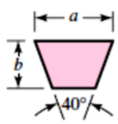
V-Belts

The cross sectional dimensions of V-belts are standardized. Each letter designates a certain cross section (see *Table 17-9*).

Table 17–9

Standard V-Belt Sections



Belt Section	Width a, in	Thickness b, in	Minimum Sheave Diameter, in	hp Range, One or More Belts
A	$\frac{1}{2}$	$\frac{11}{32}$	3.0	$\frac{1}{4}$–10
B	$\frac{21}{32}$	$\frac{7}{16}$	5.4	1–25
C	$\frac{7}{8}$	$\frac{17}{32}$	9.0	15–100
D	$1\frac{1}{4}$	$\frac{3}{4}$	13.0	50–250
E	$1\frac{1}{2}$	1	21.6	100 and up

• A V-belt can be specified by the cross section letter followed by the inside circumference length.

❖ *Table 17-10* gives the standard lengths for V-belts.

Table 17–10

Inside Circumferences of Standard V Belts

Section	Circumference, in
A	26, 31, 33, 35, 38, 42, 46, 48, 51, 53, 55, 57, 60, 62, 64, 66, 68, 71, 75, 78, 80, 85, 90, 96, 105, 112, 120, 128
B	35, 38, 42, 46, 48, 51, 53, 55, 57, 60, 62, 64, 65, 66, 68, 71, 75, 78, 79, 81, 83, 85, 90, 93, 97, 100, 103, 105, 112, 120, 128, 131, 136, 144, 158, 173, 180, 195, 210, 240, 270, 300
C	51, 60, 68, 75, 81, 85, 90, 96, 105, 112, 120, 128, 136, 144, 158, 162,173, 180, 195, 210, 240, 270, 300, 330, 360, 390, 420
D	120, 128, 144, 158, 162, 173, 180, 195, 210, 240, 270, 300, 330, 360,390, 420, 480, 540, 600, 660
E	180, 195, 210, 240, 270, 300, 330, 360, 390, 420, 480, 540, 600, 660

▪ However, calculations involving the belt length are usually based on pitch length for standard belts.

❖ Table 17-11 gives the quantity to be added to the inside length.

Table 17–11

Length Conversion Dimensions (Add the Listed Quantity to the Inside Circumference to Obtain the Pitch Length in Inches)

Belt section	A	B	C	D	E
Quantity to be added	1.3	1.8	2.9	3.3	4.5

Example: Pitch length of *C-1500* belt is: *1500 + 72 = 1572 mm*.

- The standard angle for the V-belts cross section is *40˚*; however the sheave angle is slightly smaller causing the belt to wedge itself inside the sheave to increase friction.
- The operating speed for V-belts needs to be high and the recommended speed range is from *5* to *25 m/s*. Best performance is obtained at speed of *20 m/s*.

- For V-belts, the pitch length L_P, and center-to-center distance are found as:

$$L_p = 2C + \pi(D+d)/2 + (D-d)^2/(4C) \qquad (17\text{–}16a)$$

And

$$C = 0.25\left\{\left[L_p - \frac{\pi}{2}(D+d)\right] + \sqrt{\left[L_p - \frac{\pi}{2}(D+d)\right]^2 - 2(D-d)^2}\right\} \qquad (17\text{–}16b)$$

➢ While there are no limitations on the center-to-center distance for flat belts, for V-belts the center-to-center distance should not exceed *"3(D+d)"* because the excessive vibrations of the loose side will shorten the belt life. *why?*

➢ Also the centers distance should not be less than D.

- **Horsepower:**

❖ *Table 17-12* gives the horsepower rating for each belt cross-section (*according to sheave pitch diameter and belt speed*).

▪ The allowable horsepower per-belt, H_a is found as:

$$H_a = K_1 K_2 H_{tab} \qquad (17\text{–}17)$$

Power that can be transmitted by each belt

H_{tab}: *from Table 17-12*

where,

K_1: contact angle correction factor (*Table 17-13*).

Note: the contact angles for V-belts are found using the same equations used for flat belts.

K_2: belt length correction factor (*Table 17-14*).

