



## SECTION 1 BELT TENSIONING

### 1-1 What Is Proper Installation Tension

One of the benefits of small synchronous belt drives is lower belt pre-tensioning in comparison to comparable V-belt drives, but proper installation tension is still important in achieving the best possible drive performance. In general terms, belt pre-tensioning is needed for proper belt/pulley meshing to prevent belt ratcheting under peak loading, to compensate for initial belt tension decay, and to pre-stress the drive framework. The amount of installation tension that is actually needed is influenced by the type of application as well as the system design. Some general examples of this are as follows:

**Motion Transfer Drives:** Motion transfer drives, by definition, are required to carry extremely light torque loads. In these applications, belt installation tension is needed only to cause the belt to conform to and mesh properly with the pulleys. The amount of tension necessary for this is referred to as the minimum tension ( $T_m$ ). Minimum tensions on a per span basis are included in **Table 1**. Some motion transfer drives carry very little torque, but have tight registration requirements. These systems may require additional static (or installation) tension in order to minimize registration error.

**Normal Power Transmission Drives:** Normal power transmission drives should be designed in accordance with published torque ratings and a reasonable service factor (between 1.5 and 2.0). In these applications, belt installation tension is needed to allow the belt to maintain proper fit with the pulleys while under load, and to prevent belt ratcheting under peak loads. For these drives, proper installation tension can be determined using two different approaches. If torque loads are known and well defined, and an accurate tension value is desired, **Equation (1-1)** or **Equation (1-2)** should be used. If the torque loads are not as well defined, and a quick value is desired for use as a starting point, values from **Table 2** can be used. All static tension values are on a per span basis.

$$T_m = \frac{0.812 DQ}{d} + mS^2 \quad (1-1)$$

(For drives with a Service Factor of 1.3 or greater)

$$T_m = \frac{1.05 DQ}{d} + mS^2 \quad (1-2)$$

(For drives with a Service Factor less than 1.3)

where:  $T_m$  = Static tension per span (lb)

$DQ$  = Driver design torque (lb-in)

$d$  = Driver pitch diameter (in)

$S$  = Belt speed/1000 (ft/min)

where: Belt speed = (Driver pitch diameter x Driver rpm)/3.82

$m$  = Mass factor from **Table 1**



## Belt Technical Information



Table 1 Belt Tensioning Force

Belt	Belt Width	$\alpha$	$\gamma$	Minimum $T_u$ (lbs) Per Span
2 mm GT2	4 mm	0.026	1.37	1.3
	6 mm	0.039	2.65	2.6
	9 mm	0.058	3.88	3.8
	12 mm	0.077	4.90	4.9
3 mm GT2	6 mm	0.077	3.22	2.2
	9 mm	0.120	4.83	3.3
	12 mm	0.150	6.45	4.4
	15 mm	0.180	8.06	5.5
5 mm GT2	9 mm	0.170	14.9	8.4
	15 mm	0.280	24.9	14.1
	20 mm	0.380	33.2	18.7
	25 mm	0.470	41.5	23.4
3 mm HTD	6 mm	0.068	3.81	2.5
	9 mm	0.102	5.71	4.3
	15 mm	0.170	8.52	7.8
6 mm HTD	9 mm	0.180	14.9	8.3
	15 mm	0.272	24.9	12.6
	20 mm	0.480	41.5	21.3
MXL	10"	0.060	1.40	1.0
	3/16"	0.064	2.11	1.2
	1/4"	0.065	2.81	2.3
XL	1/4"	0.010	3.30	3.2
	3/8"	0.015	4.94	5.1

NOTE:  $\gamma$  = constant used in Equations (1-6) and (1-8).

**Registration Drives:** Registration drives are required to register, or position accurately. Higher belt installation tensions help in increasing belt tensile modulus as well as in increasing meshing interference, both reduce backlash. Tension values for these applications should be determined experimentally to confirm that desired performance characteristics have been achieved. As a beginning point, use values from Table 2 multiplied by 1.5 to 2.0.

