V - Belt Drives And Their Care

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It has been estimated that almost half a million oil wells today use V-belt drives to transmit power from a prime mover to the pumping unit. Of all the desirable characteristics of the V-belt drive as a power transmission medium—such characteristics as resilience, dependability, adaptability, campactness, ease of speed change, and cleanliness—perhaps the major characteristic responsible for this widespread use of V-belt drives is the fact that inherently they need very little care. In those rare instances where difficulties arise in the operation of the V-belt drive, those difficulties can generally be traced to lack of understanding of the fundamentals of such drives—or to ignoring them.

In practice, service and operating problems arise so seldom that when they do, the operator often feels frustrated, simply because these fundamentals are generally discussed only in connection with the original design of the drive. At first glance, there appears to be quite a gulf between design theory and operating practice. Actually, this isn't true.

The purpose of this discussion is to review some of the fundamentals of V-belt drives and then to consider some of the occasional misapplications of these fundamentals which can lead to difficulty in operating the drive, or to short drive service life.

Fundamentals of V-Belt Drives

The first fundamental of a V-belt drive is that it uses friction force to turn wheels. Friction force is simply the resistance to sliding offered by two bodies in contact with each other. A simple example is illustrated on the left-hand side of Figure 1 which shows one block resting on another. The weight of the upper block furnishes the normal force between the contact surface of the two blocks. The friction force is the maximum force parallel to the surface which can be applied before the top block starts sliding across the lower one. Many experiments have established that the ratio between the friction force and the normal force is essentially constant for specific materials and surface finishes. Thus, if, on the upper block, one were to put weights equal to the weight of the upper block, and so double the normal force, the friction force would be doubled. The ratio of the frictional force to the normal force is known as the coefficient of friction, often designated by the Greek letter Mu.

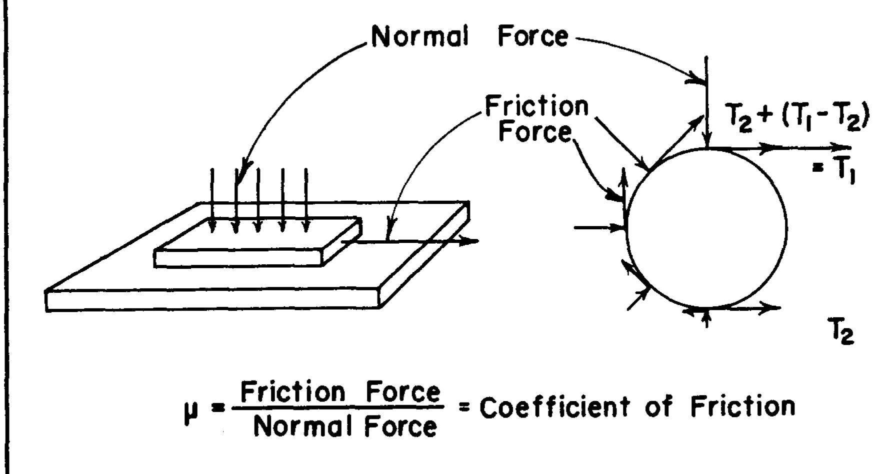

Fig. 1

Applying this to a flat-belt drive *for simplicity, we have the situation* illustrated in the right-hand sketch of Figure 1. Here the tension, T2, pulls the belt against the face of the pulley. The normal force consists of a distributed force around the pulley, everywhere directed toward the center. This force, of course, can exert no turning effect; but if in one strand of the belt additional force, T1 — T2, is applied, the friction force at right angles to the normal force (or in this case, tangent to the pulley face) can be used to turn the pulley. (The mathematics shows that both the normal and friction force increase from the slack side to the tight side, as shown in the sketch. But this need not concern us here.)

As shown in the sketch, the total tension in the tight side of the belt is designated as T1. It can be thought of as the sum of the slack-side tension, T2, which furnishes the necessary normal force, and the friction force, T1 — T2, which actually turns the pulley to do useful work. The quantity, T1 — T2, is frequently referred to as the "effective tension".

The V-belt drive uses the same principal as the flat-belt drive. But instead of using the slack-side tension, T2, to develop force between the face of the pulley and the belt, it uses that tension to develop the force between the sidewalls of the belt and the inclined grooves of the sheave. This applies the principal of the wedge and makes it possible to develop considerably higher normal forces against the sides of the groove than could be developed by the same tensions against the face of a flat pulley.

Figure 2 illustrates the force system when a V-belt is turning a sheave. OP is the normal force between the belt and groove faces, and this force is actually developed through the tension. The friction force developed is FP. This friction force has two components: one, RP, is directed toward the center of the sheave and does not contribute to turning the sheave; the other, TP, is directed along the tangent. It is that part of the friction force which actually can produce movement of the sheave.

