Electrical Level 3

Motor Controls 26311-14

Objectives

When trainees have completed this lesson, they should be able to do the following:

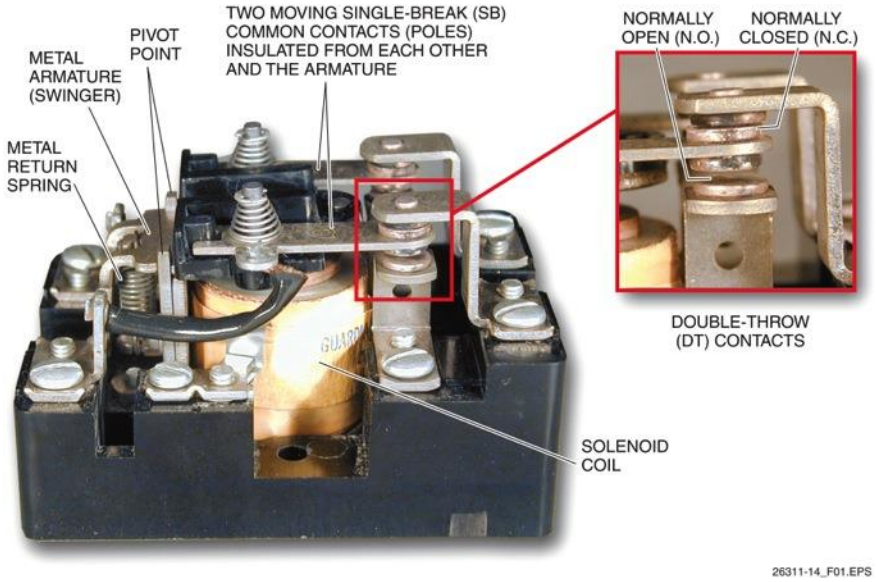
1. Identify contactors and relays both physically and schematically and describe their operating principles.
2. Identify pilot devices both physically and schematically and describe their operating principles.
3. Interpret motor control wiring, connection, and ladder diagrams.
4. Select and size contactors and relays for use in specific electrical motor control systems.
5. Select and size pilot devices for use in specific electrical motor control systems.
6. Connect motor controllers for specific applications according to *National Electrical Code*® (*NEC*®) requirements.

Performance Task

1. Make all connections for a magnetic motor controller, controlled by two pushbutton stations, including the connections for holding the circuit interlock.

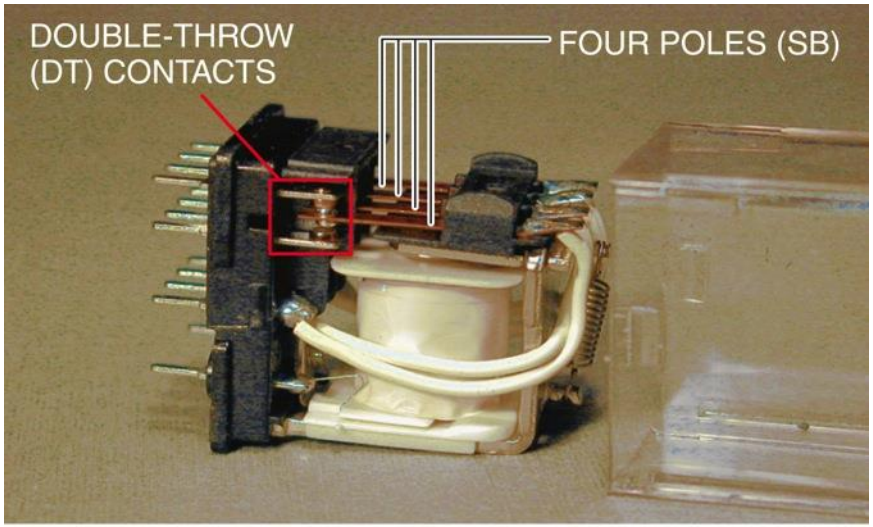
Introduction; Electromechanical Relays

- Electromechanical relays (EMRs) are used in control circuits to operate low-current loads.
- A typical double-pole, double-throw, single-break (DPDT-SB) open-frame power relay is shown here.



Miniature Four-Pole, Double-Throw, Single-Break (4PDT-SB), Plug-In Relay

Each of the poles on this relay has a normally closed (N.C.) and a normally open (N.O.) contact with a common single-break (SB) moving contact.



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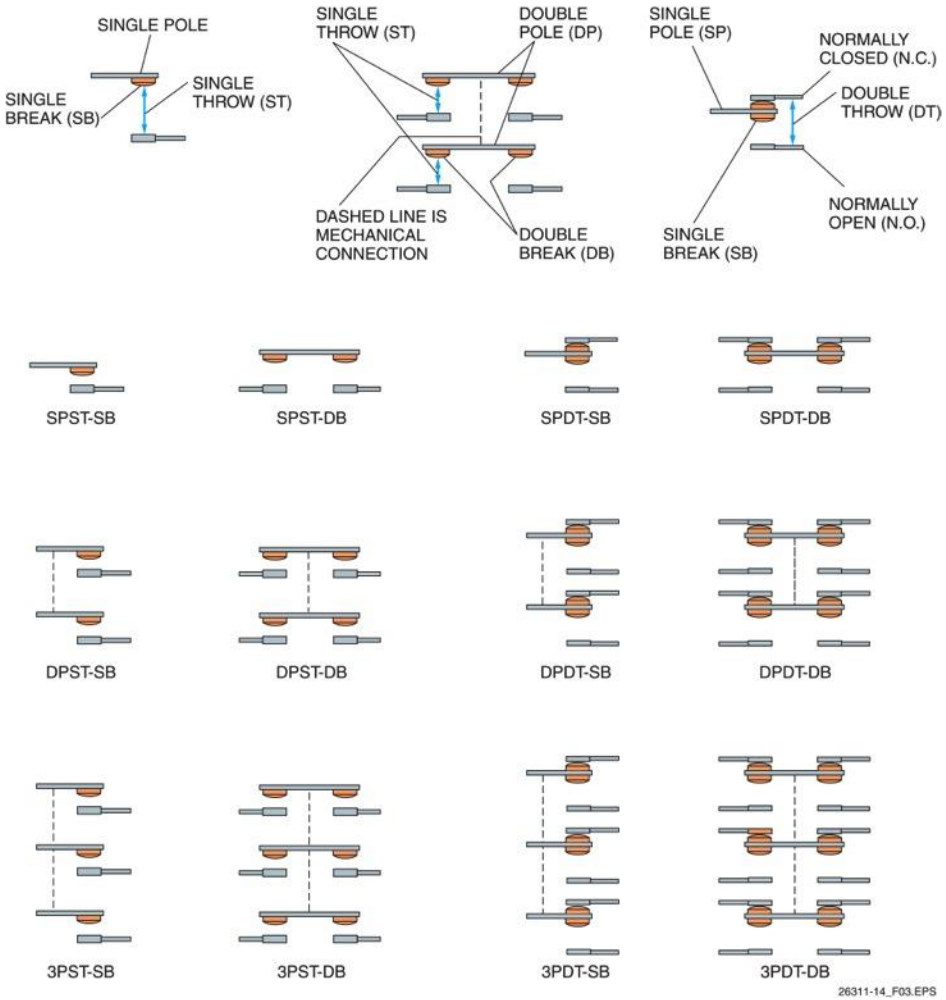
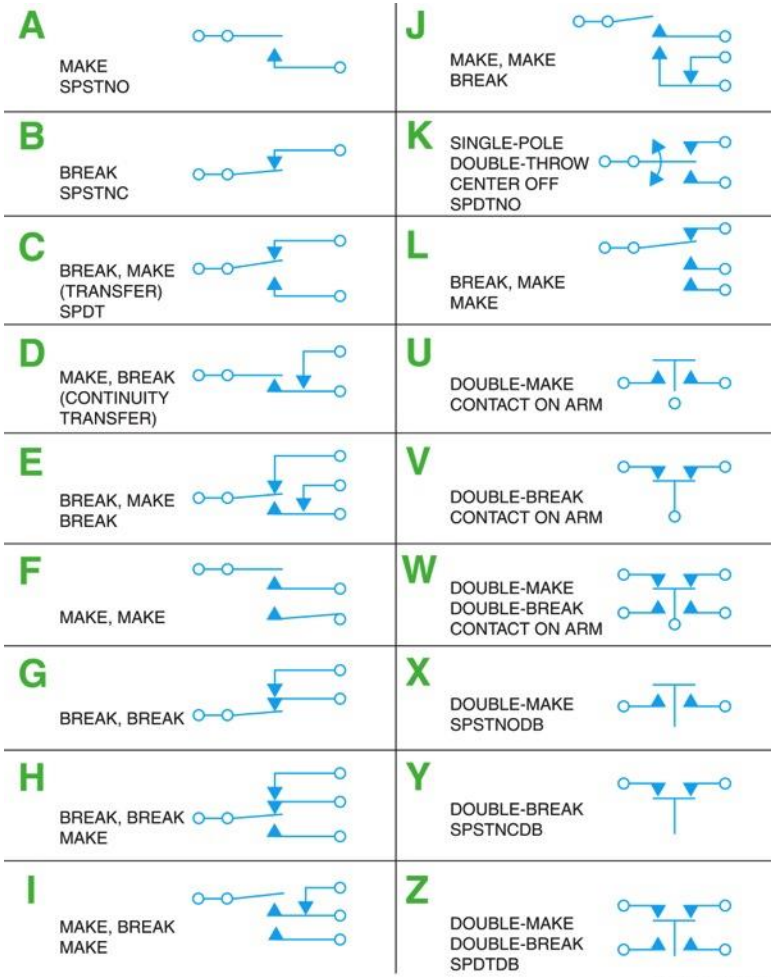
Relay Contact and Pole Designations

Designation	Meaning
ST	Single Throw
DT	Double Throw
N.O.	Normally Open
N.C.	Normally Closed
SB	Single Break
DB	Double Break (industrial relays)
SP	Single Pole
DP	Double Pole
3P	Three Pole
4P	Four Pole
5P	Five Pole
6P	Six Pole
(N)P	N = numeric number of poles

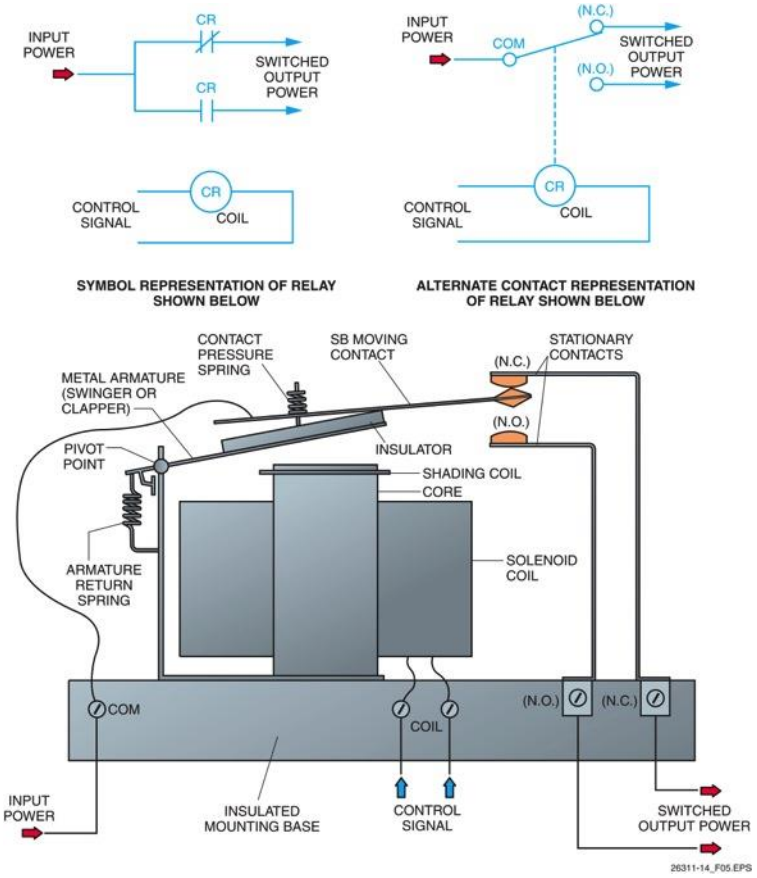
Examples of Relay Contact Configurations



Relay Contact Form Identification

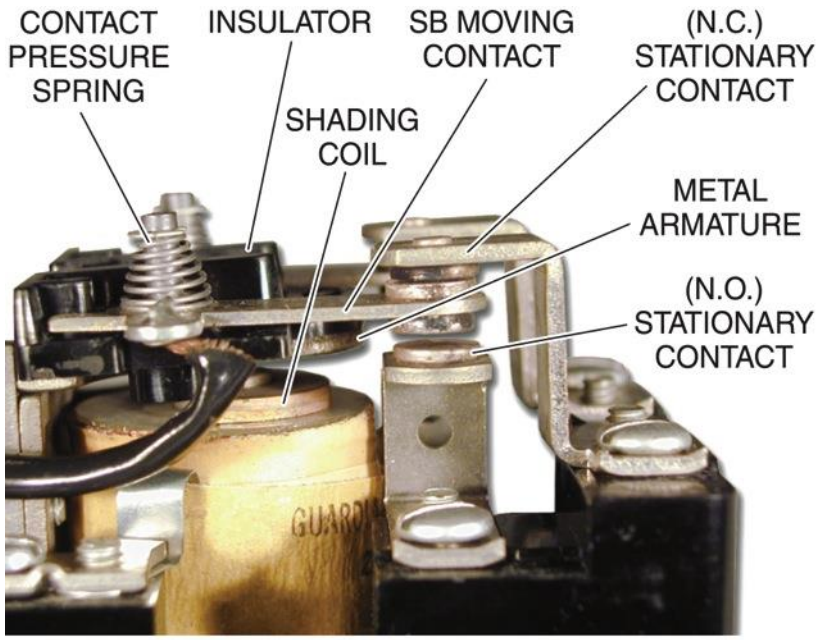


Typical SPDT-SB Power Relay and Symbol Representation



Detail View of a Power Relay

- When a control signal voltage is applied to the relay solenoid coil, the magnetic field created through the core attracts the metal armature and draws it into contact with the core.
- The moving contact then breaks from the N.C. contact and makes with the N.O. contact. A shading coil is used to prevent relay chatter.



Detail View Typical Loads and Their Inrush Currents a Power Relay

- Relays are rated by their inrush current, normal or continuous-carrying capacity, and current break or opening capacity.
- For loads with inrush current, the steady-state and inrush loads should be measured to determine the proper contactor or relay rating.

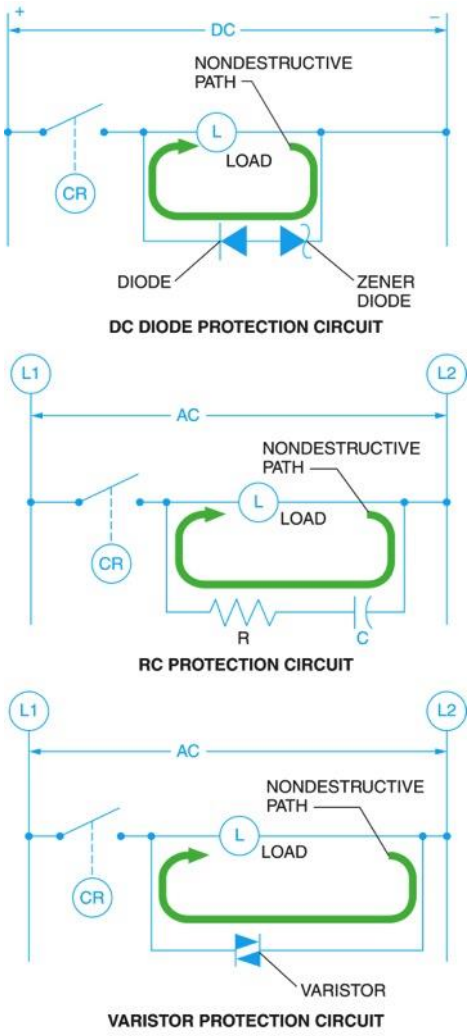
Type of Load	Approximate Inrush Current
Resistive heating	Steady-state current
Sodium vapor lamps	1 to 3 times steady-state current
Mercury lamps	About 3 times steady-state current
Motors	5 to 10 times steady-state current
Transformers	5 to 15 times steady-state current
Incandescent lamps	10 to 15 times steady-state current
Solenoids	10 to 20 times steady-state current
Capacitive loads	20 to 40 times steady-state current

Contact Material Characteristics

Material	Advantages	Disadvantages
Silver	This metal has the highest conductivity and thermal properties of any contact material.	This metal is subject to welding and sticking under arcing conditions. Rapid sulfidation (tarnishing) in many applications creates a film that increases contact resistance. Normal contact wiping usually removes the film. It is not used in intermittent or arcing applications.
Silver-cadmium alloy or silver-cadmium oxide alloy	These alloys have good conductivity and thermal properties. Cadmium oxide alloy conducts even when oxide forms on surface of contacts.	These alloys resist arcing damage but are subject to some sulfidation. Normal contact wiping usually removes the film. When used in circuits drawing several amperes at more than 12V, any sulfidation is burned off.
Gold-flashed silver	This metal has the same advantages as silver. Gold flashing protects against sulfidation. It is used in intermittent applications and is good for switching current of 1A or less.	This metal is not used in applications where arcing occurs because gold burns off quickly.
Tungsten or tungsten-carbide alloy	These alloys experience minimal damage from arcing due to their high melting temperature. They are good for high-voltage and repetitive switching applications.	These alloys offer higher contact resistance than other materials.
Silver tungsten-carbide alloy	This alloy has the same advantages as tungsten or tungsten-carbide but lower contact resistance.	This alloy is subject to minor sulfidation; however, wiping action or any arcing removes the film.

Contact Protection Circuits

- Some applications add arc protection circuits to reduce the arcing caused by inductive loads.
- This provides a nondestructive path for the voltage generated by the collapsing field of the inductive load when the relay contacts open.

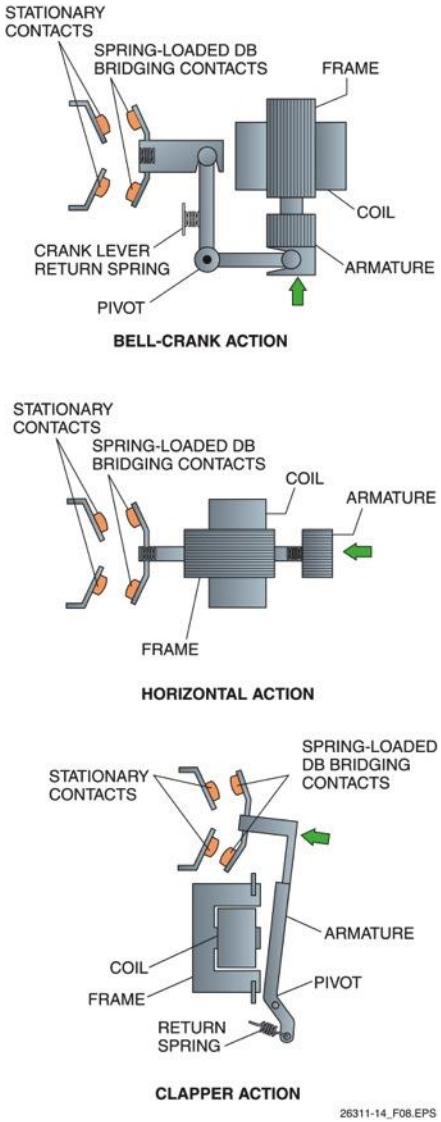


Magnetic Contactors

Category	Application
Lighting contactors	These contactors are current-rated only for resistive loads and do not have horsepower ratings for motor use. The current rating of these contactors is for the maximum continuous current required by a resistive load. At the maximum current rating, the contactors are designed to withstand the large initial inrush currents of tungsten and ballast lamp loads, as well as nonmotor (resistive) loads, without contact welding. They are generally available in versions that are locally or remotely controlled via AC or DC control circuits and are magnetically held, mechanically held, or magnetically latched. The mechanically held or latched contactors are quiet (no AC hum) and remain closed during power interruptions so that their loads will come back on when power is restored.
Definite-purpose contactors and motor starters	Low-duty cycle, definite-purpose contactors and motor starters are intended for use in applications where the control requirements are well defined. These contactors carry dual ratings (ampere and horsepower) for either resistive or inductive loads found in applications such as refrigeration, air conditioning, resistance heating, and other Standard Industrial Classification (SIC) applications. The motor starters are usually equipped with bimetallic motor overcurrent protective devices (overload relays).
NEMA-rated contactors and motor starters	These are contactors for general use and for use as motor starters when equipped with overcurrent protective devices (overload relays). They are identified in eleven overlapping ranges (sizes) and rated in horsepower (for motor starters) and/or continuous current capacity. They are primarily designed for use with inductive motor loads and to withstand the interrupt current of a locked rotor. They are designed with reserve capacity to perform over a broad range of applications without the need for an assessment of life requirements. The motor starters are either manual or magnetically actuated and are equipped with melting-alloy, bimetallic, or solid-state overload relays. Most of these contactors have replaceable contacts and encapsulated (sealed) coils.
IEC-rated contactors and motor starters	These contactors and motor starters perform the same functions as NEMA-rated devices but are smaller than NEMA devices for the same horsepower or current ratings. As a result, they are very application sensitive and may require rating and life assessment matches to the load. U.S. manufacturers normally provide size tables similar to NEMA tables to facilitate selection. The motor starters are usually equipped only with bimetallic overload relays. Most of these contactors do not have sealed coils and, except for the larger sizes, have nonreplaceable contacts.

