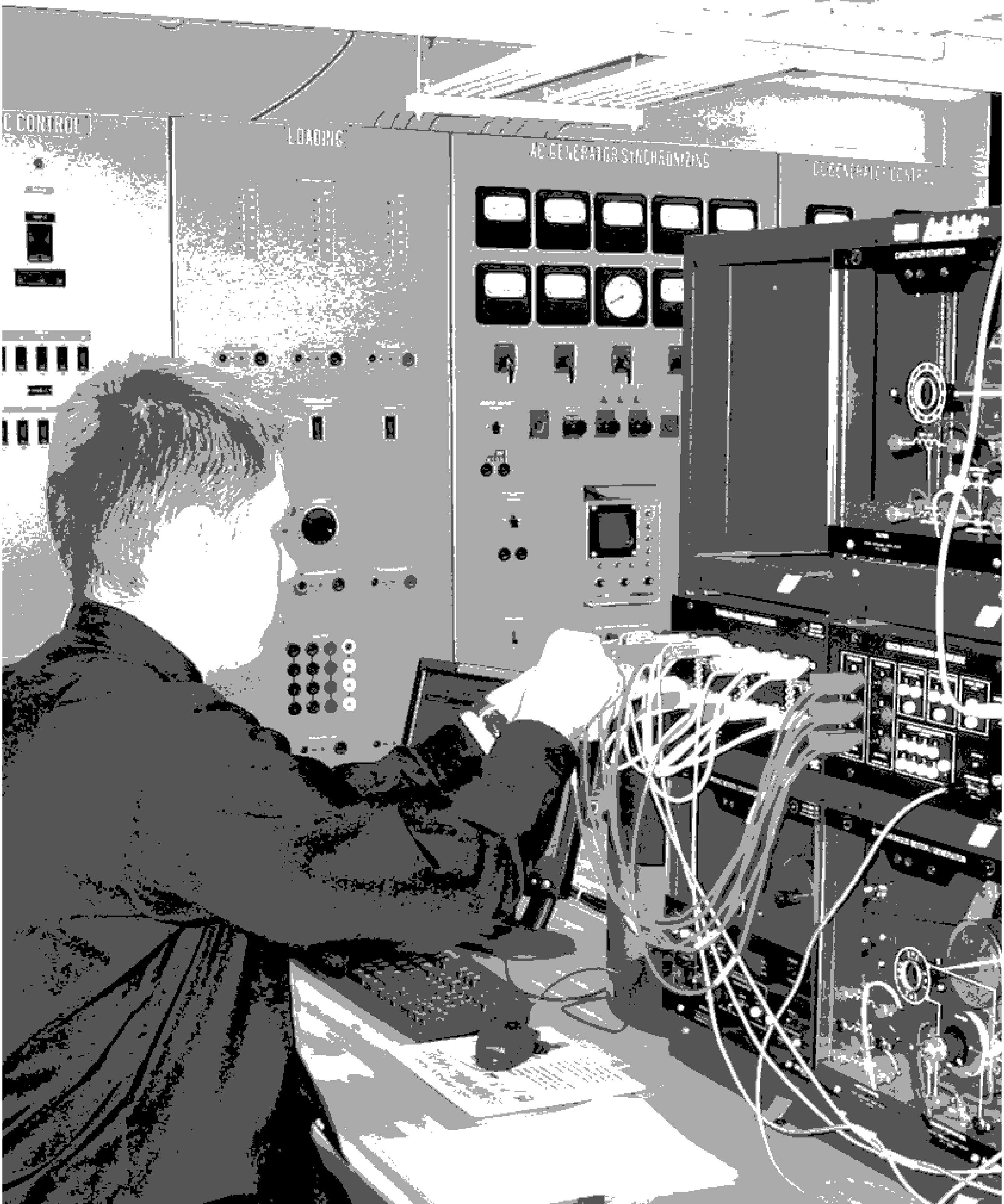
EN 3111L

Electrical Machines Lab



Massachusetts Maritime Academy

Instructors

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Course Goal

The purpose of the Electrical Machine Lab is to increase your understanding of the theory, design, construction, operation, and maintenance of electrical machinery commonly found aboard ship and in industrial facilities.

