MOTOR SELECTION
for
BELT-CONVEYOR DRIVES

by
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Abstract—**Rated power is the motor parameter always specified when motors are selected for a belt conveyor—motor slip is usually ignored. This paper shows how the running and starting characteristics of a belt conveyor are influenced by slip. It shows that high-slip motors improve load sharing between directly coupled motors, and it shows that high-slip motors reduce the effect of belt stretch to improve load sharing between belt-coupled drums. The interaction between stretch and slip is illustrated graphically to show the percentage of connected power available to a conveyor without overloading the motor(s) driving the secondary drum. If the power requirement for the conveyor has been determined correctly and if the power available is inadequate, the stretch-to-slip ratio is too high—probably the result of an inadvertent selection of high-efficiency motors with low slip and poor starting characteristics. With these motors, mechanical devices that introduce slip are required if the conveyor is to operate near design capacity. A preferable solution is to avoid the problem by using directly coupled high-slip motors to improve load sharing and increase starting torque. Examples are given of two motors that eliminate the need to introduce slip mechanically.**

I. POWER REQUIREMENT

The power-requirement for a belt conveyor is a function of five components:

1) the power required to run the empty belt,
2) the power required to horizontally move the load,
3) the power required for vertical lift,
4) the power required for friction from additional equipment such as skirting or side-travel rollers, and
5) the power required for acceleration.

The sum of the first four components is the power required to run the conveyor. The acceleration component is only required during starting. For acceleration times longer than 15 seconds, the acceleration component is usually small with respect to connected power and little advantage is obtained by increasing acceleration time above 20 or 25 seconds. The usual method used to determine total power required is to multiply the sum of all five components by 1.1 and choose the next largest standard size. The result of the acceleration component, the 1.1 factor, and rounding up is that belt conveyors typically utilize about 70% of connected power when operating at design capacity. This is an excellent operating point because motors operate efficiently in this range and it allows a margin for running overloads, heavy starts, and unbalances in load sharing.

II. THE RUNNING CONVEYOR

When directly coupled motors start a conveyor, slip is high and load sharing among motors occurs because small differences in motor speed result in small differences in motor torque. In fact, motors with different power ratings and operating speeds will share a starting load according to their respective power ratings. When running, load sharing can be a problem because small differences in motor speed result in large differences in motor torque. The problem can be illustrated by expanding the operating range of the torque-speed curve of a 1770- and a 1785-rpm motor as shown in Fig. 1.

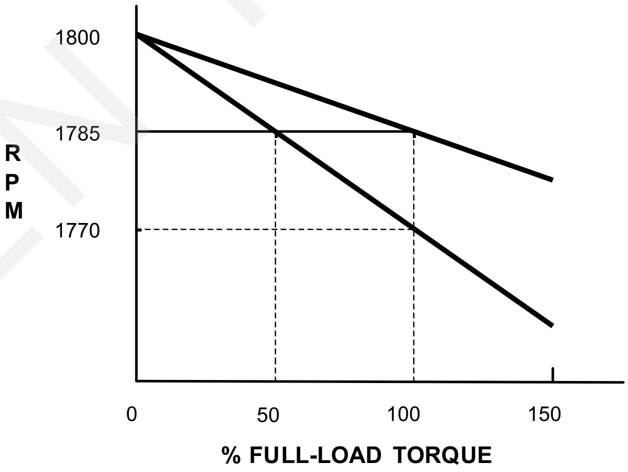

Fig. 1. Operating-range torque-speed curves for 1770- and 1785-rpm induction motors.

In the operating range, torque-speed characteristics are very nearly linear. If these two motors are directly coupled to the same drive drum, they are forced to run at the same speed and the 1770-rpm motor will be 50% loaded when the 1785-rpm motor is delivering rated power. Assuming equal power ratings, any loading beyond 75% of the total rating will cause the 1785-rpm motor to be overloaded. A corollary to this observation is that motors with different power ratings can be directly coupled and they will load share according to their power ratings if their rated speeds are the same. On the other hand, new motors with the same nameplate data might not equally share the load. Unless a premium is paid for dynamometer testing, motors are rated to the nearest 5 rpm. This means that two low-slip motors rated at 1785 rpm could be load mismatched by up to 23.5%

when they are directly coupled. The equivalent worst-case figure for 1770-rpm motors is 12.5%.