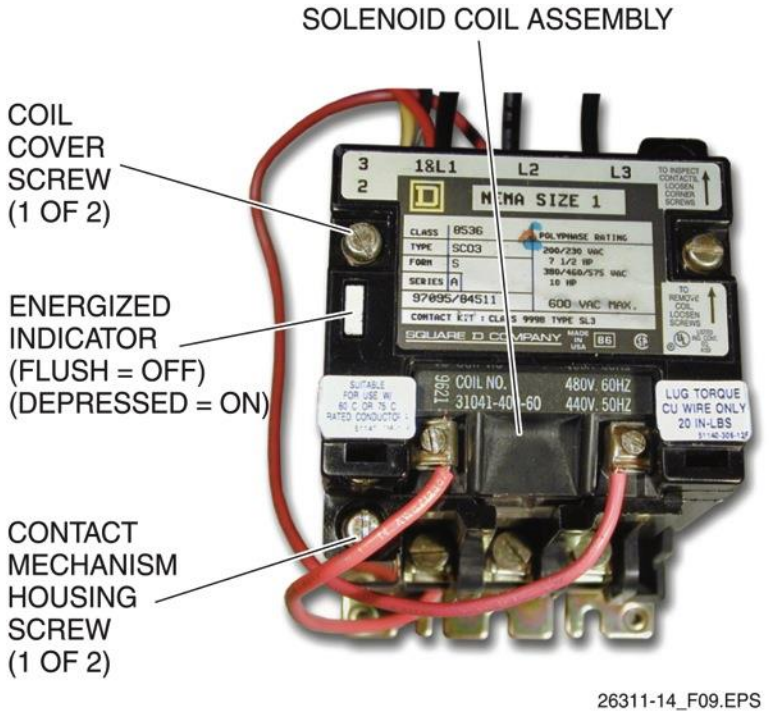
Mechanical Actions Used for Magnetic Contactors

- Like relays, magnetic contactors are used to energize or de-energize loads using a control signal and are actuated by a solenoid.
- The solenoid can be operated using a bell-crank, horizontal, or clapper action. Energizing the solenoid causes moving contacts to make with stationary contacts to close the circuit.



Typical Bell-Crank Actuated Three-Pole Magnetic Contactor

- This contactor is closed by a mechanical bell-crank assembly when the solenoid coil is energized.
- The coil and contacts are replaceable, saving the cost of having to change out the entire contactor when these components wear out.



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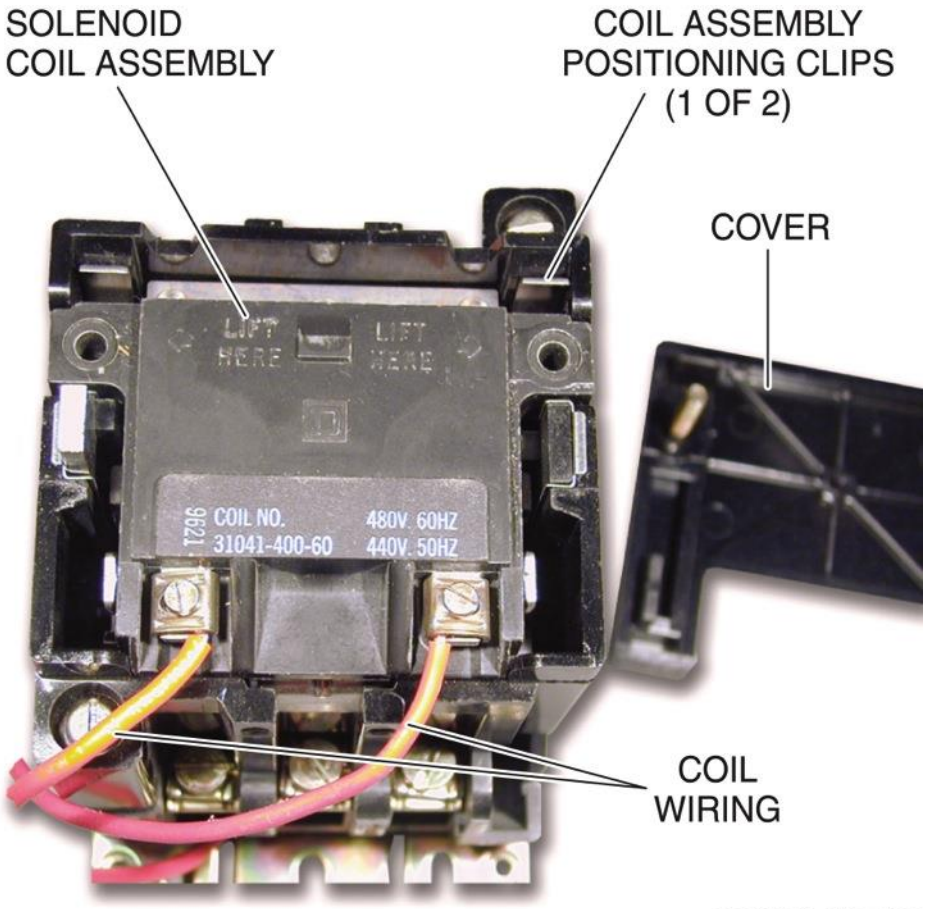
Contactor with Cover Removed



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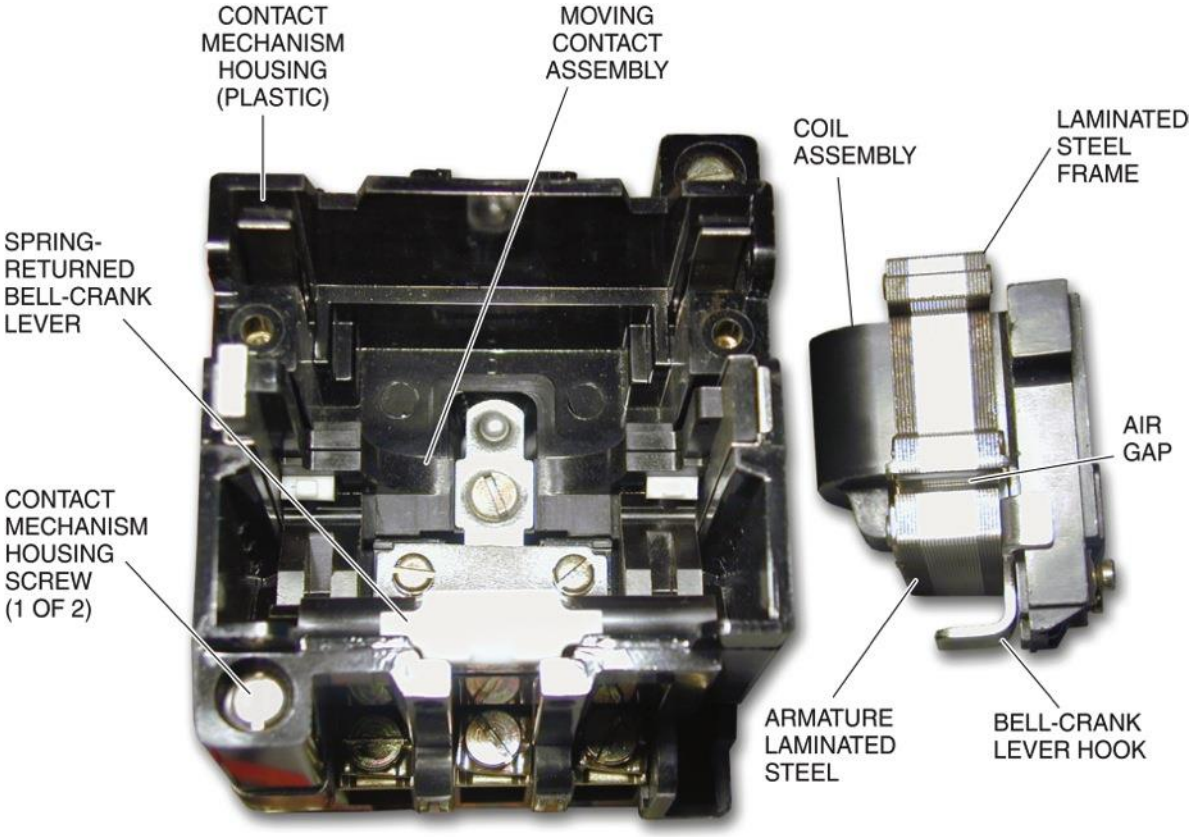
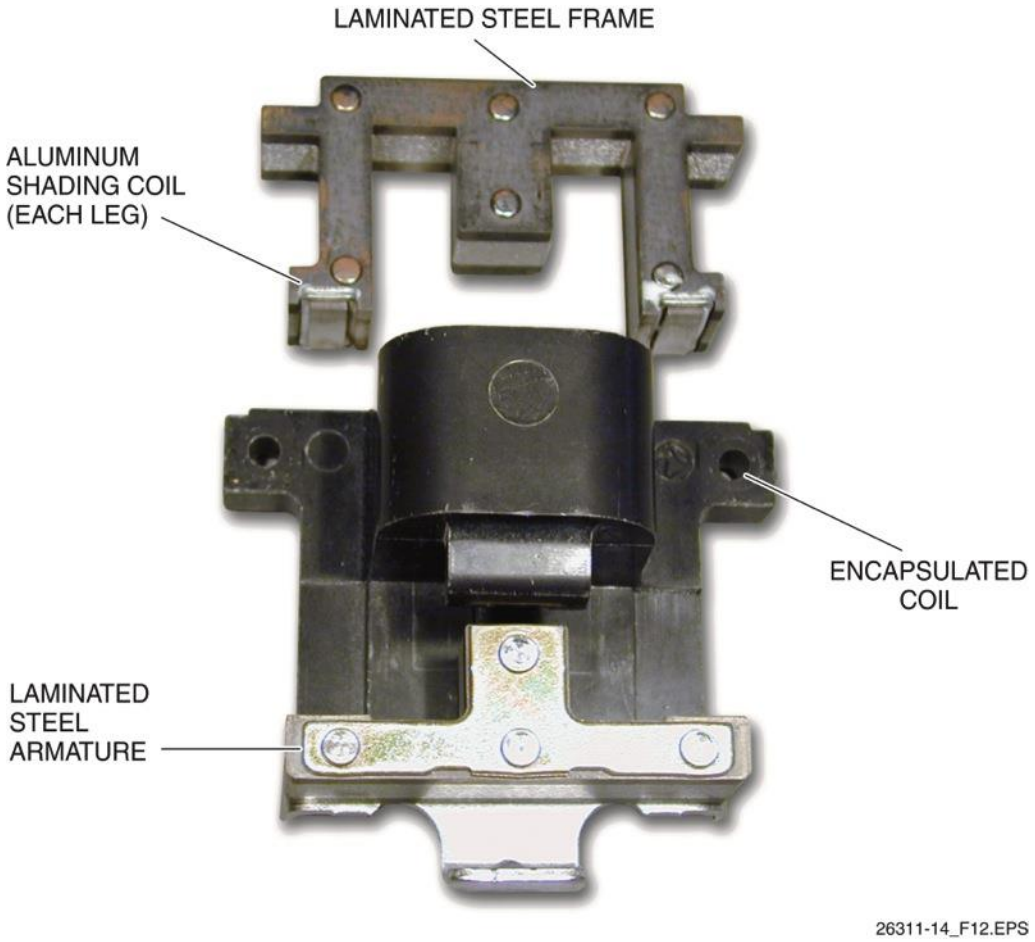
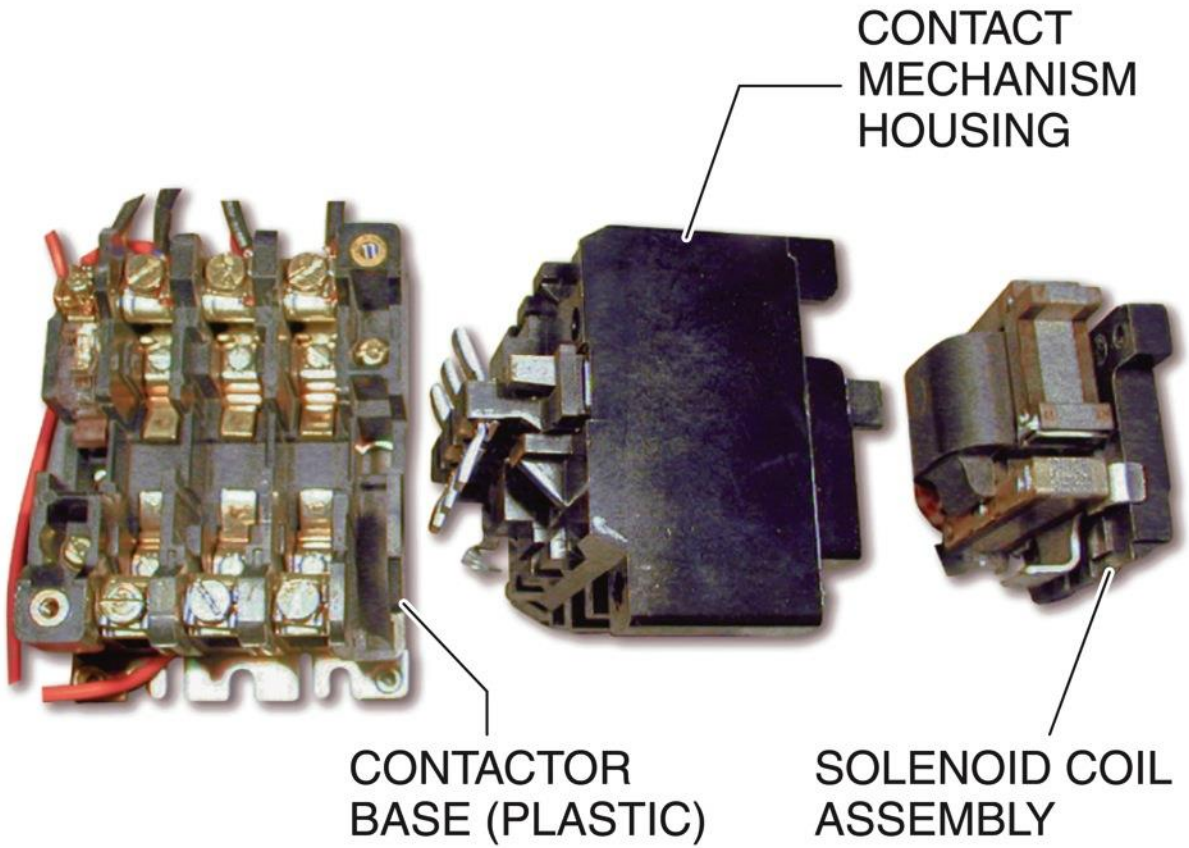
Contactor with Solenoid Coil Assembly Removed



Disassembled Solenoid Coil Assembly

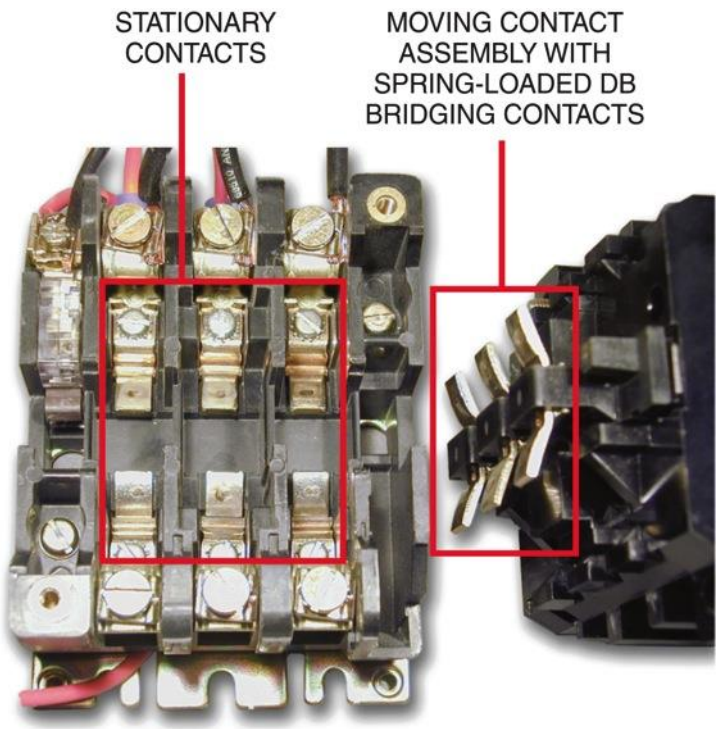


Disassembled Contactor

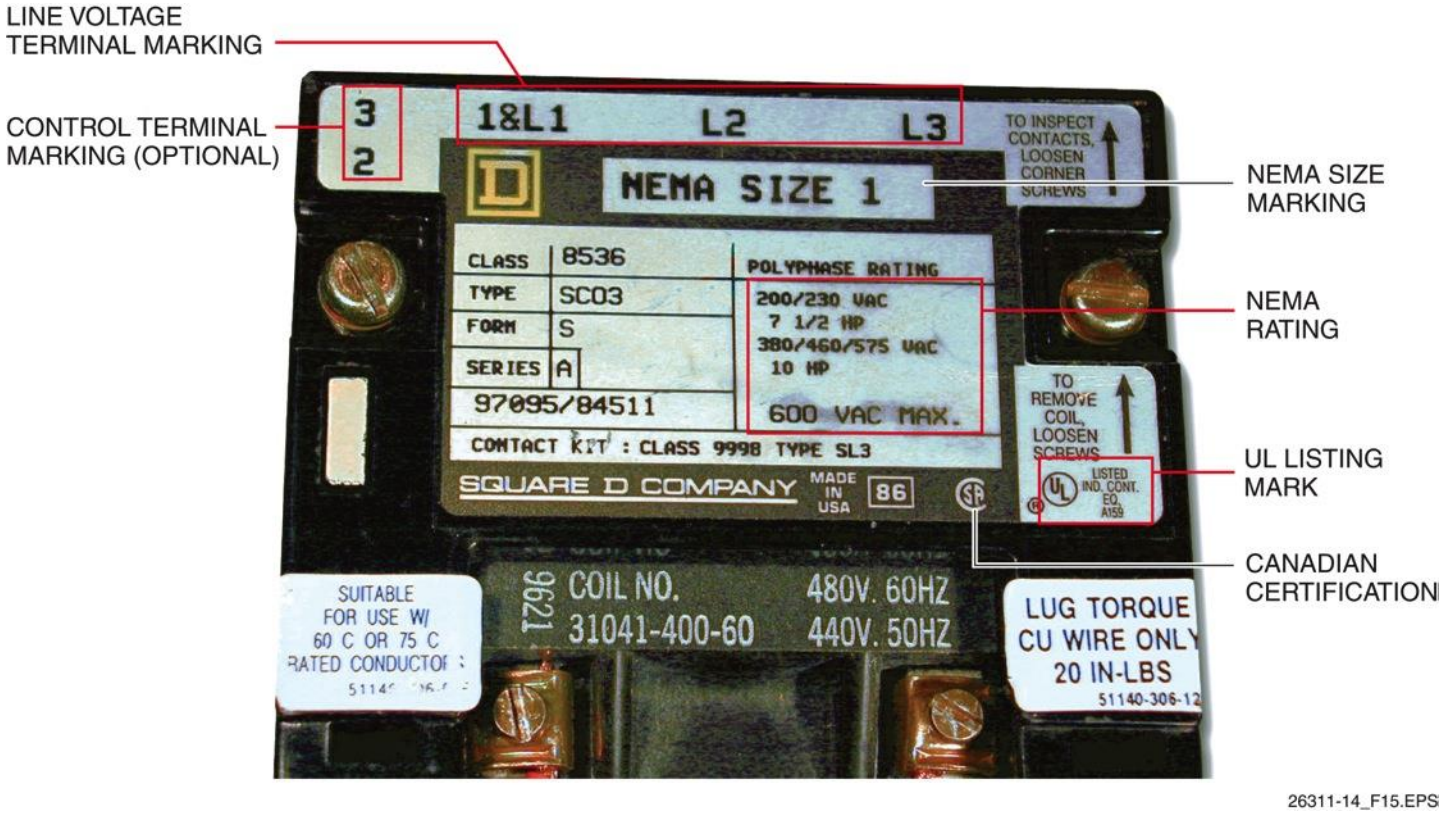


Close-Up View of Stationary and Moving Contacts

- Each bridging contact can be removed by sliding it out from its spring-loaded clip in the moving contact assembly.
- Each pair of stationary contacts can be replaced by removing the screws securing them to the contactor base.



Typical NEMA Contactor Nameplate Showing Size, Rating, and UL Listing Mark



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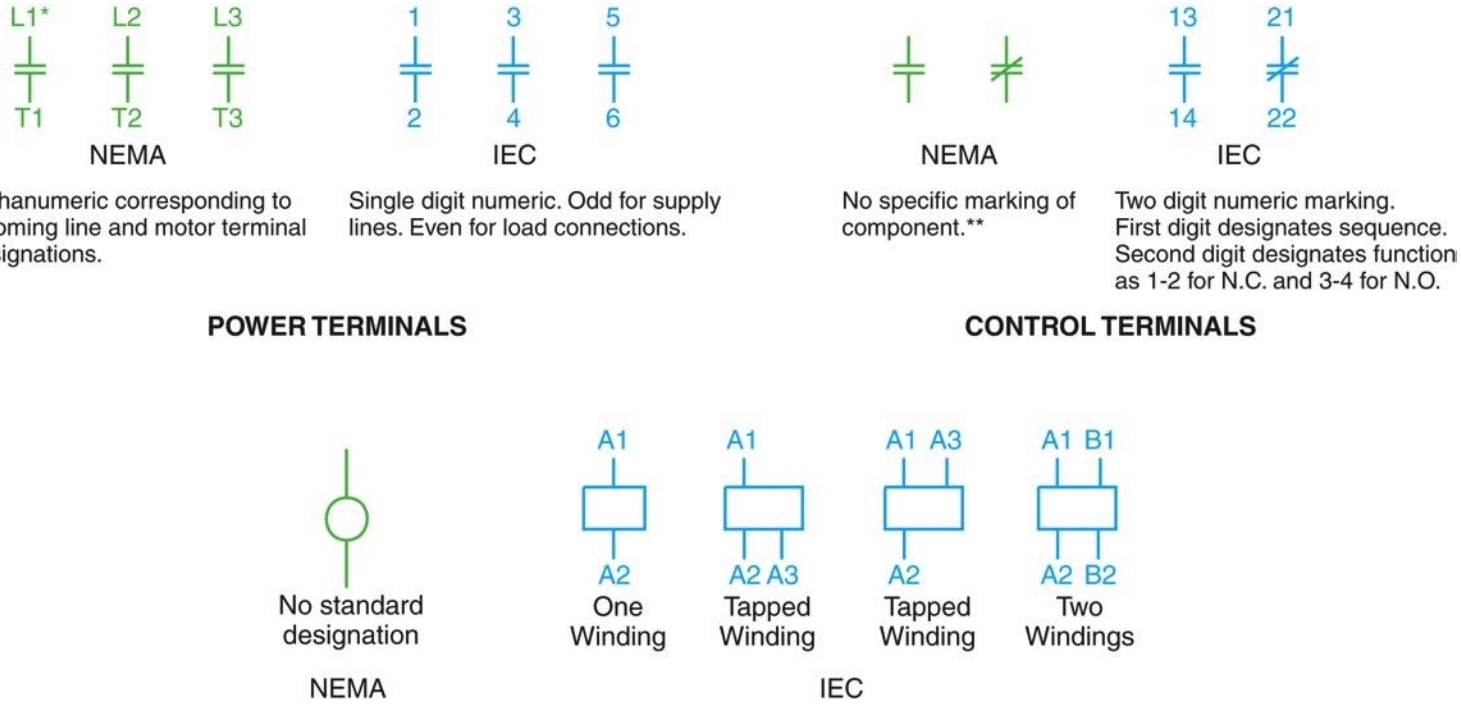
Conventional Terminal Markings



* Some manufacturers add a 1 before the L1 to designate a control-circuit voltage source connection (See *Figure 15*).
** Some manufacturers label a factory-installed control circuit (N.O.) with terminal numbers 2 and 3 (See *Figures 15* and *17*).

