ADJUSTABLE-SPEED DRIVES

Adjustable-speed drives adjust the speed of a driven shaft to a speed selected by an operator or by an automatic speed selection device. These automatic devices include speed reference signals generated by other drives, process controllers, programmable controllers, or other devices.

In addition to changing the speed of a machine, adjustable-speed drives are also used to maintain the speed of a machine, regardless of load, to very close tolerances: ± 0.1%, is not uncommon. This is more accurate than the speed regulation offered by a conventional ac motor, which can vary 3%, from no load to full load.

There are many applications that require adjustable-speed capability. Just a few include:

- Large paper machines and printing presses must accelerate smoothly from standstill to running speed without breaking the webs.
- Drill presses often use a wide range of speeds for a single job: low speeds for drilling large holes and high speeds for small holes.
- Pump and fan efficiencies greatly increase by adjusting their speeds rather than regulating flow by throttling.
- Metering pumps require different speeds to produce different compounds.
- Speeds and positions of robots must be precise and change with each phase of a task.

SOFT START

One type of unit closely resembles an adjustable-speed drive, but performs only one function — slowly increasing the voltage applied to an ac motor. In essence, it is a solid-state reduced-voltage starter — often called "soft start," because it smoothly accelerates the motor to running speed. This soft acceleration prevents breaking belts, damaging conveyors, etc. It also reduces high peak electrical currents usually encountered while starting an ac motor across the line. These electrical units, covered in the Controls and Sensors department in this handbook, under "Motor Controllers," are similar in appearance and use much of the same technology as electrical adjustable-speed drives.

There are other methods for softly starting loads, such as fluid couplings between the motor and the driven load. These are discussed in the Couplings and U-Joints department.

COMMON TERMS

Most of the following terms apply to all types of adjustable-speed drives. Additional information is given for some terms as indicated.

Adjustable-frequency drive (AFD) — common term for ac, adjustable-frequency drive, inverter, and ac drive. (See "AC drives.")

Adjustable speed — where speed is adjusted manually or automatically. The set speed (desired operating speed) is relatively constant regardless of load, as opposed to "variable speed."

Adjustable-speed drive — a unit that adjusts the speed of a shaft to a set speed that remains relatively constant regardless of changes in required load torque. How close this set speed remains constant depends on the type of drive and its capabilities, and on "other variables." (See "Speed regulation.")

Armature control — short term for "armature voltage control" of a dc motor, this describes the usual method of changing the speed of a dc motor — controlling the armature voltage. When this method is used, most dc motors are capable of delivering constant torque.

Base speed — used primarily in specifying dc shunt-wound motors. Base speed is the motor speed while delivering rated torque with field current and armature voltage at rated values.

Brushless dc, brushless ac, and brushless PM servo motor — generally refer to motors with permanent magnet rotors and wound stators that are wound similar to 3-phase induction motors. Often abbreviated BLDC, BDC, and BLAC, this design is also similar to an ac permanent-magnet synchronous motor. (See "Positioning drives.")

Constant horsepower operation — see "Field control" and Figures 1 and 2.

Drift — speed change at constant load caused by many factors, most of

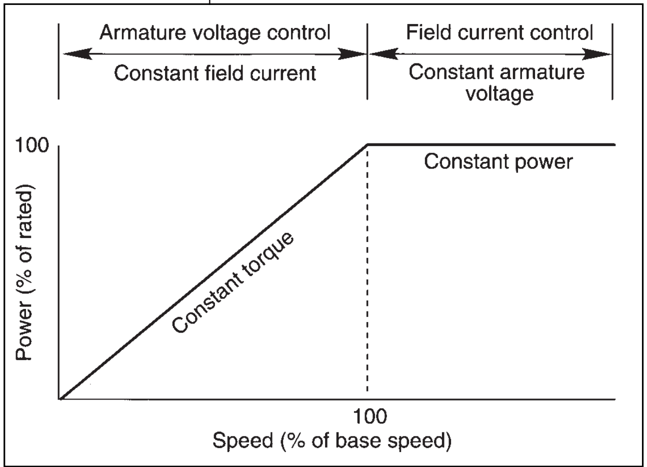


Figure 1— Output power of dc motor with armature-voltage and field-current control.

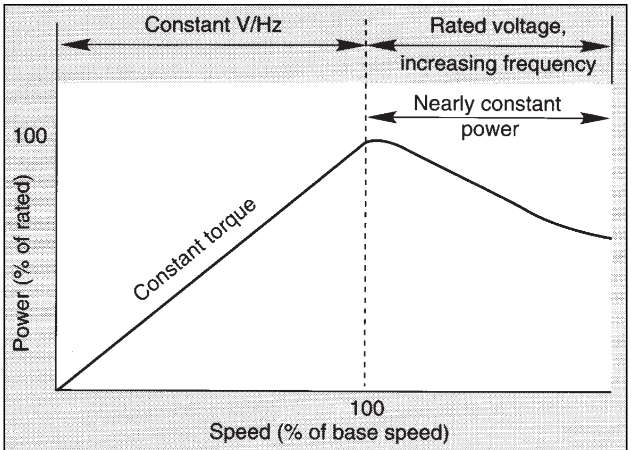


Figure 2 — Typical output power of an ac motor operating above and below base speed.

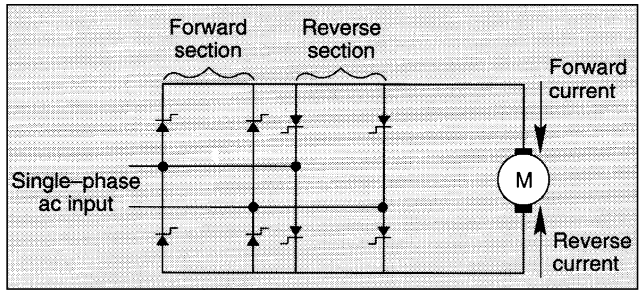


Figure 4 — Regenerative power module for SCR-type dc drive with single-phase input. (Field supply not shown.) The forward section controls power during motoring, and the reverse section controls power while it is regenerating to the ac power source. Power module for three-phase power is similar, except each section has six SCRs.

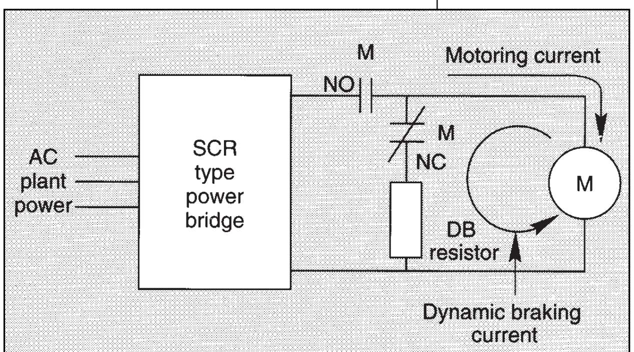


Figure 3 — DC motor with conventional dynamic-braking (DB) circuit. When controller powers motor, the normally open (NO) M contact is closed. Upon stopping, this NO contact opens, and the normally closed (NC) contact closes, connecting the DB resistor across the motor armature. The DB resistor then dissipates the rotating mechanical energy as heat.

which are undefined.

Dynamic braking — method of stopping a dc motor faster than coasting to rest. This method requires a resistor connected across the motor armature. During stopping the DB resistor dissipates the rotating energy, Figure 3. Dynamic braking does not offer controlled stopping as does regeneration, discussed later.

Electrical adjustable-speed drive — includes motor and drive controller. However, in some cases, "drive" is used to denote only the controller that converts plant ac power to adjustable-voltage dc or to adjustable-frequency, adjustable-voltage ac.

Electrically commutated motor (ECM) — same as brushless dc (BLDC). (Also see later discussion, "Brushless dc drives.")

Field control — a shortened term, this means adjusting the speed of a dc motor by controlling the motor field current. When the field current is reduced, the motor tends to increase speed and decrease in torque capability. Thus the motor power output is essentially constant, Figure 1.

Near-constant-horsepower capability can also be obtained from ac drives by operating the motor at rated voltage and above rated frequency. This also increases motor speed and decreases motor torque capability, Figure 2.

Inverter — usually refers to an electrical adjustable-speed drive that uses an ac motor. Actually, this term applies only to the inverter section that inverts dc to controlled-frequency ac in an ac adjustable-frequency drive controller.

Other variables — changes in line voltage, line frequency, ambient temperature, humidity, transients on the ac power line, and drift, which is caused by undefined factors.

Preset speed — one or more speeds at which the drive should operate. Relay contacts or programmable-controller outputs select which preset speed is operational.

Pulse-width modulation (PWM) — inverter technique for chopping (modulating) a dc voltage usually at 2,000 to 20,000 Hz to produce adjustable-frequency, adjustable-voltage ac, or adjustable-voltage dc.

Regeneration — occurs when the load overhauls the motor, which puts power back to the drive controller. *Most mechanical adjustable-speed drives and motor-generator types of electrical adjustable-speed drives inherently offer regenerative capability.* Therefore, replacement drives must be carefully selected so they have regenerative capability if the application requires it.

Regenerative drive — in SCR-type dc drives, regenerated power is usually put back to the ac power source through a second set of SCRs, Figure 4. In transistorized dc drives and most AFDs, this power is dissipated by a resistor across the dc bus that is between the input rectifier and the power amplifier, Figure 5.