Belt stretch introduces an extra dimension to the load-sharing problem. In order for a drive drum to transfer power to a belt, it must increase tension in the belt by stretching the belt so that a section of belt entering the drum is longer than the same section of belt as it leaves the drum. In order to stretch a belt, speed of the drum must be equal to or greater than belt speed at all points of contact. Ideally, the speed of a belt entering a drum is equal to the speed of the contact surface of the drum, and the speed of the belt leaving the drum is lower by the amount of belt stretch. Fig. 2 applies to a drive drum with 1782-rpm motors (1% slip) and a belt that stretches by 1% at rated power—a stretch-to-slip ratio of 1.0 for the drum. For illustration, speed is referenced to the motor shaft.

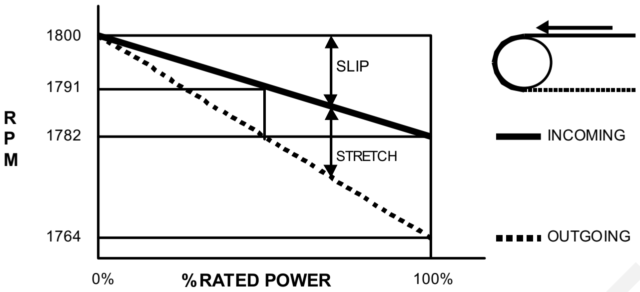

Fig. 2. Incoming and outgoing belt speed as a function of rated power.

Provided tension in the outgoing belt and the coefficient of friction between the belt and the drum are sufficient to maintain incoming belt speed equal to drum speed, outgoing belt speed will be less than incoming belt speed by the product of slip and the ratio of stretch to slip.

With belt-coupled drive drums, incoming belt for the secondary drum is the outgoing belt from the primary drum as shown in Fig. 3.

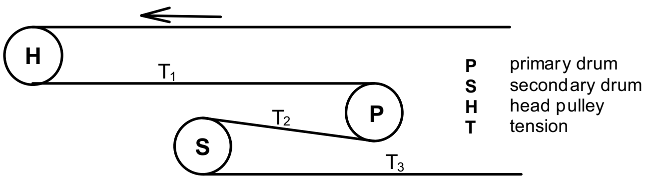

Fig. 3. Belt-coupled drive drums.

Since belt stretch is proportional to belt tension, speed of the primary drum is greater than the speed of the secondary drum when $T_1>T_2>T_3$ and both drums are driving. Maximum power available to the conveyor, without a motor overload, occurs when the motors driving the secondary drum are at rated power. If the primary and secondary drives are the same as the one in the 1%-slip, 1%-stretch example, Fig. 2 indicates that, at rated secondary output, the speed of the primary drum is 1791 rpm. At 9-rpm slip, the primary drum delivers 50% rated power and the tandem drive delivers 75% of connected power before an overload occurs. This example uses specific values for illustration—the following graph in Fig. 4 is a general solution showing percent of connected power available as a function of the stretch-to-slip ratio for 3- and 4-motor drives. Stretch is per motor and identical drums and motors are assumed.

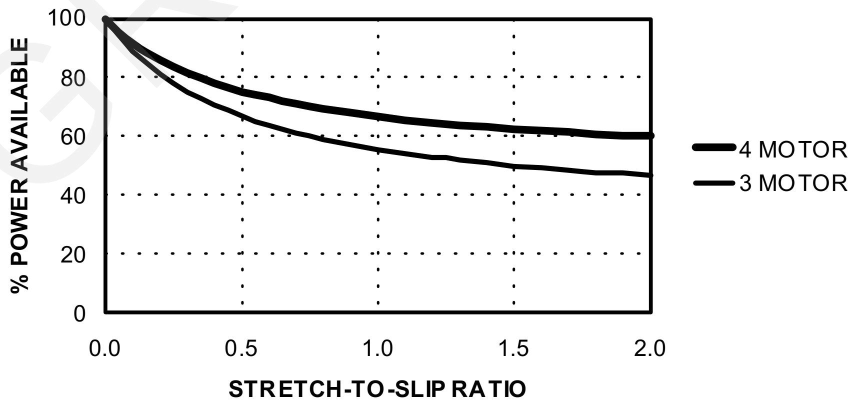

Fig. 4. Power available before overload occurs as a function of stretch and slip.