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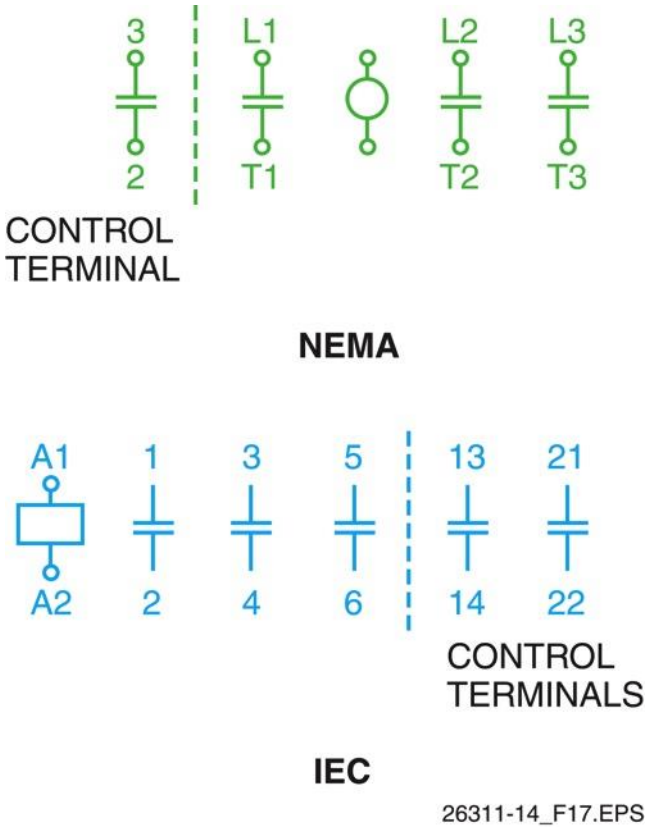
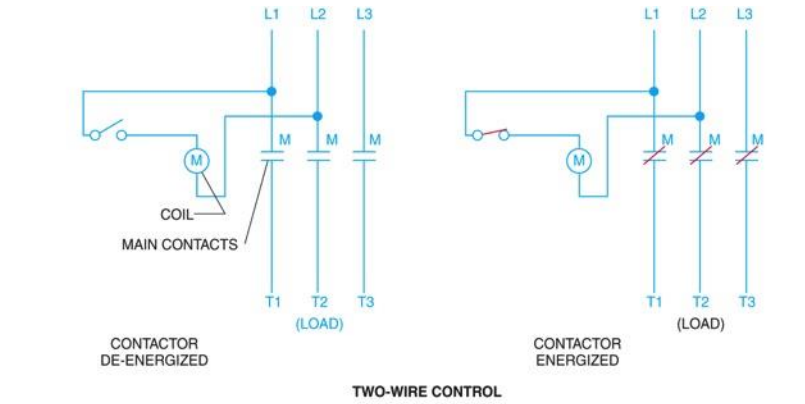
Typical Contactor/Motor Starter Marking and Symbols

- For NEMA products, the most common practice is to connect all terminals that have the same marking (i.e., T1 on the starter is connected to terminal T1 on the motor, T2 to T2, and so on).
- IEC devices use power terminals marked 1, 3, 5 and 2, 4, 6 that correspond to L1, L2, L3 and T1, T2, T3 on NEMA devices. IEC terminals carrying the same numbers are normally not connected.

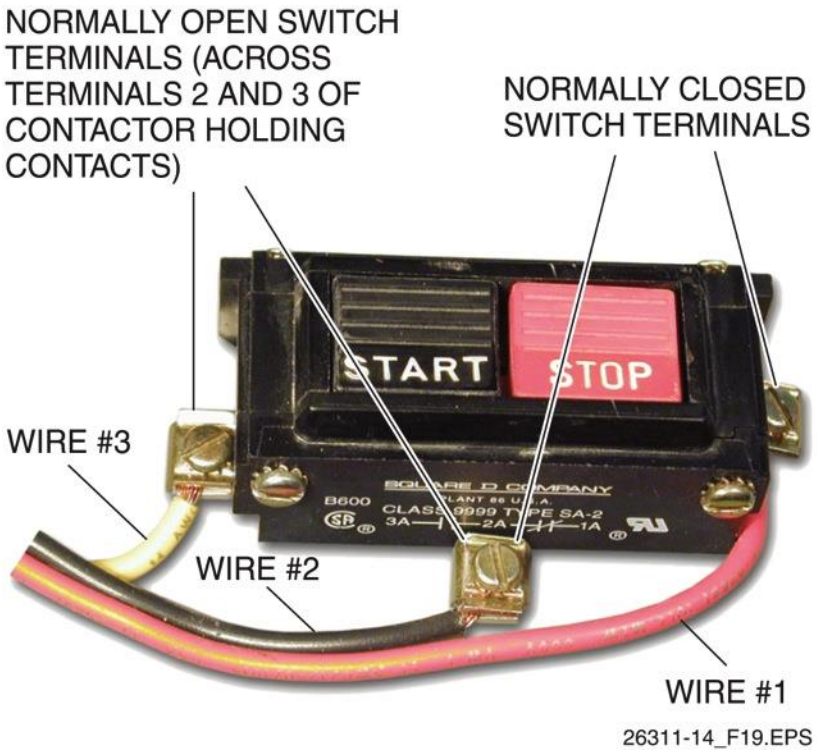


Two-Wire and Three-Wire Control Schematics



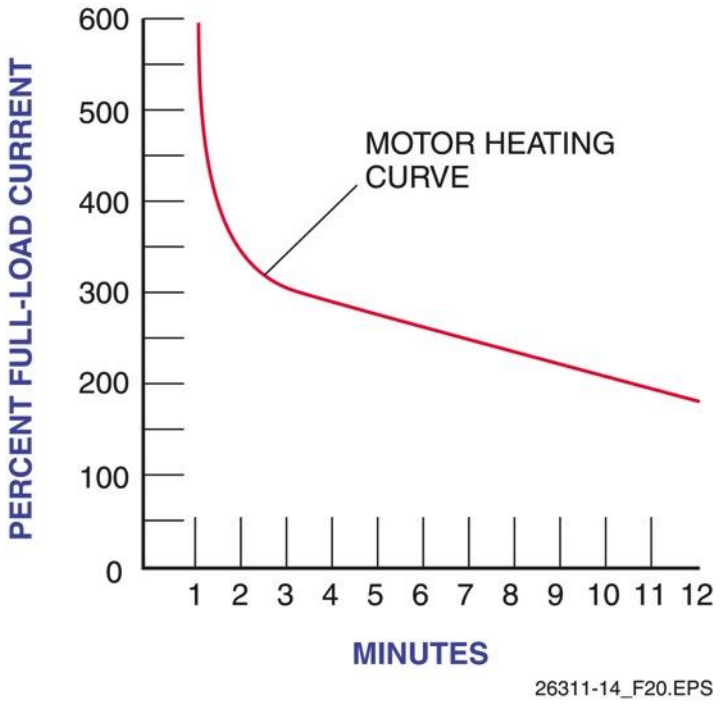
Momentary Start/Stop Switch Assembly

- A momentary start/stop switch is used to provide loss-of-voltage protection and personnel safety.
- The contactor is energized when the start button is pressed. A parallel holding contact then operates to apply control voltage to the coil. In the event of a power loss, the contactor de-energizes until the start button is pressed again.



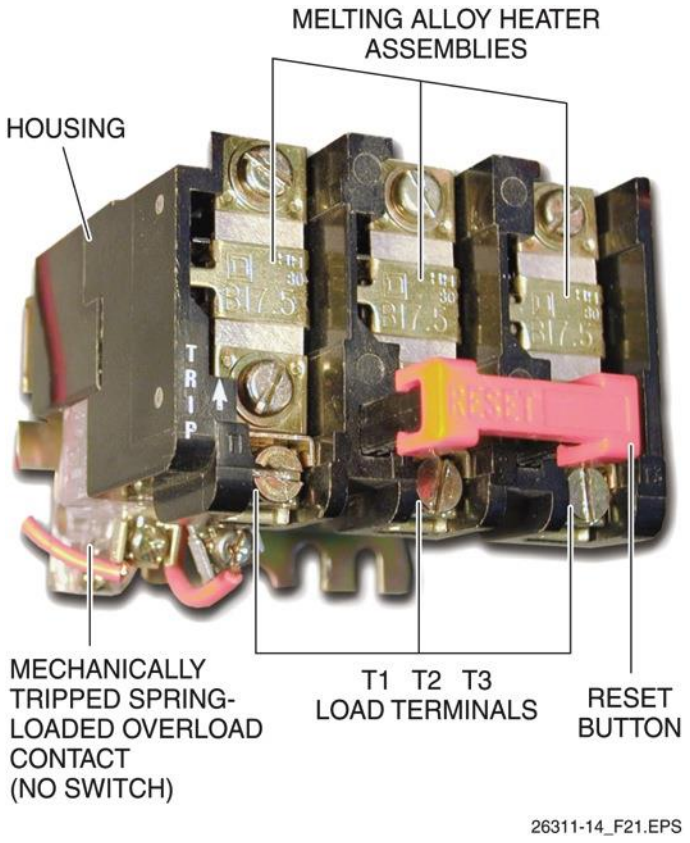
Overload Protection

- Overload relays limit the current draw of a motor due to excessive loading, low line voltage, or an open line resulting in single-phase operation.
- Overload protection is also known as running protection. The time-current curve of an overload device is similar to the heating curve of the motor.

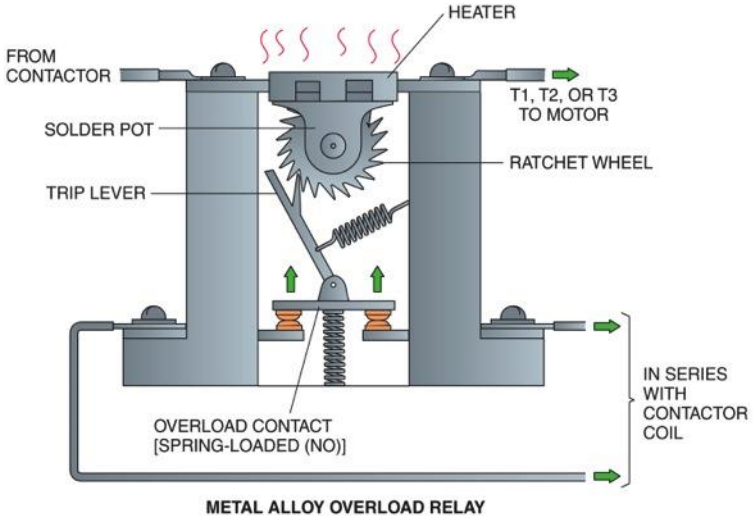


Typical Melting-Alloy Overload Relay

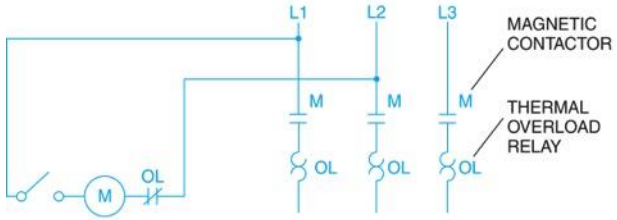
- Due to the high inrush current, a single-element fuse cannot be used to provide motor overload protection.
- Overload relays provide inverse trip-time characteristics, permitting initial high-current draw while providing protection from overloads above the full-load current. Melting-alloy relays are commonly used as overload relays.



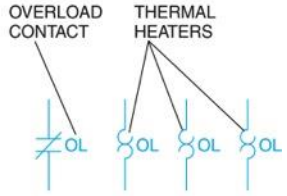
Mechanical and Symbol Representation of a Thermal Overload Relay



METAL ALLOY OVERLOAD RELAY



TYPICAL APPLICATION



THERMAL OVERLOAD RELAY SYMBOL

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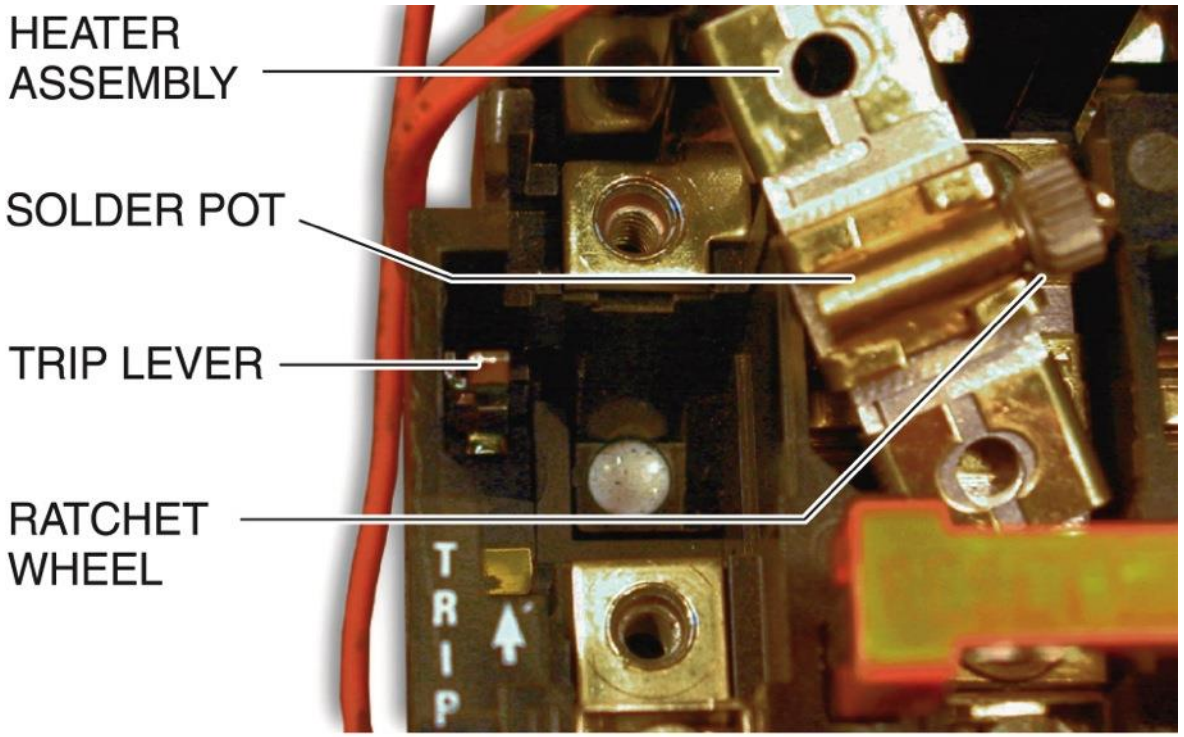
View of Melting-Alloy Heater Assembly and Trip Lever



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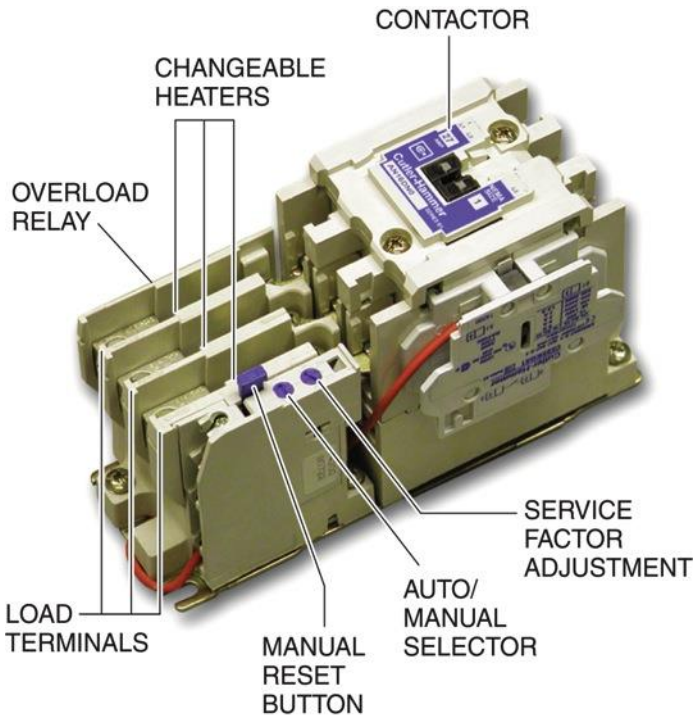
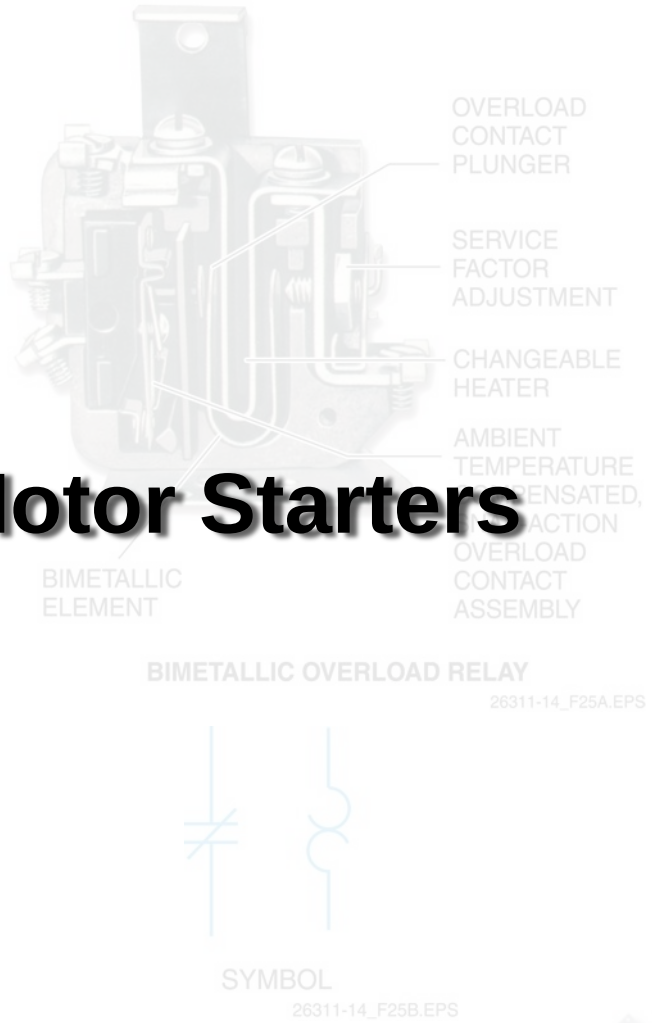
Typical Three-Pole Bimetallic Overload Relay

- IEC bimetallic overload relays have fixed heaters, while NEMA relays use interchangeable heaters to accommodate the FLCs of various motors.
- Unlike a melting-alloy relay, bimetallic overload relays are automatic reset devices. They also include service factor adjustment and ambient temperature compensation.



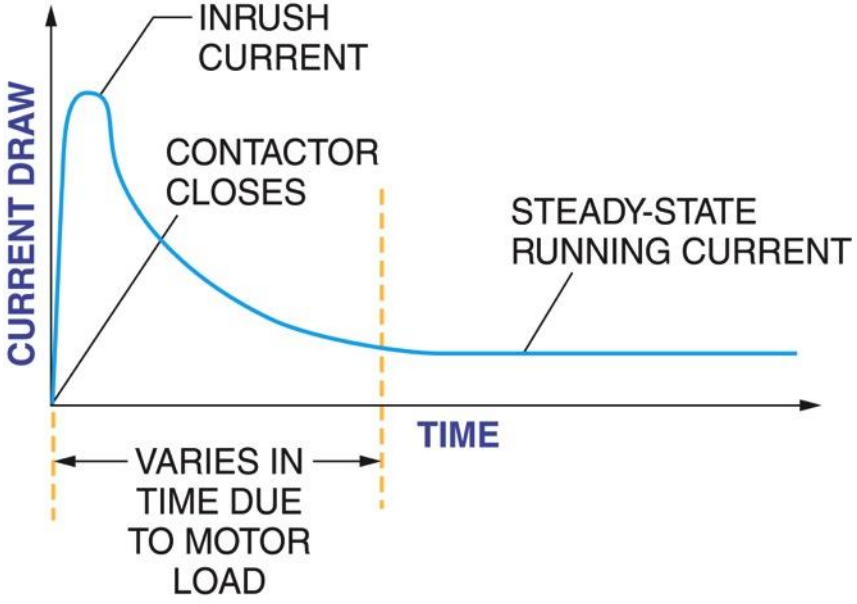
Next Session…

Magnetic and Manual Motor Starters



Magnetic and Manual Motor Starters

- NEMA-rated motor starters contain magnetic contactors and overload relays assembled into a controller that includes complete control circuit wiring and power circuits from the line to load terminals.
- IEC-rated motor starters are not factory-wired and must be assembled onsite.



