Adjustable Speed Drives — What They Are, How They Work

ADJUSTABLE SPEED DRIVES – WHAT THEY ARE, HOW THEY WORK

The primary function of any adjustable speed drive is to control the speed, torque, acceleration, deceleration and direction of rotation of a machine. Unlike constant speed systems, the adjustable speed drive permits the selection of an infinite number of speeds within its operating range.

Most multi-purpose production machines benefit from adjustable speed control, since frequently their speeds must change to optimize the machine process or adapt it to various tasks for improved product quality, production speed or safety. Lathes and other machine tools run small diameter work pieces at high speeds and large diameter pieces at low speeds to optimize the feed rate into the cutting tool. A printing press is operated at the speed that produces the best quality product, which may vary greatly with the weight and coating of paper, and the characteristics of the inks used. Also, the controlled acceleration provided by an adjustable speed drive allows the press to accelerate smoothly to prevent breaking the web of paper. A pump supplying water in a high rise building may run at very slow speeds at 3 o'clock AM to maintain system pressure, but be called upon at 3 o'clock PM to run at high speeds to provide high flow rates necessitated by water usage by the inhabitants.

While early types of adjustable speed drives based upon mechanical and hydraulic principles still remain in limited usage, the overwhelming choice today for industrial applications is the electrical adjustable speed drive. No other type offers the combined benefits of high performance, high efficiency, low maintenance, versatility and moderate initial cost. Electrical adjustable speed drives are offered in a number of basic types, but the two most versatile for general purpose applications and therefore the most common, are direct current (DC drives) and adjustable frequency (AC drives) as manufactured by Fincor Electronics. Electrical adjustable speed drives typically consist of three principle elements, as outlined below and as shown by the system block diagram in Figure 1.

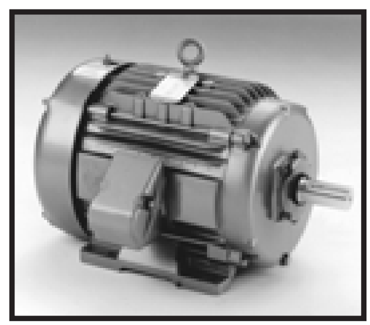
1. OPERATOR CONTROL STATION – THE BOSS

Allows the operator to start and stop the drive controller by push buttons or switches, and set the motor speed by turning a potentiometer to the desired dial setting. Operator controls may be integrated into the controller or mounted remotely from the drive controller.

2. DRIVE CONTROLLER – THE BRAINS

Converts the fixed voltage and frequency of the alternating current (AC) plant power source into an adjustable power output to control the drive motor over a wide speed range. The output is established by the speed control potentiometer. The controller includes sensing circuits to hold or regulate the motor at the desired speed with variations in the source voltage and changes in motor load. The controller also includes protective circuitry and devices to prevent damage from overloads, power source transients and output power faults.

3. DRIVE MOTOR – THE MUSCLE



Translates electrical energy into mechanical motion. The output is a shaft rotation (RPM), which varies in proportion to the power applied by the drive controller. The motor shaft is normally coupled to a gear reducer or other mechanical power transmission device to further reduce the motor speed to a level useable by the driven machine.

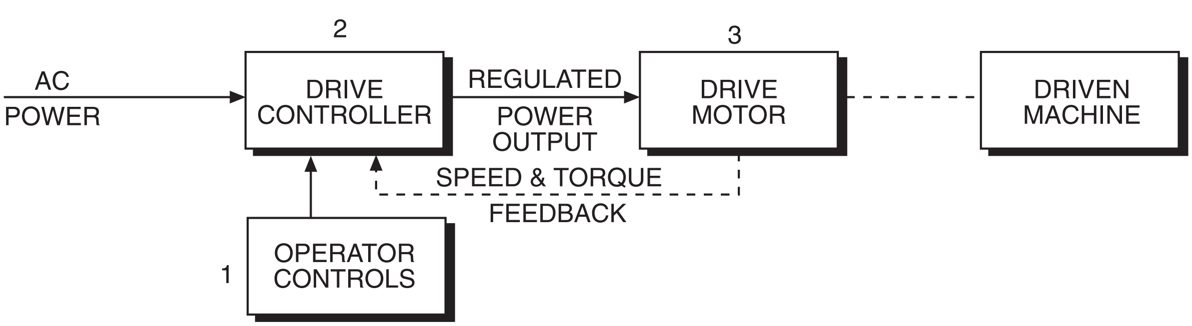


FIGURE 1. Functional Block Diagram

DC DRIVES – PRINCIPLES OF OPERATION

DC drives, because of their simplicity, ease of application, reliability and favorable cost have long been a backbone of industrial applications. A typical adjustable speed drive using a silicon controller rectifier (SCR) power conversion section, common for this type unit, is shown in Figure 2. The SCR, (also termed a thyristor) converts the fixed voltage alternating current (AC) of the power source to an adjustable voltage, controlled direct current (DC) output which is applied to the armature of a DC motor.

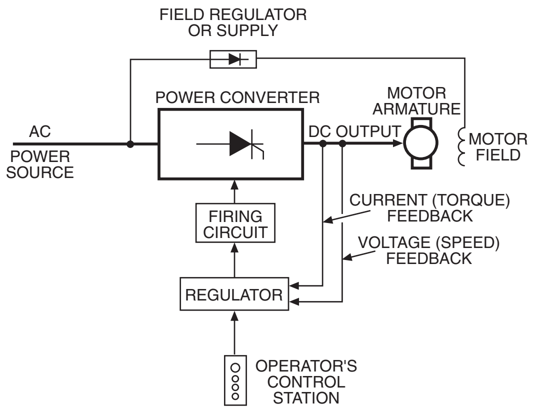


FIGURE 2. Typical DC Drive

SCR's provide a controllable power output by "phase angle control", so called because the firing angle (a point in time where the SCR is triggered into conduction) is synchronized with the phase rotation of the AC power source. If the device is triggered early in half cycle, maximum power is delivered to the motor; late triggering in the half cycle provides minimum power, as illustrated by Figure 3. The effect is similar to a very high speed switch, capable of being turned on and "conducted" off at an infinite number of points within each half cycle. This occurs at a rate of 60 times a second on a 60 Hz line, to deliver a precise amount of power to the motor. The efficiency of this form of power control is extremely high since a very small amount of triggering energy can enable the SCR to control a great deal of output power.

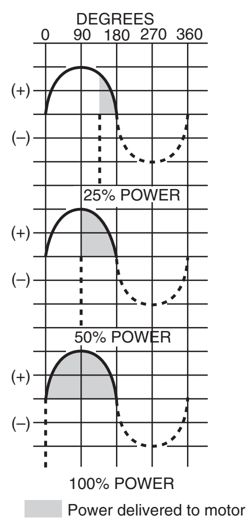


FIGURE 3. Triggering Points for Various Power Outputs

DC DRIVE TYPES

Nonregenerative DC Drives – Nonregenerative DC drives are the most conventional type in common usage. In their most basic form they are able to control motor speed and torque in one direction only as shown by Quadrant I in Figure 4. The addition of an electromechanical (magnetic) armature reversing contactor or manual switch (units rated 2 HP or less) permits reversing the controller output polarity and therefore the direction of rotation of the motor armature as illustrated in Quadrant III. In both cases torque and rotational direction are the same.

Regenerative DC Drives – Regenerative adjustable speed drives, also known as four-quadrant drives, are capable of controlling not only the speed and direction of motor rotation, but also the direction of motor torque. This is illustrated by Figure 4.

The term regenerative describes the ability of the drive under braking conditions to convert the mechanical energy of the motor and connected load into electrical energy which is returned (or regenerated) to the AC power source.

When the drive is operating in Quadrants I and III, both motor rotation and torque are in the same direction and it functions as a conventional nonregenerative unit. The unique characteristics of a regenerative drive are apparent only in Quadrants II and IV. In these quadrants, the motor torque opposes the direction of motor rotation which provides a controlled braking or retarding force. A high performance regenerative drive, is able to switch rapidly from motoring to braking modes while simultaneously controlling the direction of motor rotation.

A regenerative DC drive is essentially two coordinated DC drives integrated within a common package. One drive operates in Quadrants I and IV, the other operates in Quadrants II and III. Sophisticated electronic control circuits provide interlocking between the two opposing drive sections for reliable control of the direction of motor torque and/or direction of rotation.

Converter Types – The power conversion or rectified power section of a DC drive is commonly called the converter. The individual characteristics of the various converter types used in standard industrial applications have had a definite influence in the design of compatible DC motors as shown in Table 2.

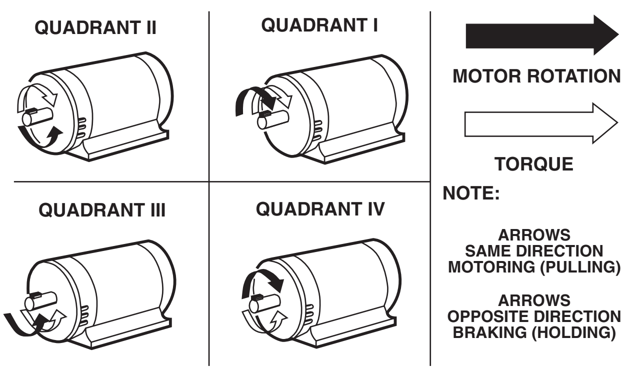


FIGURE 4.

TABLE 1. COMPARISON OF NONREGENERATIVE VS. REGENERATIVE DC DRIVE CAPABILITIES

	Nonregenerative	Regenerative
Braking	No inherent braking capability. Requires the addition of a dynamic braking circuit which dissipates the braking energy as heat in a resistor. Braking effort is exponential with initial high torque which reduces to zero at zero speed. Braking circuits are rated for stopping only, not continuous hold back, or as a holding brake.	Inherent electronically by regeneration whereby the kinetic energy of the motor and driven machine is restored to the AC power source. Can be regulated to control the braking torque down to, and at zero speed. Typically capable of continuous braking torque for hold back applications.
Reversing	No inherent reversing capability. Requires the addition of reversing contactors or a switch to reverse the polarity of DC voltage applied to the motor. Normally rated for occasional reversing.	An inherent capability. Motor polarity is reversed electronically with no contacts to arc, burn or wear. Desirable for applications requiring frequent reversals.
Simplicity	The least complex and least expensive form of electronic adjustable speed motor control.	More complex since it includes double the nonregenerative circuitry.
Efficiency and Speed Range	Controller efficiency up to 99%, complete drive with motor 87%. Speed range up to 50:1 without a feedback tachometer, 200:1 and greater with a tachometer or encoder.	

TABLE 2.