Fig. 4 shows that a decrease in belt elasticity and an increase in rated slip both have the same effect of increasing the power available when the secondary motor(s) are on the verge of becoming overloaded.

In a study on a 3-motor, 750-hp drive, manufacturer's data indicated belt stretch to be 0.765% per motor. The motors were rated at 1776 rpm resulting in a stretch-to-slip ratio of 0.57 per motor. Fig. 4 shows that for a 3-motor drive with a stretch-to-slip ratio of 0.57, only 64% of rated power is available. When the secondary motor delivers rated power the sum of stretch and slip for the primary motors is 24 rpm. Since the stretch-to-slip ratio is 1.15 for the primary drum, slip on the primary motors is 24 ÷ 2.15 = 11.2 rpm and total power available is 250 + 500(11.2/24) = 480 hp or 64%. To improve load sharing, a 1769-rpm motor was used on the secondary drum. Fig. 4 cannot be used directly for this example because it assumes all motors are the same; however, the increase in power available is easy to calculate since the sum of stretch and slip for the primary motors is increased to 31 rpm when the secondary motor delivers rated power. Slip on the primary motors is 31 ÷ 2.15 = 14.4 rpm and total power available is increased to 250 + 500(14.4/24) = 550 hp or 73%. For comparison, 1785-rpm motors on the same conveyor would have a stretch-to-slip ratio of 0.92 and power available would be only 57%.

Tie gears between the primary and secondary drums eliminate the load-sharing problem associated with belt stretch between belt-coupled drums. Tie gears force the primary and secondary drums to run at the same speed so that all drive motors are forced to share the running load to the extent that their individual rated speeds allow. However, tie gears do not permit load sharing between the drums. Tie gears effectively transfer all motors to the secondary drum and the primary drum does not contribute to belt tension unless the belt slips on the secondary drum due to the increased torque available to it—this is most likely to happen during starting.

III. THE STARTING CONVEYOR

There are two common misconceptions with respect to the torque required to start a belt conveyor. One misconception is that a belt conveyor has a high breakaway torque. Static friction is higher than rolling friction; but a belt conveyor does not break away all at once. Rather, it breaks away one element at a time due to belt stretch and the action of the belt-tensioning device—static friction does not have a significant influence on starting. The other misconception is that it takes significantly more torque to start a belt conveyor than to run it. The only component of the power requirement associated with starting is the acceleration component. The torque required for the other four components increase with speed and their sum is a maximum at rated speed. Consequently, a starting torque just slightly higher than the running torque will eventually start the conveyor. If the power requirement has been determined correctly, any starting technique that can deliver 75% rated torque, or more, throughout the start sequence should be able to start the conveyor. However, in order to control acceleration and to allow for occasional overloads, it is prudent to choose a starting technique capable of providing at least 100% rated torque throughout the start sequence.

IV. CONCLUSIONS

Unbalanced load sharing is not a problem unless it unnecessarily forces one or more motors into overload. Some unbalance is expected between motors on the same drum and between the primary and secondary drums. It is impractical and unnecessary to try to eliminate unbalance. The simple solution is to use high-slip motors that reduce unbalance to a tolerable amount. Stretch-to-slip ratios of 0.3 and 0.5 in 3- and 4-motor drives respectively allow 75% of connected power to be available without overloading the secondary motor(s). Any solution that involves motor matching or individual adjustments for each motor is unnecessary and expensive. The logistics of maintaining an industrial plant with numerous similar installations are simplified if one motor can be used in any location. Design-C motors are high-slip motors and they are recommended for conveyor applications. In addition to minimizing the load-sharing problem, the torque-speed characteristics of design-C motors also solve most conveyor starting problems.