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IEC and NEMA Product Comparison Summary

Subject	IEC	NEMA
Starter size	Physically smaller	Physically larger
Contactor performance	Electrical life [equals] 1 million for AC-3 category operations with 30,000 for AC-4 category operations	Electrical life typically 2.5 to 4 times more than equivalently rated IEC device
Contactor application	Application sensitive—more knowledge and care in selection required	Application selection easier and less critical with fewer parameters to consider
Overload relay trip reset characteristics	Class 10 (fast) typical	Class 20 (Standard) typical
Overload relay adjustability	Fixed, noninterchangeable heaters; adjustable to suit different motors at the same horsepower	Field changeable heaters allow adjustment for motors of different horsepower
Overload relay reset mechanism	Manual/Auto typical; some use Reset/Stop dual function mechanism	Manual/Auto or Manual Only typical
Short circuit current rating	Typically designed for use with fast-acting, current-limiting fuses	Designed for use with common domestic current rating fuses and circuit breakers

Typical NEMA Nonreversing and Reversing Magnetic Motor Starters and Symbol Representations

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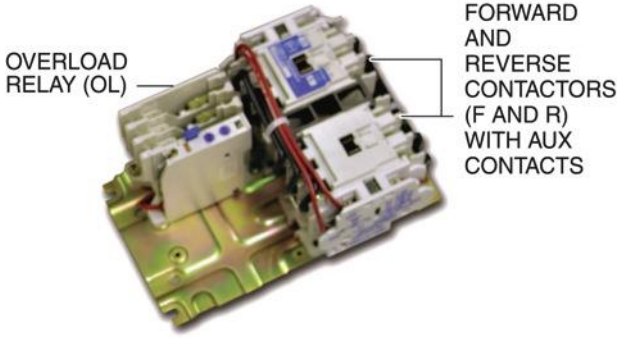

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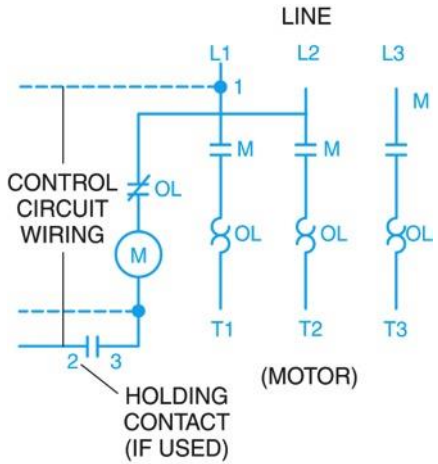

NONREVERSING STARTER

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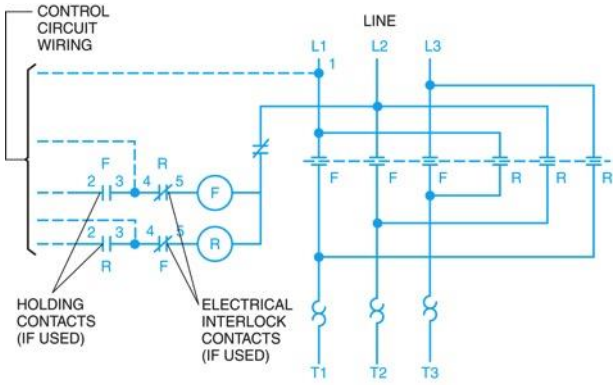

REVERSING STARTER

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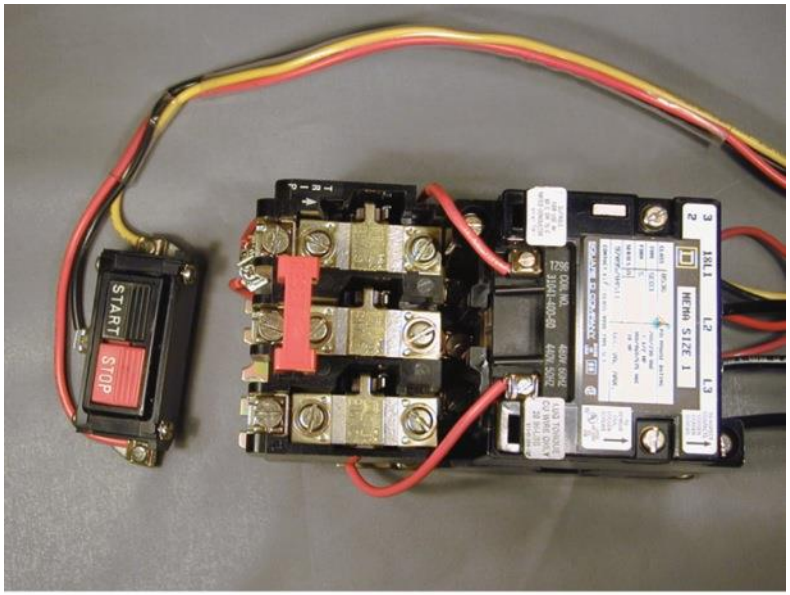
Typical NEMA Size 1 Motor Starter Wired with a Three-Wire Stop/Start Switch

The most common NEMA or IEC magnetic motor starters are nonreversing and reversing types for wye, delta, and wye/delta combination motors.



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Sizes for Contactors and Motor Starters

NEMA Size	Volts	Maximum Horsepower Rating—Nonplugging and Nonjogging Duty[1]		Maximum Horsepower Rating—Plugging and Jogging Duty[1]		Continuous Current Rating, Amperes 600V Max[2]
		Single Phase	Poly-Phase	Single Phase	Poly-Phase	
00	115	⅓	—	—	—	9
	200	—	1½	—	—	9
	230	1	1½	—	—	9
	380 (50Hz)	—	1½	—	—	9
	460	—	2	—	—	9
	575	—	2	—	—	9
0	115	1	—	½	—	18
	200	—	3	—	1½	18
	230	2	3	1	1½	18
	380 (50Hz)	—	5	—	1½	18
	460	—	5	—	2	18
	575	—	5	—	2	18
1	115	2	—		—	27
	200	—	7½	—	3	27
	230	3	7½		3	27
	380 (50Hz)	—	10	—	5	27
	460	—	10	—	5	27
	575	—	10	—	5	27
2	115	3	—	2	—	45
	200	—	10	—	7½	45
	230	7½	15	5	10	45
	380 (50Hz)	—	25	—	15	45
	460	—	25	—	15	45
	575	—	25	—	15	45
3	115	7½	—	—	—	90
	200	—	25	—	15	90
	230	15	30	—	20	90
	380 (50Hz)	—	50	—	30	90
	460	—	50	—	30	90
	575	—	50	—	30	90
4	200	—	40	—	25	135
	230	—	50	—	30	135
	380 (50Hz)	—	75	—	50	135
	460	—	100	—	60	135
	575	—	100	—	60	135
5	200	—	75	—	60	270
	230	—	100	—	75	270
	380 (50Hz)	—	150	—	125	270
	460	—	200	—	150	270
	575	—	200	—	150	270
6	200	—	150	—	125	540
	230	—	200	—	150	540
	380 (50Hz)	—	300	—	250	540
	460	—	400	—	300	540
	575	—	400	—	300	540
7	230	—	300	—	—	810
	460	—	600	—	—	810
	575	—	600	—	—	810
8	230	—	450	—	—	1215
	460	—	900	—	—	1215
	575	—	900	—	—	1215
9	230	—	800	—	—	2250
	460	—	1600	—	—	2250
	575	—	1600	—	—	2250

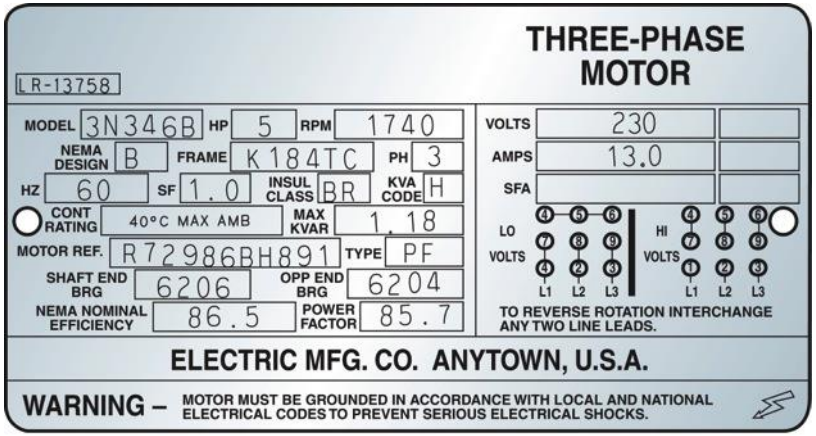
its locked-rotor current rating is not exceeded. (2) The continuous current ratings represent the maximum rms current, in amperes, which the controller shall be permitted to carry continuously without exceeding the temperature rises permitted by *NEMA Standard ICS 1*. (3) The service limit current ratings represent the maximum rms current, in amperes, which the controller shall be permitted

Sizes for Contactors and Motor Starters

Service-Limit Current Rating, Amperes[3]	Tungsten and Infrared Lamp Load, Amperes 250V Max[2]	Resistance Heating Loads, kW other than Infrared Lamp Loads		KVA Rating for Switching Transformer Primaries at 50 or 60 Cycles		3-Phase Rating for Switching Capacitors Kvar
		Single Phase	Poly-Phase	Single Phase	Poly-Phase	
11	5	—	—	—	—	—
11	5	—	—	—	—	—
11	5	—	—	—	—	—
11	—	—	—	—	—	—
11	—	—	—	—	—	—
11	—	—	—	—	—	—
21	10	—	—	0.9	1.2	—
21	10	—	—	—	1.4	—
21	10	—	—	1.4	1.7	—
21	—	—	—	—	2.0	—
21	—	—	—	1.9	2.5	—
21	—	—	—	1.9	2.5	—
32	15	3	5	1.4	1.7	—
32	15	—	9.1	—	3.5	—
32	15	6	10	1.9	4.1	—
32	—	—	16.5	—	4.3	—
32	—	12	20	3	5.3	—
32	—	15	25	3	5.3	—
52	30	5	8.5	1.0	4.1	—
52	30	—	15.4	—	6.6	11.3
52	30	10	17	4.6	7.6	13
52	—	—	28	—	9.9	21
52	—	20	34	5.7	12	26
52	—	25	43	5.7	12	33
104	60	—	—	0.9	7.6	—
104	60	—	—	—	13	23.4
104	60	—	—	1.4	15	27
104	—	—	—	—	19	43.7
104	—	—	—	1.9	23	53
104	—	—	—	1.9	23	67
156	120	—	45	—	20	34
156	120	30	52	11	23	40
156	—	—	86.7	—	38	66
156	—	60	105	22	46	80
156	—	75	130	22	46	100
311	240	—	91	—	40	69
311	240	60	105	28	46	80
311	—	—	173	—	75	132
311	—	120	210	40	91	160
311	—	150	260	40	91	200
621	480	—	182	—	79	139
621	480	120	210	57	91	160
621	—	—	342	—	148	264
621	—	240	415	86	180	320
621	—	240	515	86	180	400
932	720	180	315	—	—	240
932	—	360	625	—	—	480
932	—	450	775	—	—	600
1400	1080	—	—	—	—	360
1400	—	—	—	—	—	720
1400	—	—	—	—	—	900
8590	—	—	—	—	—	—
2590	—	—	—	—	—	—
2590	—	—	—	—	—	—

Typical Motor Nameplate

- The motor nameplate information is essential and must be used instead of measured values or manufacturer tables whenever possible.
- Nameplate data includes the rated voltage and frequency, FLC or FLA, phase, NEMA Design letter, horsepower, service factor, and power factor.



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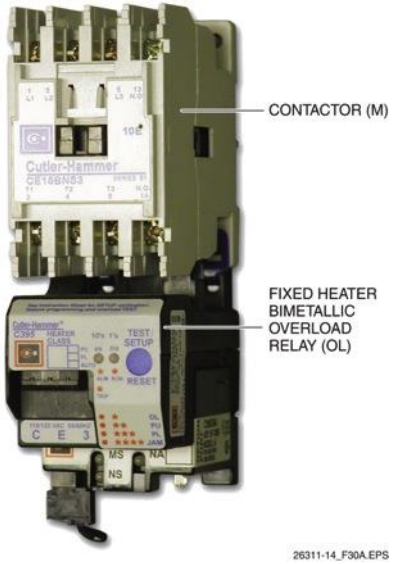
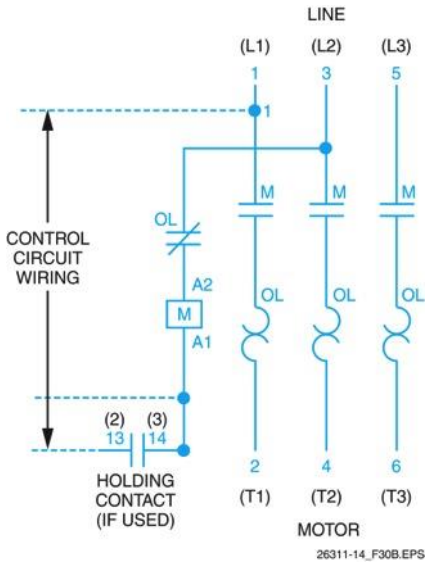
Typical IEC-Rated, Nonreversing Motor Starter and IEC Symbol Representation

- IEC-rated contactors and motor starters are not produced in standard sizes like NEMA-rated starters.
- The characteristics, marking, and construction requirements for IEC-rated contactors and motor starters are covered in *IEC Standard 60947*.





IEC Categories for Lighting and Motor Control

IEC-rated contactors/motor starters are built to meet the requirements of defined applications called utilization categories.

Category	Typical Application
AC-1	Noninductive or slightly inductive loads
AC-2	Slip-ring motor starting and switching off
AC-3	Squirrel-cage motor starting and switching off
AC-4	Squirrel-cage motor starting, plugging, and jogging
AC-5a	Switching electric discharge lighting loads
AC-5b	Switching large incandescent lighting loads
AC-6a	Switching transformer loads
AC-6b	Switching capacitor loads
AC-11	Control of AC electromagnetic circuits (auxiliary contacts)

Common IEC Categories for Motor Control Devices

- IEC contactor/motor starter selection is based on the percent that jogging and plugging (AC-4) is of the nonjogging and plugging (AC-3) condition in the duty cycle and the desired contact electrical life.
- Jogging and plugging applications generally require the use of a larger contactor/motor starter.

Category	Application
AC-1	These devices are used with noninductive or slightly inductive loads, such as resistive furnaces, fluorescent lights, and incandescent lights.
AC-3	These devices are used in squirrel-cage motors for starting and switching off while running at rated speed. They include contact-make capability for locked-rotor current and break at full-load current. They are occasionally used for jogging and plugging for limited times such as machine setup. During such periods, the number of operations should not exceed five per minute nor more than ten in a ten-minute period.
AC-4	These devices are used in squirrel-cage motors for starting and switching off while running at less than rated speed. They provide jogging, plugging stop, and plugging reverse, and include contact make-and-break capability for locked-rotor current. Very few applications in the industry are totally Category AC-4.

Typical NEMA Manual Motor Starter

- Manual motor starters are used on small machine tools, fans, blowers, pumps, compressors, and conveyors.
- Instead of magnetically closed contacts, these starters are operated using a pushbutton or toggle switch.

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Typical Contactor/Motor Starter Accessories

DOUBLE-POWER POLE ADDER

EXTERNAL SINGLE-CIRCUIT AUXILIARY

INTERNAL SINGLE-CIRCUIT AUXILIARY

TRANSIENT SUPPRESSION MODULE

FUSE KIT

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Control Transformers and Pilot Devices

- Control transformers provide the operating voltage for motor control circuits and their components, while pilot devices control the operation of relays and other motor controls.
- The advantages of using a low-voltage control circuit include increased operator safety, reduced faults, and lower-cost equipment.

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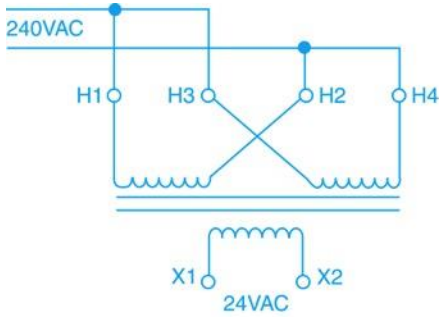
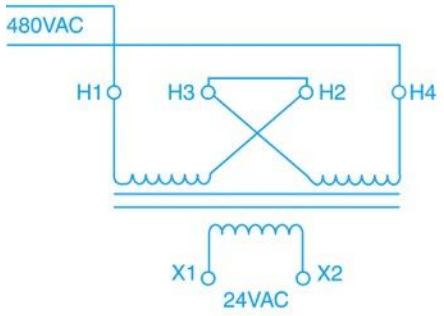
Control Transformer Schematic Shown Connected for 240V/480V Primary and 24V Secondary Operation

- This control transformer has two primary windings and one secondary winding. It can be connected to step down either 240V or 480V.
- The factors involved in selecting a control transformer include the inrush and steady-state VA, the primary voltage, and the secondary voltage required for the control circuit.



(A) CONNECTED FOR 240-VOLT TO 24-VOLT OPERATION



(B) CONNECTED FOR 480-VOLT TO 24-VOLT OPERATION

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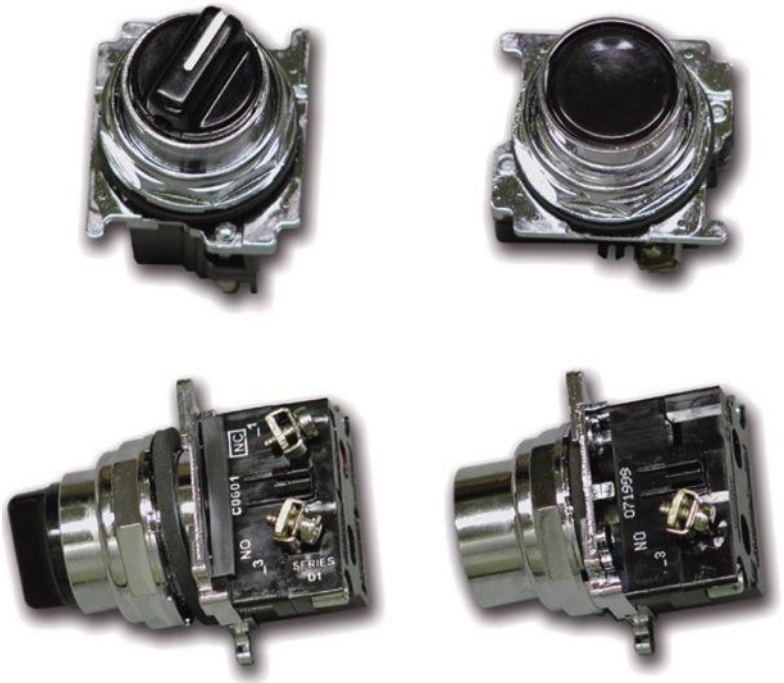
Regulation Data Chart

- Selecting a control transformer begins by calculating the application inrush VA.
- Next, select a secondary voltage percentage based on the stability of the primary voltage. Find the application inrush VA equal to or greater than the calculated inrush VA, and locate the transformer size in the first column.

	Application Inrush VA at 20% Power Factor		
Transformer VA Rating	95% Secondary Voltage	90% Secondary Voltage	85% Secondary Voltage
25	100	130	150
50	170	200	240
75	310	410	540
100	370	540	730
150	780	930	1,150
200	810	1,150	1,450
250	1,400	1,900	2,300
300	1,900	2,700	3,850
350	3,100	3,650	4,800
500	4,000	5,300	7,000
750	8,300	11,000	14,000

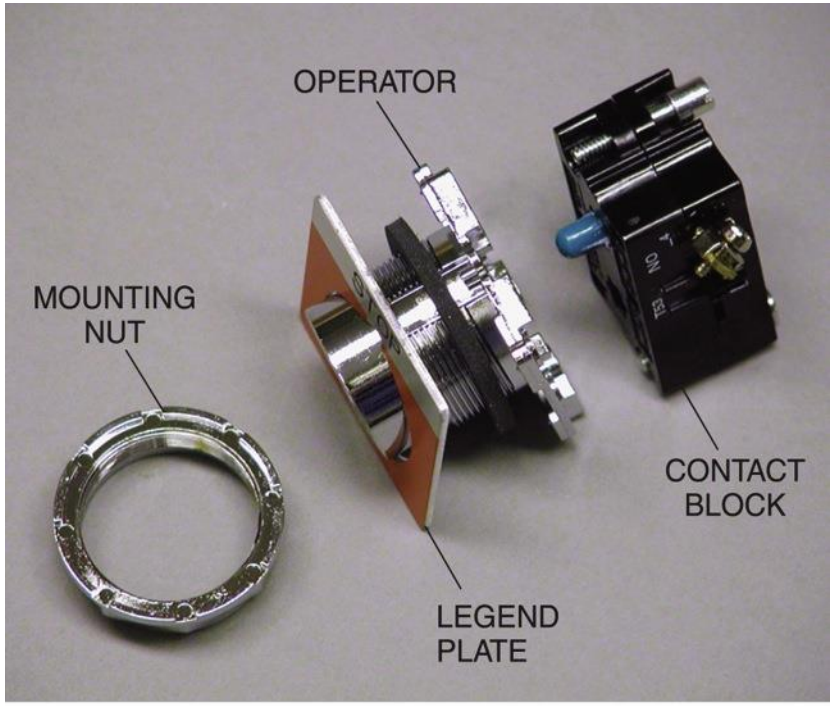
Typical Pushbutton and Selector Switches

- Two common types of pilot devices are pushbutton and selector switches. Both standard-duty and heavy-duty versions are available.
- Many pushbutton switches have interchangeable parts that can be assembled to suit the specific application.



Typical Parts of a Pushbutton Switch

- The main components of a pushbutton switch include the operator, the contact block, and the legend plate.
- Operators are the part of the switch that is pressed or pulled to activate the contacts. The switch contact block can contain N.O. or N.C. contacts or both.



