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DRIVES FOR HIGH-TORQUE APPLICATIONS

High-torque applications include high momentary overloads created when a system starts, receives a sudden shock load, or must supply constant torque over a wide range of operating speeds.

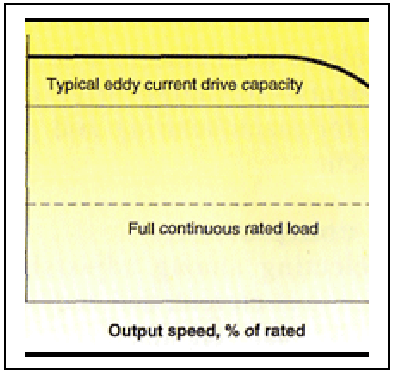
The range of torque needed to start and operate specific conveyors, presses, and other industrial machines presents a distinct torque-versus-speed profile, similar to an individual's fingerprint. For example, a typical torque-speed requirement for a metal-stamping press might be:

200% of full motor load for starting
75% of full motor load for accelerating
100% of full motor load for peak running

Frequently there is a significant difference between the drive's normal operating torque and occasional torque demands experienced at start-up or when loading changes. These overloads create conditions that favor the use of adjustable-speed (Eddy-Current) drives, because these drives have an inherent capability of generating momentary high torque. Engineers should consider them when torque requirements exceed 200% of rated torque. For cooling, these drives have built-in fans that operate at motor speed rather than output-shaft speed. This feature allows the fan to run much faster than rated output speed.

Industrial drives routinely must handle overloads as great as 150-250% of normal running torque, as shown in **Figure 1**. Often, too, they must maintain constant torque over speed ranges exceeding 200% of rated speed. These high-torque conditions present particular problems to engineers who specify components – including drive components – for manufacturing and process equipment.

Figure 1



Drive Comparisons

In selecting among adjustable-frequency, direct-current, and Eddy-Current drives, the plant engineer must review various considerations:

- Maximum horsepower (hp) requirements of the load.
- How required power varies with speed.
- Whether torque requirements are constant or variable with speed.
- Maximum and minimum speeds required.
- Acceleration required.
- Minimum and maximum speed adjustments required.
- Required speed regulation due to load changes and other variables.
- Environment, controlling method, and available maintenance capabilities.
- Duty cycle, including starts and stops per hour.

Defining High Torque

In selecting an electrical drive to suit an industrial application, calculate drive horsepower by determining the application's required torque and speed. To determine the required torque, measure the current used by the existing prime mover and relate this to motor torque by comparing the current used to full-load motor amps. To determine the speed of the application, either consult the nameplate of the existing prime mover or relate the process speed back to the prime mover through the gear box to belt ration. Then, calculate horsepower using the formula, $hp=(t \times N) \div 5250$

where
Hp = horsepower
T = torque (lb-ft)
N = shaft speed (rpm)

There are three types of torque that engineers should consider in the calculation: breakaway force, accelerating force, and running force.

Breakaway force is the torque necessary to start the operation. In general, this torque sets the upper limits of the operation. Combined with process torque, it determines the drive selection. The breakaway force is usually 150% to 250% higher than running torque in high-torque applications.

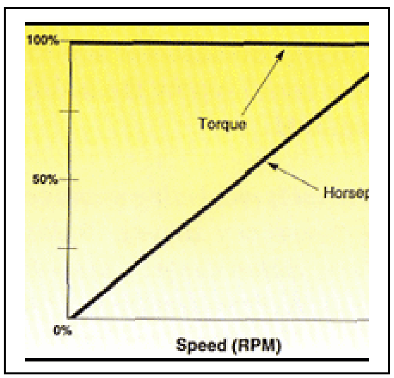
Accelerating force is the torque necessary to bring a system to operating speed within a defined period of time. With most machines, the load is largely friction, and a standard drive rating must have adequate torque for satisfactory acceleration. However, certain machines in high-torque applications, using flywheels, bull gears, or other large, rotating masses, may require drive selection based upon the accelerating torque requirement.