You will develop practical electrical skills such as using electrical measuring equipment, reading schematic diagrams, wiring circuits, troubleshooting faulty circuits, and following safe working practices. Additionally you will verify electrical theory by making measurements of electrical machinery in operation.

The material covered in the laboratory supplements the material studied in *EN-3111 Electrical Machines* and it is assumed that anyone taking the laboratory has either passed this course or is taking it concurrently with the lab. Three STCW skills will be demonstrated during the lab.

Learning Objectives

At the completion of this course, the student should be able to:

- Measure voltage, amperage, and resistance with a DMM
- Measure amplitude, frequency, period and phase shifts of sine waves using an oscilloscope
- Measure wattage, vars, va, and power factor using a power meter
- Lock-out and tag out electrical circuits
- Wire a three-way lighting circuit
- Understand the difference between grounded and ungrounded electrical distribution systems
- Connect three phase transformers in delta and wye configurations, and describe the resulting voltage and current relationships
- Demonstrate the operating characteristics of three phase induction motors
- Demonstrate the operating characteristics of single phase motors
- Demonstrate the operation of unloaded and loaded synchronous generators
- Parallel a AC Generator with the bus or another generator
- Demonstrate the operating principles of two-wire and three-wire control circuits
- Demonstrate the operating principles jogging and breaking circuits
- Demonstrate the operating principles reduced voltage and soft starters
- Wire single- and three-phase motors to UVR and UVP motor controllers
- Describe the operation and troubleshoot a magnetic motor controllers
- Describe the purpose a thermal overload relay
- Describe what is meant by sustained overload protection and interrupting capacity
- Demonstrate proficiency in the following STCW elements:
    - OICEW-3-1A Plan and use test equipment
    - OICEW-3-1B Troubleshoot electrical motor control system
    - OICEW-7-1E Parallel generators

Schedule

This course meets for two hours every week and consists of twelve lab exercises. Six are conducted in the upstairs laboratory and six are conducted in the downstairs lab. At each class meeting students will complete one upstairs or one downstairs lab.

The laboratory schedule is posted on the course website. It is critical that you make every effort to come to your scheduled lab since usually all sections are filled to capacity. If you must miss a lab due to unavoidable circumstances, you may attend another session of the same lab if space is available, however you are only guaranteed a space at your scheduled lab. Make up labs may be offered at the end of the semester if time permits. If you need to attend a make up lab, contact your instructor in advance.

Technology

The course website at http://weh.maritime.edu/juice is where you can find important information and policies regarding the course. The instructors use this site to maintain communications with the class. You should check this site weekly, or you may subscribe to its *RSS feed* using a newsreader to be notified whenever there are new posts. A number links to interesting electrically related websites are also found here.

Homework

Part of your grade will be determined by your score on the Simutech **Troubleshooting Simulator**. Instructions for connecting to the simulator and more details about the assignment are found on the course website at http://weh.maritime.edu/juice/troubleshooting. Read this info and create an account and finish the assignment by the deadlines listed below. Satisfactory completion of this assignment satisfies STCW 3-1B (Troubleshoot electrical motor control system).

Troubleshooting Homework Deadlines

Week of March 20	Create your account before you come to lab this week.
April 17 Midnight	Complete all 12 Basic and Advanced Faults

Quizzes

Quizzes will be given at the end of each lab, worth 50% of your course grade. Quizzes will not be returned.

Textbook

You will receive a lab manual during the first class meeting. This manual will be used in every lab, so always bring it with you. Review each lab before you come to the lab.

The Electrical Machines course textbook, *Operating, Testing, and Preventive Maintenance of Electrical Power Apparatus*, by Charles I. Hubert, and *Electrical Machines, Drives, and Power Systems*, by Theodore Wildi are also recommended.

Attendance

Students will be penalized as follows for absences:

Miss 1 lab	Course Grade reduced by 1 Letter Grade
Miss 2 lab	Course Grade reduced by 2 Letter Grades
Miss 3 or more	Automatic course failure

Grades

Your final grade will be determined using the following weights

Troubleshooting Software	25%	Penalties may be applied for missing deadlines.
Upstairs Lab Quizzes	25%	
Downstairs Lab Quizzes	25%	
Lab Final Exam	25%	Lab final will be held preceding course final exam.
Attendance Deduction	See above	

STCW Assessment

This lab addresses the STCW Function: *Electrical, electronic and control engineering at the operational level*. All students are required to satisfy the STCW assessments of the course.

