Out with mechanical, in with electrical

The speed of a driven shaft can be varied by mechanical methods, but electrical drives often perform better.

Jeff Lovelace
Baldor Electric
Fort Smith, Ark.

Most mechanical linkages for speed adjustment work well and are easy to understand. However, maintenance can become a headache in both labor and replacement costs. Too, if machinery is upgraded to operate more quickly, mechanical solutions must usually be replaced. In contrast, adjustable speed drives (or *ASDs*) exhibit no mechanical failures, and change speeds and torque with simple parameter entries, on the fly. Also, because processor speed and memory are constantly being increased, drive intelligence is always on the rise.

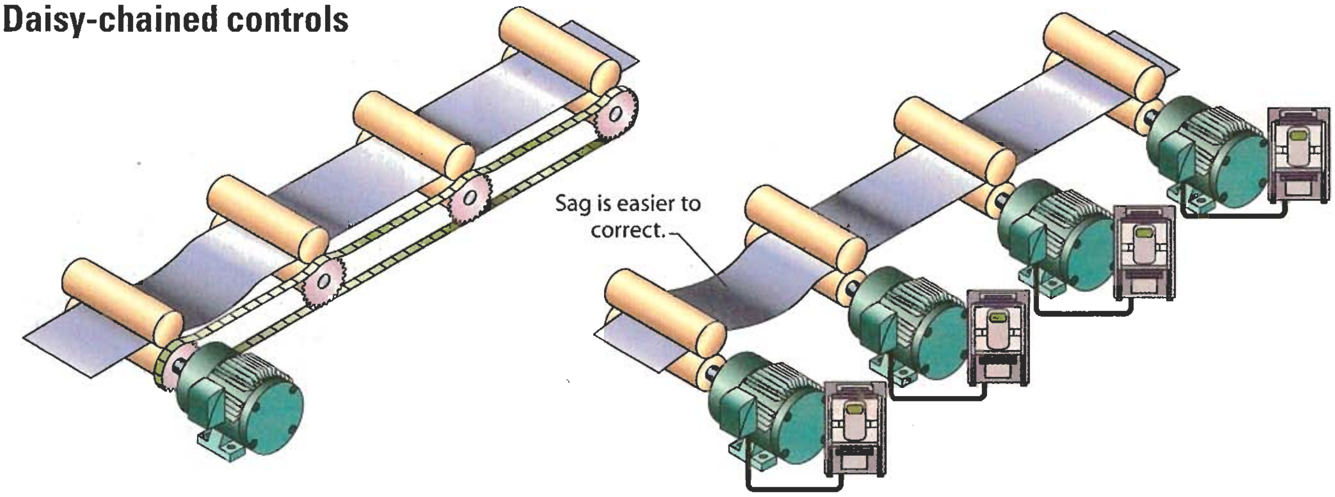
Belt-drive comparison

One common system used for speed adjustment is a belt drive. Variable-pitch pulley mechanisms on these systems change the speed of the load. In its simplest form, the ratio of an adjustable pulley is opened or closed to regulate speed, and a spring-loaded pulley self-adjusts in the opposite way. Several different manufacturers offer systems designed to specific turn-up or turn-down ratios. More advanced pulley systems are mechanically linked so that as one pulley is opened or closed, the opposing pulley is changed as well. This prevents belt slippage.

As with any mechanical gear change, whether it be a true gearbox or rational pulley system, speed and torque are inversely proportional. As the load goes faster, torque drops. Conversely, as load slows, torque increases. This is useful in applications such as cutting, where high torque might be needed on a drill bit, but low torque (and high speeds) is needed for polishing and finishing cuts. Typical ratios are around 3:1, but can be as high as 9:1; horsepower is generally limited to about 50. Because these systems can be a safety hazard, guards must prevent contact with rotating equipment.

More sophisticated arrangements include a pneumatic or hydraulic system to make mechanical changes without manual adjustment. PID controllers make this automatic. However, load torque must be considered anytime this setup is used. If drivers turn faster than the load, available torque on the load goes up.