Compared with a flat belt, a V-belt can produce about twice as much friction force to turn the sheave for each pound of tension in the drive. The mathematical analysis of the differ-

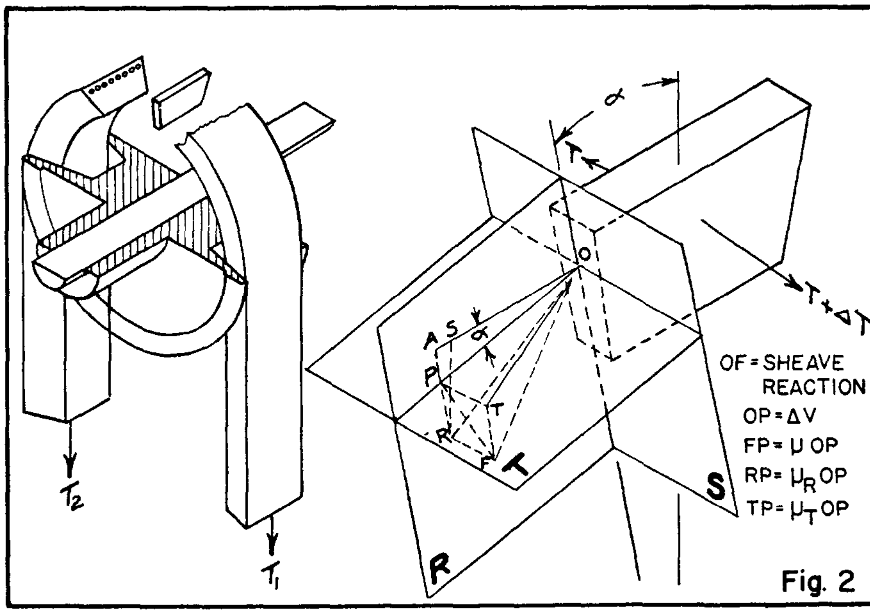

Fig. 2

ence between slack and tight-side tensions, which result from this force system, is beyond the scope of this discussion..

It is important to recognize that the above discussion involves force and not pressure, which is force per unit area. As shown in Figure 3, if the upper block of Figure 1 is turned on its side, the pressure against the lower surface increases. In fact, with the dimensions shown, the pressure has been quadrupled. But the normal force, and the friction force as well, remain unchanged.

This same principal holds true in a V-belt drive. The total effective tension which can be developed to turn the sheaves on a given drive depends on the total force between the belts and the sheave. This force may be distributed among one, two, or any number of belts. But is is the total force—hence, the total belt tension—which determines the maximum effective tension which can be applied to the rims of the sheaves before the belt slips.

A very practical conclusion to be drawn from the above discussion is that, when a V-belt drive is slipping, the thing to do is to tighten the belts. If the drive has been properly designed, as we assume here it has, the belts will show a slight bow in the slack side when operating. But regardless of the appearance of the belts, either while running or standing still, if the drive slips, it should be tightened up.

We are occasionally asked if this won't overload the bearings, and whether it wouldn't be better to add more belts. Such a question is often based on someone's observation that he once had a drive which slipped, so he added more belts and the drive quit slipping. This observation was not followed through with the realization that to increase total tension by 20 percent, for example, it is possible either to add 20 percent more belts, each at the same tension as the original ones, or to increase the tension in each belt by 20 percent. In either case, the result is the same.

The above discussion, of course, refers to the maximum effective tension which can be transmitted by a given drive. Pumping unit drives do not require this maximum tension transmitted continuously. On a given well, it is known that the power requirement is zero at each end of the pumping stroke and reaches a maximum near the center of the up-stroke and down-strokes, assuming that the well is properly counterbalanced. The effective tension required likewise fluctuates from zero to a maximum through each pumping stroke. Therefore, the drive must be sufficiently tensioned to transmit the maximum effective tension that will be required.

On the other hand, except for changes which might bring the pumping speed nearer a resonance speed for the sucker rods, the maximum power required to pump the well will be nearly independent of the speed at which it is pumping. So the effective tension required in the drive, will