Students who fail to demonstrate competence in all of these areas will receive an *Incomplete* for the course. You can clear an *incomplete* by demonstrating the missing competencies. It is your responsibility to make up any missed assessments. Contact your instructor to schedule a make-up.

Downstairs Labs

Lab 1 Alternating Current
Lab 2 Three Phase Transformers
Lab 3 DC Generators
Lab 4 Induction Motors
Lab 5 AC Synchronous Generators
Lab 6 Generator Paralleling Satisfies: STCW 7-1E (Parallel generators)

Upstairs Labs

Lab 1 Residential Wiring
Lock-out / Tag-out Procedures
Use of Voltmeter, Ammeter, Wiggy, DMM
Satisfies: STCW 3-1A (Use of Meters)
Lab 2 Basic Principles of Motor Control: Exercises 1-1 to 1-5
Homework: Read Unit 2 in Lab Volt Manual before Lab 3
Lab 3 Basic Control Circuits Exercises 3-1, 3-2, 3-3, 3-4, and 3-5
Lab 4 Jogging Control Circuits. Exercises 4-1, 4-2, and 4-3
Lab 5 Reduced Voltage Starters. Exercises 5-1 and 5-2
Lab 6 Time Relays Exercises 6-1, 6-2, and 6-3
High Voltage Switchgear

IMPORTANT RULES:

Safety First!

No food or drink in the lab!!

Spring 2017

	27 *Academic Orientation*	28	1	2	3
March	6 H1	7 *Last day to add*	8 H1	9 H1	10
	13 L1	14	15 L1	16 L1	17
	20 H2	21 *Last day to drop*	22 H2	23 H2	24
	27 L2	28	29 L2	30 L2	31
April	3 H3	4	5 H3	6 H3	7
	10 L3	11	12 L3 *Thursday Schedule*	13 *No Classes*	14 *No Classes*
	17 *Patriots' Day*	18 *Deficiencies due*	19 L3	20 H4	21
	24 H4	25	26 H4	27 L4	28
	1 L4	2	3 L4	4 H5	5
May	8 H5 *Last day to withdraw*	9	10 H5	11 L5	12
	15 L5 ← *USCG Exam Class of 2017*	16	17 L5	18 H6 →	19
	22 H6	23	24 H6 *Change of Command*	25 L6	26
	29 *Memorial Day*	30 L6 *Monday Schedule*	31 L6	1 MU	2
June	5 MU	6	7 MU	8 *Begin Finals*	9
	12	13	14		

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Lab 1

Alternating Current

Introduction

Objective

In the laboratory exercise, you will verify Ohm's law by measuring circuit current for various combinations of voltage and resistance; observe sinusoidal waves on an oscilloscope and determine important circuit parameters such as frequency, period, amplitude and RMS values; and identify phase shifts between voltage and current in an LRC circuit on both the oscilloscope and the phasor analyzer.

After completing this lab, you should be able to calculate the resistance of various combinations of resistors in series and parallel; use Ohm's law; adjust, use, and interpret an oscilloscope display; determine whether and by how much one sinusoidal wave leads or lags another and represent them using a phasor diagram.

Sinusoidal waves

Alternating current (AC) is used throughout the world for powering electrical equipment. As its name suggests, alternating current is an electrical current that continuously alternates in direction and magnitude. This alternating current is caused by a similarly alternating voltage produced by a generator. The term *alternating current* is used describe many aspects of the electrical system, so for example we speak of ac generators, ac voltages, and ac meters, etc.

AC voltages and currents change in value from instant to instant in a repeating pattern which can be plotted as a function of time or viewed on an oscilloscope. The shape of this *periodic* waveform depends on the power supply generating the voltage, and it is possible to create square waves, triangular waves or other forms, but the type of wave form created by standard electrical generators is *sinusoidal*. A sine wave of voltage permits us to obtain the highest efficiency from motors, generators, and transformers, and results in the quietest operation.

One *cycle* is one complete sequence of positive and negative values that make up the repeating pattern of the periodic waveform. After completing one cycle, the waveform returns to its starting value, and begins the cycle again. The length of time it takes to complete one cycle is called the *period*, and the number of times that the cycle repeats in one second is called the *frequency* of the waveform. Therefore the frequency and period are inverses of each other.

