Electrical Tech Note — 350

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Electric Motor Circuit Requirements

An electrical motor converts electrical power into mechanical power. Electric motors have some characteristics that are different than most other electrical devices, and the motor circuit must be capable of dealing with these differences. In general, an electric motor circuit only supplies one motor, and all circuit components are sized to that one motor. To gain a better understanding of the unique problems of dealing with a motor circuit, lets review a few basic fundamentals and electrical circuit safety requirements.

Electrical wires and other circuit components have a finite resistance and when they carry current heat is produced. Different sizes of wires and electrical components such as switches and receptacles have a maximum safe current rating that must not be exceeded except for very short periods of time.

Electrical circuits are required to originate at a circuit breaker or set of fuses that are sized to open the circuit and shut off power when current exceeds a safe level. The main purpose is to prevent a fire due to the heat produced by an excessive circuit current. This excessive current can be the result of a circuit overload, or it can be the result of a short-circuit or a ground-fault. Circuit breakers and fuses are designed to provide protection from excessive overloads as well as short-circuits and ground-faults.

Electric motors typically create unique conditions that make it difficult for a circuit breaker or a set of fuses to provide both overload protection as well as short-circuit and ground-fault protection. Motors draw a very high current when they are started, and a much lower current during normal operation. Starting time can range from a fraction of a second to several seconds. This is illustrated in the time-current graph of Figure 350.1. Because of these extreme conditions, the fuses or circuit breaker provide the circuit short-circuit and ground-fault protection, and usually a different device in another location in the circuit provides the overload protection. These subjects will be discussed in this Tech Note.

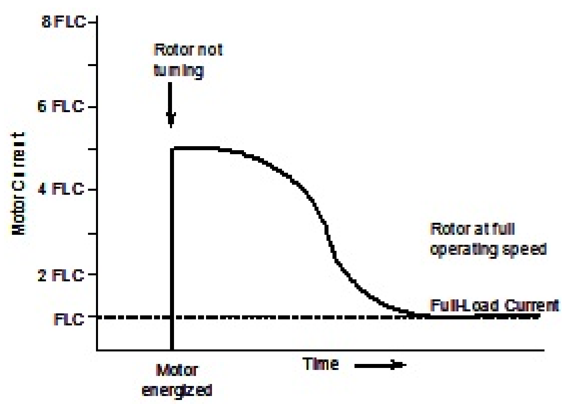

Figure 350.1 *The instant an electric motor is energized and the rotor is not turning, there is an inrush current that typically can range from four to eight times higher than the full-load current when the rotor is up to full operating speed.*

An electric motor responds to the power demand of the load and attempts to provide the power required. If the load power required exceeds the motor's design capability for too long a period of time, it will sustain internal damage due to excessive heat resulting in premature failure. Because an electric motor will attempt to provide the power required, it will fail if not provided with proper protection. Motor current draw will increase above the rated full-load current if the power delivered by the motor exceeds the motor full-load power rating. Internal winding heat will become excessive.

The wire used to make the windings inside the motor always has some resistance. Some heat is produced as the current flows thorugh these windings. Heat produced is proportional to the square of the current. Even a small increase in winding current above the maximum design rating can result in a large amount of excess heat produced. The insulation on the winding wire is thin and delicate. It has a maximum temperature rating it can withstand before it fails. If an electric motor is placed in a hot or very warm environment it more than likely will not be able to produce it's design power rating without danger of failure.

The electrical circuit that supplies a motor must provide protection to prevent motor overload in addition to providing circuit overcurrent protection. What makes this circuit and motor protection difficult is the large inrush current when it starts as illustrated in Figure 350.1. The overcurrent protection for the circuit must be capable of allowing the inrush current to pass and still provide proper safety at the much lower full-load current level. In order to accomplish this task, the general rule is that a circuit is only permitted to supply one motor.

Electrical circuits must be provided protection for major overcurrent events such as short circuits and ground faults. These conditions are usually the result of component failure or external damage to the circuit or equipment. Circuits must also be protected from overloads where the current exceeds the rating of the wires or components. In the case of an electric motor circuit, the short-circuit and ground-fault protection is located at the origination of the circuit in the form of a circuit breaker or set of fuses. The overload protection is usually located at or near the electric motor and can be a device that senses motor current or sometimes motor winding temperature. The overload protection must be selected for each motor. Motor nameplates are required to provide information necessary to properly select these overcurrent devices. Motor nameplates are discussed in detail in Tech Note 103. A typical motor circuit is illustrated in Figure 350.2 showing the common location of these overcurrent devices.

