ENGINEERING DETAIL ON VARIABLE SPEED PULLEYS

A V-Flat drive is one where the normal V belt runs from the variable pitch spring-loaded pulley mounted on the motor to a flat pulley mounted on the driven unit.

When running on the flat pulley, the torque transmitted is less than if the belt were running in a V groove pulley and, therefore, the drive should be rated by a reduced factor. This is true unless the flat pulley becomes large enough to drop the arc of contact on the small spring-loaded pulley to approximately 127°, at which point the belt will always slip first on the small pitch diameter, irrespective of whether the large pulley is flat or grooved. From this, it will be seen that best results are obtained when the flat pulley diameter is large compared with the spring-loaded pulley, and the center distance is relatively short.

Below is a table of correction factors for V to flat drives, where D = Dia. of large pulley, d = Dia. of small pulley, C = center distance.

$\frac{D - d}{C}$	Arc of Contact On Small Sheave Degrees	Correction Factor
0.00	180	.75
0.10	176	.77
0.20	169	.81
0.30	163	.83
0.40	157	.86
0.50	151	.88
0.60	145	.92
0.70	139	.95
0.80	133	.98
0.90	127	1.0

EXAMPLE

A Model 810 one side movable flange pulley is rated for a V to V configuration at 10 HP, running on a 10 HP 1800 RPM motor. The diameter of the V companion sheave is 14". The belt length is 72.3 pitch length, with a minimum center distance of 17.9". What would be the rating, if the V companion sheave was changed to a flat companion pulley?

D = 14"   d = 10.2" (from 810 specifications)   C = 17.9"

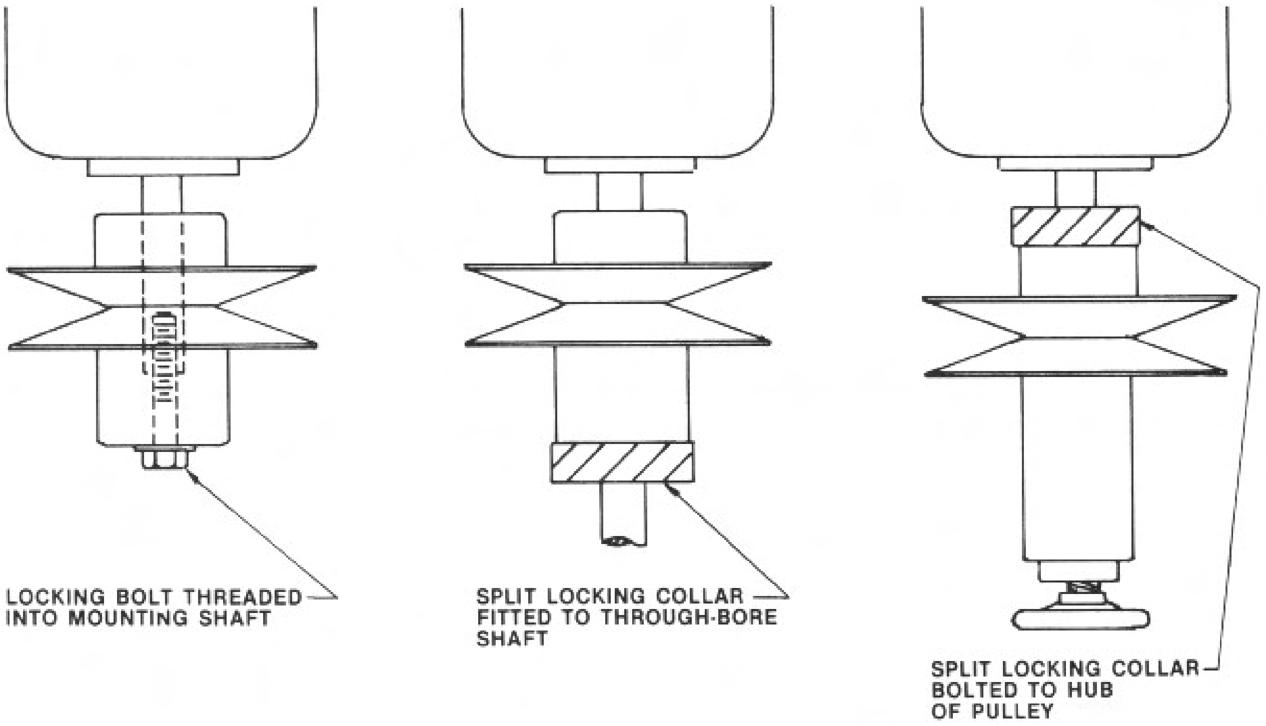
$\frac{D - d}{C} = \frac{14 - 10.2''}{17.9} = .21$ From above table (interpolating) .21 = 168°