Table 17–12

Horsepower Ratings of Standard V Belts

Belt Section	Sheave Pitch Diameter, in	Belt Speed, ft/min 1000	2000	3000	4000	5000
A	2.6	0.47	0.62	0.53	0.15	
	3.0	0.66	1.01	1.12	0.93	0.38
	3.4	0.81	1.31	1.57	1.53	1.12
	3.8	0.93	1.55	1.92	2.00	1.71
	4.2	1.03	1.74	2.20	2.38	2.19
	4.6	1.11	1.89	2.44	2.69	2.58
	5.0 and up	1.17	2.03	2.64	2.96	2.89
B	4.2	1.07	1.58	1.68	1.26	0.22
	4.6	1.27	1.99	2.29	2.08	1.24
	5.0	1.44	2.33	2.80	2.76	2.10
	5.4	1.59	2.62	3.24	3.34	2.82
	5.8	1.72	2.87	3.61	3.85	3.45
	6.2	1.82	3.09	3.94	4.28	4.00
	6.6	1.92	3.29	4.23	4.67	4.48
	7.0 and up	2.01	3.46	4.49	5.01	4.90
C	6.0	1.84	2.66	2.72	1.87	
	7.0	2.48	3.94	4.64	4.44	3.12
	8.0	2.96	4.90	6.09	6.36	5.52
	9.0	3.34	5.65	7.21	7.86	7.39
	10.0	3.64	6.25	8.11	9.06	8.89
	11.0	3.88	6.74	8.84	10.0	10.1
	12.0 and up	4.09	7.15	9.46	10.9	11.1
D	10.0	4.14	6.13	6.55	5.09	1.35
	11.0	5.00	7.83	9.11	8.50	5.62
	12.0	5.71	9.26	11.2	11.4	9.18
	13.0	6.31	10.5	13.0	13.8	12.2
	14.0	6.82	11.5	14.6	15.8	14.8
	15.0	7.27	12.4	15.9	17.6	17.0
	16.0	7.66	13.2	17.1	19.2	19.0
	17.0 and up	8.01	13.9	18.1	20.6	20.7
E	16.0	8.68	14.0	17.5	18.1	15.3
	18.0	9.92	16.7	21.2	23.0	21.5
	20.0	10.9	18.7	24.2	26.9	26.4
	22.0	11.7	20.3	26.6	30.2	30.5
	24.0	12.4	21.6	28.6	32.9	33.8
	26.0	13.0	22.8	30.3	35.1	36.7
	28.0 and up	13.4	23.7	31.8	37.1	39.1

- The design horsepower is found as:

$$H_d = H_{nom} K_s n_d \tag{17–19}$$

Power that needs to be transmitted from the power source to the driven machine

where,

H_{nom}: nominal horsepower of the power source.

K_S: service factor for overloads (*Table 17-15*).
n_d: design factor of safety.

Table 17–13

Angle of Contact Correction Factor K_1 for VV* and V-Flat Drives

$\frac{D-d}{C}$	θ, deg	K_1 VV	K_1 V Flat
0.00	180	1.00	0.75
0.10	174.3	0.99	0.76
0.20	166.5	0.97	0.78
0.30	162.7	0.96	0.79
0.40	156.9	0.94	0.80
0.50	151.0	0.93	0.81
0.60	145.1	0.91	0.83
0.70	139.0	0.89	0.84
0.80	132.8	0.87	0.85
0.90	126.5	0.85	0.85
1.00	120.0	0.82	0.82
1.10	113.3	0.80	0.80
1.20	106.3	0.77	0.77
1.30	98.9	0.73	0.73
1.40	91.1	0.70	0.70
1.50	82.8	0.65	0.65

*A curvefit for the VV column in terms of θ is
$K_1 = 0.143\,543 + 0.007\,46\,8\,\theta - 0.000\,015\,052\,\theta^2$
in the range $90° \leq \theta \leq 180°$.

Table 17–14

Belt-Length Correction Factor K_2*

Length Factor	Nominal Belt Length, in — A Belts	B Belts	C Belts	D Belts	E Belts
0.85	Up to 35	Up to 46	Up to 75	Up to 128	
0.90	38–46	48–60	81–96	144–162	Up to 195
0.95	48–55	62–75	105–120	173–210	210–240
1.00	60–75	78–97	128–158	240	270–300
1.05	78–90	105–120	162–195	270–330	330–390
1.10	96–112	128–144	210–240	360–420	420–480
1.15	120 and up	158–180	270–300	480	540–600
1.20		195 and up	330 and up	540 and up	660

*Multiply the rated horsepower per belt by this factor to obtain the corrected horsepower.

Table 17–15

Suggested Service Factors K_S for V-Belt Drives

Driven Machinery	Source of Power: Normal Torque Characteristic	Source of Power: High or Nonuniform Torque
Uniform	1.0 to 1.2	1.1 to 1.3
Light shock	1.1 to 1.3	1.2 to 1.4
Medium shock	1.2 to 1.4	1.4 to 1.6
Heavy shock	1.3 to 1.5	1.5 to 1.8

- The number of belts needed to transmit the design horsepower is found as:

$$N_b \geq \frac{H_d}{H_a} \qquad N_b = 1, 2, 3, \ldots \qquad (17\text{–}20)$$

Where, N_b is an integer

- The belting equation for V-belts is the same equation used for flat belts. The effective coefficient of friction for *Gates Rubber Company* belts is *0.5123*

Thus,

$$\frac{F_1 - F_c}{F_2 - F_c} = e^{0.5123\phi}$$

- Where the centrifugal tension F_c is found as:

$$F_c = K_C\left(\frac{V}{2.4}\right)^2$$

Or

$$F_c = K_c\left(\frac{V}{1000}\right)^2 \qquad (17\text{–}21)$$

K_C: accounts for mass of the belt (*Table 17-16*).