Rectified Power Source				Motor Ratings			
Converter Type	NEMA Code	Form[2] Factor	Ripple[2] Hz	Source VAC	HP Range	Armature VDC	Field VDC
Full Converter 6 SCR Nonregenerative 12 SCR Regenerative	C	1.01	360	230	1-250	240	150
				460	1-1000	500	300
Semiconverter 3 SCR, 4 Diode	D	1.05	180	230	1-150	240	150
				460	1-150	500	300
Half Wave Converter 3 SCR Nonregenerative 6 SCR Regenerative	E	1.10	180	230[3]	1-250	240[3]	300[3]
				460	1-250	240[3]	300
Semiconverter 2 SCR, 3 Diode[1]	K	1.35	120	115 230	1/6-1 1/2-5	90 180	50 100
Full Converter 4 SCR Nonregenerative 8 SCR Regenerative[1]	–	–	120	115 230	1/6-1 1/2-5	90 180	100 200

NOTES: (1) Single-phase: others are three-phase
(2) Ripple frequency shown for 60 Hz power source. 50 Hz power sources result in ripple currents 20%, higher than those for a 60 Hz source under the same operating conditions. The higher ripple produces additional heating which may be compensated by reducing the continuous load capability below base speed by approximately 5%. Form factor is at base speed, full load. Form factor of the current is the ratio of the rms current to the average current. For pure DC, such as a battery, the form factor is 1.0. For motors operated on rectified power the AC ripple content of the rectified current causes additional heating which increases as the square of the form factor. A motor is suitable for continuous operation of the form factor stamped on the data plate at rated load and rated speed. Actual motor heating when run from a half-wave converter should be determined by test, and is the responsibility of the purchaser.
(3) Center tap step-up isolation transformer used on primary to increase converter voltage to 480V.

DC MOTOR CONTROL CHARACTERISTICS

A shunt-wound motor is a direct-current motor in which the field windings and the armature may be connected in parallel across a constant-voltage supply. In adjustable speed applications, the field is connected across a constant-voltage supply and the armature is connected across an independent adjustable-voltage supply. Permanent magnet motors have similar control characteristics but differ primarily by their integral permanent magnet field excitation.

The speed (N) of a DC motor is proportional to its armature voltage; the torque (T) is proportional to armature current, and the two quantities are independent, as illustrated in Figure 5.

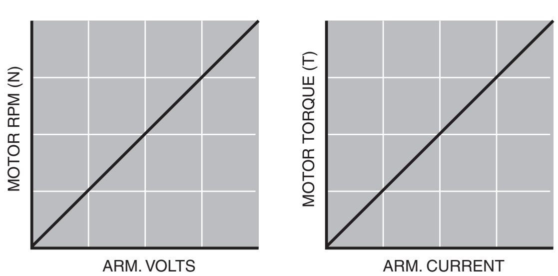


FIGURE 5. DC Motor Characteristics

CONSTANT TORQUE APPLICATIONS

Armature voltage controlled DC drives are constant torque drives. They are capable of providing rated torque at any speed between zero and the base (rated) speed of the motor as shown by Figure 6. Horsepower varies in direct proportion to speed, and 100% rated horsepower is developed only at 100% rated motor speed with rated torque.

CONSTANT HORSEPOWER APPLICATIONS

Armature Controlled DC Drives – Certain applications require constant horsepower over a specified speed range. The screened area, under the horsepower curve in Figure 6, illustrates the limits of constant horsepower operation for armature controlled DC drives. As an example, the motor could provide constant horsepower between 50% speed and 100% speed, or a 2:1 range. However, the 50% speed point coincides with the 50% horsepower point. Any constant horsepower application may be easily calculated by multiplying the desired horsepower by the ratio of the speed range over which horsepower must remain constant. If 5 HP is required over a 2:1 range, an armature only controlled drive rated for 10 (5 x 2) horsepower would be required.

Table 3 provides a convenient listing of horsepower output at various operating speeds for constant torque drives.

Field Controlled DC Drives – Another characteristic of a shunt-wound DC motor is that a reduction in field voltage to less than the design rating will result in an increase in speed for a given armature voltage. It is important to note, however, that this results in a higher armature current for a given motor load. A simple method of accomplishing this is by inserting a resistor in series with the field voltage source. This may be useful for trimming to an ideal motor speed for the application. An optional, more sophisticated method uses a variable voltage field source as shown by Figure 6. This provides coordinated automatic armature and field voltage control for extended speed range and constant HP applications. The motor is armature voltage controlled for constant torque-variable HP operation to base speed where it is transferred to field control for constant HP-variable torque operation to motor maximum speed.

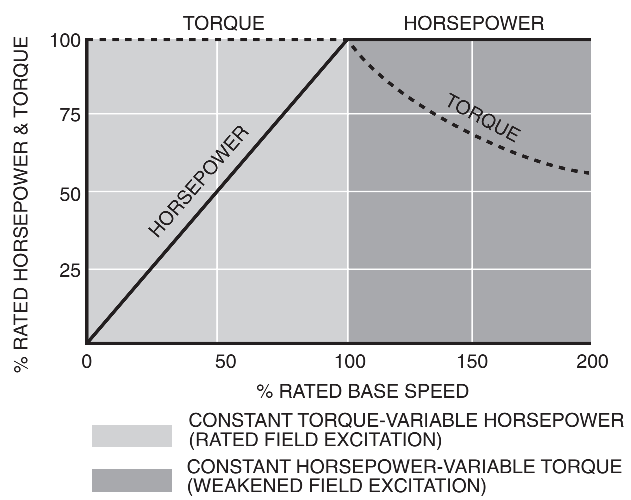


FIGURE 6.

AC DRIVES – PRINCIPLES OF OPERATION

Adjustable frequency AC motor drive controllers frequently termed inverters are typically more complex than DC controllers since they must perform two power section functions, that of conversion of the AC line power source to DC and finally an inverter change from the DC to a coordinated adjustable frequency and voltage output to the AC motor. The appeal of the adjustable frequency drive is based upon the simplicity and reliability of the AC drive motor, which has no

TABLE 3. HORSEPOWER OUTPUT AT VARIOUS MOTOR SPEEDS WITH 1750 RPM BASE SPEED CONSTANT TORQUE DRIVES

Rated HP At 1750 RPM Base Speed	Rated Torque At All Speeds Lb. -Ft. (1)(2)	HP Ratings at Various Motor RPM										
		1575	1400	1225	1050	875	700	525	350	175	87.5	35
1/6	0.50	.150	.133	.117	.100	.083	.067	.050	.033	.017	.008	.003
1/4	0.75	.225	.200	.175	.150	.125	.100	.075	.050	.025	.013	.005
1/3	1.00	.300	.267	.233	.200	.167	.133	.100	.067	.033	.017	.007
1/2	1.50	.450	.400	.350	.300	.250	.200	.150	.100	.050	.025	.010
3/4	2.25	.675	.600	.525	.450	.375	.300	.225	.150	.075	.038	.015
1	3.00	.900	.800	.700	.600	.500	.400	.300	.200	.100	.050	.020
1-1/2	4.50	1.350	1.200	1.050	.900	.750	.600	.450	.300	.150	.075	.030
2	6.00	1.800	1.600	1.400	1.200	1.000	.800	.600	.400	.200	.100	.040
3	9.00	2.700	2.400	2.100	1.800	1.500	1.200	.900	.600	.300	.150	.060
5	15.00	4.500	4.000	3.500	3.000	2.500	2.000	1.500	1.000	.500	.250	.100
7-1/2	22.50	6.750	6.000	5.250	4.500	3.750	3.000	2.250	1.500	.750	.375	.150
10	30.00	9.000	8.000	7.000	6.000	5.000	4.000	3.000	2.000	1.000	.500	.200
15	45.00	13.500	12.000	10.500	9.000	7.500	6.000	4.500	3.000	1.500	.750	.300
20	60.00	18.000	16.000	14.000	12.000	10.000	8.000	6.000	4.000	2.000	1.000	.400
25	75.00	22.500	20.000	17.500	15.000	12.500	10.000	7.500	5.000	2.500	1.250	.500
30	90.00	27.000	24.000	21.000	18.000	15.000	12.000	9.000	6.000	3.000	1.500	.600
40	120.00	36.000	32.000	28.000	24.000	20.000	16.000	12.000	8.000	4.000	2.000	.800
50	150.00	45.000	40.000	35.000	30.000	25.000	20.000	15.000	10.000	5.000	2.500	1.000
60	180.00	54.000	48.000	42.000	36.000	30.000	24.000	18.000	12.000	6.000	3.000	1.200
75	225.00	67.500	60,000	52.500	45.000	37.000	30.000	22.500	15.000	7.500	3.750	1.500
100	300.00	90.000	80.000	70.000	60.000	50.000	40.000	30.000	20.000	10.000	5.000	2.000
125	375.00	112.500	100.000	87.500	75.000	62.500	50.000	37.500	25.000	12.500	6.250	2.500
Percent of Base Speed		90	80	70	60	50	40	30	20	10	5	2

NOTE: ON SHADED AREA: Motors may require supplemental cooling when operated continuously at rated load at reduced speeds. See Specifications 9100, 9200, 9300, 9700.

NOTE: (1) lb-in = lb - ft x 12

(2) Torque ratings for other base speed motors:
2500 RPM Motor = 1750 RPM Torque x .7 Approx.
1150 RPM Motor = 1750 RPM Torque x 1.52 Approx.
850 RPM Motor = 1750 RPM Torque x 2.06 Approx.

brushes, commutator or other parts that require routine maintenance, which more than compensates for the complexity of the AC controller. The robust construction, and low cost of the AC motor makes it very desirable for a wide range of uses. Also, the ability to make an existing standard constant speed AC motor an adjustable speed device simply by the addition of an adjustable frequency controller creates a very strong incentive for this type of drive.

AC CONTROLLER TYPES

A number of different types of AC motor controllers are currently in common use as general purpose drives: Pulse Width Modulated (PWM), Current Source Input (CSI), and the Load Commutated Inverter (LCI). Each type offers specific benefits and characteristics but the PWM type has been selected by Fincor Electronics as offering the best combination of simplicity, performance and economy for general purpose applications.

PWM Controllers – The PWM controller converts the AC power source to a fixed DC voltage by a full-wave rectifier. The resultant DC voltage is smoothed by a filter network and applied to a pulse width modulated inverter using high power transistors. The speed reference command is directed to the microprocessor which simultaneously optimizes the carrier (chopping) frequency and inverter output frequency to maintain a proper volts/Hz ratio and high efficiency throughout the normal speed range. See Block Diagram, Figure 7.

The voltage applied to the motor is a pulsed approximation of a true sinusoidal waveform as shown in Figure 8. This is commonly called a PWM waveform because both the carrier frequency and pulse-

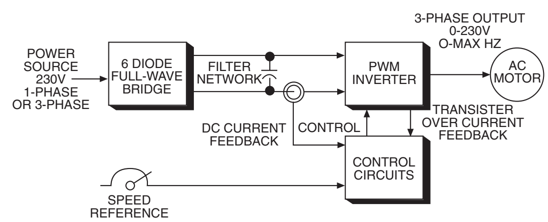


FIGURE 7.

width is changed (modulated) to change the effective voltage amplitude and frequency. The current waveform very closely follows the shape of a sine wave and therefore provides improved low speed motor performance, efficiency, and minimal motor heating.

