ECET 4530

Industrial Motor Control

1 – Control System Components

Control System Components

Components commonly used in industrial control systems:

- **Push Buttons**
- **Contactors**
- **Relays**
- **Timers**
- **Overload Relays**
- **Optical (Beam) Detectors**
- **Proximity Detectors**
- **Limit Switches**

- **Programmable Logic Controllers (PLCs)**
- **Variable Frequency Drives (VFDs)**
- **Human-Machine Interface Panels (HMIs)**

Push-Buttons

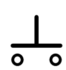
Push-Button

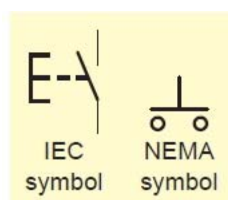
- A Momentary contact device that contains one or more sets of contacts which actuate when the button is pressed and return back to their “normal” position when the button is released

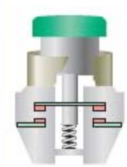
Push-Buttons

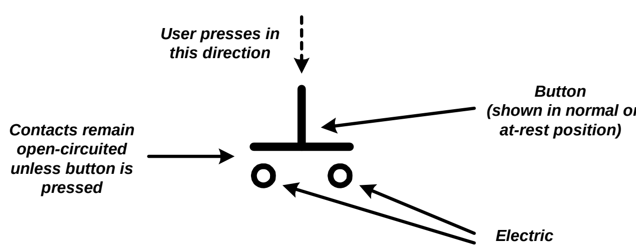
Types of Push-Buttons

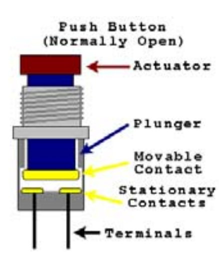
Normally Open (NO)







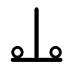


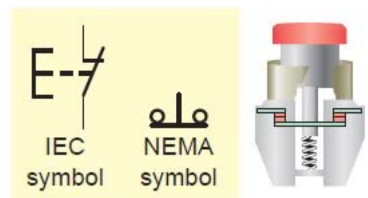


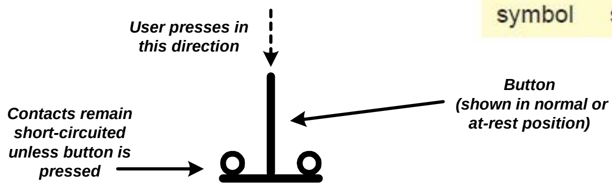
Push-Buttons

Types of Push-Buttons

Normally Open (NO) 

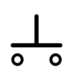
Normally Closed (NC) 

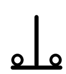


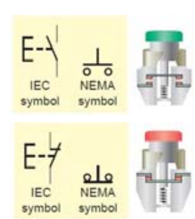


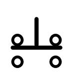
Push-Buttons

Types of Push-Buttons

Normally Open (NO) 

Normally Closed (NC) 



Combination 

- contains both NO and NC contacts

Contactors

Contactor

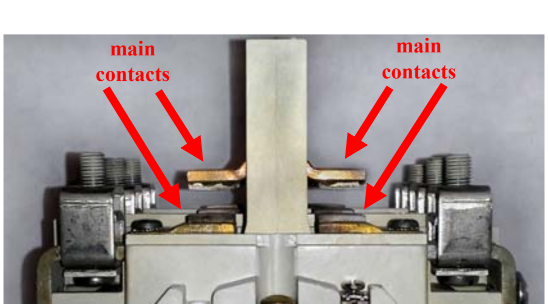
- An electrically controlled switch (relay) that is used to energize/de-energize high-current devices such as electric motors, heating elements, lighting, etc…
- The switching function is provided by one or more sets of contacts that are attached to the armature of an electromagnet.

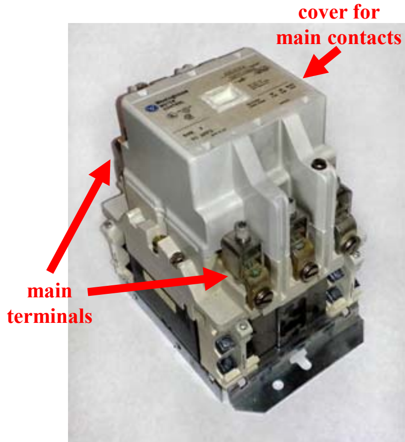
Contacts – Two pieces of conductive material that are pressed-together to complete (close) and pulled-apart to break (open) an externally-connected circuit.

Contactors

Contactor Operation

- The "main" (power) contacts are used to provide power to large motors or other high-current, industrial loads.