Correction Factor = .81 10 HP x .81 = **8.1 HP = New Rating**

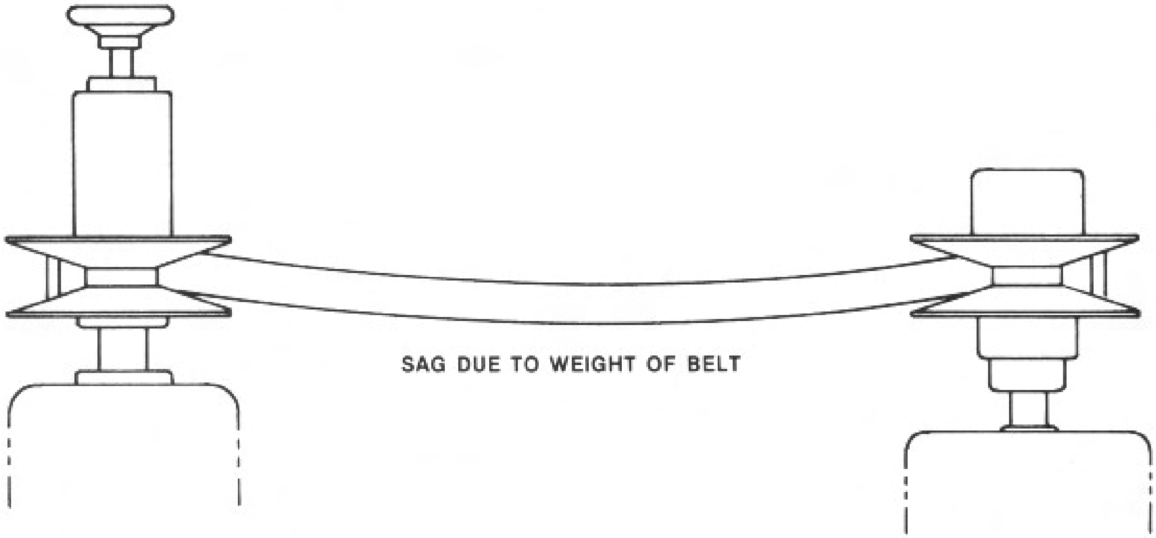
One other point to observe is that the pulley should be flat and not crowned. Also that the face is wide enough to allow side movement of the belt when changing speed, using a one side movable type pulley as driver.

VERTICAL APPLICATIONS

The mounting of pulleys in a vertical plane, with the shafts pointing downwards should be avoided wherever possible. However, if the installation cannot be arranged in any other way, then certain precautions should be taken. Shown below are some practical methods which will ensure a trouble free mounting.



LONG BELTS FITTED IN VERTICAL INSTALLATIONS



In any installation fitted with a long belt, there is a tendency for some belt whip at certain periods through the speed range, simply due to the weight of the belt itself, plus the possibility of insufficient flywheel action in the drive itself.

If the drives are mounted in a vertical plane, then over a period of time the weight of the belt may cause it to take a "banana" shape, which if continued for a long enough time, may cause the belt to "flip" and turn over. On the larger drives, of 10 H.P. and upwards, a center distance of over 30", will probably mean some reduced belt life owing to the above reasons. Sensible precautions are to align the drives as accurately as possible, and to change the belt when a noticeable sag is evident.

LOAD CARRYING CAPACITIES AND SERVICE FACTORS

The load capability of a variable speed pulley system is dependent on (1) the belt, (2) the mechanical parts of the pulleys, and/or accessory equipment.

The belt life is always difficult to predict with any real accuracy owing to the many variables in a system. For example, if a belt were running constantly at one pitch diameter on the pulleys under rated load, then everything else being equal, the life can be predicted with fair accuracy. However, in practice, the load rating of the belt will be often exceeded when running at the high and low ends of the speed range. Start up loads, shock loads, and intermittent loading will all have some effect. Dirt, heat, and environment will also play a part. Aluminum sheaves have helped to dissipate heat to a large extent, so there are many checks and balances.