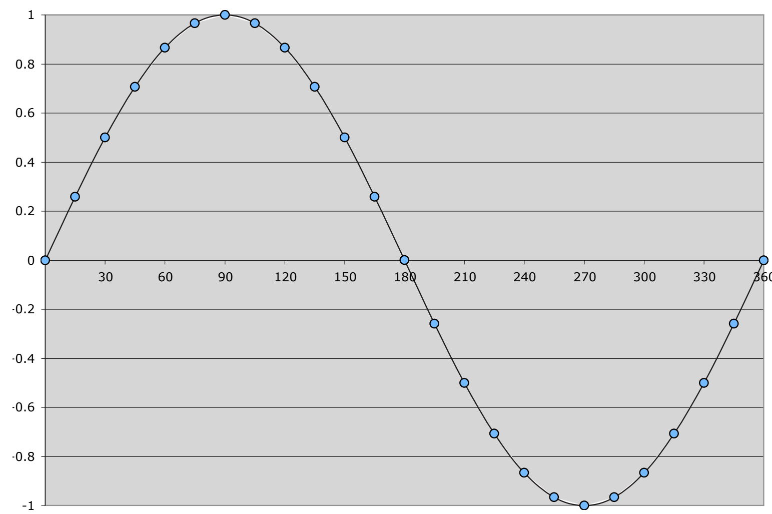


Figure 1.1: The sine wave

$$T = 1/f \qquad f = 1/T$$

Frequency is measured in Hertz (Hz) where 1 Hz is 1 cycle/sec. The normal ac line frequency in North America is 60 Hz, while most countries in Europe, and several others, have an ac line frequency of 50 Hz. When the value reaches zero for the second time, a full revolution of 360 angular degrees has been completed. For a 60-Hz system, in one second, 60 complete cycles, or periods, of the sine wave take place. Therefore, the period of a 60-Hz sine wave is 1/60 of a second.

$$T = 1/60\,\text{sec} = 0.01667\,\text{sec} = 16.67\,\text{mS}$$

Angular velocity, ω, describes the frequency in radians per second and since there are 2π radians per revolution, the relationship between angular velocity and frequency is

$$\omega = 2\pi f$$

Phasors

Each cycle of a sine wave is equivalent to one 360° revolution of a *rotating vector*. The vector rotates with an angular velocity $\omega = 2\pi f$. The instantaneous value of voltage is the y-component of the vector, and its value changes through one cycle as the vector rotates through 360°. Time is taken to be zero when the vector is aligned with the positive x axis, and the vector is always considered to be rotating in the counterclockwise direction. A *phasor* is a similar rotating vector which uses the rms value rather than the peak value as the length of the phasor. Using the rms values makes calculations involving rms values simpler.

The sinusoidal value starts at zero, increases to a maximum, then decreases until it reaches zero again, at which point the value changes sign. When an electrical quantity changes sign, we say

θ	$\sin\theta$	θ	$\sin\theta$
0°	0.000	180°	0.000
15°	0.259	195°	-0.259
30°	0.500	210°	-0.500
45°	0.707	225°	-0.707
60°	0.866	240°	-0.866
75°	0.966	255°	-0.966
90°	1.000	270°	-1.000
105°	0.966	285°	-0.966
120°	0.866	300°	-0.866
135°	0.707	315°	-0.707
150°	0.500	330°	-0.500
165°	0.259	345°	-0.259
180°	0.000	360°	0.000

Table 1.1: Values of the Sine Function for One Cycle

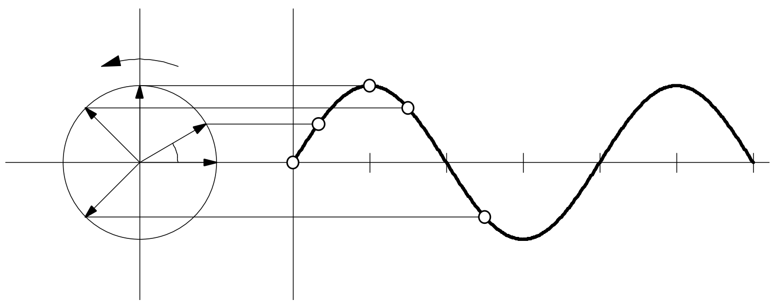


Figure 1.2: Relation between rotating vector and the sin wave.

that it has reversed its *polarity*. The quantity then continues to decrease until it reaches a negative maximum, and then returns to zero. The maximum value, which is equal to the length of the rotating vector, is called the *Amplitude*, or sometimes, the *peak value*. The *peak-to-peak* value is the difference between the maximum and minimum values, which is simply twice the peak value.