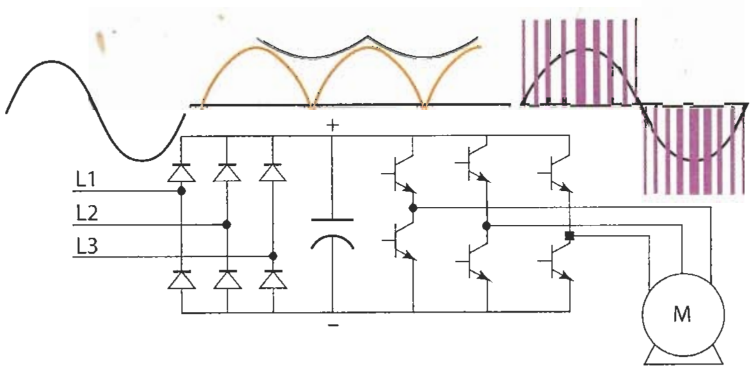
Daisy-chained controls



Instead of using one 20-hp motor with mechanical links to synchronize motion, four 5-hp drives with motors can be used instead. This eliminates the wear that can cause asynchronous motion.

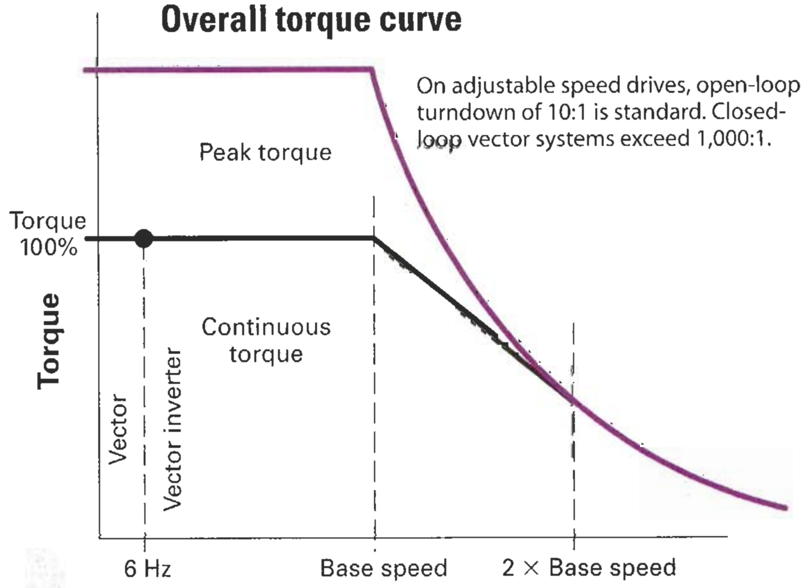
A typical ASD takes incoming line voltage and converts it to dc voltage. Horsepower ranges for ASDs now reach 2,000-plus for low-voltage controls, defined as about 600 V or less.

Ac drive topology



By separating torque-producing current from that for flux, vector drives can produce full torque down to zero rpm. Note that horsepower remains constant beyond base speed — impossible with certain mechanical systems.

Overall torque curve



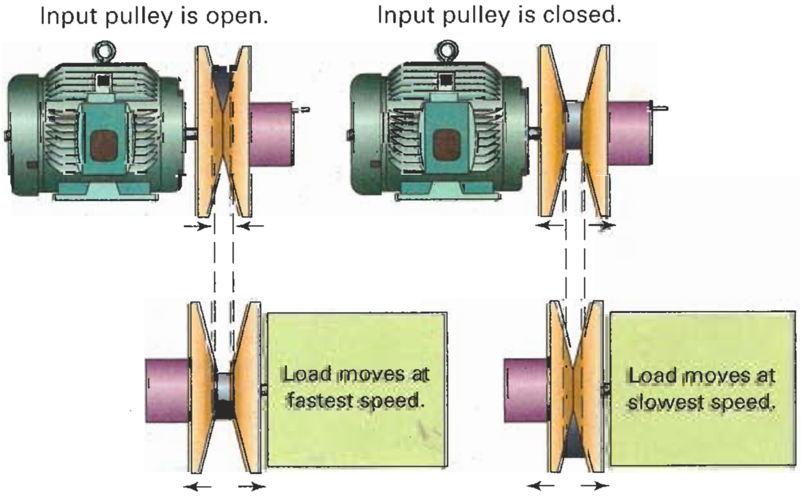
This can pose a problem when a designer must change speed, but maintain available torque. Another issue is wear and tear. Over time, springs lose their effectiveness and belts loosen and begin to slip. If springs are overtightened, then belts tend to create more drag, and further losses occur. So if belt drives are used, much engineering effort must be involved up front for sizing and scheduled future maintenance.