AC MOTOR CONTROL CHARACTERISTICS

The synchronous speed of an AC induction motor is directly proportional to the applied frequency.

$$\text{Speed} = \frac{120 \times \text{Frequency}}{\text{No. of Motor Poles}}$$

The synchronous speed is the speed of the rotating electrical field, not the actual motor rotor speed. The difference between the synchronous speed and the full-load motor speed is called slip,

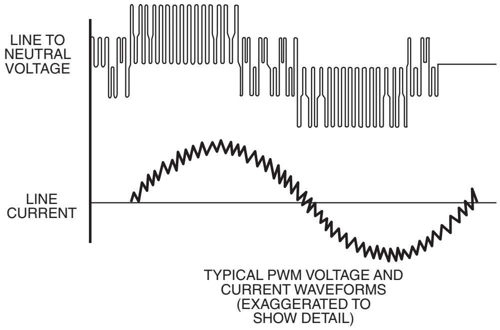


FIGURE 8.

which is normally expressed in percent. The percentage of slip is determined by the design of the motor, primarily the rotor resistance. NEMA has assigned code letters (A, B, C, D, etc.) to standardize motor characteristics including slip. The type most commonly used is NEMA Design B with 3% slip at rated operating conditions. Figure 9 shows typical speed/torque curves for NEMA Design B and D motors.

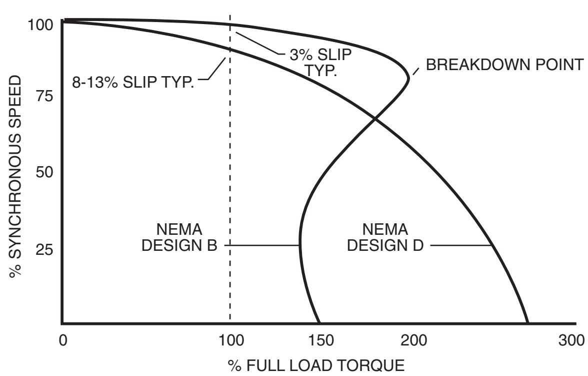


FIGURE 9. Typical Speed-Torque Characteristics at Rated Voltage & Frequency

As the applied frequency is changed, the motor will run faster or slower as shown by Figure 10. The actual full-load motor slip (as a percent of the motor synchronous speed) varies in inverse proportion to the frequency, where a 3% slip motor 60 Hz would have a 6% slip at 30 Hz or 1 1/2 % slip at 120 Hz. Motor speed is limited only by the maximum inverter output frequency, load torque requirements, and the mechanical integrity of the motor.

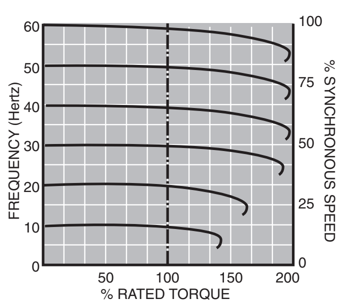


FIGURE 10. Typical Speed Torque Curves for 60 Hz NEMA Design B Motor (Without Voltage Boost)

MOTOR SELECTION

Constant Torque Applications – About 90% of all general industrial machines, other than fans and pumps, are constant torque systems where the machine's torque requirement is independent of its speed. If the machine speed is doubled, its horsepower requirement doubles. Conversely a reduction in machine speed by 50% will result in an equal reduction in horsepower, but no reduction in torque.

1. Standard three-phase AC motors, designed for fixed speed operation at standard line frequency, may be easily adapted for use with the AC controller by considering the following:
   a. A slight increase in motor losses occurs with inverter power.
   b. The motor thermal capacity must typically be derated as a function of the minimum, continuous operating speed in accord with Figure 11, due to the reduced ventilation provided by the integral motor fan. Where the application requires 100% rated torque at speeds below 50% of synchronous speed, a separately powered ventilation blower, a nonventilated motor with greater reserve thermal capacity or, a motor with higher rated capacity should be used. When a separately powered ventilation blower is used, a thermostat should be built into the motor to prevent damage which may result from a failure in the ventilation system.

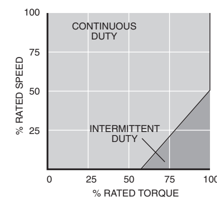


FIGURE 11. Typical Standard AC Motors Adjustable Speed Operation

2. Any three-phase synchronous or induction AC motor designed expressly for adjustable speed service by inverter control may normally be used over its design speed range with the AC controller.

Variable Torque Applications – The application of standard AC motors to adjustable speed variable torque applications such as centrifugal fans or pumps is ideal from a motor cooling standpoint. The torque characteristics of a variable torque (cubed exponential horsepower) load are such that the load falls off rapidly as the motor speed is reduced. The variable torque load eliminates the necessity to derate the motor due to excessive heat resulting from diminished motor cooling at reduced speeds. Figure 12 illustrates the relationship between speed and torque in variable torque applications.

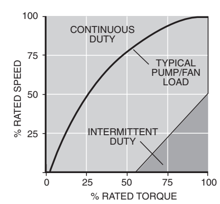


FIGURE 12. Typical Standard AC Motor Application with Variable Torque Loads

Potential Power Savings – Most fan and pump applications require the system to run for sustained periods at reduced outputs by either reducing the speed of the motor or by mechanically altering the flow. Figure 13 illustrates typical energy savings, in percent of rated power, which can be realized when using an adjustable frequency controller to reduce motor speed and thereby system flow as opposed to a constant speed motor which has its system flow varied by an outlet damper.

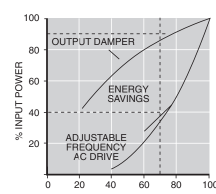


FIGURE. 13. Energy Savings

Constant Torque Operation – The ability of the AC controller to maintain a constant volts/Hz relationship is ideal from a motor standpoint. This permits operation of the motor at rated torque from near standstill to rated speed.

Figure 14 represents the relationship between torque, horsepower and motor speed with a maintained volts/Hz ratio using a 60 Hz controller for illustration. A standard 4-pole 460V motor can be controlled by this method to its synchronous speed of 1800 RPM. If the same motor were wound for 50% of the input voltage (230V), it could be controlled with constant torque to double the normal rated speed and horsepower. The motor would not be "overvoltaged" because the volts/Hz ratio could be maintained e.g.: a motor wound for 230 VAC can supply constant torque to twice the AC line frequency when used

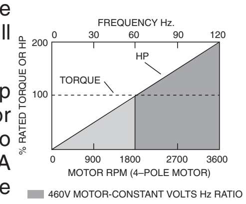


FIGURE 14. Constant Torque Operation

on a 460V power source without overvoltaging the motor because the volts/Hz ratio of 230V/60 Hz is the same as 460V/120 Hz. The horsepower would also double since the same torque would be developed at twice the normal rated speed.

Caution must be observed when applying standard motors for continuous low speed, rated torque operation. The motor's self-cooling capability is dependent upon self-ventilation schemes with efficiency that is considerably reduced at lower operating speeds.

Constant Horsepower Operation – AC motor controllers are also adaptable to constant horsepower operation as shown by Figure 15. With this mode of operation, the volts/Hz ratio is maintained to a specific frequency, normally 50 or 60 Hz. At this point, the voltage is "clamped" at a constant level while the frequency is adjusted further to achieve the desired maximum speed. Since the controller maximum output voltage is limited to the voltage of the AC power source, the volts/Hz ratio must decrease beyond this point as the frequency increases. The motor becomes "voltage starved" above the clamping point and torque decreases as speed increases, resulting in constant horsepower output.

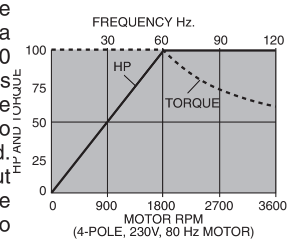


FIGURE 15. Typical Constant HP Operation

As shown in Figure 15 the drive provides conventional constant torque/variable horsepower operation up to 60 Hz which is equivalent to the 1800 RPM base speed of the 60 Hz motor. Between 1800 and 3600 RPM, the drive provides constant horsepower/variable torque operation. If constant horsepower is required between 900 and 3600 RPM (a 4:1 speed range) – using the same 1800 RPM base speed motor, the drive rated horsepower must be increased since 900 RPM intersects the curve at a point which is 50% of rated horsepower.

Constant HP operation (above synchronous speed) is limited to induction motors only. In addition, at some point, typically around three times base speed for a four-pole induction motor, the breakdown torque of the motor prevents further constant horsepower operation. Synchronous reluctance motor characteristics prevent operation in this mode.

Multiple Motor Operation (From a Common Controller) – An adjustable frequency AC motor controller is ideally suited for simultaneous control of multiple motors in process line applications. All motors are operated at a common frequency and are therefore synchronized at a common speed. Tracking accuracy between the individual motors varies only by the difference in their loads, typically 0.5% to 3% with standard NEMA Design B motors and 0.0% with synchronous reluctance types.

Where tracking ratios other than 1:1 are desirable, gear boxes, fixed or adjustable sheaves may be used to attain the desired individual speeds. Two-pole, four-pole and six-pole motors may also be mixed to obtain various individual motor operating speeds when operated from a common adjustable frequency controller. Selection of a properly rated controller should be made with consideration for the total KVA required by all the motors which are normally started and stopped simultaneously. Some process line applications require the ability to selectively start and stop one or more of the motors while the others are operated at the desired speed. A standard motor started under this condition instantaneously draws locked-rotor current of 600-800%. Unless this factor is considered in the selection of an adequately rated controller, the additional load may exceed the capacity of the power unit, reducing the voltage to the entire system which could cause the line to stall or trip off.

AC VS. DC DRIVE COMPARISON

AC and DC drives both continue to offer unique benefits and features that may make one type or other better suited for certain applications.

AC DRIVES MAY BE BETTER BECAUSE . . .

- They use conventional, low cost, 3-phase AC induction motors for most applications.
- AC motors require virtually no maintenance and are preferred for applications where the motor is mounted in an area not easily reached for servicing or replacement.
- AC motors are smaller, lighter, more commonly available, and less expensive than DC motors.
- AC motors are better suited for high speed operation (over 2500 rpm) since there are no brushes, and commutation is not a problem.
- Whenever the operating environment is wet, corrosive or explosive and special motor enclosures are required. Special AC motor enclosure types are more readily available at lower prices.
- Multiple motors in a system must operate simultaneously at a common frequency/speed.
- It is desirable to use an existing constant speed AC motor already mounted and wired on a machine.
- When the application load varies greatly and light loads may be encountered for prolonged periods. DC motor commutators and brushes may wear rapidly under this condition.
- Low cost electronic motor reversing is required.
- It is important to have a back up (constant speed) if the controller should fail.

