Control System Components

What is in this lesson?

1. How to identify typical components found in an electrical control system
2. The electrical diagram symbols used to identify typical control system components
3. The operation of common components found in an electrical control system
4. The differences between overcurrent and overload protection

Key Words

- Auxiliary contacts
- Float switch
- Fuse
- Motor starters
- Overcurrent protection
- Overload protection
- Three-phase power

Control System Components

Introduction

Overview

As was discussed in the previous lesson, the electrical system in water and wastewater utilities can be divided into three basic segments: the source power, the internal power system, and the control system. The previous lessons dealt with the source power and the power system. This lesson will concentrate on the common components found in the control system.

Transformer

Introduction

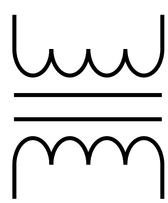
Transformers were discussed in depth in the previous lesson. More information can be found in the lesson on power system components.

Description/Function

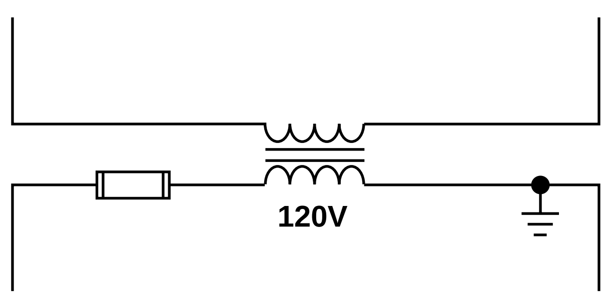
The transformers used on the control system are normally step-down transformers. They are used to step the voltage down from the line voltage (440, 460 or 480, 600 and 4,170 volts are typical line voltages) to the control circuit voltage. Normal control circuit voltage in an AC system is 120 volts. Used in this way, the transformer is called a control power transformer or CPT.

Symbol

The common symbol used to identify a control power transformer is shown below:

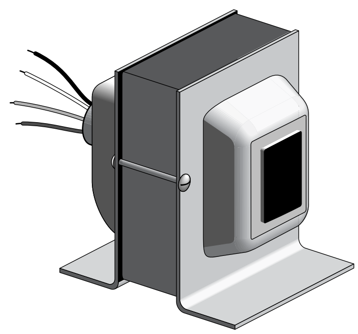


In a control diagram the transformer might look like this:

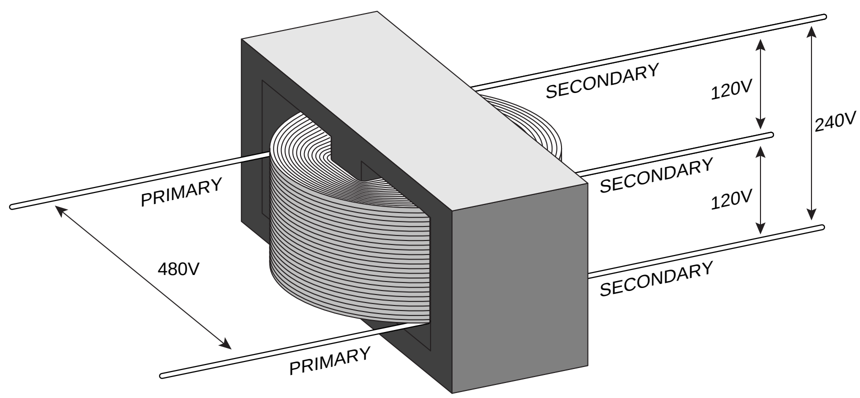


Components

The normal control power transformer is an iron core transformer. At the center of the transformer is a laminated core. The primary windings are wrapped around the center bar of the core and they are overlaid with the secondary windings. The windings are then covered with an insulating material. Some control power transformers provide more than one secondary voltage. To provide this second voltage there is a third connection to the secondary windings. This third connection is usually half way between the two ends of the winding. Thus, it is called a center tap. Typical output voltages for this type of transformer are 240 volts end-to-end and 120 volts between one end and the center tap.



Standard CPT
Control Power Transformer



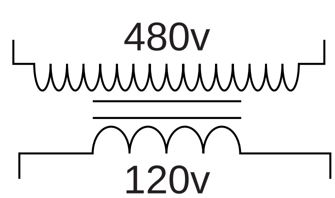
Operation

When alternating current is applied to the primary coil of the transformer, magnetic lines of force are produced through the laminated core and in the air immediately around the transformer. As these lines of force expand and contract they cut through the secondary windings, inducing a current in the secondary.

Turns Ratio

The difference between the primary and secondary voltages is determined by the ratio of primary and secondary windings. For example, the turn ratio for a 480 volt to 120 volt step down transformer would be 4:1.

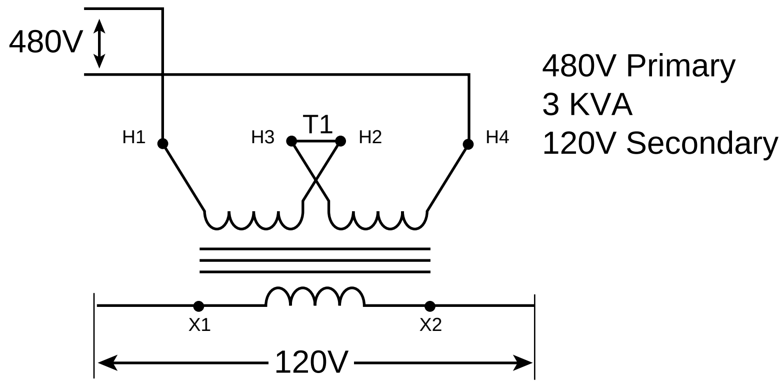
$$\text{Turns Ratio} = \frac{480v}{120v} = 4$$



Special Considerations

KVA Rating

In reviewing the drawing below, note the control power transformer is labeled 480v to 120v and 3KVA. The voltages are the primary and secondary voltages; the 3KVA is read as 3 kilovolt amps, which is the same as 3,000 volt amps. A volt amp is the same as a watt, if the power factor is 1.0. Therefore, this transformer is a 3,000 watt power transformer. That is, it will transfer 3,000 watts from the primary to the secondary, minus the losses in the transformer.



Primary Amperage

With the KVA rating and the voltage applied to the primary windings, the maximum input amperage can be calculated. The amperage in the primary is calculated as:

P = V X A

$$A = \frac{3{,}000 \text{ watts}}{480V} = 6.25 \text{ amps}$$

This is the maximum amperage that the primary windings will handle without breaking down the insulation and shorting out.

Secondary Amperage

The maximum amperage in the secondary windings can be calculated one of two ways. First, it can be calculated in the same manner as the primary amperage:

P = V x A

$$A = \frac{3{,}000 \text{ watts}}{120V} = 25 \text{ amps}$$

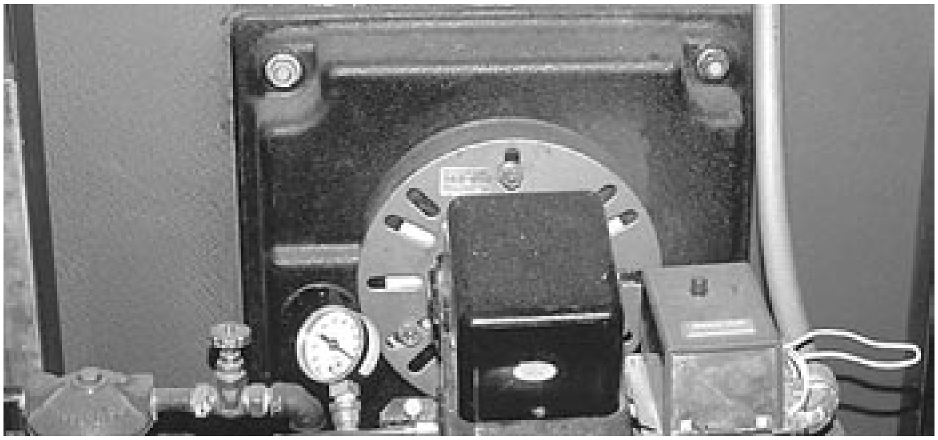
Or the amperage could be calculated using the turns ratio. In this example the turns ratio is 4:1. This is a step down transformer, meaning that the voltage is stepped down and the amperage is stepped up. Therefore, the amperage can be calculated as:

(Primary amperage) X Turns ratio = Secondary amperage

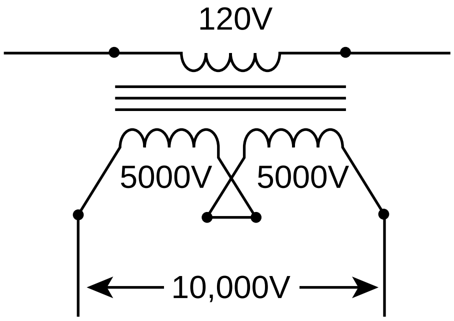
6.25 amps X 4 = 25 amps

Boiler Transformers

Oil-fired boilers utilize a step up transformer in order to obtain sufficient voltage to fire the boiler. The primary side of the transformer is 120 volts. The secondary winding is center tapped. The center tap is grounded to the transformer case. The voltage between ground and either end of the secondary windings is 5,000 volts. Therefore, the voltage across the transformer is 10,000 volts. This voltage is applied to the electrodes in the burner and is sufficient to ignite the burner oil.



A symbol for a boiler transformer is shown below.



Overcurrent Protection

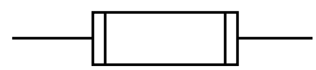
Fuses

Description/Function

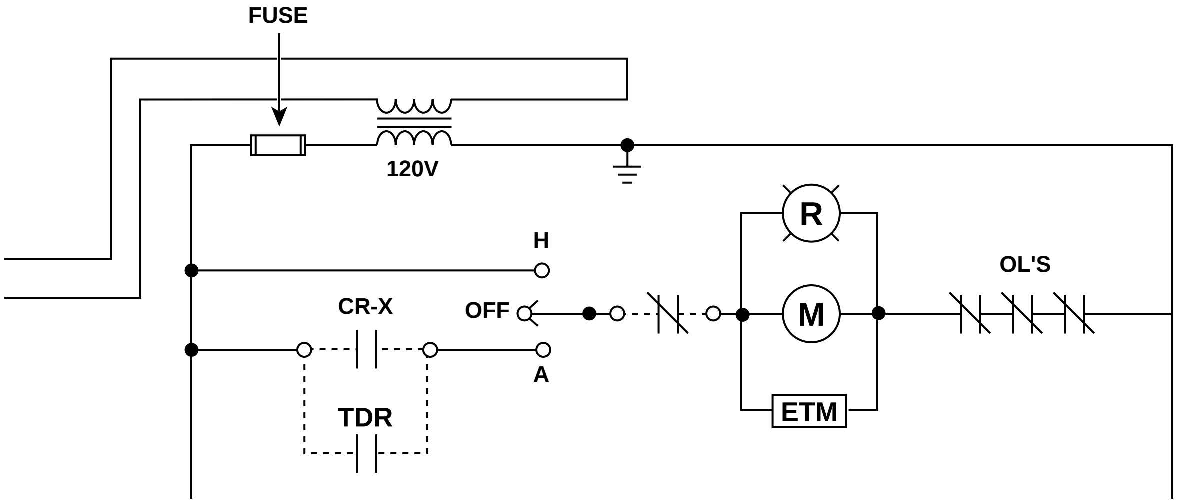
In the control circuit, overcurrent protection[1] (high current draw and/or a short circuit) is provided by either fuses or magnetic breakers. When fuses are used they can be placed on the primary or secondary windings. In some cases both primary leads are fused, and in a few cases the primary and secondary windings are fused.

Symbol

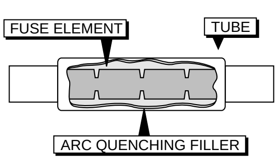
The following is the common symbol used to identify a fuse[2] in an electrical drawing:



In the drawing below the control power circuit is protected by fuses.



Components



The most common fuses used for control power and overcurrent protection are the "cartridge" fuses. These are low voltage, non-time delay, single element, type H or K fuses. (More discussion on fuse types is found in the power system lesson). This type of fuse has a center element is made of a melting alloy and divided into two or three sections. This element is encased in a round tube that is filled with an arc-quenching powder or granules. A metal cap or ferrule is placed on each end of the fuse and connected to the element.

[1] **Overcurrent protection** - The protection of electric devices with the use of fuses and magnetic breakers.

[2] **Fuse** - An overcurrent protective device. A fuse has a fusible (meltable) link that is severed due to heat that results from an overcurrent condition.

Operation

When a high amperage exists for a predetermined time, one of the fuse elements melts at one of the sections. When a short to ground occurs, several of the sections will melt instantly.

Special Considerations

One of the major operational problems with the use of fuses is the difficulty in determining that a fuse has failed. Most of the time there are no visual clues.

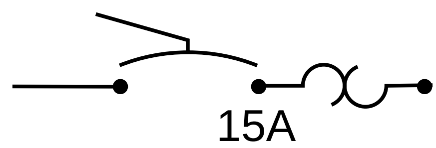
Breakers

Description/Function

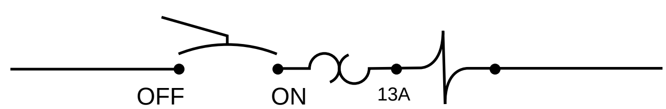
Breakers, like fuses, provide overcurrent protection for the control circuit. The breaker is usually wired into the primary side of the transformer and may be part of several breakers used to provide protection to other electrical components in the pumping installation.