Contactors

Contactor Operation

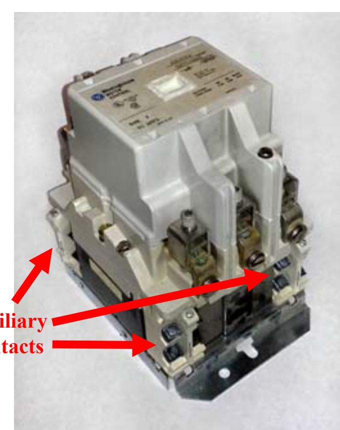
- The "main" (power) contacts are used to provide power to large motors or other high-current, industrial loads.

Ratings of Size 3, 90A, 3Φ Contactor
200V – 25HP
230V – 30HP
460/575V – 50HP

Contactors

Contactor Operation

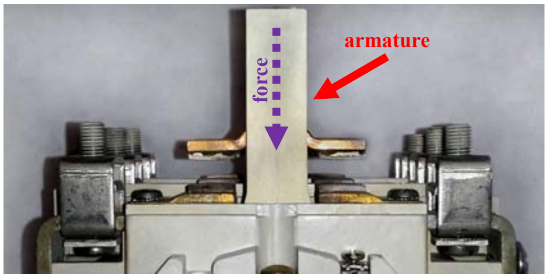
- The "main" (power) contacts are used to provide power to large motors or other high-current, industrial loads.
- **One or more sets of auxiliary contacts, including at least one set of NO contacts, are included to provide additional logic or other switching function within the control circuit.**

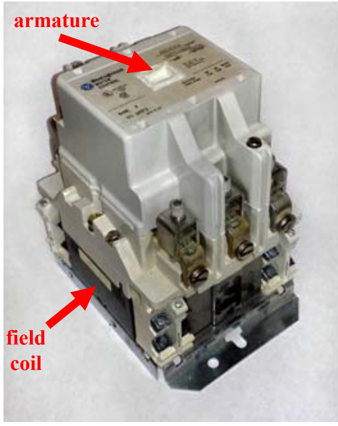


Contactors

Contactor Operation

- **When the electromagnet's field coil is energized, a force is developed that moves the armature, in-turn actuating all of the contacts.**





Contactors

Contactor Operation

- When the electromagnet's field coil is energized, a force is developed that moves the armature, in-turn actuating all of the contacts.
- **When the electromagnet's field coil is de-energized, a spring-force retracts the armature, returning the contacts back to their original positions.**

Contactors

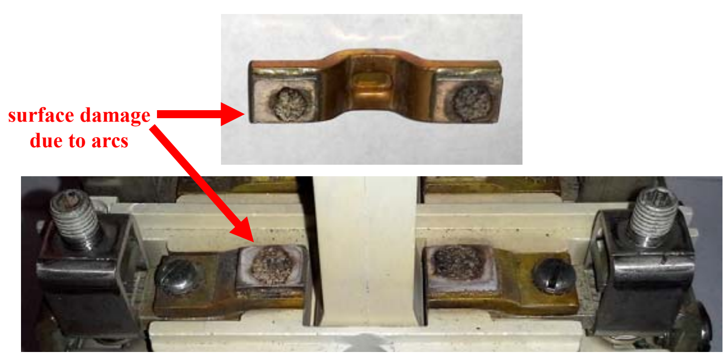
Voltage Ratings

- The main contacts may be rated for either AC or DC operation at a variety of different voltage levels.
- Likewise, the contactor's the field-coil may be designed to be supplied by either an AC or a DC source.
- Although the field-coil may operate at the same voltage magnitude as the load, lower "control" level voltages are often utilized due to safety and other design concerns.

Contactors

Current Interrupting Capability

- Whenever a set of contacts make or break an energized circuit, the arcing that occurs may damage the contact surfaces, in-turn degrading the contact connection.



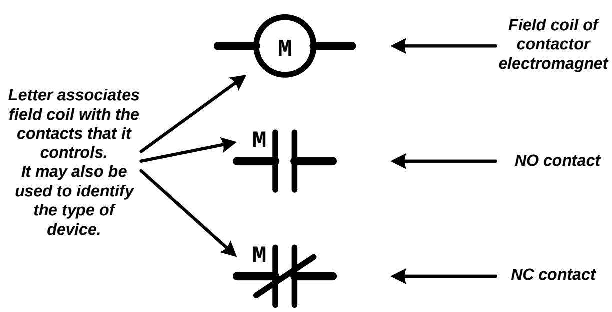
Contactors

Current Interrupting Capability

- The main contacts of a contactor are designed to safely interrupt the connected load's maximum operational current without causing excessive surface damage.
- The main contacts of a contactor are NOT designed to disrupt "short-circuit" or fault current.
- In terms of "short-circuit" protection, fuses and circuit-breakers are designed specifically to disrupt fault current.

