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Calculation of V-Belt Tensions And Shaft Loads

MPTA STANDARD

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Abstract

This standard provides a method for calculating and measuring belt tensions and for calculating shaft loads on a two sheave locked center V-Belt drive.

Copyright Position Statement

1. Foreword

This foreword is provided for informational purposes only and is not to be construed to be part of any technical specification.

V-Belts will transmit power satisfactorily over a wide range of tensions. An experienced user can develop a “feel” when a drive is tensioned within this range. However, in order to optimize belt life and performance and to avoid undue stress on shafts and bearings it is desirable to calculate and measure belt tension based on drive loads. This standard provides a method for calculating and measuring V-Belt tensions and for calculating shaft loads associated with these tensions on two sheave locked center drives. A locked center drive is one on which belt tension is adjusted by moving one of the sheaves on the drive and then “locking” it in place.

Section 1 of this standard provides methods for calculating and measuring belt static tension on a two sheave locked center drive.

Section 2 provides a method for calculating belt operating tensions on a two sheave locked center drive running under load.

Sections 3, 4, and 5 provide a method for calculating shaft loads, bearing loads, and overhung loads for a two sheave locked center belt drive. The user can go directly to these sections if belt tensions have already been determined by other methods.

Suggestions for the improvement of, or comments on this publication are welcome. They should be mailed to Mechanical Power Transmission Association, 5672 Strand Court, Suite 2, Naples, FL 34110 on your company letterhead.

This standard was updated to format defined in MPTA-A1 and to update the Contributors List.

2. Scope

This standard covers two sheave locked center drives using Classical and Narrow industrial V-Belts and Sheaves covered under ARPM IP-20, IP-22, and IP-23. This standard does not cover drives that are tensioned using spring-loaded idlers or other constant tension drives, nor does it cover V-Ribbed belts or automotive belts.

Nomenclature

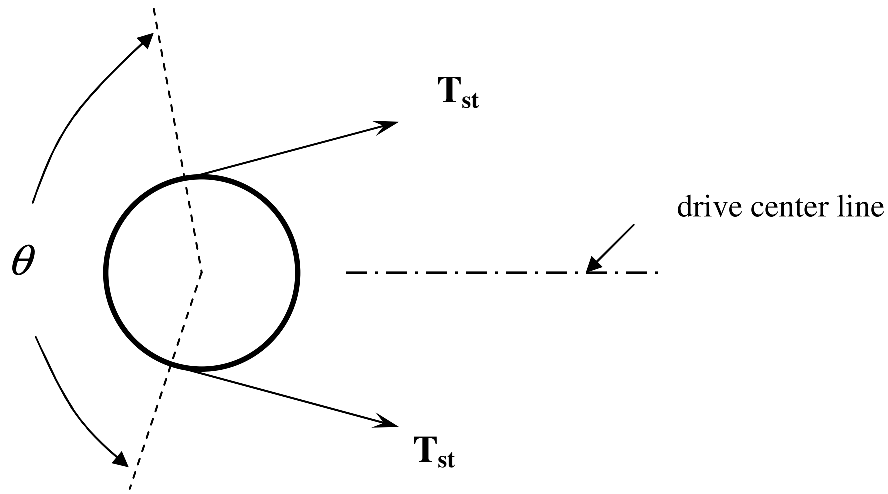
Symbol	Description	Units
A	Location of max. manufacturer rated overhung load. See Figure 8	inches
B	Location of actual overhung load, see Figure 8	inches
C	Drive center distance	inches
D_p	Pitch diameter of large sheave	inches
d_p	Pitch diameter of small sheave	inches
E	Belt modulus of elasticity	inches /inch
F_{dy}	Dynamic shaft load due to belt pull	lbf
F_{st}	Static shaft load	lbf
g_c	Gravitational constant: 32.2	ft/sec^2
K_Y	Belt modulus factor: modulus of elasticity at 1% strain	----------
K_Θ	Arc of contact correction factor	----------
L	Belt pitch length (classical) or effective length (narrow)	inches
L_A	Bearing load / reaction force	lbf
L_B	Bearing load / reaction force	lbf
L_s	Belt span length between two sheaves	inches
N_b	Number of individual belts, joined or not joined. A joined belt for a four groove sheave counts as 4	----------
P_{actual}	Actual transmitted power	horsepower
P_d	Drive design power	horsepower
p_{max}	Maximum belt deflection force	lbf
p_{min}	Minimum belt deflection force	lbf
p_{actual}	Known (not calculated) belt deflection force	lbf
Q	Drive torque	lbf-inches
q	Belt tension deflection distance	inches