Symbol

A common symbol used to identify a magnetic breaker in a control circuit is shown below:

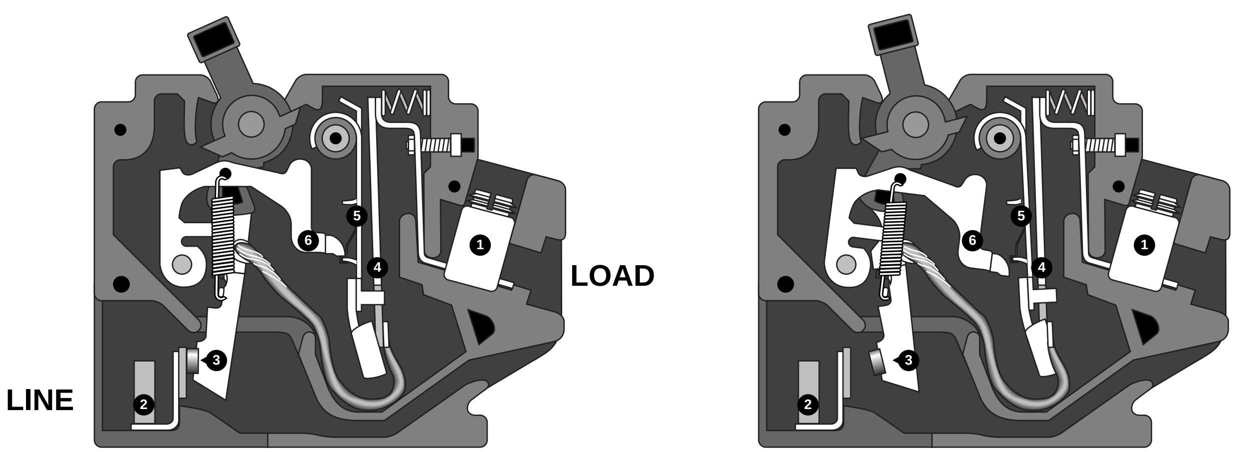


In a control circuit diagram, the breaker may appear as it does below:



Components

The small breaker shown below is very similar to the one used in the electrical control panel in a house. This type of breaker has two electrical connections (1 & 2). An electromagnet (4), a trip lever (6) resting on a ledge that is connected to a movable bar (5), and a set



In operation

Tripped

of contacts (3) held in place by a trip mechanism which is connected to a lever that extends out of the enclosure. The entire unit, except for the operating lever, is encased in a plastic material.

Operation

In order to allow power to pass through the breaker, the operating lever is placed in the “ON” position. This mechanically closes the contacts (3) in the breaker. When current passes through this device, a magnetic field is developed in the bar (4). The intensity of this field is focused through a large piece of metal at the end of the movable arm (5). When the current exceeds a predetermined amount, the magnetic field will pull the bar (5) to the right, releasing the lever (6) and the trip mechanism, allowing the spring to pull the contacts (3) open. This will disconnect power to the control circuit. To reset the breaker, it must first be placed in the “OFF” position and then returned to the “ON” position.

Special Considerations

Breakers are rated in amps. The maximum, normal operating amps that the breaker will allow to pass is written on the end of the control lever.

Switches

Introduction

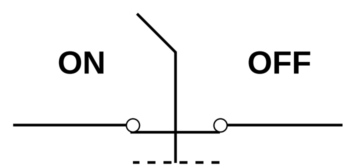
There are a wide variety of switches used in the electrical industry. In this section only those switches commonly used in water and wastewater pumping installations will be discussed.

On - Off

Description/Function

ON/OFF switches are also called supplementary contact switches. This switch appears as a vertical lever on the control panel. When the switch is operated it remains in position until it is physically moved. This type of switch is called a single pole, single throw switch, (SPST) and has the following symbol:

Symbol

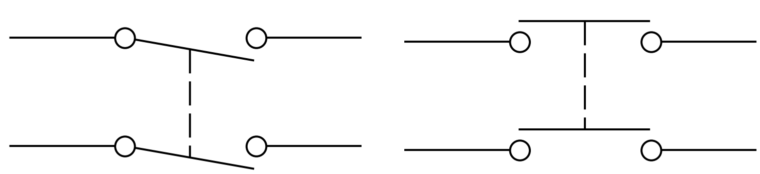


DPST

In some instances a switch contains two sets of contacts. They are both located at the back of the same switch and are operated by the same lever. This type of switch is called a double pole, single throw switch (DPST).

Symbol

In the symbol for the DPST switch, notice there is a dotted line running from the top switch set to the bottom. This type of dotted line indicates the two switches are physically connected together. The moving of one switch will move the second switch.



H-O-A

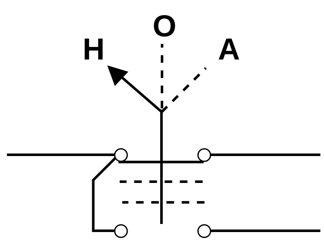
Description/Function

The hand-off-auto switch (H-O-A) is actually a SPDT (single pole, double throw) switch. This switch has three positions, hand, off, and auto. In some instances the labels may be changed to Local-off-Remote. The switch looks almost identical to the ON/OFF switch. The switch stays in whatever position it is set until it is physically changed.

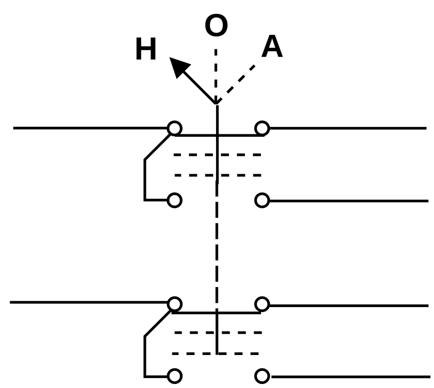
Symbol

There are two common H-O-A switches used in pumping installations: single-gang and the multi-gang switch. Notice, in the multi-gang symbol that there is a dotted line between the top and bottom switch. This indicates the two switches are physically in one housing. Moving the switch lever changes the position of both switches. With the H-O-A switch, the left position is normally the Hand, the center position is Off and the right position is Auto.

Below are examples of the single-gang and multi-gang H-O-A switches:



Single-gang



Multi-gang

Momentary Contact

Description/Function

A switch commonly used with the “push-to-start” circuit is the momentary contact switch. This switch only operates when the button is depressed.

Operation

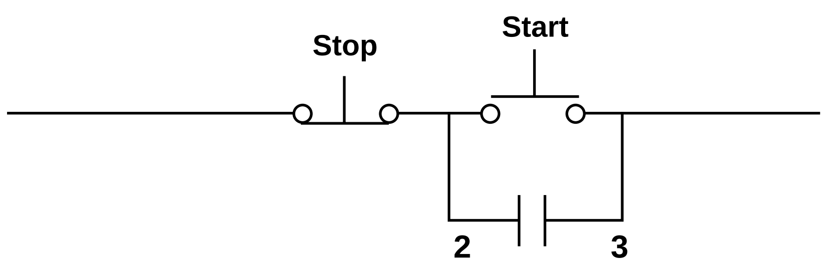
There are two basic styles of this switch: normally open (N.O.) and normally closed (N.C.). With the normally open momentary contact switch, electrical contact is only made when the push button is depressed. In a control circuit, such as the “push-to-start” circuit, the push button is labeled the START button.

The normally closed switch is opened when the button is depressed. In a control circuit this button is usually called the STOP button.

Symbol

The following are the two symbols used for momentary contact switches:

Below is an example of N.O. and N.C. momentary contact switches installed in a circuit:



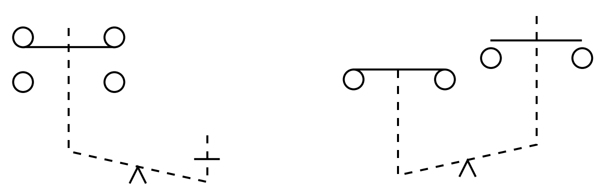
Maintained Contact

Description/Function

Rather than using the momentary contact on-off switch in a circuit, the designer may choose the maintained contact push button switch. This is a single push button that looks like the momentary contact switch.

Symbol

The diagram below is used to identify the maintained contact switch:



One Double Contact   Two Single Contact

Operation

When the button is depressed, the circuit is closed and current flows. To turn the circuit off or open the circuit, the button is pressed a second time and then released. This opens the contacts and opens the circuit.

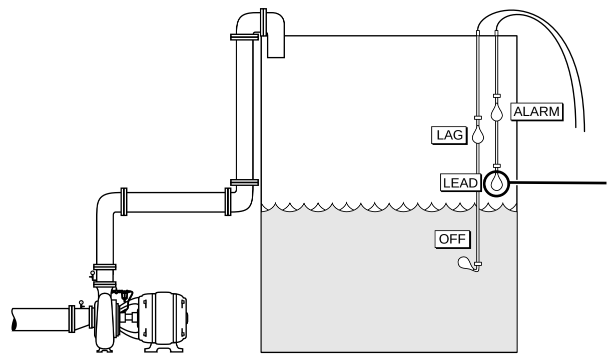
Floats

Description / Function

There are three types of float switches used in pumping systems. Floats are used to turn pumps on, and off, as emergency alarms, or shut downs.

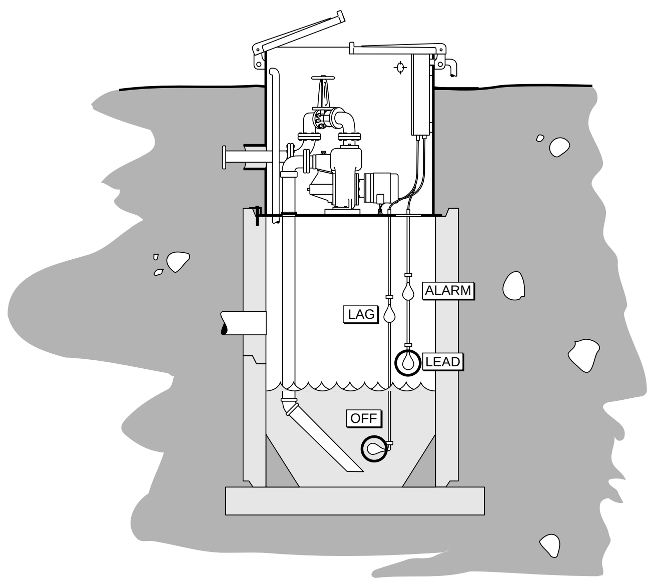
A float used to turn a pump on or off in a water reservoir is the mechanical lever operated float switch[3].

Storage tank with floats for level control



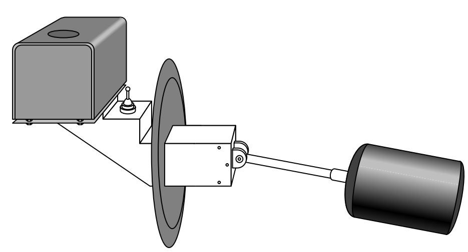
In wastewater lift stations and some drinking water reservoirs the mercury float is often used.

Lift station with floats for level control



A simple lever operated float switch can be installed in the water jacket of a low pressure boiler or hydro pneumatic tank to shut down the system when there is a loss of water.

Float switch for low pressure boiler or hydropneumatic tank

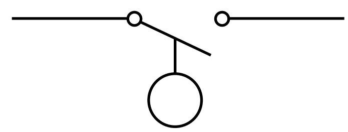


3 **Float switch** - A switch that is operated by a physical float and is responsive to water level.

Float switches are available with either normally open or normally closed contacts.

Symbol

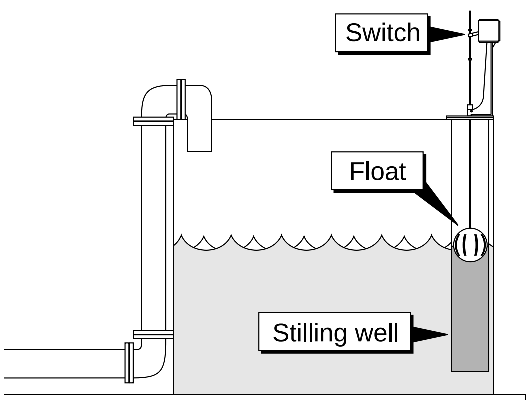
The same symbol is used to identify all three of these float switches:

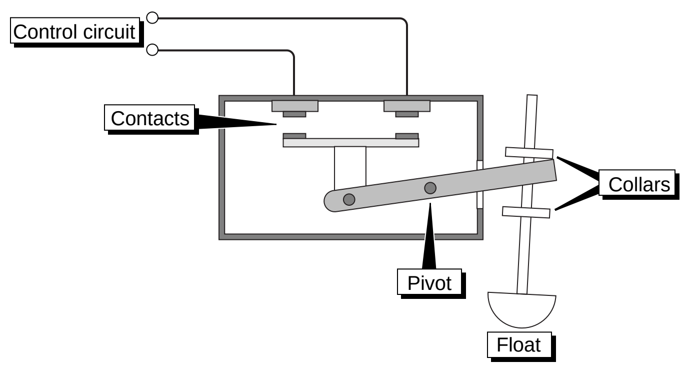


Normally Open Float Switch

Operation - Mechanical

The mechanical float uses a copper or plastic float attached to a rod. The rod passes through a holding bracket. The vertical movement of the rod is restricted by collars above and below the holder. These same collars are used to operate a lever that is attached to a set of contacts. As the float moves up and down, the lever is moved, opening or closing the contacts.