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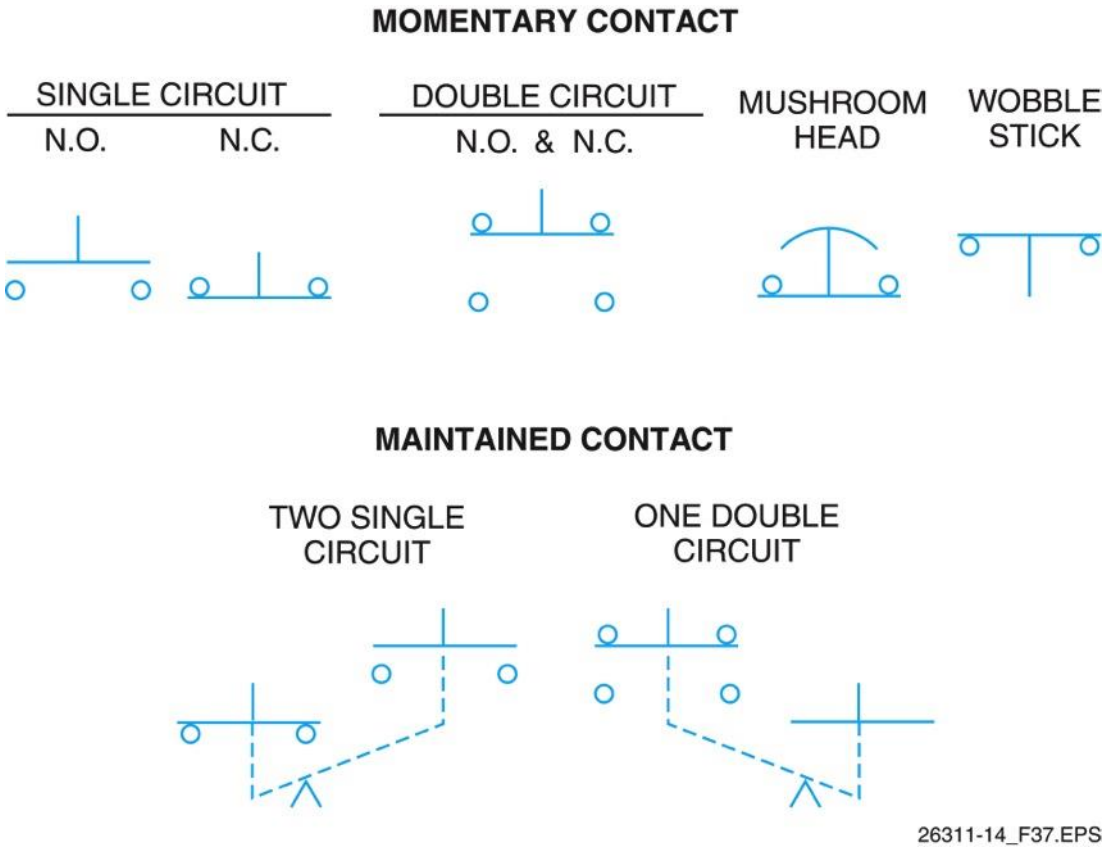
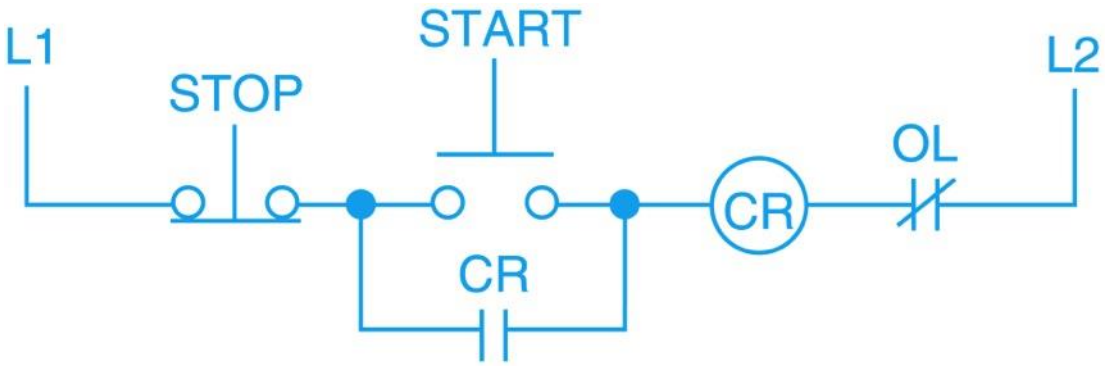
Schematic Symbols for Pushbutton Switches



Stop and Start Pushbutton Switches Used in a Basic Control Circuit



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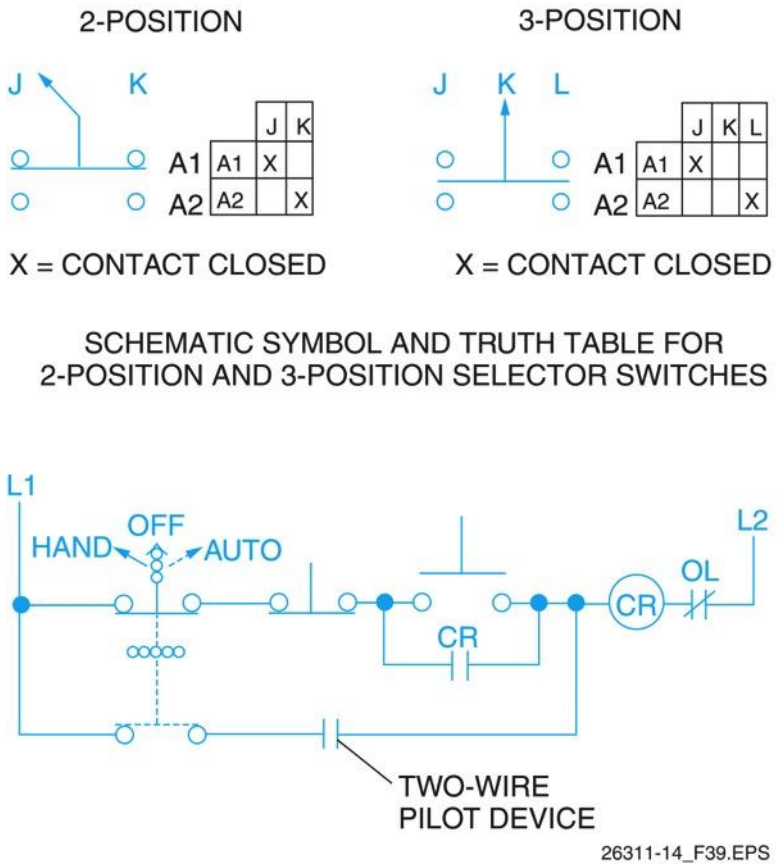
Selector Switch Schematic Symbols and Typical Control Circuit



- Selector switches can be rotated to activate the contacts for each switch position.
- The contact positions for each switch position can be found using a truth table.

Joystick Operated Selector Switch

- Some selector switches use a joystick operator that can provide up to eight switch positions.
- Joystick switches are commonly found in equipment such as hoists and cranes where only one circuit is to be energized at a time.

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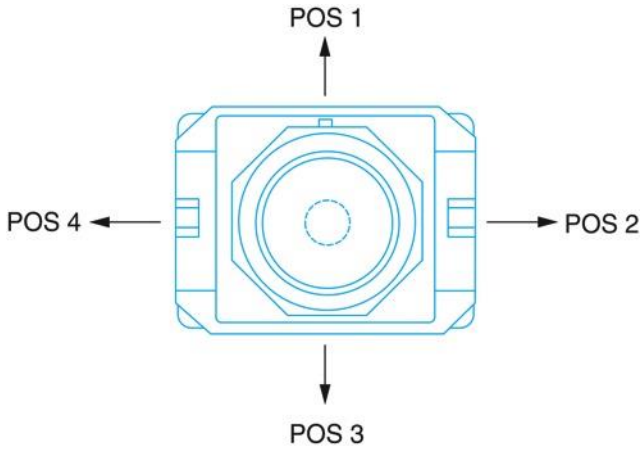

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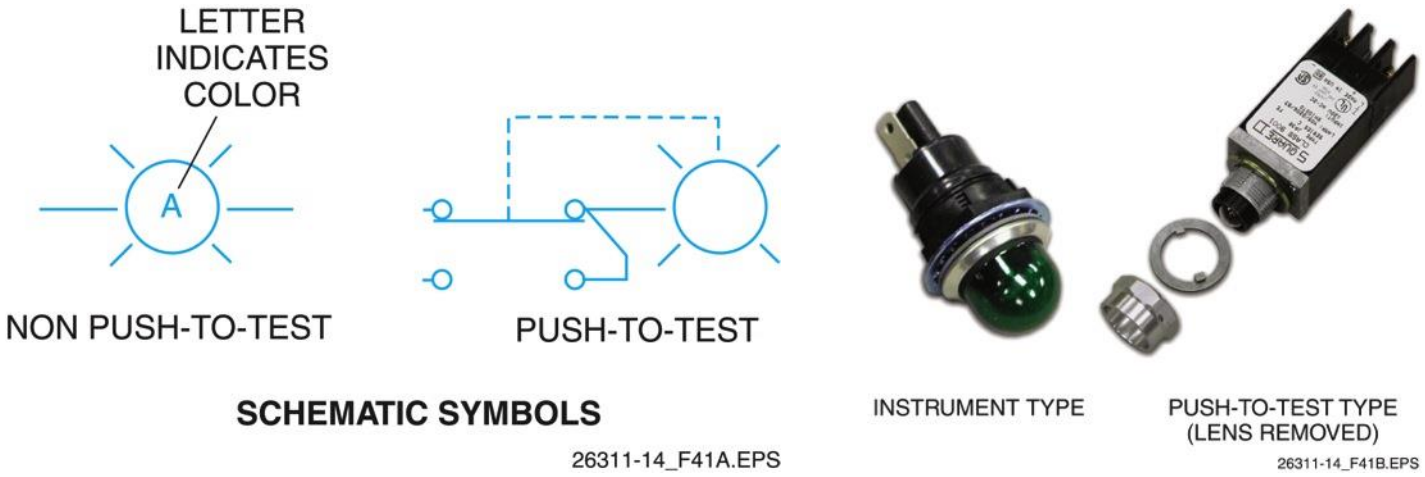
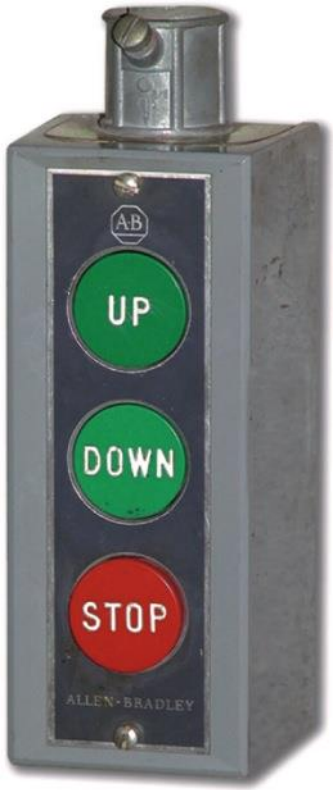
Typical Pilot Light Assemblies

- A pilot light provides a visual indication of a circuit condition. Pilot lights can either be separate assemblies or built into a pushbutton switch assembly.
- Lights are available with various lens colors and may use either small incandescent bulbs or LEDs.



Example Pushbutton Station

- Pushbutton stations are used to house one or more pushbutton assemblies, selector switches, and/or pilot lights to protect them from dust, dirt, or fluids.
- They are available unassembled or with pre-installed switches.



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Rating Codes for AC and DC Control Circuit Contacts

Rating Codes for AC Control Circuit Contacts at 50 and 60 Hertz(†)

Contact Rating Code Designation*	Thermal Continuous Test Current (Amperes)	120 Volt		240 Volt		480 Volt		600 Volt		Maximum Volt-Amperes	
		Make	Break	Make	Break	Make	Break	Make	Break	Make	Break
A150	10	60	6.0	—	—	—	—	—	—	7200	720
A300	10	60	6.0	30	3.00	—	—	—	—	7200	720
A600	10	60	6.0	30	3.00	15	1.50	12	1.20	7200	720
B150	5	30	3.00	—	—	—	—	—	—	3600	360
B300	5	30	3.00	15	1.50	—	—	—	—	3600	360
B600	5	30	3.00	15	1.50	7.50	0.75	6	0.60	3600	360
C150	2.5	15	1.5	—	—	—	—	—	—	1800	180
C300	2.5	15	1.5	7.5	0.75	—	—	—	—	1800	180
C600	2.5	15	1.5	7.5	0.75	3.75	0.375	3.00	0.30	1800	180
D150	1.0	3.60	0.60	—	—	—	—	—	—	432	72
D300	1.0	3.60	0.60	1.80	0.30	—	—	—	—	432	72
E150	0.5	1.80	0.30	—	—	—	—	—	—	216	36

*)The numerical suffix designates the maximum voltage design values, which are to be 600, 300, and 150 volts for suffixes 600, 300, and 150, espectively. The test voltage is to be 600, 240, or 120 volts. (†) For maximum ratings at voltages between the maximum design value and 20 volts, the maximum make and break ratings are to be obtained by dividing the volt-amperes rating by the application voltage. For voltages elow 120 volts, the maximum make current is to be the same as for 120 volts, and the maximum break current is to be obtained by dividing he break volt-amperes by the application voltage, but these currents are not to exceed the thermal continuous test current.

Rating Codes for DC Control Circuit Contacts

Contact Rating Code Designation*	Thermal Continuous Test Current (Amperes)	Maximum Make or Break Current, Amperes			Maximum Make or Break Volt-Amperes At 300 Volts or Less
		125 Volt	250 Volt	301 to 600 Volt	
N150	10.0	2.2	—	—	275
N300	10.0	2.2	1.1	—	275
N600	10.0	2.2	1.1	0.40	275
P150	5.0	1.1	—	—	138
P300	5.0	1.1	0.55	—	138
P600	5.0	1.1	0.55	0.20	138
Q150	2.5	0.55	—	—	69
Q300	2.5	0.55	0.27	—	69
Q600	2.5	0.55	0.27	0.10	69
R150	1.0	0.22	—	—	28
R300	1.0	0.22	0.11	—	28

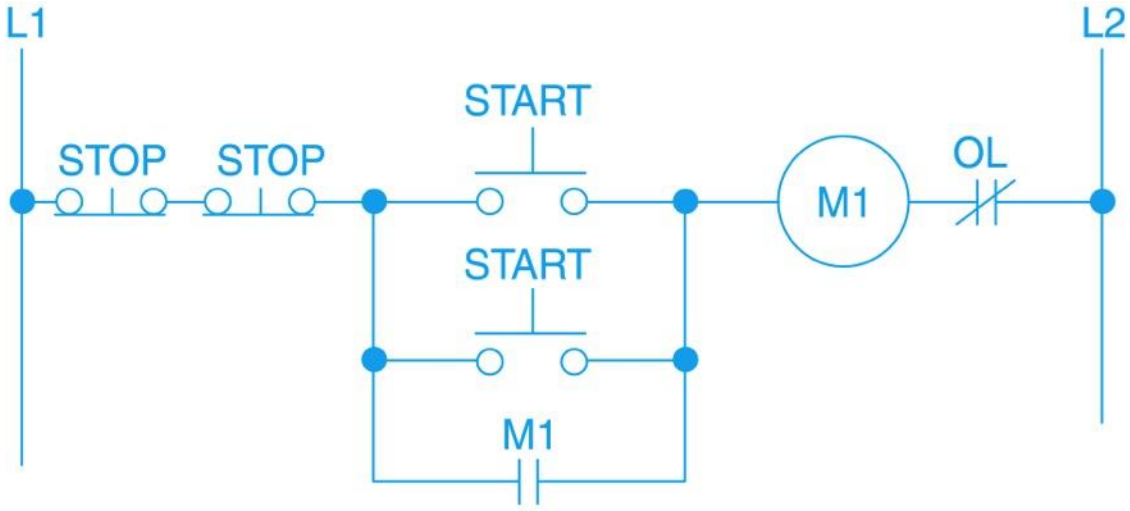
*)The numerical suffix designates the maximum voltage design values, which are to be 600, 300, and 150 volts for suffixes 600, 300, and 50, respectively. Test voltage shall be 600, 240, or 120 volts. (†) For maximum ratings at 300 volts or less, the maximum break ratings are to e obtained by dividing the volt-ampere rating by the application voltage, but the current values are not to exceed the thermal continuous test urrent.

Utilization Categories for Control Circuit Switching Elements

Utilization Categories for Switching Elements		
Kind of Current	**Category**	**Typical Applications**
Alternating Current	AC-12	Control of resistive loads and solid-state loads with optical isolation
	AC-13	Control of solid-state loads with transformer isolation
	AC-14	Control of small electromagnetic loads (max. 72VA closed)
	AC-15	Control of electromagnetic loads (greater than 72VA closed)
Direct Current	DC-12	Control of resistive loads and solid-state loads with optical isolation
	DC-13	Control of electromagnets
	DC-14	Control of electromagnet loads having economy resistor in circuit

Multiple Start and Stop Pushbuttons

- Multiple Start and Stop pushbuttons are used where motors must be controlled from more than one location.
- Start buttons are connected in parallel with the original Start button, while Stop buttons must be connected in series with the original Stop button.



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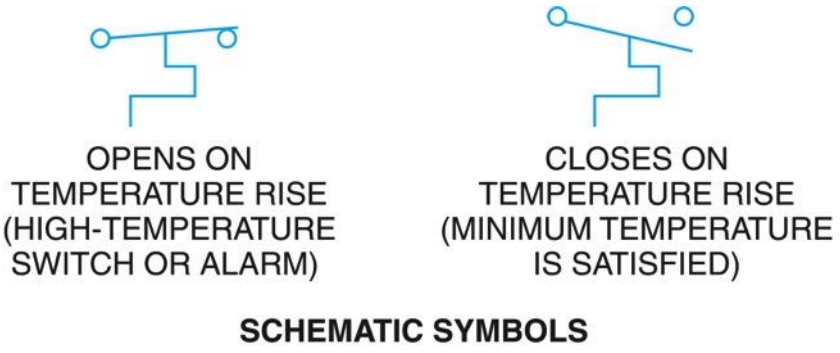
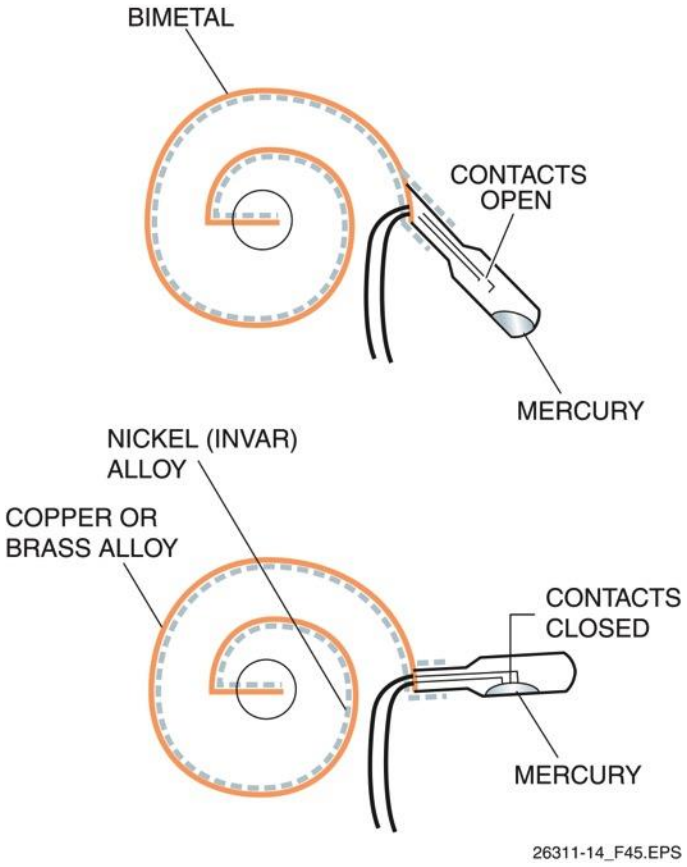
Typical Temperature Switches

- Temperature switch contacts open or close in response to a rise or fall in temperature.
- Temperature switches are used in the control circuits of many applications, including heating/cooling systems, fire alarm systems, and process control systems.



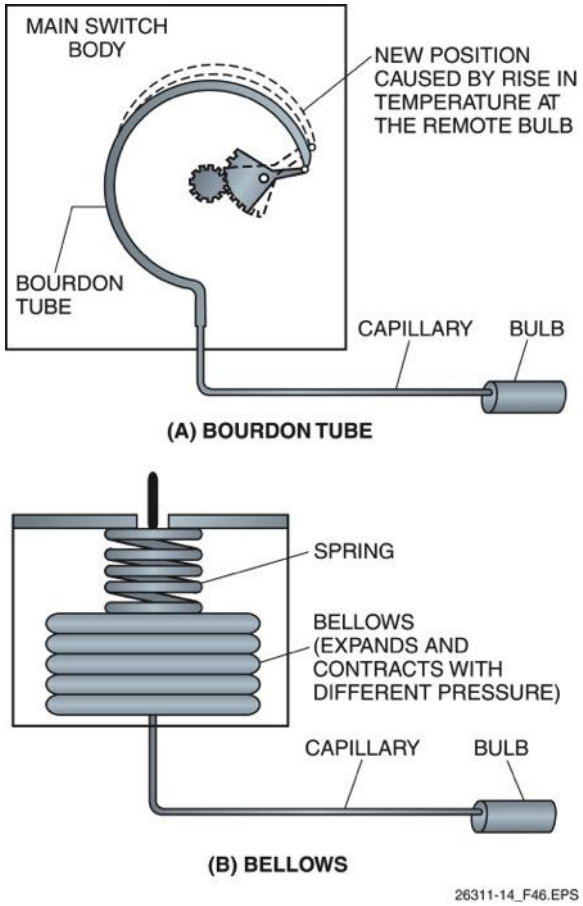
Bimetal Strips Used in Temperature Switches

- Simple temperature switches operate using a bimetal element.
- This bimetal temperature switch uses a coiled bimetal element attached to a mercury bulb containing the switch contacts. It is commonly found in simple household thermostats.