Since an ac voltage constantly changes in value, a 100 V (peak) ac voltage will not deliver the same amount of power as a steady 100 V dc voltage. To facilitate this comparison, we define the *rms (root-mean-square)* or *effective value* of an ac voltage to be the value of a dc voltage that would produce the same amount of heat in a given resistor.

For example, suppose that a sine-wave voltage with a peak value of 100 V were connected to a load resistor and the resistor's temperature was measured after it had stabilized. The effective value of the ac voltage could be found by using a variable dc supply, and adjusting the dc voltage until the temperature of the resistor stabilized at the same point as before. The resulting dc voltage would be 71 V, meaning that the rms value of the ac voltage is 71 V. Another way to obtain a measure of the rms value would be to connect a dc voltage to one lamp and an ac voltage to another. The lamp brightness will be a fairly accurate indicator of the power being dissipated, and the dc voltage could be adjusted to obtain the same brightness as the ac voltage. Naturally, these methods would be time consuming and not very efficient for determining the rms value of an alternating voltage or current. Fortunately, they are rarely necessary because standard ac voltmeters and ammeters are calibrated to indicate the rms value directly. In equations, the rms subscript is understood, and not usually indicated unless required for clarity.

Mathematically, the rms voltage is determined by taking the square root of the average of the square of the instantaneous voltage over one cycle. When this process is carried out for a sinusoidal waveform, the rms value is always found to be equal to the peak value times $1/\sqrt{2}$.

$$V_{rms} = \frac{V_{max}}{\sqrt{2}} = 0.707\,V_{max}$$
$$I_{rms} = \frac{I_{max}}{\sqrt{2}} = 0.707\,I_{max}$$

Phase Angle

Phase angle is used to measure the amount of separation in time or angle between two sine waves of the same frequency. The sine waves being compared must have the same frequency, but they do not have to be the same amplitude. When making comparisons, one of the two sine waves is designated the *reference waveform*, and taken to have a *phase angle* of $\theta = 0$ at $t = 0$. The other waveform is said to *lead* or *lag* the reference.

To determine the phase shift using an oscilloscope, the waveform on one channel is designated the reference waveform, and the other channel displays the waveform for which we wish to measure the relative phase difference. The horizontal separation between two corresponding points on the waveforms is measured, and using the horizontal scale of the oscilloscope, the time difference T_d is determined. The angular phase difference can be easily found since the ratio of the time difference to the period is the same as the ratio of the phase difference to 360°.

