Electrical Tech Note — 351

Biosystems &Agricultural Engineering Department
Michigan State University

Control System Design Basics[1]

Introduction: Control systems are commonly used to operate machines and equipment systems. This Tech Note deals with several basic control systems to operate equipment by means of a magnetic contact device. The first part will involve the simple connection of a 2-wire device to operate a motor and then a 3-wire control using a momentary push button start-stop station to operate a motor. Motor operated systems may require interlocking or sequencing of components to insure proper sequence of operation or to prevent the failure of one component from creating damage or problems. This can be accomplished by adding extra auxiliary contacts to a relay or motor starter that are installed in series with another control system. This technique is known as interlocking or sequencing. A control system will be constructed so that the second motor will not operate unless the first motor is operating. Another control system will be constructed so that if one motor is operating the other motor cannot operate. Some control systems will involve the use of a time-delay on energize. A control circuit will be examined where the first motor is operated manually, and a second motor starts automatically after a pre-determined time-delay.

Control Diagram Symbols: Equipment such as motors and heaters are usually supplied power with solenoid activated switching devices known as relays, magnetic motor starters, or contactors. A control device completes a circuit that supplies power to the solenoid coil. This Tech Note deals with the basic concepts of operation of control circuit. Figure 351.1 shows some of the common symbols used in these control circuits.

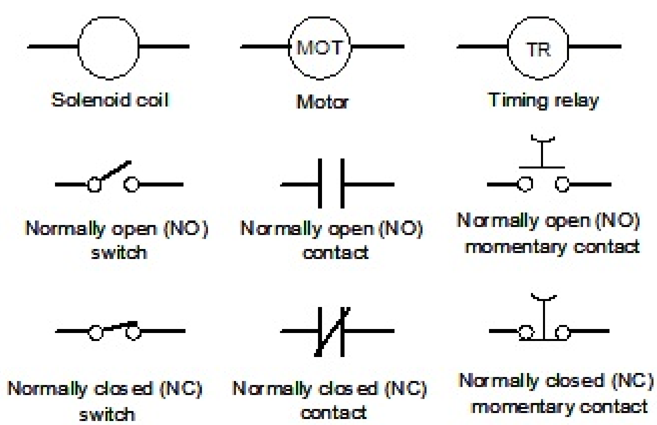


Figure 351.1 Utilization equipment such as a solenoid is usually designated with a circle while switching devices are generally represented as one of three types.

[1]Developed by Truman C. Surbrook, Ph.D., P.E., Master Electrician and Professor, Jonathan R. Althouse, Master Electrician and Instructor, Biosystems & Agricultural Engineering Department, Michigan State University, East Lansing, MI 48824-1323. For a copy of this Tech Note and other educational papers, visit the Electrical Technology web site at http://www.egr.msu.edu/age/

Control systems are usually activated automatically by a sensor controlled switches. Figure 351.2 shows some common symbols for sensor controls. In the case of the thermostat symbol, think of the diagram expanding on temperature rise and contracting on temperature fall. In the case of the time delay contacts, the switch moves in the direction of the arrow after the time delay period has expired. A limit switch physically touches a material. There are many variations of these devices that do not actually touch the material. Also shown in Figure 351.2 are pressure switches and float switches.

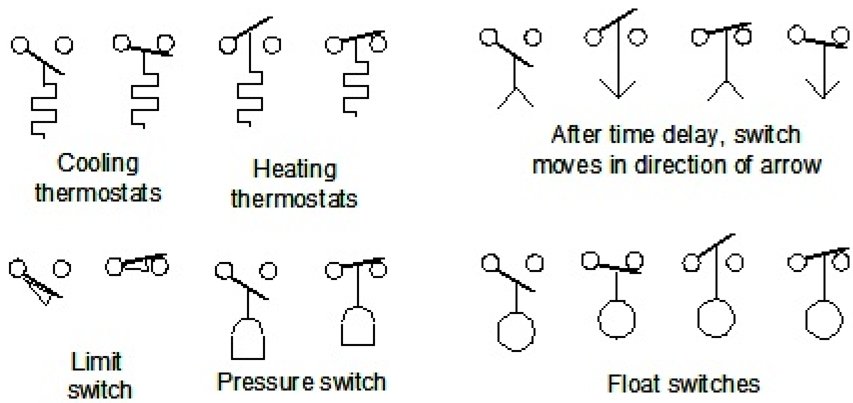


Figure 351.2 It is important to know the contacts are to be closed on a rise in the quantity sensed, or closed on a fall in the quantity sensed. An example is a thermostat which closes on temperature rise to activate a ventilation fan, or an air-conditioning system. A heating thermostat closes contacts on a fall in temperature.