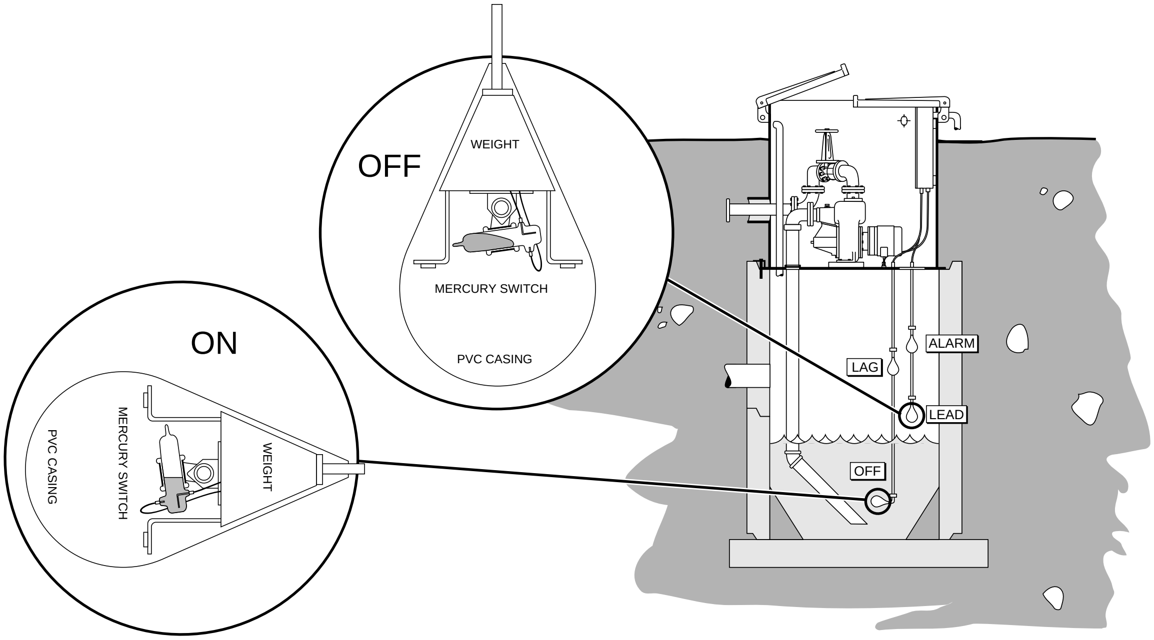


Operation - Lever

The lever float switch is composed of a small metal float on the end of a shaft. The shaft slides through a opening in a lever. The other end of the lever is connected to a set of contacts. As the float is raised or lowered by water level, the switch is opened or closed by the collars attached to the float shaft. The distance between the collars determines the water level differential.

Operation - Mercury

The heart of the mercury float switch is a vial, usually made of glass, with two contacts and a puddle of mercury. The vial is encased with a very dense foam material which is covered with a waterproof plastic case. A weight is usually placed at the top of the float. With a normally open float switch the electrodes are at the top of the glass vial. When the water level rises, the float tips sideways and the mercury runs across the electrodes, making connection. With a normally closed float, the electrodes are in the bottom of the vial. Tipping the float causes the mercury to run away from the electrodes, opening the circuit.



Special Considerations

Mercury float switches are one of the most common sewage lift station controls. In a normal two pump lift station there are four floats. The bottom float is the pump off float, the second float is the lead pump on float, the third is the lag pump on, and the fourth float is the high level alarm float.

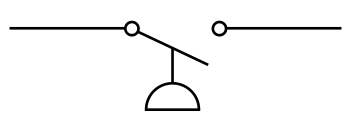
Pressure Switch

Description/Function

In many instances, it is desirable to turn pumps on or off based on system pressure. It may also be desirable to prevent a pump from coming on if the suction pressure drops below a certain level or if the discharge pressure goes above a predetermined level. Pressure switches are used for this purpose.There are three common pressure switches: the diaphragm, the metal bellows, and the piston operated hydraulic switch. The diaphragm pressure switches are used for low pressure, below 250 psi; the metal bellows in pressure conditions up to 2,000 psi; and the piston operated hydraulic switches in pressure conditions up to 15,000 psi. Because low pressure diaphragm switches are the common pressure switch used in pumping installations, only their operation will be discussed.

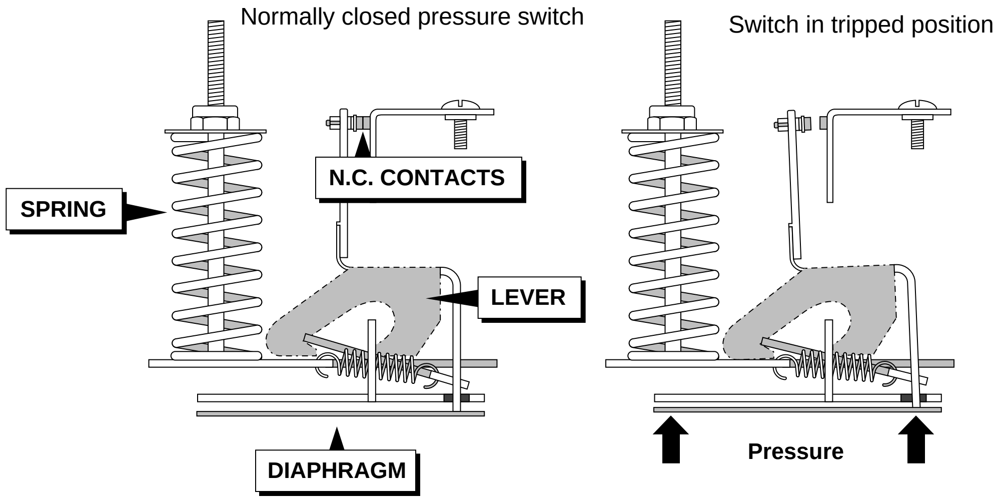
Symbol

The symbol for a pressure operated switch is shown below.



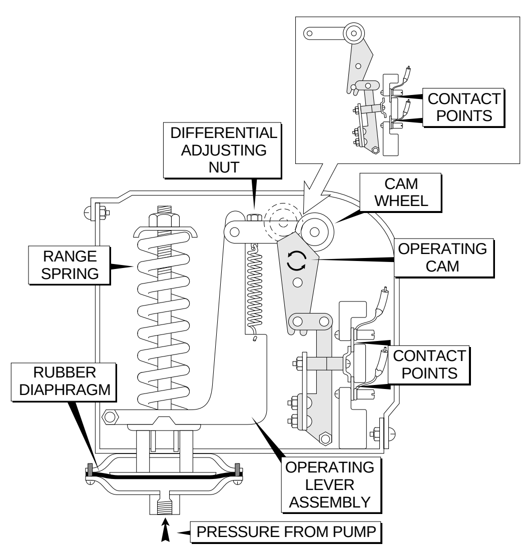
Components

The diaphragm pressure switch uses a flexible, rubber like diaphragm to sense the water pressure, a spring to hold the contacts in their normal position, and one or more sets of contacts.



Operation

Pressure switch contacts can be N.O. or N.C.; the following explanation uses the N.C. switch shown above. When the pressure below the diaphragm increases the upward force sufficiently to overcome the spring tension, the diaphragm is raised up causing the lever to rotate to the left, opening the contacts. When the pressure on the diaphragm drops sufficiently for the spring tension to overcome its upward force the contacts are closed. This type of pressure switch could be used to turn on a pump when the system pressure drops below a set point and turn the pump off when the pressure exceeds a set point.



Special Considerations

A common installation for this type of pressure switch is a small groundwater system that uses a hydropneumatic tank. This pressure switch is installed between the pump and the tank and is used to turn the well pump on and off. The switch shown on the bottom of page 202 contains two controls, low pressure and differential pressure. It would turn the pump on when the pressure dropped below a set pressure and turn it off when the pressure rises above a set value. This upper value is controlled by the differential pressure adjustment.

Mercroid Switch

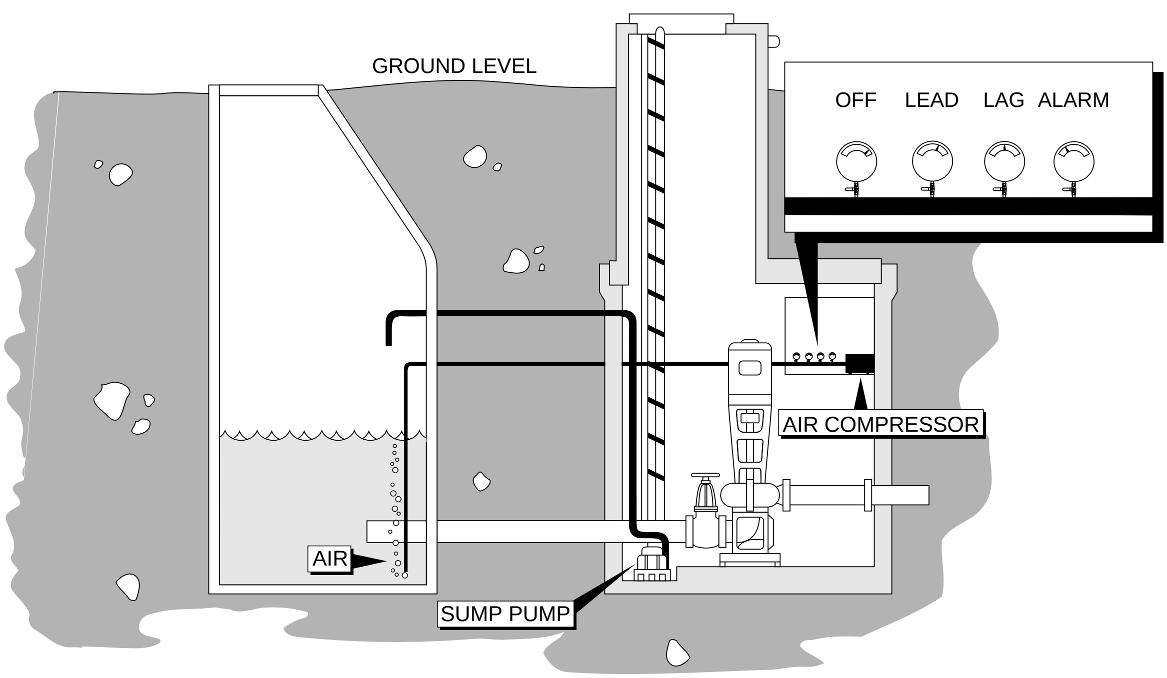
Description/Function

A second method used to turn pumps on and off based on pressure is the Mercroid switch. This switch utilizes a bourdon tube and a glass vial with two electrodes and a puddle of mercury. These switches are used to turn pumps on and off and perform fail safe functions such as sensing low or high pressure.

Bubbler System

Description/Function

A second, very common method used to control pumps in a sewage lift station is the bubbler system. This system forces air pressure through a small tube into the wet well of the lift station. The back pressure caused by water above the end of the tube is sensed by a group of pressure switches. These pressure switches are used to turn pumps on, off, and send a high water alarm.



Components

The most common bubbler systems use a small compressor, air filter, rotometer, air control valve, a manifold, four pressure switches, and a plastic or stainless steel tube in the wet well. Air supplied by the compressor is filtered to prevent damage to the pressure switches. The rotometer is used to indicate the rate of air flow. In some installations air is bubbled through a water-filled glass tube to indicate rate of air flow. The air is piped into a manifold in the electrical control panel. Four pressure switches are connected to the manifold. The pressure switches may be the single pressure diaphragm type or mercroid switches.

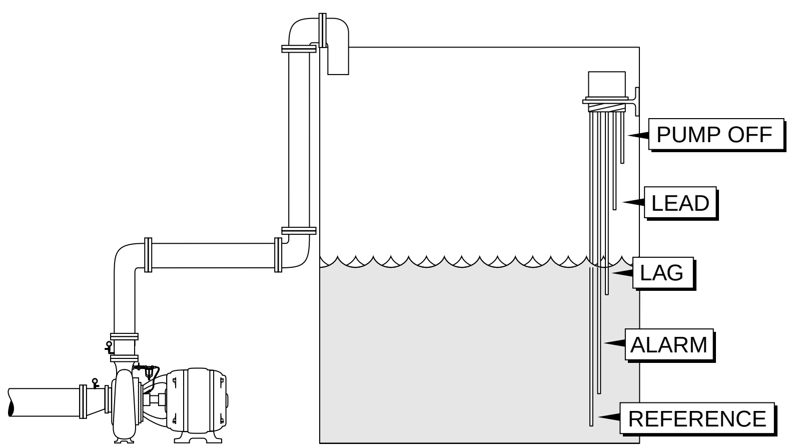
Operation

The pressure in the manifold is directly proportional to the height of water above the top of the bubbler tube in the wet well. This pressure is sensed by the pressure switches. The first switch is set at a low pressure and is used to turn the pumps off. The second switch is set at a slightly higher pressure and is used to turn on the lead pump. The third switch turns on the lag pump and the fourth switch turns on the high water alarm.

Electrode

Description/Function

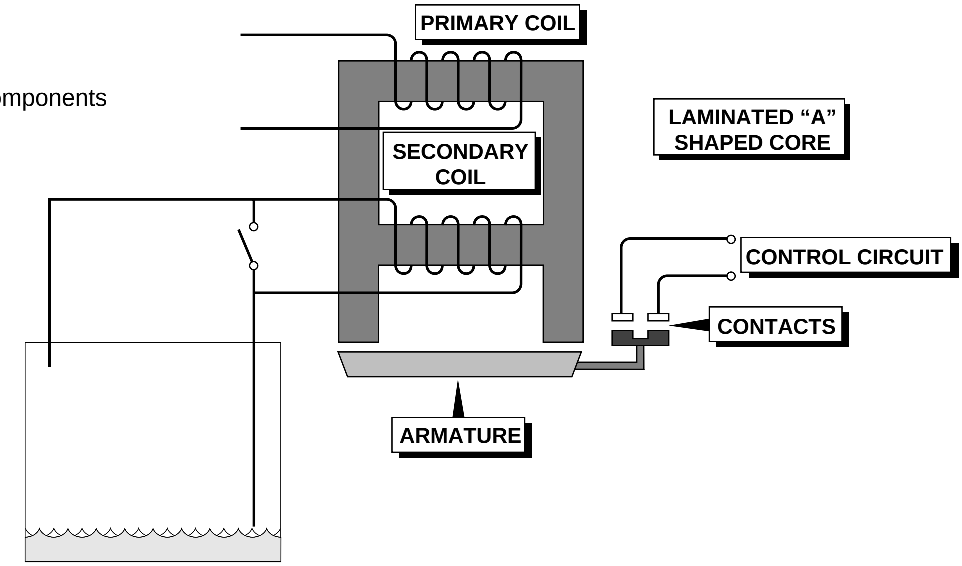
Another method used to turn pumps on and off is the electrode. This device is used in storage tanks and chemical tanks. Two to four electrodes of different lengths are placed in the tank. Water makes an electrical connection between the electrodes starting or stopping pumps and/or opening and closing valves.