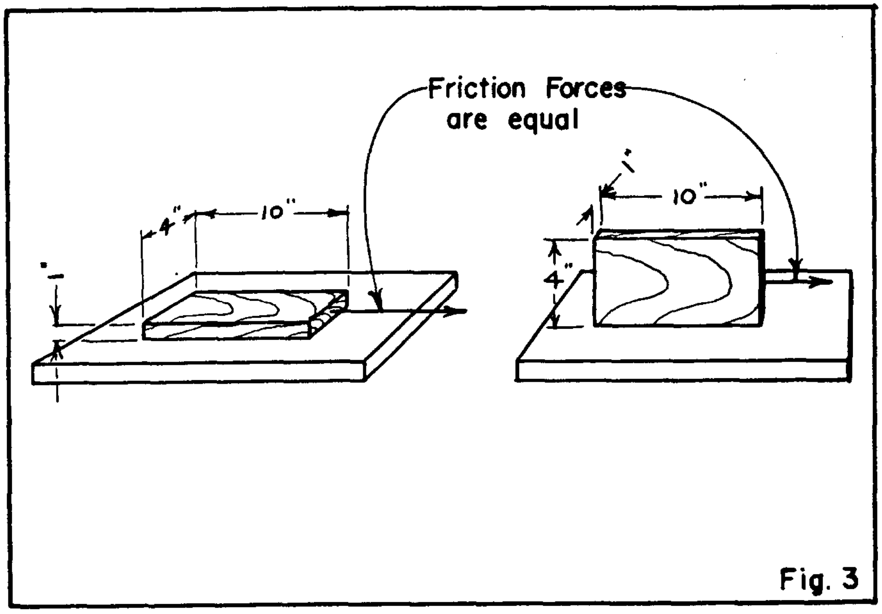

Fig. 3

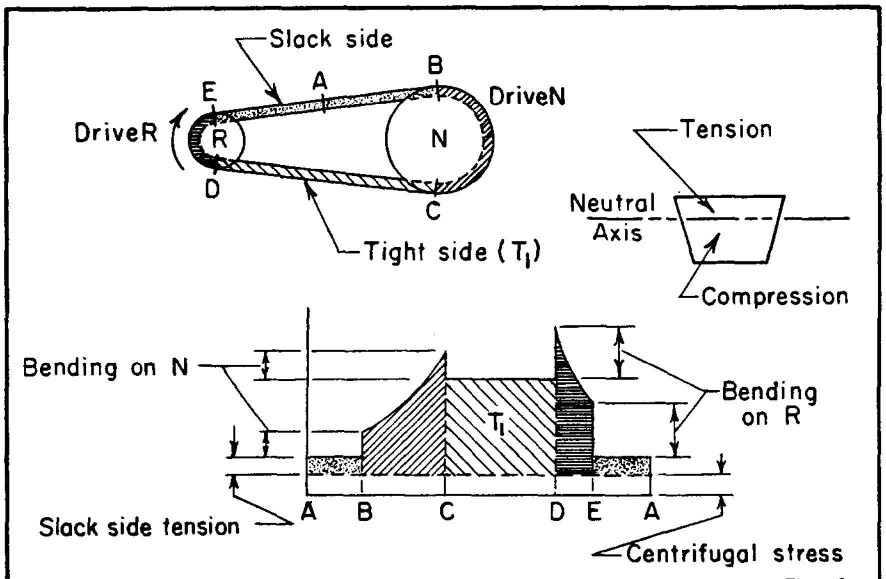

Fig. 4

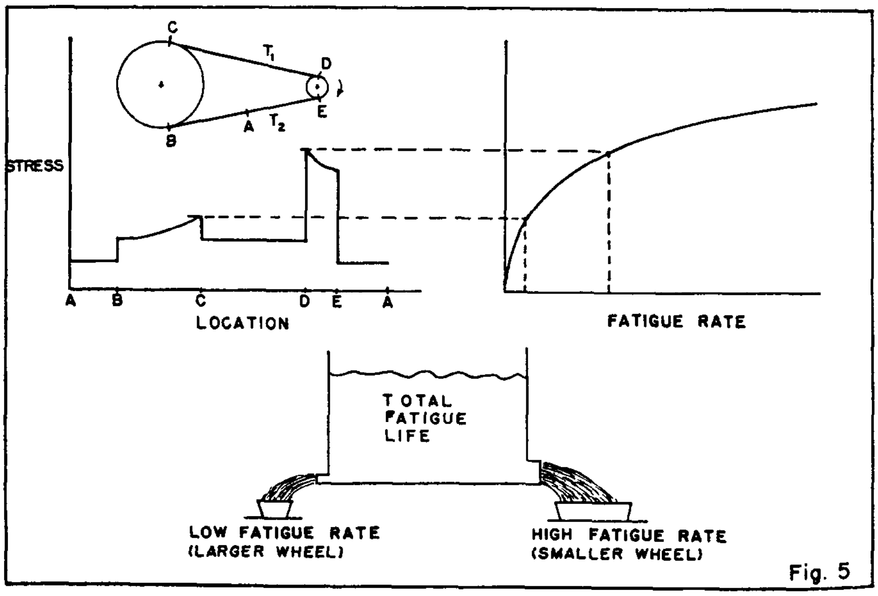

Fig. 5

ordinarily not change when the pumping speed of the well is changed.

Besides the change in tension which occurs in the belts as they go from the slack to the tight side of the drive, the belts are also subjected to centrifugal force and to forces due to bending while on the sheave. Figure 4 shows the stress to which a plane of the belt located above the neutral axis is subjected as it operates around a two-wheel drive. Stresses from the tight-side tension, bending, and centrifugal force combine to produce a peak stress at each sheave. Extensive laboratory and field tests have proved that the belt fails by fatigue under this cyclic stress and that the peak stress determines how fast this fatigue failure will take place.

In Figure 5 we have illustrated the relationship between the peak stress at each wheel and the rate at which the belt fatigues. This process is like draining a reservoir with two pipes of different sizes. The larger pipe corresponds to the small sheave diameter with its higher peak stress and greater fatigue rate. The smaller pipe corresponds to the larger sheave.

Figures 4 and 5 might be considered typical of the cyclic or recurring stresses observed by the tensile section of the belt. While the tensile section of the belt is the component doing the useful work, other components of the belt also have a very definite role in helping the tensile section do its work.

Figure 6 shows a typical V-belt in cross section. The underscore or compression member is below the tensile section. It may be made of rubber or fabric, and serves to support the tensile section in the groove. It also furnishes a path by which shear stresses can be transmitted from the side of the belt into the tensile cords in the center of the belt. A cover is generally furnished to protect the interior of the belt from dust, oil, and grease, and to act as the wearing surface against the sheave sidewall.

Just as the tensile section is subjected to cyclic stresses as it operates around the drive, so the other components are similarly subjected to cyclic stresses.

In Figure 7, for example, we have shown the shear stress between the sidewall of the belt and the sheave groove. Notice that it, too, is characterized by stress peaks and that the peak is greatest on the small sheave where the rate of tension increases per degree of wrap is the greatest.