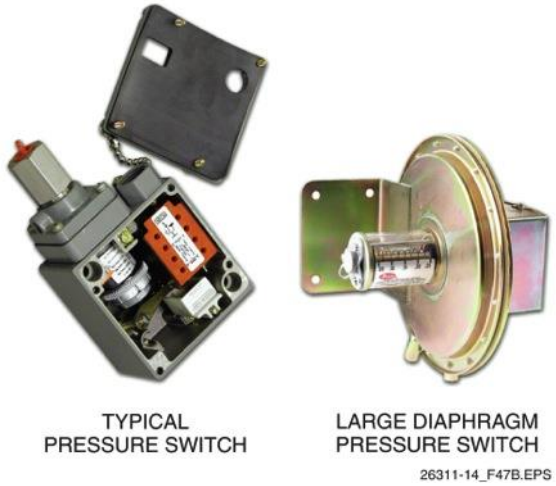
Bourdon Tube and Bellows Temperature Switch Mechanisms

- Other temperature switches use Bourdon tube or bellows switch mechanisms.
- Most temperature switches have user-adjustable temperature setpoints that can be selected based on the desired temperature limits and the operating temperature differential or deadband.



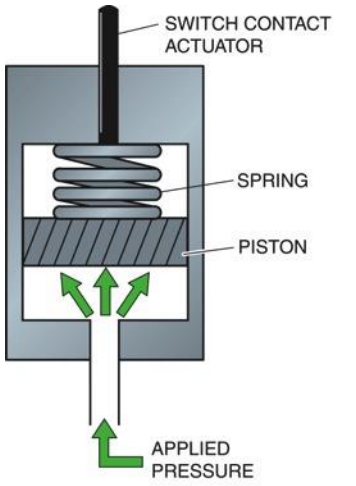
Typical Pressure Switches

- Pressure switches open and close switches in response to positive, negative (vacuum), or differential pressures.
- Single-stage pressure switches are used in machine and process applications. Dual-stage pressure switches are commonly used in air conditioning equipment.

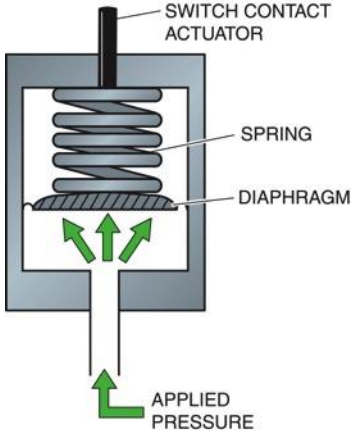


Sealed Piston and Diaphragm Pressure Switch Mechanisms

- Adjustable pressure switches use a Bourdon tube, bellows, sealed piston, or diaphragm. Each of these devices responds to changes in the applied pressure, which are then transferred to a spring or other mechanism to operate the switch.
- The spring tension can be adjusted for different pressure setpoints.



(A) SEALED PISTON



(B) DIAPHRAGM

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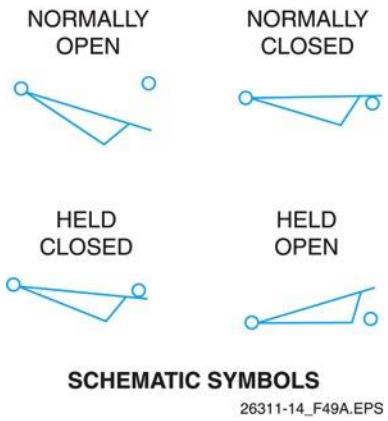
Rotary Lever-Actuated Limit Switch

- Mechanical limit switches rely on physical contact of an object with a switch actuator, and are used in applications such as conveyor belts or tool guards.
- There are two types of mechanical limit switches: rotary lever-actuated and plunger-actuated. Lever-actuated limit switches use a lever arm to operate the switch contacts.



SCHEMATIC SYMBOLS

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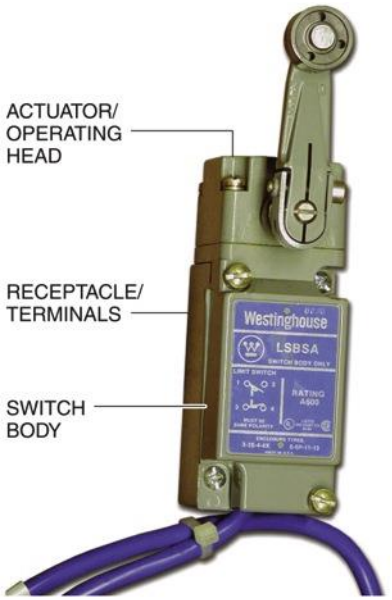

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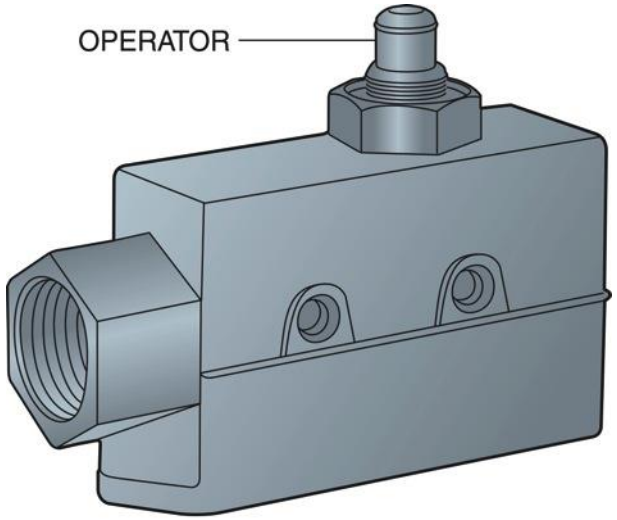
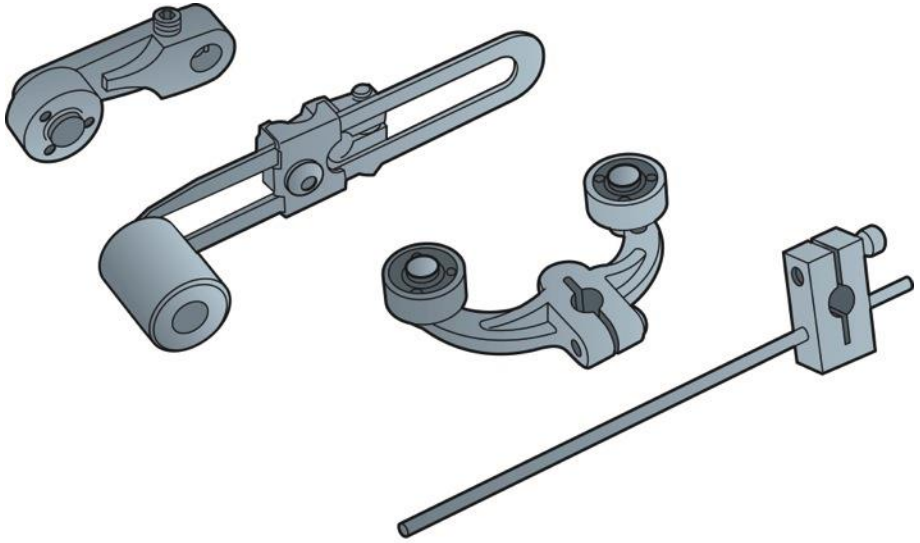
Plunger-Actuated Limit Switch

- Plunger-actuated limit switches include a cam or plate that hits the end of a plunger to operate the switch contacts.
- Plunger-actuated limit switches are best suited for short, controlled machine movements or where space restrictions would not permit the use of a lever-actuated switch.



Rotary Lever-Actuated Limit Switch Actuators

Some rotary lever-actuated limit switches are supplied with interchangeable actuators to be used in different applications.



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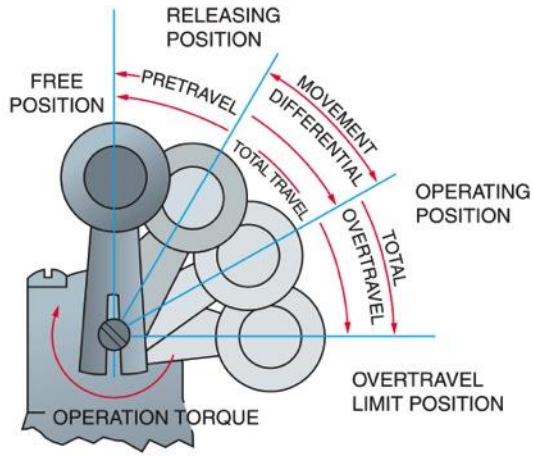
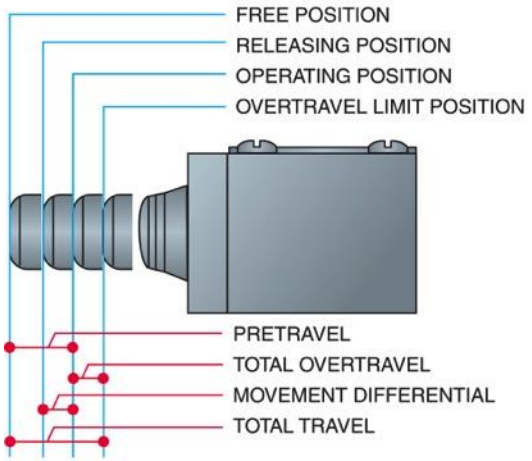
Positions of Limit Switch Actuators

- Each lever position in a rotary lever-actuated limit switch corresponds to a different travel or switch position.
- Rotary lever-actuated limit switches provide the most flexibility and are the best choice for most applications.



ROTARY LEVER-ACTIVATED LIMIT SWITCH



PLUNGER-ACTIVATED LIMIT SWITCH

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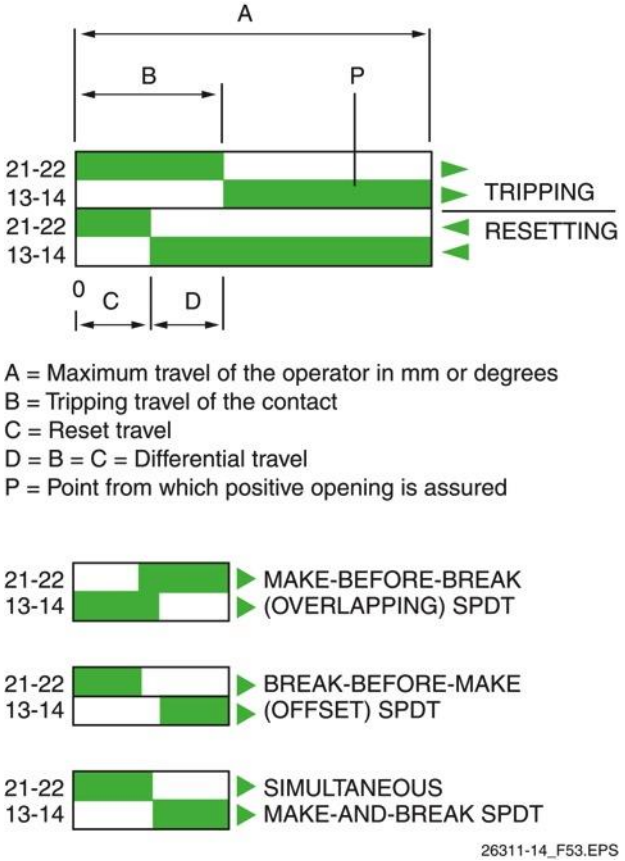
Example of a Limit Switch Contact Function Diagram

- Limit switch manufacturers provide contact function diagrams to define various modes of operation and show any contact overlap between positions.
- Limit switches are selected based on the voltage and current of the load.

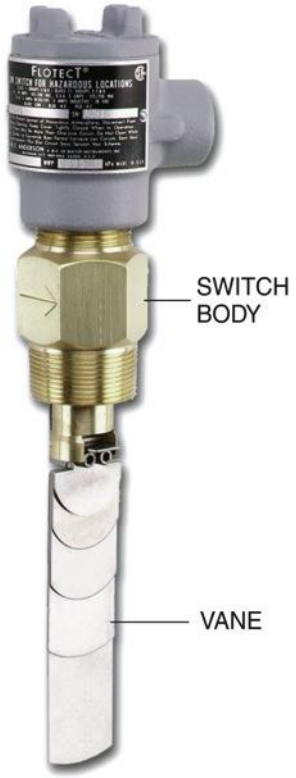


Vane Liquid Flow Switch

- Flow switches are used to detect the flow of air or fluid through a duct or pipe.
- A vane attached to a spring moves in response to the air/fluid flow and actuates the switch contacts. Some flow switches allow spring tension adjustments to correspond to different flow rates.

SCHEMATIC SYMBOLS

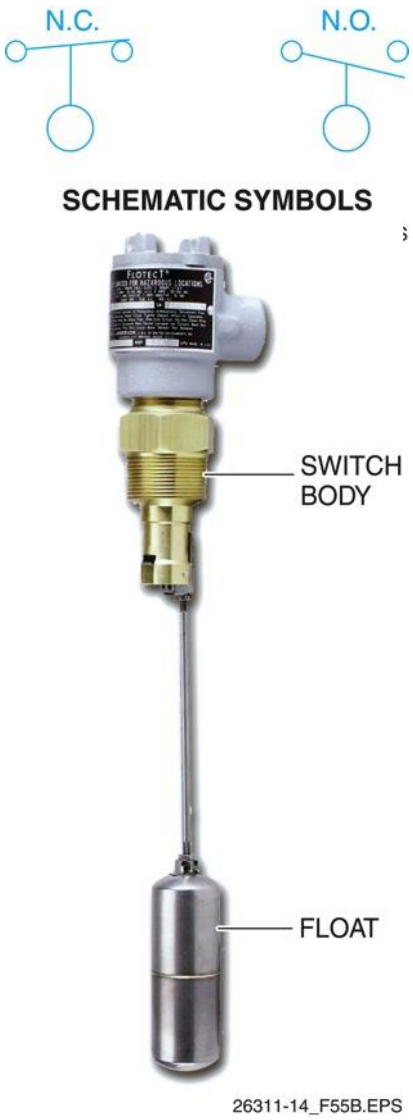
26311-14_F54A.EPS



26311-14_F54B.EPS

Liquid Level Float Switch

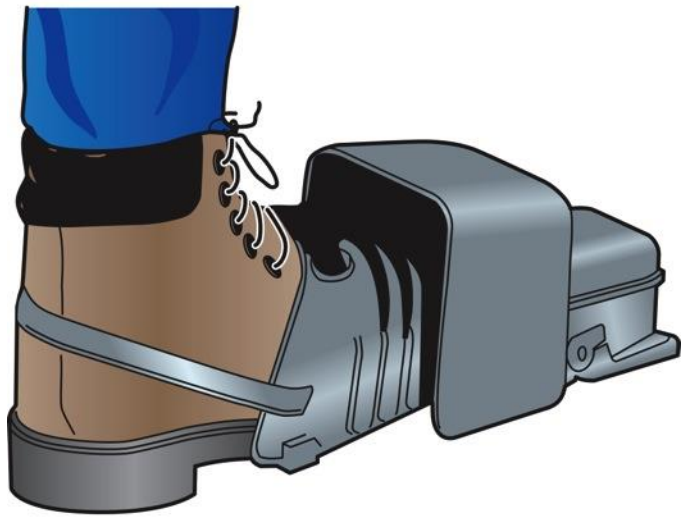
- Float switches are used to monitor the liquid level in a storage tank or other container. They are typically used to operate alarms and/or pumps.
- A basic mechanical switch consists of a float and a sealed, magnetically operated snap switch.



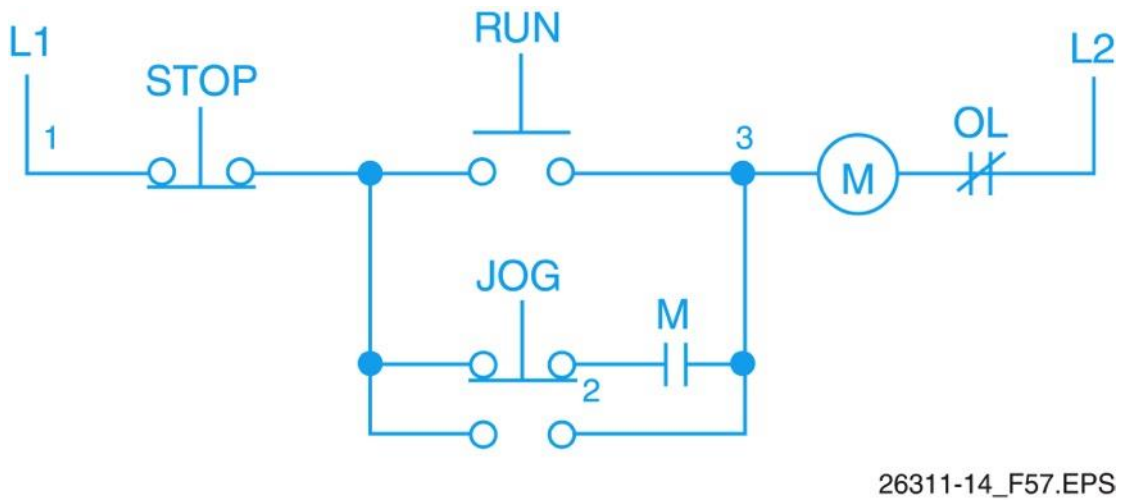
Foot-Operated Switch

- Foot switches are operated using a pedal and are ideal in applications in which the operator requires the use of both hands.
- Foot switches are typically momentary contact devices with two positions, a toe-operated On position and a spring-loaded Off position.

SCHEMATIC SYMBOLS


26311-14_F56.EPS

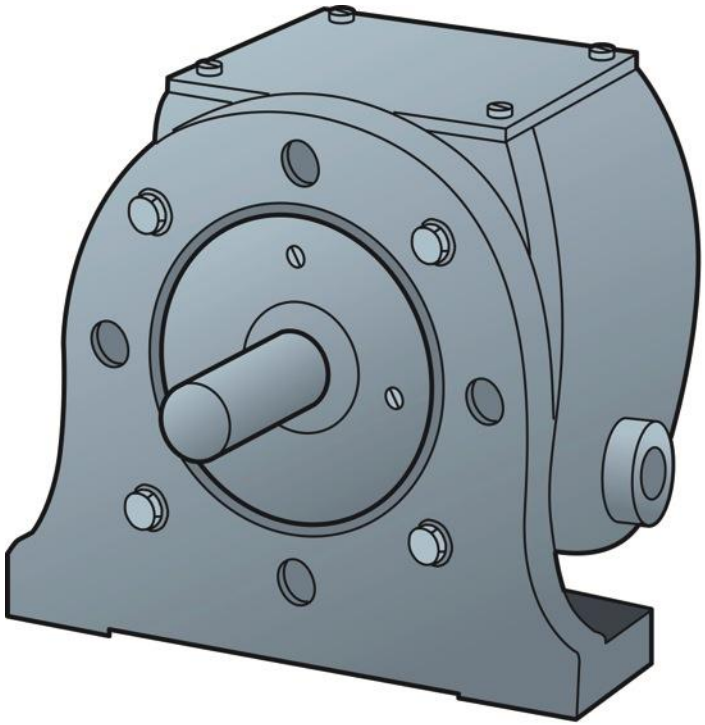
Basic Motor Jogging Control Circuit



- Jogging is used to precisely start and stop a motor in rapid succession, such as when making fine position adjustments using a crane.
- Jog pushbutton switches are connected in series with the holding circuit contact of a magnetic starter.

Plugging Switch

- Plugging is when a motor is brought to a quick stop (braked) by reversing the phase sequence of the motor.
- Plugging can only be done if the phase reversal will not damage the motor or the attached load.