Components - B/W Controls

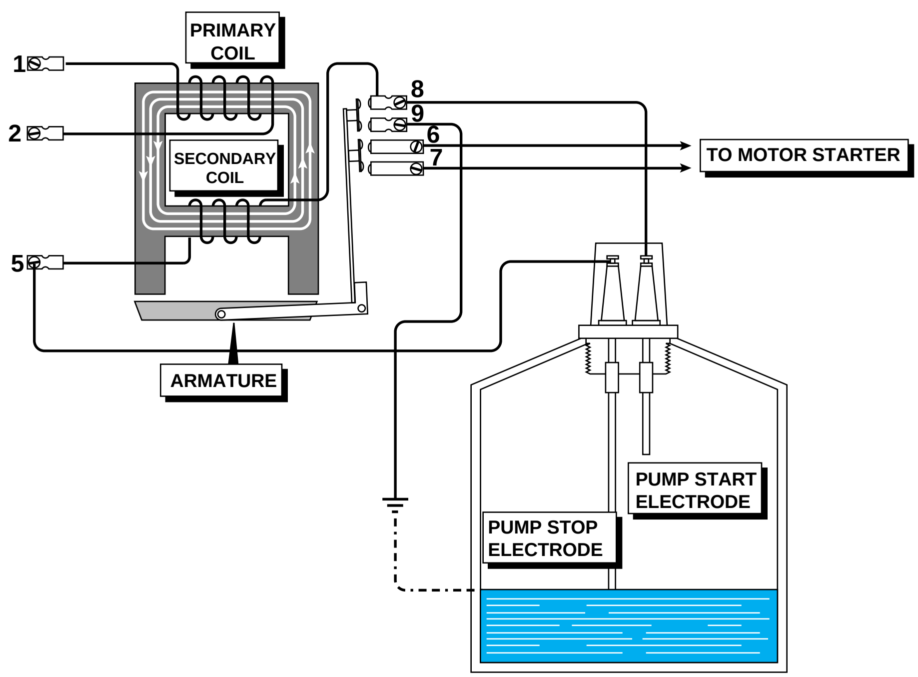
There are two popular electrode systems used to control water levels. One is the B/W Controls Inc. system and the other is the Warrick level control. The B/W Controls system uses an “A”-shaped laminated core coil, two sets of contacts, and two electrodes. One electrode is the pump on and the second is the pump off. This system is designed to be used with a metal tank. The ground is connected to the tank. When a nonmetallic tank is used, a third reference electrode that extends nearly to the bottom of the tank is used.

B/W Control Relay Components



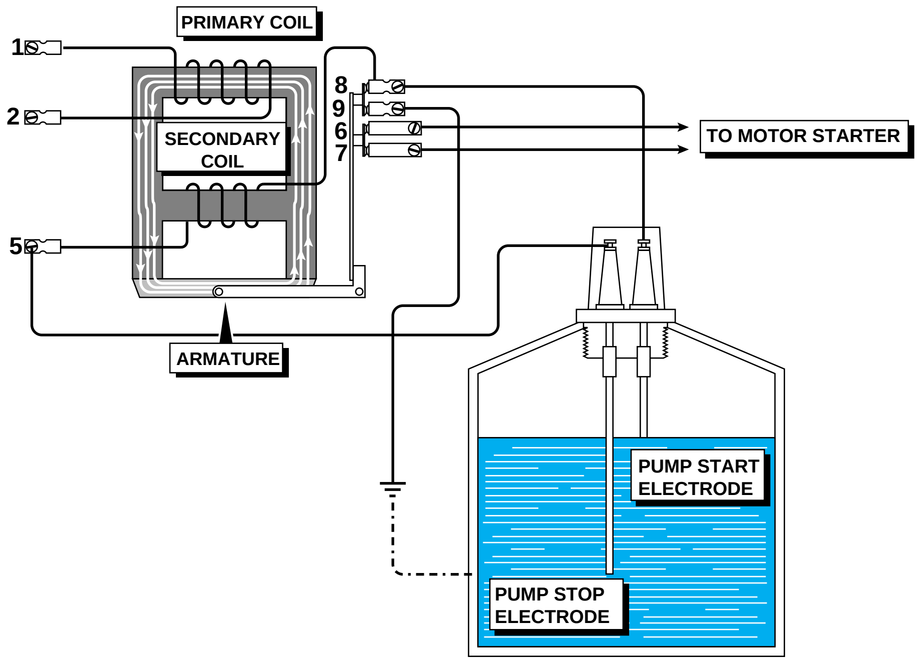
Operation - B/W Controls

AC power is applied to the primary windings of the relay. When power is applied, current flowing through the primary coil produces magnetic lines of flux. These lines of flux take the path of least resistance, through the bottom portion of the "A". This induces a current in the secondary coil. However, since the secondary coil is attached across the two electrodes, which are not connected, an open circuit exists and there is no current flow in the secondary coil.



When the water level rises so that there is a connection between the two electrodes, (pump start and pump stop electrodes) a current flows in the secondary coil. This current creates magnetic lines of flux in the lower part of the “A” that break the lines of flux created by the primary coil.

The result is the lines of flux in the laminated core are diverted into the legs of the “A” causing the armature of the coil to be lifted to the core. This closes the contacts at 8, 9, 6, and 7.



The closing of the contacts between 8 & 9 connects the circuit between the electrodes and ground. This is called a holding circuit and prevents the pump from shutting off until the water level is lowered below the off electrode.

Warrick Control

The Warrick controls use two to five electrodes. The most common in wastewater lift stations are the five electrode set-ups. These electrodes are the reference, pumps off, lead pump, lag pump, and high level alarm.

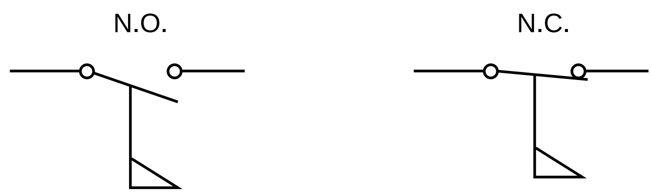
Flow Switch

Description/Function

In many pumping installations it is desirable to prevent a device from turning on if there is no flow in a line or to turn the pump off if flow in the line suddenly stops. To do this a flow switch is used. One of the common uses of a flow switch is in a small ground water system with a hypochlorite and/or a fluoride saturator feed system. In this instance, it is not desirable for the chemical feed pumps to operate if there is no flow from the well pump.

Symbol

The symbol used to identify a flow switch is shown below.



Two Types

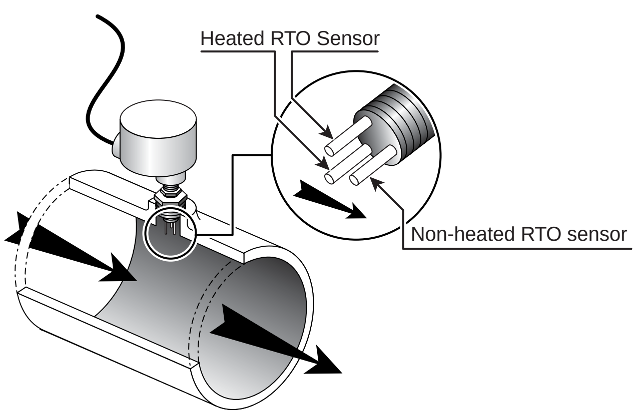
There are two common types of flow switches used in pumping system; RTD and paddle.

Paddle Type

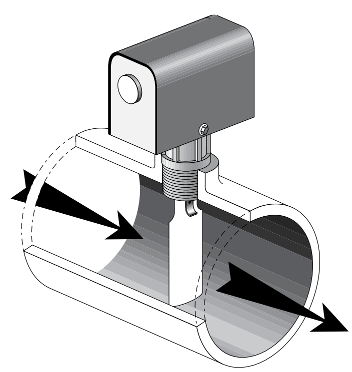
With the paddle type, a metal paddle is placed directly into the line. The upper end of the paddle is connected to a lever that opens or closes a set of contacts. When there is sufficient flow in the line, the paddle is moved forward, closing the contacts in the switch.

RTD

With the RTD (Resistance Temperature Device) two electrodes are heated. Flow past the heated electrodes reduces their temp. This drop in temperature and reduces the electrical potential between them and the unheated electrode indicating a flow.



RTD Type Flow Switch



Paddle Type Flow Switch

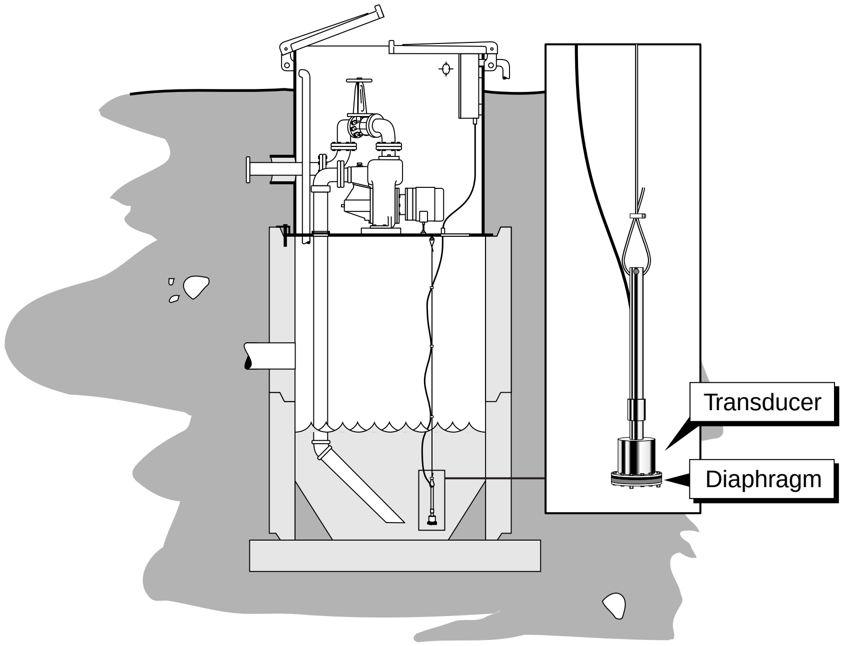
Operation - Feed Pumps

When the flow switch is installed with a chemical feed pump, it is wired to control power through the auxiliary contacts on the motor starter which are used to control power to the duplex plug used to supply power to the chemical feed pump. When the flow switch verifies flow power is applied to the duplex plug thus staring the chemical feed pump.

Transducer

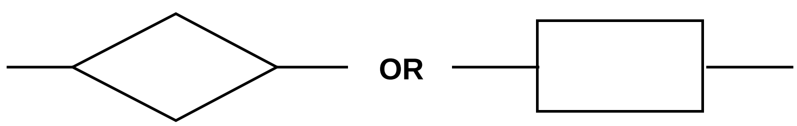
Description/Function

Transducers are electro-mechanical devices which convert physical quantities, such as pressure, to a proportional electrical value, such as voltage or current. Pressure transducers are very effective in detecting water level and are used to control pumps in wet wells.



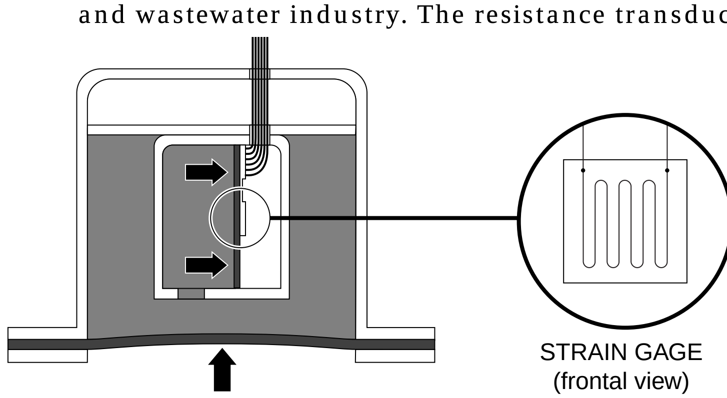
Symbol

The symbol used to identify a transducer is shown below:



Components

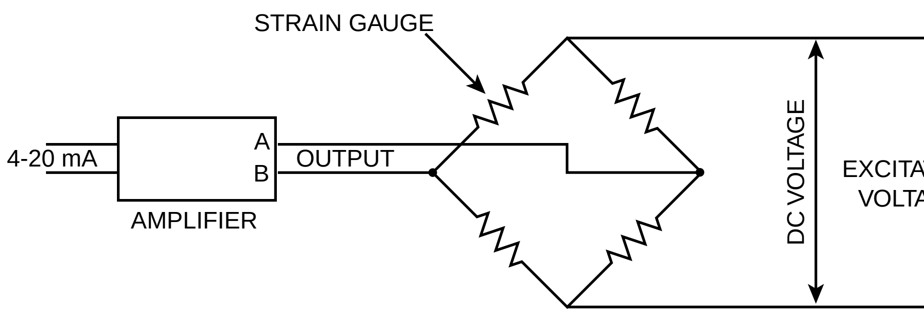
There are a wide variety of pressure transducers used to detect changes in pressure. The most common types are the inductance, capacitance, and resistance. The resistance type is the most common in the water and wastewater industry. The resistance transducer



uses a strain gauge. The strain gauge is wired into an electrical circuit and placed against a flexible diaphragm.

