

Table 2.... Effect of Voltage and Frequency Variation on Induction Motor Characteristics*

Voltage and Frequency Variation	Starting & Maximum Running Torque	Synchronous Speed	% Slip	Full Load Speed	Efficiency		
					Full Load	1/2 Load	1/4 Load
Voltage Variation	120% Voltage	Increase 44%	No Change	Increase 1.5%	Small Increase	Decrease 1/4 to 2%	Decrease 7 to 20%
	110% Voltage	Increase 21%	No Change	Increase 1%	Increase 1/4 to 1%	Practically no change	Decrease 1 to 2%
	Function of voltage	(Voltage) ¹	Constant	1 (Synchronous Speed Slip) (Voltage) ¹	—	—	—
	90% Voltage	Decrease 19%	No Change	Increase 23%	Decrease 2%	Practically no change	Increase 1 to 2%
Frequency Variation	105% Frequency	Decrease 10%	Increase 5%	Practically no change	Slight Increase	Slight Increase	Slight Increase
	Function of frequency	1 (Frequency) ²	Frequency	— (Synchronous Speed Slip)	—	—	—
	95% Frequency	Increase 11%	Decrease 5%	Practically no change	Slight Decrease	Slight Decrease	Slight Decrease

* These variations are general and will differ somewhat for specific ratings.

torque. The starting current, or locked-rotor current, is usually 400 to 600 percent of the current at rated full-load.

Full-load torque is the torque developed to produce the rated hp at the rated speed. Full-load speed also depends upon the design of the motor. For induction-motors, a speed of 1725 rpm is typical for 4-pole motors, and a speed of 3450 rpm for 2-pole motors (60 cycles).

Motors have a maximum or breakdown torque which cannot be exceeded without causing an abrupt change in speed. The relation between breakdown torque and full-load torque varies widely depending upon motor design.

Horsepower. The horsepower delivered by a motor is a product of its torque and speed. Since a given motor will deliver increasing horsepower up to maximum torque, a basis for horsepower rating is needed. The National Electrical Manufacturers Association (NEMA) bases horsepower rating upon breakdown torque limits. Full-load rating is related to the winding temperature rise. For open-type general purpose motors, temperature rise is limited to 40 C by thermometer, and of 50 C by resistance for Class A insulation. Higher temperature rises may be allowed for enclosed and special-purpose motors and for other insulations.

The service factor of a general purpose motor is defined as "a multiplier which, applied to the normal horsepower rating, indicates a permissible loading which may be carried under the conditions specified for the service factor." Motors other than general purpose motors have a service factor of 1.0.

MOTOR CONTROL

In general motor control equipment should provide (1) means of disconnecting the motor and controller from the power supply, (2) means for starting and stopping the motor, (3) overheating protection for the motor, (4) protection for the operator, (5) control of motor speed, and (6) protection of motor branch circuit conductors and control apparatus.

Circuit-breakers are used for disconnecting as well as circuit protection and are available in ratings for use with small household refrigerators as well as in very large commercial installations. Manual switches for disconnecting and fuses for short-circuit protection are also used. For single-phase

motors up to 2 hp, 230-volt, a wall plug is an acceptable disconnecting device.

Controllers must meet the requirements of power supply, size and type of motor, and of automatic control. They are available in a multiplicity of designs, ranging from manual across-the-line starters to current-limiting acceleration controllers for both alternating- and direct-current motors and variable-speed control devices.

Three basic types of motor protection devices may be used: (1) devices sensing current only; (2) devices sensing both current and temperature; (3) devices sensing temperature only.

Devices sensing current only include magnetic and thermal overload relays. They may be used separately, or in conjunction with controllers.

Devices sensing both motor current and temperature are inherent overheating protective devices, and are called thermal protectors (see the *National Electrical Code*). They are used in fractional and small integral hp single-phase and polyphase motors (usually under 10 hp).

In open motors, the thermal protector is mounted near, on, or in the winding; in hermetically-sealed motors, it may be mounted either outside the compressor shell or inside the shell on or near the stator winding. Sealed protectors must be used for the latter application.

Temperature sensing devices are used with integral hp single-phase and three-phase motors. They are installed directly on or buried in the motor winding. Three basic types and their use are:

1. Bimetallic thermostats used in conjunction with thermal overload relays and connected in series with the control circuit of the magnetic starter which disconnects the motor. The thermostat protects against excessive motor winding temperature for running overload. On locked rotor, the thermal relays protect for the initial heating cycle and the combined functioning of relays and thermostats protect for subsequent cycles.