The belt manufacturer's purpose is to design the belt for proper balance between the fatigue lives of the belt components, considering the particular nature of the cyclic stress to which each is subjected. When such a balance is achieved, the failure of one component of the belt occurs at a time when the remaining components have about reached the end of their fatigue lives. Most maintenance and service problems on V-belt drives arise from stressing one or more of the components more severely than usual.

Industrial V-belts are available today in two horsepower rating levels. One is known as a standard V-belt, the other as a premium V-belt. The fundamentals of V-belt construction are essentially the same as discussed above. The premium V-belt can withstand substantially higher peak stresses in its several components than the standard belt for a given fatigue life. This allows horsepower ratings for the premium belts about 40 percent greater than those for standard belts—or at the same horsepower load, the premium V-belt will give much longer life.

When operating on a pumping unit, the stress cycle shown in Figure 4 will change as the effective tension changes. Figure 8 shows the extremes in the stress cycle. The upper sketch represents the drive at the midstroke when the maximum is transmitted. The lower sketch shows the situation at either end of the stroke when no power is being transmitted.

This periodic change in the stress cycle during a pumping stroke is allowed for by the designer when he is deciding on the size of driveR sheave and number of belts to be used. The average power is multiplied by a "service factor" which results in a steady load for which the drive would give the same service as it will on the actual, fluctuating load.

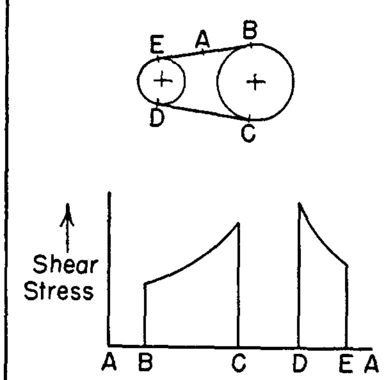

Fig. 7

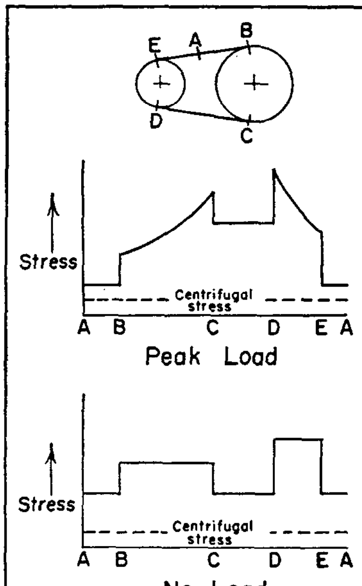

Fig. 8

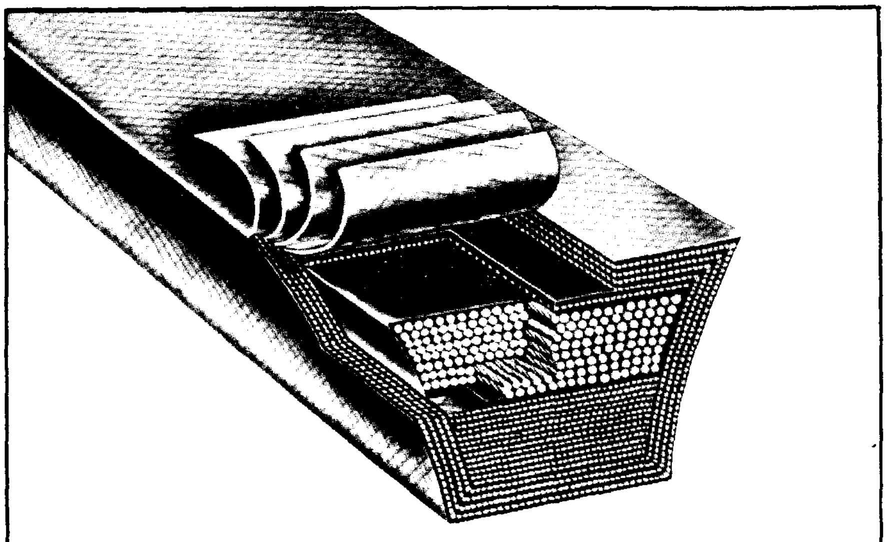
Fig. 6

As the V-belt bends, those parts of the belt above a certain plane, known as the pitch line, grow longer. Those parts below the pitch line grow shorter, while at the pitch line the belt remains unchanged in length. The diameter at which this pitch line operates in the grooves is known as the pitch diameter of the sheave. The speed ratio between the driveR and the driveN sheave is given by the ratio of the pitch diameters of those sheaves. The diameter of the pumping unit sheave is generally set by the manufacturer of that unit. The designer, then, chooses a pitch diameter for the driveR sheave to give the correct speed ratio. The pitch diameter and RPM of the small sheave determine the belt speed which, in turn, determines the centrifugal force in the belt. At the same time, the diameter of the small sheave also determines the bending stress at the sheave.

This leaves only the tight side tension, T1, for setting the peak stress at each sheave. The designer chooses enough belts to share the total load so that the tight-side tension, T1, in each belt gives low enough peak stresses that the fatigue rates at the driveR and driveN sheave will assure adequate service life. The various belt manufacturers' manuals have been designed to simplify this computation as greatly as possible. The casual user may never realize the complex analysis underlying the proper design of a V-belt drive.