Operation

The strain gauge is made by placing a special wire onto a ceramic wafer. When the wafer is distorted by pressure, the length of the wire is increased and its cross-sectional area is reduced. The result is an increase in its resistance. The wire is placed into a special circuit called a wheatstone bridge. In the bridge all four resistors are the same exact value causing the voltage difference between points “A” and “B” to be zero. When the resistance of the strain gauge is changed, the voltage difference between points “A” and “B” is changed causing a current to flow between these two points. The current flow is directly proportional to the pressure applied to the gauge. The current flow is very small and requires an electronic amplifier to be used in order to provide a signal that is usable. Standard transducers produce a 4 to 20 mA signal.



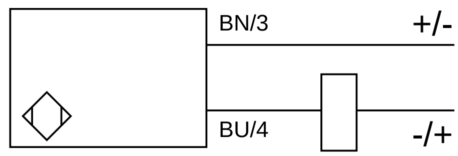
Proximity Sensor

Description/Function

Proximity sensors have no external arms or levers. When an object comes close (proximity) to the sensor, it opens or closes a set of contacts. The sensor may use inductance, capacitance, or a magnet in order to operate. Inductive and capacitance proximity sensors are solid state devices with no moving parts. They are used to detect the position of a valve positioner on a pump control valve or the position of the arm on a swing check valve. In this latter use, the sensor may be wired to shut down a pump if the check valve fails to open.

Symbol

The symbol used to identify a solid state inductance proximity sensor is shown below. Magnetically operated proximity sensors use the limit switch symbol.

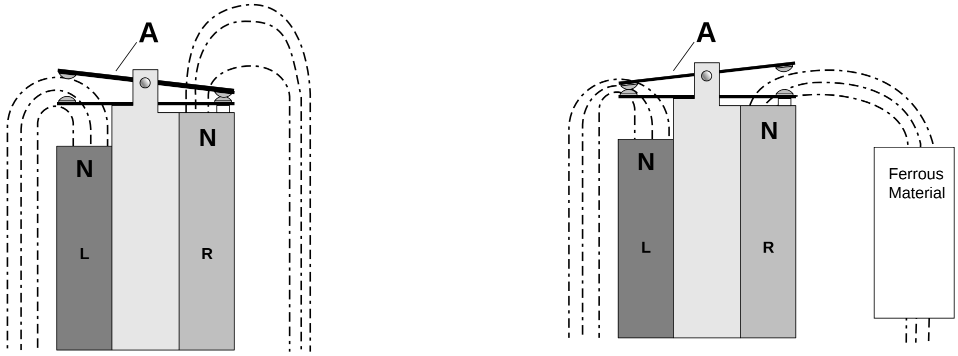


Components

The inductive proximity sensors used in the water and wastewater industry are solid state devices housed in a metal tube.

Operation

The operation of solid state devices is beyond the scope of this text. Therefore, a magnetically-operated, mechanical proximity sensor will be used to explain its operation. The magnetic sensor is composed of two magnets, (shown as “L” and “R” below), and a movable armature (A) all housed in a plastic case. The magnets are different lengths and the armature holds the contacts. Under normal conditions the “R” magnet holds the contacts just above it in a closed position. When a ferrous device is placed close to the “R” magnet, the lines of flux travel through the ferrous device, reducing their strength on the armature and allowing magnet “L” to switch the position of the contacts. Moving the ferrous device away from the sensor allows the contacts to return to their original position.



Normal Position

Actuated Position

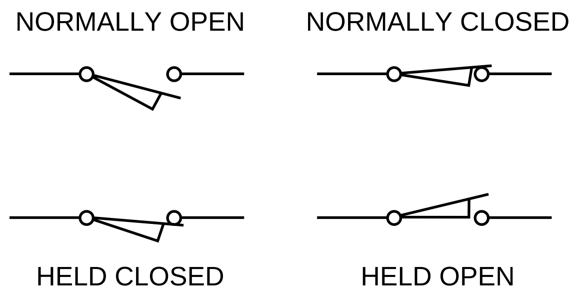
Limit Switch

Description/Function

One of the common uses of limit switches is with wide body globe valves used to control pressure surge from a pump. The limit switch is placed on top of the globe valve. The valve stem is used to turn the switch on or off and thus control when the pump shuts down.

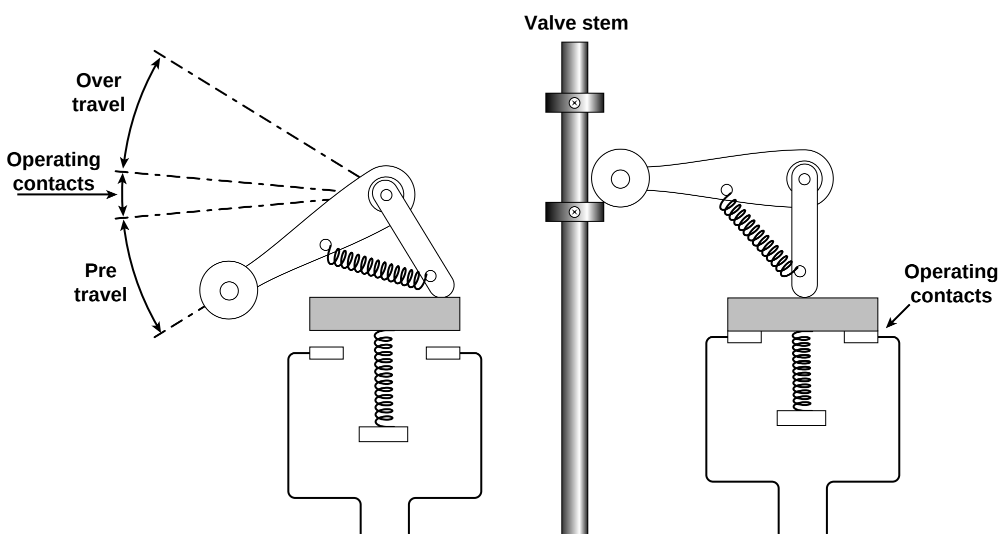
Symbol

The symbols used to identify mechanical limit switches are shown below:



Components

The mechanical limit switch uses an arm with a small wheel attached to the end. This wheel runs against a rod attached to the control valve diaphragm. A movable stop is attached to the rod. The switch arm is attached to a second arm. This second arm can be made to contact a contact jumper that is held away from the contacts by a spring.



Operation

When the control valve closes, the rod on the valve diaphragm drops down and the movable stop causes the arm of the limit switch to move. As this arm moves, it moves through the pre-travel area. If the valve continues to close, the arm is moved further, causing the second arm to push the jumper across the contacts. This sends a signal to stop the pump. The arm may continue to move beyond the initial contact position. This is because it takes time for the valve to completely close. This last distance is called “over travel.”

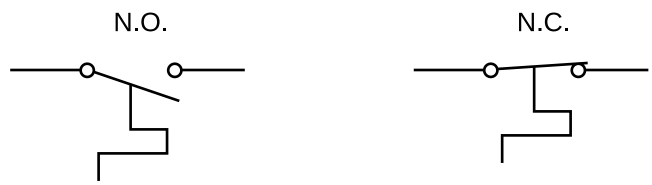
Temperature Switches

Description/Function

Temperature switches can be used to turn circulation pumps on and off to control temperature in a digester or water circulation loop as found in the arctic and subarctic. They can also be used to regulate the temperature in low pressure boilers or they could be used to merely provide an electronic signal that is used to indicate the temperature of the water, air, etc. In a low pressure boiler system these devices are called aquastats.

Symbol

The symbol below is the standard symbol used to identify a temperature switch.



Components

The temperature switch is composed of a sealed bulb filled with a temperature sensitive fluid. The bulb is attached to the switch through a capillary tube that may be a few inches or a few feet in length. At the top of the capillary tube is a diaphragm much like the diaphragm used in a pressure switch. The fluid that is in the bulb also fills the capillary tube and lower area under the diaphragm. The diaphragm is attached mechanically to a normally open or normally closed set of contacts.

Operation

The temperature sensitive fluid in the switch expands with an increase in temperature. The fluid was formulated so that the rate of expansion is linear with an increase in temperature. As the temperature rises, the diaphragm is flexed upward, moving the lever and opening or closing the switch contacts. When the temperature decreases, the diaphragm lowers, lowering the rod and returning the contacts to their original position.

Lights

Indicator (pilot) Lights

Description/Function

Lights of various colors are placed on control panels to indicate the status of a pump (on or off) and signal various types of alarms (low water, high water, high motor heat, water in the motor casing, water in the oil, etc.) These lights are usually 120 volt devices that utilize a small wattage bulb. The bulb is covered by a colored lens.

Symbol

Below is the standard symbol used for indicator lights. The letter in the center of the symbol indicates color. The common letters and colors are:

A = amber

B = blue

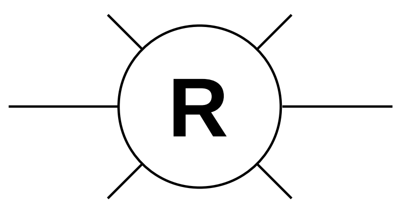
C = clear

G = green

O = orange

R = red

W = white



Special Considerations

One of the major operational problems with indicator lights is burning out. The only way they can be tested is to remove the colored lens and bulb. As a result, some designs place “push to test” indicator lights in critical alarm positions.

Transformer Type

A second option is to use a transformer type indicator light. This type extends the life of the bulb by using a low voltage (6V) bulb. However, it costs more than the 120V type.

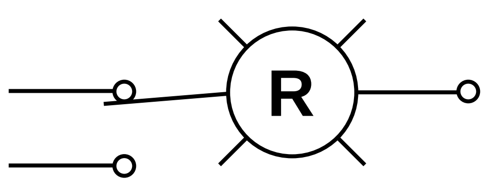
Push to Test Indicator (pilot) Lights

Description/Function

A push to test indicator light provides all the functions described above with regular indicator lights plus the opportunity to determine if the bulb is working without removing the bulb.

Symbol

Below is the symbol used to identify push to test indicator lights.



Operation

The push to test light contains the standard light circuit and an additional switch connection. When the lens of the light is pushed in, it causes a momentary contact switch to be disconnected from the standard circuit and pressed against a second lead that is connected directly to the control power hot lead. If the bulb is good, it will be illuminated.

Electro-Mechanical Devices

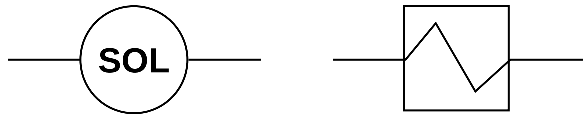
Solenoids

Description/Function

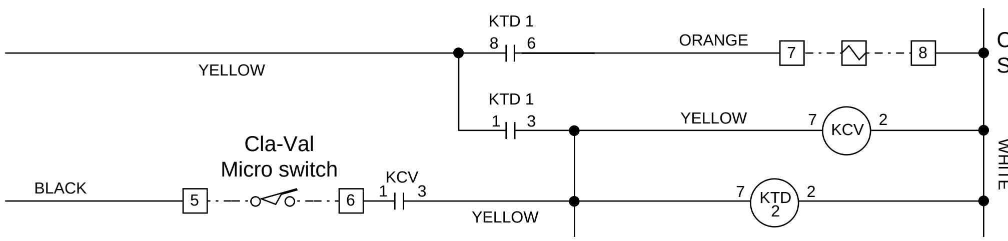
Solenoids were discussed in great detail in the lesson on electromagnetism, therefore this portion will be a general review. Solenoids are used to open and close valves and move mechanical devices. They are an electro-mechanical device.

Symbol

The following symbols are used to identify solenoids:

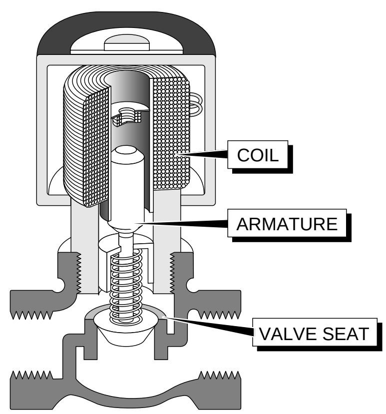


Below is an example of a solenoid as it would be seen in an electrical diagram.



Components

The solenoid is composed of an electromagnet and a movable metal rod called the armature. In the solenoid below the armature is connected to the movable disc in a globe valve. A spring is placed between the valve bonnet and the disc.



Operation

There are two types of solenoids, the normally open (NO) and the normally closed (NC). The normally open solenoid valve uses a spring to hold the valve open. The normally closed solenoid valve uses a spring to hold the valve closed. Once the electromagnet is with the NC solenoid valve energized, the armature is pulled up lifting the valve disc against the spring. This opens the valve. When power is shut off to the electromagnet the spring forces the valve closed.

Special Considerations

In the water and wastewater industry, solenoid valves are commonly used to control the flow of seal water to a pump, fill a chemical solution tank, control the water level in a fluoride saturator, and operate the lawn sprinkler system.

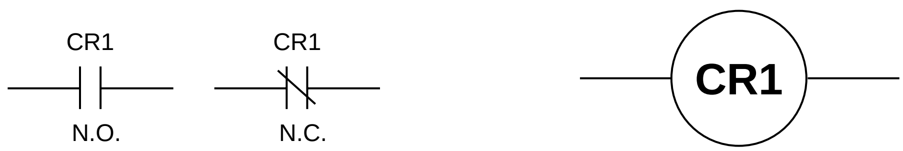
Control Relays

Description/Function

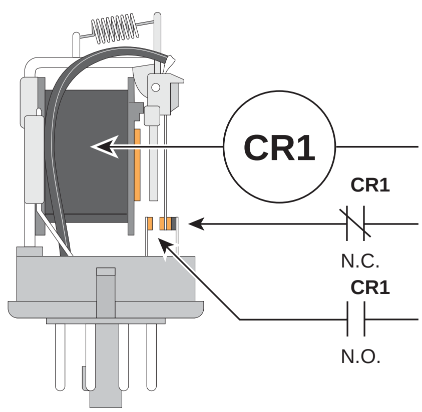
Control relays are electro-mechanical devices used to turn pilot lights on and off, control mechanical equipment, and send signals from a sensing device, such as a float switch, to another component, such as a motor. The control relay is the key component in a motor control system. These relays were discussed in depth in the lesson on electromagnetism and, therefore, will only be reviewed here.