Contactors

Contactor Symbols



The same symbols are utilized for both the main and the auxiliary contacts.

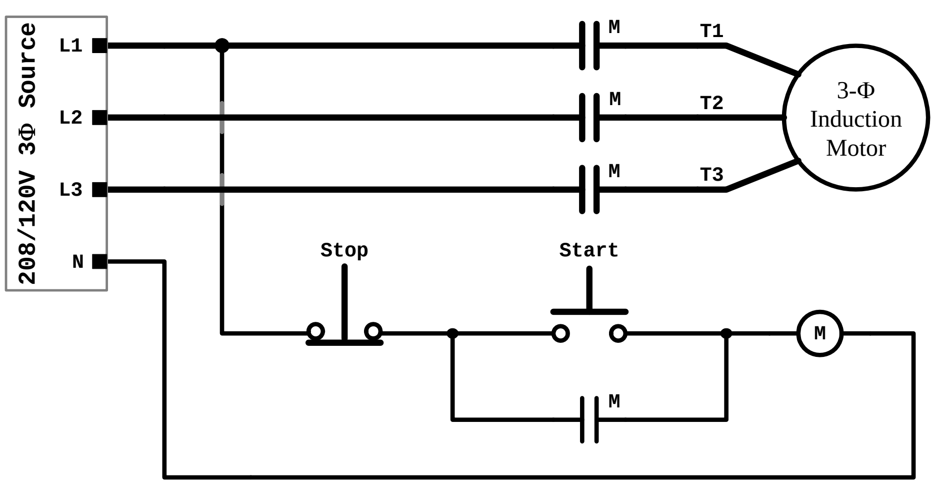
Basic Motor Controller Example

Motor Controller – Design a basic, two-pushbutton, start/stop motor controller for a three-phase (3Φ), 208V, induction motor.

Required Components:

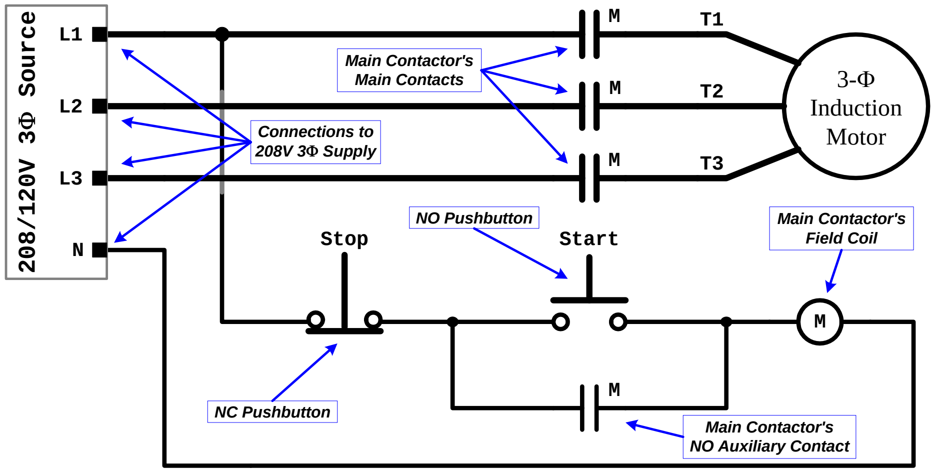
- **1 – NO Pushbutton** (“Start” button)
- **1 – NC Pushbutton** (“Stop” button)
- **1 – Three Phase Contactor** with one NO auxiliary contact and a $208V_{AC}$ rated field coil.

Basic Motor Controller Example



Schematic Diagram of a Basic Start/Stop 3Φ Motor Controller

Basic Motor Controller Example

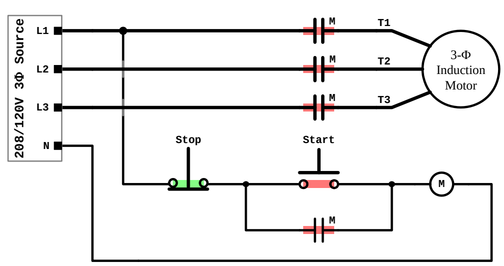


Schematic Diagram of a Basic Start/Stop 3Φ Motor Controller

Basic Motor Controller Operation

Initial Conditions:

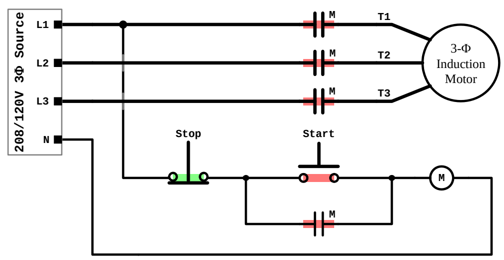
When the 3Φ supply is first switched on, the initially de-energized field coil will remain de-energized since current cannot flow through the NO "Start" button or the NO auxiliary contact.