Designed to control current flow in

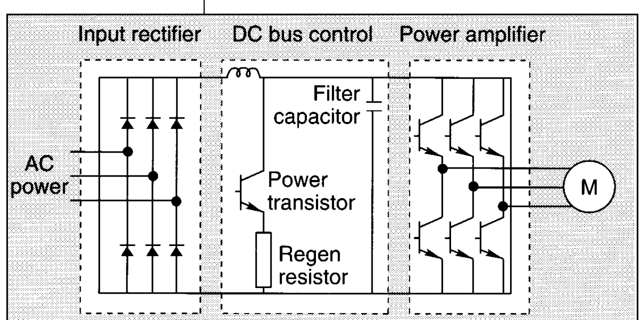


Figure 5 — Basic diagram of the power section of transistorized adjustable-speed drive, including PWM ac and BLDC. PWM dc has the same configuration, but with only four power transistors in the output (power amplifier) section. Units that operate from single-phase power have four instead of six rectifiers in the input rectifier section. Although the power-section configurations are similar for the various drive types, the regulator and firing circuits are completely different.

both directions, these drives are used for controlled stopping (regenerative braking) of high-inertia loads. This design also offers contactorless reversing, which is beneficial for high-cyclic-duty applications.

Set speed — the desired operating speed. When a regulation value is quoted for set speed, the same percentage applies at all speeds. Such regulation is generally available only with drives equipped with complex or digital control systems.

Slip — the difference between the electrical and mechanical speeds of a motor. For example, slip is the difference between synchronous field speed (typically 1800 rpm) and rotor speed (often 1750 rpm) of an induction motor. This gives a 50 rpm (3%) slip. Slip is always manifested as a power loss, which appears as heat.

Speed regulation — the percentage of change in speed between full load and no load.

$$R = \frac{N_{NL} - N_{FL}}{N_{FL}} \times 100$$

Where:
R = Speed regulation, %
N_{NL} = No load speed, rpm
N_{FL} = Full load speed, rpm

Unless otherwise stated, regulation is assumed to be plus-or-minus a percentage of base speed, not of set speed.

Variable speed — often considered synonymous with adjustable speed, but variable speed is where speed varies widely with load. Speed is determined by the intersection of the speed-torque curves of load and drive. Examples include uncontrolled units such as series-wound motors, Wound-rotor ac motors, eddy-current clutches without tachometer feedback, and fluid drives. Any of these may be equipped with automatic speed controls, and then operate as controlled-speed drives.

Vector control — controller for standard ac induction motors that delivers response equivalent to dc servos. (See "Positioning drives.")

Voltage boost — adjustment to enable an adjustable-frequency drive to give a larger-than-normal voltage at low frequencies (normally 0 to 10 Hz) so the motor can start with extra short-term torque for breakaway and initial acceleration.

V/Hz (Volts per Hertz) — common adjustment in adjustable-frequency drives that establishes the voltage relationship to the frequency. For example, the controller for a 240-V, 60-Hz motor normally has a V/Hz adjustment set at 4-V per Hertz.

APPLICATION CONSIDERATIONS

Since there are many types of adjustable-speed drives available, it is essential to establish the required functions and the application constraints. The following lists many of the major factors that should be considered:

- Maximum horsepower requirements of the driven load, and how the required power varies with speed.
- Torque. Constant or variable with speed?
- Minimum and maximum speeds.
- Unidirectional or bidirectional?
- Acceleration. Fast, slow, or adjustable? Also, are any special acceleration or deceleration characteristics required, such as constant jerk so there is no change in acceleration rate, or an S-curve? These are typically required for controlling conveyors carrying tall bottles.
- Drive response to changes in speed and direction commands.
- Programmability needed. Will it be necessary to change frequently the operating parameters, thereby requiring a microprocessor-based drive?
- Minimum and maximum speed adjustments. Is it necessary to limit the minimum and maximum speed capabilities if the drive has a wider speed range than required by the load?
- Speed regulation due to load changes and other variables, such as temperature, humidity, line-voltage fluctuation, and drift.
- Maintenance capabilities. What types of equipment can the maintenance personnel service — mechanical, simple electrical, or complex electrical? What are service capabilities of suppliers?
- Control method. Will manual control be used or will a motion or system controller give commands to the drive controller?
- Environments. Will all or part of the drive be subjected to hazardous, abrasive, moisture, or other harsh environments?
- Duty cycle, including number of starts and stops per hour. If the reflected load inertia (see Basic Engineering department in this handbook, Formulas 9-13) is several times the motor armature inertia, or if the duty cycle involves several starts and stops a minute, a regenerative drive may be required.
- Communication requirements. Will it be necessary, now or in the future, to send instructions to the drive or receive information from the unit? Will network communications be required? These capabilities are often needed in coordinated systems connected to a master or host computer.
- Diagnostic capabilities. Should the drive or system malfunction, will a remote computer interrogate the drive to determine the cause of the trouble and status of the system during the last moments of operation? Such capabilities require a communication channel.

TYPES OF DRIVES

There are three basic types of adjustable-speed drives, and each has its strengths and weaknesses:

Electrical drives — ac adjustable frequency, dc adjustable voltage, slip-ring (wound-rotor) motor, eddy-current, and special purpose types, including servo and step.

Fluid drives — hydrostatic, hydrokinetic, and hydroviscous drives are discussed in the Fluid-Power Drives department of this handbook.

Mechanical drives — metallic-contact traction type and adjustable-sheave type using belts or chains.

ELECTRICAL ADJUSTABLE SPEED

Both ac and dc drives receive ac plant power and convert it to an adjustable output for controlling motor operation. DC drives power dc motors, and ac drives control ac motors. Both usually use solid-state conversion systems.

A dc drive is the simpler of the two and is frequently used as part of an ac drive controller. Therefore, we will discuss the dc design first.

DC drive

Usually, a solid-state power unit converts incoming ac plant power to adjustable-voltage dc. This voltage is fed to the dc motor armature. The dc motor speed varies proportionally to the dc armature voltage assuming:

1. The motor is large enough to power the connected load.
2. The motor field current is constant.

DC motors, discussed in detail in the Motor department, contain two major components — armature and field. Interacting magnetic fields from these two components turn the armature.

Two basic methods are used for converting ac to controlled dc — SCRs (thyristors) and transistors.

SCR drives — silicon controlled rectifiers (SCRs) in the power unit convert ac to controlled voltage dc. The SCR conducts current when a small voltage is applied to the SCR gate, Figure 6.

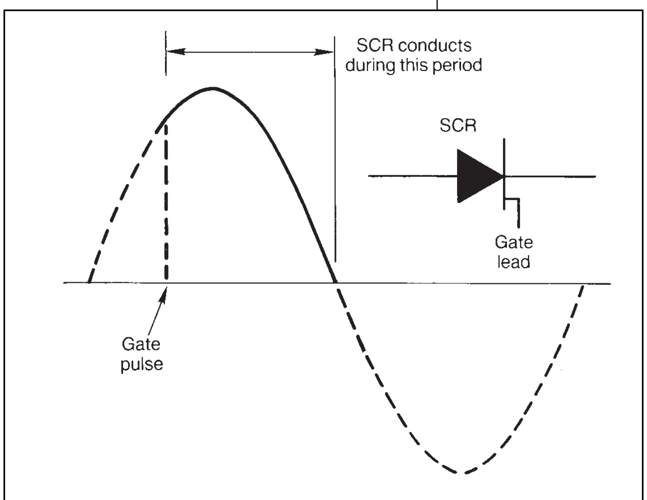


Figure 6 — SCR conducts current from the time of the gate pulse to the end of that half cycle.

Most SCR-type dc drives designed to operate from a single-phase input have four SCRs. Units operating from three-phase ac are frequently built with six SCRs, Figure 7. One variation of these designs includes replacing the SCRs on the bottom row with diodes (rectifiers) and adding a back or commutating diode across the dc output.

To physically disconnect the motor from the solid-state power module, a motor contactor (M) is connected between the power module and the motor, Figure 3. When the start button is pushed, the M contactor picks up, closing the normally open (NO) contact; then the SCRs are turned *on* in sequence, supplying power to the motor.

Should the application require the motor to stop faster than coasting to rest, a normally closed (NC) contact on the M contactor is used to connect a dynamic braking resistor across the motor armature, Figure 3. Thus, the rotating mechanical energy in the motor armature is dissipated as heat in this DB resistor. Although this is effective for occasional stopping, each stop requires operating the M contactor, which eventually wears out contacts. Plus, the motor slow-down rate is not controlled, as it is with regenerative braking.

Regenerative SCR dc drives — By adding another set of SCRs (labeled "Reverse section") that are connected in the reverse polarity, Figure 4, the drive has regenerative capabilities, and can operate in all four quadrants, Figure 8.

This configuration offers bidirectional operation without using reversing contactors and controlled regenerative stopping. (See "Regeneration with ac/dc drives" later in this section).

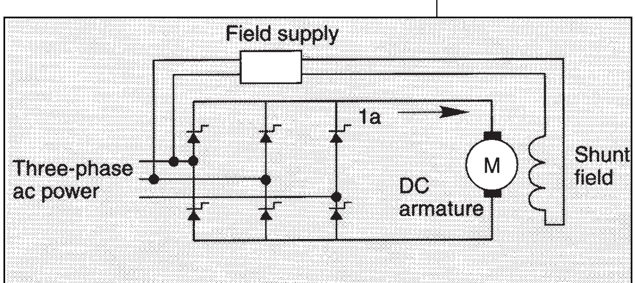


Figure 7 — Typical full-wave SCR bridge for dc drive operating from three-phase ac power.