DC DRIVES MAY BE BETTER BECAUSE . . .

- DC drives are less complex with a single power conversion from AC to DC.
- DC drives are normally less expensive for most horsepower ratings.
- DC motors have a long tradition of use as adjustable speed machines and a wide range of options have evolved for this purpose:
- Cooling blowers and inlet air flanges provide cooling air for a wide speed range at constant torque.
- Accessory mounting flanges and kits for mounting feedback tachometers and encoders.
- DC regenerative drives are available for applications requiring continuous regeneration for overhauling loads. AC drives with this capability would be more complex and expensive.
- Properly applied brush and commutator maintenance is minimal.
- DC motors are capable of providing starting and accelerating torques in excess of 400% of rated.
- Some AC drives may produce audible motor noise which is undesirable in some applications.

BASIC MECHANICS

The curve in Figure 6 shows a distinct relationship between speed, torque and horsepower. Torque is constant at any speed while there is a direct proportional relationship between horsepower and speed; horsepower varies directly with the speed. Therefore, horsepower is motion dependent, torque is not.

TORQUE

A force applied in a manner that tends to produce rotation, such as a pipe wrench on a shaft. Torque (force) without rotation is termed static torque, since no motion is produced.

Torque is measured in lb-in or lb-ft which is the product of the force in pounds (lb) x the distance in inches (in) or feet (ft) from the center of the point of apparent rotation. Figure 16 shows 120 lb-in (12 inches x 10 lbs) or 10 lb/ft torque.

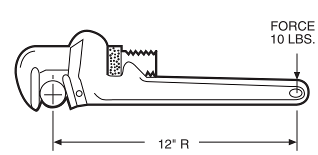


FIGURE 16.

Because most power transmission is based upon rotating elements, torque is important as a measurement of the effort required to produce work (horsepower).

POWER (Horsepower)

A force applied in a manner that produces motion and, therefore, work over a specified time period. A common unit of power is horsepower. **One horsepower (HP) is defined as the force required to lift 33,000 lbs, one foot in one minute.**

Three basic factors are involved:

Factor	Unit
Distance (Radius)	Foot (or inches)
Force (Push or Pull)	Pounds
Time	One (1) Minute

$$HP = \frac{F\ (\text{Load in Pounds}) \times \text{Feet per Minute}}{33{,}000}$$

HORSEPOWER-TORQUE, GETTING IT TOGETHER

As shown in Figure 17, the 50 lb load is acting on the 5 inch radius (distance) of the winch, producing a load torque of 250 lb-in (50 lbs x 5 inches) that must be overcome to lift the load. Since the hand crank arm has a 10 inch radius (distance), a minimum force of 25 lbs must be exerted to overcome the load torque (25 lbs x 10" = 250 lb/in). If no motion is involved, the system is in balance. Although torque is being exerted, no work is accomplished and no horsepower is developed.

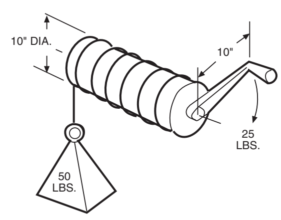


FIGURE 17.

The winch diameter is 10 inches. Therefore, each revolution of the hand crank will lift the weight 10 inches x π = 31.416 inches (2.618 feet).

If the crank is turned at 10 RPM, 50 lbs will be lifted a distance of 26.18 feet in one minute:

$$HP = \frac{\text{Load in Pounds} \times \text{Feet per Minute}}{33{,}000}$$

$$HP = \frac{50 \times 26.18}{33{,}000} = .03966\ HP$$

Turning the crank twice as fast (20 RPM) will develop twice the horsepower.

$$HP = \frac{50 \times 52.36}{33{,}000} = .07933\ HP$$

Thus, the horsepower of rotating elements can be calculated from the following formula:

$$HP = \frac{F \times 2\pi \times R \times RPM}{33{,}000} = \frac{T \times RPM}{5252}$$

where,

F = force in pounds
R = radius (lever length in feet)
RPM or N = revolutions per minute
T = torque in lb/ft (F x R)

SELECTING A DRIVE FOR A MACHINE

The application of an adjustable speed drive to power a machine is a mechanical, rather than an electrical problem. When applying the drive, the speed/torque/horsepower characteristics developed at the drive motor shaft must be considered, and how well these characteristics suit the machine. Four essential parameters are: Breakaway Torque, Process Torque, Accelerating Torque and Running Torque.

BREAKAWAY TORQUE

The torque required to start the machine in motion. It is most always greater than the torque required to maintain motion (running torque). Breakaway torque combined with process torque frequently determines drive selection. Table 5 lists typical breakaway torques for various machine types.

TABLE 5. TYPICAL BREAKAWAY TORQUES FOR VARIOUS MACHINE TYPES

Machine Types	Breakaway Torque(1)	Drive Selection
Machines with ball or roller bearings	110 to 125%	Standard drive rating
Machines with sleeve bearings	130 to 150%	Standard drive rating
Conveyors and machines with excessive sliding friction	160 to 250%	Oversize drive
Machines that have "high" load spots in their cycle, e.g., printing and punch presses, and machines with cam or crank operated mechanisms	250 to 600%	Oversize drive
High Inertia – Machines with fly-wheels or other heavy rotating masses. Also, some machines that move large masses by cranks, centrifuges, etc.	Nominal rating of drive will depend on the breakaway torque requirements	Drive rating dependent upon desired acceleration time and drive torque

NOTE: (1) Typical percentages of running torque

PROCESS TORQUE

The torque required to pull, push, compress, stretch or otherwise process or act upon the material being transported by or through the machine. On some machines, process torque may be so significant as to determine the drive power rating. On other machines, this load may be insignificant. The process torque load is superimposed on all other static and dynamic torque requirements of the machine.

ACCELERATING TORQUE

The torque required to bring the machine to an operating speed within a given time. With most machines, the load is largely friction and a standard drive rating may have adequate torque for satisfactory acceleration. However, certain machines classified as "high inertia" with flywheels, bull gears or other large rotating masses may require drive selection based upon the power required to accelerate the load within a given time.

RUNNING TORQUE

The torque required to maintain machine motion after it accelerates to the desired operating speed. The characteristics of the speed-torque curves of various machines are very important to proper adjustable speed drive selection. Virtually all machines fall into four basic categories which provide common and useful classifications for machine types: Constant Torque (Figure 18), Constant Horsepower (Figure 19), Squared Exponential Horsepower (Figure 20), and Cubed Exponential Horsepower (Figure 21).

A limited number of machines may have operating characteristics which are a composite of the basic types.

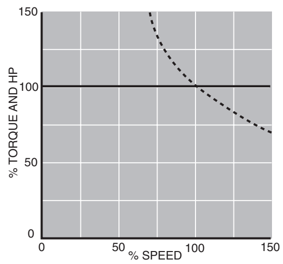


FIGURE 18. Constant Torque

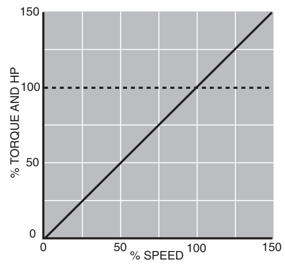


FIGURE 19. Constant Horsepower

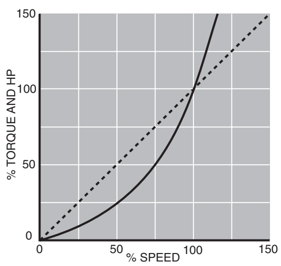


FIGURE 20. Squared Exponential Horsepower

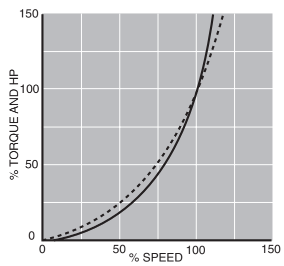


FIGURE 21. Cubed Exponential Horsepower

– – – – Torque _______ HP

Constant Torque – About 90% of all general industrial machines, other than pumps, are constant torque systems. The machine's torque requirement is independent of its speed. If the machine speed is doubled, its horsepower requirement doubles. This fact is commonly overlooked when replacing a constant speed drive with an adjustable speed drive and the machine operating speed is increased.

Constant Horsepower – For machines with constant horsepower loads, the power demand is independent of speed, and torque varies inversely with speed. This type is most often found in the machine-tool industry and with center driven winders. When drilling, shaping, milling, or turning metal, the loads all tend toward constant horsepower. At low speed there is high torque; at high speed, light torque. A drive must be selected for its highest torque condition which is at the lowest speed of the range. With most machines, the "constant horsepower range" seldom covers even a 3:1 range, though some applications may require 5:1 or more.

Squared-Exponential Loads – With machines of this type, torque varies directly as the speed, and power as the square of speed. Such relationships are frequently found in positive-displacement pumps and mixer applications.

Cubed-Exponential Loads – It is a characteristic of these machines that torque varies as the square of speed, and power as the cube of speed. This type of load is imposed on centrifugal pump drives and most fan or blower drives. In some uses, fan or blower horsepower varies as the fifth power of speed. The exponential relationship is characteristic of these machines. This fact must be considered when sizing motors for adjustable speed drives. If the speed of a centrifugal pump is doubled, its power requirement increases by a factor of eight.

OTHER APPLICATION FACTORS

Constant Torque Speed Range – On large motors, minimum speed limitations may be necessary for self-ventilated motors, since their cooling is entirely dependent upon motor speed and, there fore, diminishes as speed is reduced. Where rated torque operation is required continuously at lower speeds, either a higher rated drive motor or supplemental motor ventilation, such as a motor mounted cooling blower or external air duct, is required.

Torque Limitations – Most adjustable speed drives feature a torque limiter to protect the drive and the machine from torque overloads. The torque limiter (current limit) is normally adjusted to 150% of rated torque to allow extra momentary torque for breakaway, acceleration or cyclic overloads. Most drive systems are capable of sustaining the 150% torque overload for one minute or less.

Duty Cycle – Certain applications may require continuous reversals, long acceleration times at high torque due to inertia loads, frequent high rate acceleration, or cyclic overloads which may result in severe motor heating if not considered in the selection of the drive. Most drives with 150% overload capability will operate successfully if there are compensating periods of operation where motor temperatures can be normalized.

MEASURING MACHINE TORQUE

To measure the torque required to drive a machine, fasten a pulley securely to the shaft which the motor is to drive. Fasten one end of a cord to the outer surface of the pulley and wrap a few turns of the cord around the pulley. Tie the other end of the cord to a spring scale. See Figure 22.

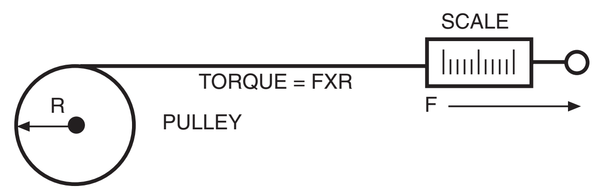


FIGURE 22.

