CONTROL CIRCUITS

By Tom Henry

This book was written as a study-aid for an electrician preparing to take an electrical examination.

As you read this study-aid book you will note that complicated electrical circuits and explanations have been put in a clear, concise, understandable language for the *electrician*..

"Written for an electrician by an electrician".

Tom Henry

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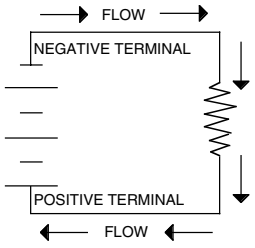
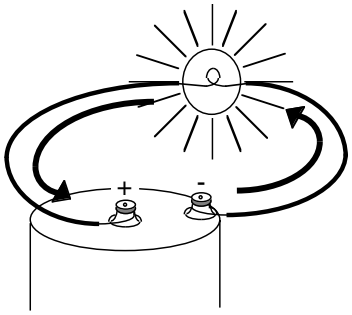
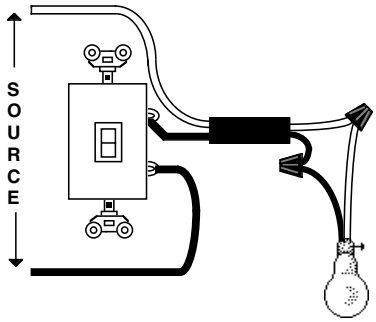
Let's start at the beginning, in theory we learned to have a complete circuit we need a source of supply, wire and a load.



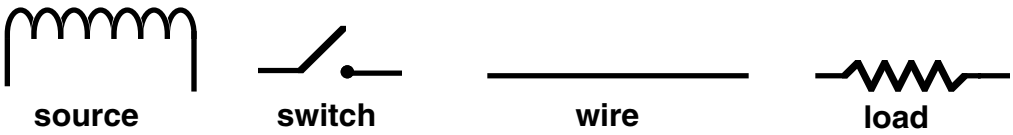


The ceiling light in your home is **controlled** by a switch. This is called the basic two-wire circuit.

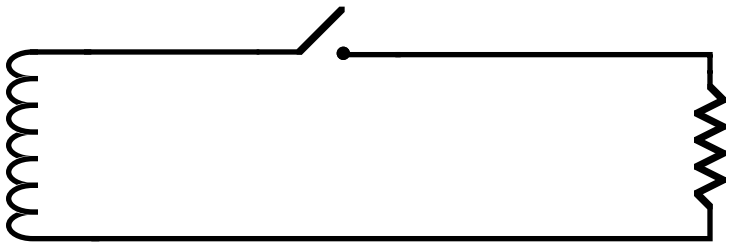
As the circuit is shown to the right, this would be called a main wiring diagram. These diagrams are converted in **schematic** (ladder) diagrams. The schematic diagram provides a short cut for troubleshooting a control circuit. The schematic diagram includes **symbols** as well as words and phrases. The symbols are interconnected by lines to show the flow of current through the devices.



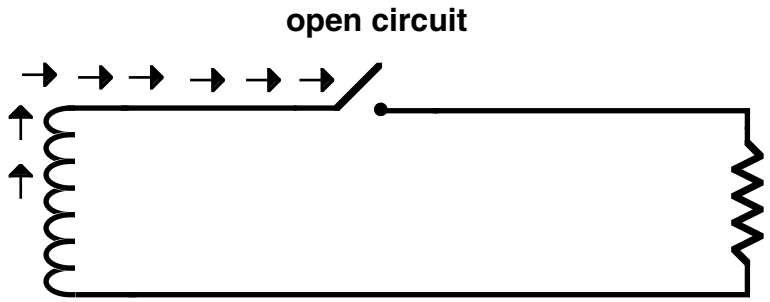
SYMBOLS



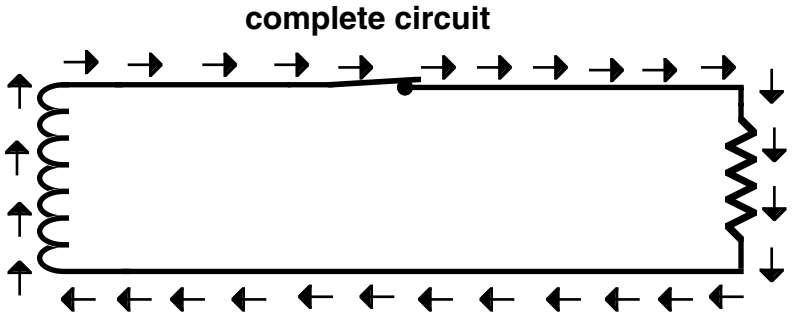
Using the symbols we will put the same two-wire light circuit into a schematic diagram.



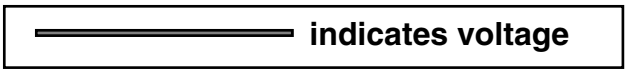
With the switch open there is not a complete path for current to flow back to the source, this is called an **open circuit**.

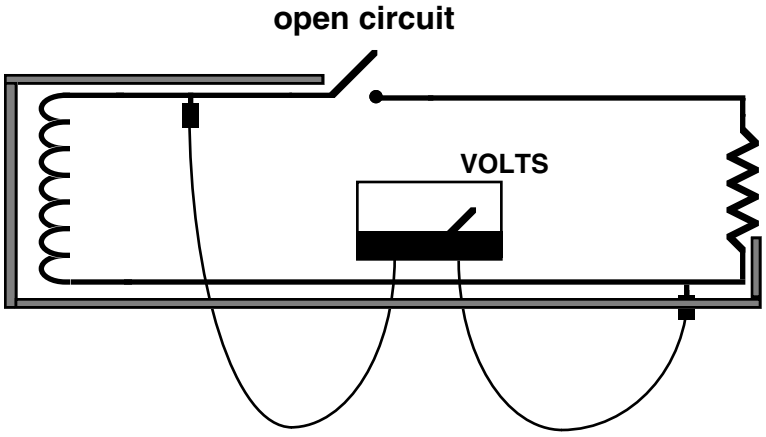


Once the switch is closed there is a complete path for the current to flow back to the source, this is called a **complete circuit**. The switch is the **control** for the circuit.

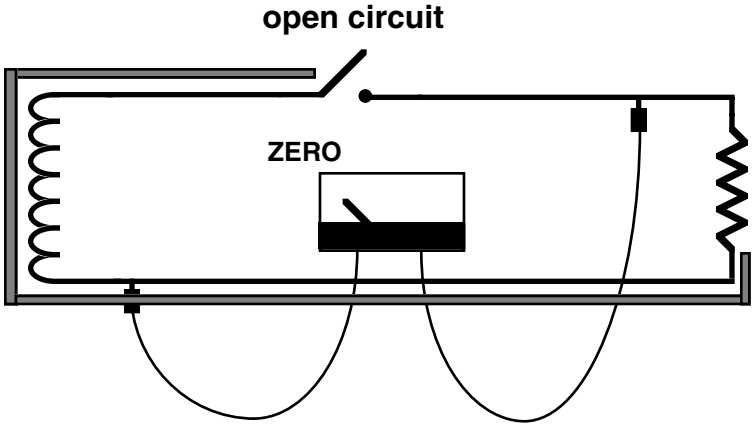


With the circuit **open** there would be **voltage** from the source to the open switch and from the source to one side of the load as shown below.



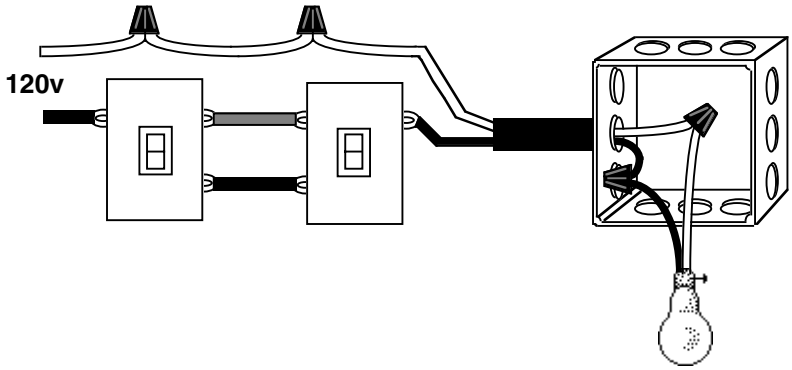


From the source to the **open** side of the switch there are zero volts.

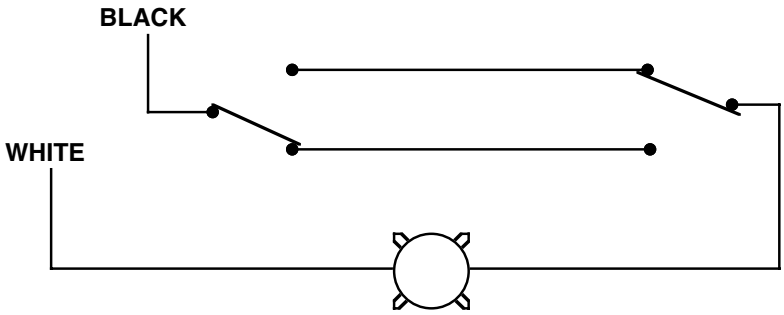


The **load** must have a source voltage applied to both sides to complete the circuit and allow the current to flow.

Shown below is a wiring diagram of a light connected through two 3-way switches. The light can be turned on or off from either switch.



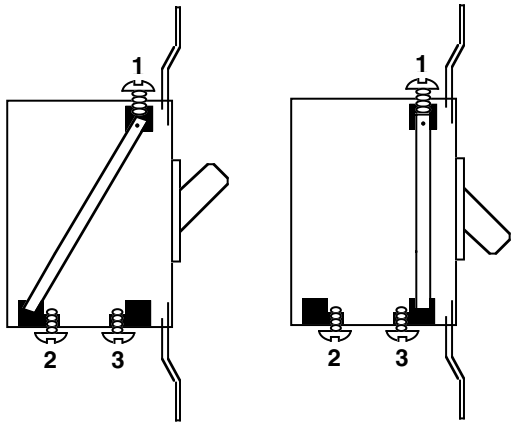
This same 3-way switch circuit is shown below in **schematic** form.



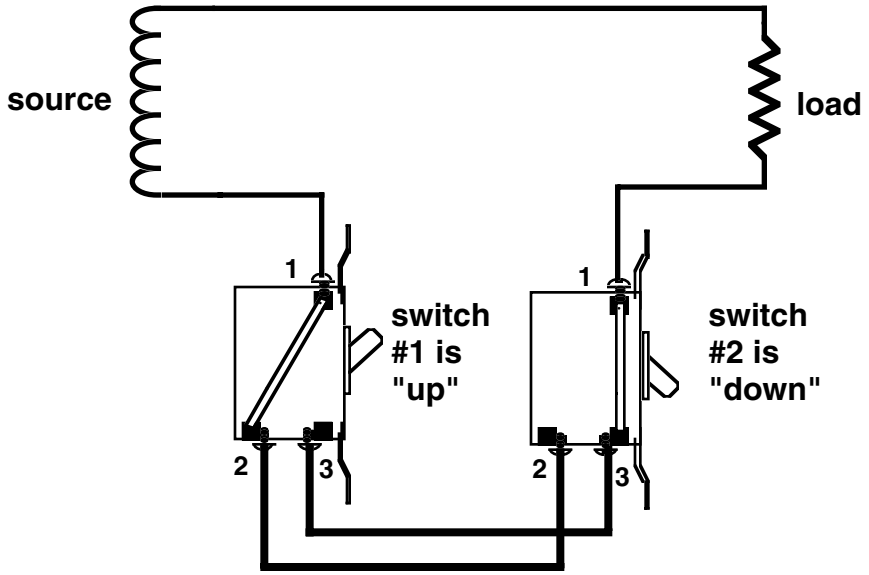
One wire is connected from the source directly to the load. The other wire is connected through the switches to control the load.