Basic Motor Controller Operation

Initial Conditions:

Since the field coil remains de-energized, the main contacts will also remain in their "normally" open positions, isolating the motor from the 3Φ source.

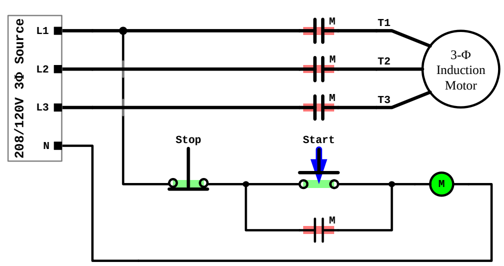


Basic Motor Controller Operation

Starting the Motor:

If the "Start" button is pressed:

1) The pushbutton's contacts close and complete the circuit containing the field coil, thus energizing the field coil…

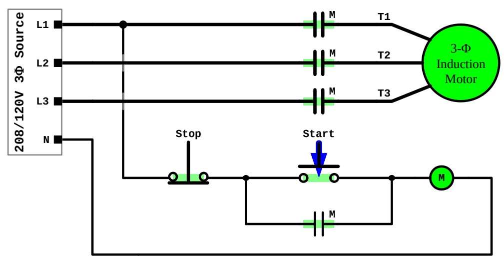


Basic Motor Controller Operation

Starting the Motor:

If the "Start" button is pressed:

2) The energized field coil activates the contactor's electromagnet which, in-turn, actuates (closes) all of it's (NO) contacts after a small time-delay…

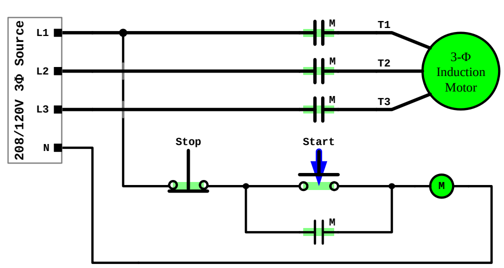


Basic Motor Controller Operation

Starting the Motor:

If the "Start" button is pressed:

3) When the main contacts close, the motor's terminals are connected to the line terminals of the 3Φ supply, thus providing full-voltage to the Induction motor.

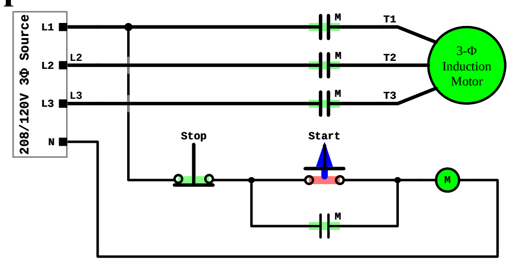


Basic Motor Controller Operation

<u>Starting the Motor</u>:

If the "Start" button is <u>released</u>:

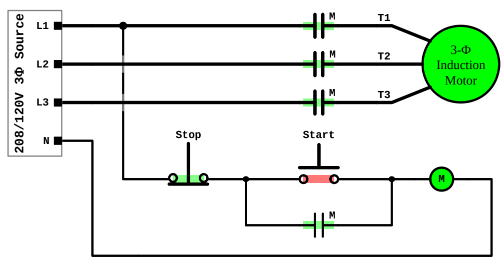
The auxiliary contact maintains a current path to the field coil, keeping the electromagnet energized and thus "holding-in" the contacts in order to continuously provide power the motor.



Basic Motor Controller Operation

<u>Steady-State Operation</u>:

Thus, once the "Start" is pressed (and released), the motor will continue running until the "Stop" button is pressed.