• The transmitted force per belt ($F_1 - F_2$) is found as:

$$F_1 - F_2 = \frac{H_d/N_b}{n(d/2)}$$

Where, n (rad/s) & d are for the driver pulley.

Table 17-16

Some V-Belt Parameters*

Belt Section	K_b	K_c
A	220	0.561
B	576	0.965
C	1 600	1.716
D	5 680	3.498
E	10 850	5.041
3V	230	0.425
5V	1098	1.217
8V	4830	3.288

*Data courtesy of Gates Rubber Co., Denver, Colo.

- Thus, F_1 can be found as:

$$F_1 = F_c + (F_1 - F_2)\frac{e^{f\phi}}{e^{f\phi} - 1} \qquad (17\text{–}23)$$

- Then F_2 can be found from:

$$F_2 = F_1 - (F_1 - F_2) \qquad (17\text{–}24)$$

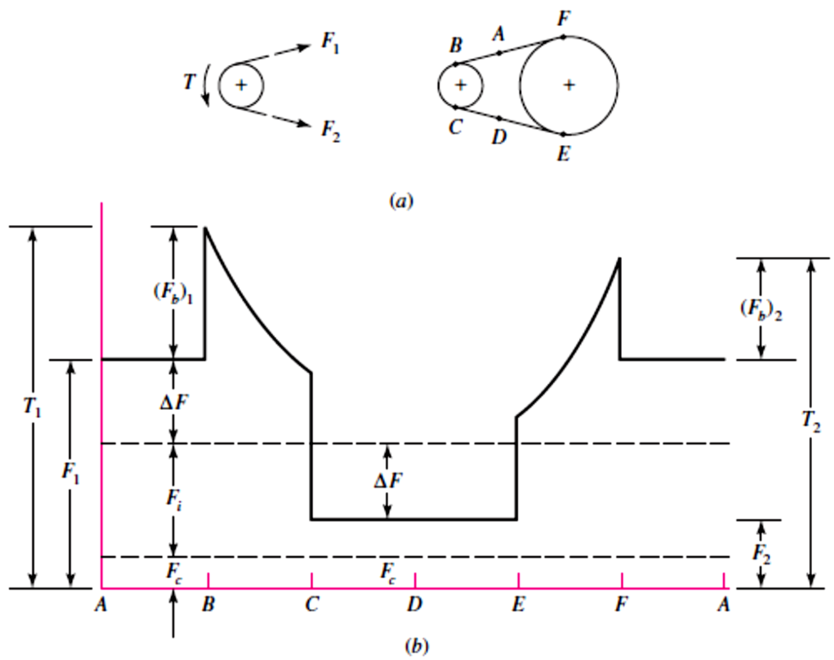
- And F_i is found as:

$$F_i = \frac{F_1 + F_2}{2} - F_c \qquad (17\text{–}25)$$

• In flat-belt force analysis, the tension induced from bending the belt was ignored (*since belt thickness is not that large*), however, in V-belts the effect of flexural stress is more pronounced, and thus it affects the durability (*life*) of the belt. The figure shows the two tension peaks T_1 & T_2 resulting from belt flexure.

Figure 17–14

V-belt tensions.



▪ The values of tension peaks are found as:

$$T_1 = F_1 + (F_b)_1 = F_1 + \frac{K_b}{d}$$

$$T_2 = F_1 + (F_b)_2 = F_1 + \frac{K_b}{D}$$

Where,

(F_{b1}) & (F_{b2}) are the added components of tension due to the flexure of the belt on the smaller and larger pulleys.

K_b is used to account for belt flexure and it is found from *Table 17-16*.

• The life of V-belts is defined as the number of passes the belt can do (N_P), and it is found as:

$$N_P = \left[\left(\frac{K}{T_1}\right)^{-b} + \left(\frac{K}{T_2}\right)^{-b}\right]^{-1} \qquad (17\text{–}27)$$

❖ where K & b are found from *Table 17-17*.

Table 17–16

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5V	1098	1.217
8V	4830	3.288

*Data courtesy of Gates Rubber Co., Denver, Colo.

Table 17–17

Durability Parameters for Some V-Belt Sections

Source: M. E. Spotts, *Design of Machine Elements*, 6th ed. Prentice Hall, Englewood Cliffs, N.J., 1985.