3-WAY SWITCH

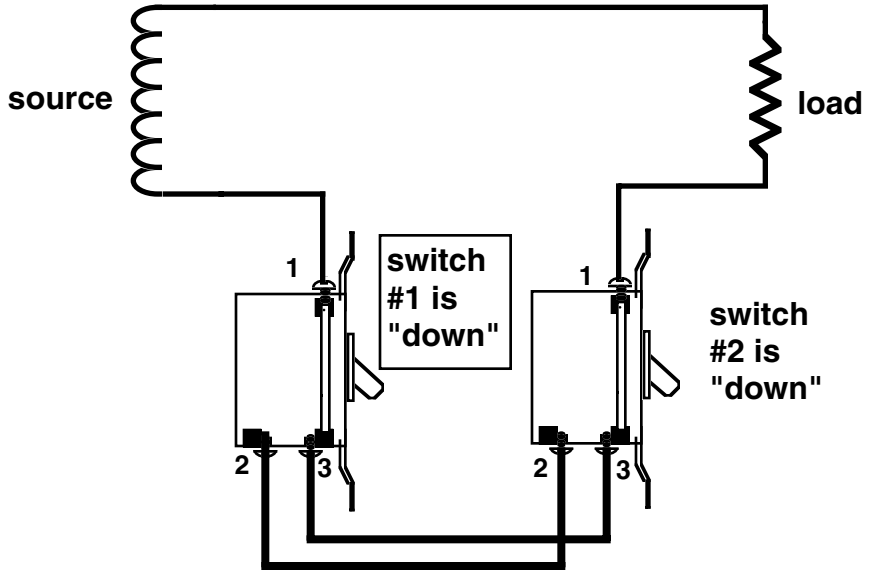
It is easier to understand how the 3-way switches can control the light if you see how the switch is built internally. Shown below is a side view of how the 3-way switch is contructed. The black wire is connected to terminal screw **1**. The view to the left shows when the toggle is turned to the "up" position there is a **complete** circuit through terminal screws **1** and **2** and an **open** circuit between **1** and **3**. The view to the right shows that when the toggle on the same 3-way switch is turned to the "down" position there is a **complete** circuit through terminal screws **1** and **3** and an **open** circuit between **1** and **2**.



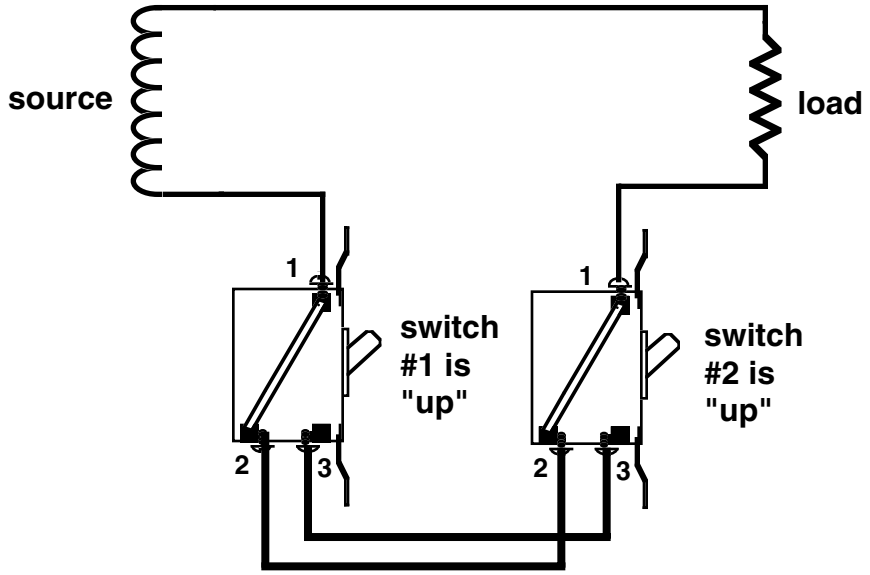
The load would **not** be energized in the circuit shown below. One wire is connected directly from the source to the load. The other wire from the source is controlled through the two 3-way switches. There is voltage from the source through terminal screw **1** and **2** on switch #1. The voltage continues through the wire and stops at terminal screw **2** on switch #2. There is an **open** circuit between terminal **2** and terminal **1** on switch #2.



When switching switch **#1** from "up" to the "**down**" position the load now becomes **energized** as there is a complete circuit through terminal screws **1** and **3** on switch #1 and through terminals screws **3** and **1** on switch #2 and on to the load. By switching **either** switch #1 or switch #2 the load can be turned off.

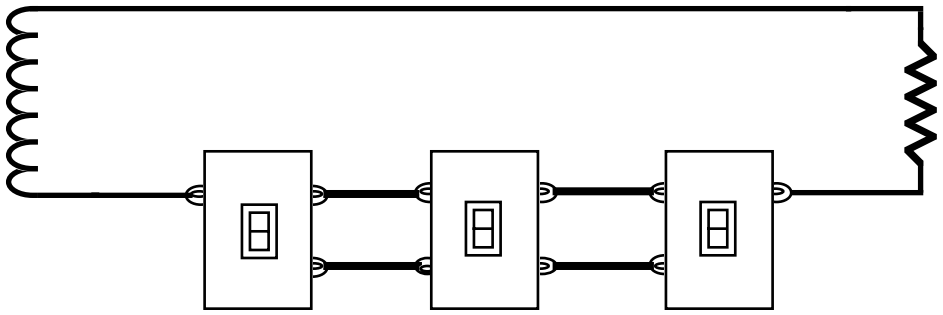


Turning both switches #1 and #2 to the "up" position will also **energize** the load as shown below. And by turning either switch the load can be shut off. It is very important for the student, at this point, to be able to trace a **complete** circuit from the source to the load through the action of the switches, terminals and wiring before advancing to the more complex motor control circuits.

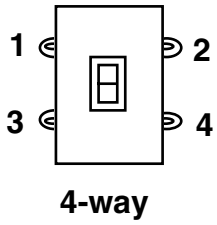


4-WAY SWITCH

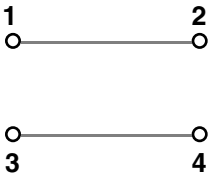
When a load is required to be switched from more than two switching points a 4-way switch must be used in the circuit. 3-way switches are connected to the source and to the load with the 4-way switches connected in between.



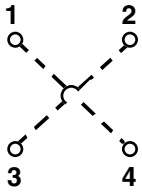
Don't confuse a 4-way switch with a double-pole switch. A double-pole switch will have "on" and "off" marked on the toggle. A 4-way switch has **no** "on" or "off" markings and is constructed so that the switching contacts can alternate their positions as shown below.



4-way



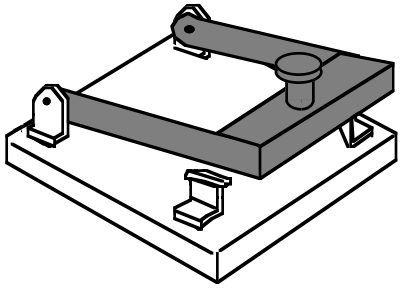
HANDLE UP



HANDLE DOWN

There are many different types of **switches** used in control wiring. It is important for the student to be able to trace the circuit through these different switches.

One of the first control switches was a knife switch, used to control the starting and stopping of motors.

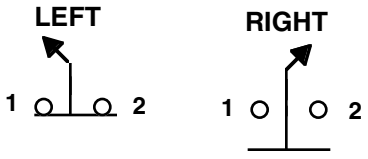


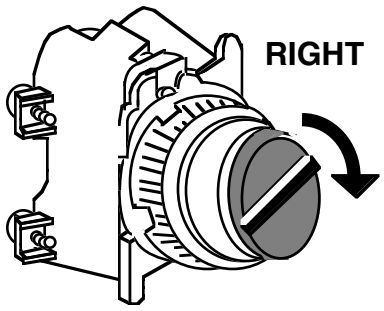
knife switch

SELECTOR SWITCH

one normally open

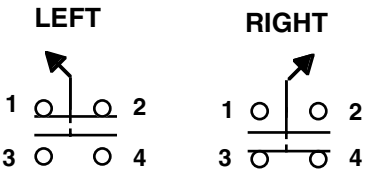
2 position

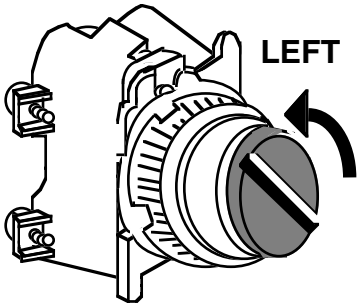




one normally open - one normally closed

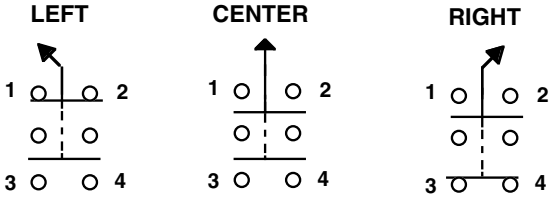
2 position

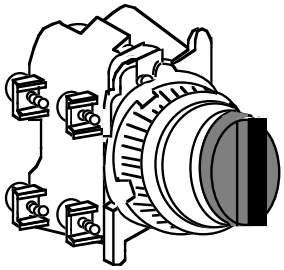


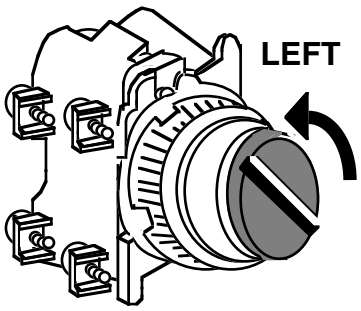


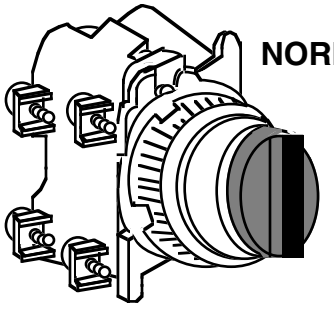
one normally open - one normally closed

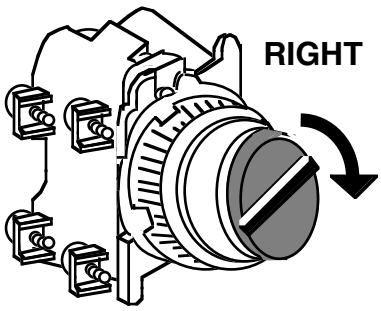
3 position











LIMIT SWITCH

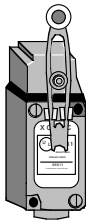
A limit switch is used in a control circuit to start, stop, forward, reverse, etc. some operation of a machine.

A limit switch generally has two contacts, one normally open and one normally closed quick make, quick break, snap action type.

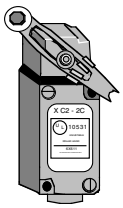
It is very important when reading a schematic diagram that contains limit switches that you are familar with the symbols for limit switches.

Shown below are the symbols for limit switches. Note the position of a normally open contact in the **normal** position and then in a position with the arm moved to the right or left. Now the normally open contact is **held** closed by some mechanical function in the sequence of the machine operation.