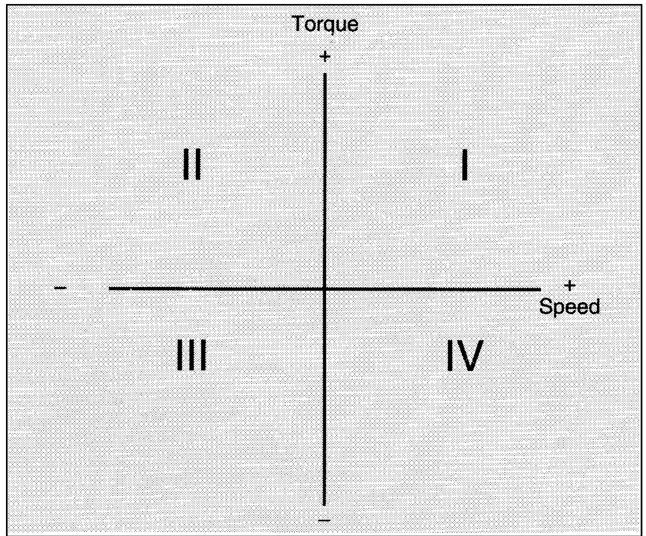


Figure 8 — Four quadrants of motor operation. Most systems operate in the first quadrant where both torque and speed are positive. During dynamic braking and regeneration, speed is positive and torque is negative — the second quadrant.

Transistor dc drives — Largely because of the capabilities offered by microprocessors and the availability of power transistors, transistor dc drives are now rated from fractional to over 100 hp.

Unlike SCR-type drives, transistorized units contain three major power sections, Figure 5. The first converts ac plant power to fixed-voltage dc for the dc bus. The second section filters and regulates the dc bus voltage. If the dc bus voltage goes outside the proper values, this section signals a fault and shuts the drive down. The third section contains the power transistors and chops (modulates) the fixed voltage dc to form adjustable-voltage dc for powering and controlling the dc motor.

If the load overhauls the dc motor, it regenerates by sending power back to the power amplifier section. This, in turn, sends power to the dc bus where the dc bus control dissipates the power in a resistor connected across the bus. If the resistor does not have the capacity to dissipate the power, the bus control section will sense a bus over-voltage and shut the drive down.

DC drive regulator—Instructions from an operator's control station, or other input, feed into the regulator, Figure 9. The regulator compares the instructions with the voltage and current feedbacks and sends the appropriate signal to the

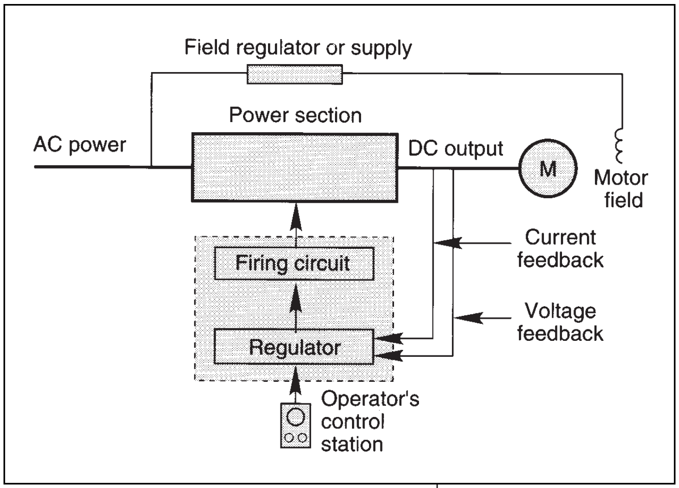


Figure 9 — DC drive with voltage (for approximate speed) and current (for torque) feedbacks. In most drives, the regulator and firing circuit are in the same physical unit. These can be analog, digital, or a combination of both. For more precise speed feedback, a tachometer-generator (tach) or encoder must be driven by the motor shaft, Figure 10A.

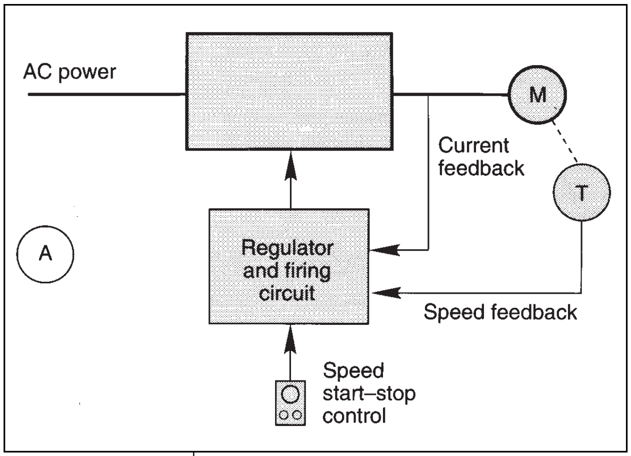


Figure 10A — DC drive with speed feedback in place of voltage feedback. The motor-driven tach or encoder gives more accurate signal than estimating speed based on applied voltage.

firing circuit. This section supplies the gate pulses that fire the transistors or SCRs, causing them to conduct. In some designs, the regulator and firing circuit are combined in one digital circuit.

The voltage feedback gives an indication of the motor speed, and current indicates relative motor torque.

Typical basic adjustments in the regulator include minimum speed, maximum speed, current (torque) limit, IR (load) compensation, and acceleration rate adjustment.

For more precise speed control, an encoder or a tachometer-generator — usually called a tach — is mounted on the motor to give a feedback signal, Figure 10, that is proportional to actual motor speed. The quality of this tach and of the regulator determine the total drive accuracy.

Applications — DC drives without tach feedback frequently offer a 20:1 speed range. If tach feedback is used, the speed range is usually increased to at least 100:1.

If the motor has sufficient cooling capacity, the drive can usually deliver constant torque over the full speed range. TENV (totally enclosed, nonventilated) and some TEFC (totally enclosed, fan cooled) motors rated to about 5 hp often have sufficient heat dissipating capacity to deliver rated torque during low-speed operation. On larger motors, a common practice is to use a separately powered blower to force air through the motor so the motor is properly cooled, even when it is running at low speeds and delivering full torque. The alternative is to specify a larger motor that can dissipate the heat.

If a motor field regulator is added to control the motor field current, the motor can deliver constant horsepower above motor base speed, Figure 1. Some motors can run at four to six times the motor base speed. These drives have both armature voltage and field control. They are applied on machine tool spindles, center winders, and similar applications where the torque requirements decrease with an increase in speed.

DC drives can regulate motor speed (the most frequent type of application), motor current, which is proportional to motor torque, and position. Drives with current regulators are used for un-

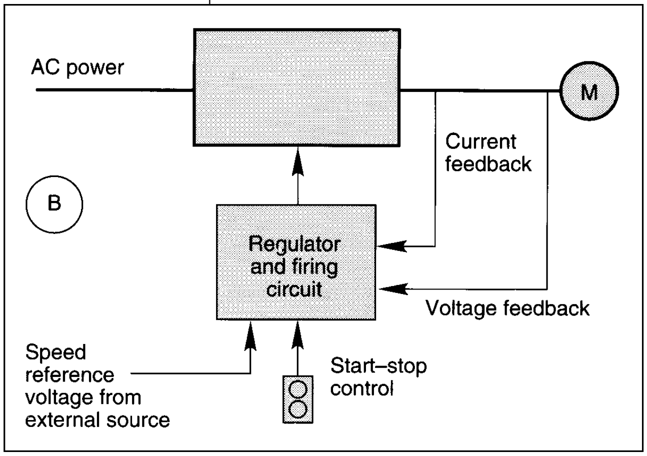


Figure 10B — Follower drive, which is often confused with speed regulated drive (Figure 10A). Above voltage-regulated drive follows a speed reference signal, usually produced by a tach on another motor or by a digital command from the master drive's speed feedback.

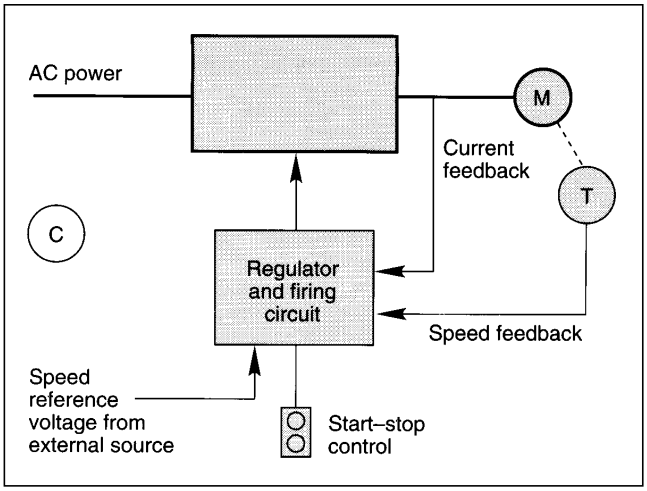


Figure 10C — Combination of a follower drive (Figure 10B) and a speed-regulated drive (Figure 10A). The above configuration accurately maintains speed established by the reference signal produced by a source outside the drive.

Power semiconductors in a-s drives

Silicon controlled rectifiers (SCR) were introduced in the 1950s. Gate turn-off devices (GTO) became available for widespread usage in the late 1970s, then power (giant) transistors (GTR) in the early 1980s and, most recently, insulated gate bipolar transistors (IGBT).

Under normal operating conditions, they function as one-way switches; current flows in one direction, from the higher voltage potential to a lower voltage potential. Connections include terminals for input power, output power and a control signal to turn the device *on* and *off*.