Pull on scale until the shaft turns. The force in pounds or ounces, indicated on the scale, multiplied by the radius of the pulley (measured from the centerline of the machine shaft) in inches gives the torque value in lb-inches or oz-inches. On some machines, this torque may vary as the shaft rotates. The highest value of torque must be used when selecting a motor.

The running torque required by a machine will be approximately equal to the starting torque if the load is composed almost entirely of friction. If the load is primarily inertia or windage, the producing elements must be determined.

The running torque of a machine can be accurately determined by making a test run with an armature controlled DC drive (with a shunt wound or permanent magnet DC motor) of known horsepower rating. The DC drive should have an ammeter in the armature circuit so significant current readings can be observed and recorded throughout the speed range of the machine. Since armature current and torque are directly proportional within very close limits, the current readings will provide accurate information for selecting the drive rating required by the machine.

Most machines require a higher torque value to break it away, but once running, the torque requirement will decrease. Many drives have 150% load capability for one minute, which may allow the required additional breakaway torque to be obtained without increasing the drive horsepower rating.

If the running torque is equal to or less than the breakaway torque divided by 1.5, use the breakaway torque divided by 1.5 as the full-load torque required to determine the motor horsepower.

If the running torque is greater than the breakaway torque divided by 1.5, but less than the breakaway torque, use the running torque as the full load rated torque required to determine the motor horsepower.

MECHANICAL FORMULAS

HOW TO CALCULATE TORQUE

If the horsepower and base speed of a motor are known, the full-load torque of the motor is determined by:

$$T = \frac{(5250)\,(HP)}{N}$$

Where, T = Torque (ft-lb)
HP = Horsepower
N = Base speed of motor (RPM)

HOW TO CALCULATE HORSEPOWER

For Rotating Objects:

$$HP = \frac{TN}{63{,}000}$$ Where, T = Torque (in-lb), N = Speed (RPM)

or:

$$HP = \frac{TN}{5250}$$ Where, T = Torque (ft-lb), N = Speed (RPM)

For Objects in Linear Motion:

$$HP = \frac{FV}{396{,}000}$$ Where, F = force (lb), V = velocity (IPM)

or:

$$HP = \frac{FV}{33{,}000}$$ Where, F = force (lb), V = velocity (FPM)

For Pumps:

$$HP = \frac{(GPM) \times (\text{Head in Feet}) \times (\text{Specific Gravity})}{3950 \times (\text{Efficiency of Pump})}$$

For Fans and Blowers:

$$HP = \frac{CFM \times (\text{Pressure in Pounds/Sq ft})}{33{,}000 \times \text{Efficiency}}$$

When calculated horsepower falls between standard motor ratings, select the next higher rating.

Calculating Accelerating Force For Linear Motion – The following formula can be used to calculate the approximate accelerating force required for linear motion. However, before sizing the drive, add the torque required to accelerate the motor armature, gears, pulleys, etc. to the linear-motion accelerating force converting to torque.

$$\text{Acceleration Force (F)} = \frac{W\,(\Delta V)}{1933t}$$

Where, W = Weight (lb)
ΔV = Change in velocity (FPM)
t = Time (seconds) to accelerate weight

Calculating Accelerating Torque For Rotary Motion – When, in addition to the selection of a motor with proper torque capacity to start and maintain machine motion, a desired time for acceleration is involved and the required torque value may be affected, an additional formula must be considered. This formula makes it possible to calculate the average torque required over the complete range of speed change to accelerate a known inertia (WK^2).

The formula to calculate acceleration torque (torque required above load torque) of a rotating member:

$$T = \frac{(WK^2)\,(\Delta N)}{308t}$$

Where, T = Acceleration torque (ft-lb)
WK^2 = Total system inertia (lb-ft²) that the motor must accelerate. This value includes motor armature, reducer and load.
ΔN = Change in speed required (RPM)
t = Time to accelerate total system load (seconds)

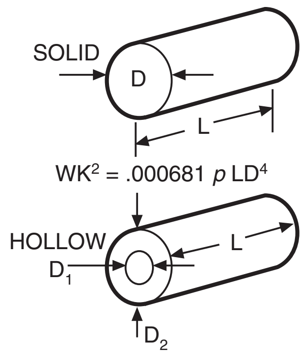
The same formula can also be used to determine the minimum acceleration time of a given drive, or if it can accomplish the desired change in speed within the required time period.

$$t = \frac{(WK^2)\,(\Delta N)}{308T}$$

INERTIA (WK^2)

The factor WK^2 is the weight (lbs) of an object multiplied by the square of the radius of gyration (K). The unit measurement of the radius of gyration is expressed in feet.

For solid or hollow cylinders, inertia may be calculated by the equations shown in Figure 23.



$$WK^2 = .000681\,pL\,(D_2^4 - D_1^4)$$

WK^2 = lb. ft.²
D, D_1, D_2 and L = in.
p = lb./in.³
p (aluminum) = .0924
p (bronze) = .320
p (cast iron) = .260
p (steel) = .282

FIGURE 23.

The inertia of solid steel shafting per inch of shaft length is given in Table 6. To calculate for hollow shafts, take the difference between the inertia values for the O.D. and I.D. as the value per inch. For shafts of materials other than steel, multiply the value for steel by the factors in Table 7.

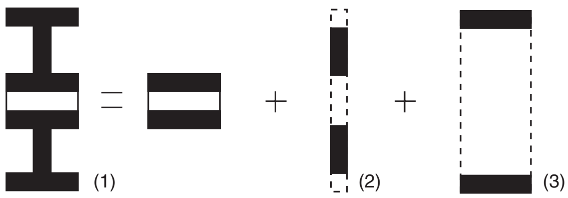
TABLE 6. INERTIA OF STEEL SHAFTING (PER INCH OF LENGTH)

Diam. (In.)	WK² (lb ft²)	Diam. (In.)	WK² (lb ft²)
3/4	.00006	10-1/2	2.35
1	.0002	10-3/4	2.58
1-1/4	.0005	11	2.83
1-1/2	.001	11-1/4	3.09
1-3/4	.002	11-1/2	3.38
2	.003	11-3/4	3.68
2-1/4	.005	12	4.00
2-1/2	.008	12-1/4	4.35
2-3/4	.011	12-1/2	4.72
3	.016	12-3/4	5.11
3-1/2	0.029	13	5.58
3-3/4	0.038	13-1/4	5.96
4	0.049	13-1/2	6.42
4-1/4	0.063	13-3/4	6.91
4-1/2	0.079	14	7.42
5	0.120	14-1/4	7.97
5-1/2	0.177	14-1/2	8.54
6	0.250	14-3/4	9.15
6-1/4	0.296	15	9.75
6-1/2	0.345	16	12.59
6-3/4	0.402	17	16.04
7	0.464	18	20.16
7-1/4	0.535	19	25.03
7-1/2	0.611	20	30.72
7-3/4	0.699	21	37.35
8	0.791	22	44.99
8-1/4	0.895	23	53.74
8-1/2	1.00	24	63.71
8-3/4	1.13	25	75.02
9	1.27	26	87.76
9-1/4	1.41	27	102.06
9-1/2	1.55	28	118.04
9-3/4	1.75	29	135.83
10	1.93	30	155.55
10-1/4	2.13	—	—

The inertia of complex, concentric rotating parts is calculated by breaking the part up into simple rotating cylinders, calculating their inertia and summing their values, as shown in Figure 24.

TABLE 7.

SHAFT MATERIAL	FACTOR
Rubber	.121
Nylon	.181
Aluminum	.348
Bronze	1.135
Cast Iron	.922



$$WK^2 = WK_1^2 + WK_2^2 + WK_3^2$$

FIGURE 24.

FORMULAS TO APPROXIMATE WK²

For a solid cylinder or disc = $W \times \frac{r^2}{2}$

where r = radius in feet and W is weight in pounds.

For a hollow cylinder: $W \; K^2 \times W \frac{r_1^2 + r_2^2}{2}$

where r_1, is $\frac{ID}{2}$ and r_2 is $\frac{OD}{2}$.

WK² Of Rotating Elements – In practical mechanical systems, all the rotating parts do not operate at the same speed. The WK² of all moving parts operating at each speed must be reduced to an equivalent WK² at the motor shaft, so that they can all be added together and treated as a unit, as follows:

$$\text{Equivalent } WK^2 = WK^2 \left[\frac{N}{N_M}\right]^2$$

Where, WK^2 = Inertia of the moving part
N = Speed of the moving part (RPM)
N_M = Speed of the driving motor (RPM)

When using speed reducers, and the machine inertia is reflected back to the motor shaft, the equivalent inertia is equal to the machine inertia divided by the square of the drive reduction ratio.

$$\text{Equivalent } WK^2 = \frac{WK^2}{(DR)^2}$$

$$\text{Where, DR = drive reduction ratio} = \frac{N_M}{N}$$

WK² Of Linear Motion – Not all driven systems involve rotating motion. The equivalent WK² of linearly moving parts can also be reduced to the motor shaft speed as follows:

$$\text{Equivalent } WK^2 = \frac{W(V)^2}{39.5(N_M)^2}$$

Where, W = Weight of load (lbs)
V = Linear velocity of rack and load or conveyor and load (FPM)
N_M = Speed of the driving motor (RPM)

This equation can only be used where the linear speed bears a continuous fixed relationship to the motor speed, such as a conveyor.

SPEED REDUCER SELECTION

Continuous operation at rated torque and low speed can damage adjustable-speed drive motors since their self-cooling ability diminishes as speed is reduced.

The motor should always be coupled to the driven machine by a power transmission device that will permit maximum motor RPM at maximum machine speed. The power transmission may be a simple belt-sheave or sprocket-chain arrangement or a compact gear reducer. Where applications require reductions greater than 5:1, the gear reducer may be the most economical choice.

The primary function of a gear reducer is to convert power into a useable form. This may mean a change of speed with a corresponding change in torque, a change in output direction or position, or more commonly, a combination of the above.

The gear reducer serves as a torque amplifier, increasing the torque by a factor proportional to the reducer ratio, less an efficiency factor. For example:

A 1 HP, 1750 RPM motor has an output torque of 3 ft-lb. If a 30:1 ratio reducer with 85 percent efficiency is used, the reducer output torque will be 3 x 30 x .85 = 76.5 ft-lb.

SELECTION OF GEAR REDUCERS

A typical application involves selecting a gear reducer that permits the drive motor to operate at base speed when the driven machine is at maximum speed, and also provide adequate torque to drive the machine.

Problem: *A 1750 RPM motor is selected for a machine which is to operate at a 57.5 RPM maximum speed and requires 70 ft-lb of torque.*

The solution involves two steps:

Step A: Determine the required ratio:

$$\text{Drive Ratio} = \frac{\text{Motor RPM (max.)}}{\text{Driven Machine RPM (max.)}}$$

$$D\,R = \frac{1725}{57.5} = 30 \quad \text{(or 30:1)}$$

NOTE: When the drive ratio, thus calculated, is not one of the handbook-listed speed reducer ratios, a chain, belt or additional gears with further reduction for either the input or output side are necessary.