$$\frac{T_d}{T} = \frac{\Delta\theta}{360°} \tag{1.1}$$

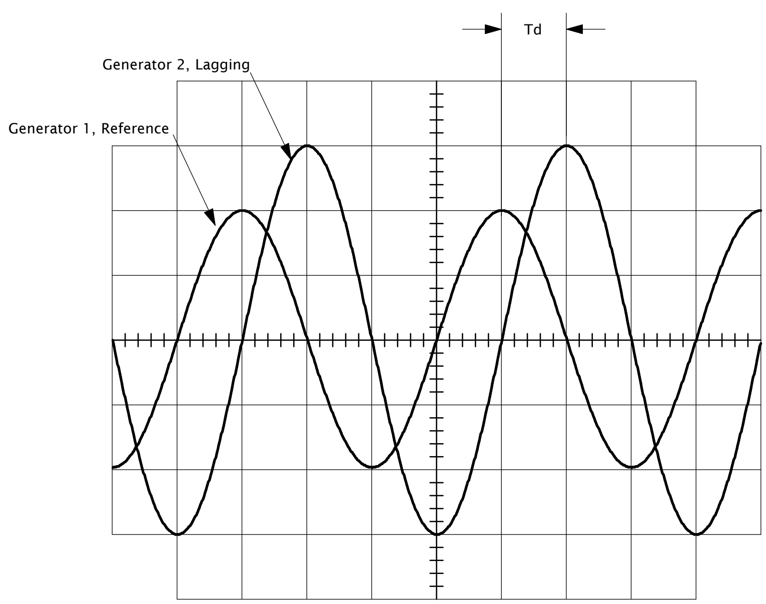


Figure 1.3: Phase shift

For example, in Figure 1.3 The two sin waves are separated by one major division on the oscilloscope. If the horizontal scale is 20 ms/div, then the two waves are out of phase by 20 ms, so $T_d = 20$ ms. It takes the waves 4 major divisions to complete one cycle, so the period $T = 80$ ms. Using equation 1.1 to find the phase difference we have

$$\begin{aligned}\Delta\theta &= \frac{T_d}{T} \cdot 360^\circ \\ &= 20/80 \cdot 360^\circ \\ &= 90^\circ\end{aligned}$$

Lead or lag is determined by the relative positions of the two waveforms. Choosing two corresponding points that are less than or equal to 180° apart, the wave that reaches the point earliest in time is said to lead the other. A leading wave appears to the left of the reference, while a lagging wave is shifted to the right. In this case, generator 2 lags. When the phase is lagging, it is common to see a minus sign or the word *lagging* included with the number, i.e. –90° or 90° lagging. Note that when generator 2 lags the reference, the reference leads generator 2 by the same amount. When a wave lags by 90°, it also leads by 270°, but the convention when speaking of phase difference is to use the value closest to zero.

Three Phase Power

Electrical power is most commonly generated by *three-phase* generators. Three phase generators have three identical windings 120° apart, that produce three identical sine waves of voltage simultaneously. The three voltage phases, typically called A, B and C have identical amplitudes, but are evenly separated in time, and therefore separated from each other by a phase shift of 120°. Figure 1.4 shows three phase voltage, and the corresponding phasor diagram.

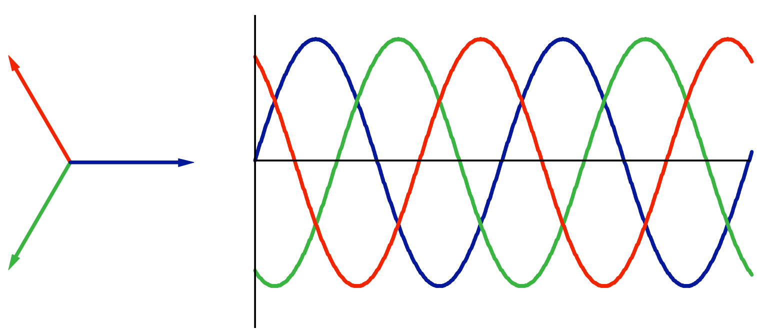


Figure 1.4: Three phase voltage

Procedure

Sine Waves

☐ 1. Verify that the *Power Supply*, *Data Acquisition Interface*, and *Resistive Load Modules* are installed in the *EMS Workstation*.

Warning
High voltages are present in this laboratory exercise! Do not make or modify any banana jack connections with the power on unless

☐ 2. Make sure the main power switch of the *Power Supply is off*, and that the output control knob is turned fully ccw. Set the voltmeter select switch on the power supply to the 4-N position.

☐ 3. Ensure that the 24 V power supply is connected to the DAI, and that the USB cable from the computer is connected to the DAI. Set the 24 V - ac power switch to the 1 (ON) position and leave it turned on throughout the exercise. Loss of power to the DAI will cause it to lose communication with the metering software.

Hint
When building circuits, start at the power supply and construct around the circuit and back to the power supply. Ignore the voltmeters until the main circuit is built, then add them last.

☐ 4. Display the *Metering Application* by clicking on the icon and then open meter configuration file *Lab 1 AC*, which will set up the virtual meters as indicated in the table:

Meter	Setup
E1, E2, E3	AC Volts
I1	AC Amps
Programmable meter A	Power PQS1 (E3, I1) Mode P
Programmable meter B	Frequency (E3)

☐ 5. Set up the circuit shown in Figure 1.5. Note the symbol used to indicate a *variable ac source* in this circuit. Set the resistances of R_1 and R_2 to **300** □ each. Note that E3 is placed across the power supply and measures the supply voltage, and that I1 is placed in series with the load, and measures the load current.