Symbol

There are two symbols used to identify the parts of the control relay. The coil is identified by a circle with a letter and number placed in the center. The contact(s) are identified by two parallel lines. The contacts may be normally open (NO) or normally closed (NC).



The symbols below show the relationship between the coil and the contacts as they would be observed in a standard electrical drawing.



Components

The control relay is composed of a single iron core electromagnet which operates an armature. The armature is used to open and close one or more electrical contacts. A control relay may have all NO or NC contacts or have a combination of normally open and normally closed contacts. The control relay above has one normally-open and one normally-closed set of contacts both operated by the same electromagnet. A spring is usually used to hold the contacts in one position.

Operation

When the electromagnet is energized, the iron core attracts the armature and pulls it to the core. This opens the normally closed contacts and closes the normally open contacts. When the power is shut off, the spring pulls the contacts back to their “off the shelf” or “normal” position.

Special Considerations

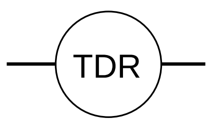
The most important feature of the control relay is the fact that the pair of contacts are not electrically connected to the coil or each other. There are independent circuits. The contacts and the coil are connected physically.

Time Delay Relays

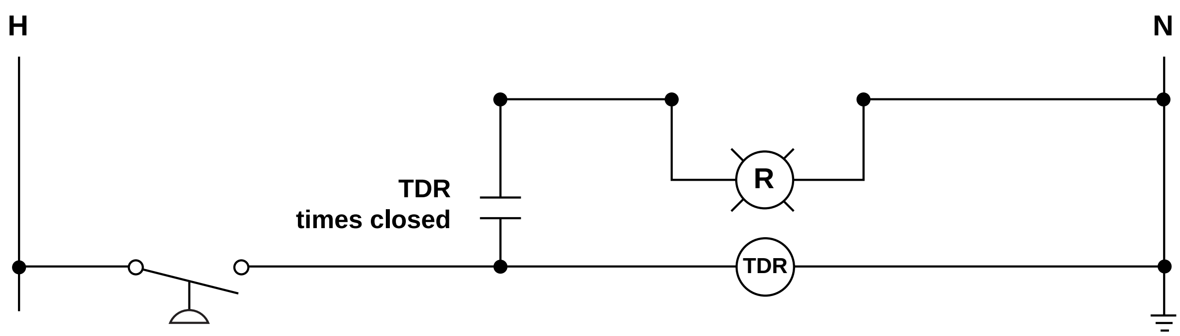
Description/Function

As the name implies, time delay relays are used to delay the time for a component to start or stop. When a pump is controlled by pressure in the system, a sudden change in this pressure could cause the pump to start. However, if the pressure change were the result of a surge in the line, the pump might turn on and off several times until the pressure stabilized. By placing a time delay relay in the system and setting it for 15 seconds, a condition could be established where the pressure would have to rise or drop to a set level and stay at that level for 15 seconds before the pump was energized.

Symbol



The standard symbol used to identify the time delay relay is nearly identical to the control relay. The only difference is in the letter indicator associated with the coil and contacts. The letters usually used are TD or TDR. Below is an example of a time delay relay in a pump circuit.



Components

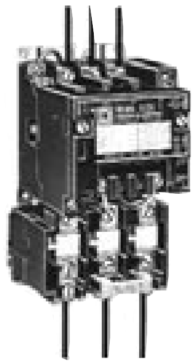
There are two common types of time delay relays: the pneumatic and the solid state.

Operation

Solid state time delay relays use electrical circuitry to delay the close or open time. The pneumatic timer uses an air bellows that is connected to a small orifice. When the coil is energized, the armature is pressed against the bellows, causing it to collapse and force air out through the orifice. The rate of closing is controlled by a needle valve in the orifice. When the bellows is completely collapsed, it mechanically closes or opens the contacts.

Motor Starters

Description/Function

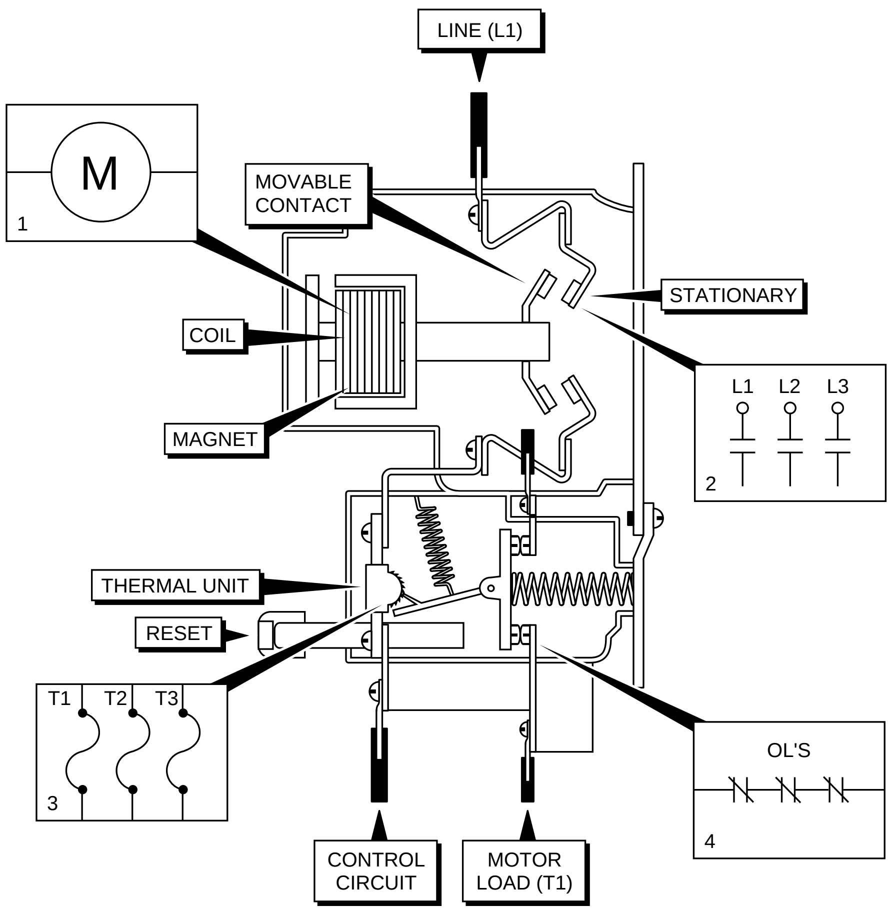


Motor starters[4] allow low voltage (24 VDC, 48 VDC and 120 VAC) to be used to mechanically close a switch that applies high voltage to an electric motor. Motor starters are the link between the power circuit and the control circuit. The two are not connected electrically but are connected physically in the starter. As was mentioned in the power system lesson, the typical motor starter is composed of five items. Two of these, the contacts and the heater elements, were discussed in the power system lesson. In this lesson we will discuss the coil, thermal overload contacts, and the auxiliary contacts.

Symbol

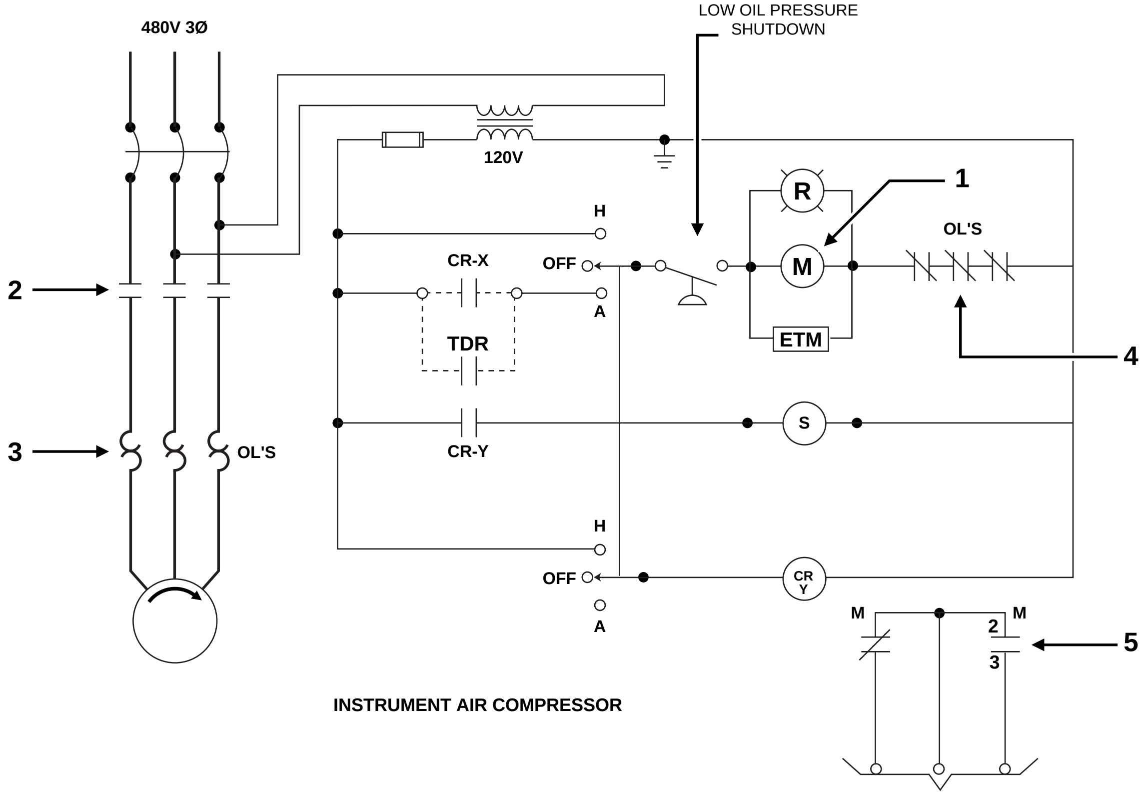
Since there are five items in the motor starter, there are five symbols used to identify these items.

1. Coil
2. Contacts
3. Heater elements
4. Thermal overload contacts
5. Auxiliary contacts



[4] **Motor Starters** - Electrically operated switches used to connect power to electric motors. Also called a magnetic starter.

The diagram below is used to show the relationship of these five items in an electrical drawing. (The notes are normally not provided on the drawing.)



Components

The starter is composed of five basic components, show above. There are a set of contacts placed in the power circuit (2) along with the heat sensing elements (3). The control system contains an electromagnet (1), the thermal overload device contacts (4), and the auxiliary contacts[5](5). The power system contacts are held in an open position by a spring. This same spring can be used to hold the auxiliary contacts in a power-off position. Auxiliary contacts can be either normally open or normally closed. Most starters are constructed with one set of normally open auxiliary contacts. Additional normally open or normally closed contacts can be installed.

Operation

The discussion thus far pertains only to the operation of the closing and opening of the power circuit by the starter. The thermal overloads and auxiliary contacts operation are discussed below.

When there is a demand for the pump to start, power is applied to the magnetic coil of the starter. Once the coil is energized, it moves the armature which is attached to the contacts. This closes the contacts and applies power to the motor.

[5] **Auxiliary Contacts -** An additional set of contacts found on a motor starter or contactor. These auxiliary contacts operate with the main contacts.

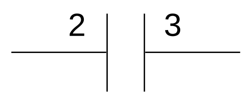
Auxiliary Contacts

Description/Function

Most starters are built with one set of extra contacts. These contacts are called the auxiliary contacts and are normally open. They are used in a holding circuit if a start button is used, or to turn on or start equipment and/or status lights that are critical to the operation of the motor. This might include shaft oilers on lineshaft turbines, prelube lines on lineshaft turbines, chemical feed pumps, and status lights.

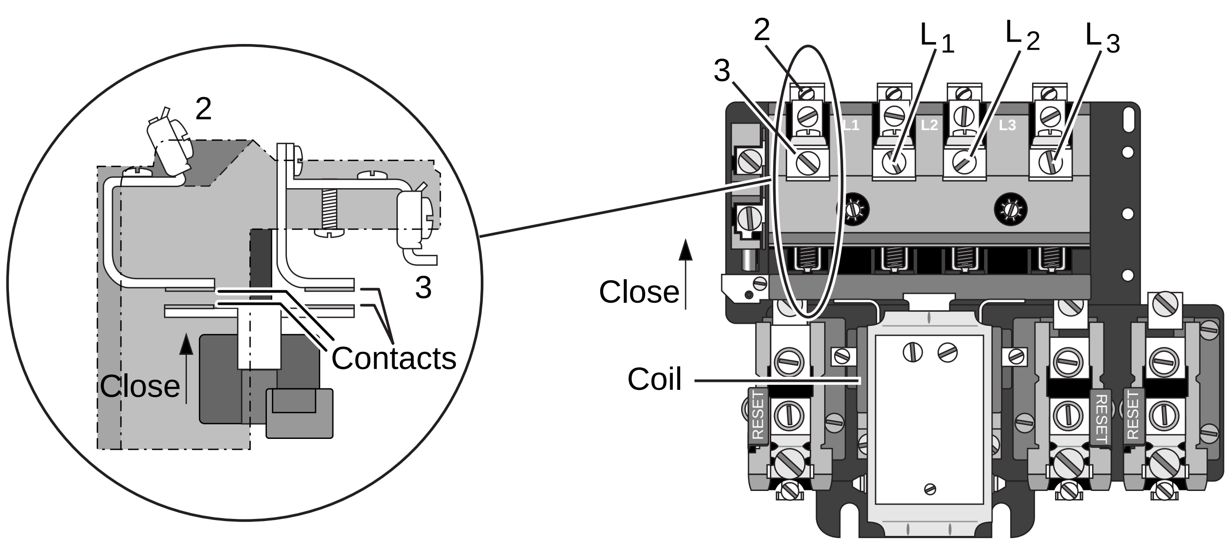
Symbol

The standard symbol for the auxiliary contacts is the normally open contact symbol with the numbers 2 and 3 placed next to the contacts.



