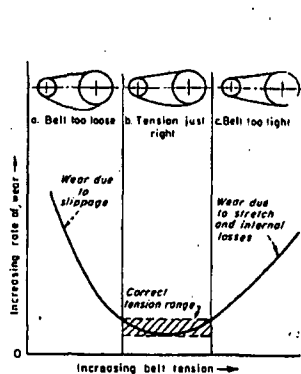
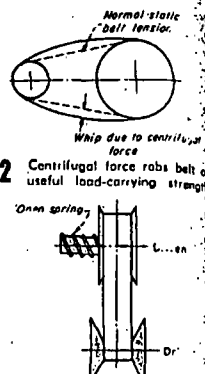


Here are fundamentals back of today's most popular variable-speed drives:

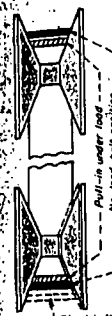
- How torque is transmitted
- Why manufacturers rate their units conservatively
- Why efficiency improves from low to rated output



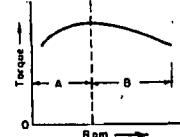
1 Belt tension must fall in a narrow range for long life, maximum power transmission



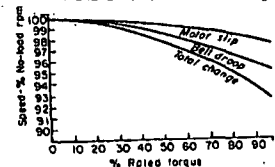
2 Centrifugal force robs belt of useful load-carrying strength



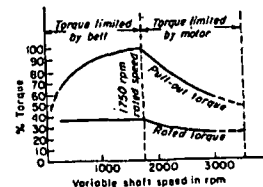
3 Cone pressure against belt changes with speed variation



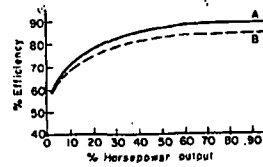
4 Maximum output torque varies as tension and driven-cone radius change



5 As torque increases, the speed ratio is changed, sometimes as much as 7%



6 Manufacturers' torque rating is conservative, to protect transmission



7 Typical efficiency values are essentially flat from 50 to 100% output

Mechanical Variable-Speed Transmissions: IV

By W L BYLER, North Wales, Pa.

► TO UNDERSTAND operation of variable-speed transmissions, we need to know the theory behind them. Here are four fundamentals of the currently popular variable-cone transmission: driving force, speed-torque relationships, unit ratings, efficiency. See parts II and III for commercial applications of this principle in use today.

Driving force in any belt system is the difference between tensions in tight and slack sides of the belt. For maximum life and transmission effectiveness tension must be just right, Fig. 1. If belt is too loose it will slip, increasing wear and power loss. If too tight, extra stress causes heating, fatigue and wear. Power is wasted, belt and bearing life shortened.

Initial tension limits the maximum force that can be transmitted, so most transmissions incorporate some arrangement for "loading" the belt or chain. The loading device can assume any one or a combination of several forms: a spring-loaded variable cone; a spring- or weight-loaded floating belt tensioner; pressure on belt cleat reinforcements; adjustable base, spring or floating pulley to increase center distance and add direct pull.

As speed changes, three factors affect maximum belt tension: (1) arc of

contact, sometimes called the angle of wrap (2) centrifugal force (3) pressure of cone faces against belt.

Arc of contact affects both ends of the speed-torque curve, Fig. 5. The smaller the arc of contact (less wrap), the lower the friction force between belt end cone or pulley. Pull is reduced.

Centrifugal force, Fig. 2, affects only the high-speed end of the speed-torque curve. It varies as the square of speed. Hence, a stress of but one unit of centrifugal force at 800 rpm would increase to nine units at 2400 rpm—a speed change of only three to one. Centrifugal force becomes an important factor at 3000-fpm belt velocity, and at 5000 fpm it becomes the controlling factor.

This force is independent of pulley diameter. It depends entirely on belt velocity. A belt traveling 3000 fpm over 10-in. pulleys is subject to the same centrifugal force as one traveling 3000 fpm over 20-in. pulleys.

There are two ways that centrifugal force is detrimental—first, it imposes stresses that rob the belt of useful load-carrying strength, and second, it throws belt outward from its normal driving path, reducing arc of contact. Full torque cannot be transmitted.