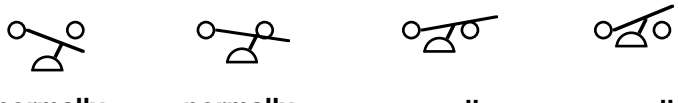
LIMIT SWITCH SYMBOLS

Normal position of the arm	Normally open contact	Normally closed contact
		

Arm position to the right	Normally open contact HELD CLOSED	Normally closed contact HELD OPEN
		

Arm position to the left	Normally open contact HELD CLOSED	Normally closed contact HELD OPEN
		

PRESSURE SWITCH

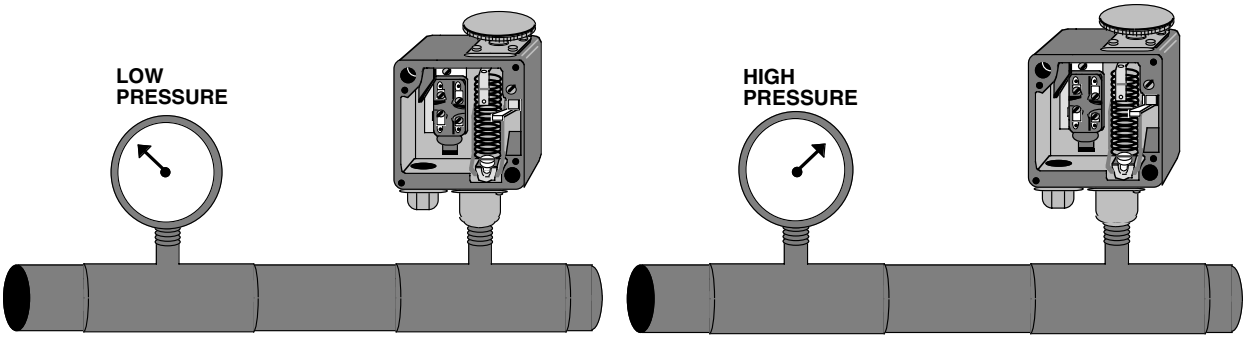


normally open

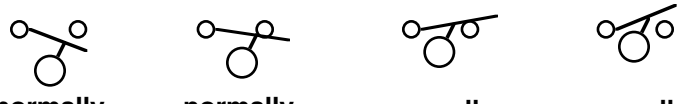
normally open - HELD closed

normally closed

normally closed - HELD open



FLOAT SWITCH

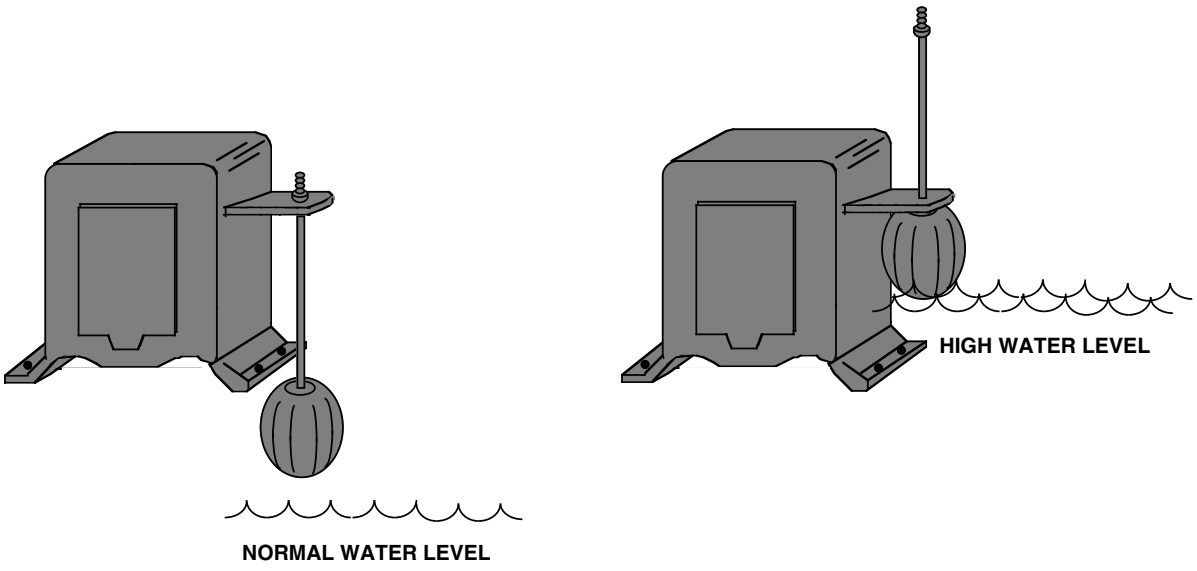


normally open

normally open - HELD closed

normally closed

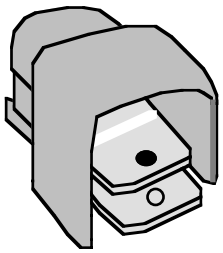
normally closed - HELD open



FOOT SWITCH

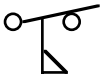
normally open

normally closed

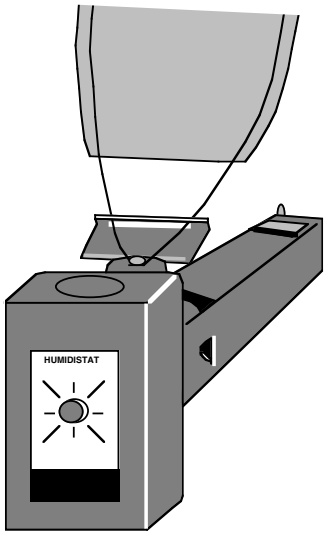


FLOW SWITCH

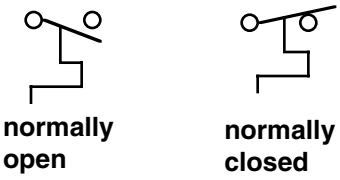
normally open



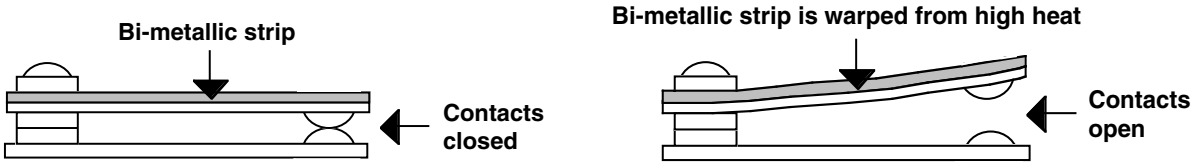
normally closed



TEMPERATURE SWITCH

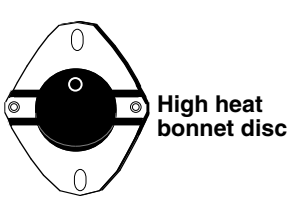


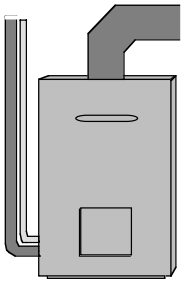
A temperature switch is a control device that responds to temperature changes. A bi-metallic strip is used to actuate the electrical contacts. The bi-metallic strip is made of two pieces of different metal laminated together. Metals when heated, will expand and contract at different rates. Heating the bi-metallic strip will cause it to warp or curve which will open the normally closed contacts.

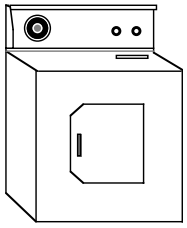


Once the tripping action has taken place, the bi-metallic strip will cool and the warped shape will go back to the normal shape, closing the contacts. A circuit breaker uses the bi-metallic action only the circuit breaker will need to be manually reset to close the contacts.

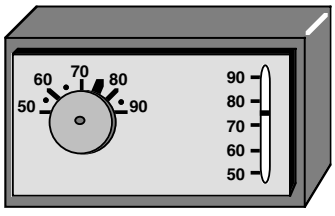
A gas furnace and a clothes dryer are examples of equipment that uses the bi-metallic action for safety precautions when high heat arises. A gas furnace has a high heat bonnet which will open the contacts to the main gas valve shutting off the gas so the furnace will not be exposed to high heat damage. An electric clothes dryer also utilizes a high heat safety, opening the power contacts to the heating elements when a dangerous high heat is reached.

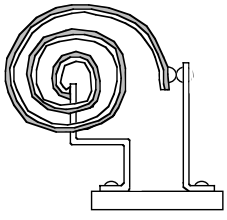






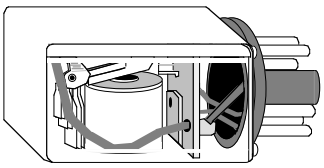
A thermostat uses a **spiraled** bi-metallic strip which increases temperature range and sensitivity.



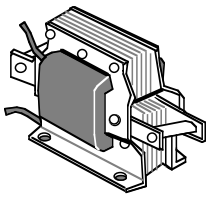


RELAYS

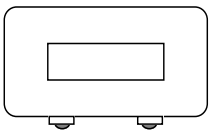
Relays, solenoids, etc. contain a magnetic coil when energized by an electrical current passing through it causes the iron armature to move in the frame.



relay



solenoid

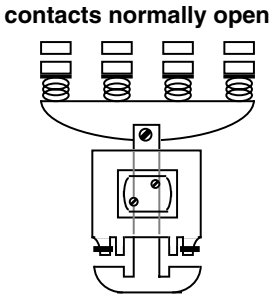


coil

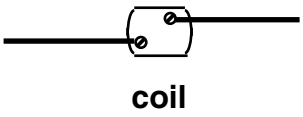
Relays are used in industrial assembly lines, machine tool control and commercial equipment. Relays are **switching devices**. A relay is used in a control circuit as a switch. Relays are not designed to carry large currents.

The 4-pole relay shown has four normally open contacts. The contacts are referred to as poles.

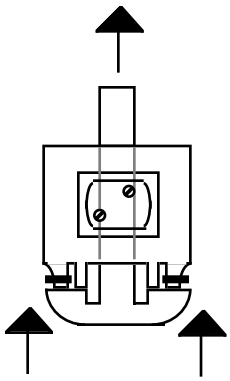
When the coil is **energized** creating a magnetic field it will draw the iron plunger "up" closing the normally open contacts. This is the switching action of a relay. The 4-pole relay contains four switches which can be normally open or normally closed.

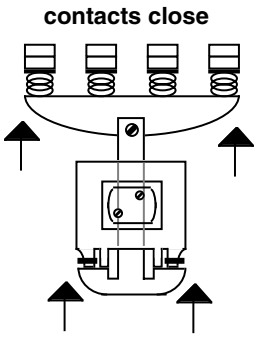


4-pole relay



coil





On the schematic the coil will have a symbol. 

coil

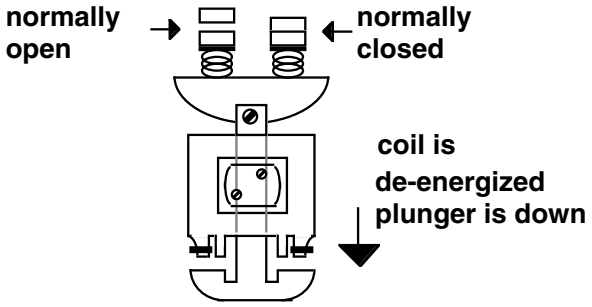
The relay will be given a designation such as R1. 

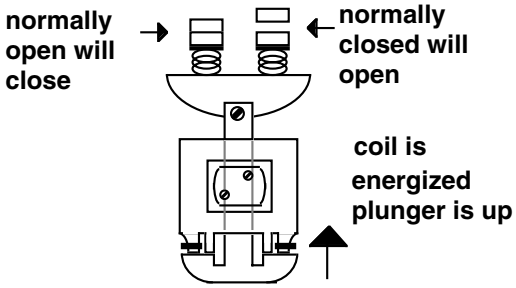
coil

The four **normally open** contacts will be shown on the schematic as: 

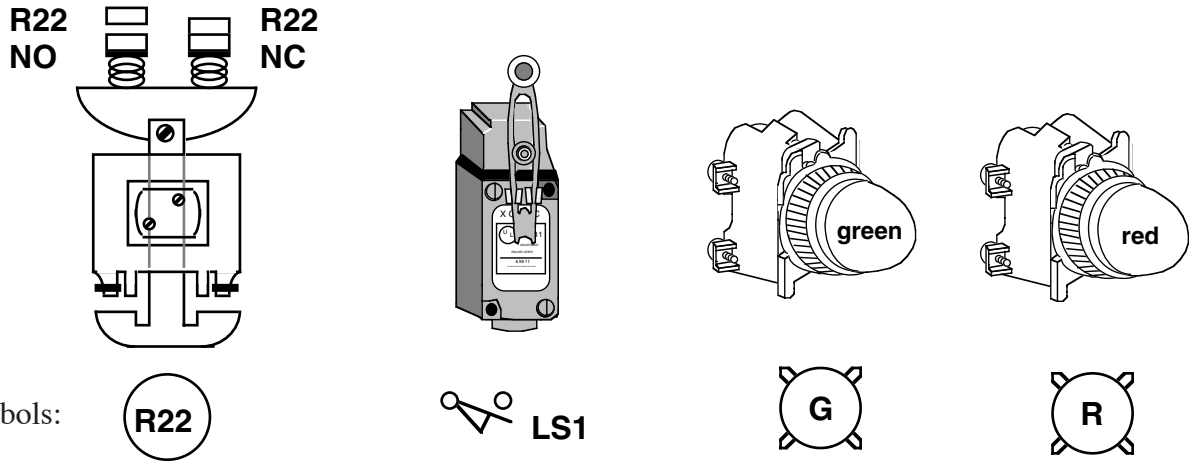
If the relay had normally closed contacts the symbol on the schematic would be: 

If the relay designation is R22, the relay coil and relay contacts would also be designated R22. Any contacts physically attached to the frame of R22 would be marked R22 on the schematic. Schematics are shown in the de-engergized (power off) position. When R22 is energized the normally open contact becomes closed and the normally closed contact becomes open.