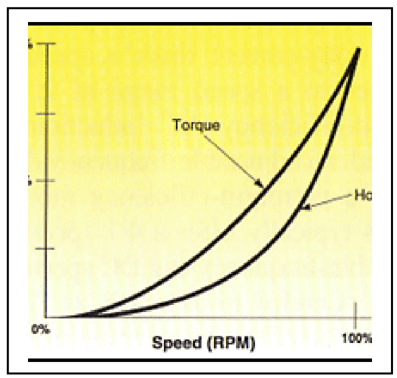
Running force is the torque required to pull, push, compress, stretch, or otherwise process and act upon materials transported by or through a machine. This torque is independent of friction and acceleration. Generally, this torque is classified into one of three types of load profiles: constant torque, variable torque, or constant horsepower.

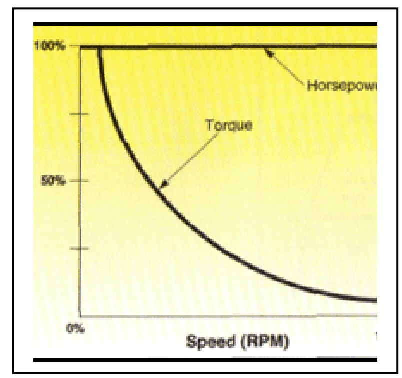
Figure 2 depicts a *constant torque* situation, in which torque remains constant regardless of speed. Most conveyors, extruders, and stamping presses fall into this category.

Figure 3 shows a *variable torque* situation, in which torque varies with the square of the speed. Centrifugal pumps and fans fall into this category.

Figure 4 represents a *constant horsepower* situation, in which torque varies directly with speed. Machine tool spindles and center winders are examples of machines in this category.







Calculating Torque

Running torque is calculated using the horsepower required to maintain the process and the speed at which the horsepower is applied to the process. Let's say, for example, that a metal stamping press requires 25 hp to draw sheet metal into the desired shape. If the press operates at a rate of 15 strokes/min (spm), the gear ratio is 25:1, and the belt ratio between the flywheel and the motor is 3:1, then

15 spm x 25:1 x 3:1 - 1125 rpm (motor)

A calculation based on this speed and the 25 hp yields a running torque of 117 lb-ft — (25 hp x 5250) - 1125 rpm.

In addition to the torque required to run the process, the engineer also must know the accelerating torque. Failure to take the required accelerating torque into consideration may result in a process that will run but not start. Accelerating torque is equal to running torque only if the load is composed entirely of friction. High-torque applications, however, often have high levels of inertia. To calculate the accelerating torque of a rotating machine, use the following formula: $T = [(WK^2) \times AN] + 308t$,

where:
T =Torque required (lb-ft)
WK =Total inertia of load to be accelerated (lb-ft^2)
N =Change in speed (rpm)
t =Time to accelerate load (sec)

For example, let's assume the same metal stamping press described earlier has a system inertia of 350 lb-ft reflected to the motor shaft. As the die makes contact with the metal, some energy is removed from the flywheel and transferred to the metal as the metal forms. This removal of energy causes the flywheel to slow down. In this example, let's say the flywheel slows down by 10%. The flywheel must re-accelerate prior to another stroke. To determine what this time is, use the reciprocal of the 15 spm operating speed, i.e., 0.07 *mm/stroke.* Converted to seconds, this is 4.20 sec/stroke.

The change in speed is simply 10% of the motor's 1125 rpm, or 113 rpm. As the flywheel slows down by 10%, the motor, which is physically connected to the flywheel by belts—disregarding any unusual slippage—also slows down by 10%. The accelerating torque required to return the press to full operating speed, then, is 31 lb-ft:

$$(350 \text{ lb-ft}^2 \times 113 \text{ rpm}) - (308 \times 4.2 \text{ sec})$$

Calculate the breakaway torque for this press in the same manner. Note, however, that the change in speed (ΔN) is 1125 rpm as the press starts from a stop and accelerates to its full operating speed of 15 spm. Normally, breakaway torque is determined by the service factor of the drive and limited by an overload-preventing acceleration circuit in the drive controller.