Pressure of cone faces against the belt decreases at low speeds, Fig. 3. On some

transmissions, movement of the variable cones reduces spring compression. On others the center distances are modified, thus lowering belt tension. In either case, torque transmission at low speeds falls off.

Speed-torque relationships. Maximum output torque, Fig. 5, is the product of varying driving tension and changing driven-cone radius. At low speeds, *A*, torque droops due to decreased cone pressure on belt or to shift of belt position. At high speeds, *B*, centrifugal force causes droop.

Fig. 6 shows performance of a typical variable-cone drive (transmission with motor). At output speeds less than rated motor speed, belt limits torque transmission. Above full-load motor speed, motor limits torque.

To protect the transmission against heavy starting loads, shock and overload, manufacturers rate their machines conservatively as shown on the "rated torque" curve. Such ratings create a constant-torque illusion. But variable-speed transmissions are fundamentally torque converters, and torque can increase from rated to pull-out values as output speed decreases.

Unit ratings. Most commercial transmissions are rated for moderate service conditions—8 hr per day, non-shock

infrequent starting and stopping. Next month we'll discuss a way to evaluate manufacturers' ratings.

Tests show that wear on belts and cone faces is fairly constant if drives are rated as constant-torque machines up to 1:1 speed ratio, Fig. 6, and constant-power above 1:1. The machine doesn't actually behave as a constant-torque transmission. It is only rated that way. Considering a variable-speed unit as a constant-torque machine will often lead to trouble in the plant.

In rating their units, manufacturers consider at least three other factors:

(1) All mechanical variable-speed transmissions are necessarily a design compromise with limitations like torque and speed sensitivity, limited accuracy in speed duplication, limited strength of the lubricant used.

(2) Speed ratio changes due to the torque transmitted. Belts and chains may pull-in to a smaller cone diameter when torque is high, Fig. 4. Such deviations usually reduce operating speed, thus preventing exact speed control. This causes an output speed variation from 2 to 7% below catalog ratings when the transmission is operated with locked controls, Fig. 7.

On the right-type transmission, using metallic cones and rings, increased

torque loading may reduce output speeds due to sliding between cone and ring. Driving forces are ordinarily carried by an oil film between ring and cone—much as a journal is carried on its bearing. When torque demands are increased beyond some maximum, the oil film ruptures and direct metal-to-metal contact occurs. At this peak torque, output speed can actually fall to zero, so the torque-speed droop can range from 1 or 1½%, when properly applied, to 100% on severe overloading. Overall operating performance is similar to the variable-cone type, as shown in Fig. 7.

(3) Speed ratio changes due to input speed variations. Under a constant-torque load, a change from low to normal input speed may produce a downward ratio change. This is usually less than ½% of 1%.

Efficiency. Having considered the major variables affecting operation, let's consider five principal losses affecting efficiency:

(1) **Belt losses.** Rubber and cords create friction as the belt stretches and flexes. With chain drives, there is flexing and surface friction of laminations. On ring-and-cone drives, friction is due either to excessive pressure or viscosity of the lubricant used.

(2) **Entering and leaving losses.** caused by friction between belt and sheave, or chain and radial slotted cone face. This is not slip.

(3) **Windage**—created by ribs or fins on cones, velocity of belt, rotating cone carriers, etc.

(4) **Friction**—in bearings, floating belt tensioner, etc.

(5) **Miscellaneous**—friction of gears or other driving elements, heat losses from rotating parts churning through oil reservoir, etc.

These transmission losses are essentially constant. They do not change much with changes in speed or load. Fig. 8 is a generalized efficiency curve for a belt-driven variable-cone drive and an all-metal ring-and-cone drive. It illustrates the general characteristic pattern for these machines. Actual values may be somewhat different for a given machine. In fact, they will change for two identical machines doing different jobs or operated at different input speeds. Always review these points carefully with the manufacturers before purchasing or putting a transmission in service.

Lower efficiency at lower output is due to constant losses being a larger percentage of power output. This is especially true at low operating speeds.