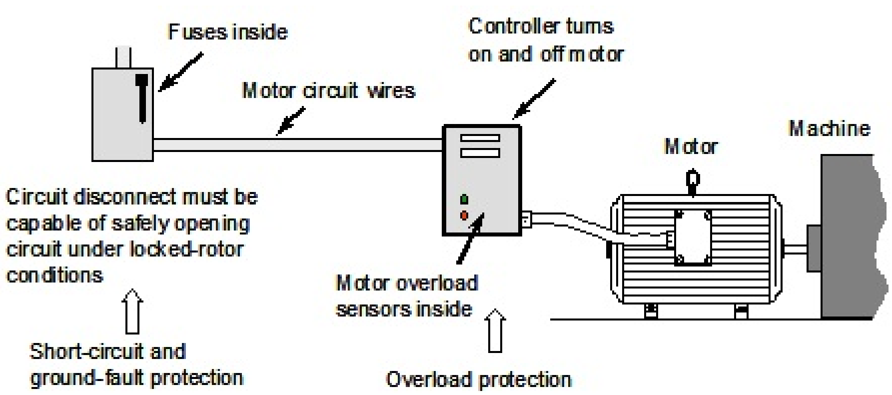

Figure 350.2 *A motor circuit has a disconnect that provides short-circuit and ground-fault protection, and a controller that frequently provides the running overload protection. For this circuit the controller is operated manually with a set of push buttons at the controller.*

A motor circuit, such as the one in Figure 2, originates at a circuit breaker or a switch containing a set of fuses. The circuit breaker or fuse rating must be set high enough to handle the motor inrush current, but with a rating low enough to open the circuit if there is a ground-fault or short-circuit somewhere in the circuit. The *National Electrical Code* provides very specific rules that are followed by an electrician when installing a motor circuit.

To ensure safety to personnel either working on the motor circuit or working near the device powered by the motor, additional disconnects may be required. If the circuit disconnect is not within sight of the motor controller, then an additional disconnect must be installed that is within sight of the controller. If the motor is not within sight of a disconnect, then an additional disconnect must be installed within sight of the motor. These are safety rules that are found in the *National Electrical Code*. The Code provides exceptions for some unique situations.

It is always possible that something can happen that would cause the shaft of the motor to stop turning. A mechanical failure or overloading of the device being powered are common examples. When a motor shaft stops turning the condition is called a locked rotor. Motor current will increase to as much as four to eight times normal full-load running current in this locked-rotor condition. Any device that opens the circuit to disconnect power to the motor must be capable of safely disconnecting this locked-rotor current. Motor switches and controllers are specially designed to safely handle these extreme conditions.

There must be some type of overload protection, specifically selected for the motor that will sense when the current to the motor is too high for too long a period of time. The motor rated full-load current is printed on the motor nameplate. Motors that are rated continuous duty can usually withstand a 15% overload for a long period of time. Some motors can withstand up to a 25% overload without sustaining damage. That overload sensing device must be capable of automatically activating the switch or controller to disconnect power to the motor when these safe limits are exceeded. The overload sensing device must be slow enough at responding to an overload condition that it will allow the starting inrush current to pass, but sensitive enough to detect a longer term overload that may damage the motor.

The motor is turned on and off with a switch or controller that is capable of safe operation under the most extreme conditions. Motor switches and controllers have a nameplate that provide maximum horsepower ratings at various circuit voltages. Some switches and controllers must be operated manually. It is common for a controller to be operated by a magnetic solenoid so that it can be operated from a remote location either manually or automatically. The electrical circuit that operates the solenoid in the controller is called a control circuit. Basic control circuits will be discussed in this Tach Note, but first examine Figure 350.3 which is a schematic diagram of a magnetic controller.