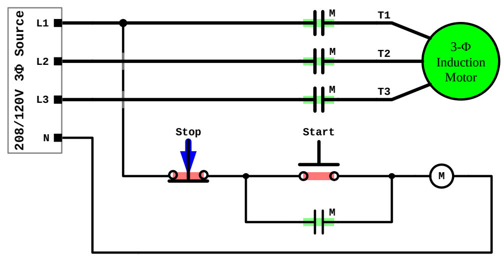


Basic Motor Controller Operation

Stopping the motor:

If the "Stop" button is pressed:

1) The "Stop" button's NC contact opens and breaks the circuit supplying the field coil, thus de-energizing the field coil (electromagnet)…

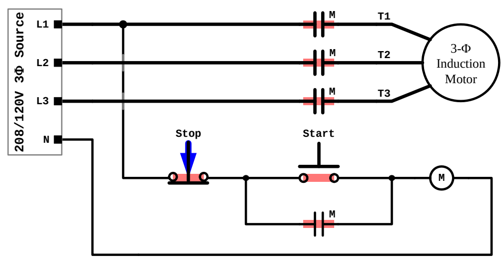


Basic Motor Controller Operation

Stopping the motor:

If the "Stop" button is pressed:

2) When the electromagnet is de-energized, the contacts "drop-out" (return to their NO positions) after a small time delay, and…

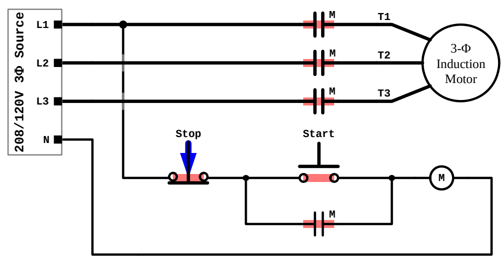


Basic Motor Controller Operation

Stopping the motor:

If the “Stop” button is pressed:

3) When the main contacts re-open, the Induction motor is disconnected from the 3Φ supply (ie – de-energized), thus stopping the motor.



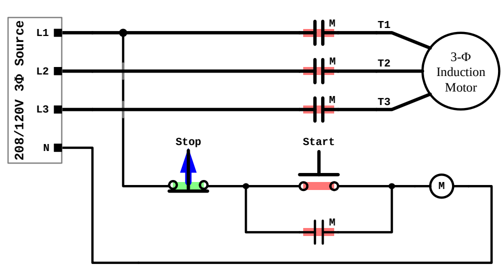
Basic Motor Controller Operation

Stopping the motor:

If the “Stop” button is released:

The “Stop” button’s contact re-closes, but the auxiliary contact prevents the field coil from being re-energized.

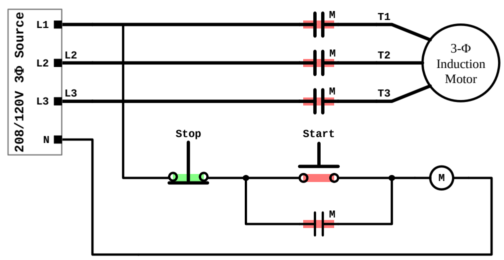
→ The motor remains stopped.



Basic Motor Controller Operation

Non-Operational Motor:

Once the motor is stopped, the system is back to it's initial conditions and it will remain that way until the "Start" button is pressed again.



Relays

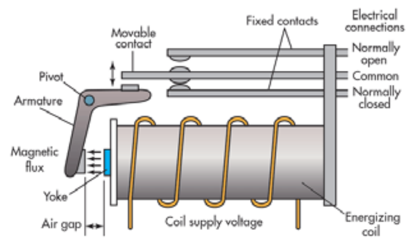
Relay

- **Electrically controlled switch that is similar in operation compared to a contactor but is not designed to supply high-current loads.**
- **May be AC or DC controlled.**
- **May be electro-mechanical or solid-state.**

Relays

Relay

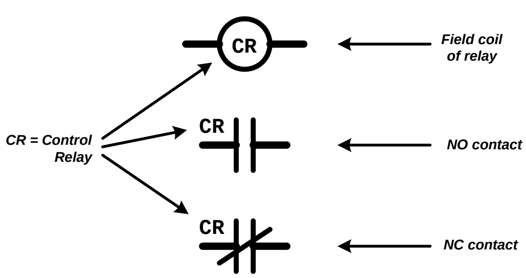
- Electrically controlled switch that is similar in operation compared to a contactor but is not designed to supply high-current loads.
- May be AC or DC controlled.
- May be electro-mechanical or solid-state.
- **May contain multiple NO and/or NC contacts that provide logic or switching within the control system.**

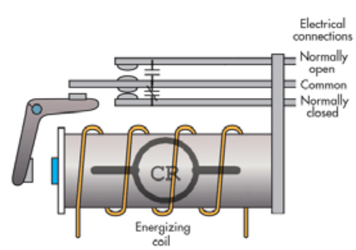


Relays

Relay Symbols

- **The same symbols used for contactors are also used to depict relays in schematic diagrams.**