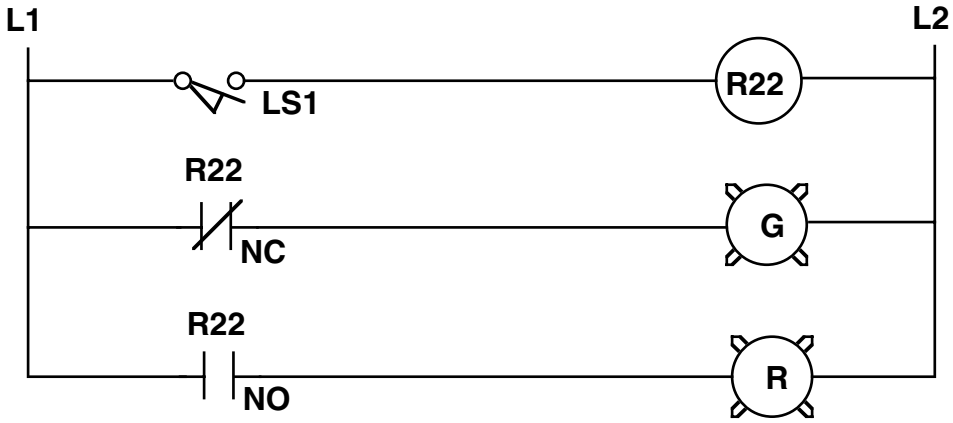




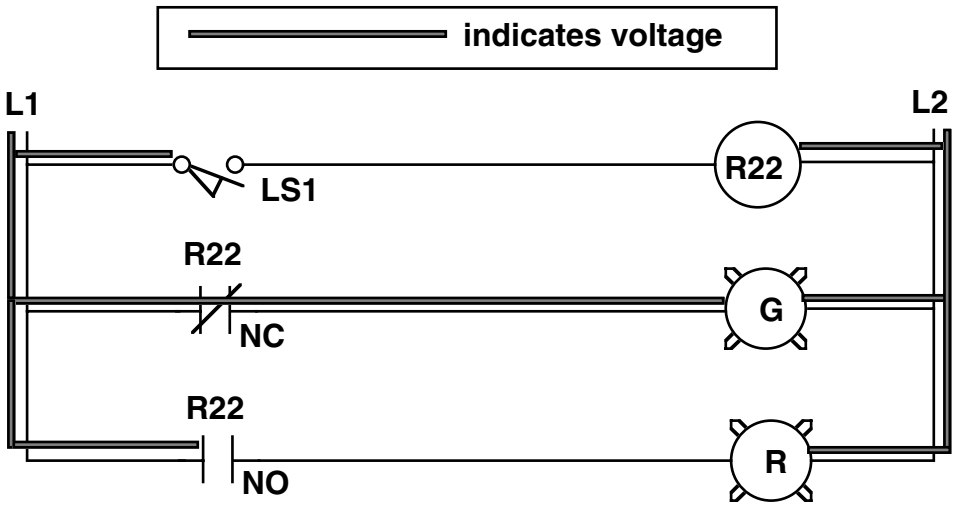
Shown below is a 2-pole relay with one normally open contact and one normally closed contact in a circuit with a limit switch with a normally open contact and two lights. The industrial control circuit requires the "**green**" light to be lit in a **normal** condition. When the limit switch is "**closed**" the "red" light is to be lit and the "green" light is to be off.



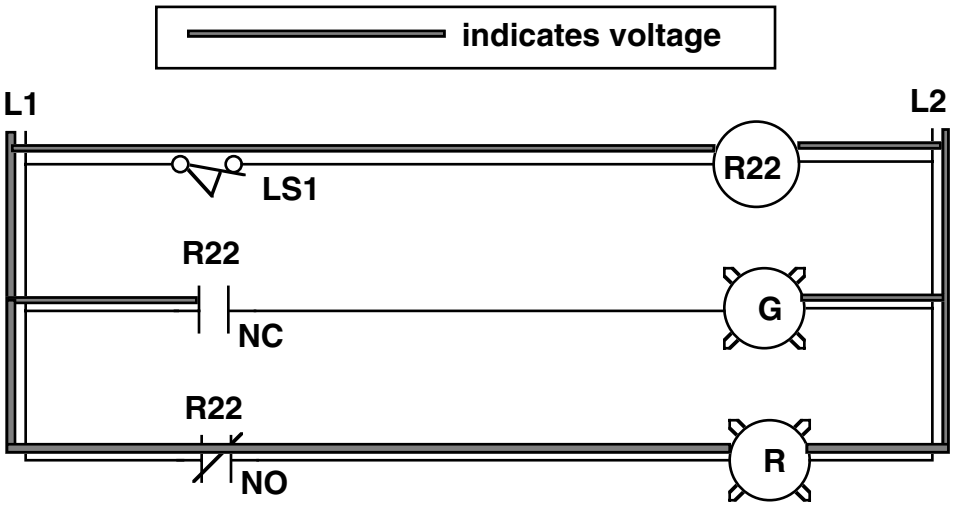
The source will be shown on the schematic as "L1" (line one) and "L2" (line two).



Shown below is the same circuit with the source turned on to **L1** and **L2.** L2 supplies voltage to one side of the relay coil and to one side of each light. R22 relay cannot energize until limit switch LS1 is closed. The **green** light will come on when the source L1 and L2 is turned on as there is a complete circuit to the **green** light through R22 normally closed contact. The green light will stay lit until the limit switch is closed.

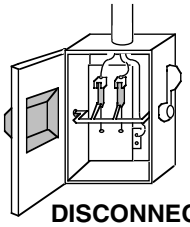


Shown below is the circuit with limit switch LS1 **closed**. When limit switch LS1 closes it completes the circuit to R22 relay. When R22 energizes it opens the normally closed contact which **opens** the circuit to the green light. At the same time when R22 relay energizes the normally open contact will **close** completing the circuit to the red light.

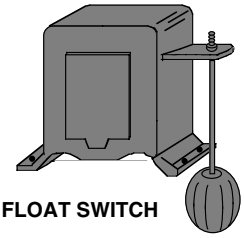


FLOAT SWITCH

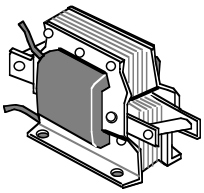
The next circuit is a float switch that energizes a solenoid that opens a drain valve.



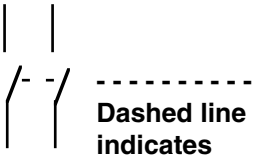
DISCONNECT



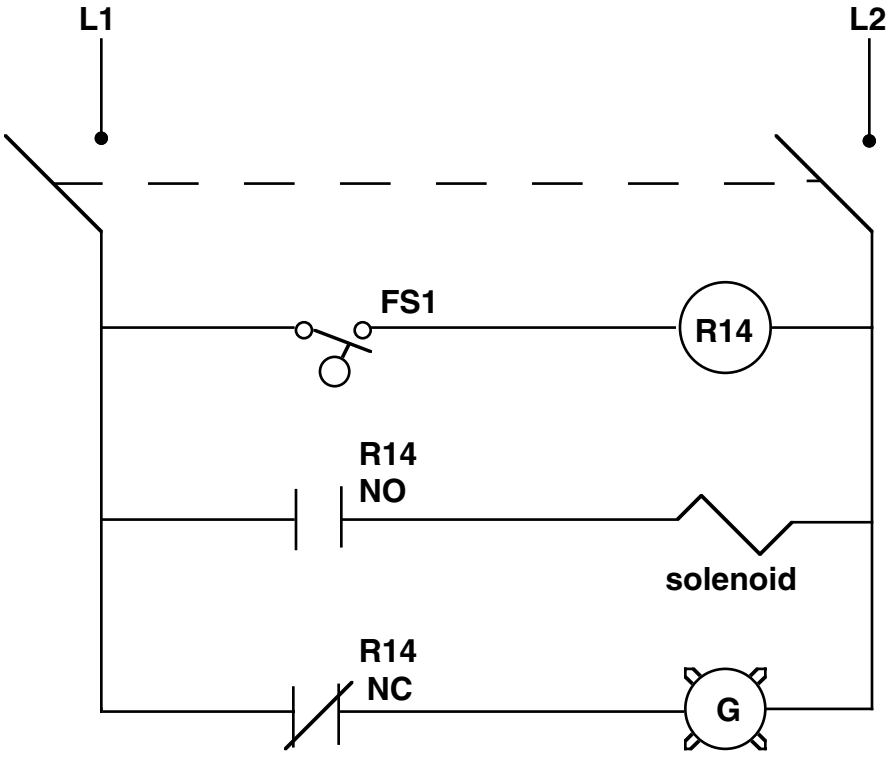
FLOAT SWITCH



SOLENOID



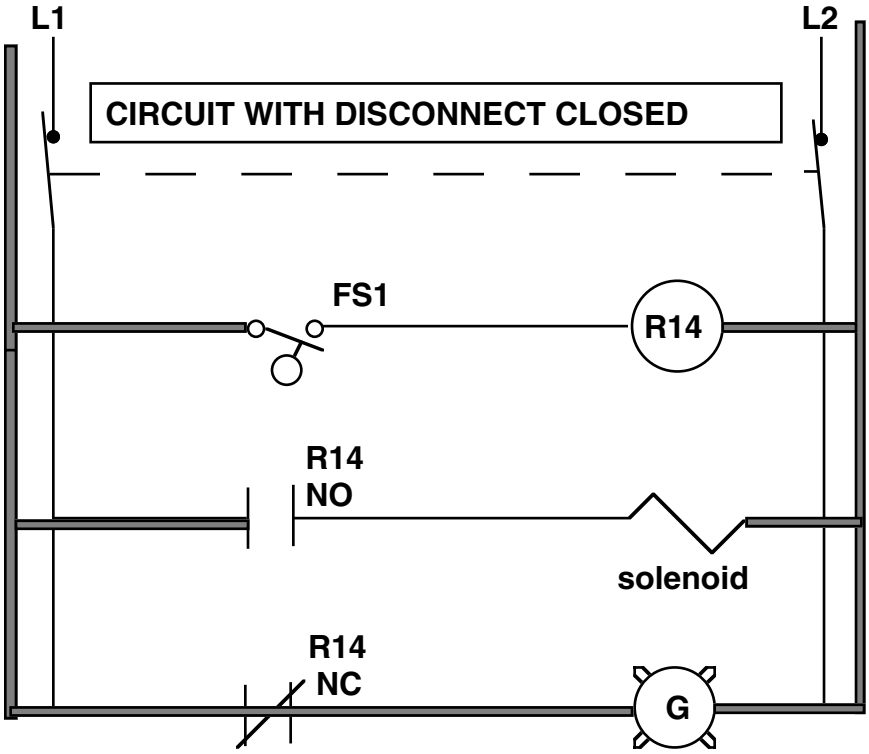
Dashed line indicates mechanically connected



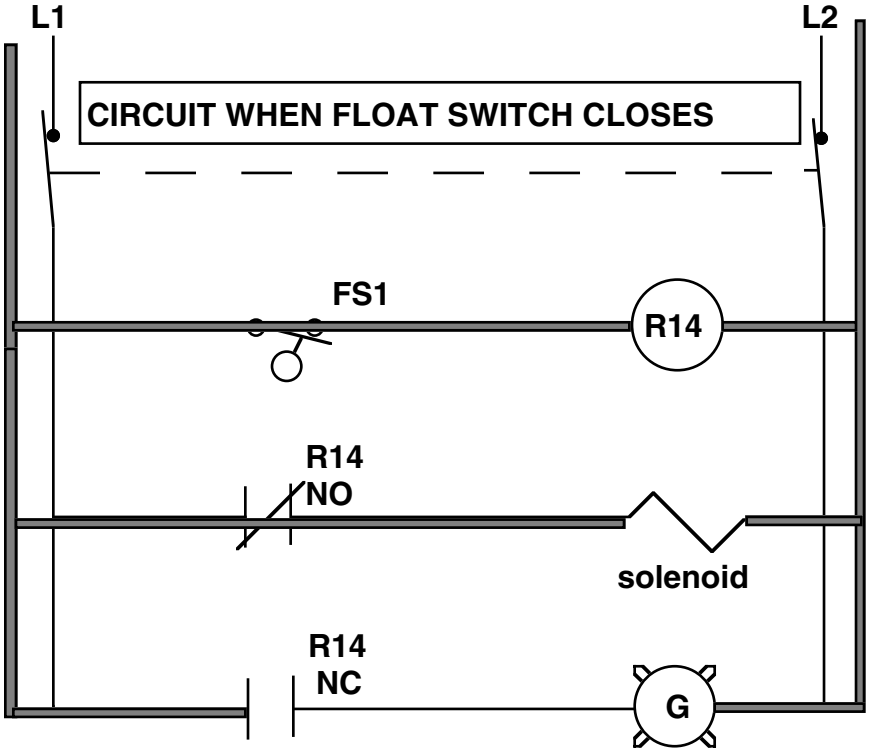
When the disconnect is closed, L2 will flow to one side of the R14 coil, solenoid and light. L1 will flow to one side of float switch, R14 NO interlock and through R14 NC interlock to the light.