Symbol	Description	Units
R	Tension ratio, = $e^{0.0089413\,(\Theta)}$	----------
T_e	Belt effective tension	lbf
Θ	Arc of contact on small sheave	degrees
T_S	Belt operating slack side tension	lbf
T_{st}	Static belt tension	lbf
$T_{st,actual}$	Actual applied static belt tension	lbf
T_T	Belt operating tight side tension	lbf
V	Belt speed	feet per minute
W	Belt mass per lineal foot	lbm
X	Location distance, see figures 6 & 7	inches
Y	Location distance, see figures 6 & 7	inches

3. Calculating And Measuring Belt Static Tension (T_{st})

Locked center belt drives are tensioned at rest by increasing the center distance between the sheaves to impose a static tension (T_{st}) in the belts. See Figure #1. There are two common approaches for determining static tension as outlined in Sections 3.1 and 3.2 below. Section 3.1 provides a recommended method for calculating and measuring static tension based on drive parameters. Section 3.2 provides a method for calculating static tension based on deflection force recommendations that are commonly available in manufacturers' catalogs or tension gauge literature.

Figure # 1: Belt Static Tension



3.1 Recommended Method For Calculating And Measuring Belt Static Tension Based on Drive Parameters

V-belt drives can operate satisfactorily over a wide range of tensions. The ideal tension is the lowest tension at which the belts will not slip excessively at the highest load condition. This will result in the best belt life and lowest shaft loads. However, this ideal tension is hard to determine and difficult to maintain. This section provides a practical method for calculating and measuring belt static tensions based on drive parameters and design power. An alternate method is provided in Section 3.2 for the case where belt deflection forces are known.

3.1.1 Determining Design Power (P_d)

The optimal belt drive tension is dependent on many factors. The goal is to tension the belts just enough to prevent them from slipping, however it is rare that all of the information necessary to do this is known. The formula for Design Power below covers the vast majority of belt drives. However, there are some cases (discussed below) where it may not be adequate.

Formula #1: P_d = Motor Horsepower X 1.15

Since motors are available in specific horsepowers, most drives use a motor larger than actually needed to drive the load. Once the drive has reached operating speed, it may not need all of the available horsepower, and thus may not need the tension provided by this formula. On the other hand, upon start-up most motors provide more than their nameplate rating until the drive reaches its operating speed. The above formula covers most common motors and applications, however it is possible for a high start-up torque motor to cause a high inertia drive to slip (and perhaps squeal) upon start up with this value. If this happens, P_d should be increased.

There are cases where the drive horsepower capacity significantly exceeds the need. This can happen due to drive availability at the time of purchase, but usually the drive is purposefully oversized. Sometimes this is done to increase life or to accommodate harsh loads, and sometimes it is done to provide belt redundancy. In these cases, the above formula can result in insufficient tension. For example, if the drive required one belt and 4 were used, each belt would get only ¼ of the required tension. A belt requires a minimum tension to begin grabbing the sheaves. In these situations, the manufacturer should be consulted.

Though rare, it is possible for the above formula to result in too much tension. For example, if equipment required 1 horsepower and a 1 horsepower belt drive was used, but a 20 horsepower motor was used, the above formula would result in excessive tension (and bearing loads). This could result in belt drive and other equipment failure.

If there is any question as to the adequacy of this general purpose formula, the manufacturer should be consulted.

3.1.2 Calculating Belt Static Tensions (T_{st})

Using an average coefficient of friction and the wedging effect of the average groove angle (38 degrees), it can be shown that at 180 degrees of wrap a practical level of V-Belt operating tension can be achieved with a 5:1 ratio between the tight side tension and the slack side tension. This ratio changes with the angle of contact on the small sheave. Formula #2 below establishes the static tension required to transmit the load under operating conditions (power, speed, angle of wrap, etc.). A factor of 0.9 is used to average the effect of other variables such as sheave size, belt length, and belt stiffness. Section 4 provides more information regarding operating tensions.