There is a service factor built into each pulley to compensate for normal start up conditions and moderate stops and starts. For sizing a drive in practice, the following service factors should be helpful. When applied to the standard rating of the pulleys, good results should be obtained. Severe conditions such as high inertia loads or high reversal applications should be referred to the factory.

TYPES OF DRIVEN MACHINES	TYPES OF DRIVING UNITS					
	AC Motors; Normal Torque. Squirrel Cage. Synchronous and Split Phase. DC Motors; Shunt Wound. Multiple Cylinder Internal Combustion Engines.			AC Motors; High Torque. High Slip, Repulsion-Induction, Single Phase Series Wound and Slip Ring. DC Motors; Series Wound and Compound Wound. Single Cylinder Internal Combustion Engines. Line Shafts. Clutches.		
	Intermittent Service (3-5 Hours Daily or Seasonal)	Normal Service (8-10 Hours Daily)	Continuous Service (16-24 Hours Daily)	Intermittent Service (3-5 Hours Daily or Seasonal)	Normal Service (8-10 Hours Daily)	Continuous Service (16-24 Hours Daily)
Agitators for Liquids Blowers and Exhausters Centrifugal Pumps and Compressors Fans up to 10 HP Light Duty Conveyors	1.0	1.1	1.2	1.1	1.2	1.3
Belt Conveyors for Sand, Grain, etc. Dough Mixers Fans Over 10 HP Generators Line Shafts Laundry Machinery Machine Tools Punches-Presses-Shears Printing Machinery Positive Displacement Rotary Pumps Revolving and Vibrating Screens	1.1	1.2	1.3	1.2	1.3	1.4
Brick Machinery Bucket Elevators Exciters Piston Compressors Conveyors (Drag-Pan-Screw) Hammer Mills Paper Mill Beaters Piston Pumps Positive Displacement Blowers Pulverizers Saw Mill and Woodworking Machinery Textile Machinery	1.2	1.3	1.4	1.4	1.5	1.6
Crushers (Gyratory-Jaw-Roll) Mills (Ball-Rod-Tube) Hoists Rubber Calendars-Extruders-Mills	1.3	1.4	1.5	1.5	1.6	1.8

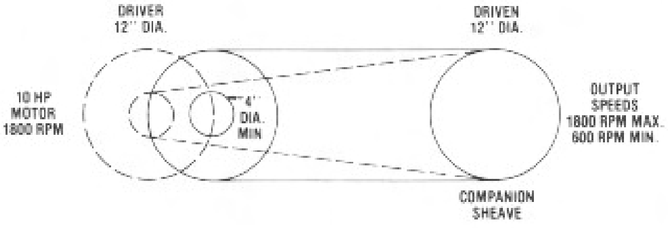
Note 1 The use of a service factor of 2.0 is recommended for equipment subject to choking.
Note 2 For devices used in grain and milling properties, refer to Mill Mutual Fire Prevention Bureau Bulletin VB-601.

REVERSE MOUNTED DRIVES

Sometimes it is necessary to reverse mount two pulleys. In other words, the pulley that normally fits on the motor would be changed to act as the driven pulley, with the normally driven pulley on the motor shaft.

The basic changes encountered here are: 1.) The Power Capacity 2.) The Speed Range

A. ADJUSTABLE CENTER SYSTEM



STANDARD MOUNTING

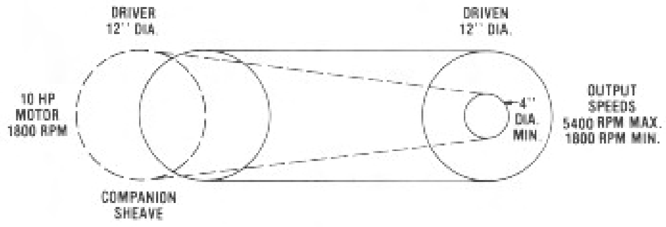
10 H.P. available at **max.** speed

Available torque at **max.** speed $= \frac{10 \times 63000}{1800} = 350$ in/lbs

3⅓ H.P. available at **min.** speed

Available torque at **min.** speed $= \frac{3\frac{1}{3} \times 63000}{600} = 350$ in/lbs

Above is constant torque
H.P. decreases as speed decreases
Speed Range = 1800 max. 600 min.