The design procedure described above assumes that each belt will carry the same share of the total load. If all of the belts are not of the same length, the shorter belts will operate under more tension than the longer ones, and their service life may be correspondingly shortened. There must be, of course, practical length limits within which the belts of a set are selected. The limit is within 0.10 inch for belts shorter than 100 inches, 0.20 inch for belts between 100 and 200 inches, 0.30 inch for belts between 200 and 300 inches, etc. Most industrial V-belts today are marked with a number which indicates the deviation of the belt from an "ideal length." Each number represents a range of 0.10 inch. A set of matched belts would all have the same number if the belts were under 100 inches long; two consecutive numbers if between 100 and 200 inches; and three consecutive numbers if between 200 and 300 inches, and so on.

When first placed on the drive, some of the belts in a set with this range of matching numbers may appear somewhat longer or shorter than the others. The additional tension in the shorter belts will allow them within a reasonably short time to come to the length of the longer belts. From that time on, all the belts should appear about equally tensioned.

As has been discussed above, the pressure or force per unit area does not determine the effective tension that a belt can transmit. On the other hand, the pressure between the belt sidewall and the sheave is important to the service given by the sidewall.

We have shown in Figure 7 the cyclic stresses in shear to which the belt sidewall is subjected as it operates on the drive. If the belt does not fit the groove reasonably well, the shear force required for transmitting the power may concentrate on a relatively small area of the sidewall with undesirable increases in the pressure between sidewall and grove.

Figue 9 shows the sort of thing which can occur. The groove may be narrow, concentrating high pressure on the lower part of the cover (Figure 9A), or the angle of the groove may not be the same as that of the belt, concentrating pressure at the bottom or top corners (Figure 9B). In any of these cases, the resulting high pressure may cause the cover to wear out before the rest of the belt. We see, then, that a belt should fit the groove so that the pressure on the sidewalls is as uniform as possible.

The problem of getting a uniform fit is complicated by the fact that a V-belt deforms in bending. The top becomes narrower and the bottom wider. As shown in Figure 10, this results in a change in the angle between the sidewalls of the belt. To compensate for this, grooves for standard sheaves are made with an angle which depends on the diameter of the sheave. The smaller the diameter, the smaller the groove angle. For practical reasons the range in groove angle, which is from 34 to 38 degrees, is made in a few steps of 2 to 4 degrees each.

While the belt angle is changing during bending, the width of the belt at the pitch line will remain constant. To provide for the same fit in the grooves on sheaves of different diameter and angle, standard sheaves have a canstant width at the point where the belt pitch line will run. The groove top width is adjusted to correspond to different groove angles. The following table gives standard sheave groove diameters, angles, and

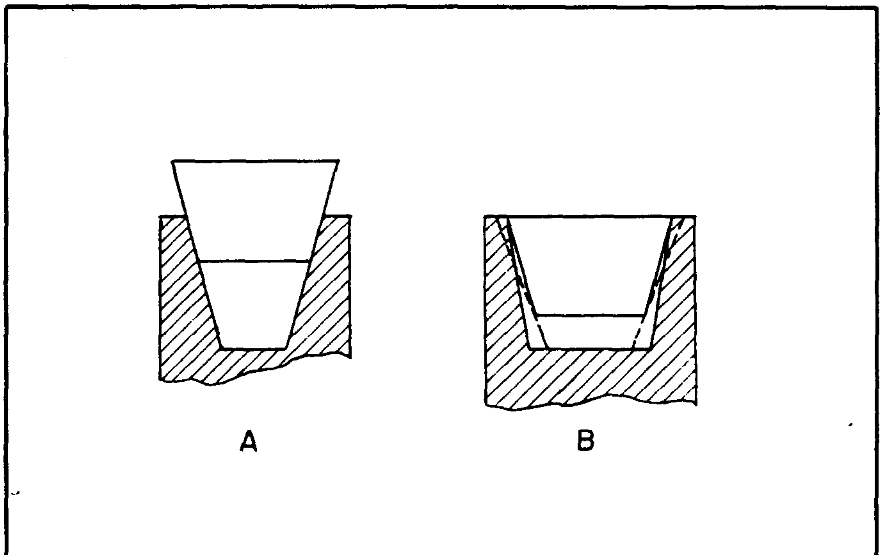

Fig. 9

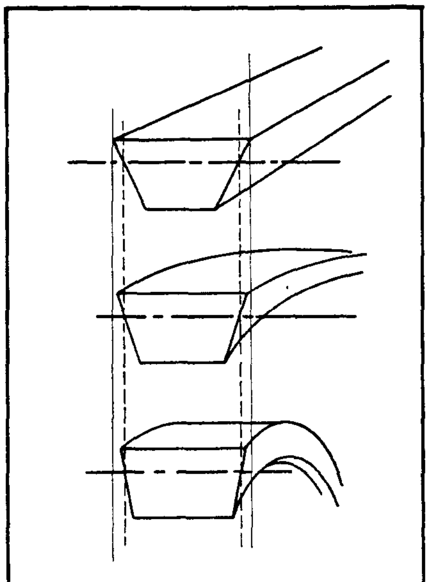

Fig. 10

top widths. It illustrates the care used in supplying sheaves which, when new, will fit the belt.