ASDs are suitable for applications where speed (and *not* torque) changes. There is no mechanical wear, and if the operation requires speed changes at a new ratio, the drive can deliver that without equipment change.

Traction-drive comparison

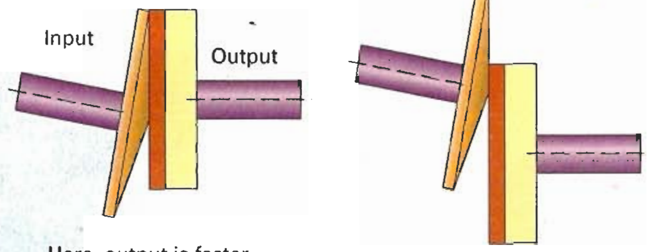
Another method of changing speed is with traction drives. With these systems, two rotors are meshed together at varying angles. Change in contact point changes load speed. Best suited for continuous loading

Pulley speed control



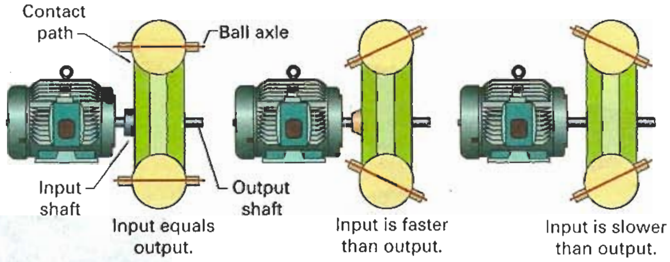
Some belt systems are mechanically linked so that as one pulley is open or closed, the opposing pulley is changed as well — to regulate speed.

Traction drives ...



In traction drives, two rotors mesh at varying angles. Changing the contact adjusts load speed.

... one motor, many speeds



Or, as shown here, drive balls mounted on tiltable shafts press upon cone faces. By moving a lead screw, the balls tilt the shafts to increase or decrease the overall speed ratio.

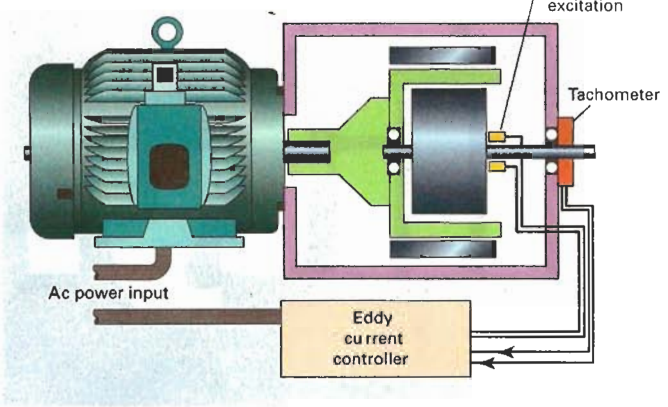
applications, traction drives quickly fail under spike loading, as slippage can easily occur and quickly reduce the life of moving parts.

In comparison, adjustable speed control can tolerate spike loading and reduce transients seen from the shock. With continuous current regulation, the control reduces peak currents to a reasonable level. Even applications with the worst shock loading (like rock crushers, for example) can benefit from this type of control. The downside of traction drives — the inability to adjust torque — is no problem with an adjustable speed control. Too, overspeeding is acceptable unless the motor mechanically prevents it.