REVERSE MOUNTING

10 H.P. available at **min.** speed

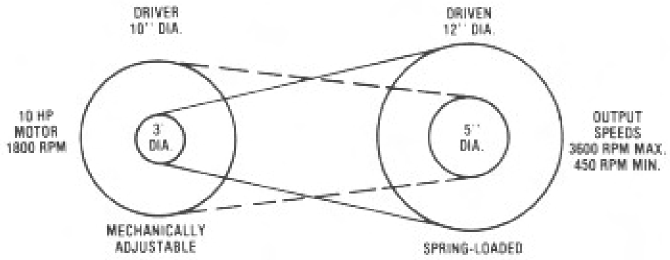
Available Torque at **min.** speed $= \frac{10 \times 63000}{1800} = 350$ in/lbs

10 H.P. available at **max.** speed

Available torque at **max.** speed $= \frac{10 \times 63000}{5400} = 116$ in/lbs

Above is constant H.P.
Torque decreases as speed increases
Speed Range = 5400 max. 1800 min.

B. FIXED CENTER SYSTEM



STANDARD MOUNTING

10 H.P. available at **max.** speed

Available torque at **max.** speed $= \frac{10 \times 63000}{3600} = 175$ in/lbs

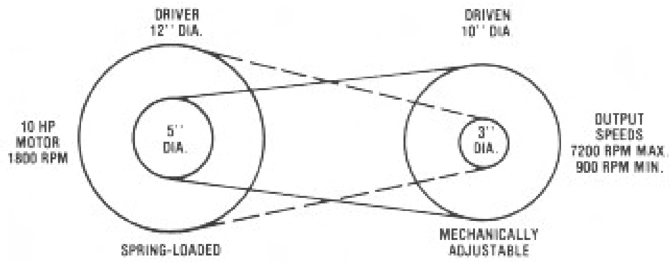
10 H.P. available at **mid** speed

Available torque at **mid** speed $= \frac{10 \times 63000}{1800} = 350$ in/lbs

2½ H.P. available at **min.** speed

Available torque at **min.** speed $= \frac{2\frac{1}{2} \times 63000}{450} = 350$ in/lbs

Above is constant torque from low to mid speed
Constant H.P. from mid to high speed.
Speed Range = 3600 max. 450 min.



REVERSE MOUNTING

Derate H.P. capacity by 1/3, owing to spring-loaded pulley acting as driver. Otherwise, rate as for standard mounting.

Max. output speed limited to 3600 R.P.M., owing to bearing rotation in mechanically adjustable pulley, which is now **driven.**

Above is constant torque from low to mid speed
Constant H.P. from mid to high speed.
Speed Range = 3600 max. 900 min.

OVERHUNG SHAFT LOADS

The primary force acting on the pulley mounting shaft and support bearings is the total belt pull plus the weight of the pulley. The total belt pull is known as T1 + T2, where T1 is the tight side tension of the belt, and T2 the slack side tension.

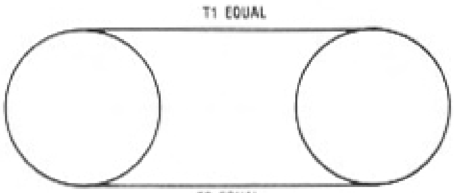


FIGURE 1

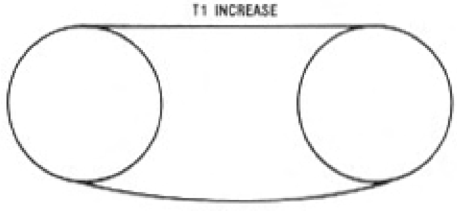


FIGURE 2

With a drive shown at rest, Figure 1, T1 and T2 are equal. With the drive in motion, Figure 2, T1 will **increase** and T2 will **decrease**. T1 - T2 is the effective pull, or the difference in tensions necessary to drive the unit. The difference in tensions is called the tension ratio, and for 'V' Belt Pulleys is based on Ratio (r) = 5:1 at 180° ARC of contact (or 1:1 speed ratio).