Belt Section	Pitch Diam. Range	Groove Angle In Degrees	Width of Grove
A	2.6 to 5.4	34	0.494
	Over 5.4	38	0.504
B	4.6 to 7.0	34	0.637
	Over 7.0	38	0.650
C	7.0 to 7.99	34	0.879
	8.0 to 12.0	36	0.887
	Over 12.0	38	0.895
D	12.0 to 12.99	34	1.259
	13.0 to 17.0	36	1.271
	Over 17.0	38	1.283
E	18.0 to 24.0	36	1.527
	Over 24.0	38	1.542

The angle at which a belt is molded is determined by each belt manufacturer so that the best fit is achieved in the above grooves. One manufacturer, in addition, molds the belt with a concave sidewall so that even more uniform pressure is developed between the belt and the groove.

If there were no movement between the belt and the sheave groove during power transmission, then the problem of belt and sheave wear would never arise. But movement between belt and sheave must take place when power is being transmitted. This arises because of the elasticity of a belt.

Since there must be a difference in the tensions on the slack and tight sides to transmit power, there is also a difference in the amounts the belt is stretched between the slack and tight sides. (See Figure 11). To get from the slack side to the tight side, any given portion of the belt must stretch as it travels over the driveN sheave. This means that it must travel slightly faster than the driveN sheave. Over the driveR sheave, the opposite situation exists. The belt must lose some of its stretch as it travels over the driveR sheave from the tight side to the slack side. It must, therefore, travel slightly more slowly than the driveR sheave.

The belt will appear not to turn the driveN sheave as fast as one might think it would, and the driveR sheave will not turn the belt as fast as one might think it would. Generally speaking, there will be about ½ percent difference in RPM, which is usually referred to as "creep". The exact amount of creep, of course, will depend on how heavily the drive is loaded.

Besides this movement which must take place between the belt and sheave, there is another possible source of movement between belt and sheave known as differential driving. This occurs when a belt in one groove is operating with its pitch line at a different position from the belts in other grooves. The diameter at the belt pitch line establishes the speed ratio between the two sheaves. Suppose that on the driveR sheave one belt is operating at a different diameter from the others. It will attempt to make the corresponding groove on the driveN sheave go at a different speed. If the belt is riding at a lower diameter than the other belts on the driveR, it will try to make the driveN sheave run slower. The other belts, however, will pull the driveN sheave around at the higher speed which their pitch diameter dictates. As a result, the driveN sheave will drag along the belt operating at the smaller diameter.

In extreme cases, the driveN sheave may actually become a driveR for the belt at the smaller diameter. If so, this belt will run with its tight side on what is the slack side for the other belts and vice versa. In such a case, of course, not only do the other belts have to carry the load normally taken by the belt at the smaller diameter—they must also share the additional power required to pull that belt around the drive. Needless to say, this situation promotes even greater movement between belt and sheave than would normally take place, and may speed up cover wear.

We see, then, why it is important for long service life that the belts on the drive fit the grooves, not only from the standpoint of maintaining uniform pressure along the sidewalls, but also from the standpoint of maintaining reasonably uniform belt pitch line diameters among the several grooves of the sheave.

Installing and Maintaining V-belt Drives

Now, let us see how the drive fundamentals discussed above apply to the rules and suggestions which are made for the proper installation and maintenance of V-belt drives. These suggestions may only sound like common sense—perhaps that's because you have heard them so often. We will try here to show how each one is founded on one of the principles that we have discussed so far.

Suggestions for Setting Up A Drive

Use a matched set of belts of the same manufacture—do not try to make up a set consisting of belts of different manufacture or of some new and some old belts. A new belt, placed on a drive with old ones that are worn, may take far more than its share of the load, both because it will be somewhat shorter, and because it may ride higher in the grooves and cause differential driving.

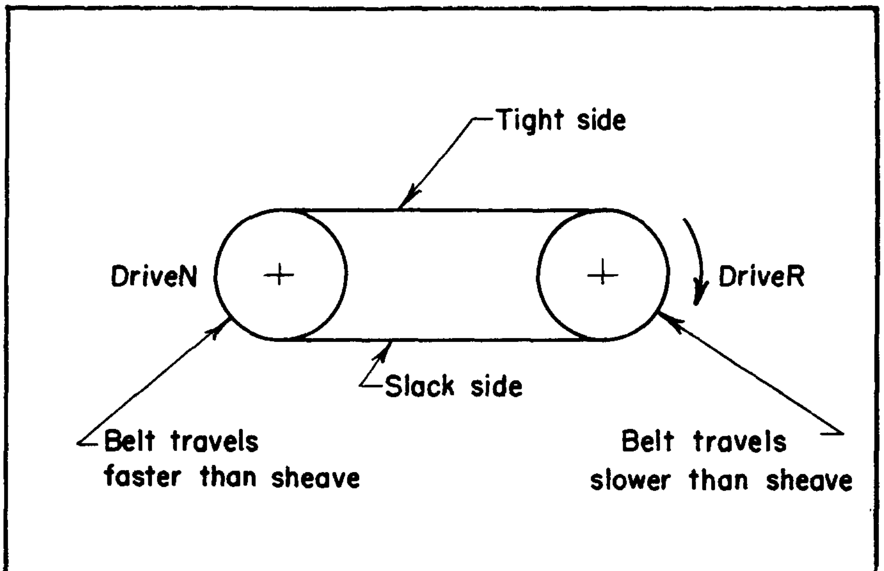

Fig. 11

If belts of different manufacture are used, there is a good chance that the pitch line locations will not be the same for each belt, and differential driving will result. It is also likely that the strain constant of the belts may be different. This will result in different amounts of creep and, again, in differential driving.