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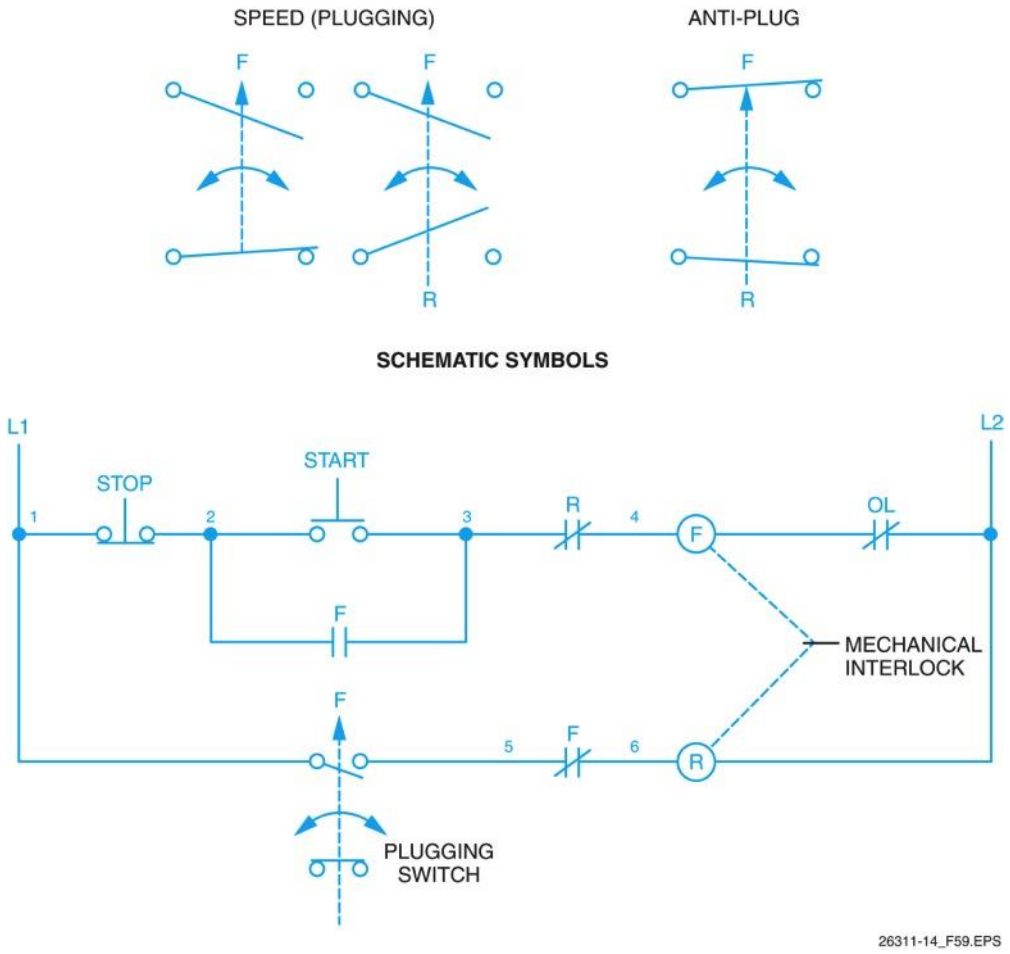
Basic Motor Plugging Control Circuit



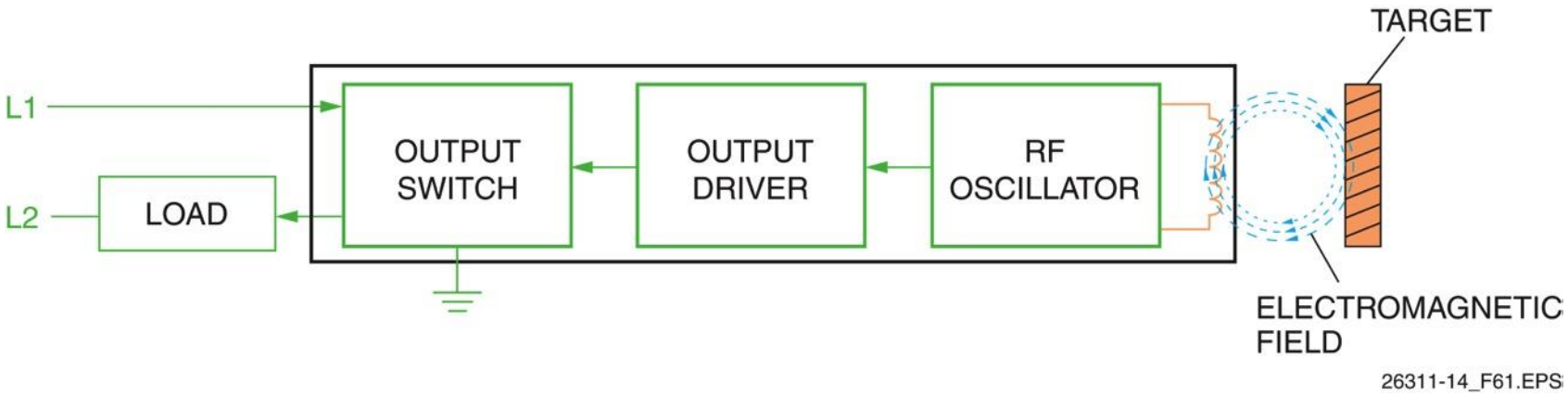
Examples of Typical Proximity Sensors

- Proximity sensors are used to detect the presence of objects without making physical contact.
- Proximity sensors can be used in place of mechanical limit switches, float switches, and level switches. They provide an advantage over these switches due to increased accuracy, faster switching speed, and no moving parts.

26311-14_F60.EPS

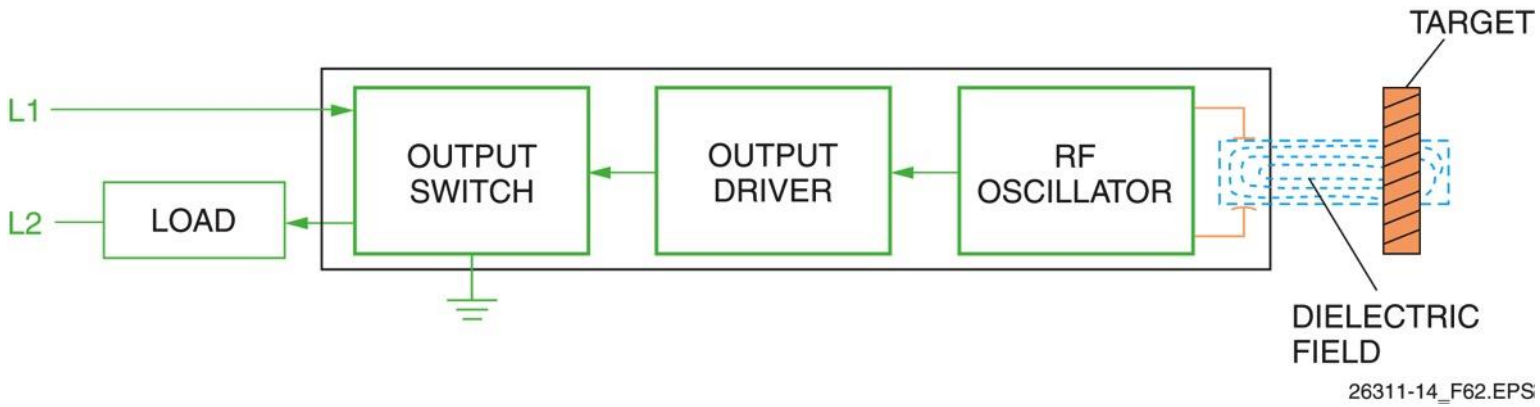
Block Diagram of an Inductive Proximity Sensor

- An inductive proximity sensor is used to detect a metal target within a specified sensing field.
- The oscillator circuit is actuated by induced eddy currents from the target, producing an On or Off output, depending on the switch design.



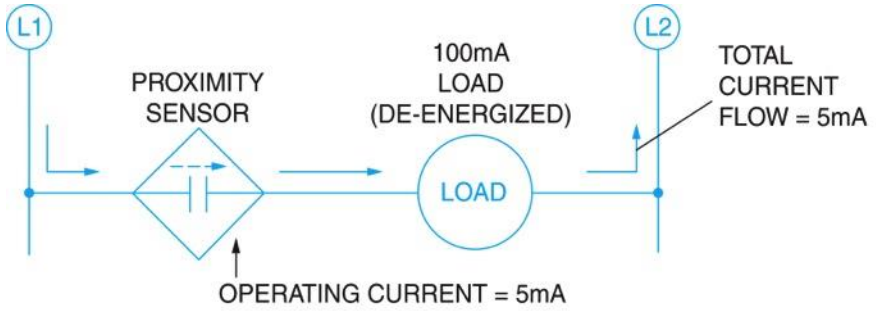
Block Diagram of a Capacitive Proximity Sensor

- Capacitive proximity sensors can be used to detect both metallic and nonmetallic targets.
- The oscillator circuit is actuated by any target with a dielectric constant greater than 1 (air), producing an On or Off output, depending on the switch design.

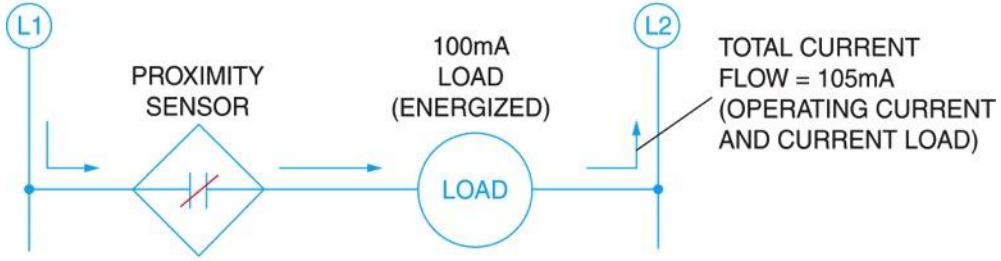


Load-Powered Proximity Sensor Circuit

- Proximity sensors can be either line-powered or load-powered.
- Load-powered sensors are two-wire sensors connected in series with and powered by the controlled load.



(A) PROXIMITY SENSOR OFF (NO TARGET DETECTED)

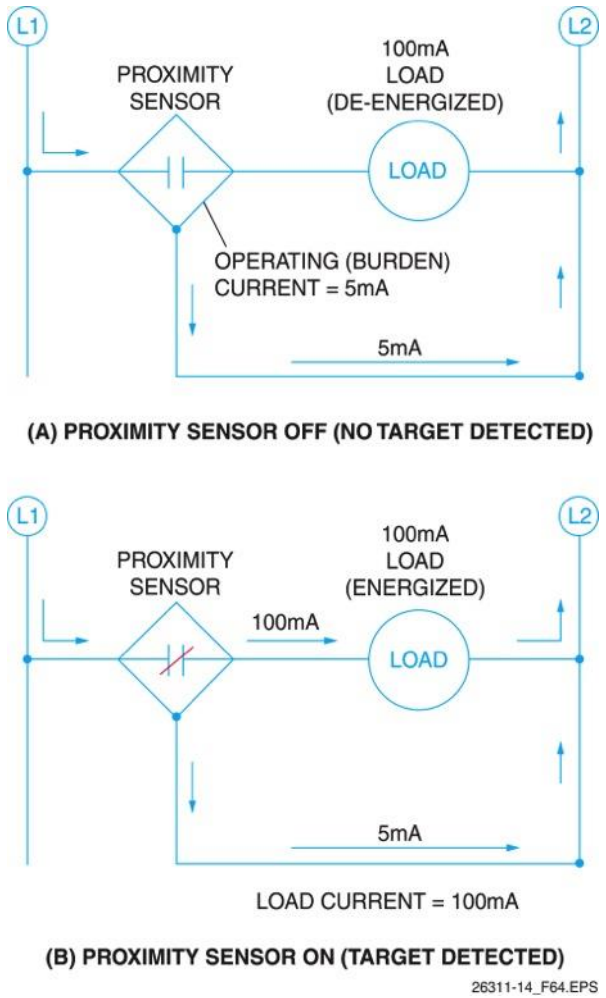


(B) PROXIMITY SENSOR ON (TARGET DETECTED)

26311-14_F63.EPS

Line-Powered Proximity Sensor Circuit

- Line-powered sensors are three-wire sensors that use power from the line rather than the load.
- Connecting line-powered sensors in series and in parallel can affect the load operation. A blocking diode can be used to prevent this problem.



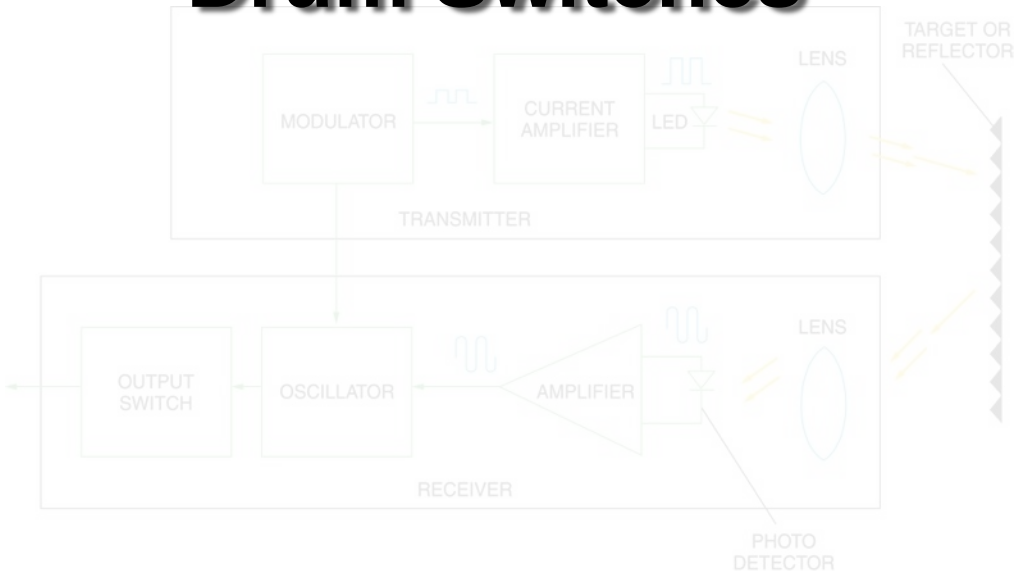
Photoelectric Sensor

26311-14_F65.EPS

- Photoelectric sensors are solid-state devices used to detect the absence or presence of targets within their sensing range.
- These sensors transmit a beam of light at a target or reflector, and an interruption of the beam is used to actuate the output switch.

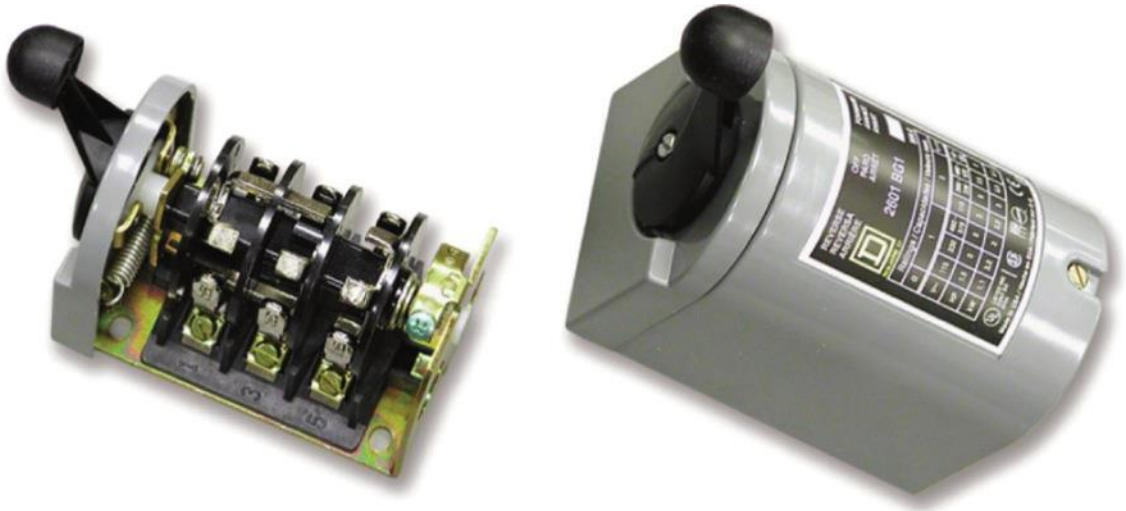
Next Session…

Drum Switches



Drum Switches

- Drum switches are multi-pole switches used to start, stop, or reverse the direction of various types of motors.
- Drum switches do not contain protective overloads and require the use of a manual or magnetic motor starter in line with the drum switch.



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Enclosures

NEMA 1

NEMA 3R

NEMA 4

NEMA 7 AND 9 BOLTED

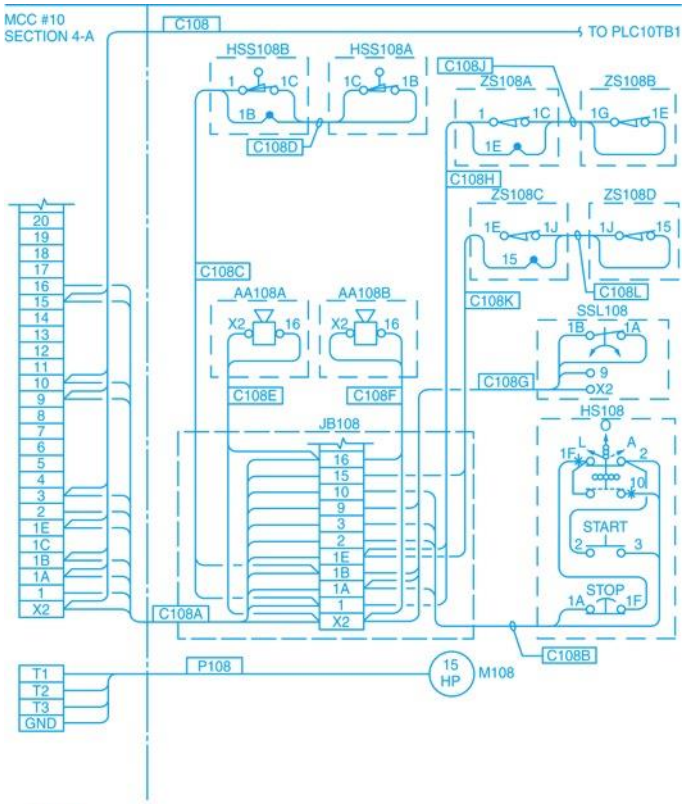
NEMA 12

26311-14_F68.EPS

IEC Enclosure IP Two-Digit Protection Code Definitions

First Digit	Description	Second Digit	Description
0	No protection	0	No protection
1	Protection against solid objects greater than 50mm	1	Protection against vertically falling drops of water
2	Protection against solid objects greater than 12mm	2	Protection against dripping water when tilted up to 15°
3	Protection against solid objects greater than 2.5mm	3	Protection against spraying water
4	Protection against solid objects greater than 1mm	4	Protection against splashing water
5	Total protection against dust; limited ingress (dust protected)	5	Protection against water jets
6	Total protection against dust (dust tight)	6	Protection against heavy seas
		7	Protection against the effects of immersion
		8	Protection against submersion

Diagrams

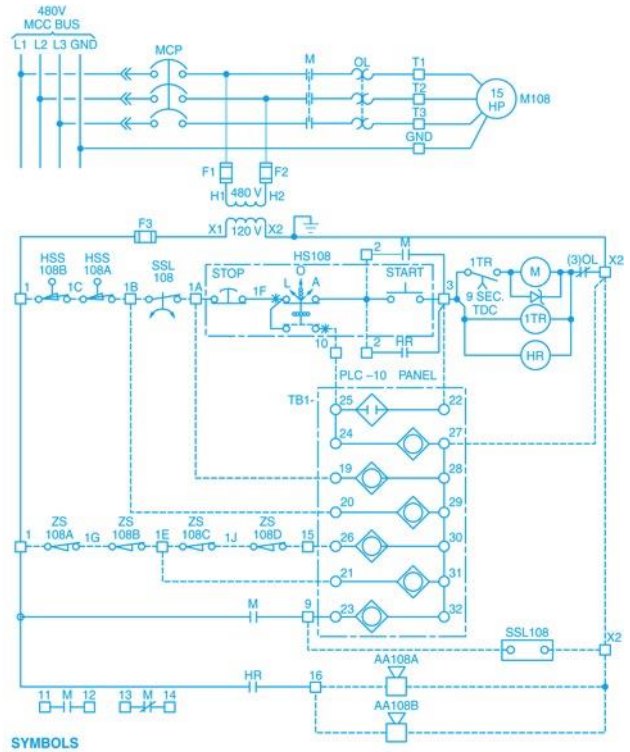

MCC #10
SECTION 4-A
C108
TO PLC10TB1
HSS108B
HSS108A
C108J
ZS108A
ZS108B
C108D
C108H
ZS108C
ZS108D
C108C
AA108A
AA108B
C108K
C108L
SSL108
C108G
C108E
C108F
JB108
HS108
START
STOP
C108A
C108B
P108
15 HP
M108
T1
T2
T3
GND
X2
LEGEND
AA108A-D Conveyor start warning horns
HS108 Local control station with stop mushroom maintained pushbutton, start pushbutton, and Local/Off/Auto selector switch
HSS108A-B Emergency pullcord safety switches
PLC Programmable Logic Controller
SSL108 Conveyor zero-speed switch
ZS108A-D Belt runoff switches
26311-14_F69.EPS

Example of a Circuit Schedule

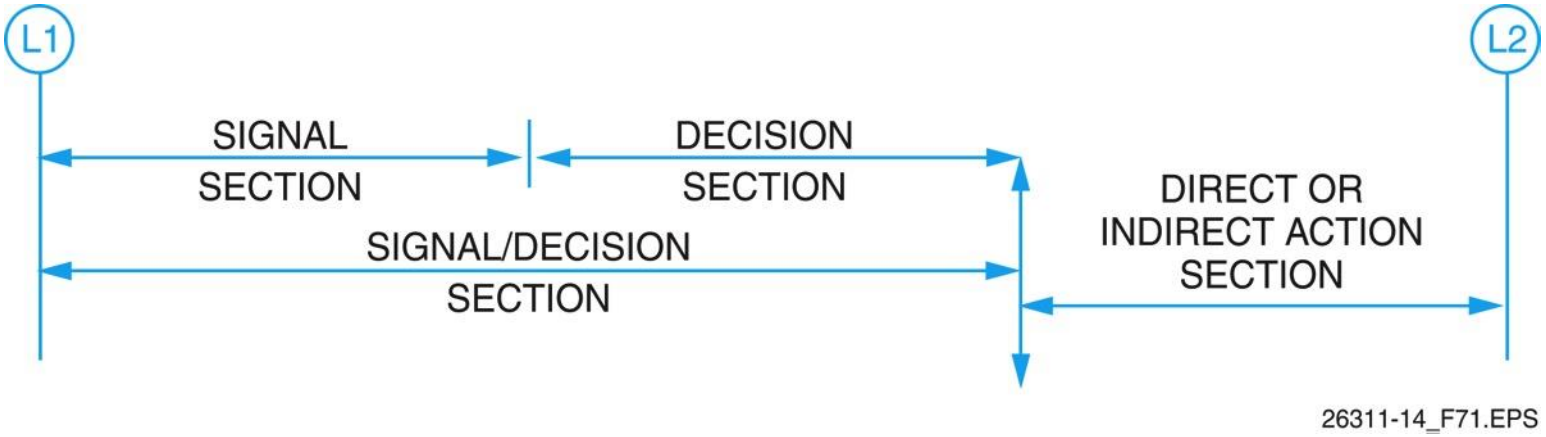
Circuit schedules show actual wire or cable point-to-point connections for a motor and its control circuits.