Silicon controlled rectifier (SCR). In a typical dc drive, SCRs control dc motor speed and torque by converting ac line voltage to adjustable dc voltage. The controller determines when in the ac half cycle to turn the SCR *on* so it conducts to the end of that half cycle. The earlier in the half cycle the SCR turns *on*, the higher the average output voltage is to the motor. To turn the SCR *on*, the controller applies a current to the SCR gate, Figure A.

SCRs can handle current from 5,000 to 10,000 A. The time it takes an SCR to turn fully *on* after receiving a gate pulse is in the order of 10s of µsec.

In the early 1960s, SCRs were used to control the frequency of ac drives. Now, GTOs, GTRs and IGBTs have replaced SCRs, particularly in low-voltage ac drives, because of their greater efficiency and controlability.

For dc drives, SCRs are the least expensive power semiconductor for applications below a power range of 200 to 500 hp. In the larger power ranges, GTOs become practical. For ac drives, SCRs are the least expensive power semiconductors, but the drives require many capacitors to commutate the SCRs *off* to produce an ac output.

Gate turn off device (GTO). A GTO, like an SCR, can handle high current levels — in the thousands of amperes. A GTO, Figure B, is similar to an SCR except that its control connection can turn the device *on* and *off*. Turn *on* occurs when a positive voltage is applied to the gate. Applying a negative voltage to the gate turns the GTO *off* and interrupts current flow in the main circuit. Once turned *on*, a GTO will stay *on* and does not require sustaining pulses. To turn a GTO *off*, the negative or turn-off control signal must be greater than the current flowing through the GTO. Typically, turn-*off* time of a GTO is about 50 µsec. GTOs require fast-acting, current-limiting fuses to protect against overcurrent situations.

Efficiency of a GTO is relatively low due to the power source required to supply the negative turn-off bias. Because GTOs turn *on* relatively slowly, high switching losses reduce efficiency.

Giant transistor (GTR). In a GTR, the control or base signal must be maintained to keep the device turned *on*. How much control signal is needed depends on how the GTR is operated. For large-gain, low-loss operation, the control signal must be large. For large-gain, large-loss operation, the control signal can be small.

Current-carrying capability is in the range of 1,000 to 2,000 A. Switching speed is about 5 µsec. Because GTRs are low-gain devices (as are all transistors), they are typically mounted with one device feeding another in a Darlington configuration, Figure C.

Relative power-semiconductor characteristics

Type	Speed	Gain	Efficiency	Control method	Max. rating, A
SCR	Slow	Medium	Low	Current	10,000
GTO	Medium	Medium	Low	Current	10,000
GTR	Fast	Low	Medium	Current	2,000
IGBT	Fastest	High	High	Voltage	2,000

Figure A — Silicon controlled rectifier (SCR), also known as a thyristor. It conducts current during a positive half cycle from the time sufficient voltage is applied to the gate to the end of that half cycle.

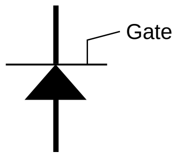


Figure B — Gate turn off thyristor (GTO). Similar to an SCR, except a GTO can be turned *on* and *off* by the voltage to the gate. Positive voltage turns the GTO *on* and a negative voltage turns it *off*.

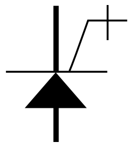


Figure C — Giant transistor (GTR) in a Darlington configuration so the transistor amplifies the signal to the base of the GTR.

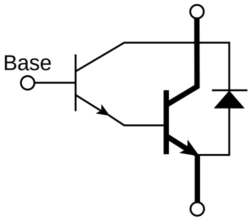
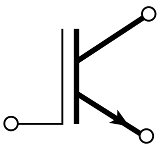


Figure D — Insulated-gate bipolar transistor (IGBT) is the most common power device used in current general-purpose and servo drive controllers. It can operate with carrier (also called chopping and modulation) frequencies to more than 20 kHz.



Today, GTRs are gradually being replaced by IGBTs. The faster switching speeds of an IGBT produce a so-called "quiet ac motor controller." Commercial pressure for smaller controller packages and a simpler control-to-power interface is forcing the early retirement of GTRs for ac motor control.

Insulated-gate bipolar transistors (IGBT). IGBTs, Figure D, differ from SCRs, GTOs and GTRs by the control scheme. To turn *on* an IGBT, a voltage is applied to its gate. The MOSFET-type input converts the voltage to the current required to turn *on* the output portion (transistor) of the IGBT.

Thus, the interface from control to power is simplified because it requires little control current to handle large amounts of power current. Small control current also avoids the time delays associated with large values of control current. A fast control change produces a fast power change. Current-carrying capability of an IGBT is 1,000 to 2,000 A.

An IGBT's fast response to signal changes — less than 1 μsec — reduces audible levels in an ac motor while controlling torque and speed. And, its high switching frequency (carrier frequency) provides a responsive current control. Also, an IGBT's low losses result in compact packaging of the ac motor controller.

Since the introduction of IGBTs, concerns have arisen about the effects of high-frequency switching and harmonic-rich waveforms during transmission of power to an ac motor. In some cases, transient voltages can damage motor winding insulation, and cause motor failure. Two factors in particular contribute to this phenomenon:

- 460-V ac drives that use the PWM power circuit and use modulation (chopping) frequencies of more than 5 kHz.
- Long cable distances (over 100 ft) between the drive controller and the motor.

These reflected waves, along with RFI and grounding issues, are current technical hot buttons. See the "Reducing motor problems caused by voltage transients" section in Motors for some solutions to these potential problems.

Excerpted from an article by Allen-Bradley Co., Inc. in the February, 1996 issue of PTD.

winders, rewinders, and other web handling functions.

Drives with position regulators are installed on machine tools, robots, winders and unwinders with storage loops, electric line shafts, and other applications where precise component position must be controlled.

Brushless dc drive

Considered both an ac drive and a dc drive — depending on who is speaking — this family of drives is frequently called brushless dc (BLDC), brushless ac, and brushless PM servo. To distinguish this type from a drive with a conventional ac motor that is usually also brushless, we use "brushless dc" to denote this drive type. It can be applied to both general-purpose and precision motion control (position-regulated) installations.

The BLDC motor is constructed much like a permanent magnet ac synchronous motor with a PM rotor and a wound stator. This BLDC design is often termed an "inside-out" construction, because most dc motors with permanent magnets have the magnets stationary in the stator, and the wound armature rotates. However, the BLDC construction puts the heat-generating windings on the outside for fast heat dissipation.

Most BLDC drives need an accurate method of sensing rotor speed. An encoder, or Hall-effect transistor, usually does this. For more precise applications, some use a resolver and a resolver-to-digital (R/D) converter. The improvement in precision depends on the components selected.

The power sections of a BLDC drive controller closely resemble a standard PWM ac drive, Figure 5. However, the controller portions (regulator and firing circuits) are completely different.

The industry is constantly improving the ability to control the shape of the current wave form. Generally, the more closely the current approaches a sine wave, the better the motor performance.

Originally, the drive controllers produced a square-wave *voltage* to the BLDC motor. With technological advances, the drive manufacturers developed controllers that commonly produce a trapezoidal voltage waveform, and some offer a sine wave. Often the sine-wave units require a resolver, rather than the more common encoder. The sine wave offers reduced torque variations (ripple) during each shaft rotation. For example — according to some manufacturers — a brush-type dc motor may have 2% to 6% torque ripple; PMDC drives with sinusoidal voltage waveforms may have 3% ripple; and the trapezoidal voltage can run 4% to 15%.

Another factor that determines torque ripple is the motor winding configuration. Some manufacturers offer distributed windings that reduce the torque ripple produced by a trapezoidal voltage.

However, methods of measurement, load inertia, and many other variables determine this ripple for each application.

AC drives

AC adjustable-speed drives are growing in popularity, mainly because ac motors are simpler than dc motors. Moreover, recent advances in inverter technology have reduced controller cost and improved performance and reliability.

AC drives operate by adjusting the frequency and voltage to ac motors. Frequency determines motor speed. To maintain constant torque, it is necessary to keep voltage and frequency in a constant relationship. Called Volts per Hertz, this is adjustable on most ac drive controllers. There is one exception — voltage at low frequencies. In this operating range, voltage may be boosted to give the motor extra torque for breakaway and initial acceleration.

General-purpose, ac adjustable-frequency drive controllers are made in four types: variable-voltage input (VVI), pulse-width modulated (PWM), current-source input (CSI), and load-commutated inverters (LCI). In addition, wound-rotor motors and eddy-current couplings offer adjustable speed with an ac motor connected across the line. Each has specific characteristics and advantages.

Variable-voltage input (VVI) — Although this design was common in the 1970s and early '80s, it is now generally limited to special applications such as high-speed drives that deliver 400 to 3,000 Hz. The VVI design, Figure 5, receives plant ac power, rectifies and controls it, and delivers variable-voltage dc to the power amplifier (inverter section).

The power amplifier inverts the variable-voltage dc to variable-frequency, variable-voltage ac. It can be built with power transistors or SCRs.

The output voltage from a VVI unit is frequently called a six-step wave form.

The VVI was one of the first solid-state ac drives to gain general acceptance.

Pulse-width modulated (PWM) — Many PWM units (also frequently termed "volts per Hertz drives" to distinguish them from vector drives) offer operation to zero speed. Some produce frequency ranges near 200:1. This wide range is possible because the controller converts ac supply power to fixed-voltage dc for the power amplifier. In this amplifier, the dc is "chopped" (modulated) to produce different widths of pulses, thus varying the effective voltage. Although the voltage is chopped, the current wave form is closer to sinusoidal than any other system.

PWM units use several types of power transistors (including insulated gate bipolar transistors (IGBTs), and gate-turn-off SCRs (GTOs).