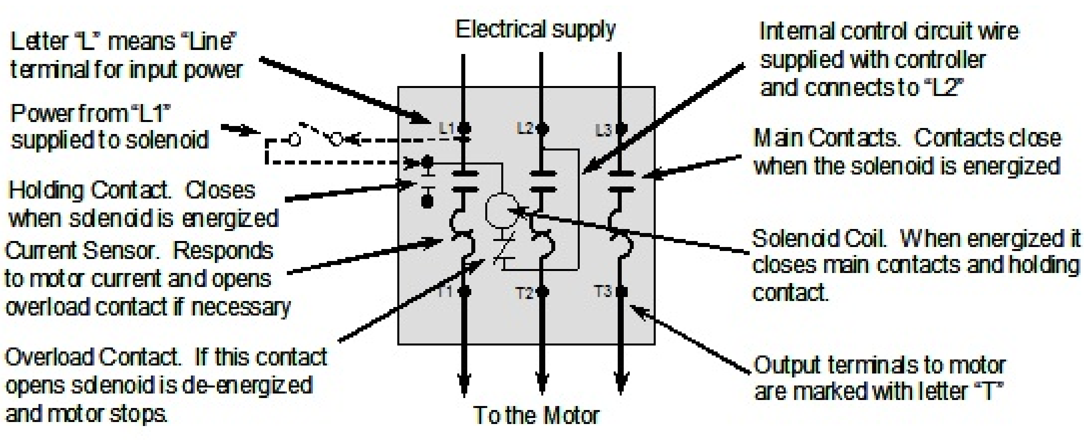

Figure 350.3 *The main contacts and the holding contact close when the solenoid is energized. The solenoid is energized with an external device.*

Control Circuit: The dashed line in Figure 350.3 is the external control circuit that is installed to operate the motor supplied by the controller. The control circuit of Figure 350.3 is a manual switch that when closed completes a circuit to supply power from supply circuit wire "L1" to the solenoid. The other side of the solenoid passes through the overload contact and then connects to supply circuit wire "L2." The controller shown in Figure 350.3 has three supply conductors and is controlling a 3-phase motor. Typical voltages between 3-phase supply conductors are 208 volts, 240 volts, and 480 volts. Solenoid coils are interchangeable and must be selected for the proper supply voltage. There are other methods of supplying power to the control circuit that are beyond the scope of this Tech Note.

The overload contact in the control circuit of Figure 350.3 is closed. There are typically three motor current sensors, one in each of the three supply conductors. If any one of the current sensors detects an overload that potentially can damage the motor windings, it opens the overload contact which breaks the control circuit and shuts off the motor.

Two-Wire Control Circuit: The control circuit indicated by the dashed lines of Figure 350.3 is a two-wire control circuit. Power from supply conductor "L1" is connected to a control device such as a manual switch, a thermostat, a pressure switch, a liquid level float switch, a proximity switch, or any other sensing device operated switch. When the sensing switch closes, the solenoid is energized and the motor operates. Two wires are needed to connect the external control sensor switch to the motor controller.

Three-Wire Control Circuit: A three-wire control circuit operated by two momentary push buttons is shown in Figure 350.4. One push button starts the motor and the other stops the motor. The stop push button switch is closed unless pressed, than it opens. The start push button is open unless pressed, then it closes. This type of control device requires three wires, and also uses the holding contact inside the controller. This same concept is used when one sensor switch turn on a motor and another sensor switch turns off the motor.

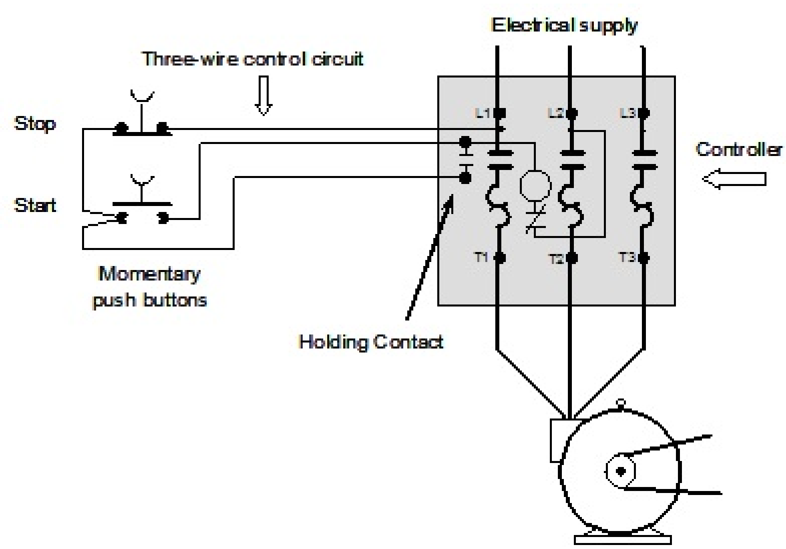

Figure 350.4 *Pressing the start push button completes the circuit and energizes the solenoid to close all contacts. When the start push button is released the contact opens, but the circuit remains complete through the holding contact inside the controller. Pressing the stop push button will break the control circuit and the motor will turn off.*