When the disconnect is closed, the green light is "ON". When the water level rises and closes the float switch, this will energize R14 relay and R14 NO will close energizing the solenoid opening a mechanical drain valve and at the same time R14 NC will open and the light will go "OFF". When the water level lowers, the float switch will open and the green light will come back "ON".

The circuit below shows the path of voltage at the first step, when the disconnect is closed.

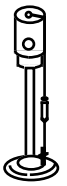


The circuit below shows the path of voltage when the water level rises and the float switch closes.



PRESSURE SWITCH

Lift stations, sump pumps, submersible pumps use different types of float switches for controls.

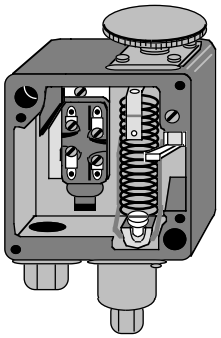


Sump pump

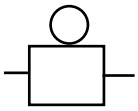
Submersible pump

The load can be **controlled** by many different devices such as single-pole switches, 3-way switches, limit switches, pressure switches, temperature switches, time-delay switches, foot switches, push-button switches, etc.

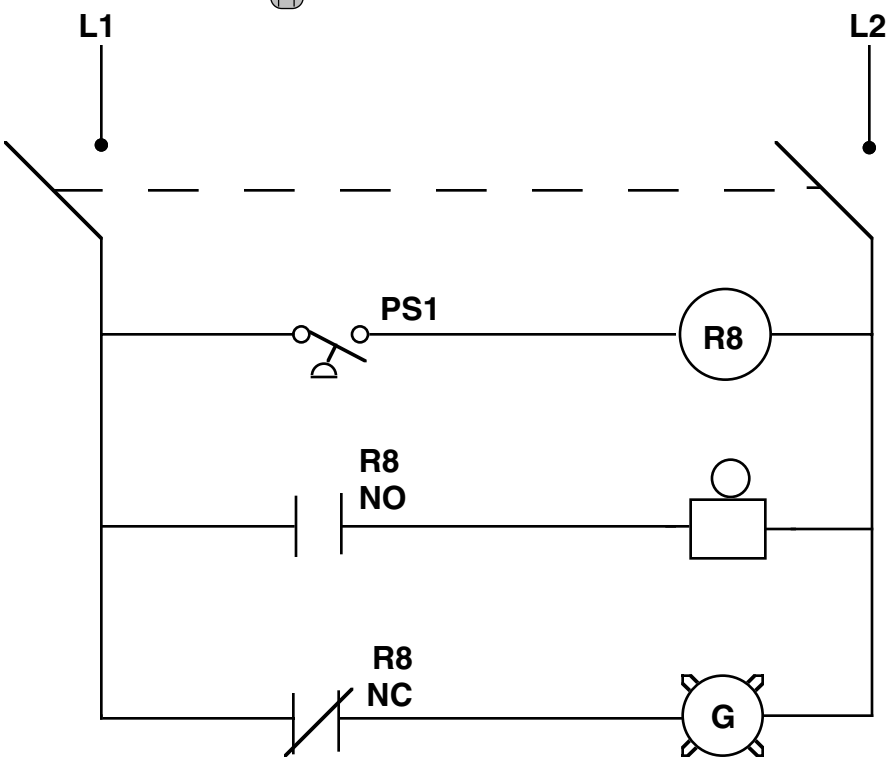
The circuit below is controlled by a pressure switch. When the pressure builds to a pre-set limit the pressure switch contact will close energizing R8 relay which will energize the alarm bell through R8 NO contact as it closes and the green light will shut off at the same time as R8 NC contact will open.



pressure switch



bell

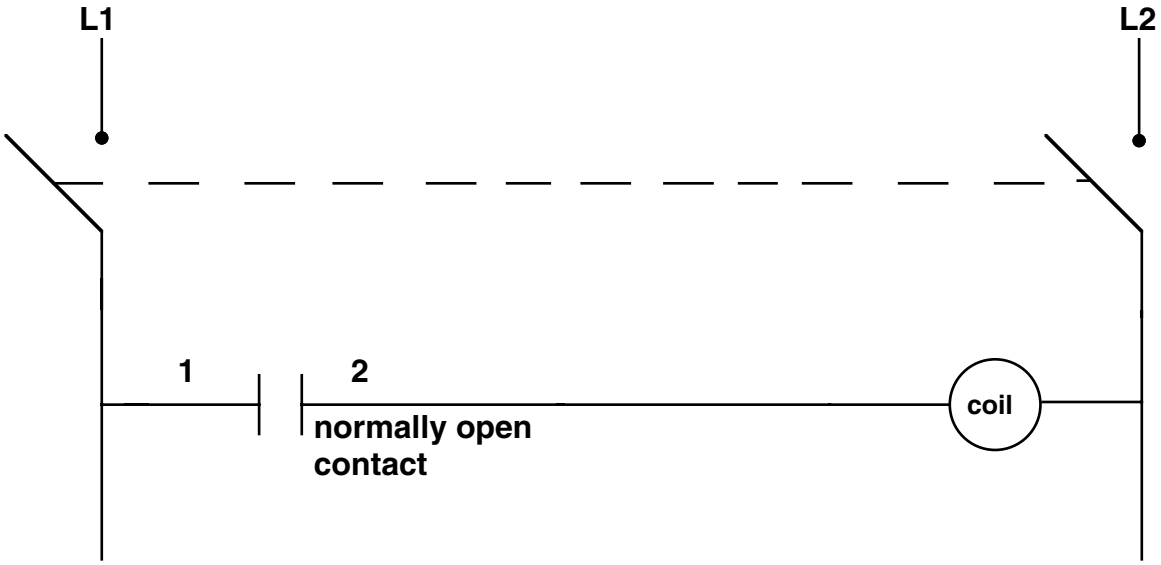


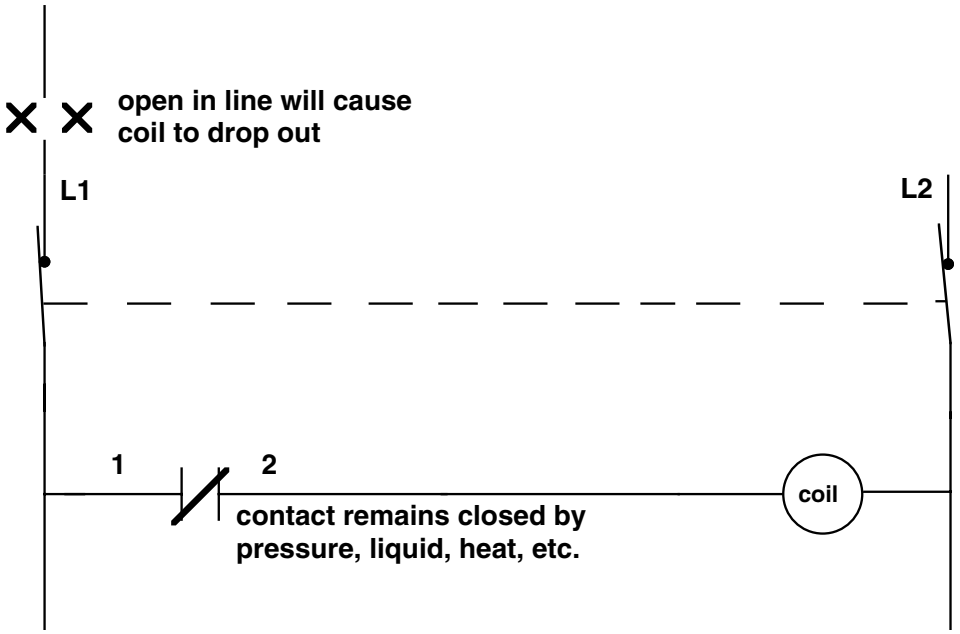
2-WIRE CONTROL

The term "2-wire" control arises from the fact that the basic circuit requires only two wires to connect the controlling contact to the coil. The contact could be on a pressure switch, float switch, temperature switch, etc. which requires no operator as the contact is **automatically** closed by pressure, liquid, heat, etc.

If a power failure occurs while the contact of the device is closed, the coil will de-energize. When power is restored, the coil will energize **automatically** through the contact that is being held by pressure, liquid, heat, etc.

This can become a dangerous situation if the circuit is being used to start a machine where fingers and hands may be in the machine when it **automatically** starts when the power is restored again.

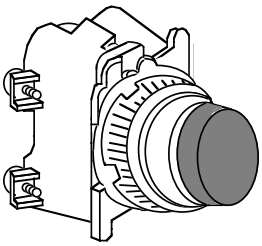




3-WIRE CONTROL

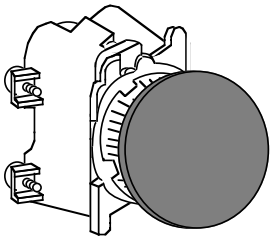
The term "3-wire" arises from the fact that the basic circuit requires at least three wires to connect the control devices to the coil.

The 3-wire control uses momentary contact push buttons or similar devices to energize the coil.