Clean oil and grease from the sheaves. Remove rust and burrs. Since the belts operate by friction, anything which tends to reduce the coefficient of friction between the belts and the sheaves can mean that higher belt tensions are required to handle the load.

It might be well to point out here that the V-belt wedging effect multiplies the normal force produced by belt tension to the point that belt dressings are not required on V-belt drives. In fact, such dressings can do far more harm than good. Not only do they tend to act as solvents which attack the rubber in the belts. They also pick up dirt and sand to which pumping unit drives are exposed. As the belt moves with respect to the sheaves, the sand acts as an excellent lapping compound which quickly wears down the groove sidewalls.

Make sure that the sheaves are reasonably lined up and that shafts are reasonably parallel. Of these two suggestions, keeping shafts reasonably parallel is the more important. Notice in Figure 12 that when the shafts are not parallel, the belts will be progressively tighter from one side of the drive to the other.

This does not mean that it is necessary to use a transit to set up V-belt drives. An ordinary steel tape intelligently used can insure that the shafts are reasonably parallel. The sheaves can be aligned simply by sighting along the edge of one sheave to the other, or by stretching a string across the face of one sheave to the other.

Slack off on the drive take-up so that the belts can be put on without forcing. Although V-belts are elastic, they are not rubber bands. Forcing a belt over the groove as in Figure 13

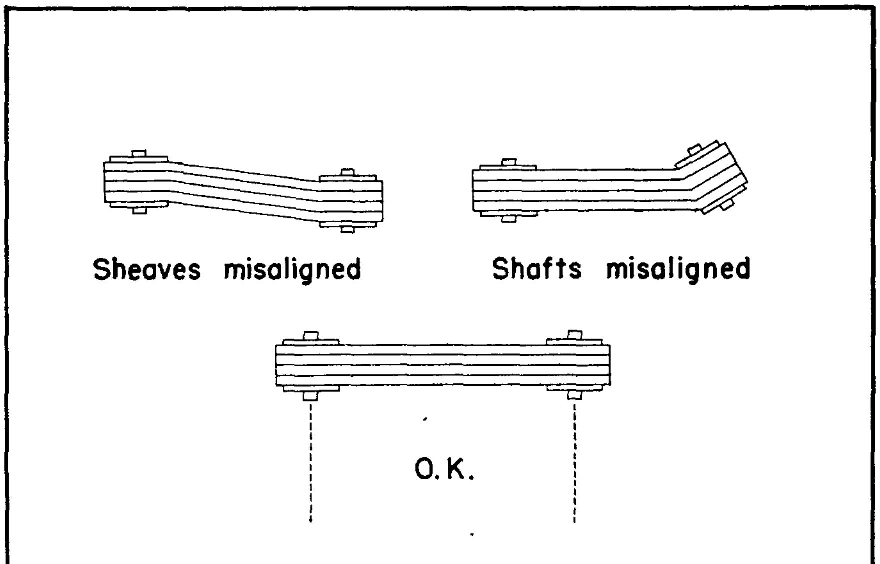

Fig. 12

can result in breaking the tensile cords in the belt. The belt will then be unable to carry its share of the load, and this will force the other belts in the set to carry more than their share.

Tension the drive until only a slight bow appears in the slack side of the belts when operating. If the belts slip, tighten them up. If they appear mismatched, but have the right range of length numbers, tighten a little more, and let the drive operate for a while.

After the drive has been installed and has operated for a few hours to give the belts a chance to seat themselves properly in the grooves, retension the drive.

Maintenance Suggestions

Once the drive has been set up, only a minimum of maintenance will be required—and that maintenance will primarily consist of preventive inspections to see that everything is all right.

The operator will occasionally want to check to see that the drive is up to speed and that the belts are clean and free from oil and grease, are not rubbing against a belt guard or other obstruction, appear reasonably matched, and are all operating. If something seems to be wrong, he will want to take the necessary steps to determine the trouble and correct it.

If the pumping speed is down, and the engine speed isn't, then, of course, the drive is slipping, and a take-up should be made. If the belts are greasy and oil-soaked, they should be cleaned off with a gasoline-soaked rag and prevented from getting that way again. (If this can't be prevented, then recommend putting oil-resistant belts on when a replacement is made.)

After the first belt or so has failed, continue to operate the drive—retensioning the remaining belts if necessary—until a replacement set has been secured and it is convenient to shut the drive down and make the replacement. When it is about time to get a set of replacement belts, it is a good idea to make a careful check of the sheave grooves so that, if necessary, a new sheave can be ordered at the same time. A template similar to that shown in Figure 14 will prove very useful. In using such a template, the proper stub (which is shorter than the minimum depth) to fit the angle of the groove is found by experimenting. The wear is observed by seating the template squarely in the groove and sighting between the sides of the template and the sides of the groove.