Actual wiring of a control system can be very confusing because of wires going every which way. To give some logic and order to a control system diagram, the two power wires for a control system are drawn vertically, one on the right and one on the left sides of the diagram. To cause a control action, a circuit must be completed from the left to the right through a utilization device such as the solenoid in a magnetically controlled switch. Typical control systems may have many interrelated devices thus resulting in multiple lines on the control diagram. When finished the diagram tends to resemble a ladder, and therefore, the origin of the name ladder control diagram. In larger diagrams, the contacts and devices are labeled with letters or numbers. Figure 351.3 shows a one rung ladder diagram where thermostat completes a circuit to operate a fan motor.

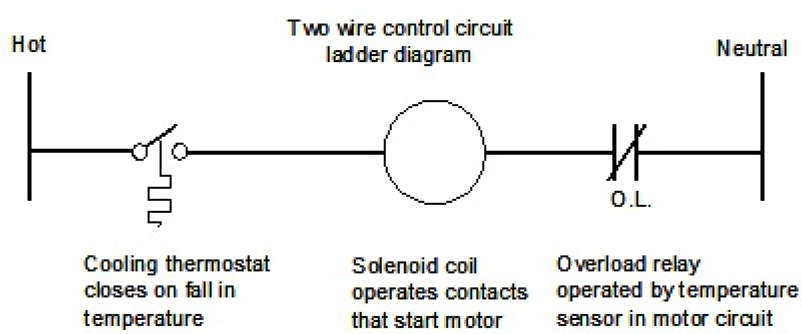


Figure 351.3 Control circuits are usually drawn as ladder diagrams such as this one where a solenoid is being operated with a cooling thermostat.

The actual fan motor circuit is not shown in Figure 351.3, only the control circuit that supplies power to the solenoid of the fan motor controller is shown. Motor must be protected from overloads, therefore, note the normally closed switch in the control circuit used as a overload control device to protect the motor. A sensor, usually responding to heat crated by motor current activates this overload relay. The diagram of Figure 351.3 is known as a 2-wire control circuit because one wire originates at the motor controller, runs out to the thermostat, then returns to the motor controller.

Another common type of control circuit is where one push button turns on a motor, and another adjacent push button turns it off. This type of action requires a normally open push button as the start and a normally closed push button as the stop. Because the start push button in only pushed (closed) for a moment then opened, some means must be provided to keep the controller solenoid energized when the start push button opens. This is accomplished using a set of contacts in the motor controller that are closed when the solenoid is activated. Known as holding contacts, they are connected in parallel with the start push button to act as a by-pass when the start switch is open. This type of circuit requires three wires from the motor controller to the start-stop push button station, this known as a 3-wire control circuit. A typical 3-wire control circuit is illustrated in Figure 351.4. This same type of circuit can be used where a fluid fills a container with a switch at the bottom to start the pump and another switch at the top to shut off the pump. A container can be drained of a fluid where a switch at the top turns on a pump and another switch at the bottom turns off the pump when the container is empty.

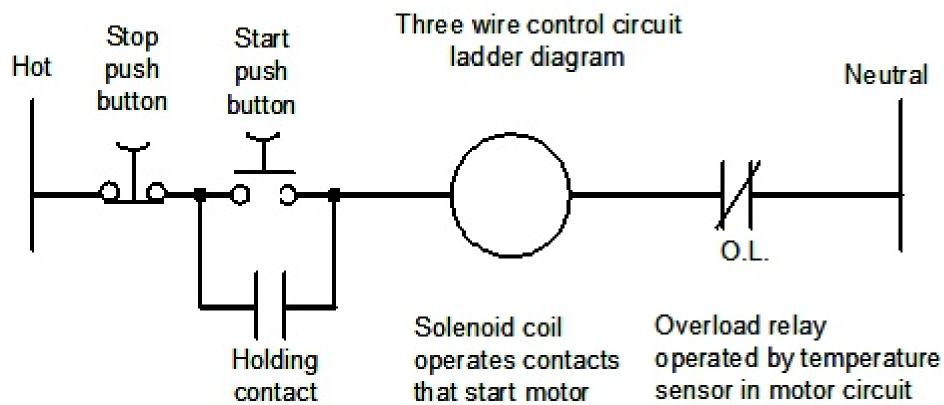


Figure 351.4 When two switches, one used as the turn-on and the other used as the turn-off, are used to operate a motor the start switch will be normally open and the stop switch will be normally closed. A set of momentary contact push buttons is shown controlling a motor.