Table 2 Static Belt Tension,  $T_u$  (lbs) Per Span - General Values

Belt	4 mm	6 mm	9 mm	12 mm	15 mm	20 mm	25 mm
2 mm GT2	2	3	4	5	—	—	—
3 mm GT2	—	6	11	15	19	25	—
5 mm GT2	—	—	18	22	27	35	43
3 mm HTD	—	9	9	12	16	22	—
6 mm HTD	—	—	13	16	24	33	43
Belt	10"	3/16"	1/4"	3/8"	1/2"	7/16"	13/16"
MXL	2	3	3	4	5	—	—
XL	2	3	4	5	6	8	9

Most synchronous belt applications often exhibit their own individual operating characteristics. The static installation tensions recommended in this section should serve as a general guideline in determining the level of tension required. The drive system should be thoroughly tested to confirm that it performs as intended.



## 1-2 Making Measurements

Belt installation tension is generally measured in the following ways:

**Force/Deflection:** Belt span tension can be measured by deflecting a belt span 1/64" per inch (0.4 mm per 25 mm) of span length at midspan, with a known force (see Figure 1). This method is generally convenient, but not always very accurate, due to difficulty in measuring small deflections and forces common in small synchronous drives. The force/deflection method is most effective on larger drives with long span lengths. The static (or installation) tension ( $T_s$ ) can either be calculated from Equation (1-1) or Equation (1-2), or selected from Table 1 or Table 2. The deflection forces can be calculated from Equation (1-4) and Equation (1-5). The span length can either be calculated from Equation (1-3), or measured. If the calculated static tension is less than the minimum  $T_s$  values in Table 1, use the minimum values.

$$t = \sqrt{CD^2 - \left(\frac{PD - pd}{2}\right)^2} \quad (1-3)$$

where:  
*t* = Span length (in)  
*CD* = Drive center distance (in)  
*PD* = Large pitch diameter (in)  
*pd* = Small pitch diameter (in)

$$\text{Deflection force, Min.} = \frac{T_s + \left(\frac{t}{L}\right) Y}{16} \quad (\text{lbs}) \quad (1-4)$$

$$\text{Deflection force, Max.} = \frac{1.1 T_s + \left(\frac{t}{L}\right) Y}{16} \quad (\text{lbs}) \quad (1-5)$$

where:  
*T<sub>s</sub>* = Static tension (lbs)  
*t* = Span length (in)  
*L* = Belt pitch length (in)  
*Y* = Constant, from Table 1

**Shaft Separation:** Belt installation tension can be applied directly by exerting a force against either the driver or driven shaft in a simple 2-point drive system (see Figure 2). The resulting belt tension will be as accurate as the force applied to driver or driven shaft. This method is considerably easier to perform than the force/deflection method and, in some cases, more accurate.

Deflection 1/64" per inch of span



Fig. 1 Force/Deflection Method

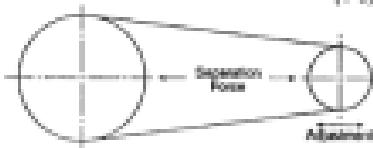


Fig. 2 Shaft Separation Method



Fig. 3 Single Tension Vector Force



In order to calculate the required shaft separation force, the proper static tension (on a per span basis) should first be determined as previously discussed. This tension value will be present in both belt spans as tension is applied. The angle of the spans with respect to the movable shaft should then be determined. The belt spans should be considered to be vectors (force with direction), and be summed into a single tension vector force (see Figure 3).

**Idler Forces:** Bolt installation tension can also be applied by exerting a force against an idler pulley within the system that is used to take up belt slack (see Figure 4). This force can be applied manually, or with a spring. Either way, the idler should be locked down after the appropriate tension has been applied.

Calculating the required force will involve a vector analysis as described previously in the shaft separation section.

**Sonic Tension Meter:** The Sonic Tension Meter (Figure 5) is an electronic device that measures the natural frequency of a free stationary belt span and instantly computes the static belt tension based upon the belt span length, belt width, and belt type. This provides accurate and repeatable tension measurements while using a nonintrusive procedure (the measurement process itself doesn't change the belt span tension). A measurement is made simply by plucking the belt while holding the sensor close to the vibrating belt span.