Step B: Determine motor torque and horsepower:

A 30:1 gear reducer is selected which is capable of supplying 70 ft-lb of output torque. Since the machine torque requirement is known, this value is divided by the reduction ratio and an efficiency factor to arrive at required motor torque (T_M).

$$T_M = \frac{\text{Torque Required (ft-lb)}}{\text{(D R) (Eff. Factor)}}$$

$$T_M = \frac{70}{30\,(.85)} = 2.75 \text{ ft-lb}$$

Since a 1 HP, 1750 RPM base speed motor delivers 3 ft-lb of torque, it is chosen for this application along with a 30:1 gear reducer with a minimum of 70 ft-lb output torque.

Where the reduction ratio permits the use of chain or belt, the same formulas are used as for reducers.

GEAR REDUCER, OVERHUNG LOAD

Overhung load is defined as the dead weight the gear reducer bearings can support, on an output shaft, at a distance equal to the shaft diameter. This distance is measured from the outside end of the bearing housing along the shaft.

When a speed reducer is driven by a belt, chain or gear drive, or when the speed reducer drives a driven unit through a belt , chain or gear drive, an overhung load (side thrust) is produced. The overhung load must not exceed the rating of the gear reducer as listed in the manufacturer's handbook. The magnitude of the overhung load should always be kept to a minimum. Excessive loads could lead to fatigue failure of either the bearing or shaft. The sprocket or pulley should always be located as close to the gear housing as possible. Also, increasing the sprocket or pulley diameter results in a reduced overhung load. Use the following formula to determine overhung load:

$$OHL = \frac{2\,TK}{D}$$

where, OHL = overhung load (lb)
T = actual shaft torque (in-lb)
D = diameter of sprocket, sheave, pulley or gear (inches)
K = 1.0 for chain drives
= 1.25 for gears or gear-belt drives
= 1.50 for V belt drives
= 2.50 for flat-belt drives

No overhung loads are encountered when the gear reducer is directly coupled to the motor and/or driven machine shaft. However, care must be taken in aligning the shafts to avoid pre-loading bearings by misalignment.

ELECTRICAL FORMULAS

OHMS Law:

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}$$

$$\text{Ohms} = \frac{\text{Volts}}{\text{Amperes}}$$

$$\text{Volts} = \text{Amperes} \times \text{Ohms}$$

POWER IN DC CIRCUITS:

$$\text{Watts} = \text{Volts} \times \text{Amperes}$$

$$\text{Horsepower} = \frac{\text{Volts} \times \text{Amperes}}{746}$$

$$\text{Kilowatts} = \frac{\text{Volts} \times \text{Amperes}}{1000}$$

$$\text{Kilowatt-Hours} = \frac{\text{Volts} \times \text{Amperes} \times \text{Hours}}{1000}$$

POWER IN AC CIRCUITS:

Kilovolt - Amperes (KVA)

$$\text{KVA (Single-Phase)} = \frac{\text{Volts} \times \text{Amperes}}{1000}$$

$$\text{KVA (Three-Phase)} = \frac{\text{Volts} \times \text{Amperes} \times 1.73}{1000}$$

Kilowatt (Kw)

$$\text{Kw (Single-Phase)} = \frac{\text{Volts} \times \text{Amperes} \times \text{Power Factor}}{1000}$$

$$\text{Kw (Two-Phase)} = \frac{\text{Volts} \times \text{Amperes} \times \text{Power Factor} \times 1.42}{1000}$$

$$\text{Kw (Three-Phase)} = \frac{\text{Volts} \times \text{Amperes} \times \text{Power Factor} \times 1.73}{1000}$$

$$\text{Power Factor} = \frac{\text{Kilowatts}}{\text{Kilovolts} \times \text{Amperes}}$$

CONVERSION FACTORS

	MULTIPLY	BY	TO OBTAIN
Length	Meters	3.281	Feet
	Meters	39.37	Inches
	Inches	.0254	Meters
	Feet	.3048	Meters
	Millimeters	.0394	Inches
Torque	Newton-Meters	.7376	Lb-Ft
	Ft-Lb	1.3558	Newton-Meter
	In-Lb	.0833	Lb-Ft
	Ft-Lb	12.00	Lb-In
Rotation	RPM	6.00	Degrees/Sec.
	RPM	.1047	Rad./Sec.
	Degrees/Sec.	.1667	RPM
	Rad./Sec.	9.549	RPM
Moment of Inertia	Newton-Meters^2	2.42	Lb-Ft^2
	Oz-In^2	.000434	Lb-Ft^2
	Lb-In^2	.00694	Lb-Ft^2
	Slug-Ft^2	32.17	Lb-Ft^2
	Oz-In-Sec^2	.1675	Lb-Ft^2
	Lb-In-Sec^2	2.68	Lb-Ft^2
Power	Watts	.00134	HP
	Lb-Ft/Min	.0000303	HP
Temperature	Degree C = (Degree F -32) × 5/9 Degree F = (Degree C × 9/5) + 32		

CURRENT RATING OF INSULATED COPPER CONDUCTORS

TABLE 8. ALLOWABLE CURRENT-CARRYING CAPACITIES (Amperes) of Insulated Copper Conductors. Not more than three conductors in raceway or direct burial, based on 30°C (86°F) ambient (Condensed from National Electrical Code)

Type of Insulation	Maximum Operating Temperature	Wire Size AWG or MCM												(1)Correction Factors	
		14	12	10	8	6	4	3	2	1	0	00	000		
		Allowable Line Amperes												31–40°C	41–50°C
T-TW	60°C	15	20	30	40	55	70	80	95	110	125	145	165	.82	.58
RH,RHW, THW,THWN, XHHW	75°C	15	20	30	45	65	85	100	115	130	150	175	200	.88	.75
V-C(V) V-C(AVB) THHN,RHH, XHHW	85-90°C	25	30	40	50	70	90	105	120	140	155	185	210	.90	.80

Type of Insulation	Maximum Operating Temperature	Wire Size AWG or MCM												(1)Correction Factors	
		0000	250	300	350	400	500	600	700	750	800	900	1000		
		Allowable Line Amperes												31–40°C	41–50°C
T-TW	60°C	195	215	240	260	280	320	355	385	400	410	435	455	.82	.58
RH,RHW, THW,THWN, XHHW	75°C	230	255	285	310	335	380	420	460	475	490	520	545	.88	.75
V-C(V) V-C(AVB) THHN,RHH, XHHW	85-90°C	235	270	300	325	360	405	455	490	500	515	555	585	.90	.80

NOTE: (1) For room temperatures above 30°C.

Fincor Electronics

DEFINITIONS

Performance specifications listed for the basic Fincor Electronics adjustable-speed drives in the standard specification sheets and those provided with companion functional options are based upon the following conditions:

DRIVE SPEED REGULATION

The motor speed change between minimum load and full-load torque, expressed as a percentage of the full-load motor speed. This change is measured after all transient disturbances, due to load change, have terminated.

(1)
$$\% \text{ Regulation} = \frac{(\text{Min-Load Speed})-(\text{Full-Load Speed})}{(\text{Motor Rated Speed})} \times 100$$

Minimum-load is normally expressed as 5% of rated full load.

For drives with armature controlled DC motors, the rated speed is the motor operating speed when developing full-load torque with 100% rated armature voltage and field power applied. This is normally termed base speed.

For drives operated in the field weakened range, regulation is specified as a percentage of top speed.

Speed regulation for Fincor Electronics standard drives is expressed as a percentage of base speed. Set speed regulation is expressed as a percentage change in speed from an operating point (set speed) due to load changes. If a drive had 1% regulation of base speed, a 2% change of set speed could result at 1/2 motor speed.

Formula (1) is more realistic than Formula (2), since the friction in the driven machine normally loads the motor appreciably, and the changing work load on the machine subjects the motor to a smaller speed change than from absolute no-load to full-load torque.

(2)
$$\% \text{ Regulation} = \frac{(\text{No-Load Speed})-(\text{Full-Load Speed})}{(\text{Motor Rated Speed})} \times 100$$

DRIVE SPEED RANGE

Any motor speed between minimum and maximum that can be obtained in a stable manner. For most static, electronic drives it is normally specified that the minimum speed is zero and the maximum speed is the motor base speed.

"Controlled Speed Range" specifies the operating range with respect to the quoted drive speed regulation. This is typically expressed as a ratio of the minimum to maximum speeds such as 20:1, 50:1, etc. Typically, high performance drives will offer close speed regulation along with wide speed range capability.

DRIVE SERVICE FACTOR

A multiplier, which when applied to the drive rated horsepower, indicates a permissible maximum loading at which the drive can be operated continuously. To determine the horsepower required for greater than standard service factor, multiply the rated horsepower by the service factor. If the rating thus calculated is not standard, select a drive (same base speed motor) with the next higher rating. Fincor Electronics's standard drives have a 1.0 service factor.

STEADY-STATE REGULATION

The regulated value due to the following variation in operating parameters occurring independently or simultaneously. (Load remaining constant for speed and voltage regulators.)

VARIABLE	VARIATION	RANGE
AC Supply Voltage	10% with rate of change not to exceed 2.5% per second	±10% of nominal voltage
AC Supply Frequency	2% variation with rate of change not to exceed 2.5% per second	58-62 Hz (60 nominal) 48.5-51.5 Hz (50 nominal)
Ambient Temperature Random Drift	15°C 8 hour period after 1 hour warmup	0 to 40°C

TEMPERATURE

A change in ambient temperature produces a change in the control variable expressed as a percentage change for a specified temperature change of ±10°C. All standard units are designed to operate with a maximum enclosure interior temperature of 55°C surrounding the regulator power conversion module.

TRANSIENT DEVIATION

A momentary speed change from a speed set point, occurring at the result of a specified rate of load change. Performance is dependent on load inertia, motor inertia, load friction, etc.

TRANSIENT RESPONSE TIME

Time required to recover and maintain speed within the specified regulation tolerance after a specified change in load. Performance is dependent on load inertia, motor inertia, load friction, etc.

RANDOM DRIFT

A change from initial set speed during an unchanging load condition over specified time period with constant reference input, constant temperature, constant line voltage, and constant line frequency. Equipment must be operating at a specified ambient condition for a warm-up of one hour before the drift specification is applicable. Drift is specified as a percentage change (may be plus or minus) of base speed, unless otherwise stated. Drift is caused by random changes in operating characteristics of drive components.

DISPLACEMENT POWER FACTOR

The ratio of the active power of the fundamental wave to the apparent power of the fundamental wave in rms voltamperes. Displacement power factor is the power factor for which electric power utility companies charge penalties for low power factor.