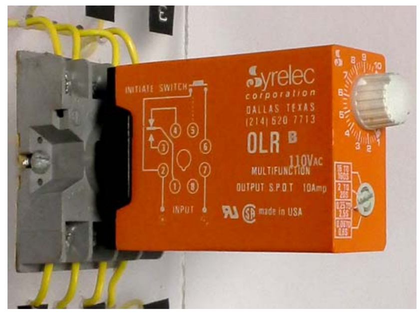




Timers

Timer

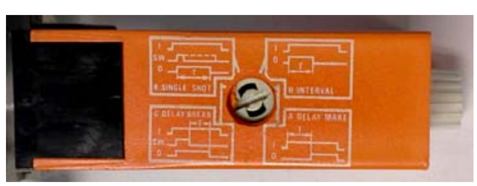
- **A device that delays opening and/or closing a set of contacts for a preset amount of time.**



Timers

Timer

- A device that delays opening and/or closing a set of contacts for a specific amount of time.
- **Timers may be solid-state, electro-mechanical or mechanical in construction.**
- **Solid-state timers can often be configured to provide a variety of timing functions.**



Overload Relays

Overload Relay

- A type of relay that, in conjunction with a contactor, is designed to protect a motor from an "overload".

An overload is defined as any current above the rated Full Load current of the motor but limited to the motor's Locked Rotor (starting) current.

Overload Relays

Overload Relay

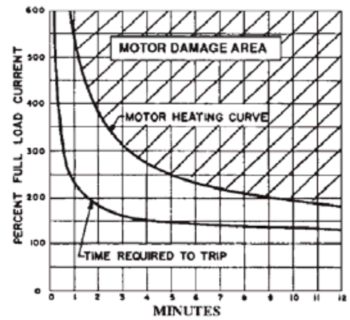
- Overload currents occur normally at startup. They also occur during times of excessive mechanical loading of the motor and during times of low supply voltage.
- Overload currents cause excessive heating in the motor's windings that can damage or decrease the lifespan of the motor. Even a small overload can be damaging to the motor if sustained over time.

Overload Relays

Overload Relay – Time Curve

- **Overload relays typically operate on a time curve such that they will "trip" (activate) faster for large overloads but will delay tripping temporarily for small overloads.**

- **The time curve for an overload relay is set based upon the motor's heating curve.**



Graph shows motor heating curve and overload relay trip curve. Overload relay will always trip at a safe value

Figure 3-7 Overload Relay Trip Curve

Taken from: "Fundamentals of Motor Control" - Square D Corp. 1991

Overload Relays

Overload Relay

- **During startup, motors draw a large inrush current until they are able to accelerate to normal operating speeds. This current can up to 6x larger than full rated current.**

- **If set properly, the overload relay's time curve allows the motor time to accelerate from startup, but will trip in cases of slow or failed starts to prevent motor damage.**

Overload Relays

Overload Relay – **Components & Symbols**

Overload Relay's Heater

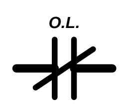
- **a heater is placed in-series with each line that supplies the motor.**
- **an overload will eventually cause the heaters to overheat, in-turn opening the relay's NC contact.**

Overload Relays

Overload Relay – **Components & Symbols**

Overload Relay's Heater

Overload Relay's NC Contact



- **the NC contact is placed in-series with the main field coil.**
- **opening the relay contact will de-energize the main field coil, in-turn stopping the motor.**

Motor Starters

A basic <u>Motor Starter</u> is a combination device that utilizes a <u>contactor</u> to provide/remove power to/from a motor along with an <u>overload relay</u> to provide protection for the motor.

Motor Starters

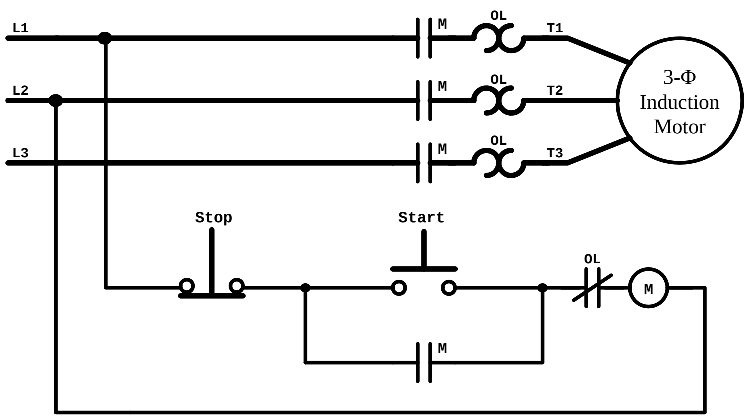
A basic <u>Motor Starter</u> is a combination device that utilizes a <u>contactor</u> to provide/remove power to/from a motor along with an <u>overload relay</u> to provide protection for the motor.