The unit is about the size of a portable phone (8-1/8" long x 3-3/8" wide x 1-3/8" thick or 208mm long x 95mm wide x 35mm thick) so it can be easily handled. The sensor is about 10" (13mm) in diameter for use in cramped spaces, and the unit is either battery operated for portability or AC operated for production use. The unit measures virtually all types of light power and precision belts. A gain adjustment allows measurements to be made in environments with high noise levels. Data can also be collected through an IBM Compatible RS-232 serial port, if desired. For additional details, see the product section of this handbook.

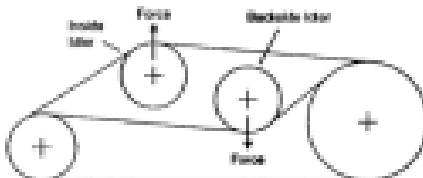


Fig. 4 Idler Forces



Fig. 5 Sonic Tension Meter

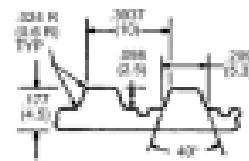
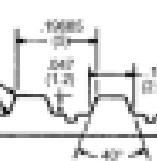
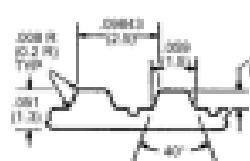
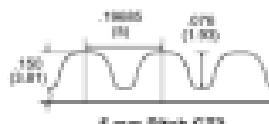
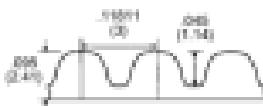
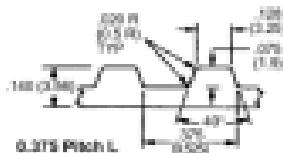
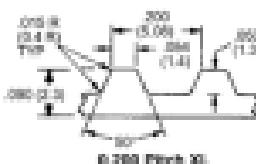
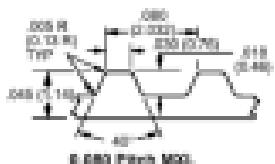


## Belt Technical Information



### BELT TOOTH PROFILES

There are several belt tooth profiles which are the result of different patented features, marketing and production considerations.



Dimensions in ( ) are mm

### WORKING TENSION

Recommended belt working tensions are based upon:

1. Near-minimum recommended pulley/sprocket diameters.
2. Operating speeds below 300 rpm.
3. The working tension for the minimum belt width extrapolated out to a full 1" belt width (to calculate recommended belt working tensions, proportion directly from the 1" value).

## Belt Technical Information

Stock Drive Protector/Stripping Instrument ■ Phone: 616-628-3386 ■ Fax: 616-628-8827

## Characteristics Of Belt Body Materials

Basic characteristics of the four most often used materials are shown in Table 3. The tabulated characteristics give rise to the following assessment of these materials:

**Natural Rubber**

- High resilience, excellent compression set, good molding properties
- High coefficient of friction; does not yield good ground finish
- High tear strength, low crack growth
- Can withstand low temperatures
- Poor oil and solvent resistance; unusable for ketones and alcohol
- Ozone attacks rubber, but retardants can be added

**Neoprene**

- High resilience ▪ Flame resistant
- Aging good with some natural ozone resistance
- Oil and solvent resistance fair

**Polyurethane**

- Excellent wear resistance, poor compression set
- Low coefficient of friction ▪ Oil and ozone resistance good
- Low-temperature flexibility good ▪ Not suitable for high temperatures

**Polymer Compound (EPDM), Cream-Colored**

- Clean running ▪ Nonmarking
- High operating temperature
- Quieter functioning
- Good environmental performance