The PWM power circuit requires a more complex regulator than does the VVI design. However, the increasing use of microprocessors has nearly eliminated significant economic differences.

Because a fixed-voltage dc bus supplies the inverter section, a large single dc supply can be used to power several inverter sections.

Types of regulators — The PWM power circuit is commonly used with three basic types of regulators. It is these regulators that largely determine the drive capabilities, including response, speed regulation due to transient load changes, and low-speed torque capabilities.

Volts/Hertz — The most common and lowest cost configuration, it is usually available with or without a speed feedback capability. This design generally offers the basic drive adjustments — including set speed, torque limit, V/Hz, voltage boost at low speeds, minimum and maximum speeds, acceleration and deceleration rates, and other similar adjustments, which meet the requirements for most applications.

Basic vector — Introduced in the mid-80s, this regulator was a significant advancement over the Volts/Hz design. Such units use an approximation method to control the stator and rotor flux angles to optimize motor operation.

Some vector drives were expected to have open-loop speed regulation (no speed feedback signal from the motor) equivalent to a dc drive with speed feedback. Many units didn't quite live up to the expectations. Regardless, the basic vector does offer improved performance, which in some cases may be suitable for simple coordinated systems.

Vector — More recently, in the mid-90s, much improved vector regulators were introduced. These have more advanced microprocessors and DSPs that significantly enhance drive operation, including response and position regulation capabilities. One reason for the vector's capability to perform so well is its ability to "see" the counter EMF produced by the motor, then the circuitry adjusts the start of each PWM pulse train and the specific duration of each pulse.

Such vector drives are powering high-speed printing presses, paper machines, winders and other coordinated engineered systems. Vector drives are also used on servo positioning systems, such as machine tool spindle and feed drives. Some, depending on the rating, can accelerate from standstill to full speed in 1 to 200 msec.

For more on these positioning drives, see a following section, "Positioning Drives."

With all types of these drives, a speed or position feedback signal will improve the drive's performance.

Current-source inverter (CSI) — Usually applied to drives of 50 hp and larger, CSI units are well suited for powering pumps and fans as an energy-saving alternative to throttling for flow control.

Capable of operating with efficiencies close to dc drives, the CSI design offers economies over both the VVI and PWM units for pump, fan, and similar applications.

The CSI inherently offers regenerative capabilities. With an overhauling load, the controller feeds power back into the ac power system.

Comparison of typical servo drives

Servo motor-amplifier combination	Typical values[1]		
	Relative motor rotor inertia	Relative response (bandwidth)	Maximum acceleration rate (radians/sec^2)
Brushless dc (BLDC) ferrite motor with PWM amplifier.	Low	High (150 Hz)	High (90,000)
Brushless dc (BLDC) rare-earth motor with PWM amplifier.	Low	Very high (200 Hz)	High (175,000)
AC induction motor with PWM amplifier. (Vector controlled)	Medium	High (100 Hz)	Medium (4,000)
DC ferrite PM motor with PWM amplifier.	Medium	High (100 Hz)	Medium (7,000)
DC rare-earth PM motor with PWM amplifier.	Medium	High (130 Hz)	Medium (12,000)
DC moving-coil motor with PWM amplifier.	Low	Very high (200 Hz)	High (150,000)
DC wound-field motor with PWM amplifier.	High	Medium (25 Hz)	Low (500)
DC permanent-magnet motor with 3-phase, half-wave, SCR amplifier.	Medium	Medium (25 Hz)	Medium (4,000)
DC wound-field motor with 3-phase, half-wave, SCR amplifier.	High	Low (15 Hz)	Low (500)

Load-commutated inverter (LCI) — Designed for controlling synchronous motors rated in hundreds or thousands of horsepower, these units use the leading power-factor capabilities of synchronous motors to commutate the power SCRs *off*. These inverters, some rated up to 6,000 Vac, control large blowers and induced-draft fans in power plants.

Due to the higher cost of synchronous motors over conventional induction motors, LCI systems become economical in the 400-600 hp range, and larger.

Wound-rotor motor control — Another system for controlling ac motors rated in hundreds of horsepower, a wound-rotor motor controller applies constant voltage and frequency to the primary of a wound-rotor motor. Speed is adjusted by varying the resistance of the motor secondary, Figure 11. As resistance is increased, rotor losses increase, thus reducing the motor shaft speed.

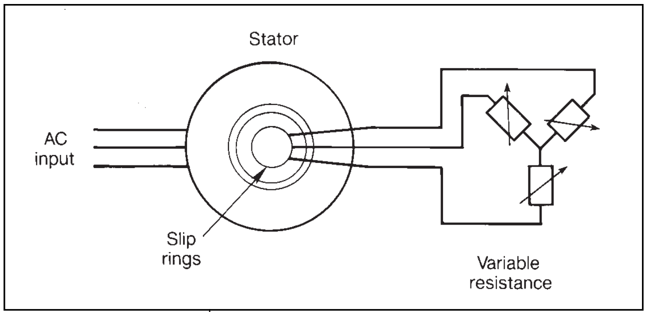


Figure 11 — Wound-rotor ac motor and controller. Increasing the resistance in the motor secondary decreases motor speed.

A solid-state controller effectively changes the resistance of the rotor secondary; and, rather than dissipate the energy as heat, it feeds this energy back to the ac supply. This slip-recovery system greatly increases motor efficiency. Wound-rotor motor control serves many pump and fan installations that need a speed range of 2:1 or 3:1.

Eddy-current coupling — A moving magnetic field induces eddy currents in nearby metal. These currents, in turn, create their own magnetic fields. Properly used, the eddy-current magnetic fields can interact with the primary magnetic field.

The eddy-current coupling is built with two parts: one is coupled to the input shaft, and, in many applications, powered by an ac motor; the other is connected to the output shaft. There is no mechanical connection between the two parts; rather, the connection is purely magnetic. An electromagnet coil generates the coupling magnetic force, Figure 12. The magnetic strength, (coil current) determines the slip between the input and output parts. There must be some slip between these two parts, usually a minimum of 3 to 5%, depending upon the design, for the system to work. (Eddy-current clutches and brakes are discussed in the Clutch and Brake department in this handbook.)

In some smaller ratings, the magnet coil rotates with the output shaft.

Typical values[1]			
Usable speed range (rpm)	**Maximum continuous torque capability (lb-in.)**	**Maximum continuous rating (hp)**	**Primary Advantages**
High (0-9000)	1800	50	No brushes.[2] High response. Low rotor inertia. High acceleration rates. High torque at high speeds. Low maintenance required (no brushwear). Better acceleration rates than ac induction with PWM amplifier.
High (0-9000)	800	30	
High (0-3000)	1250	30	No brushes.[2] Good response. High torque at high speeds. Low maintenance required (no brushwear).
Medium (0-3000)	500	15	Wide selection available. Good response. Better response than permanent-magnet motor with SCR amplifier.
Medium (0-3000)	750	20	
Medium (0-3000)	200	5	Low rotor inertia. High response. Short motor profile.
Low (0-1750)	1250	30	Wide selection available. Better response than wound-field motor with SCR amplifier.
Medium (0-2000)	500	15	Wide selection available. Peak torque up to 5 times continuous rating.
Low (0-1750)	6500	150	Wide selection available. Available above 30 hp. Peak torque up to 5 times continuous rating.

Notes:
1. These are typical values for each drive type and do not reflect state-of-the-art products or special designs.
2. Brush wear becomes critical on high duty-cycle applications where the motor constantly accelerates and decelerates. Although the absence of brush wear is not as important in other applications, many specifiers select brushless units to eliminate brush maintenance completely.
3. Many times, load rotary inertia reflected to the motor shaft can be reduced by installing a speed reduction means (gears or timing belt) between the motor and driven load. (The reflected inertia is reduced by a square of the reduction ratio.) This technique is frequently used when the load inertia significantly exceeds the motor rotor inertia.

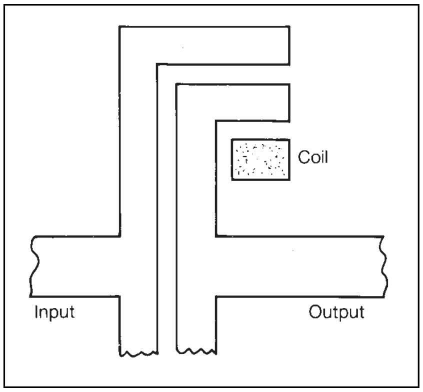


Figure 12 — Typical eddy-current coupling.

Slip rings carry the current from the supply wires to the rotating coil. In larger units, the coil is stationary and induces magnetic fields in both the input and output members.

In operation, the operator selects the desired speed, which establishes the speed reference signal. The exciter control converts this signal to the proper dc voltage for the coil, Figure 13. The tachometer-generator sends an output speed signal back to the exciter, which makes any needed change in the coil voltage to maintain the set speed.

Since any slip generates heat, each coupling must be designed for adequate cooling. Usually, the smaller couplings rated from fractional to over 100 hp are air cooled, and larger units that can control thousands of horsepower are water-cooled.

Selection factors include load (speed-torque) characteristics, ratings, efficiency when slip is considered, and cooling method.

Motor-mounted drive controllers

Although motors with built-on controllers have been made, they are generally limited to dc subfractional and fractional-horsepower motors and appliance motors. For integral ratings, the controller has been too big. But, that is changing.