CALCULATED POWER FACTOR

Expressed by the formula: Watts = 3 × E Line (rms) × I Line (rms) × Cos θ (Power-Factor), represents the ratio of total watts input to total rms voltamperes input. This considers the harmonic content of line input, as well as the fundamental wave of the line, and is always lower than the displacement power factor.

AC Contactor
An alternating-current (AC) contactor is designed for the specific purpose of establishing and interrupting an alternating-current power circuit.

ADC (Analog Digital Converter)
A circuit which converts an analog voltage or current to a digital word (Series of bits) also referred to as A/D or A to D converter. The complementary circuit is a DAC.

Ambient Temperature
Ambient temperature is the temperature of the medium such as air, water, or earth into which the heat of the equipment is dissipated.

For self-ventilated equipment, the ambient temperature is the average temperature of the air in the immediate neighborhood of the equipment.

For air or gas-cooled equipment with forced ventilation or secondary water cooling, the ambient temperature is taken as that of the ingoing air or cooling gas.

For self-ventilated enclosed (including oil-immersed) equipment considered as a complete unit, the ambient temperature is the average temperature of the air outside of the enclosure in the immediate neighborhood of the equipment.

Antihunt
Antihunt is the means of reducing or suppressing the oscillation of a system.

Antiplug Protection
The effect of a control function or a device that operates to prevent application of counter torque by the motor until the motor speed has been reduced to an acceptable value.

Armature
The laminated iron core with wire wound around it in which electromotive force is produced by magnetic induction in a motor or generator: usually a revolving part, but in an AC machine often stationery.

ASCII (American Standard Code for Information Interchange)
A standard code for alphanumeric and related characters made up of 7 bits per character (this allows a unique code for 128 characters). An 8 bit ASCII code also exists which extends the number of characters to 256.

Auxiliary Contacts
Auxiliary contacts of a switching device are contacts in addition to the main-circuit contacts and function with the movement of the latter.

Base Speed (of an adjustable-speed motor)
The lowest rated speed obtained at rated load and rated voltage at the temperature rise specified in the rating.

Bit
The most basic unit of digital information. A bit can only be one of two states: 1 or 0, Hi or Low, On or Off. In electronic terms, the state of a bit can be determined by the presence or absence of voltage.

Bit Parameter
A 3160 or 3260 selectable operating condition which has only two states (such as accel ramp control — On or Off).

Byte
A string of bits

Cogging
The non-uniform rotation of a motor armature caused by the tendency of the armature to prefer certain discrete angular positions.

Constant Horsepower Applications
See Application Information, page 3.

Constant Torque Applications
See Application Information, page 3

Contactor
A contactor is a two-state (on-off) device for repeatedly establishing and interrupting an electric power circuit. Interruption is obtained by introducing a gap or a very large impedance.

Continuous Rating
The continuous rating is a maximum constant load that can be carried continuously without exceeding established temperature-rise limitations under prescribed conditions of test and within the limitations of established standards.

Control Circuit
The control circuit of a control apparatus or system is the circuit which carries the electric signals directing the performance of the controller but does not carry the main power circuit.

Control Device
A control device is an individual device used to execute a control function.

Control-Circuit Transformer
A control-circuit transformer is a voltage transformer utilized to supply a voltage suitable for the operation of control devices.

Converter
A converter is a network or device for changing the form of information or energy.

Coupling Ratio
A general term to define the relative motion between motor armature and the driven load.

Crystal
A piezoelectric device which oscillates at a predetermined frequency when energy is applied. A crystal is used in microprocessor circuits to establish the speed with which the micro steps through its program. This frequency is usually in the range of several megahertz.

Cubed-Exponential Load
See Application Information, page 4

Current-Limit
A control function that prevents a current from exceeding its prescribed limits. Note: Current-limit values are usually expressed as percent of rated-load value.

Current-Limit Acceleration
A system of control in which acceleration is so governed that the motor armature current does not exceed an adjustable maximum value.

Current-Limiting Fuse
A fuse that, when it is melted by a current within its specified current-limiting range, abruptly introduces a high arc voltage to reduce the current magnitude and duration.

Current Relay
A current relay is a relay which functions at a predetermined value of current. It may be an overcurrent relay, an undercurrent relay, or a combination of both.

DAC (Digital to Analog Converter)
A circuit which converts a digital word to an analog voltage or current. Also referred to as D/A or D to A converter. The complementary circuit is an ADC.

Damping
Damping is the reduction or suppression of the oscillation of a system.

Data Bus
A computer bus is a series of conductors used as a path over which information is communicated from chip to chip and device to device. An address bus communicates address information for memory access. A data bus contains the data found at the accessed address.

DC Contactor
A direct-current contactor is a contactor for the specific purpose of establishing and interrupting a direct-current power circuit.

Digital Regulation
In the case of the speed regulator in the 3160 and 3260, speed is controlled to 0% regulation long term by counting the encoder pulses for a known time period. This count is compared to the

calculated value for the commanded speed and a plus or minus count error is established. The SCR gating is adjusted to reduce the count error and the sampling occurs again with the resultant error added to the previous error. Long term error is a few counts (degrees of motor rotation) out of many thousands of counts (many revolutions) — essentially 0% error.

Dimension or Outline Drawing
A dimension or outline drawing (base plan, floor plan, etc.) is one which shows the physical space and mounting requirements of a piece of equipment. It may also indicate ventilation requirements and space provided for connections or the location to which connections are to be made.

Diode
An electronic device having two electrodes; one being the cathode, and the other the anode. A diode allows current to pass in only one direction from anode to cathode.

Drift (as applied to systems)
Drift (as applied to systems) is an undesired but relatively slow change in output over a specified time with a fixed reference input and fixed load, with specified environmental conditions. The specified time is normally after the warm-up period. Drift shall be expressed in percent of the maximum rated value of the variable being measured.

Dynamic Braking
A system of electric braking in which the motor, when used as a generator, converts the kinetic energy of the load into electric energy, and in doing so, exerts a retarding force on the load.

Electronic Direct-Current Motor Controller
An electronic direct-current motor controller, is a phase-controlled rectifying system using semiconductors for power conversion to supply the armature circuit or the armature and shunt-field circuits of a direct-current motor, to provide adjustable-speed, adjustable and compensated-speed, or adjustable and regulated-speed characteristics.

EPROM
See ROM

E²PROM (Electrically Erasable Programmable Read Only Memory)
This device behaves like a RAM but is nonvolatile. Its only drawback is cost and a limit of the number of write cycles (about 10,000) before the chip is unreliable. Both of these will improve in the future. The 3160/3260 use this type of memory for parameter storage.

Fault Current
Fault current is a current which results from the loss of insulation between conductors or between a conductor and ground.

Field Controlled DC Drives
See Application Information, page 2.

Field Weakening
A method of increasing the speed of a wound field motor by reducing stator magnetic field intensity by reducing current.

Firmware
Programs or instructions that are stored in read only memories. Software stored in a hardware form (chip, interconnection, etc.).

Follower Drive
A drive in which the reference input and operation are direct functions of another drive, called the master drive.

Full-Load Current
The armature current of a motor operated at its full load torque.

Full-Load Speed
The speed that the output shaft of the drive motor attains with rated load connected and with the drive controller adjusted to deliver rated output at rated speed.

Full-Wave Rectification
Full-wave rectification inverts the negative half-cycle of the input sinusoid so that the output contains two half-sine pulses for each input cycle.

Gain
The ratio of system output signal to system input signal.

Half-Wave Rectification (power supplies)
In the rectifying process, half-wave rectification passes only one-half of each incoming sinusoid, and does not pass the opposite half-cycle. The output contains a single half-sine pulse for each input cycle. A single rectifier provides half-wave rectification.

Heater Element (Thermal Overload Relay)
A heater element is the part of a thermal overload relay that is intended to produce heat when conducting current. Heater elements are sometimes referred to as heaters, thermal units, current elements, or heating elements.

Hunting
The oscillation of system response about theoretical steady-state value due to insufficient damping.

Indoor (See NEMA Standards Publication No. ICS 6)
Indoor means suitable for installation within a building which protects the apparatus from exposure to the weather.

Interconnection Diagram
An interconnection diagram is one which shows only the external connections between controllers and associated machinery and equipment.

Interrupting Capability
The interrupting capability is the maximum value of current that a contact assembly is required to successfully interrupt at a specified voltage for a limited number of operations under specified conditions.

IR-Drop Compensation
A provision in the system of control by which the voltage drop (and corresponding speed drop) due to armature current and armature-circuit resistance is partially or completely neutralized. The amount of IR-drop compensation shall be expressed in percent of rated voltage, i.e.,

$$\text{IR-drop Compensation Percent} = \frac{\text{Volts compensation at full-load current}}{\text{Rated full-load voltage}} \times 100$$

Jog (Inch)
Jog (inch) is a control function which provides for the momentary operation of a drive for the purpose of accomplishing a small movement of the driven machine.

Jogging Speed
Jogging speed is the steady-state speed which would be attained if the jogging pilot device contacts were maintained closed. It may be expressed either as an absolute magnitude of speed or a percentage of maximum rated speed.

Linearity
For a speed control system it is the maximum deviation between actual and set speed expressed as a percentage of set speed.

Master Drive
A drive that sets the reference input for one or more follower drives.

Modem
A device which converts digital information to analog for transmitting and analog to digital for receiving over telephone lines.

Modular Construction
The major circuit elements are mounted in replaceable modules which can be removed and replaced by anyone. Equipment can be serviced without delay by personnel with little or no electrical knowledge.

Module
A unit of circuit elements usually packaged so it can be readily replaced by anyone.

Motor Constant
The ratio of motor torque to motor input power.

Multi-Motor Operation
This is a system in which one control operates two or more motors

simultaneously, maintaining a constant ratio between speeds of the motors.

Negative Feedback
Negative feedback is a feedback signal in a direction to reduce the variable which the feedback represents.

No-Load
The state of a machine rotating at normal speed under rated conditions, but when no output is required of it.

No-Load Speed
The speed that the output shaft of the drive motor attains with no external load connected and with the drive controller adjusted to deliver rated output at rated speed.

Nonvolatile Memory
A memory device that does not require power to maintain its contents.

Off Delay
"Off Delay" signifies that the timing period of a time delay relay is initiated upon deenergization of its coil.

Oiltight Control-Circuit Devices
Oiltight control-circuit devices are devices such as pushbutton switches, pilot lights and selector switches which are so designed that, when properly installed, they will prevent oil and coolant from entering around the operating or mounting means.

On Delay
"On Delay" signifies that the time period of a time delay relay is initiated upon energization of its coil.

Operating Overload
Operating overload is the overcurrent to which electric apparatus is subjected in the course of the normal operating conditions that it may encounter. For example, those currents in excess of running current which occur for a short time as a motor is started or jogged are considered normal operating overloads for control apparatus.

Overcurrent Relay
An overcurrent relay is a relay that operates when the current through the relay during its operating period is equal to or greater than its setting.