START BUTTON

Spring held normally open contacts

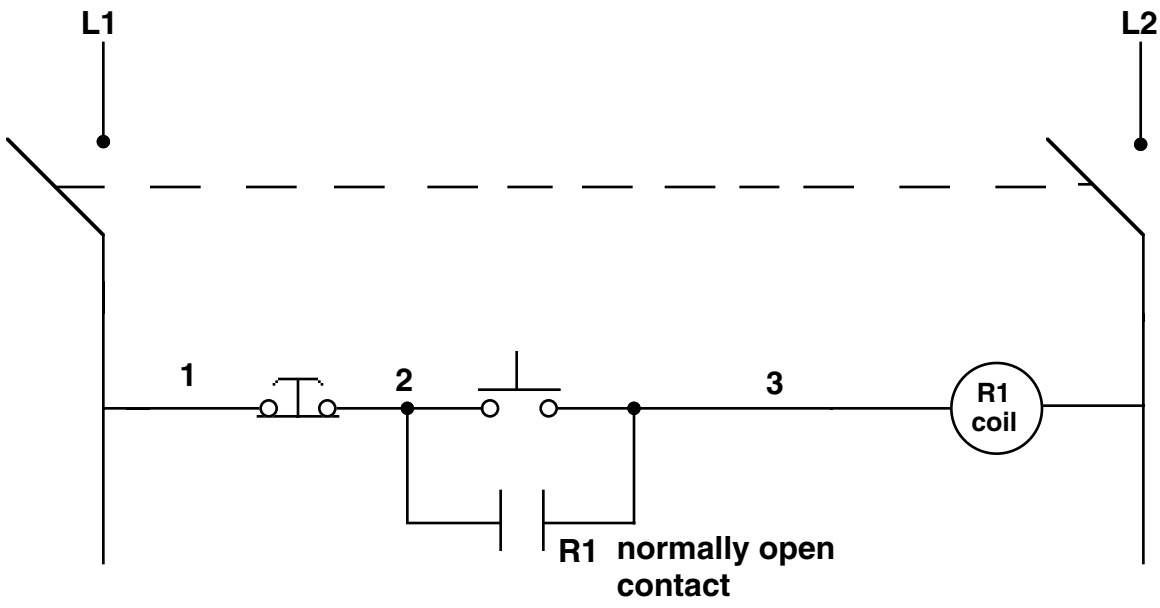


STOP BUTTON

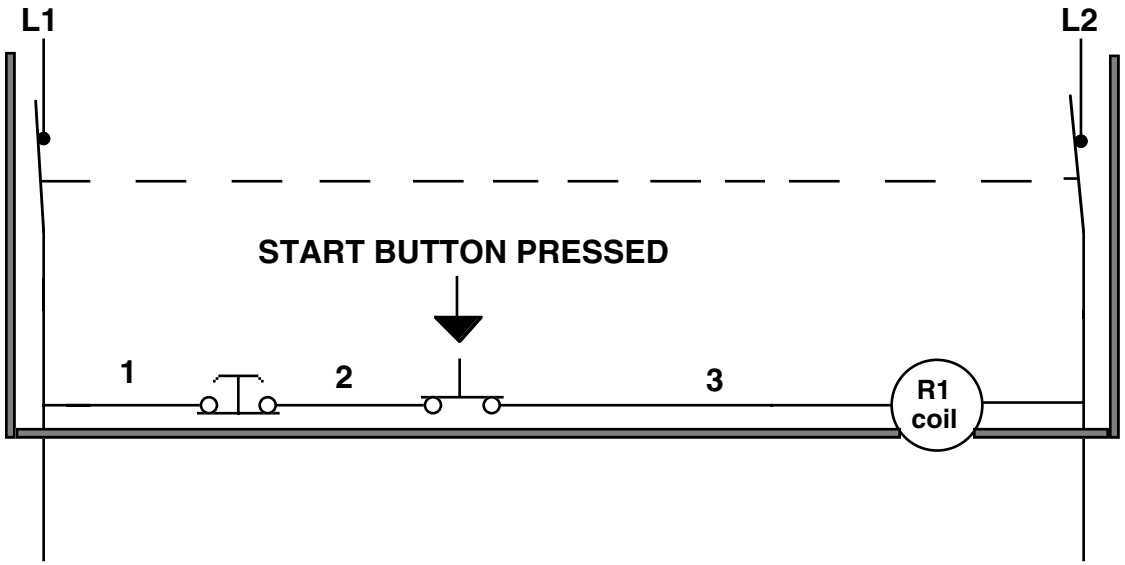
Spring held normally closed contacts

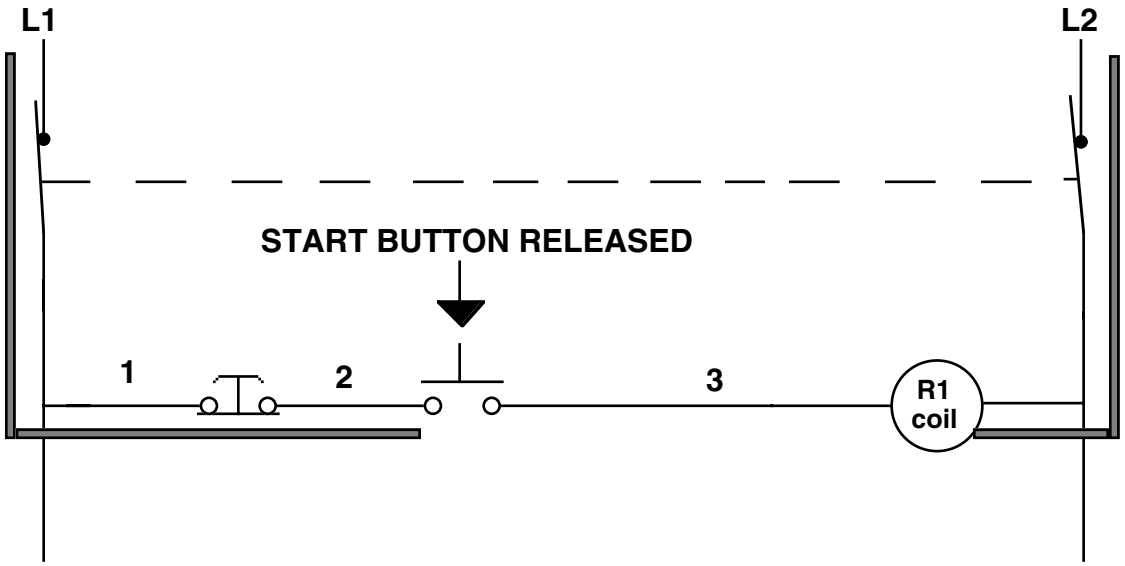
The 3-wire control circuit is used to prevent the unexpected energizing of the coil which could result in possible injury to machine operators or damage to the machinery.

The coil is energized by pressing the start button. An auxiliary "holding circuit" normally open contact on the relay, forms a parallel circuit around the start button contacts keeping the coil energized after the start button is released. If a power failure occurs, the coil will de-energize and will open the holding circuit contact. When power is restored, the **start** button **must** be pressed before the coil will energize again, thus preventing unexpected starting of the machine.

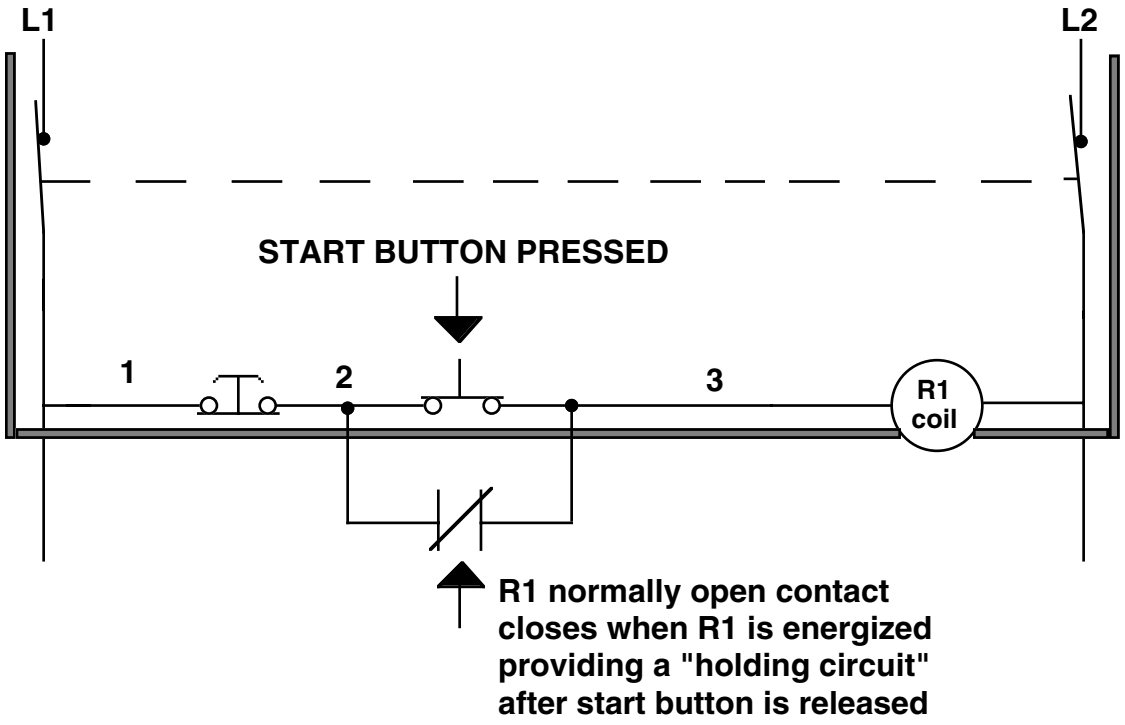


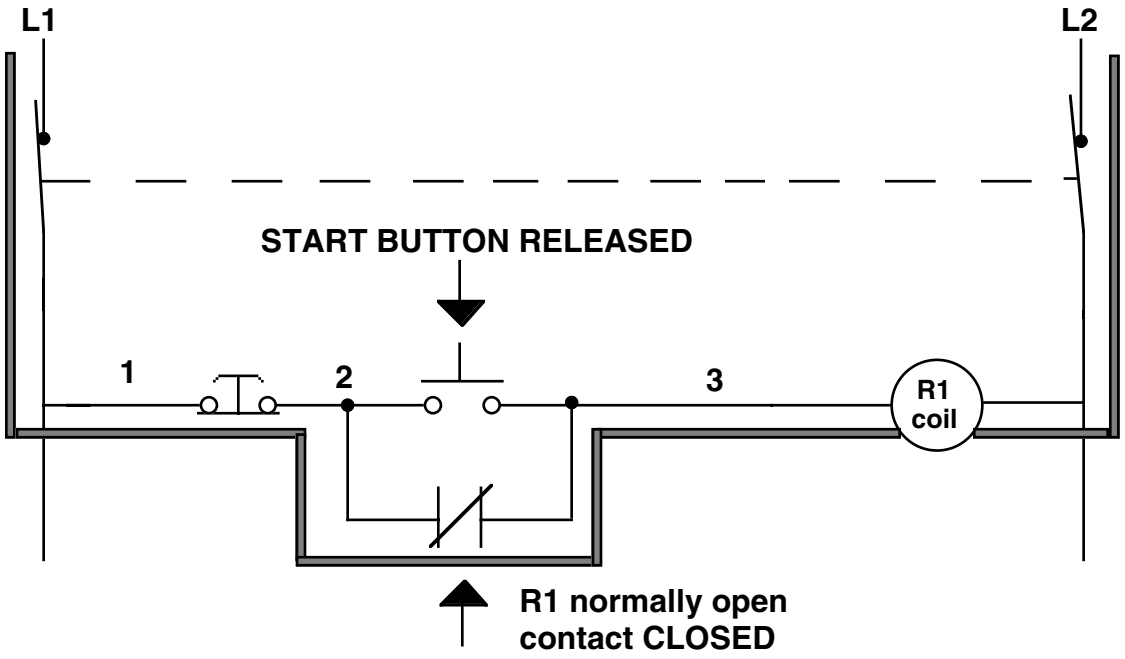
When the start button is pressed it completes the circuit energizing R1 coil. But, without a "holding circuit" R1 coil would de-energize when the start button is released. This would be a "jog" or "inch" type circuit.



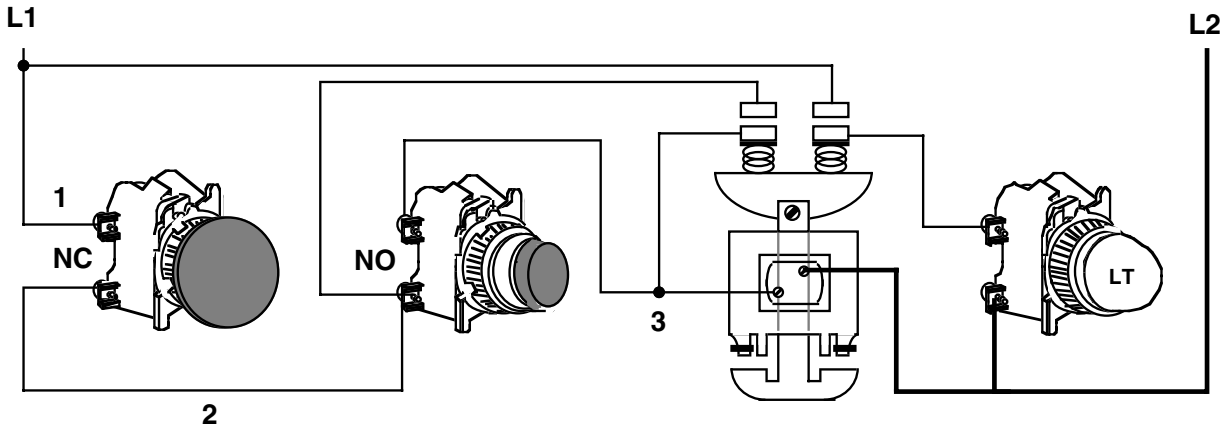


Shown below is a "holding circuit". R1 normally open contact has been connected in parallel with the start button so when the start button is released R1 coil is **held** energized through the R1 NO contact.