Following and synching

Mechanics can also be used for *following* — applications in which one part of the system is a function of another. Some machinery relies strictly on one motor with multiple gearing to provide synchronous motion throughout the machine. As parts wear, this gearing usually degrades into asynchronous operation, resulting in a

Controlled Eddy-current clutch



In a system using an Eddy-current clutch for speed control, the motor is started while the clutch is disabled. After the motor has reached its speed, a controller engages the clutch by allowing current to flow to it.

poor product. The user must repair the machine by replacing gearing. Making adjustments is not easy, either. And then in the case of web processes, adjusting for slack is difficult as well.

For these applications, adjustable speed drives — specifically, vector versions — provide simpler control. For example, one mechanically linked 20-hp motor can be replaced with four 5-hp drives with motors. A line-shaft encoder (or the encoder from another control) allows connection of an unlimited number of motors for running in daisy chain or parallel configuration.

Incorporating this electronic gearing, accuracy can be maintained to plus or minus one encoder count, and can manipulate any gearbox range. Should the process be changed or different materials used, updating is a matter of adjusting the ratio in the controls.

Eddy-current clutches

Though not a mechanical solution, Eddy-current clutches are another speed-control mechanism that has been around for some time. By adding one of these inductive-type clutches to a motor, load speed can be varied for regulation down to 0.5% of maximum speed when the load goes from 10% to 100%. (From no load to full load, the tightest regulation is 3% or so.) At start, the motor is started across the line, with the clutch disabled — so that it receives no current flow. After the motor has reached its target speed, its controller engages the Eddy clutch.

Eddy-current clutches consist of a field, tachometer, and Eddy-current control module. The control module supplies dc current to the clutch, which in turn causes the load to spin. Feedback from the tachometer is fed to the control module in a PID setup. The more torque required by a load, the more current the clutch requires to prevent slippage. But with no load, the least amount of leakage into the clutch can cause the shaft to spin — so holding an unloaded system at zero speed is extremely difficult. Too, no additional torque can be supplied to the load; at best, the load attached to one of these clutches sees 95% of motor speed. For example, with a 1,780-rpm drive motor, load spins at 1,690 rpm; the load never sees full speed. This must be taken into account when sizing for speed and torque.

In contrast, ASDs change frequency to the motor to make speed directly proportional to the frequency supplied by the motor. The only caveat is that motors do have inherent *slip*. Thus at 60 Hz, a four-pole motor might operate at 1,780 rpm at full load and 1,800 rpm at no load. That said, full motor range is available, and (unlike systems with Eddy-current clutches) overspeeding is possible.

VSD operation review

The speed of a three-phase induction motor is based on line frequency. In the U.S., this frequency is 60 Hz or 60 cycles per second. The most common is a four-pole design. Synchronous motor speed is:

$$Speed = \frac{120 \times f}{Poles}$$

where f = frequency

So, a four-pole motor running across the line in the U.S. has a synchronous speed of 1,800 rpm. That said, all motors do exhibit slip at full load; therefore, true motor rated speed would be more like 1,750 to 1,780 rpm.

Adjustable speed drives (also called variable frequency drives, inverters, and adjustable speed controls) change the actual frequency the motor sees. Typically, ASDs take incoming line voltage, convert it to dc voltage, and then filter to remove ac ripple. Next, transistors invert current back to ac. Because the transistors are controlled via a processor, any voltage and frequency can be regulated to the motor — so speed can be set simply by adjusting the frequency to the motor.

Vector drives offer a level of sophistication higher than that of inverters by using encoder feedback to determine actual speed. By separating torque-producing current from flux current, vector drives can also produce full torque down to zero rpm. Open-loop control with turndown of 10:1 is standard, but with encoders and vector technology, turndown can exceed 1,000:1. Turn-ups are only limited by motor mechanical limitations: Drives can generate frequencies to 1,000 Hz, so horsepower is constant beyond base speed, and speed possibilities are infinite.

For more information, visit baldor.com, or e-mail the editor at eeitel@penton.com.