Technological breakthroughs enable integral horsepower ac motors to include sophisticated controls. Several companies have developed an integrated module that contains the control and power circuits for an ac adjustable-speed drive, Figure 14. Moreover, these modules are small enough to fit on ac motors rated 1-hp and larger. Benefits of these drives include:

- Save space by eliminating the need for a separate controller (which is often as big as the motor).
- Reduce installed costs because power wiring between the motor and controller is eliminated.
- Eliminate motor problems caused by high-voltage transients.
- Wipe out the finger pointing between the motor and controller manufacturers when a problem comes up.
- Enable using adjustable-speed drives in applications that previously could not justify the expenses of a separate drive controller.

The controller modules include most functions: Start, stop, forward, reverse, speed control, preset speeds, adjustable acceleration and deceleration rates and curves (S-curve or other), readouts of speed and motor current in rpm and amperes or in engineering units, motor and controller protection, selectable modulating frequency from 1.25 to 18 kHz, stall protection, and many others.

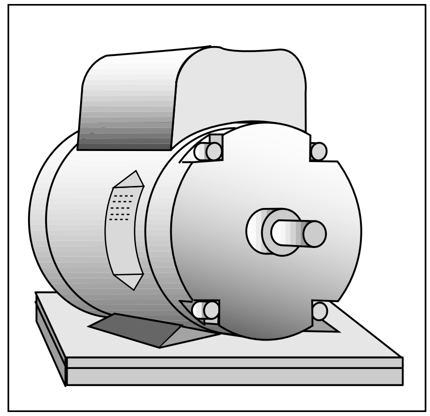


Figure 14 — More adjustable-speed controllers are mounted in a housing that is often attached to the top of the motor.

Within the module, a mathematical model of the motor accurately calculates motor temperature and improves motor operational stability, especially for larger motors.

A crucial design requirement is to eliminate the heat generated by the motor and the control electronics. Some solutions use a multifinned assembly that mounts on the motor so the air forced by the external motor fan goes through the module cooling fins as well as over the motor shell.

Regeneration with ac/dc drives

Like dc drives, ac drives can regenerate when a load pulls the motor faster than its synchronous speed. Because the synchronous speed of an ac motor is proportional to the applied frequency, a four-pole motor operating on 60-Hz power could encounter regeneration at speeds over 1,800 rpm, its synchronous speed. At 30 Hz, regeneration could occur at a speed over 900 rpm.

A typical example of a regenerative application is a fully loaded elevator. The motor is loaded as it lifts the elevator car and its contents. When traveling downward, the motor "holds back" on its descent (negative torque) and must have some place to deposit this regenerated energy. Other examples of regenerative applications include winders and unwinders, machine tools, dynamometers, centrifuges, hoists and cranes, downhill conveyors, press feeders, and rolling mill run-out tables.

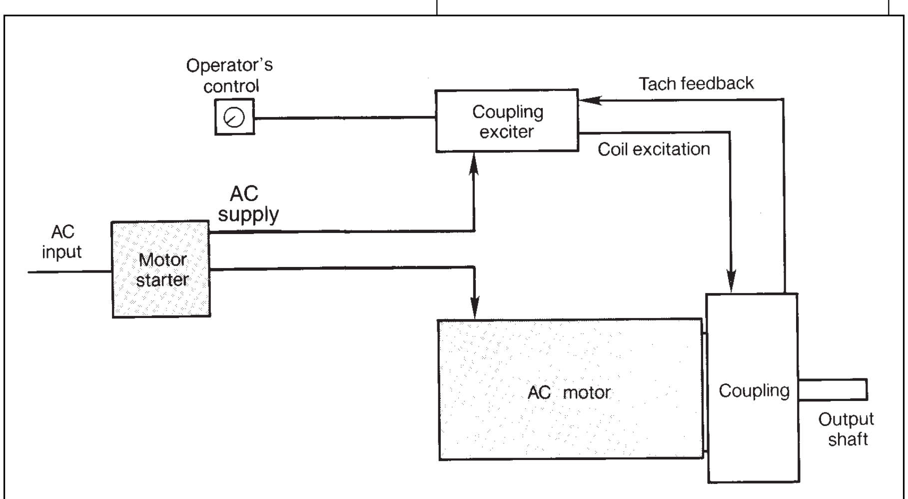


Figure 13 — Control scheme for eddy-current coupling.

Many seemingly innocuous applications can turn regenerative during certain parts of their operation. Every load should be examined to determine what an overhauling load can be during any part of the operating cycle.

To dissipate excess power, users can:

- De-tune high-inertia loads by lengthening deceleration time.
- Add a resistive snubber across the dc bus to handle short-term, intermittent regenerative loads. In these units, sensors measure the dc bus voltage. When it exceeds specific limits, a power circuit connects a resistor across the dc bus to dissipate the excess energy.
- Use a line-regenerative AFC or add-on regenerative module for more severe regenerative situations. AFCs equipped with line regeneration handle intermittent and continuous overhauling loads.

Three recent technological advances have brought the regenerative AFC into vogue: better power semiconductors, faster microprocessor control, and PWM vector AFCs.

Synchronous rectifier drives contain two complete IGBT bridges, both PWM controlled. The input ac power currents are nearly sinusoidal and devoid of the 5th and 7th harmonics produced by AFCs that use diode bridge rectifiers.

In the motoring mode, the IGBT rectifier section works with a resonant-tuned input line reactor and dc bus capacitor to create dc bus voltage. A complex switching pattern enables a higher dc bus voltage than that created by a conventional diode bridge rectifier. This ability to regulate dc voltage can be beneficial during brown-out conditions.

During regeneration, the IGBT bridge feeds pulses of the excess dc bus voltage into the ac power line, minimizing harmonic distortion and maximizing input power factor.

Benefits and features include:

- Bidirectional power flow to and from the ac power line.
- Controllable input power factor.
- Lowest ac line harmonics.
- Ability to create higher motor output voltages than the input voltage.
- Adaptable to common dc bus designs.
- Power-dip ride-through when line voltage sags.

Bi-directional transistor rectifier. Designed as an add-on module to PWM AFCs, this backward-conducting bridge is similar to the basic power bridge in a synchronous rectifier bridge. Bi-directional modules can be used independently on standalone, single-section PWM AFCs; or they can be used to augment a multiple-AFC, common-bus system.

Self-contained modules monitor the dc bus voltage. When a predetermined threshold is exceeded, the IGBT bridge switches *on* at the peak of the input power sine wave. Because power returns to the line at the exact center of the sine wave cycle, there is little angular displacement between current and voltage.

Current source inverter (CSI). Based on mature SCR technology, current source inverters (CSI) can transpose the ac line source and load during regeneration.

This AFC is a current source that regulates motor terminal voltage. At the heart of the CSI is a large dc choke. Its inductance is 10 times the motor inductance. During regeneration, the voltage across the dc bus inverts polarity. This action enables the unidirectional SCR converter to put power back into the ac line.

PWM with regenerative six-pulse SCR rectifier. Typically referred to as an S-6R, the six-pulse controlled-bridge rectifier features a second reverse-connected rectifier. A common practice with regenerative dc drives is to connect both rectifier bridges in parallel to the ac line. On an AFC, the rectifier must be protected from inverting faults. These faults occur when the dc bus voltage exceeds the peak of the sine-wave, ac line voltage. This voltage difference will usually cause one of the SCRs in the reverse-bridge to remain in conduction while a forward-bridge SCR also conducts. This dual conduction produces a phase-to-phase short circuit, turning expensive drives into smoke generators.

To avoid this problem, connect the reverse-rectifier to a higher voltage source (usually a transformer with a higher secondary voltage).

Regenerative PWM inverters with S-6R rectifiers offer:

- Reliable SCR power semiconductors.
- Reverse six-pulse power circuit that is adaptable to common-bus applications.
- Power dip ride-through using phase-back, phase-forward control.

Common dc bus configuration. To conserve energy and reduce the required capacity of the input ac-to-dc rectifier, multiple AFCs can share a common dc bus. This enables regenerating drives to supply energy to motoring drives.

If the net power is always away from the ac line (more drives motoring than regenerating), a regenerative converter isn't needed. In this case, the regenerated power is immediately re-used by the motoring drives.

One major advantage with multiple AFCs on common dc bus is that you can use a single regenerative module, sized for worst case energy return. Thus, the regenerative module must have the capacity to handle only the surplus energy that is unused by the motoring AFCs.

The engineer designing to a common dc bus must coordinate individual AFC protection. Most systems use many combinations of fusing, circuit breakers, and reactors. Plus, electrolytic capacitors in the dc bus store tremendous amounts of energy. Therefore, it is essential to prevent an isolated AFC failure from causing a catastrophic fault to the entire system.

Excerpted from an article by Reliance Electric in the June 1995 issue of PTD.

Positioning drives

As automation increases, the need for special-purpose electrical drives constantly expands. Many of these applications require not only controlling speed and direction of shaft rotation, but also controlling position of a part. This part can be an item being machined or sorted, or it can be a part of a machine that is performing the work. Examples include cutters of contour milling machines and the arm of a robot.

Two of the most common types of these special positioning drives include servo and step.

Servo — A servo positioning drive receives signals from a controller — computer numerical control (CNC), programmable logic controller (PLC), or computer — that tells the drive the direction, speed, and time to move a part from Location A to Location B.

Plus, a sensor continuously determines the exact position of the part, and sends this information to the controller. The controller then determines the difference between the intended position at any given time and the actual position. Using this error signal, the controller corrects the power to the drive motor to maintain the needed position-time relationship. Thus, the drive is controlling position, because it is using a position feedback loop.

Offering extremely fast response and precise control, some servos accelerate from standstill to 1000 rpm in a few milliseconds. Most servos are built with at least two feedback loops — speed (or current) and position.