Operation

These contacts are often smaller in size than the power contacts in the motor starter. The numbers 2 and 3 are normally stamped in the metal next to the wire connections. When the coil of the motor starter is energized, these contacts are closed at the same time the other motor starter contacts are closed. In the drawing below, energizing the starter coil will cause the armature to move upward, closing the contacts.



Special Consideration

It is possible to purchase extra normally open and normally closed contacts that are fastened to the side of the motor starter and operated when the starter is operated. These extra contacts can be used to operate status lights, send a signal to a remote facility, or start or stop auxiliary equipment.

Overload Protection

Description/Function

Overload protection[6] devices are designed to monitor the amperage to a motor. If the amperage exceeds a predetermined level and stays there for an adequate amount of time, the overload device will disconnect the power to the motor starter coil, stopping the motor. The connection between the overload circuit and the power circuit is physical and not electrical. There are three common overload devices: the bimetallic, melting alloy, and the magnetic device.

Other Names

Overload protection devices are also called heaters and thermal overload devices.

Symbols

The following symbols are used to identify the two components of the overload device. (the heating element and the contacts):

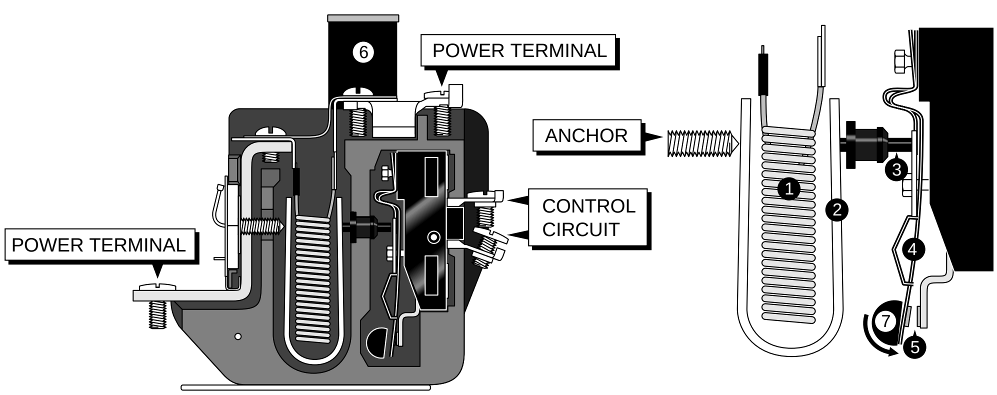
Bimetallic Type

Components

The bimetallic device is composed of a heating element that is made from two different metals fused at one end. This device is physically connected to a set of normally closed contacts. The contacts are in the control circuit.

Operation-Bimetallic Strips-Normal

Under normal operating conditions, current flows from the power-in terminal through the heating element (1) to the power-out terminal. The higher the amperage through a metallic device, the greater the heat that the device generates. The control circuit is connected to the control circuit terminals. Current flows from one of these terminals through the contact points (5) to the other terminal.



6 **Overload protection** -The protection of electric motors with the use of a heat-sensitive device placed in a control circuit, typically called a heater.

Operation - Bimetallic Strips - Trip

As current passes through the heater (1), the bimetallic strip (2), heats and bends. When it heats and bends sufficiently, the plastic plunger (3), is pressed against a spring which causes the metal strip (4), to snap away from the contacts (5), opening the control circuit. By opening these contacts, power is lost to the starter coil, it is deenergized, and the motor stops. To reset the overload, item (6), is pressed, causing the cam (7), to rotate, snapping the spring (4) back into position and closing the contacts at (5).

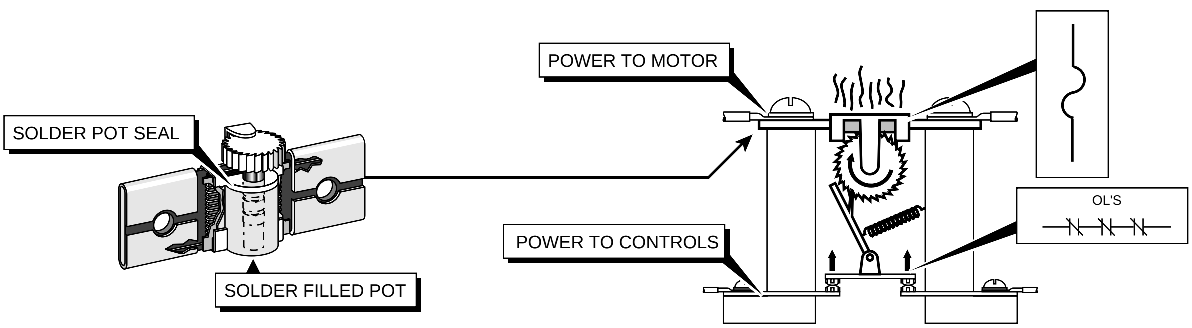
Reset

Once the overload has had an opportunity to cool, which takes a few minutes, it can be reset by pressing the reset button (6). When this button is depressed, a lever reconnects the contacts and the system is ready for operation. Caution: The power to the motor should be turned off before the reset button is pressed. The H-O-A switch should be placed in the “Off” position.

Melting Alloy

Components

The melting alloy device uses a heating coil in the power circuit. This coil is wrapped around a metal tube that contains solder. The shaft is attached to a ratchet wheel which is inserted in the solder. A small seal prevents the solder from leaking out of the tube. A latching assembly is held in place by the ratchet.



Operation

When an overload occurs, sufficient heat is generated by the coil to melt the solder. Once melted, the shaft on the ratchet wheel rotates, releasing the ratchet wheel. This in turn releases the overload contacts.

Reset

Once power has been disconnected, the solder will cool and reset. After it has reset, the reset button on the starter can be pressed and the overload contacts will be physically reconnected. It is important that power be shut off before the reset button is pressed.

Trip Time

At 600% of full load current (FLC), it takes 10 to 30 seconds for the heating element to heat sufficiently to cause the thermal overload devices to trip. More information on trip time is found in the Normal Operations lesson.

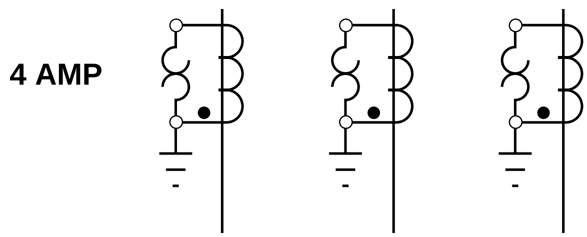
Magnetic Type

Function/Description

When motors are used in high ambient temperature conditions, the thermal overload devices trip prematurely. To overcome this problem, many facilities use the magnetic type of device or the newer solid state devices.

Symbol

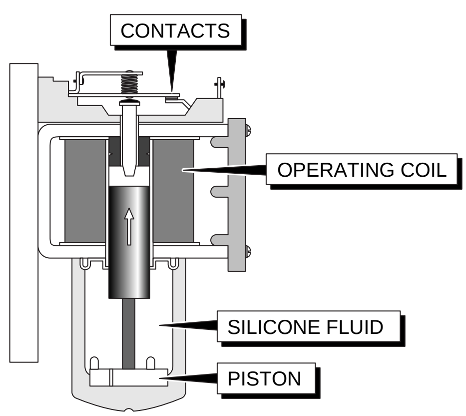
The following is the symbol used to identify magnetic type overload devices:



Components

There are two magnetic overload devices used in motor control circuits, the time limiting and the instantaneous. This discussion focuses only on the time limiting.

The time limiting device uses a current transformer (CT) to measure the amperage in the power circuit. The amperage is transferred to a coil wrapped around a movable core. The bottom of the core is attached to a piston which is placed in a liquid chamber. The liquid is normally oil or silicone. Adjustable holes with check valves are placed in the piston.



The overload contacts are placed on top of the device and are operated by the coil core.

Operation

During an overload condition, the magnetic field developed by the coil pulls the core and piston up. The rate of movement and the amount of time required to trip are controlled by the size of the hole in the piston. When the core reaches the top of the device it pushes the overload contacts open, deenergizing the motor starter coil and stopping the motor.

Other Components

GFCI

Description/Function

It is possible for electrical equipment such as drills, saws, and electrical panels, to have a short between the hot lead and the case or the panel door. In these instances, the devices may operate properly, but an individual could be shocked. To prevent shock, GFCI (Ground Fault Circuit Interrupters) are installed. These devices are sometimes required in bathrooms, all construction sites, kitchens, and sometimes in electrical control panels.

Components

The GFCI is composed of at least two coils and a switching circuit. One coil is placed around the hot lead and the second around the neutral. Both coils are connected to the switch circuit. This circuit controls a switch that is placed in the hot lead.

Operation

Under normal conditions, the current flowing in the hot lead will be the same as the current flowing in the neutral wire. However, if a connection is made through a device or a person between the hot lead and ground, the amperage flow in the two wires would not be equal. In this case there would be an imbalance produced by the two coils. This imbalance will cause the control circuit to disconnect the hot lead.

For GFCI devices used in the home, the imbalance is 5 mA. For commercial devices as found in a control panel, the imbalance is 20 mA.

Special Considerations

While the above condition would give a shock to the operator of the equipment, the duration would be so short that there would be no damage.

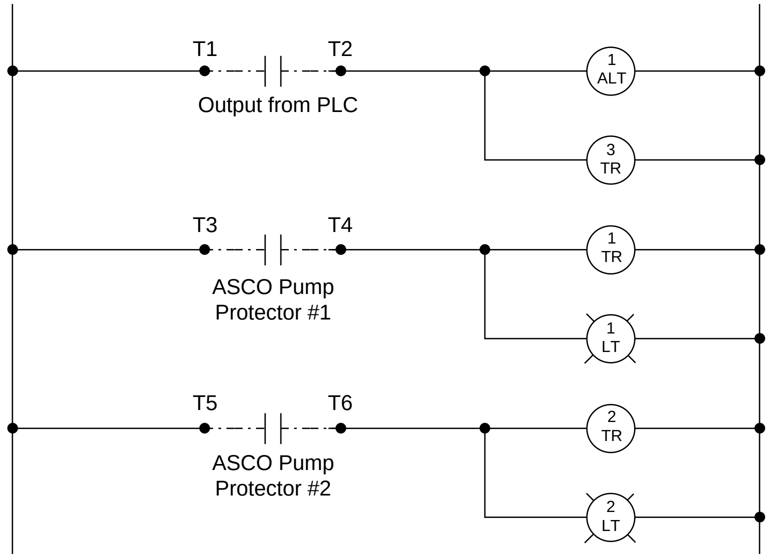
PLC

Description/Function

PLC, or programmable logic controller, is an electronic method of developing control logic circuits in an electronic “black box.” The PLC provides three major advantages over control relay circuitry. One is the ease with which the control logic can be changed. (To change the control logic, simply connect to the PLC with a computer and make the adjustments.) The second advantage is the reliability of the devices. Third is the ability to use more complicated logic than can be reasonably provided by control relays. For example, a water treatment plant could set the backwash to start if the turbidity exceeds a set point, or the headloss or the filter run exceeds a set point. Any one of these inputs could trigger the backwash cycle.

Symbol

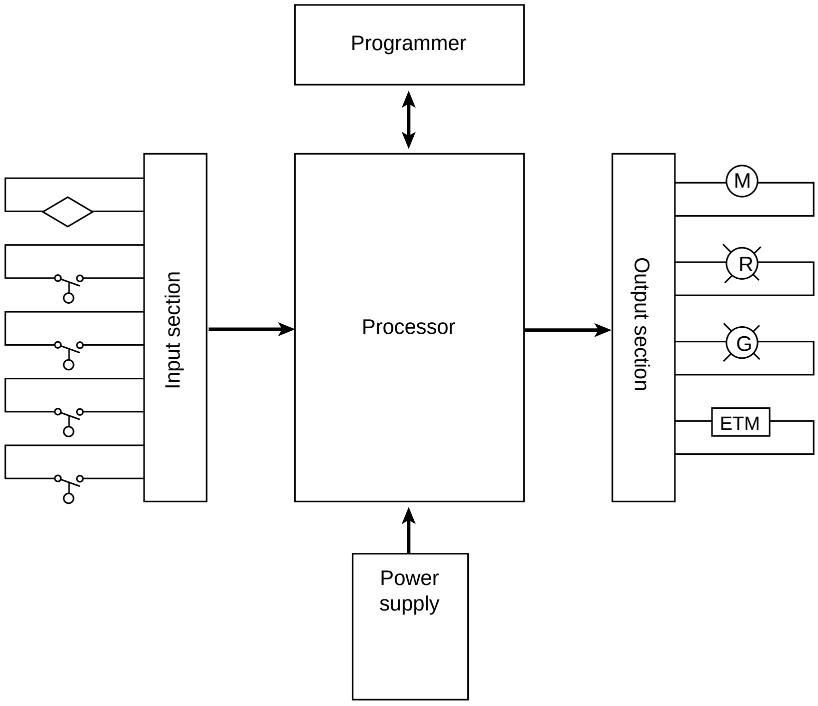
The symbol used to indicate a PLC will range from a box to providing a diagram of the ladder logic programmed inside of the controller. In this later case, the logic diagram is usually contained inside a dotted line. Note in the circuit below, the N.O. contacts at terminals T1 and T2 are an output from the PLC to start the backwash cycle of a water treatment plant.



Components

The PLC is composed of four basic elements: A programming and/or monitoring device, the processor, input and output section, and a power supply.

The programming and/or monitoring device may be portable or permanently connected directly to the PLC. This component may be a computer provided by the PLC manufacturer or a standard personal computer, depending on the requirements of the PLC.



The processor is a solid state device that can be programmed to allow a signal to pass in a certain direction.

The input and output devices, called I/O sections or cards, convert signals between AC and DC.

The power supply is normally a 120 volt supply.