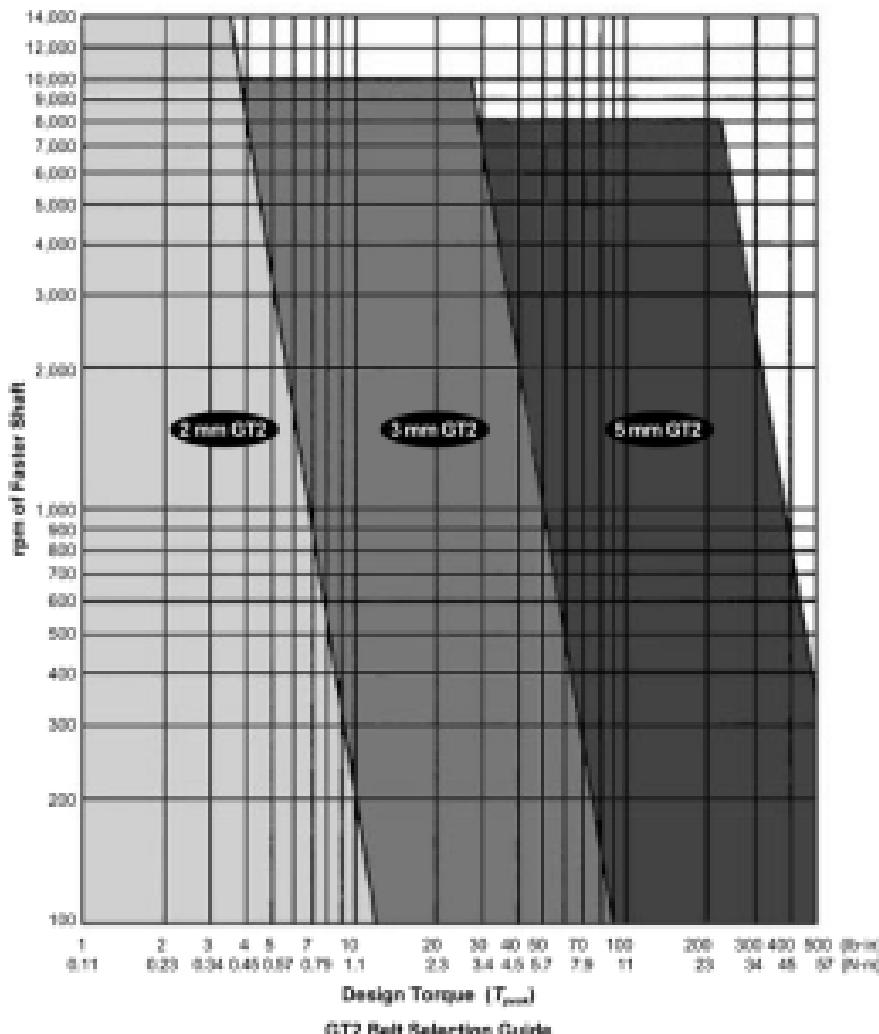
Table 3 Comparison of Different Belt Body Materials\*

Common Name	Natural Rubber	Neoprene <sup>a</sup>	Urethane	Cream-Colored Polymer Compound (EPDM)
Chemical Definition	Polysoprene	Polychloroprene	Polyester/Polymer Urethane	Ethylene Propylene Diene
Durometer Range (Shore A)	30-95	20-85	25-95	30-90
Tensile Strength Range (psi)	600-3500	600-3000	500-6000	500-2500
Elongation (Max. %)	600	600	600	700
Compression Set	Excellent	Poor to Good	Poor to Good	Poor to Excellent
Resilience - Rebound	Excellent	Fair to Good	Poor to Good	Fair to Good
Abrasion Resistance	Good to Excellent	Very Good to Excellent	Excellent	Good
Tear Resistance	Good to Excellent	Good to Excellent	Good to Excellent	Fair to Good
Solvent Resistance	Poor	Fair	Poor	Poor
Oil Resistance	Poor	Fair	Good	Poor
Low Temperature Range (°F)	-70° to +20°	-70° to +30°	-65° to -40°	-65° to -40°
Min. For Continuous Use (°F)	-60°	-60°	-65°	-65°
High Temperature Range (°F)	+180° to +220°	+200° to +250°	+180° to +220°	+220° to +280°
Max. For Continuous Use (°F)	+180°	+250°	+200°	+280°
Aging Weather - Sunlight	Poor to Fair	Good to Excellent	Good to Excellent	Excellent
Adhesion to Metals	Excellent	Excellent	Excellent	Good to Excellent