Speed feedback can be supplied by a tachometer-generator (tach). An encoder, or similar sensor, can give position feedback. In other drives, one device—usually an encoder—supplies both speed and position feedback signals. (These sensors are described in detail in the Controls and Sensors Department of this Handbook.) In some designs, the position feedback is connected to the system controller; and in others, it feeds to the drive controller.

Many multiaxis drive controllers include system control functions plus a power supply and several servo power amplifiers in one unit.

For many years, dc was the only type of high-response servo drive available. However, microprocessors and significant developments in power transistors and magnets have made several alternatives available.

Conventional dc—For some, the motor follows the general design of conventional dc motors. However, servomotors have low armature inertia and offer extremely fast response (acceleration of 4,000 radians/sec^2).

Printed-circuit or disc armature designs, operate above 4,000 rpm and offer acceleration rates of 15,000 radians/sec^2.

Servo power amplifiers usually have power transistors to produce a pulse-width-modulated (PWM) dc output. This design offers faster response and better commutation between the brushes and commutators than offered by power units with SCR designs.

Brushless dc (BLDC) — Considered both an ac and a dc design, the BLDC servo is discussed previously in this department under "Brushless dc." Nowadays, the BLDC servo is the most frequently installed type of servo, especially for those rated less than about 20 hp.

AC vector — Built with high-response, two-phase or three-phase ac induction or permanent-magnet synchronous motors, these ac servos also operate on adjustable frequency to obtain adjustable speed. The capabilities of these servo drives are constantly increasing. Recent advances made possible by microprocessors enable this type of drive to offer response equal to or better than dc units. Plus, these ac systems have no maintenance problems associated with dc brushes and commutators.

AC vector servos are increasingly the servo of choice for applications requiring more than about 20 hp. For more information on ac vector drives, see the previous department *Vector* under the

Cleaning up power-line pollution

Until recently, power line pollution — voltage and current harmonics — caused few problems and was often ignored. However, the increasing use of nonlinear-load devices — the causes of power-line pollution — makes reducing harmonics now a necessity. Examples of nonlinear-load devices include ac and dc adjustable-speed drives, static uninterruptable power supplies, programmable controllers, rectifiers, switching-type power supplies, static lighting ballasts, computers, and x-ray devices.

Power-line pollution can cause such problems as power factor reduction, power system overloading, system resonance, and failure of motors, transformers, and electronic equipment.

There are three approaches to meet the limits of current and voltage distortion as specified in IEEE Std. 519-1992:

Drive filters. A specific filter for each drive traps and eliminates unwanted harmonics as close to the source as possible so they do not affect other equipment, Figure E.

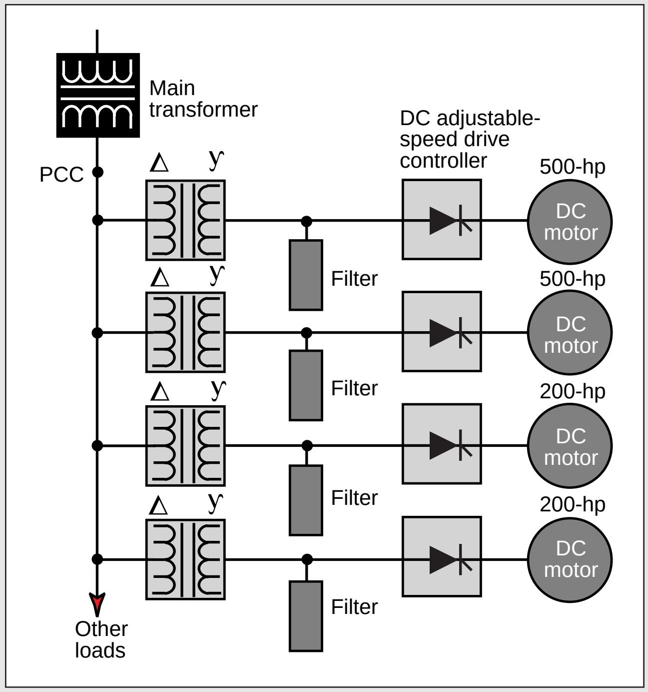


Figure E — Filter at each drive eliminates unwanted harmonics at the source. This filter placement reduces the chance of the harmonics produced by one drive from affecting the operation of another device.

An alternative, less-costly approach uses one filter to reduce the harmonics of a group. Such a filter is connected at the point of common coupling (PCC) or inboard of the plant main transformer.

The group filter enables drives within that group to affect the operation of other drives within the same group. For example, harmonics produced by one drive may cause erratic operation of another drive or other electronic devices.

If a filter is required and if electric costs require adding power-factor correcting capacitors, plan both at the same time, because part of the filter design may require capacitors. Also, be sure that the filter design does not produce a system resonance.

Simulating 12-pulse systems. Individual drive transformers connected delta-wye for half the load and other transformers connected in delta-delta can produce a combined harmonic content that approaches the

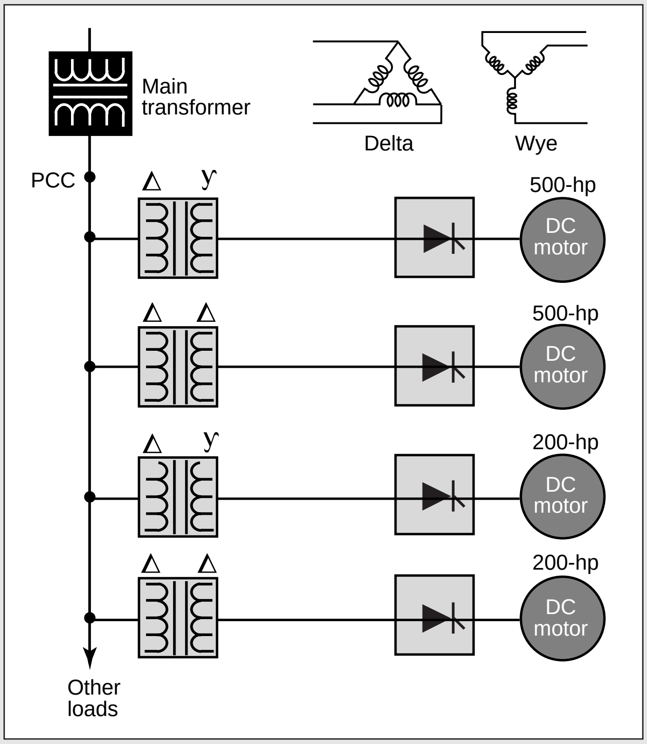


Figure F — By connecting half the load to transformers connected delta-wye and the other half to transformers with delta-delta configuation, the resulting harmonics approach those produced by 12-pulse drives.

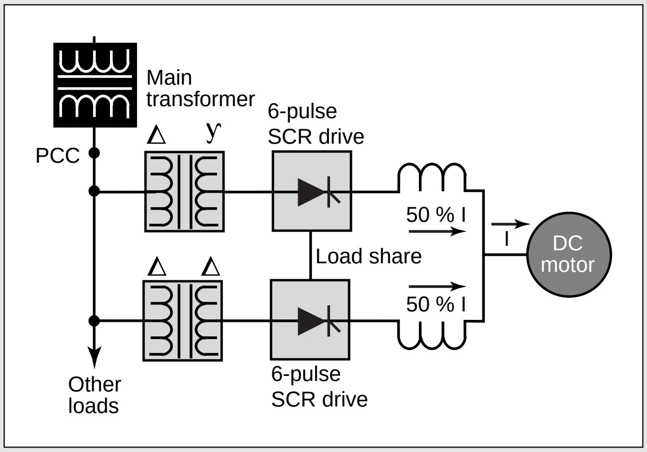


Figure G — Common two-transformer configuration for reducing harmonics produced by high horsepower six-pulse drive.

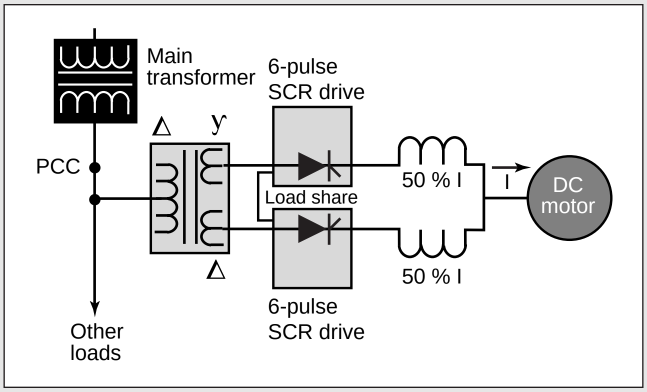


Figure H — Improvement on the configuration in Figure 3. In this single-transformer scheme, the harmonics are reduced in the primary on the transformer rather than at the PCC.

content of a 12-pulse drive, Figure F.

This method reduces harmonics at the PCC, *if* the sum of delta-wye loads equals the delta-delta loads.

This transformer configuration can be cost-effective if present drive-isolation transformers have the same primary and secondary voltages, and the secondary is reconnectable to a delta configuration and maintains the proper output voltage.

Dedicated 12-pulse system. For larger drives (over 500 hp) consider creating a dedicated 12-pulse system from two six-pulse drives that have load-sharing capability or buying a 12-pulse drive. The resultant harmonics remain fairly constant. This approach will reduce the amount of required filtering and its associated cost.

There are two basic configurations:

- Two separate isolation transformers, one connected delta-wye and the second delta-delta.
- A single transformer with two secondaries. In this case, the primary is in delta and one secondary is in wye and the second is in delta.