Circuit/Cable ID	Cable Type	Length	From	To
P108	3/c #10 w/grd	140'	MCC 10 Section 4A	M108
C108	9/c #14	120'	MCC 10 Section 4A	PLC10-TB1
C108A	12/c #14	160'	MCC 10 Section 4A	JB108
C108B	5/c #14	40'	JB108	HS108
C108C	3/c #14	30'	JB108	HSS108A
C108D	3/c #14	10'	HSS108A	HSS108B
C108E	3/c #14	30'	JB108	AA108A
C108F	3/c #14	80'	JB108	AA108B
C108G	5/c #14	70'	JB108	SSL108
C108H	3/c #14	10'	JB108	ZS108A
C108J	3/c #14	10'	ZS108A	ZS108B
C108K	3/c #14	60'	JB108	ZS108C
C108L	3/c #14	10'	ZS108C	ZS108D

Example of a Ladder Diagram

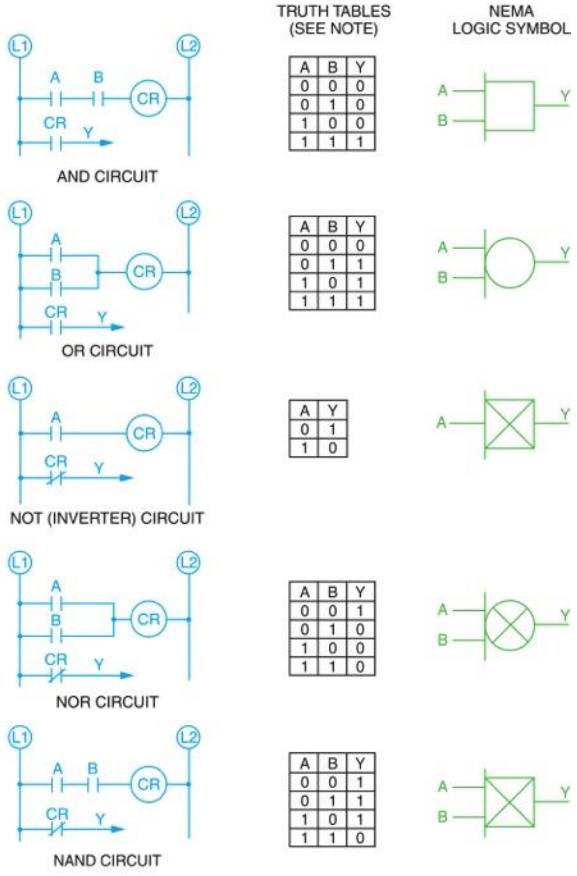


Typical Ladder Diagram Sections



- Pilot devices are the source of the control signal.
- The decision (logic) section adds, sorts, selects, and redirects the signals from the pilot devices to the load.
- The action section represents the energization of a relay or contactor coil.

Basic Logic Functions



A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

A	Y
0	1
1	0

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

NOTE:
When contacts A and/or B are shown as zero (0) in the truth table, it means that the contacts are open. If shown as one (1), it means that the contacts are closed.

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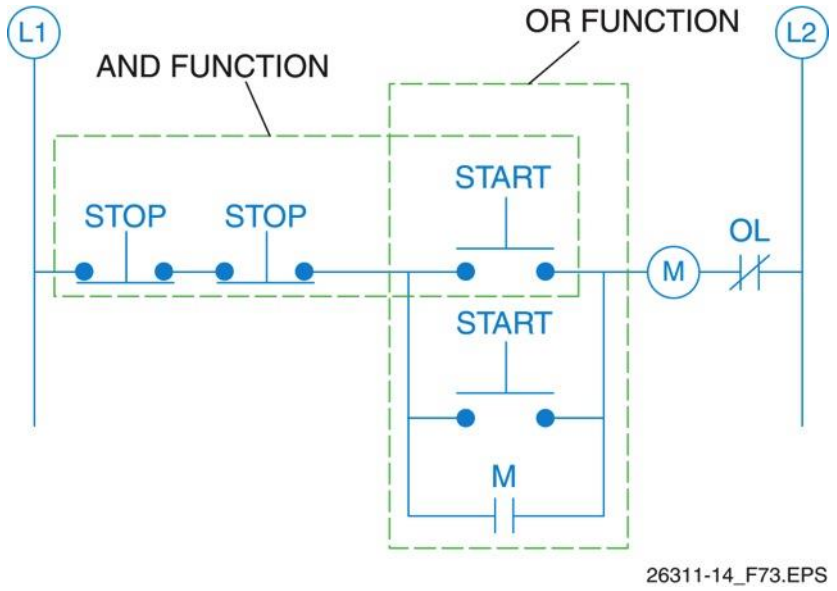
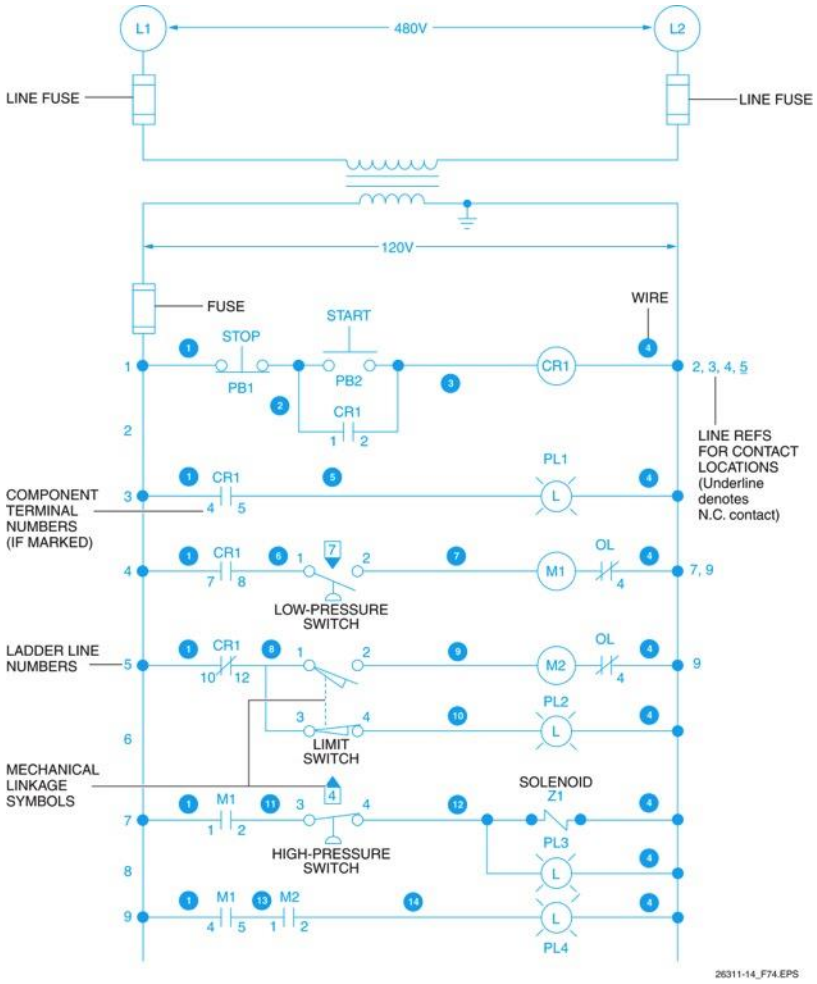
Example AND Function and OR Function in a Motor-Starter Control Circuit

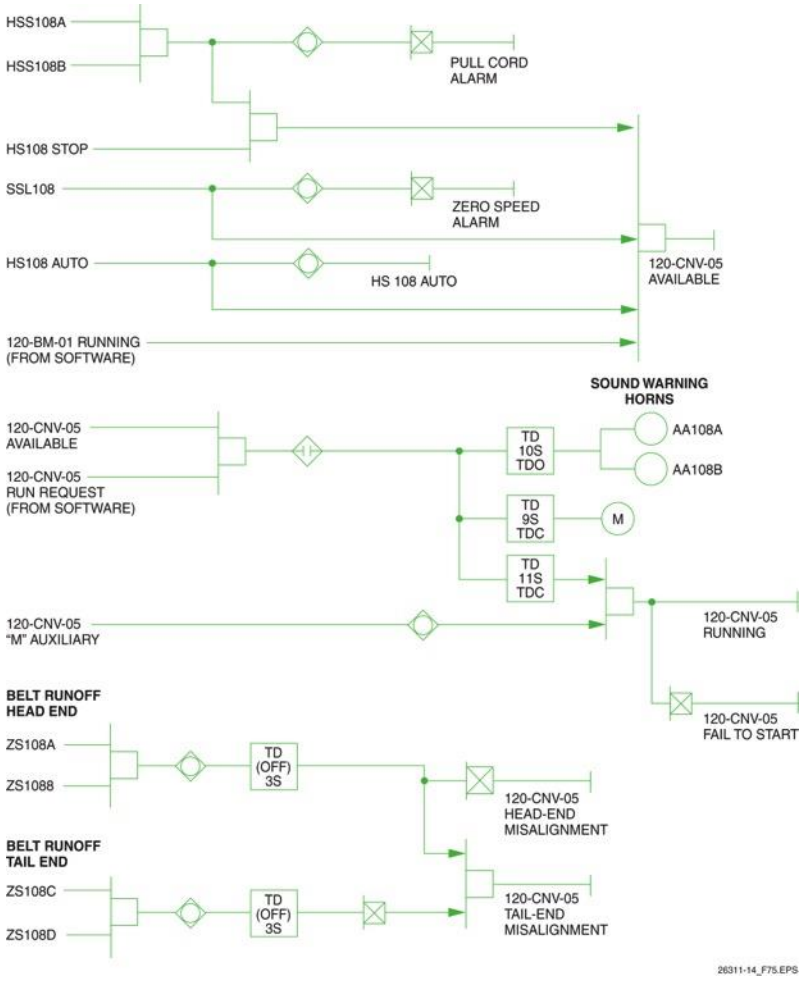
- The AND function is the Start/Stop switch and the motor overload contact. Both the Start/Stop switch and the OL contacts must be closed to energize contactor coil M.
- Once energized, the OR function consisting of the Start switch or the M holding contacts keeps the coil energized.



Typical Ladder Diagram Conventions



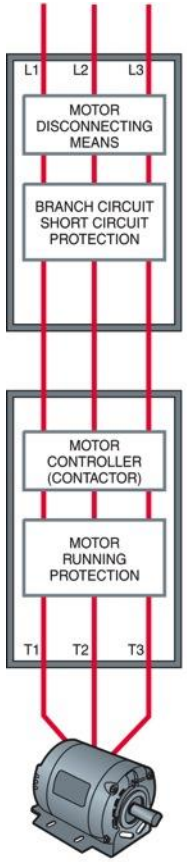
Example of a Logic Diagram



Next Session…

NEC® Regulations for the Installation of Motor Control Circuits

NEC® Regulations for the Installation of Motor Control Circuits



NEC Article 430 Part IX Sections 430.101 through 430.113	**Disconnects motor and controllers from circuit.** 1. Continuous rating of 115% or more of motor FLC. 2. Disconnecting means shall be as listed in *NEC Section 430.109.* 3. Must be located in sight of motor location and driven machinery. The controller disconnecting means can serve as the disconnecting means if the controller disconnect is located in sight of the motor location and driven machinery.
NEC Article 430 Part IV Sections 430.51 through 430.58	**Protects branch circuit from short circuits or grounds.** 1. Must carry starting current of motor. 2. Rating must not exceed values in *NEC Table 430.52* unless not sufficient to carry starting current of motor. 3. Values of branch circuit protective devices shall in no case exceed exceptions listed in *NEC Section 430.52.*
NEC Article 430 Part VII Sections 430.81 through 430.90	**Used to start and stop motors.** 1. Controllers other than inverse time circuit breakers and molded case switches shall have horsepower ratings at the application voltage not lower than the horsepower rating of the motor per *NEC Section 430.83(A)(1).* 2. Must be able to interrupt LRC per *NEC Section 430.82(A).* 3. Must be rated as specified in *NEC Section 430.83.*
NEC Article 430 Part III Sections 430.31 through 430.44	**Protects motor and controller against excessive heat due to motor overload.** 1. Must trip at following percent or less of motor FLC for continuous motors rated more than one horsepower. (a) 125% FLC for motors with a marked service factor of not less than 1.15 or a marked temperature rise of not over 40°C. (b) 115% FLC for all others. (See *NEC* for other types of protection.) 2. Three thermal units required for any three-phase AC motor. 3. Must allow motor to start. 4. Select size from FLC on motor nameplate per *NEC Section 430.6(A)(2).*
NEC Article 430 Part II Sections 430.21 through 430.29	**Specifies the sizes of conductors capable of carrying the motor current without overheating.** 1. To determine the ampacity of conductors, switches, branch circuit overcurrent devices, etc., the full-load current values given in *NEC Tables 430.247 thru 430.250* shall be used instead of the actual current rating marked on the motor nameplate per *NEC Section 430.6(A)(1).* 2. According to *NEC Section 430.22*, branch circuit conductors supplying a single motor shall have an ampacity of not less than 125% of motor FLC, as determined by *NEC Section 430.6(A)(1)*, or not less than specified in *NEC Sections 430.22(A) through (G).*

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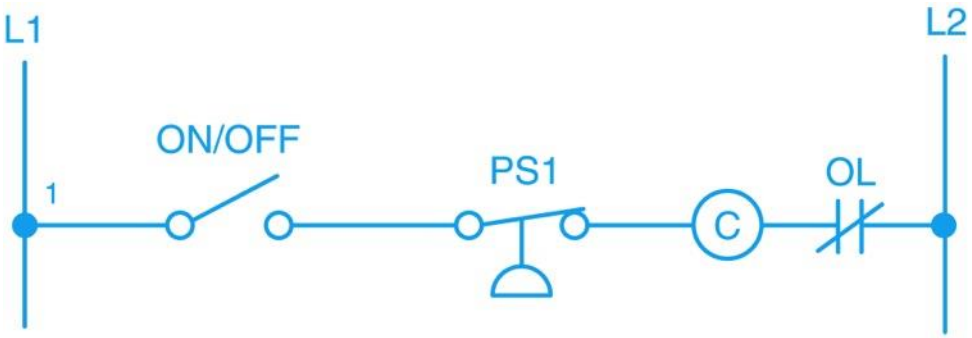
Connecting Motor Controllers for Specific Applications



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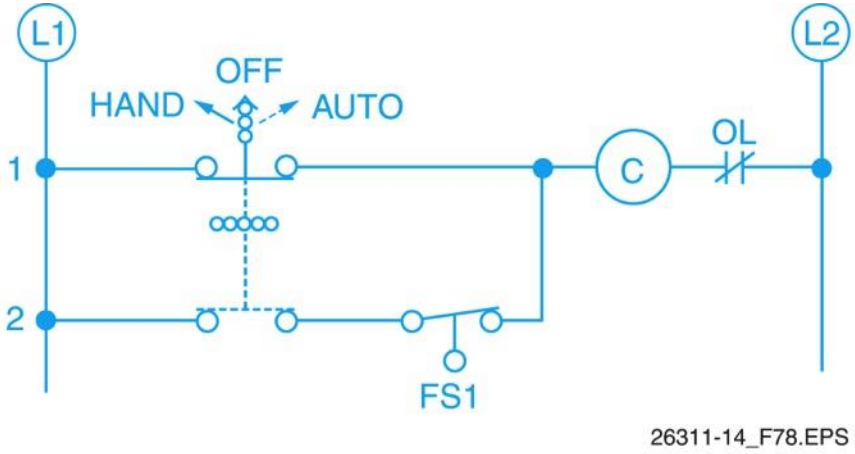
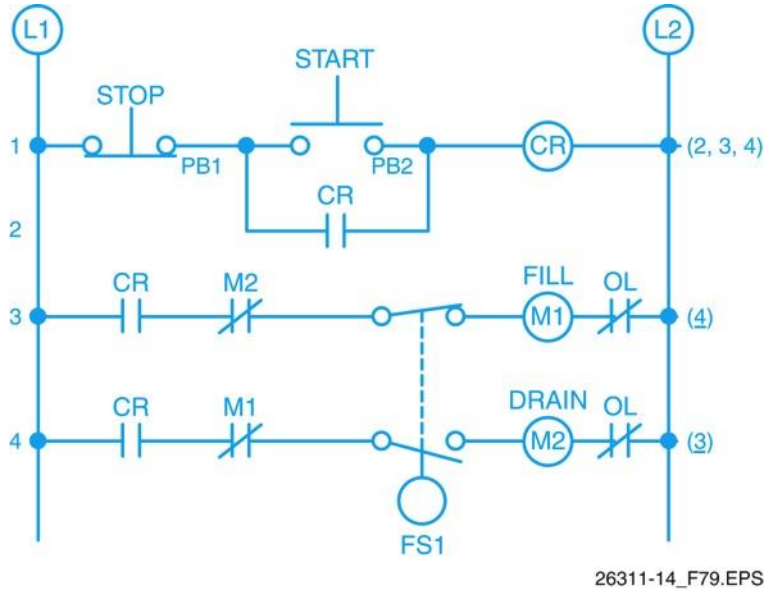
- The control circuit for an air compressor is similar to that of an AC motor, but adds a high-pressure switch that responds to the pressure in the system.
- When the pressure switch senses excessive pressure, it opens and de-energizes the contactor coil, shutting off the motor.

Control Circuit for a Pump Motor



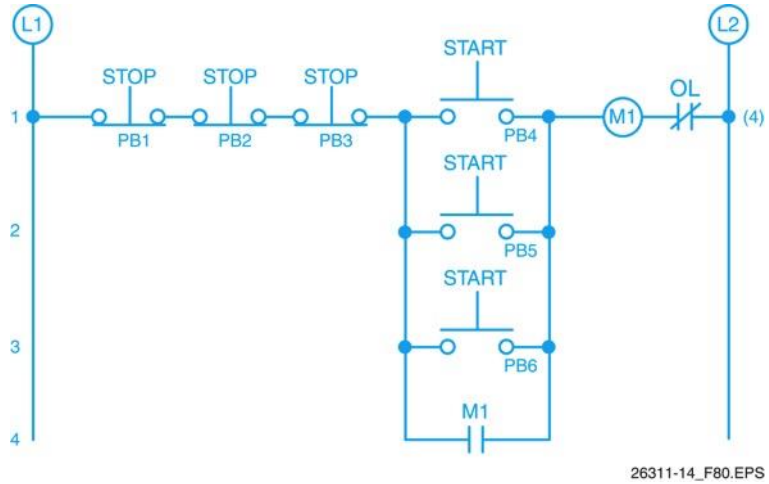
- When set to Hand, the pump operates continuously until it is turned Off.
- When set to Auto, the pump operates until the switch is set to Off or the liquid level rises to a predetermined point at which the float switch is activated, turning off the pump.

Control Circuit for Two Pumps



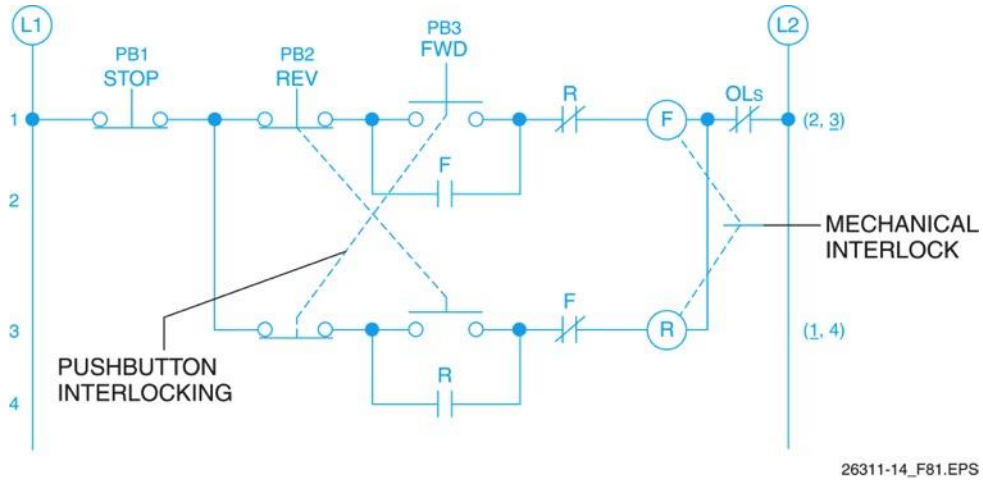
- This circuit controls two pumps that alternately operate to fill and drain a tank based on the tank liquid level.
- An electrical interlock prevents both pumps from operating at the same time.

Control Circuit for Starting and Stopping a Single Motor from Three Locations



- Multiple pushbuttons can be used to start or stop a motor from more than one location.
- In this circuit, pressing any of the Start buttons will energize coil M1 until it is de-energized by pressing any of the Stop pushbuttons.

Control Circuit for Reversing a Three-Phase Motor

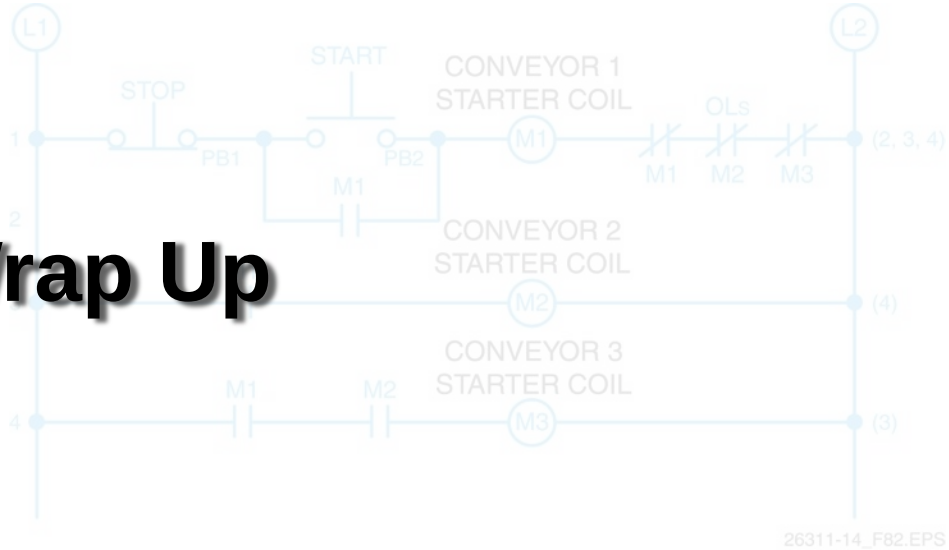


- Reversing of a three-phase motor can be done by reversing the L1 and L3 power leads to the motor using a magnetic reversing starter and control circuit.
- Circuit operation is controlled using Forward and Reverse pushbuttons.

Next Session…

Control Circuit for Turning On Three Conveyor Systems in Sequence

Sequenced operations may be required for multiple conveyor belts and other process system machinery.



Wrap Up

Performance Task

This session will conclude with trainees making all connections for a magnetic motor controller, controlled by two pushbutton stations, including the connections for holding the circuit interlock.

Wrap Up

3-2-1

3 – Write 3 important things learned during class

2 – Write 2 questions you have about the material

1 – Write 1 thought you had about the material

Next Session…

MODULE EXAM

Review the complete module to prepare for the module exam. Complete the Module Review as a study aid.