\*Courtesy of Röhmson Rubber Products

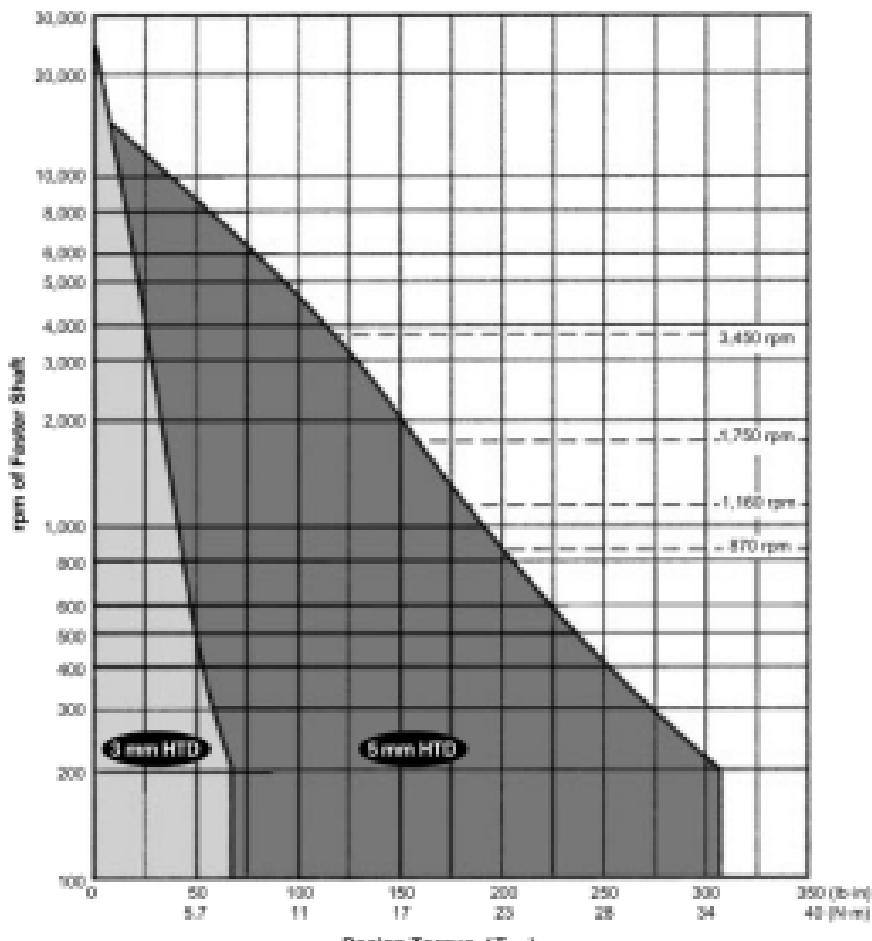


## Belt Technical Information





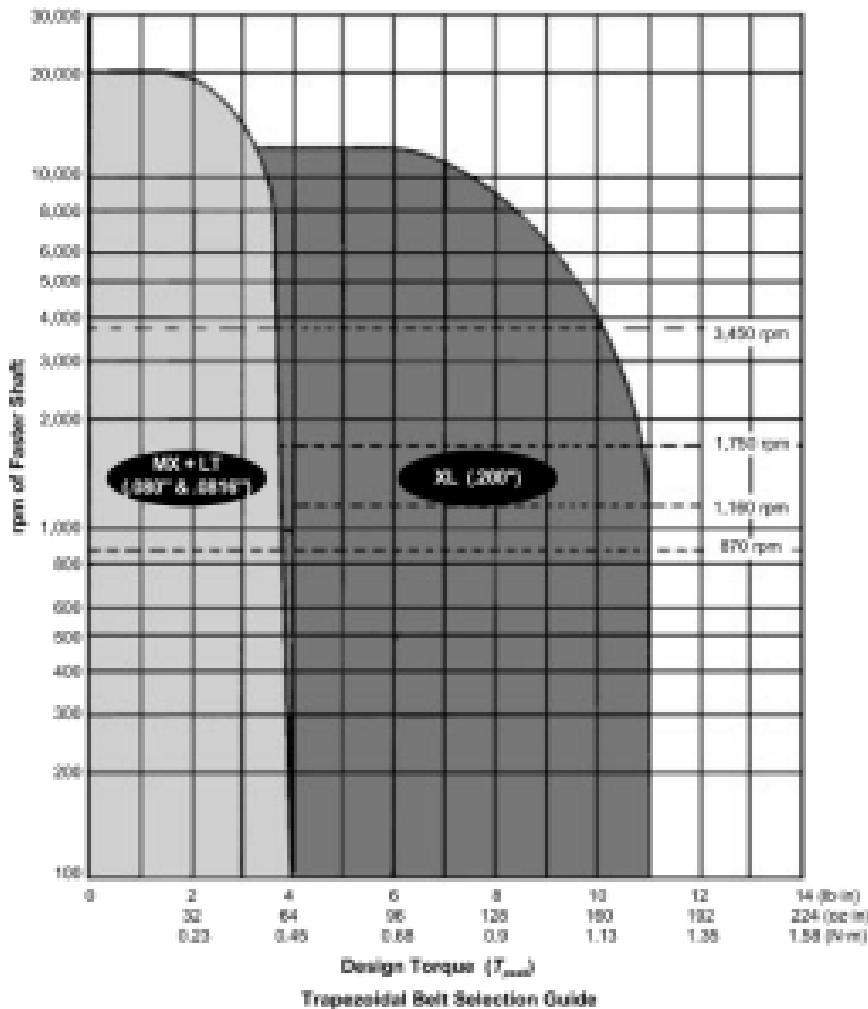
## Belt Technical Information



HTD Belt Selection Guide



## Belt Technical Information



## SECTION 2 CENTER DISTANCE FORMULAS

### 2.1 Nomenclature And Basic Equations

Figure 6 illustrates the notation involved.

The following nomenclature is used:

- C = Center Distance (in)
- L = Belt Length (in) =  $\pi C + \frac{N_1 + N_2}{2} p$
- p = Pitch of Belt (in)
- NB = Number of Teeth on belt =  $L/p$
- N1 = Number of Teeth (grooves) on larger pulley
- N2 = Number of Teeth (grooves) on smaller pulley
- $\theta$  = one half angle of wrap on smaller pulley (radians)
- $\phi$  =  $\pi/2 - \theta$  = angle between straight portion of belt and line of centers (radians)
- R1 = Pitch Radius of larger pulley (in) =  $(N_1) p/2\pi$
- R2 = Pitch Radius of smaller pulley (in) =  $(N_2) p/2\pi$
- $\pi$  = 3.14159 (ratio of circumference to diameter of circle)

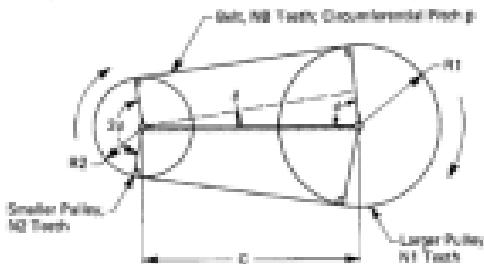


Figure 6 Belt Geometry

The basic equation for the determination of center distance is:

$$2C \sin \theta = L - \pi(R_1 + R_2) - (\pi - 2\phi)(R_1 - R_2) \quad (2-1)$$

$$\text{where } C \cos \phi = R_1 - R_2 \quad (2-2)$$

These equations can be combined in different ways to yield various equations for the determination of center distance. We have found the formulations which follow useful.