A common upper limit for AC and DC drives is a 150% overload for one minute. Eddy-Current drives supply 200% overload for one minute. This feature allows some additional accelerating torque without an increase in the horsepower rating of the drive.

Calculate the maximum horsepower needed for an application by adding the running torque and the accelerating torque. However, if running torque is equal to or less than accelerating torque divided by 1.5 (for AC/DC drives) or 2.0 (for Eddy-Current drives), use the breakaway torque divided by 1.5 or 2.0 as the full-torque load required to determine the horsepower needed for the application.

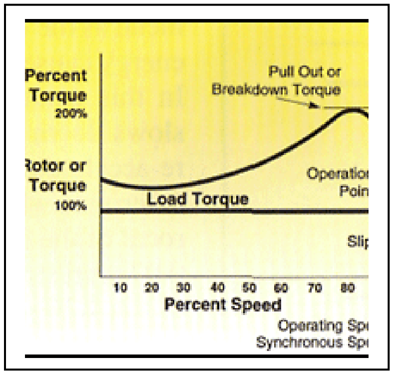
Of all electrical, adjustable-speed drives, the Eddy-Current is most often recommended for high-torque applications. The Eddy-Current drive consists of an AC motor and magnetic coupling in a single housing. A solid-state controller provides the excitation to the magnetic coupling.

An Eddy-Current drive consists of two parts. One part is connected to the shaft of the motor. The other is connected to the output shaft and coupled with a magnetic field.

Output torque is a direct function of the strength of the drive's electromagnetic field. Speed of the output shaft will never exactly match that of the motor because some slip is required to generate Eddy-Currents and transmit torque. Also, because slip generates heat, the clutch of an Eddy-Current drive is designed for self-cooling over a wide speed range. Units of 200 hp or less are air cooled, larger units are liquid cooled.

Eddy-Current drives have features that make them particularly suited to high-torque applications. For one, they provide high torque over a wide speed-range. Because the motor on an Eddy-Current drive constantly rotates at near-synchronous speed, it can provide the breakaway and intermittent torque across all operating speed ranges up to 200% of full-rated torque. As shown in **Figure 5**, the peak torque of a NEMA-rated motor is available at start-up and during overloads in the operating cycle. This capability yields smooth operation in applications where periodic shock loads are common. By contrast, adjustable-frequency and DC drives usually are limited by the current the controller can supply. They provide breakaway torque at 115% to 150% of rated load.

Figure 5



Eddy-Current drives also operate across a *wider* speed range. An Eddy-Current drive can operate across a 34:1 speed range because its internal cooling fan constantly runs at full speed. This feature is critical in many high-torque applications—conveyors and extruders, for example—that require a wide speed range.

The Eddy-Current drive's speed range compares to a speed range of 2:1 for a standard-efficiency AC induction motor used with an adjustable-frequency drive, or 4:1 for premium-efficiency motor. DC systems typically offer a 4:1 speed range. Adjustable-frequency and DC speed ranges can be extended to as much as 10:1, but doing this requires the addition of external cooling fans or oversizing the motor.

As a result of the Eddy-Current drive's capability to provide high torque over a wide speed range and to operate across a wider speed range than other types of drives, engineers can specify smaller drives and motors for high-torque applications. In effect, a 15 hp Eddy-Current drive suffices where a 25 hp adjustable-frequency drive is needed.

Typical Problems

In high-torque applications, the specifying of an incorrect drive drastically affects operations. Tell-tale signs of incorrect drive specifications are:

- *The process won't start.* When trying to break away from dead stop, the drive does not provide enough torque, and the operation remains at a standstill. Such an application requires a larger drive or one that provides more torque.
- *The motor overheats and trips off-line.* In this case, an inadequate drive system fails when it encounters high torque. If this occurs often and repeatedly, the motor insulation may sustain permanent damage, resulting in shorter motor life.
- *The controller faults on over-current.* Over-current will cause an adjustable-frequency drive to fault if the drive is undersized for the torque required. Again, a higher horsepower adjustable speed drive could supply the additional torque required.

By Mark Kenyon
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