The following basic formulas apply:

$$T1 - T2 = \frac{33{,}000 \times \text{H.P.}}{\text{Belt Speed (Ft/Min)}}$$

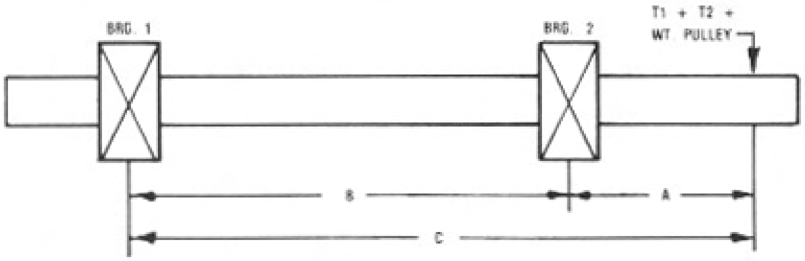
$$\text{Belt Speed} = \frac{\text{Mean P.D. of pulleys} \times \text{speed (R.P.M.)}}{3.82}$$

$$\text{Mean P.D. of Pulleys} = \frac{\text{Belt pitch length} - (2 \times \text{center distance})}{\pi}$$

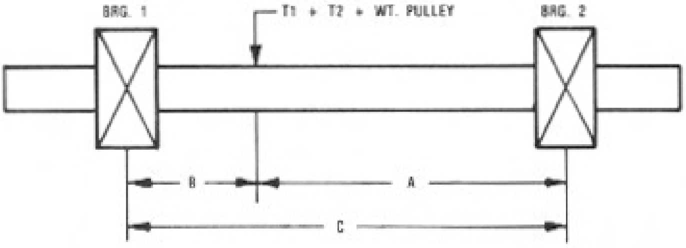
$$T1 = (T1 - T2)\left(1 + \frac{1}{r - 1}\right)$$

$$T2 = (T1 - T2)\left(\frac{1}{r - 1}\right)$$

$$T1 + T2 = (T1 - T2)\left(1 + \frac{2}{r - 1}\right)$$



$$\text{Load on Bearing No. 1} = (T1 + T2 + WT) \times \frac{A}{B} \qquad \text{Load on Bearing No. 2} = (T1 + T2 + WT) \times \frac{C}{B}$$



$$\text{Load on Bearing No. 1} = (T1 + T2 + WT) \times \frac{A}{C} \qquad \text{Load on Bearing No. 2} = (T1 + T2 + WT) \times \frac{B}{C}$$

EXAMPLE

The fixed center pair of pulleys 411-512 are to be used with a 3226V723 belt, at a center distance of 24.2". The 411 pulley is mounted on a 10 H.P. 1750 R.P.M. motor. The 512 is mounted on an outboard shaft, supported by two bearings spaced 12" apart. The distance from the belt center line to the front bearing is 5". What is the load on the front bearing, and the rear bearing as generated by the 512 pulley?

ANSWER

First determine the total belt load T1 + T2. For this we need to know:

(1) Mean P.D. of pulley $= \dfrac{\text{B.P.L.} - (2 \times \text{C.D.})}{\pi} = \dfrac{72.3 - (2 \times 24.2)}{\pi} = 7.60$

(2) Belt speed $= \dfrac{\text{mean P.D.} \times \text{speed}}{3.82} = \dfrac{7.6 \times 1750}{3.82} = 3481$ ft./min.

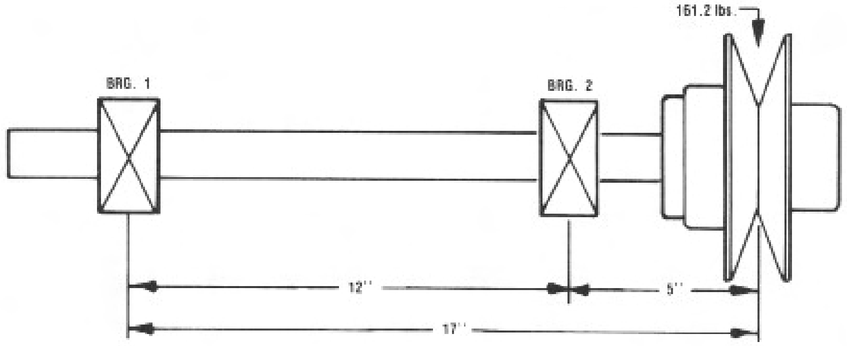
(3) $T1 - T2 = \dfrac{\text{H.P.} \times 33{,}000}{\text{Belt Speed}} = \dfrac{10 \times 33{,}000}{3481} = 94.8$ lbs.

(4) $r = 5$

$T1 + T2 = (T1 - T2)\left(1 + \dfrac{2}{r-1}\right) = 94.8\left(1 + \dfrac{2}{4}\right) = 142.2$ lbs.