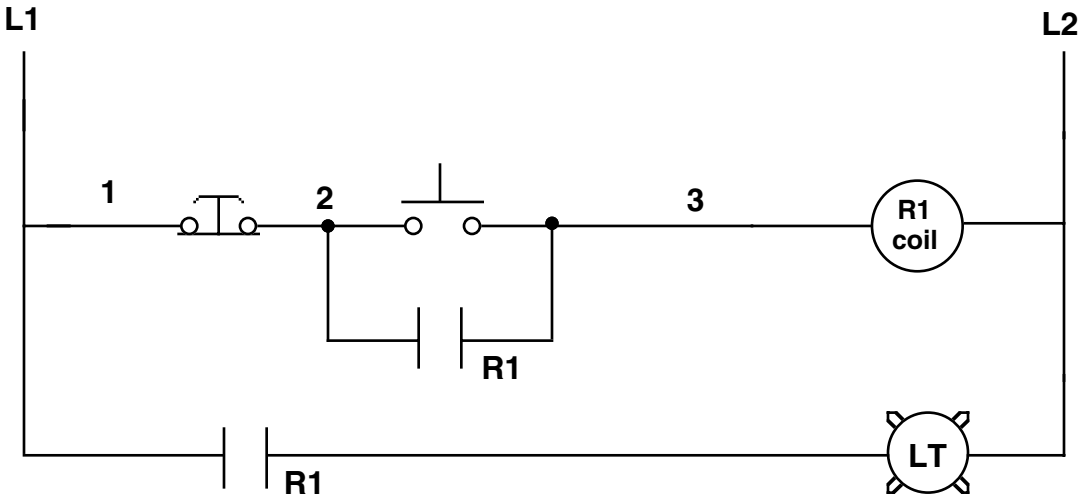




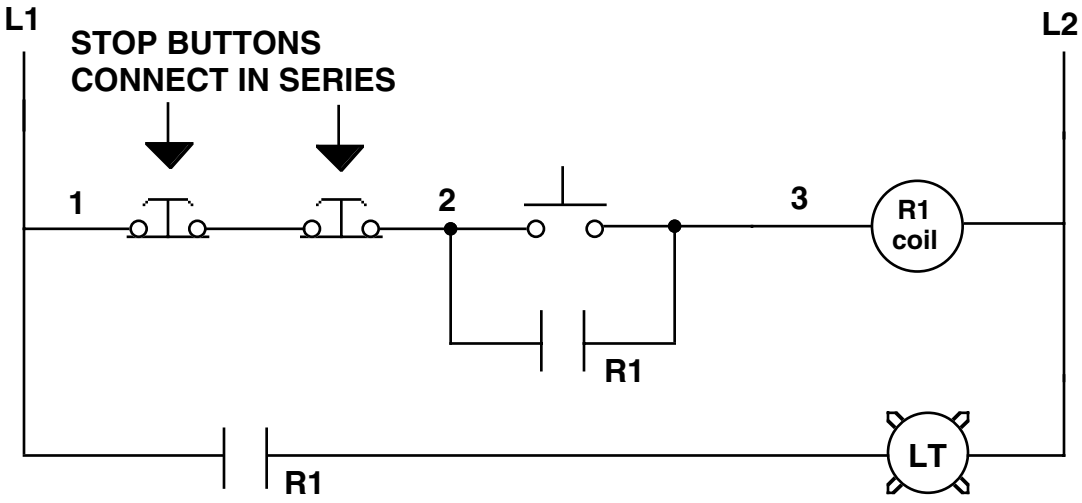
Shown below is a main wiring diagram showing the connections of stop-start push buttons controlling a relay with a light for a load.



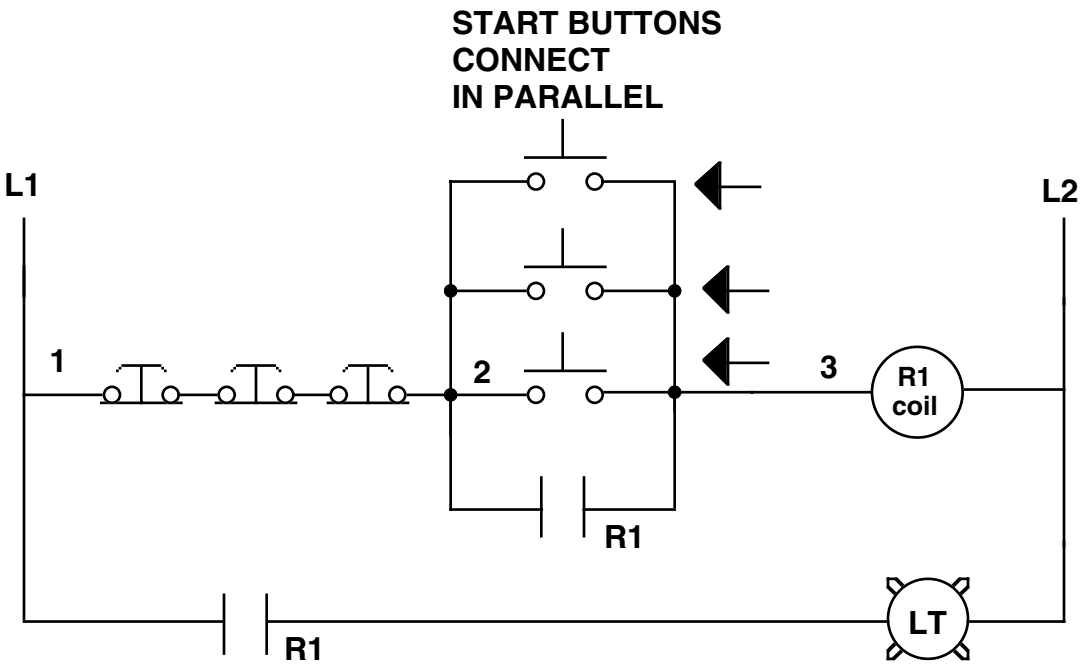
Shown below is the same circuit in a much easier to follow schematic diagram.



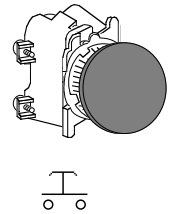
The light can be shut off from two different places by adding another stop button and connecting it in **series**. You can add as many stops as necessary as long as they are connected in series in the circuit.



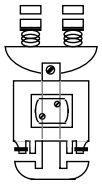
The circuit below shows the light can be turned on from three different locations and turned off from three locations. Start buttons connect in **parallel** as shown.

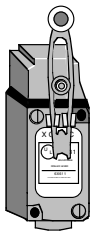


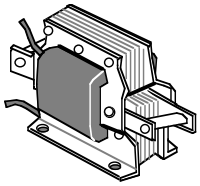
Shown below is an industrial machine with an air cylinder controlled electrically by push buttons, relays, limit switches and solenoids.