System Interlocking: Sometimes system controls are interlocked so that equipment cannot be operated out of sequence. An example is a materials handling system where one conveyer feeds into another conveyer. The second conveyer must be running before the one that feeds materials into it is operating. This type of control requires the control circuit for the first conveyer to pass through a normally open auxiliary contact operated by the second conveyer control circuit. This is illustrated in Figure 351.5. Another common example of a control system interlock is to prevent two pieces of equipment from operating at the same time. An example may be two large compressor units that do not need to operate at the same time. An interlocking system can be set up where one cannot be operated if the other is operating. This type of control requires the control circuit for one system to pass through a normally closed auxiliary contact operated by the other system. This is illustrated in Figure 351.6.

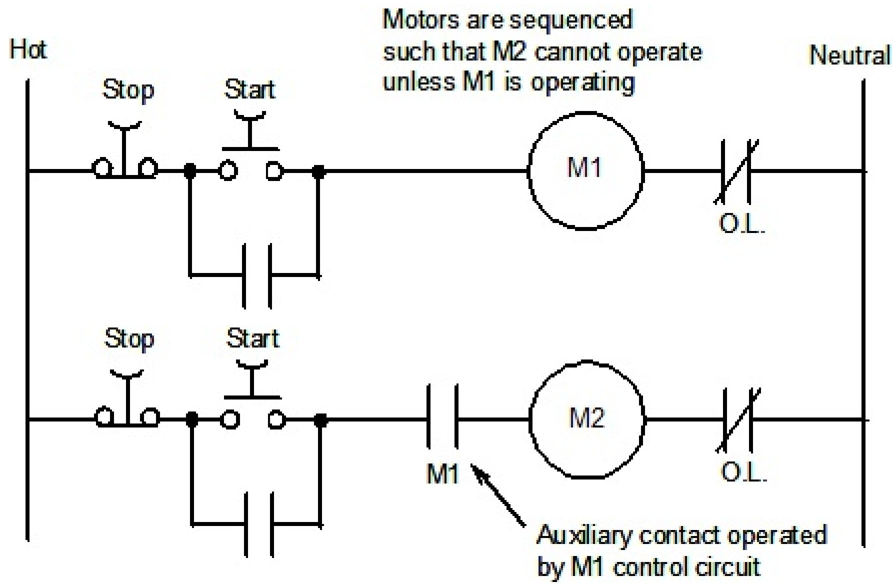


Figure 351.5 Both motors are operated using manual momentary contact push button stations, but the second motor is sequenced such that is cannot be operated unless the first motor is operating. If the first motor stops, the second motor will also shut-down.

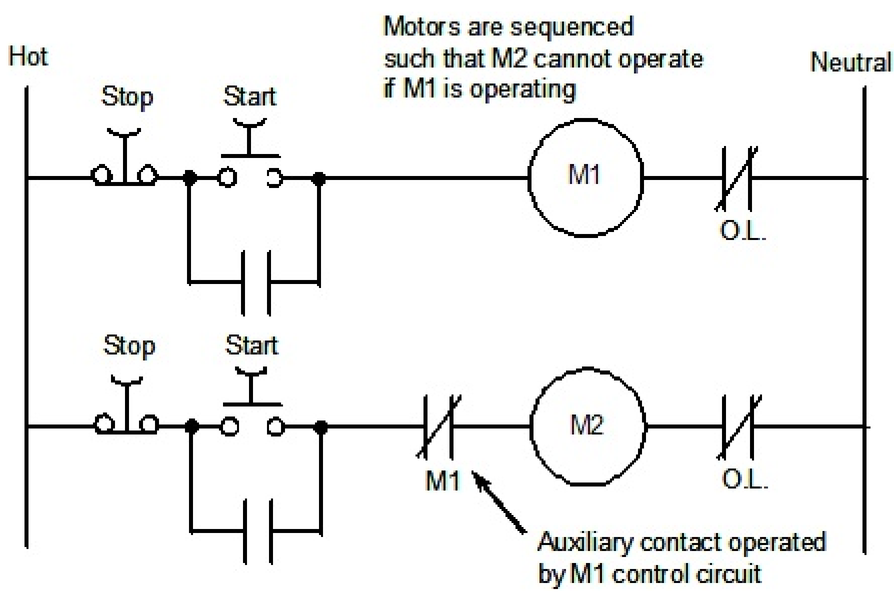
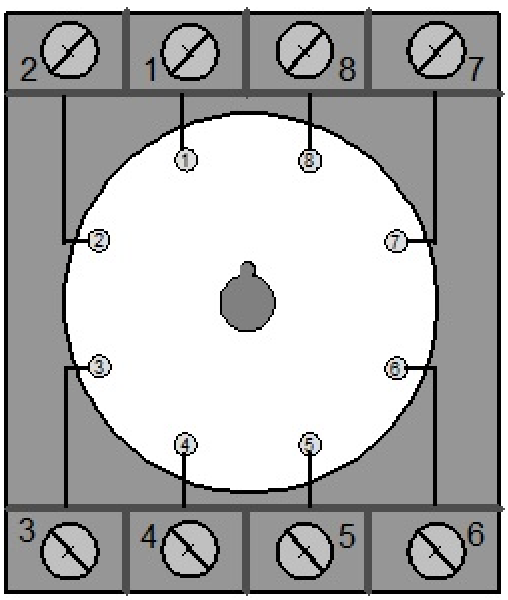
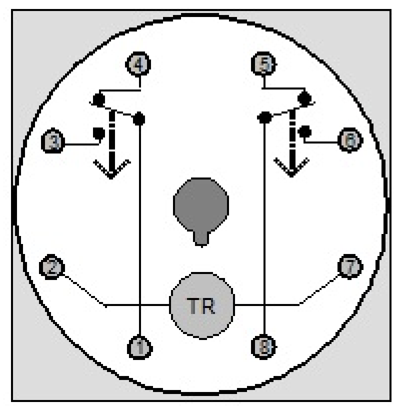