Determine the belt static tension (T_{st}) by the following formula:

Formula #2: T_{st} (lb) = $$15\left(\frac{2.5-K_\theta}{K_\theta}\right)\left(\frac{P_d 10^3}{N_b V}\right)+\left[0.9W\left(\frac{V}{60}\right)^2\left(\frac{1}{g_c}\right)\right]$$

where:

P_d = design power as determined in Section 3.1.1
W = belt weight per foot of length (lb). See Table #2 below for typical values.
V = belt speed (fpm) = $\left(\frac{\pi}{12}\right)(Driver\ RPM)(Driver\ Pitch\ Diameter\ (in))$

g_c = gravitational constant = 32.2 ft/sec^2
N_b = number of individual belts on the drive, whether they are joined together or not

Formula # 3: K_θ = arc-of-contact correction factor = $1.25\left(\frac{R-1}{R}\right)$

Note: K_θ for typical drives is shown in Table #1 below.

where:

R = tension ratio = $e^{(0.008941)(\theta)}$ Note: R = 5.0 at 180 deg arc-of-contact

and,

Formula # 4: θ = arc of contact on small sheave (deg) = $2\cos^{-1}\left(\frac{D_p - d_p}{2C}\right)$

where:

D_p = pitch diameter of large sheave (in)

d_p = pitch diameter of small sheave (in)

C = drive center distance (in)

Table #1—K_θ For Typical Drives

$\frac{Dp-dp}{C}$	Arc of Contact on Small Sheave (θ) degrees	Factor K_Θ
0.00	180	1.00
0.10	174	0.99
0.20	169	0.97
0.30	163	0.96
0.40	157	0.94
0.50	151	0.93
0.60	145	0.91
0.70	139	0.89
0.80	133	0.87
0.90	127	0.85
1.00	120	0.82
1.10	113	0.80
1.20	106	0.77
1.30	99	0.73
1.40	91	0.70
1.50	83	0.65

Table #2—W and K_y

Belt Cross-Section	Belt Weight per Foot of Length (lb) W	Belt Modulus Factor K_y
3L	0.04	5
4L	0.06	6
5L	0.09	9
A	0.07	6
AX	0.06	7
B	0.13	9
BX	0.11	10
C	0.23	16
CX	0.21	18
D, DX	0.42	30
3V, 3VX	0.05	4
5V	0.14	12
5VX	0.12	13
8V, 8VX	0.37	22

Note: W and K_Y in Table #2 are a generic blend of industry values and will provide results that are reasonable for most applications. Drive suppliers can provide a more accurate value. For reference, K_y is a function of the belt strain.

3.1.3 Measuring Static Tension

The most common method of measuring belt static tension is to apply a force (p) to the back of the belt at the midpoint of the belt span and measure the resulting deflection (q). See Figure #2. This section provides a method for determining the deflection force corresponding to the static tension calculated in Section 3.1.2.

3.1.3.1 Determining Span Length

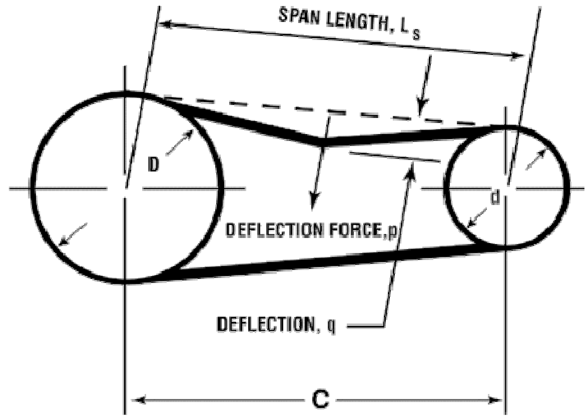
Measure the length of span (L_s) as shown in Figure #2 or calculate it with the formula:

Formula #5: $$L_s = \sqrt{C^2 - \frac{(D_p - d_p)^2}{4}}$$

where:

C = drive center distance (inches)
D_p = larger sheave pitch diameter (inches)
d_p = smaller sheave pitch diameter (inches)

Figure #2: Belt Deflection Measurement



3.1.3.2 Determine Belt Deflection Force (p)

Refer to Figure #2. Determine the minimum and maximum deflection forces as follows:

3.1.3.2.1 For Two Or More Individual Or Joined V-Belts

In this case, the sheaves are not free to rotate when each belt is tensioned individually. Calculate the minimum and maximum deflection force (p) using these formulas:

Formula #6: $p_{min} = \dfrac{T_{st} + K_y}{16}$

Formula #7: $p_{max} = \dfrac{1.5T_{st} + K_y}{16}$

where:

p_{min} = minimum recommended belt deflection force (lb)
p_{max} = maximum recommended belt deflection force (lb)
T_{st} = static tension per strand as calculated in Section 3.1.2 (lb)
K_y = belt modulus factor from Table # 2

3.1.3.2.2 For One Individual Or Joined V-Belt Where At Least One Sheave Is Free To Rotate

Note: If neither sheave is free to rotate, use section 3.1.3.2.1

Calculate the minimum and maximum deflection forces using these formulas:

Formula #8: $p_{min} = \dfrac{T_{st} + \left(\dfrac{L_s}{L}\right)K_y}{16}$

Formula #9: $p_{max} = \dfrac{1.5T_{st} + \left(\dfrac{L_s}{L}\right)K_y}{16}$

where:

T_{st} = static tension per strand as calculated in Section 3.1.2 (lb)
K_y = belt modulus factor from Table #2
L_s = span length (inches)
L = belt pitch length or effective length (inches) depending on cross section

Note: Since T_{st} is per belt, p_{min} and p_{max} are also per belt. For joined belts multiply p by the number of belt ribs in a band. For wide joined belts, the deflection method of measuring belt tension described above may not be practical. These drives can be tensioned using the elongation method. This method is based upon measuring the percentage elongation of the outside circumference of the belt as tension is applied. The elongation is directly related to the static tension in the belt. As this amount will vary among belt manufacturers, contact your belt drive supplier to get the recommended percentage elongation for your drive.

Note: For purposes of evaluating shaft loads due to belt pull it may be desirable to calculate static tension at maximum deflection force (p_{max}). To do this use the method outlined in Section 3.2 below and use p_{max} in Formulas #11 and #12

3.1.3.3 Measuring Procedure

At the center of the belt span apply a force p (see Figure #2) at the midpoint of the belt span, in a direction perpendicular to the span, until the belt is deflected (usually in reference to a straight edge) an amount q. Calculate q by the following formula:

Formula #10: q = deflection distance (in) = $\dfrac{L_s}{64}$

Where: L_s = span length (in)

If the deflection force falls between p_{min} and p_{max} calculated in Section 3.1.3.2 above, the belt tension should be satisfactory. A force below p_{min} indicates an under-tensioned drive. If the force exceeds p_{max} the drive is tighter than necessary.

The best practices involved in installing and maintaining belt drives are beyond the scope of this standard. These practices are very important for achieving maximum belt life and efficiency. Below are two rules of thumb that can be used; however, the drive supplier may be able to provide more specific guidelines.

- *A drive with new belts may be tightened initially to as much as two times p_{min} as the tension drops rapidly during the run-in period.*

- *A used belt should be tensioned near p_{max} to allow for gradual tension decay which is inherent to V-belts.*

3.2 An Alternate Method for Calculating Belt Static Tension (T_{st}) Based on a Predetermined Deflection Force (p_{actual})

This section provides a method for calculating belt static tension for the case where deflection force (p_{actual}) is selected from a table or determined by a method other than described in Section 3.1. Refer to Figure #2 in Section 3.1.3.1. The formulas provided here assume a deflection distance q as calculated in Formula #10 above. If a deflection distance other than this is used then the calculations for static tension must be adjusted accordingly.

Use the following formulas to determine static belt tension (T_{st}) for a given deflection force (p_{actual}):

Formula #11: $T_{st} = 16 p_{actual} - K_y$ (lb) for drives using two or more individual V-belts or joined V-belts

or,

Formula #12: $T_{st} = 16 p_{actual} - \left(\frac{L_s}{L}\right) K_y$ (lb) for drives using one individual v-belt or joined v-belt