2. Thermostats undergo a change in resistance with temperature and the signal is used in a control circuit to operate a relay. This relay in turn interrupts the control circuit of magnetic motor starter which is used to disconnect the motor. Thermal overload relays in conjunction with thermostats are used when required to protect for initial heating cycle locked rotor.

3. Rate-of-rise thermostats have a differential expansion thermal element responsive to the rate of temperature change and respond faster as the rate of temperature change increases.

Table 2.... Effect of Voltage and Frequency Variation on Induction Motor Characteristics* (Concluded)

Voltage & Frequency Variation	Power-Factor			Full Load Current	Starting Current	Temperature Rise Full Load	Maximum Overload Capacity	Magnetic Noise, No Load in Particular
	Full Load	1/2 Load	1/4 Load					
Voltage Variation	120% Voltage	Decrease 5 to 15%	Decrease 10 to 30%	Decrease 15 to 40%	Decrease 11%	Increase 25%	Decrease 5 to 6 C	Increase 44%
	110% Voltage	Decrease 3%	Decrease 4%	Decrease 5 to 6%	Decrease 7%	Increase 10 to 12%	Decrease 3 to 4 C	Increase 21%
	Function of voltage	—	—	—	—	Voltage	—	(Voltage) ¹
	90% Voltage	Increase 3%	Increase 2 to 3%	Increase 4 to 5%	Increase 11%	Decrease 10 to 12%	Increase 6 to 7 C	Decrease 19%
Frequency Variation	105% Frequency	Slight Increase	Slight Increase	Slight Increase	Decrease Slightly	Decrease 5 to 6%	Decrease Slightly	Decrease Slightly
	Function of frequency	—	—	—	—	1 Frequency	—	—
	95% Frequency	Slight Decrease	Slight Decrease	Slight Decrease	Increase Slightly	Increase 5 to 6%	Increase Slightly	Increase Slightly

This characteristic provides protection for running overloads as well as stalled rotor which involves slow and fast rates of heating of the motor winding. The thermostat contacts are wired in series with the control circuit of a magnetic motor contactor which disconnects the motor. Hermetically sealed thermostats must be used for hermetic motors.

Motor controllers for single-phase motors must provide means for disconnecting the starting winding of split-phase, or capacitor-start induction-run motors or the start capacitor of capacitor-start, capacitor-run motors. Open machines usually have a centrifugal switch mounted on the motor shaft, which disconnects the starting winding at about 70 percent full-load speed. Hermetic motors usually have externally mounted starting relays; current-type starting relays for small motors up to 1/2 hp, voltage-type starting relays for larger motors.

Controllers and motor protection devices should be selected and installed in accordance with state and local electrical codes. Devices with Underwriters' Laboratories seal are universally accepted in the United States as complying with the *National Electrical Code* and meeting minimum safety requirements.

CODES AND STANDARDS

Codes refer to requirements needed in the interest of public health or safety; standards present uniform methods of rating, sizing and measuring the performance of electrical equipment in order to provide a yardstick for use and comparison. Codes and standards are sponsored at a national level, and usually

Table 3.... Motor Types

Type	Horsepower Range	Type Power Supply	Suitable for Hermetic Application
Fractional Horsepower Sizes:			
Split-phase	1/4-1	single-phase	Yes
Capacitor-start	1/4-1	single-phase	Yes
Repulsion-start	1/4-1	single-phase	No
Permanent-split-capacitor	1/4-1	single-phase	Yes
Shaded-pole	1/4-1	single-phase	No
Squirrel cage induction	1/4-1	single-phase	Yes
Direct-current	1/4-1	D-C	No
Integral Horsepower Sizes:			
Capacitor-start, Capacitor-run	1-6	single-phase	Yes
Repulsion-start	1-6	single-phase	No
Squirrel cage induction (normal torque)	1-up	Polyphase	Yes
Slip-ring	1-up	Polyphase	No
Direct-current	1-up	D-C	No
Permanent-split-capacitor	1-6	single-phase	Yes

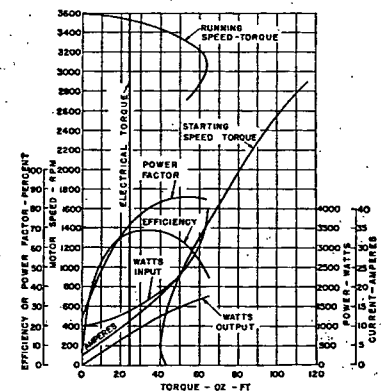


Fig. 1.... Performance Characteristics of Capacitor-Start Induction-Run 2-Pole Motor (1 hp).