Overload Relay
An overload relay is an overcurrent relay which functions at a predetermined value of overcurrent to cause disconnection of the load from the power supply.

An overload relay is intended to protect the load (for example, motor armature) or its controller, and does not necessarily protect itself.

Over Speed
A condition common in control of DC motors caused by a change in field strength due to a thermal increase as the motor reaches operating temperature. As field strength is reduced due to heating increasing field resistance, output speed is increased with a constant armature terminal voltage. Speed sensing voltage networks can be added to control equipment to compensate for over speed by increasing field current (increasing field strength), or by reducing armature voltage in the case of Permanent Magnet Motors.

Parallel Communications
A communications bus that relays several bits of information (usually a word) at a time. This requires one conductor for each bit plus any overhead conductors. Parallel buses are very fast but require many conductors.

Parameter
A value in a register of a digital controller which determines an operating mode or condition. Examples are current limit, max speed, accel ramp, On/Off.

Phase Control
The process of varying the point within the cycle at which forward conduction is permitted to begin. Note: The amount of phase control may be expressed in two ways: (1) the reduction in direct-current voltage obtained by phase control or (2) the angle of retard or advance.

Pick-Up Voltage or Current
The pick-up voltage or current of a magnetically operated device is the voltage or current, suddenly applied, at which the device starts to operate.

Plugging
Plugging is a control function which provides braking by reversing the AC motor line voltage polarity or phase sequence so that the AC motor develops a counter-torque which exerts a retarding force.

Port
A piece of hardware (connector and related chips) which allows access to a computer and/or its memory.

Positive Feedback
Positive feedback is a feedback signal in a direction to increase the variable which the feedback represents.

Potentiometer
A three-terminal rheostat, or a resistor with one or more adjustable sliding contacts, that function as an adjustable voltage divider.

Power Factor, Calculated
See Application Information, page 8.

Power Factor, Displacement
See Application Information, page 8.

Preset Speed
A control function that establishes the desired operating speed of a drive before initiating the speed change.

Printed Wiring Assembly
A printed wiring assembly is a printed wiring board with separately manufactured component parts attached to it and with all processes of fabrication, soldering, coating, etc., completed.

Printed Wiring Board
A printed wiring board is base material cut to size, bearing a pattern of conductors and with all designed holes.

Program
A sequence of instructions that tells a computer how to receive, store, process and deliver information.

Protocol
A set of conventions or rules governing the format and timing of data communication.

Pulse
A pulse is a signal of relatively short duration.

Pushbutton
A pushbutton switch (pushbutton) is a switch having a manually operable plunger, rocker or button for actuating the switch.

Pushbutton Station
A pushbutton station is a unit assembly of one more externally operable pushbutton switches, sometimes including other pilot devices such as indicating lights or selector switches, in a suitable enclosure.

RAM (Random Access Memory)
A memory whose access time is independent of the address being accessed. Unless otherwise states a RAM memory is a volatile memory (requires power to retain its contents).

Random Drift
See Application Information, page 8.

Rating (of a Controller)
A rating (of a controller) is an arbitrary designation of an operating limit. It is based on power governed, the duty and service required.

Note: A rating is arbitrary in the sense that it must necessarily be established by definite field standards and cannot, therefore, indicate the safe operating limit under all conditions that may occur.

Fincor Electronics

Rating (of a Device
A rating (of a device) is designated limit(s) of the rated operating characteristic(s).

Note: Such operating characteristics as current, voltage, frequency, etc., may be given in the rating.

Read Only
A device whose purpose is to supply information to external devices but not be overwritten by external devices. Read only parameters in the 3160/3260 display controller conditions through the top cover readout and serial port. These value cannot be changed through the keypad or serial port but are updated by the drive microprocessor.

Read/Write
A device which can supply information (be read) or can store information (be written to).

Rectification
The term used to designate the process by which electric energy is transferred from an alternating-current circuit to a direct-current circuit.

Rectifier
A circuit element bounded by two circuit terminals that has the characteristic of conducting current substantially in one direction only. Note: The rectifier may consist of more than one semiconductor cell, diode, or rectifier stack connected in series or parallel or both, to operate as a unit.

Regeneration
Regeneration is the transfer to rotational energy through a motor and its control equipment back to its electrical source.

Regenerative Braking
A form of dynamic braking in which the kinetic energy of the motor and driven machinery is returned to the power supply system.

Register
A memory storage location usually of one word size.

Regulation, Drive Speed
See Application Information, page 8.

Regulation, Steady-State
See Application Information, page 8.

Relay
A relay is an electric device that is designed to interpret input conditions in a prescribed manner and after specified conditions are met to respond to cause contact operation or similar abrupt changes in associated electric control circuits.

Remote Control
Remote control is a control function which provides for initiation or change of a control function from a remote point.

Reset
To reset is to restore a mechanism, storage or device to a prescribed state.

Response Time
Response time is the time required, following the initiation of a specified stimulus to a system, for an output going in the direction of necessary corrective action to first reach a specified value.

ROM (Read Only Memory)
A memory type which once programmed cannot be altered and which does not require battery backup. EPROM is a common form of ROM (erasable, programmable read only memory). EPROM acts like a ROM when in a circuit, however, it can be reprogrammed but only by removing it from the circuit and using a special erasing and programming device.

Rotor (Rotating Machinery)
The rotating member of a machine, with shaft. Note: in a direct-current machine with stationary field poles, universal, alternating-current series, and repulsion-type motors, it is commonly called the armature.

RS232
A hardware protocol for data communication. Basic characteristics are common ground for all signals and maximum 50 foot cable length.

RS422
A hardware protocol for data communications. RS-422 uses differential, ungrounded signals, has a maximum cable length of 4-5000 feet and can be daisy chained between multiple devices.

Scan Time
The time for a computer to execute one pass through its program.

Schematic Diagram or Elementary Diagram
A schematic or elementary diagram is one which shows all circuits and device elements of an equipment and its associated apparatus or any clearly defined functional portion thereof. Such a diagram emphasizes the device elements of a circuit and their functions as distinguished from the physical arrangement of the conductors, devices or elements of a circuit system.

Serial Communication
A communication bus that relays information one bit at a time. Serial busses use a minimum number of conductors at the cost of communication speed.

Service of a Controller
The service of a controller is the specific application in which the controller is to be used, for example:

1. General purpose
2. Definite purpose
   (a) Crane and Hoist
   (b) Elevator
   (c) Machine tool, etc.

Service Factor, Drive
See Application Information, page 8.

Silicon Controlled Rectifier (SCR)
A bi-stable semiconductor device comprising three or more junctions that can be switched from the OFF state to the ON state or vice versa, such switching occurring within at least one quadrant of the principal voltage-current characteristic.

Slaving
Method of connecting controls in cascade (series) or parallel. A number of slave units can be utilized, each running a drive at a different speed. When the manually operated master control calls for a speed change, the slave units will respond in proportion, maintaining the speed ratios between them.

Slip
The quotient of (a) the difference between the synchronous speed and the actual speed of a rotor, to (b) the synchronous speed, expressed as a ratio, or as a percentage.

Software
The instructions, codes and programs concerned with the operation of a computer.

Speed Range
All the speeds that can be obtained in a stable manner by action of the control equipment governing the performance of the motor. The speed range is generally expressed as the ratio of the maximum to the minimum operating speed.

Speed Regulation Constant
The slope of the motor speed-torque characteristic.

Squared-Exponential Loads
See Application Information, page 4.

Starting Torque
The torque exerted by the motor during the starting period. (A function of speed or slip.)

Stator
The stationary portions of the magnetic circuit and the associated winding and leads of a rotating machine. It may, depending on

design, include a frame, winding supports, ventilation circuits, coolers, and temperature detectors. A base, if provided, is not ordinarily considered to be part of the stator.

Surge
A transient wave of current, potential, or power in the electric circuit. Note: A transient has a high rate of change of voltage (current) in the system.

Surge Protection
A form of protection in which an abnormal condition causes disconnection or inhibits connection of the protected equipment in accordance with the rate of change of current, voltage, or power.

Surge Suppressor
A device operative in conformance with the rate of change of current, voltage, power, to prevent the rise of such quantity above a predetermined value.

Switch
A switch is a device for operating and closing or for changing the connections of a circuit. Note: A switch is understood to be manually operated unless otherwise stated.

Synchronous Speed
The speed of rotation of the magnetic flux of a motor, produced by or linking the primary winding.

System Efficiency (for a drive system)
System efficiency is the ratio of the mechanical power supplied to load to the total input power under specified operating conditions. The input power includes that for auxiliary functions, such as motor field, phase control, switching equipment, overload protection, and fans.

Tachometer Generator
A generator, mechanically coupled to a rotating machine, whose main function is to generate a voltage, the magnitude or frequency of which is used either to determine the speed of rotation of the common shaft or to supply a signal to a control circuit to provide speed regulation.

Thermal Overload Relay
A thermal overload relay is an overload relay that functions (trips) by means of a thermally responsive system.

Thermal Protector (rotating machinery)
A protective device for assembly as an integral part of a machine that protects the machine against dangerous overheating due to overload and, in a motor, failure to start. Notes: (1) It may consists of one or more temperature-sensing elements integral with the machine and a control device external to the machine. (2) When a thermal protector is designed to perform its function by opening the circuit to the machine and then automatically closing the circuit after the machine cools to a satisfactory operating temperature, it is an automatic-reset thermal protector. (3) When a thermal protector is designed to perform its function by opening the circuit to the machine but must be reset manually to close the circuit, it is a manual-reset thermal protector.

Time Delay
Time delay means that a time interval is purposely introduced in the performance of a function.

Torque
See Application Information, page 3.

Transient
A transient is that part of the variation in a variable which ultimately disappears during transition from one steady-state operating condition to another.

Transient Response Time
See Application Information, page 8.

Trigger (triggering circuit)
The triggering or firing circuit determines at which point in the positive half cycle of the AC line voltage the SCR's will start to conduct.

Undervoltage Protection (low-voltage protection)
Undervoltage or low-voltage protection is the effect of a device, operative on the reduction or failure of voltage, to cause and maintain the interruption of power to the main circuit.

Varistor
Trade name used by General Electric Company for a back-to-back diode pair. Used in drives to protect the SCR from high voltage transients.

Ventilated Enclosure
A ventilated enclosure is an enclosure provided with means to permit circulation of sufficient air to remove an excess of heat, fumes, or vapors.

Voltage Relay
A voltage relay is a relay which functions at a predetermined value of voltage. It may be an overvoltage relay, an undervoltage relay, or a combination of both.

Watchdog
A device or routine that continuously verifies that a computer is running.

Wiring Diagram or Connection Diagram
A wiring or connection diagram is one which locates and identifies electrical devices, terminals and interconnecting wiring in an assembly.

Word
A string of bits of specific length which is treated as an entity by a processor. The terms "32-Bit Processor", "64-Bit Processor" refer to the word length.