Belt Section	10^8 to 10^9 Force Peaks		10^9 to 10^{10} Force Peaks		Minimum Sheave Diameter, in
	K	b	K	b	
A	674	11.089			3.0
B	1193	10.926			5.0
C	2038	11.173			8.5
D	4208	11.105			13.0
E	6061	11.100			21.6
3V	728	12.464	1062	10.153	2.65
5V	1654	12.593	2394	10.283	7.1
8V	3638	12.629	5253	10.319	12.5

Life time in hours is found as:

$$t = \frac{N_P L_P}{3600V}$$

$$t = \frac{N_P L_p}{720V} \qquad (17\text{–}28)$$

Note: K & b values given in *Table 17-17* are valid only for the indicated range. Thus, if N_P is found to be larger than 10^9 it is reported as $N_P=10^9$ and life time in hours "*t*" is found using $N_P=10^9$.

- Steps for analyzing V-belts include:

- Find V, L_P, C, ? and $e^{0.5123}$?
- Find H_d, H_a then the number of belts N_b
- Find F_c, ΔF, F_1, F_2 & F_i
- Find T_1, T_2 and then belt life N_P & t

EXAMPLE 17–4 A 10-hp split-phase motor running at 1750 rev/min is used to drive a rotary pump, which operates 24 hours per day. An engineer has specified a 7.4-in small sheave, an 11-in large sheave, and three B112 belts. The service factor of 1.2 was augmented by 0.1 because of the continuous-duty requirement. Analyze the drive and estimate the belt life in passes and hours.

Solution The peripheral speed V of the belt is

$$V = \pi dn/12 = \pi(7.4)1750/12 = 3390 \text{ ft/min}$$

Table 17–11: $L_p = L + L_c = 112 + 1.8 = 113.8$ in

Eq. (17–16*b*):
$$C = 0.25\left\{\left[113.8 - \frac{\pi}{2}(11+7.4)\right] + \sqrt{\left[113.8 - \frac{\pi}{2}(11+7.4)\right]^2 - 2(11-7.4)^2}\right\}$$
$$= 42.4 \text{ in}$$

Eq. (17–1): $$\phi = \theta_d = \pi - 2\sin^{-1}(11-7.4)/[2(42.4)] = 3.057 \text{ rad}$$

$$\exp[0.5123(3.057)] = 4.788$$

Interpolating in Table 17–12 for $V = 3390$ ft/min gives $H_{tab} = 4.693$ hp. The wrap angle in degrees is $3.057(180)/\pi = 175°$. From Table 17–13, $K_1 = 0.99$. From Table 17–14, $K_2 = 1.05$. Thus, from Eq. (17–17),

$$H_a = K_1 K_2 H_{tab} = 0.99(1.05)4.693 = 4.878 \text{ hp}$$

Eq. (17–19): $$H_d = H_{nom} K_s n_d = 10(1.2 + 0.1)(1) = 13 \text{ hp}$$

Eq. (17–20): $$N_b \geq H_d/H_a = 13/4.878 = 2.67 \rightarrow 3$$

From Table 17–16, $K_c = 0.965$. Thus, from Eq. (17–21),

$$F_c = 0.965(3390/1000)^2 = 11.1 \text{ lbf}$$

Eq.(17–22): $$\Delta F = \frac{63\,025(13)/3}{1750(7.4/2)} = 42.2 \text{ lbf}$$

Eq. (17–23): $$F_1 = 11.1 + \frac{42.2(4.788)}{4.788 - 1} = 64.4 \text{ lbf}$$

Eq. (17–24): $F_2 = F_1 - \Delta F = 64.4 - 42.2 = 22.2$ lbf

Eq. (17–25): $$F_i = \frac{64.4 + 22.2}{2} - 11.1 = 32.2 \text{ lbf}$$

Eq. (17–26): $$n_{fs} = \frac{H_a N_b}{H_{nom} K_s} = \frac{4.878(3)}{10(1.3)} = 1.13$$

Life: From Table 17–16, $K_b = 576$.

$$F_{b1} = \frac{K_b}{d} = \frac{576}{7.4} = 77.8 \text{ lbf}$$

$$F_{b2} = \frac{576}{11} = 52.4 \text{ lbf}$$

$$T_1 = F_1 + F_{b1} = 64.4 + 77.8 = 142.2 \text{ lbf}$$

$$T_2 = F_1 + F_{b2} = 64.4 + 52.4 = 116.8 \text{ lbf}$$

From Table 17–17, $K = 1193$ and $b = 10.926$.

Eq. (17–27): $$N_P = \left[\left(\frac{1193}{142.2}\right)^{-10.926} + \left(\frac{1193}{116.8}\right)^{-10.926}\right]^{-1} = 11(10^9) \text{ passes}$$

Answer Since N_P is out of the validity range of Eq. (17–27), life is reported as greater than 10^9 passes. Then

Answer Eq. (17–28): $$t > \frac{10^9(113.8)}{720(3390)} = 46\,600 \text{ h}$$