The overload relay's heaters are connected in-series with the lines supplying the motor, and the overload relay's NC contact is connected in-series with the contactor's field coil.

If an overload overheats the heater, the NC contact will open to de-energize the field coil, which will cause the contactor to drop out, in-turn de-energizing the motor.

Motor Starters

The following figure shows the component connections for a basic motor starter:



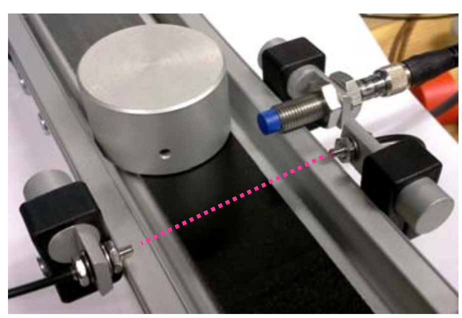
Due to their location in the circuit, the OL heaters are often <u>mistakenly</u> assumed to de-energize the motor when an overload occurs.

Remember, it is the <u>main contacts</u> of the contactor that are used to energize and de-energize the motor.

Optical Beam Detectors

<u>Optical Beam Detector</u>

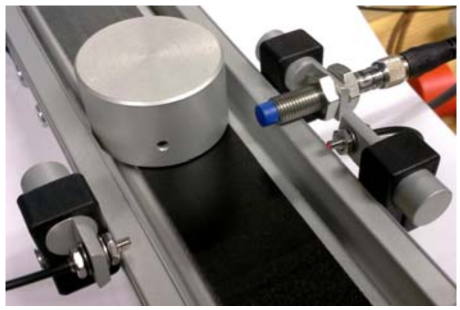
- **A device that produces a beam of light, and then actuates a set of contacts whenever an object disrupts the beam.**



Proximity Detectors

Proximity Detector

- **A device that actuates a set of contacts whenever a metallic object is in close-proximity to its sensor.**



Limit Switches

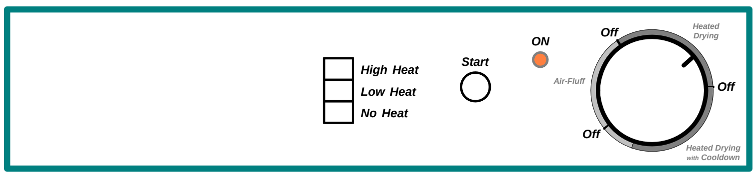
Limit Switch

- **An electro-mechanical device that consists of an actuator that is mechanically linked to a set of contacts.**
- **When an object comes into contact with the actuator, the device operates the contacts to make or break an electrical connection.**

Motor Control System Example

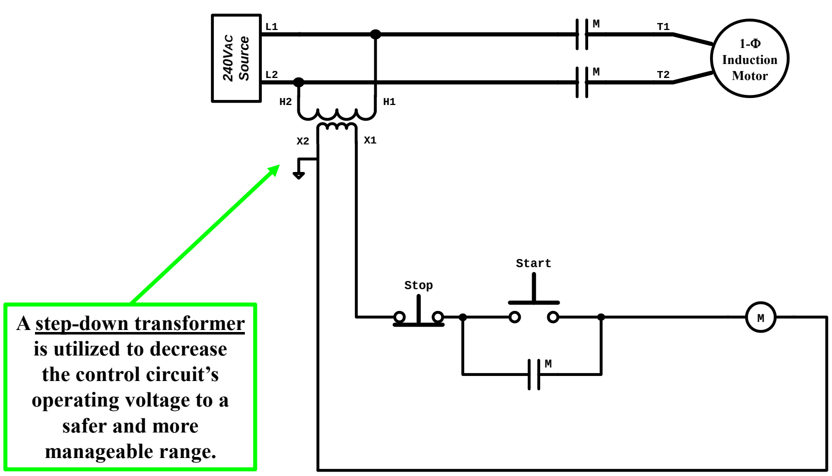
Problem – Design a basic control system for a **clothes dryer** that has the following functionality:

- **Start Button** (with Orange Indicator Lamp)
- **Door Switch** (with Interior Light)
- **Timer** with multiple functions (heat, cool-down, stop)
- **High/Low/No Heat Selection**