Utilities and regulatory agencies are encouraging the use of high-efficiency motors. These motors are acceptable in single-motor applications; however, they have the wrong characteristics for multiple-motor conveyor drives. High-efficiency motors have low-impedance rotors that operate at low slip, load share poorly, draw high locked-rotor currents, and have poor torque constants. The term “high efficiency” can be a misnomer because, in some applications, the power consumed by a high-efficiency motor exceeds that of a standard-efficiency motor.

The torque-speed curves of two motors recommended for conveyor applications are shown in Figs. 5 and 6. The Toshiba motor has a 447TZ frame and a rated speed of 1770-rpm. It has a locked-rotor torque = 243% FLT at 607% FLA, a breakdown torque = 235% FLT, and a pull-up torque = 167% FLT. It can deliver an acceptable 100% FLT with only 425% FLA at the saddle in its torque-speed curve. It is marked design B for marketing reasons, but it is actually a design-C motor.

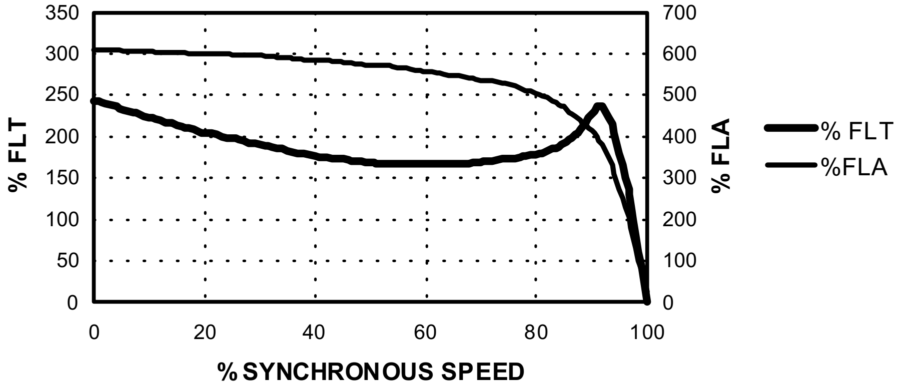

Fig. 5. Toshiba 200-hp SCIM.

The Westinghouse motor has a 449T frame and a rated speed of 1769 rpm. It has a locked-rotor torque = 259% FLT at 653% FLA, a breakdown torque = 204% FLT, and a pull-up torque = 233% FLT. Unlike the Toshiba motor, it does not have a saddle in its torque-speed curve and it can deliver 100% FLT with only 320% FLA at 60% speed. This is a design-C motor with ideal characteristics for a belt conveyor.

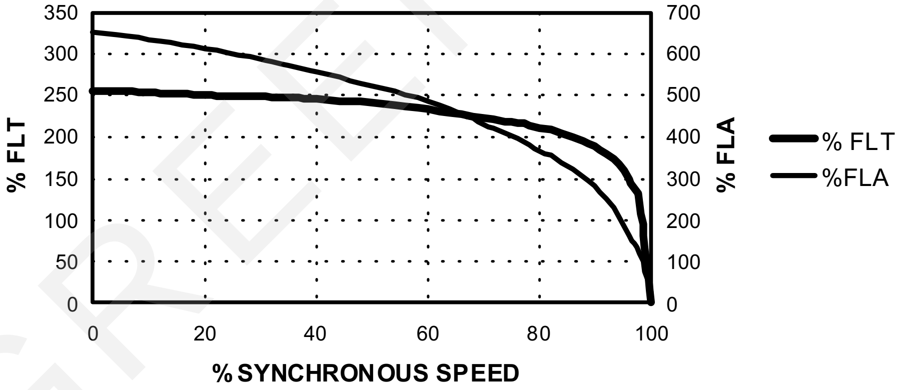

Fig. 6. Westinghouse 200-hp SCIM.