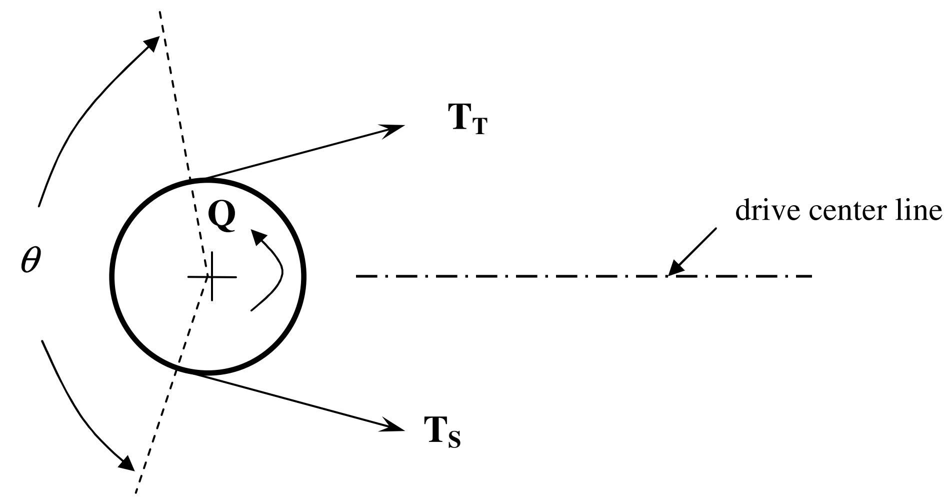
where:

p_{actual}	= actual measured deflection force (lb)
K_y	= Belt Modulus Factor Table #2
L_s	= span length (in)
L	= belt pitch length or effective length (in) depending on cross-section

***Caution**: Published tables of deflection forces are generally based upon the horsepower ratings of the belts rather than the horsepower requirements of the actual drive. Tensioning based on these tables can cause excessive shaft and bearing loads if the drive is significantly over-belted or on older drives that were based on lower horsepower ratings. Users should compare calculated shaft loads and bearing loads to motor and equipment specifications.*

4. Calculating Belt Operating Tensions Resulting From Applied Loads

Figure #3: Belt Operating Tensions



In Figure #3, a belt drive in operation develops a tight-side tension (T_T) and a slack-side tension (T_S) as a result of the drive torque (Q) and the static tension (T_{st}). Drive Torque (Q) is a function of actual transmitted horsepower (P_{actual}) and belt speed (V). These tensions are calculated as follows:

Formula #13: T_e = effective tension (lb per belt) $= T_T - T_S =$

$$\frac{2Q}{d_p} = \frac{33000(\mathrm{P}_{\mathrm{actual}})}{VN_b}$$

Formula #14: T_T = tight side tension (lb per belt) =

$$\frac{T_{st,actual}}{0.9} - \left[0.9W\left(\frac{V}{60}\right)^2\left(\frac{1}{g_c}\right)\right] + \frac{T_e}{2}$$

Then:

Formula #15: T_S = slack side tension (lb per belt) $= T_T - T_e$

where:

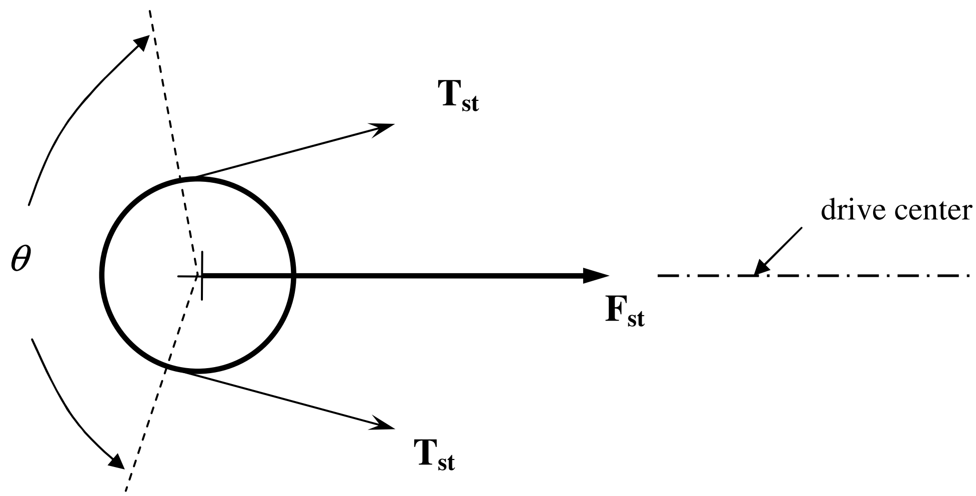
Q = actual torque requirement (lb-in)
P_{actual} = actual transmitted horsepower*
$T_{st,actual}$ = actual applied static belt tension
d_p = small sheave pitch diameter
V = belt speed (fpm) = $\left(\frac{\pi}{12}\right)(Driver\ RPM)(Driver\ Pitch\ Diameter\ (in))$
g_c = gravitational constant = 32.2 ft/sec^2
W = Belt weight per foot of length (lb). See Table 2 for typical values.
N_b = number of individual belts on the drive, whether they are joined together or not
K_θ = arc-of-contact correction factor (see Formula #3 in section 3.1.2)

* For P_{actual}, the actual transmitted horsepower is preferred. This often is less than the motor horsepower, and will result in a lower and more accurate shaft load calculation. If this is not available, the motor horsepower is usually adequate, but will increase the shaft load calculation.