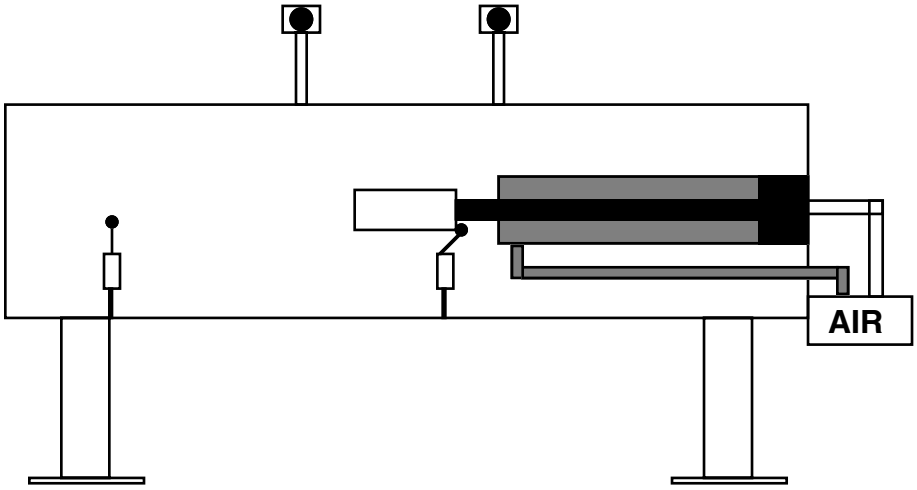
mushroom head
push button



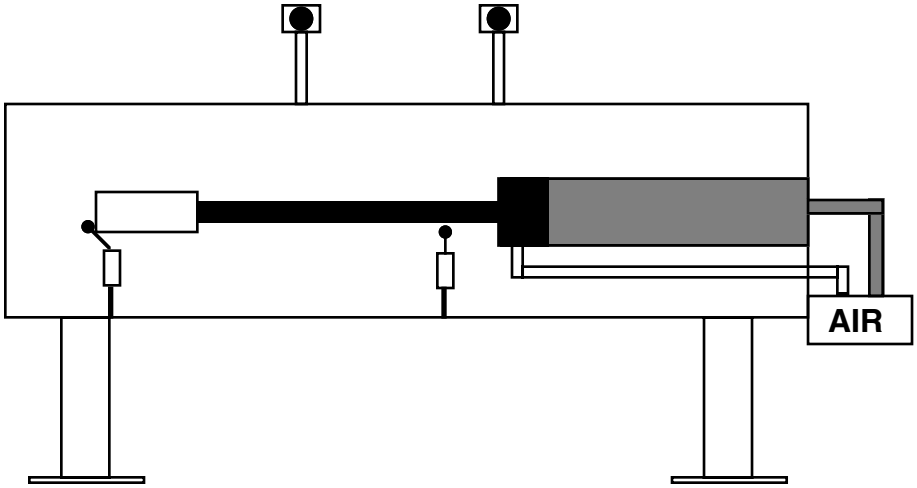


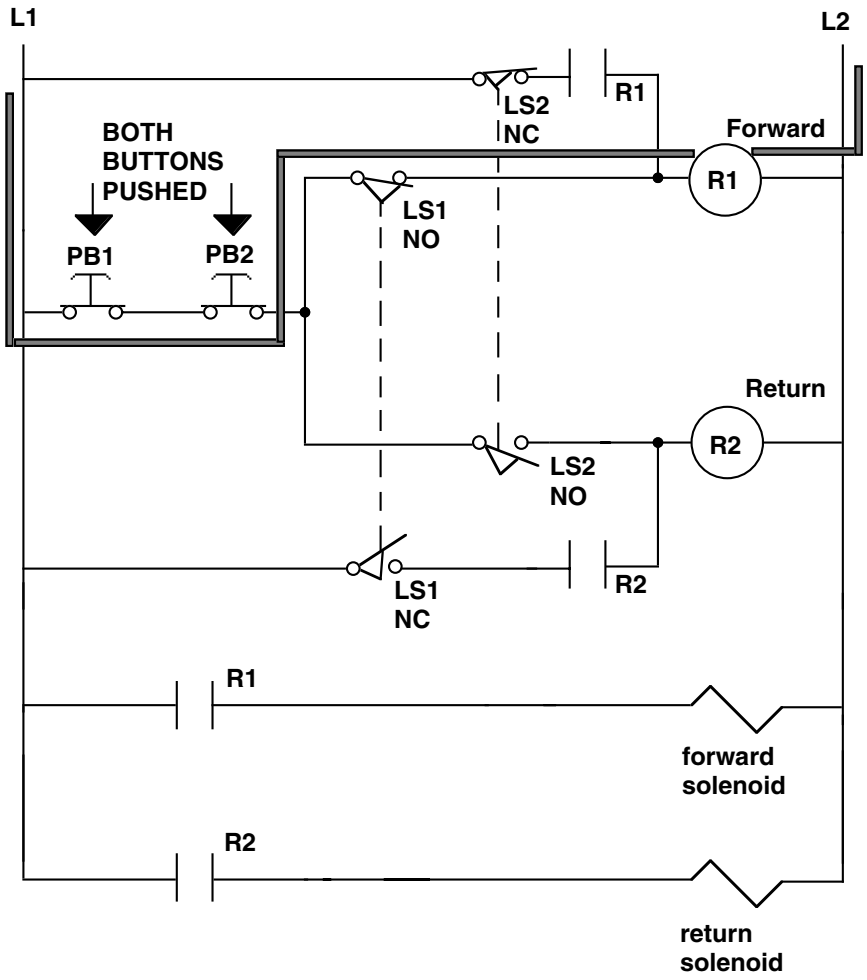


Industrial machine with air cylinder controlled by push buttons

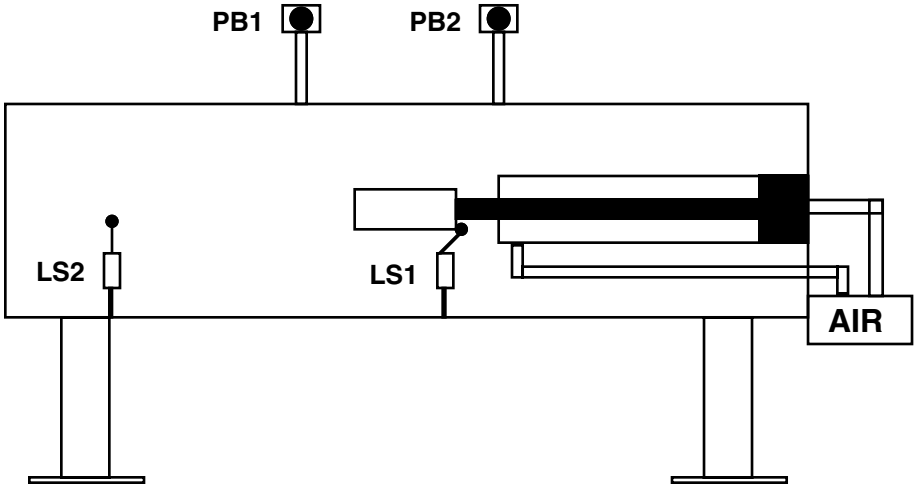


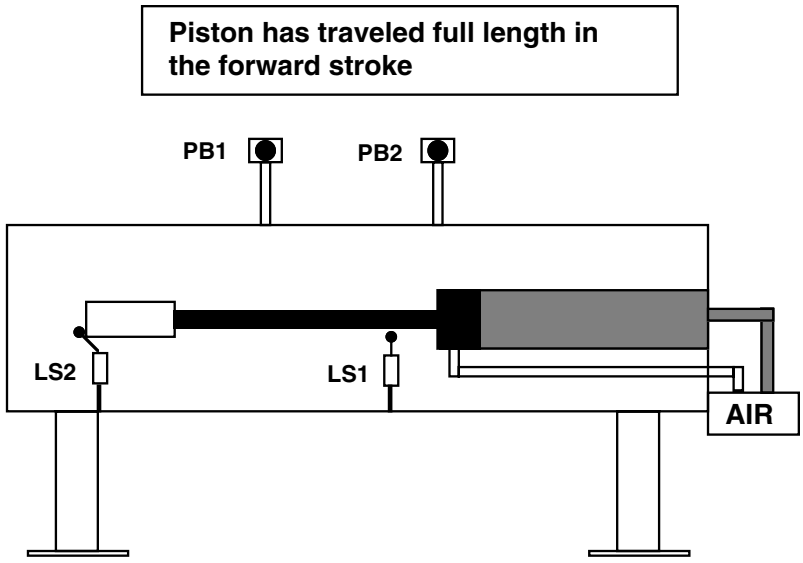
Piston has traveled full length in the forward stroke



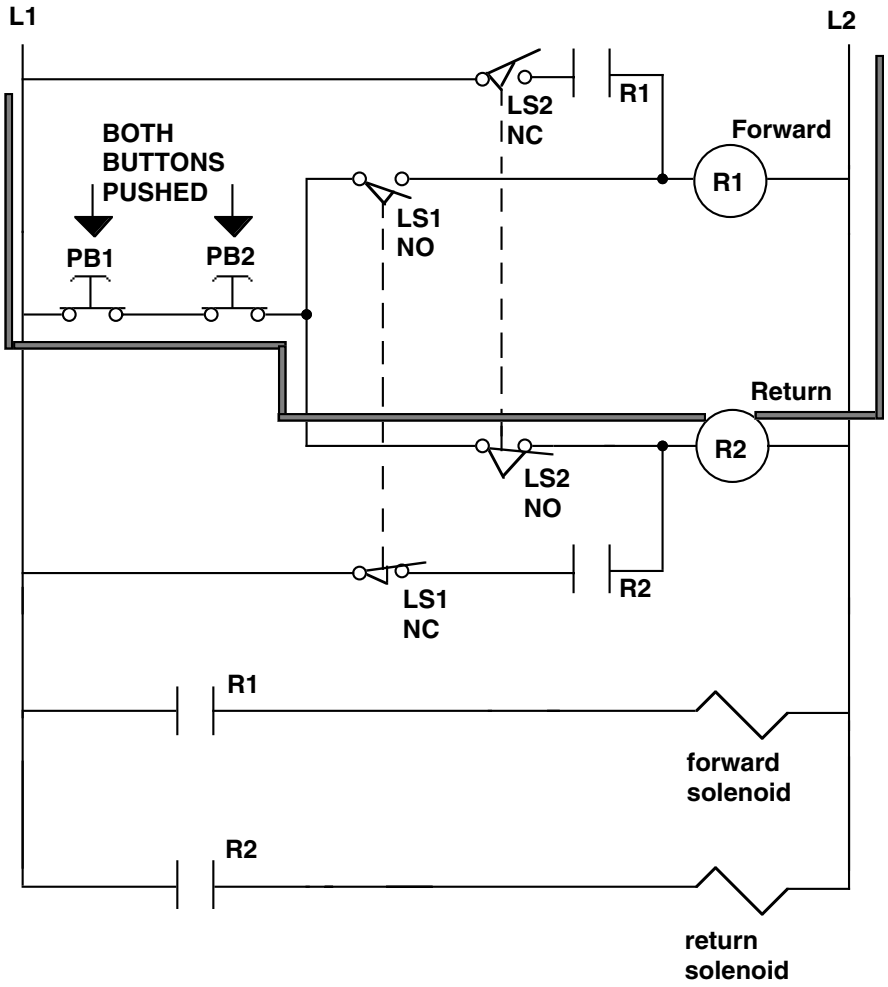


The air cylinder is in the NORMAL position with cylinder returned. LS1 NO contact is being HELD closed by the ram and LS1 NC contact is being HELD open by the ram.

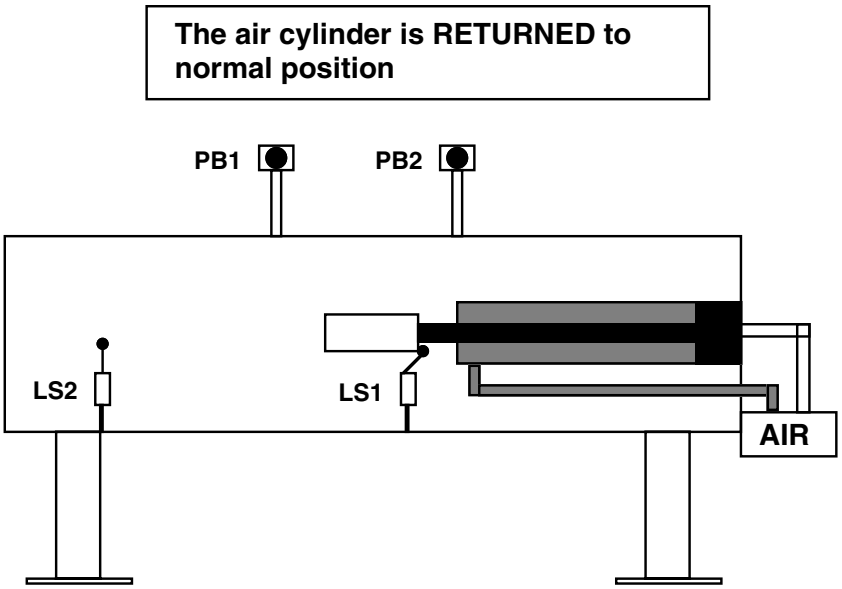


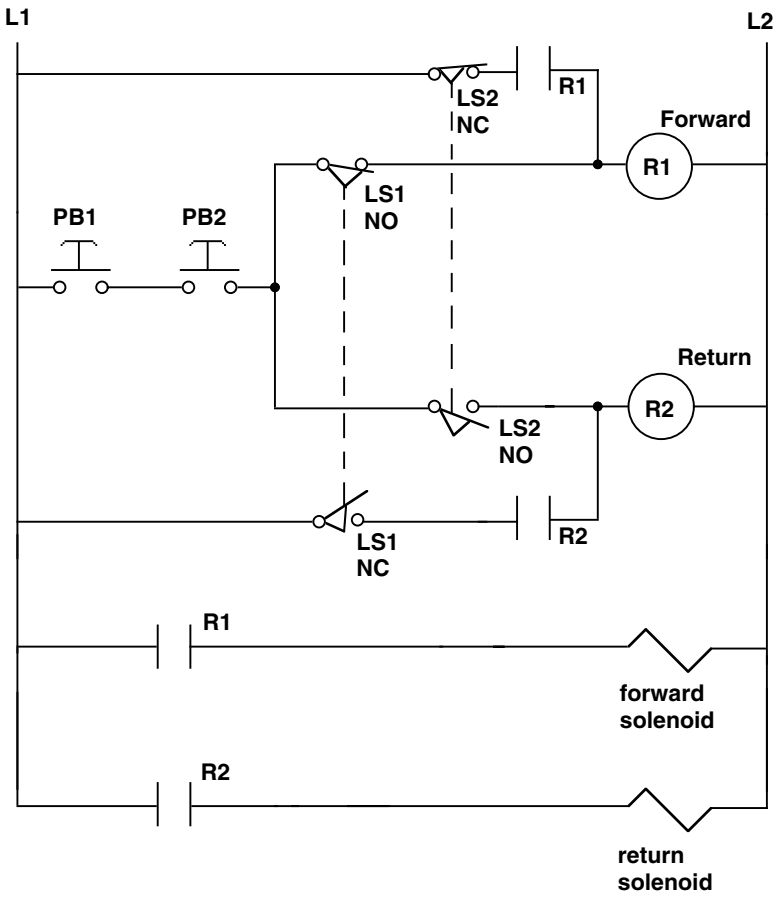


When the cylinder reaches its full stroke it makes contact with LS2 and **closes** the normally open contact which sets up the circuit for return by pressing both push buttons. R2 coil has a holding circuit through LS1 NC and R2 NO.



When the cylinder makes contact with LS1 it opens the LS1 NC contact which de-energizes R2 relay coil. When the cylinder makes contact with LS1 it also closes the LS1 NO contact which sets up the sequence of the machine for the next forward stroke.





The circuit below has two push buttons connected in series so that **both** hands must be out of the machinery before the solenoid to an air valve can be energized. Both limit switches have a NO and a NC set of contacts. LS1 NO is **held** closed and LS1 NC is **held** open in the normal position of the air cylinder. When both push buttons are pressed R1 relay is energized through the LS1 NO contact, R1 relay has a holding circuit through LS2 NC and R1 NO. When the air cylinder reaches its full stroke it will open LS2 NC and will de-energize R1 coil. LS1 NO is open and LS1 NC is closed with the air cylinder is this position. To **return** the air cylinder, press both push buttons and R2 relay is energized through LS2 NO contact, R2 relay has a holding circuit through LS1 NC and R2 NO. When the air cylinder returns to the normal position it will open LS1 NC and de-energize R2 coil.