In the first method, should either of the two transformers fail, replacement is relatively easy, because both are standard model number items, Figure G. However, the installed cost of this system is higher, because two sets of transformer primary protection are required. Also, harmonic reduction takes place at the PCC, Figure H, so the original harmonics caused by each six-pulse drive will be seen by any other loads connected to the plant main transformer.

With the alternate arrangement, harmonic reduction takes place in the transformer primary. Also, installed cost is lower, because the single transformer requires only one set of transformer primary protection. But, because the transformer has two secondary windings — one delta, the other wye — if something should happen to the transformer, repair or replacement would take time.

Excerpted from an article by Theodore J. Bryda, Consultant, in the April 1995 issue of PTD.

heading **"Types of regulators."**

Step-motor drive — Unlike a closed-loop servo drive that requires a position feedback signal, a step-motor drive usually operates open-loop. The drive control pulses the motor with a specific number of pulses to achieve the desired position change. In addition to determining the number of pulses required for a specific move set, the drive also determines the rate of these pulses and hence the speed during the transition.

These logic control devices offer complex programming capabilities, and the ability to step motors in fractions of a step for greatly improved resolution and repeatability. Some offer better than ±5 arc sec/rev unloaded. (Step-motor details are discussed in the Motor Product Department of this Handbook.)

Step drives can be used with position feedback for increased accuracy, because these motors can get out of step during unusual load conditions.

Servo-step trade-offs — Deciding which precision motion control system to select is usually not clear cut. Major factors include torque-speed capabilities, especially at the lower speeds; operating speed range; response; maximum torque; repeatability; space constraints; and cost.

MECHANICAL ADJUSTABLE-SPEED DRIVES

Two basic types of construction comprise mechanical adjustable-speed drives — belt or chain, and traction. Although electrical adjustable-speed drives have replaced mechanical units in some applications, design and specifying engineers still favor mechanical designs for many applications. The major reasons: simplicity, ease of maintenance, desirable operating characteristics, and cost.

Belt and chain drives

The drive is based on the principle of adjustable-diameter sheaves. As the diameter of one sheave increases, the other decreases—maintaining nearly constant belt or chain length—and adjusts the ratio of the input-to-output sheave diameters, Figure 15. These units offer ratios from 2:1 to the more common 6:1, with some small-power units capable of 16:1.

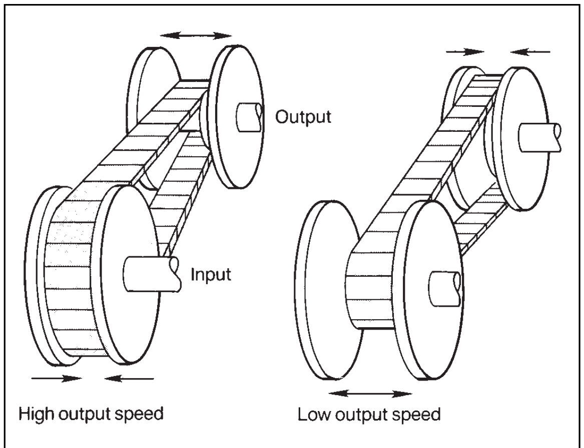


Figure 15 — Basic concept of belt-type mechanical adjustable-speed drive.

Many different types of operating mechanisms and belts or chains are used for this design. One of the simplest mechanisms involves sliding the drive motor to change the center distance between sheaves. One or both sheaves are spring loaded. As the motor moves, the spring keeps nearly constant belt tension by changing sheave diameter. This action changes the sheave ratio and the resultant output speed. These units are available with hand wheels and automatic powered devices to turn the drive control screw and move the motor.

This same principle, with added sophistication, is supplied in packaged

The best small-motor drive: ac or dc?

Advances in technology are enhancing the capabilities and lowering the costs of adjustable-speed ac and dc controllers. Here's a look at some of the tradeoffs for these two types of drives rated to 5 hp.

Cost. General-purpose dc packages are still less expensive than ac controllers due to their lower level of component complexity and fewer power controlling devices. An ac drive has a rectifier section to convert ac to dc, and an inverter section to invert dc to controlled ac. By contrast, a low-cost dc controller uses SCRs to rectify and control the power.

Customization. An ac controller is usually a digital device. Its on-board microprocessor, EPROM (electrically programmable read only memory), and ASIC (application specific integrated circuit) are easier to customize to application requirements.

Speed regulation. With simple slip compensation (similar to IR compensation on a dc drive), an ac package is capable of 1% speed regulation based on a standard NEMA Design B squirrel cage induction motor.

Speed range. Speed range is a function of the motor's ability to dissipate heat, to operate without cogging at low speeds, and to avoid flying apart at high speeds. A totally enclosed, nonventilated (TENV) dc motor is often selected for low-speed application. It is common to oversize the ac motor or add a separately powered blower. However, oversizing a motor may require selecting a larger drive controller.

High-efficiency ac motors can usually operate over a 6:1 speed range, and dc over at least 20:1 without using a speed feedback device.

Power factor. A dc drive with its SCR section has a power factor that decreases at light loads and low speeds, its measurable range is about 20% to 95%. An ac drive with a fixed-diode converter section has a displacement power factor of 95%, regardless of load or speed.

Increasing speed. DC motor speed is proportional to applied armature voltage. AC motor speed is a function of applied frequency and voltage from the ac drive, which is typically capable of 400 Hz operation (12,000 rpm on a 4-pole motor). Check with the motor manufacturer when operating above nameplate speed, regardless of whether it's an ac or dc motor.

Single-phase. Single-phase dc drives are designed and rated for operating from a single-phase power source. Many ac drives are designed for single or three-phase power for low-horsepower applications. Some, when operating from single-phase power, require derating the output current by about 50%. Other ac drives incorporate an oversized dc bus capacitor to filter the higher current ripple to allow for single-phase operation without derating. But remember, the output of an ac drive is always three phase, regardless of input power supply.

Running multiple motors. With dc drives, it is one controller per motor. AC drives can run multiple motors as long as they all run at the same speed.

Rapid stopping. Bringing a motor and load to a quick stop tends to turn the motor into a generator, which means the regenerative energy developed must be dumped usually into a dynamic-braking resistor bank or back to the ac line. Dc drives (even small, single-phase units) are available to regenerate back to the line. An ac drive requires an additional transistor and logic to monitor the dc bus-voltage level to turn the transistor *on* at the proper point to dump the regenerative energy into an external dynamic-braking resistor.

Excerpted from an article by Saftronics Inc. in the April, 1996 issue of PTD.

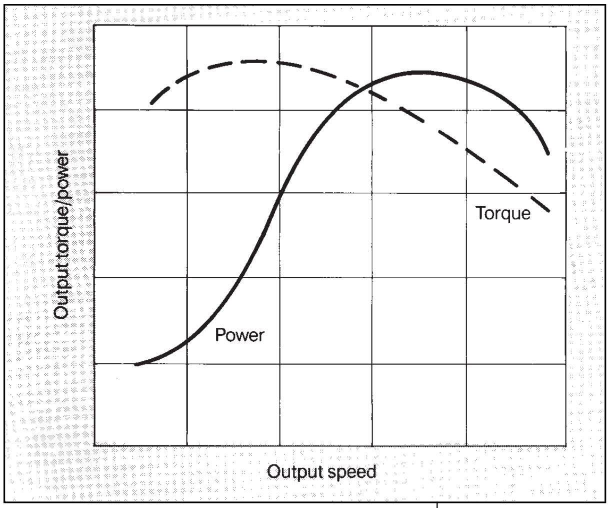


Figure 16 — Typical output torque and power vs. speed curve for belt-type adjustable-speed drive.

drives. Most of these units include an electric motor, adjustable-speed section, and geared reducer. The speed adjustment method can be a hand wheel or an air or electric motor for remote control.

Complex belt and sheave characteristics affect the torque and power that belt drives can transmit, Figure 16. The major factors include sheave pressure at various speeds, belt strength, and belt centrifugal force.

Several types of belts optimize the drive for the application. Rubber belts, among the most frequently used, include standard V-belts for applications requiring up to 2:1 speed adjustment. Also, wide-thin industrial rubber belts are designed for up to 8:1 adjustable-speed applications.

Wood block belts are still used for high torque, low-speed applications (below about 1,200 rpm). This design has a set of wood blocks bolted to a thick composition belt.

Metal chains provide no-slip connection between input and output. These units offer several other advantages: life of 10,000 hr, small size, and easy chain replacement.

Traction drives

Direct mechanical contact of smooth surfaces characterizes traction drives. These units operate on the principle that smooth surfaces transmit torque without pulsation, and that speed can be adjusted by adjusting the ratio of input-to-output contact diameters, Figure 17.

Other traction drives require a special lubricant that, in effect, hardens under high pressure, such as that created between metal surfaces in heavy contact.

Traction drives are manufactured with speed ratios from 5:1 to special units with 25:1. Power ratings vary from fractional to about 100 hp. ■

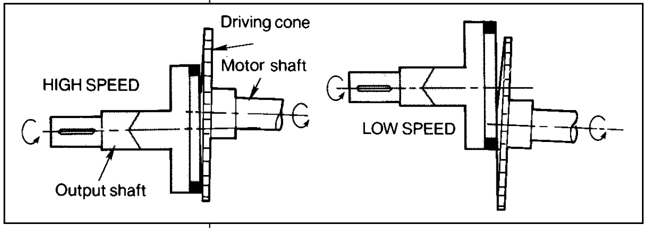


Figure 17 — Common design of metal-to-metal traction drive. A hardened ring on the output shaft disc rides on the driving cone.