5. Calculating Shaft Loads Due To Belt Pull

5.1. Determining Static Shaft Load Due To Belt Pull

FIGURE #4: Static Shaft Load (F_{st})



Static shaft load (F_{st}) is defined as the resultant of the belt static tension (T_{st}) pull along the drive center line when the drive is at rest. The magnitude of the static shaft load is the same for driver and driven sheaves in a two sheave drive. It is calculated as follows:

Formula #16: Static Shaft Load (lb) = $F_{st} = 2N_b T_{st}\left[\sin\left(\frac{\theta}{2}\right)\right]$

where:

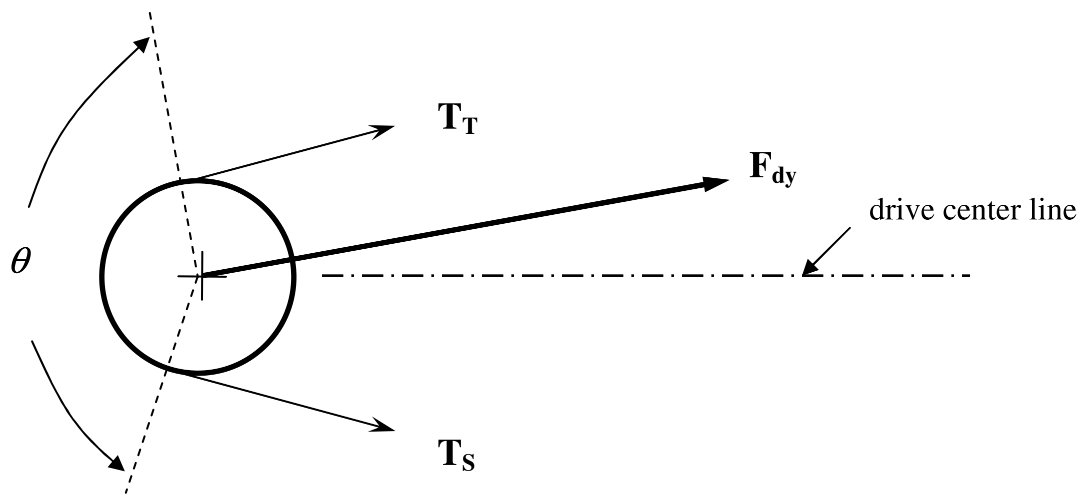
N_b = number of belts on the drive
T_{st} = belt static tension (lb) per belt strand as calculated in Section 1 or as input from other sources
θ = arc of contact on small sheave (deg) (See formula #4)
D_p = pitch diameter of large sheave (in)

d_p = pitch diameter of small sheave (in)

C = drive center distance (in)

5.2 Determining Dynamic Shaft Load Due To Belt Pull

FIGURE #5 Dynamic Shaft Load (F_{dy})



Dynamic shaft load (F_{dy}) is the resultant of the belt tensions when the drive is running under load. The magnitude of the dynamic shaft load is the vector sum of the tight-side tension in the drive (T_T) and the slack-side tension in the drive (T_S). T_T and T_S are calculated in Section 3 of this standard or can be input from other sources. The dynamic shaft load is calculated as follows:

Formula #17: $F_{dy} = N_b\sqrt{T_T^{\ 2} + T_S^{\ 2} - \left(2T_T T_S \cos\theta\right)}$ (lb)

where:

N_b = number of belts on the drive
T_T = tight side belt tension (lb)
T_S = slack side belt tension (lb)
θ = arc of contact on small sheave (deg) (See formula #4)