### 2.2 Exact Center Distance Determination – Unequal Pulleys

The exact equation is as follows:

$$C = \left(\frac{1}{2}\pi\right) \left[ (N_2 - N_1) + k(N_1 - N_2) \right] \quad (2-3)$$

$$\text{where } k = \left(\frac{1}{2}\right) \left[ \tan\left(\frac{\pi}{4} - \frac{\phi}{2}\right) + \phi \right] \quad (2-4)$$

and  $\phi$  is determined from:

$$\left(\frac{1}{2}\right) (\tan \phi - \phi) = \frac{(N_2 - N_1)}{(N_1 - N_2)} = Q \text{ (say)} \quad (2-5)$$

The value of  $k$  varies within the range (1 to 1/2) depending on the number of teeth on the belt. All angles in Equations (2-4) through (2-8) are in radians.

The procedure for center distance determination is as follows:

1. Select values of  $N_1$ ,  $N_2$  (in accordance with desired transmission ratio) and  $N_B$ .
2. Compute  $Q = (N_B - N_1)/(N_1 - N_2)$ .
3. Compute  $\phi$  by solving Equation (2-6) numerically.
4. Compute  $k$  from Equation (2-4).
5. Compute  $C$  from Equation (2-3).

### 2.3 Exact Center Distance Determination – Equal Pulleys

For equal pulleys,  $N_1 = N_2$  and Equation (2-3) becomes:

$$C = \frac{P}{2} \left( N_B - \frac{(N_1 + N_2)}{2} \right) \quad (2-4)$$

### 2.4 Approximate Center Distance Determination

Approximate formulas are used when it is desirable to minimize computation time and when an approximate determination of center distance suffices.

An alternative to Equation (2-1) for the exact center distance can be shown to be the following:

$$C = \frac{P}{4} \left\{ N_B - \frac{(N_1 + N_2)}{2} + \sqrt{\left[ N_B - \frac{(N_1 + N_2)}{2} \right]^2 - \frac{2(N_1 - N_2)^2}{\pi^2} (1 + S)} \right\} \quad (2-7)$$

where  $S$  varies between 0 and 0.1416, depending on the angle of wrap of the smaller pulley. The value of  $S$  is given very nearly by the expression:

$$S = \frac{\cos^2 \theta}{12} \quad (2-8)$$

In the approximate formulas for center distance, it is customary to neglect  $S$  and thus to obtain following approximation for  $C$ :

$$C = \frac{P}{4} \left\{ N_B - \frac{(N_1 + N_2)}{2} + \sqrt{\left[ N_B - \frac{(N_1 + N_2)}{2} \right]^2 - \frac{2(N_1 - N_2)^2}{\pi^2}} \right\} \quad (2-9)$$

The error in Equation (2-9) depends on the speed ratio and the center distance. The accuracy is greatest for speed ratios close to unity and for large center distances. The accuracy is least at minimum center distance and high transmission ratios. In many cases, the accuracy of the approximate formula is acceptable.

### 2.5 Number Of Teeth In Mesh (TIM)

It is generally recommended that the number of teeth in mesh be not less than 6. The number,  $TIM$ , teeth in mesh is given by:

$$TIM = \lambda \cdot N_2 \quad (2-10)$$

where  $\lambda = \frac{P}{\pi}$  when  $\phi$  (see Equation (2-5)) is given in radians.

## 2.6 Determination Of Belt Size For Given Pulleys And Center Distance

Occasionally, the center distance of a given installation is prescribed and the belt length is to be determined. For given pitch, number of teeth on pulleys and center distance, the number of teeth of the belt can be found from the equation:

$$NB = \frac{(N_1 + N_2)}{2} + \frac{(N_1 - N_2)}{\pi} \sin^{-1} \left[ \frac{(N_1 - N_2)p}{2\pi C} \right] + \sqrt{\left( \frac{2C}{p} \right)^2 - \left( \frac{N_1 - N_2}{\pi} \right)^2} \quad (2-11)$$

where the arcsin is given in radians and lies between 0 and  $\pi/2$ . Since NB, in general, will not be a whole number, the nearest whole number less than NB can be used, assuming a slight increase in belt tension is not objectionable.

An approximate formula can be used to obtain the belt length:

$$L = 2C + \frac{(D_1 - D_2)^2}{4C} + 1.57 \times (D_1 + D_2) \quad (2-12)$$