Here is another example of a three-wire control circuit. In this example a container fills with a fluid and a pump turns on to empty the container. A float switch turns the pump on when it is full, and another float switch turns the pump off when it is nearly empty. In order to accomplish this task with two separate switches requires a three-wire control circuit. In this case the top float switch is the same as the start push button on Figure 350.4, and the bottom float switch is the same as the stop push button of Figure 350.4. There are two illustrations to show how this control circuit operates. Figure 350.5 shows the position of the switches to turn on the pump. Figure 350.6 shows the position of the switches when just after the pump has been turned off.

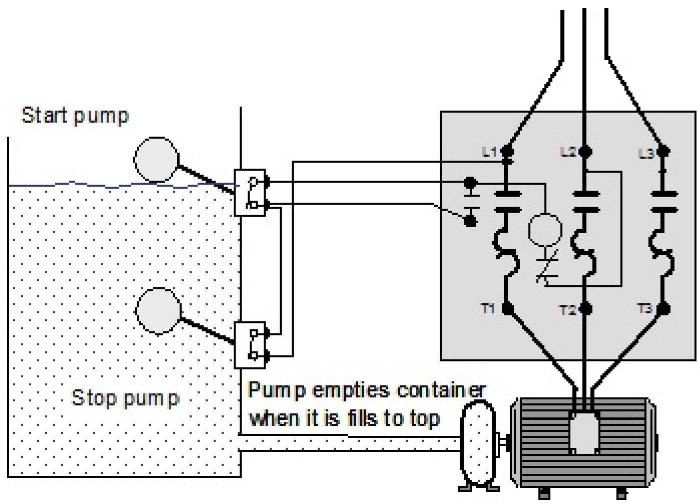

Figure 350.5 *Float switches operate a pump to empty a container when it fills to the top. This illustration shows the position of the three-wire control circuit when the pump is first turned on.*

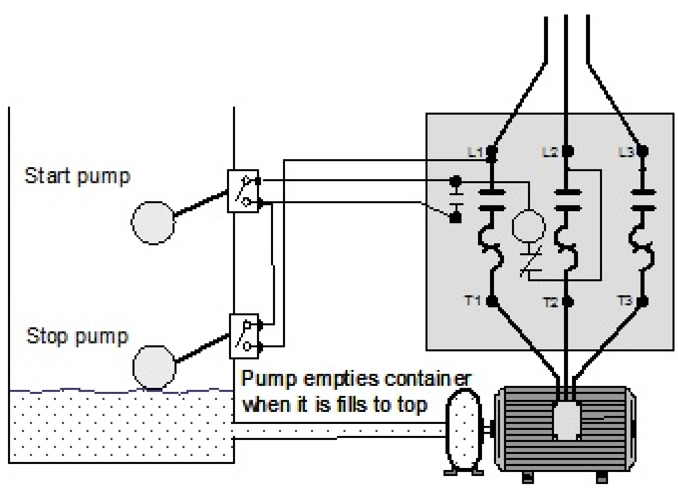

Figure 350.6 *Float switches operate a pump to empty a container when it fills to the top. This illustration shows the position of the three-wire control circuit just after the pump is turned off.*

Conclusion: Electric motors have unique operating characteristics that require special consideration when wiring the circuit. Rules for circuit wiring are provided in detail in the National Electrical Code. Small motors can be controlled with a switch, but large motors require a device called a controller. A disconnect, located within sight of the controller and the motor, is required that de-energizes all circuit conductors.

The controller can be of the magnetic type where an electrical control circuit operates the controller. Under normal conditions, the only current flow in this control circuit is the current required to operate the solenoid that operates the main contacts in the controller. As illustrated in this Tech Note, the control circuit can receive it's electrical supply by tapping two of the main motor circuit conductors. In the case of smaller motors it is not necessary to install fuses to protect the control circuit conductors. For larger motors, it is required to provide fuses in this control circuit. This Tech Note showed control circuits that operate at the same voltage as the motor itself. In many cases a transformer is installed to lower the voltage for the control circuit. This requires changes in the control circuit wires inside the controller. Sometimes the control circuit receives it's source of supply separate from the motor circuit. These cases are common and are to be installed only by experienced electricians.