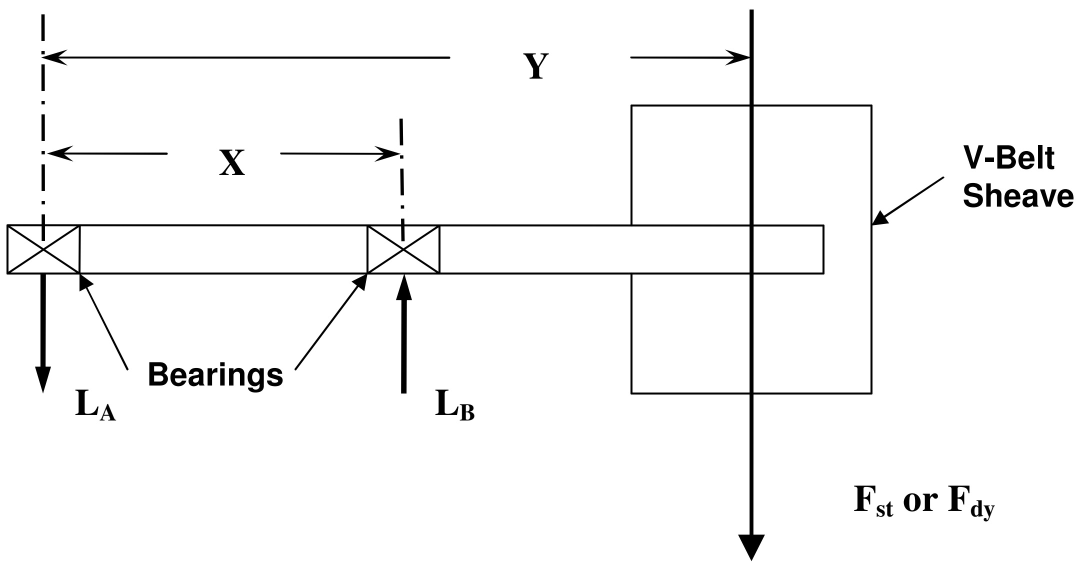
Note: The magnitude of the dynamic shaft load on the large sheave is equal to the magnitude of the shaft load on the small sheave in a two sheave drive.

6. Bearing Loads Imposed By Belt Pull

Shaft loads imposed by drive belts result in radial loads on the bearings of the driver and driven units. To calculate actual bearing loads, the weights of machine components, including the sheaves, as well as the values of other forces contributing to the load must be included. However, in many cases, it is desirable to calculate the bearing loads contributed by the belt drive alone. These bearing loads are calculated as follows:

6.1 Calculating Bearing Loads Due to Belt Pull For a Cantilever Mount Belt Drive

Figure #6: Cantilever Mount Belt Drive



A cantilever mount arrangement is shown in Figure #6 above. Because Y-X is usually small compared to X, the maximum bearing load is normally on the bearing nearest the sheave (L_B).

For the static condition:

Formula #18: $L_A = \dfrac{(Y-X)F_{st}}{X}$ = Static Load on Bearing A (lb)

where:

F_{st} = Static Shaft Load as calculated in Section 5.1

Formula #19: $L_B = \frac{Y(F_{st})}{X}$ = Static Load on Bearing B (lb)

where:

F_{st} = Static Shaft Load as calculated in Section 5.1

For the dynamic condition:

Formula #20: $L_A = \frac{(Y - X)F_{dy}}{X}$ = Dynamic Loadon Bearing A (lb)

where:

F_{dy} = Dynamic Shaft Load as calculated in Section 5.2

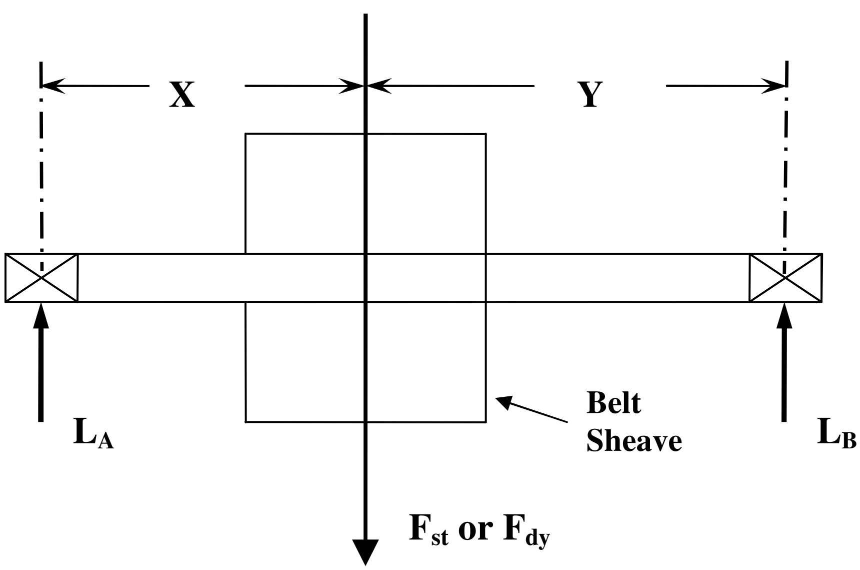
Formula #21: $L_B = \frac{Y(F_{dy})}{X}$ = Dynamic Load on Bearing B (lb)

where:

F_{dy} = Dynamic Shaft Load as calculated in Section 5.2

6.2 Calculating Bearing Loads Due to Belt Pull For a Straddle Mount Belt Drive

Figure #7: Straddle Mount Belt Drive



A straddle mount arrangement is shown in Figure 7 above. Bearing loads are calculated as follows:

For the static condition:

Formula #22: $L_A = \frac{Y(F_{st})}{(X+Y)}$ = Static Load on Bearing A (lb)

where:

F_{st} = Static Shaft Load as calculated in Section 5.1

Formula #23: $L_B = \frac{X(F_{st})}{(X+Y)}$ = Static Load on Bearing B (lb)

where:

F_{st} = Static Shaft Load as calculated in Section 5.1

For the dynamic condition:

Formula #24: $L_A = \frac{Y(F_{dy})}{(X+Y)}$ = Dynamic Load on Bearing A (lb)

where:

F_{dy} = Dynamic Shaft Load as calculated in Section 5.2

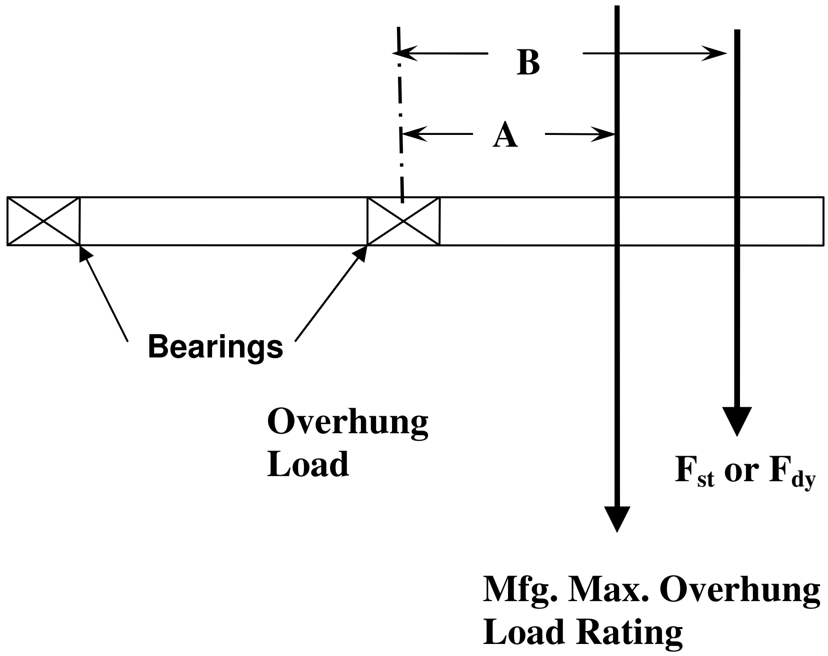
Formula #25: $L_B = \frac{X(F_{dy})}{(X+Y)}$ = Dynamic Load on Bearing B (lb)

where:

F_{dy} = Dynamic Shaft Load as calculated in Section 5.2

7. Overhung Load

FIGURE # 8: Overhung Load



F_{st} and F_{dy} are located at the middle of the belt drive. Motor and equipment manufacturers commonly specify a maximum overhung load at a specific position on the shaft (A). If the actual load is at (B), use the following formula to calculate the equivalent overhung load at (A). This value can then be directly compared to the manufacturer's recommended maximum overhung load value.

For the static condition:

Formula #26: Equivalent Overhung Load at "A" (lb) = $\frac{B(F_{st})}{A}$

where:

F_{st} = Static Shaft Load as calculated in Section 5.1

For the dynamic condition:

Formula #27 Equivalent Overhung Load at "A" (lb) = $\frac{B(F_{dy})}{A}$

where:

F_{dy} = Dynamic Shaft Load as calculated in Section 5.2

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