Weight of pulley (from catalog)	19 lbs.
Total load	161.2 lbs.

Our layout will be



Load on Bearing No. 1 $= 161.2 \times \dfrac{5}{12} = 67.1$ lbs.

Load on Bearing No. 2 $= 161.2 \times \dfrac{17}{12} = 228.3$ lbs.

BELT TOLERANCES ON LENGTH

The length of a standard belt like any other product has a manufacturing tolerance. Figures given by one leading belt manufacturer are, belt lengths up to 30" ± 1/8, 30" – 60" ± 3/16, 60" – 90" ± 1/4, 90" plus ± 5/16. These figures are much less than those called out by R.M.A. standards, and can be considered reasonable for the product. If we relate the maximum and minimum tolerance to the belt example given earlier, the 2322V421, then the belt on the maximum side of the tolerance would be 42.1 + 1/8 = 42.22, and for the minimum, 42.1 – 1/8 = 41.97. Still using the original calculated center distance of 10.4", the output speeds would be:

Belt **nominal** length gives min. speed 448 R.P.M.
max. speed 3438 R.P.M.

Belt **maximum** length gives min. speed 478 R.P.M.
max. speed 3344 R.P.M.

Belt **minimum** length gives min. speed 452 R.P.M.
max. speed 3547 R.P.M.

The top width of the belt is usually held to ± 1/32, which may also effect a slight change.

When designing a drive system, if at all practical, allowances should be made for the possible variances. Belts made to tighter tolerances than those given above, can be obtained by special order. This should be avoided if possible, owing to lead times, costs, and field replacement problems.

FIXED CENTER DRIVE COMBINATIONS, USING PULLEYS OF UNEQUAL DIAMETERS

It will be seen from the output speed charts on the 45 Series that the maximum output speed decreases as the belt length and center distance figures decrease.

Since the center distance and appropriate belt length are always calculated for the **minimum** output speed, this figure will be constant for all different belt lengths on the same two pulleys.

Taking the 409-5151 pulley combination from the 45 Series, we find for the shortest belt listed, 2322V421 which is 42.1" pitch length, a center distance of 10.29".

Proving with the standard formula:

$$P.L. = (2 \times CD) + 1.57\ (D + d) + \frac{(D - d)^2}{4 \times CD}$$

Max. P.D. of 409 = 8.75, min. P.D. of 409 = 2.53

Max. P.D. of 5151 = 10.25, min. P.D. of 5151 = 3.79

$$42.1 = (2 \times 10.29) + 157\ (2.53 + 10.25) + \frac{(10.25 - 2.53)^2}{4 \times 10.27}$$

$$42.1 = 20.58 + 20.06 + 1.45, \text{ which is correct}$$

Now, using the same belt length and the same center distance which cannot change, we have for the max speed;

$$42.1 = (2 \times 10.29)\ 1.57\ (8.75 + 3.94) + \frac{(8.75 - 3.94)^2}{4 \times 10.4}$$

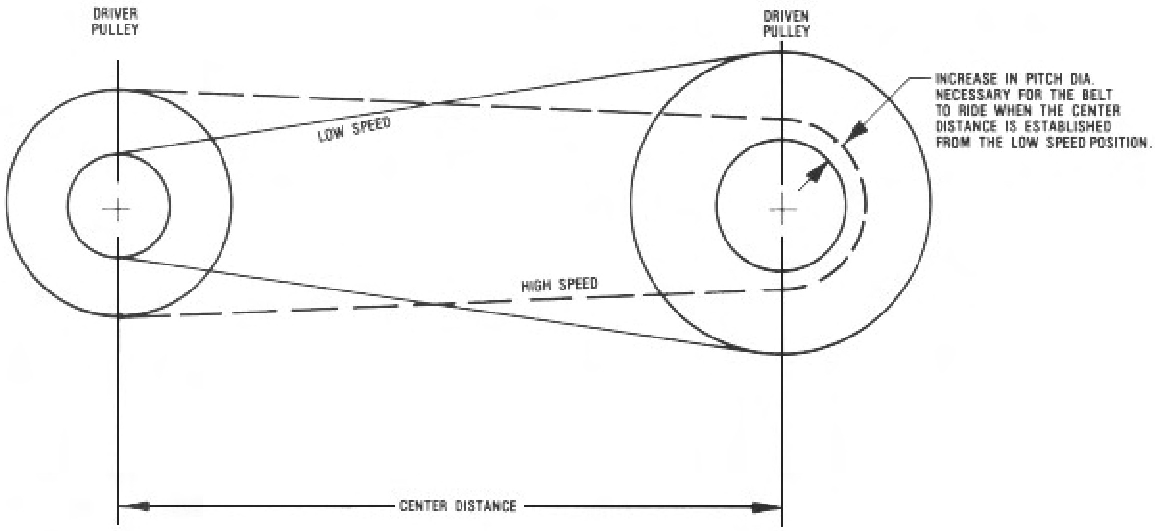
$$= 20.58 + 19.69 + .60$$ which **does not** equal 42.1