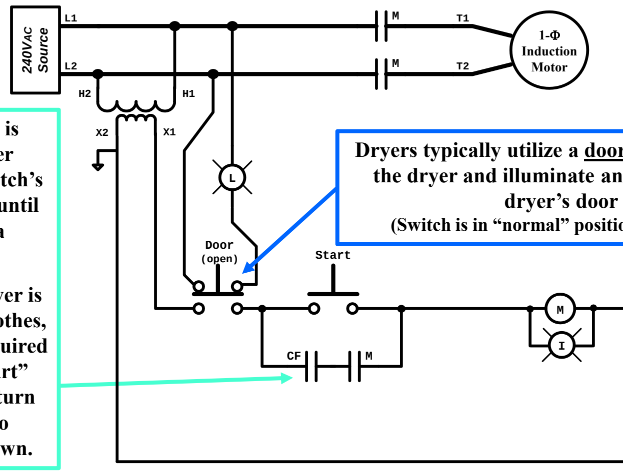
Control System for Clothes Dryer

Let's begin with a basic "Stop-Start" controller…



Control System for Clothes Dryer

Adding an Indicator, the Interior Lamp, and a Door Switch…



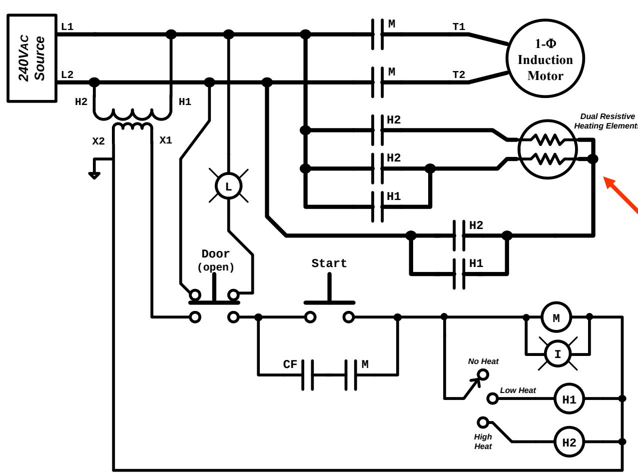
A <u>centrifugal switch</u> is attached to the dryer motor's shaft. The switch's contact remains open until the dryer reaches a minimum speed.

In the case that the dryer is overloaded with wet clothes, it will not reach the required speed before the "Start" button is released, in-turn causing the dryer to automatically shut down.

Dryers typically utilize a <u>door-switch</u> to both shut-down the dryer and illuminate and interior light when the dryer's door is opened.
(Switch is in "normal" position when the door is open.)

Control System for Clothes Dryer

Adding the Heating Elements and Selection Switch…



One heating element can be energized for "low" heat, while both elements can be energized for high heat.

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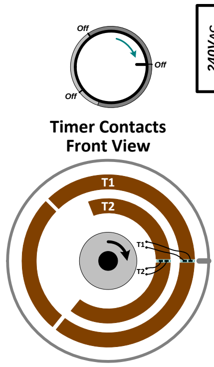
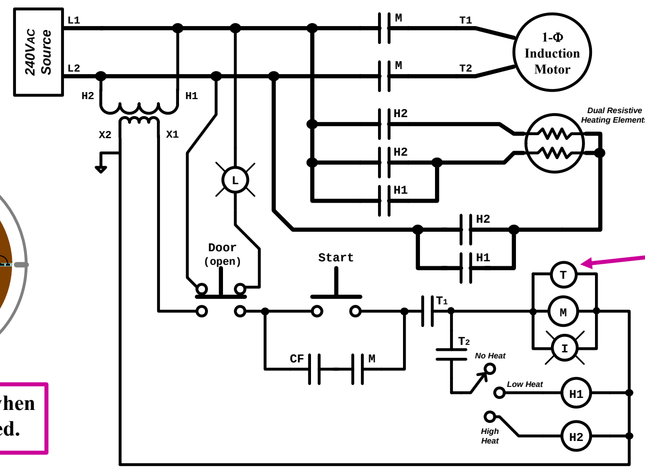
And finally adding a Timer to complete the basic circuit.





A motorized, rotating <u>timer</u> can be used to set the duration of the drying cycle and to limit during which portion of the cycle the heat is available.

Rotates clockwise when (T) is energized.

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Possible additions to the dryer control circuit:

- Overload protection for the motor?
- Additional Indicator Lamps?
- Buzzer?
- Imbalance sensors?
- Moisture sensor?
- Safety Interlock Switches?
- …