Operation

The input section of the PLC receives a signal from an input device such as a counter, limit switch, or float. The input devices commonly work on a 120 volt supply. The input section of the PLC converts the 120 volt signal to a low voltage DC signal that can be understood by the processor. The low voltage DC signal is sent to the output section where it is converted to a 120 volt AC signal which is sent to output devices such as motor coils and lights. In the example on the previous page, the output was simply the closing of a set of contacts.

Special Considerations

The ability to change a PLC program is based on the understanding of ladder logic, as described in the lesson on reading electrical diagrams.

Built in Amp and Volt Meters

Description/Function

Digital or analog amperage and volt meters installed in the electrical panel door allow the operator to frequently determine the amperage and voltage readings of a motor without opening the door. This device reduces exposure to high voltages and thus reduces the possibility of personal injury.

Symbol

The symbols below are used to identify the amperage and voltage meters:

Amp Meter   Volt Meter

Components/Operation - Amperage

In order to measure amperage, a coil is placed around each of the legs leading from the motor starter. The connections from these coils are placed on a multiple pole switch. Output from the switch is wired to the amp meter. When the motor is running, a current is induced from the power leads to the coil. By merely turning the switch, the operator is able to determine the amperage on each leg. Switches are also made that allow the operator to determine the amperage on two different motors in the same station.

Components/Operation - Voltage

In order to determine the voltage, a lead is connected from each line connection of the starter to a switch. By moving the switch, the operator is able to determine the voltage between each pair of legs (1-2, 1-3, and 2-3). As with the amp meter, switches are available that allow the measurement of voltages from two motors in the same pump station.

Phase Monitors

Introduction

There are four common conditions that can cause severe damage to three-phase[7] motors:

- Amperage unbalance - also called phase unbalance
- Loss of a phase
- Phase reversal
- Low voltage

Unbalance

An amperage or voltage unbalance of 3% between the phases will cause a 20% increase in motor temperature, and a 5% unbalance will cause a 50% increase in motor temperature. A 10% increase in motor temperature will reduce the life of the insulation on the stator windings by 50%. A discussion on how to calculate this unbalance is found in the “Normal Operations” lesson.

Loss of a Phase

The loss of a phase can occur because of the loss of a fuse, a power system problem, or a bad electrical connection. When this happens with an electric motor, the motor is said to “single phase.” Actually there are two remaining phases. This condition causes an increase in amperage draw on the remaining two phases, which causes an increase in motor temperature.

Phase Reversal

A three phase motor will change directions if any two of the three leads are switched. This can occur during installation, during restoration after a power outage, or for reasons not explainable. While this condition is not damaging to the motor, it may damage equipment that is connected to the motor. Pumps and blowers will run backward but will be of little value.

Low Voltage

Low voltage on one leg causes unbalance. However, low voltage on all legs causes an increase in amperage draw, which increases the motor temperature. The increase in amperage draw is best explained by Watt’s Law. The motor is attempting to do a specific amount, as demanded by the pump. When the voltage is reduced, the amperage must increase in order to provide this work: P = V X A.

Protection

In order to protect the motor from damage from one or more of these conditions, several manufacturers have developed devices called phase monitors. These devices are usually solid state and can be used to open a switch in the power circuit should any of these above conditions exist.

Special Consideration

Not all phase monitors or motor savers provide protec-

[7] **Three-phase** - Three separate power sources that are 120° out of phase with each other.

tion for these four conditions. The specification of each must be evaluated in order to determine which is best for a specific condition.

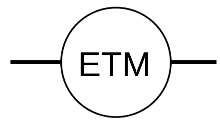
Elapsed Time Meters

Description

Elapsed time meters and hour meters are used to determine the number of hours a pump has operated. This data is used to identify preventive maintenance requirements and to determine if the system is operating properly.

Symbol

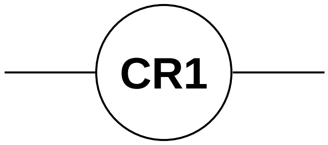
The following is the symbol used to identify ETM's.

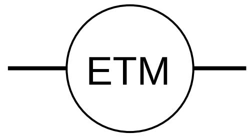


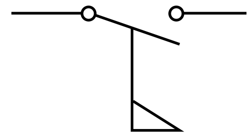
Control System Components

Worksheet

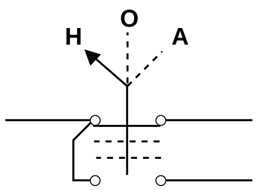
1. Identify the following electrical symbols

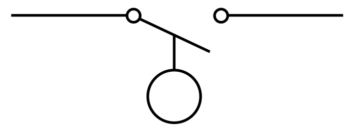




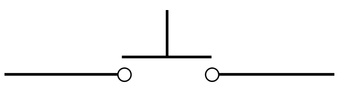


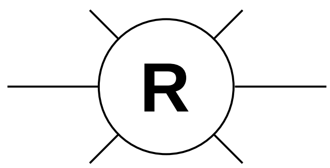
a. ______________________ b. ______________________ c. ______________________

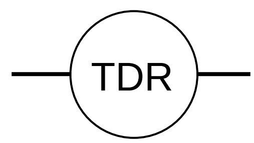




d. ______________________ e. ______________________ f. ______________________







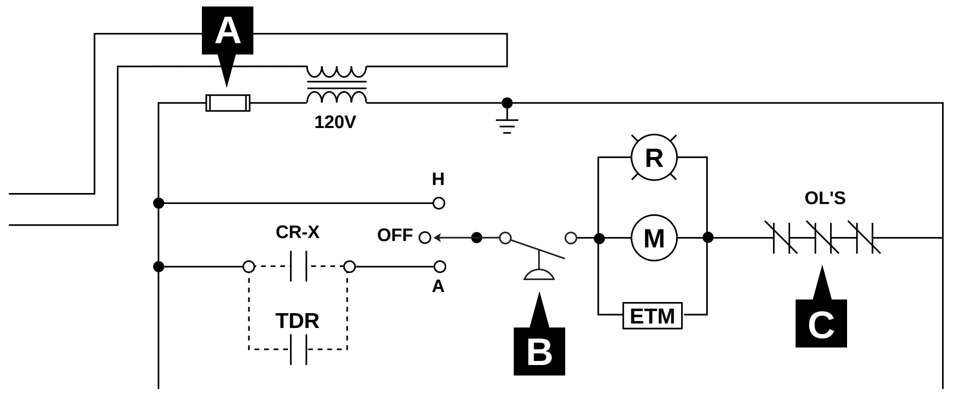
g. ______________________ h. ______________________ i. ______________________

2. Overcurrent protection is provided by what components?

3. Overload protection is provided by what component?

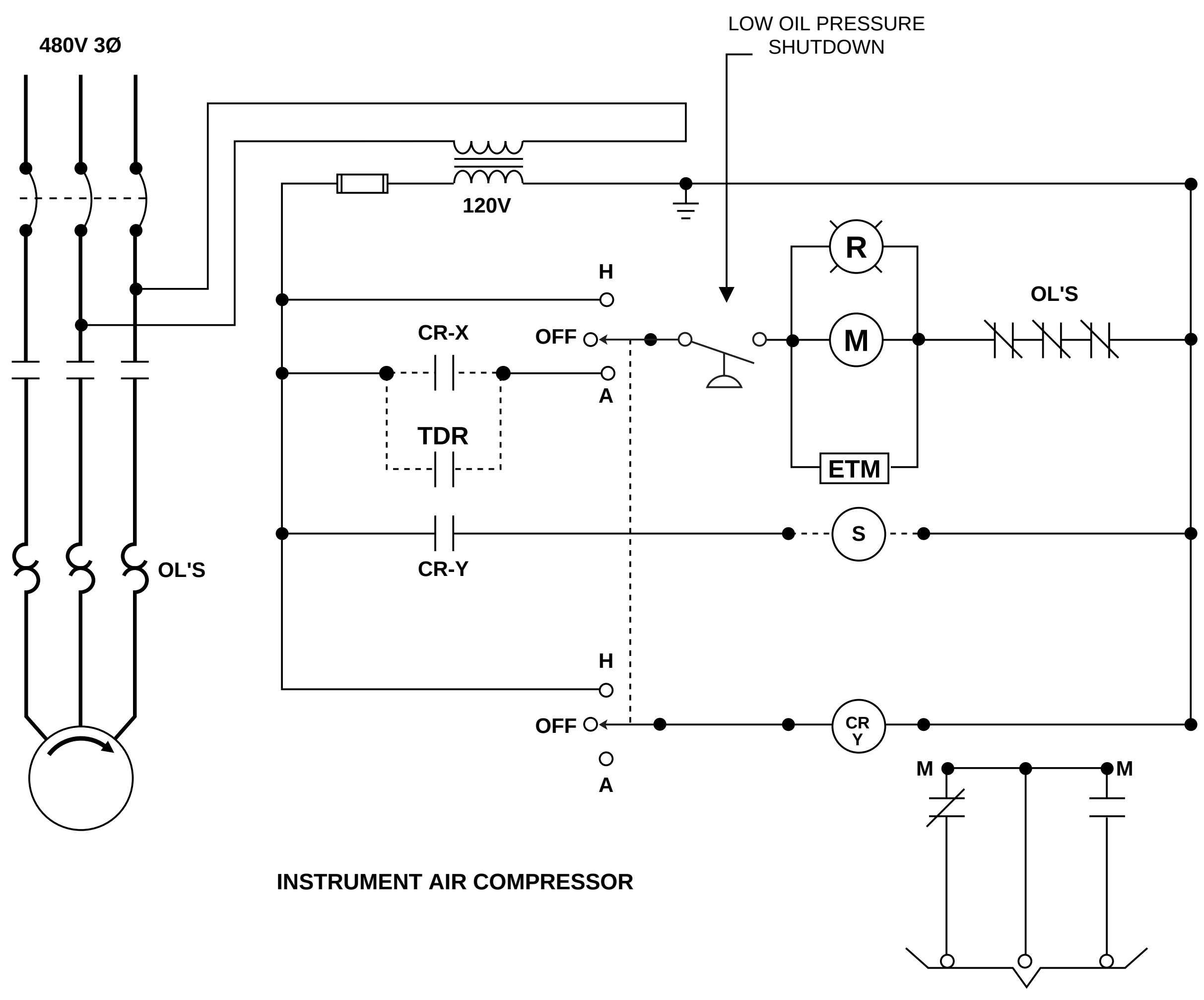
4. What is the maximum current draw on the secondary side of a 5 KVA transformer at 120 volts?

5. Identify the components indicated below.



a. ________________ b. ________________ c. ________________

6. Using the diagram below, identify the five basic components of a magnetic motor starter.



7. What are the three types of thermal overload devices discussed in this lesson?
   a. ______________________________

   b. ______________________________

   c. ______________________________

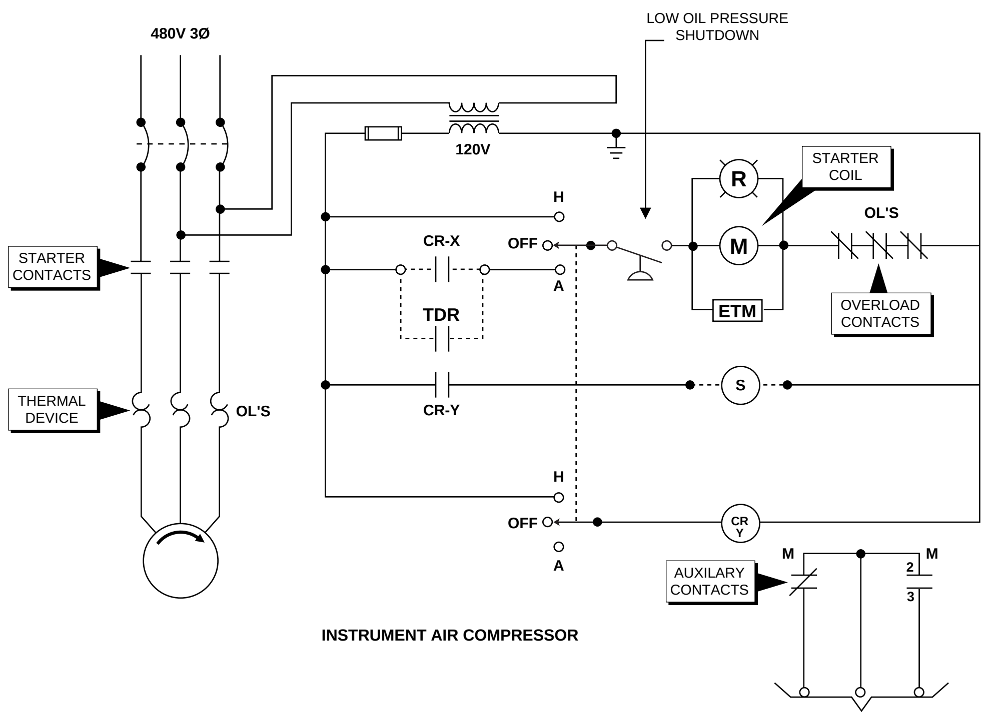
8. A reprogrammable, solid state device used in motor control systems is called a _________________.

9. The _______________________ is a level sensing device that uses a strain gauge.

10. The _______________________ contacts are located on the motor starter and are often identified as “ 2” and “ 3” in the control diagrams.

Answers to Worksheet

1.
   a. control relay coil   b. Elapsed time meter   c. Flow switch
   d. Hand-off-Auto switch   e. Limit switch   f. Float switch
   g. N O momentary contact switch   h. Red indicator light
   i. Time delay relay coil
2. Fuses and magnetic breakers
3. Thermal overload
4. $$\frac{5{,}000\ \text{Watts}}{120\text{V}} = 41.7\ \text{amps}$$
5. a. Fuse   b. N O contacts   c. Overload contacts
6.



7. Bimetallic   Melting alloy   Magnetic
8. PLC
9. Transducer
10. Auxiliary