Groove wear of about 1-64 to 1-32 inch (Figure 15A) will probably not seriously affect the service of the drive. When the wear is about 1-16 inch (Figure 15B), it will probably pay in longer belt service to replace or regroove the sheave. In extreme cases, as in Figure 15B, the shoulder is so pronounced that a new belt simply rides on the shoulder, even though the old belts—which wore in the shoulder—seemed to fit well enough. So there are obvious advantages in checking for this sort of condition before putting on a replacement set of belts.

The grooves in a sheave may not always wear down uniformly. When

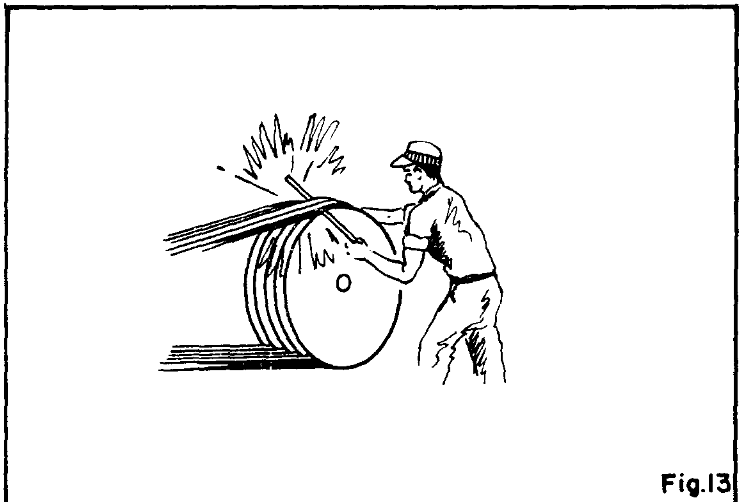

Fig.13

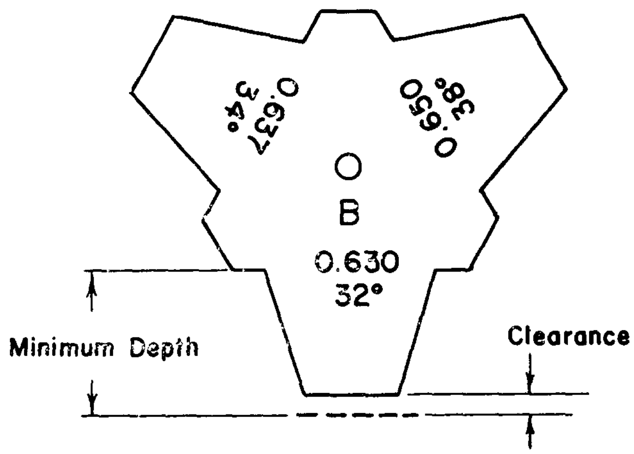

Fig. 14

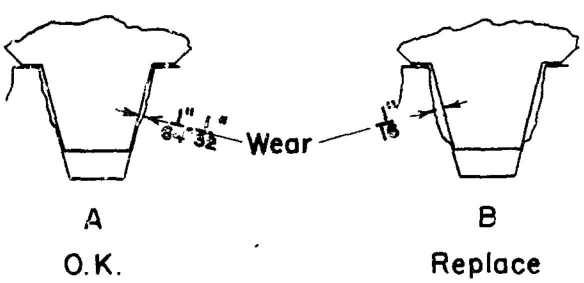

Fig. 15

checking for wear, it is good practice to check for uniformity of the grooves. Figure 16 shows the three ways in which the template may fit a groove in a sheave. If the template does not fit each groove in the same way within about 1-64 inch in the apparent groove top width, there may be enough differential driving so that regrooving or replacing the sheave will pay good dividends in longer belt service.

Unusual problems which may arise during the life of the drive can be handled by carefully considering the V-belt drive fundamentals previously discussed. For example, let's say that a matched set of belts has been operating a few days, but that one belt seems to be considerably longer than the others. The sheave grooves were checked and found satisfactory before the belts were installed, so the possibility of differential driving can be pretty well ruled out. An inspection of the apparently long belt is indicated. (Chances are that it was pried over the sheave in installing, and a spot where the belt has narrowed, or "necked down", will be found. This is the point at which the tensile section was damaged on installation.)

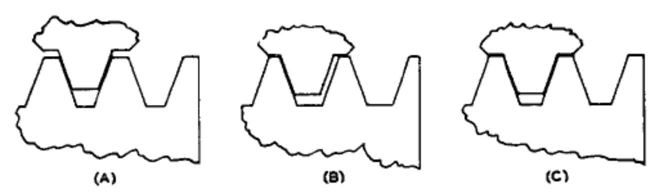

Fig. 16

Or it may be that on one particular well, or group of wells, frequent take-ups are necessary and drive service is consistently lower than on other wells. This would suggest that the drive is overloaded. The field or district engineer should be asked to check over the design or run a dynamometer card to see if this is actually a case of overloading. If so, it would pay to use premium-rated belts at the next replacement.

Then, too, there are occasional situations over which the operator has no control. If the drive consistently runs out of take-up before the belts have failed, it may mean that not enough provision for take-up has been made. This, and similar problems, should be referred to the field or district engineer for review.

Summary

In summary, a V-belt drive requires surprisingly little care and maintenance. Understanding a few fundamentals of how a V-belt operates in the sheave groove, and the stresses to which its various components are subjected while transmitting power enables one to identify and correct the troubles which infrequently arise, and to realize the long, trouble-free service for which the drive was designed.