Figure 351.6 Both motors are operated using manual momentary contact push button stations, but the second motor cannot operate if the first motor is operating. The auxiliary contact in the second control circuit will open when the first motor is operating preventing the second motor from operating.

Time-Delay on Energize Relays: It may be necessary to activate a device with a time-delay after another device has been activated. This can be facilitated with a time-delay relay upon energize relay. A relay device usually with multiple contacts has an internal timer. There will usually be a diagram on the outside of the timer showing which terminals are the timer and which are the controlled contacts. Figure 351.7 is a diagram of a time-delay on energize showing terminals 2 and 7 as the timer, and two sets of contacts available. The type shown in the diagram is an 8-pin socket configuration where a socket is wired into the circuit and the actual timer relay is removable. When the timer is energized the contacts will remain in the state shown in the diagram until the time setting has expired. The contacts will then change to the alternate position. Generally this type of time-delay relay will immediately return to the original state when de-energized. The timing sequence can immediately be repeated.



Timing relay socket



Bottom view of timing relay

Figure 351.7 This type of time-delay relay uses an eight pin socket. The timer terminals are numbered starting to the left of the center post notch and proceed in a clockwise direction. Note that the numbering of the socket is in the counter-ith the timer connected between terminals 2 and 7. This timer is energized with 120 volts with the neutral to one terminal and a 120 Vac wire to the other terminal.

The ladder diagram of Figure 351.8 shows how a time-delay on energize relay is connected to a circuit. The first motor is operated with a conventional 3-wire control circuit with momentary start-stop push button station. When the first motor is activated, the timing relay is also energized. Timing begins and the contacts remain at the state shown in Figure 351.8 until time has expired then the contacts move to the alternate position. The solenoid for the second motor controller is drawn in a separate rung of the ladder with a normally open set of contacts controller by the timing relay used to energize the control circuit of motor 2. Look at the timing relay diagram of Figure 351.7 and note that normally open contacts are either between terminals 1 and 3 or between terminals 8 and 6.

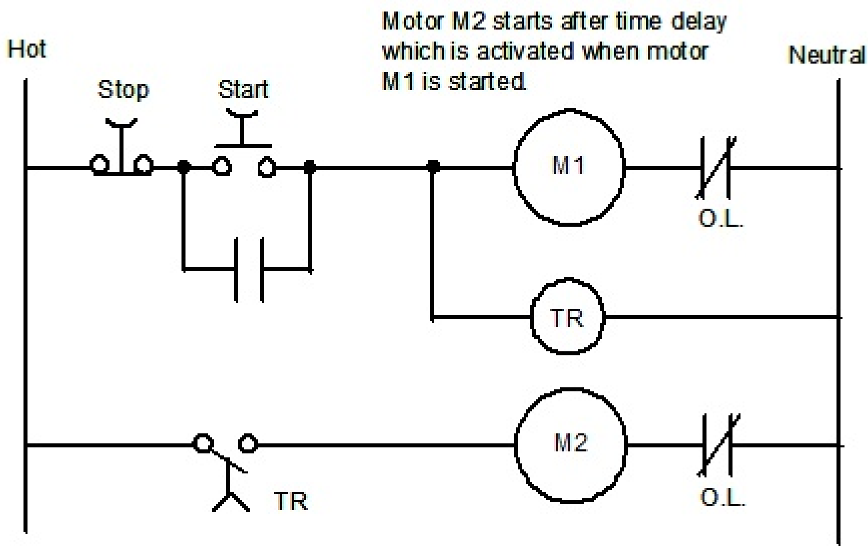


Figure 351.8 The first motor is operated using a momentary contact start-stop push button station. When motor 1 is energized the timer is also energized. After the time delay has elapsed the normally open contact in the control circuit of motor 2 will close.