\ ft/\min$$

3. What type of lubrication is recommended for this application? (Bath or disc lubrication from the bottom of Figure 14-7.

Example Problem 14-4: Chain Drives (cont'd.)

5. If sprocket centerlines are to be 10 inches apart, how long a chain will be needed in full links?

–Find large sprocket diameter:

$$D = \frac{P_c\ N_t}{\pi}$$
$$D = \frac{.5\ (24)}{\pi} = 3.82\ inches$$
$$L \approx 2C + 1.57\,(D_1 + D_2) + \frac{(D_2 - D_1)^2}{4C} \qquad (14\text{-}6)$$
$$L \approx 2\,(10) + 1.57\,(1.91 + 3.82) + \frac{(3.82 - 1.91)^2}{4\,(10)}$$
$$L \approx 29.08$$

• Use 29- or 30-inch chain.

• This formula is only approximate for chains.

Example Problem 14-4: Chain Drives (cont'd.)

6. What is the force in the chain if the power transmitted is 5.31 hp?

$$T = \frac{63{,}000\ hp}{n} \qquad (2\text{-}6)$$
$$T = \frac{63{,}000\ (5.31)}{1900}$$
$$T = 186\ in-lb$$

7. How does this force compare to the ultimate strength?

$$F = \frac{2\,T}{D} \qquad (12\text{-}3)$$
$$F = \frac{(2)\,186\ in-lb}{1.91}$$
$$F = 195\ lb$$

8. Compare the result to the ultimate strength of 3700 pounds (not a valid comparison because of speed, etc.).

Roller chain – Life

- Number of teeth on sprocket: The smaller the number of teeth, the greater the shock loading.
- Chain speed: The greater the chain speed, the greater the shock loading
- Lubrication: Poor lubrication will shorten the life of a roller due to wear
- Environment: Dirty or dusty conditions tend to have an adverse affect on roller chain life

Conclusions

- Belts and chains are used for power transmission.
- These are cheap and accommodate large center distances.
- Angle of contact is very important.
- Flat belts are made from leather, as well as rubber or canvas.
- V-belts are suitable for large torque transmission.
- A number of other types of belts are also used.
- Roller chains provide positive drive. Shock loading on the chain increases if the number of sprocket teeth are reduced or if the speed is increased.