To correct, the small Dia, d, will have to increase to compensate. If we increase this from 3.94 to 4.70*, this makes the formula agree.

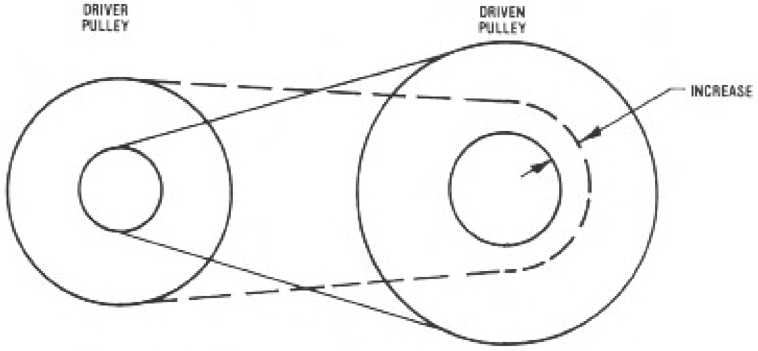
The minimum speed $= \frac{2.53 \times 1800}{10.25} = 444$ R.P.M.

The maximum speed $= \frac{8.75 \times 1800}{4.70} = 3351$ R.P.M.

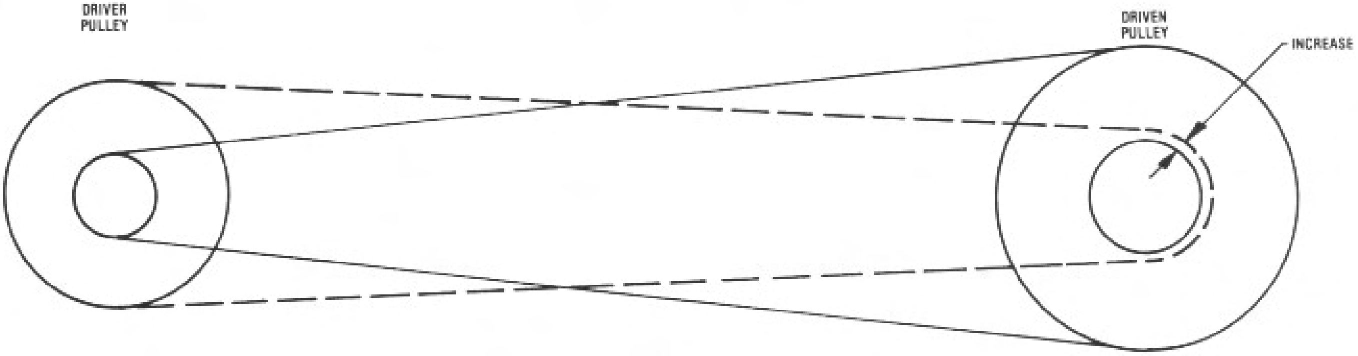
(If the original 3.79 dia. was used, then $\frac{8.75 \times 1800}{3.96} = 4155$ R.P.M.)



By the same rule, the increase in pitch dia. will also vary, as the center distance and belt length increase.



SHORT CENTER DISTANCE



LONG CENTER DISTANCE

Increase of pitch dia. is much less on a long center distance, giving a higher output speed.

If the original center distance and belt length was computed from the **high** speed position, then the low speed would increase as the belt would ride higher on the driver pulley in the low speed position.

It is obvious from the above that by changing the center distance for any length belt, various combinations of speeds can be obtained. However, by calculating initially for the low speed position as a uniform procedure, variances on the high speed for different length belts can usually be tolerated.

*To calculate an unknown pitch diameter use the formula

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

where C = Center Distance
d = Unknown Pitch Diameter
D = Known Pitch Diameter
L = Belt Pitch Length
All Dimensions in inches.