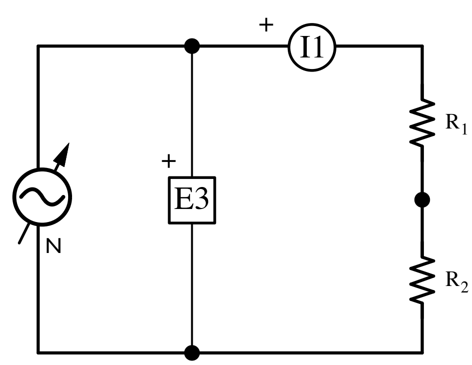


Figure 1.5: AC sine wave circuit

What is the total resistance of the circuit in this configuration? __________

☐ 6. After your circuit has been checked, turn on the power, and set the voltage control knob to 100%.

Have your circuit checked by the instructor before moving on.

☐ 7. Open the meter display, and activate it by clicking on the *continuous refresh*. Record the circuit current and voltage (rms values).

V = __________ I = __________

☐ 8. Click on the *Oscilloscope* button and display E3 and I1 on CH1 and CH2. Activate the display by clicking on the *continuous refresh* button. Set convenient vertical scales for the display, and adjust the *time base* to show one cycle of the sine wave.

☐ 9. Read the peak amplitudes of the voltage and current waves from the display and record them.

V_p = ________ I_p = ________

☐ 10. Calculate the ratios of peak to rms values.

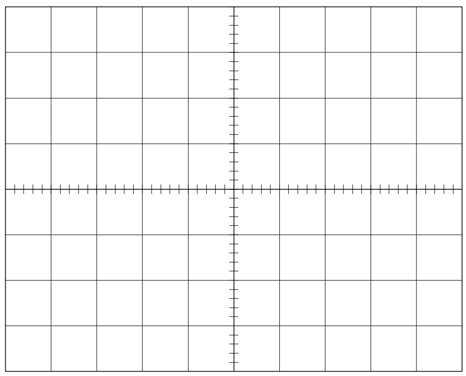
V_p/V = ________ I_p/I = ________

Are the ratios approximately equal to $\sqrt{2}$ ☐ Yes ☐ No

☐ 11. Compare the current waveform to the voltage waveform.

Are they both sine waves? ☐ Yes ☐ No
Do they have the same frequency? ☐ Yes ☐ No
Are their amplitudes approximately equal? ☐ Yes ☐ No
Are the two waves in phase? ☐ Yes ☐ No

☐ 12. Carefully sketch and label what you see on the oscilloscope.



☐ 13. The *period*, T of a sine wave is the length of time that it takes to complete one cycle. Use the *cursors* to determine the period of the voltage wave.

T = ________ ms

☐ 14. The *frequency*, f of a sine wave is the inverse of the period, and is usually expressed in Hz, which are cycles/sec. Calculate frequency in Hz based on your measurement of the period, and compare with the measurement shown on the frequency meter.

$f = 1/T =$ ________ Hz

Ohm's Law

☐ 15. Turn the voltage control knob to the zero position.

☐ 16. Click on the *Data Table* button to bring up the data table, then click on the *Record Data* button. Accept the default selection of values to record.

☐ 17. Use the *Record Data* button to record the voltage and current measurements in the *Data Table*, for **0, 25, 50, 75 and 100%** positions of the voltage control knob.

☐ 18. Adjust the load resistor R_1 to **171** □ , and repeat the previous step. Use the same data table and do not delete the data from the previous step.

What is the total resistance of the circuit in this configuration? ________

Do you remember the formula for resistors in parallel?

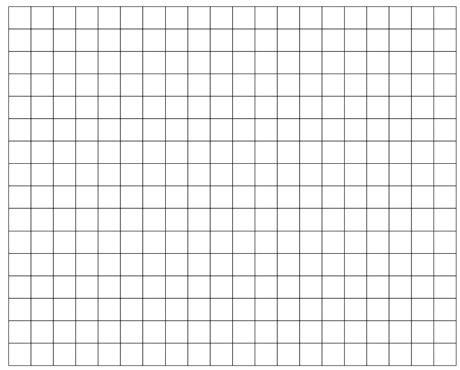
$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$$

☐ 19. Click on the graph icon, and create a graph of line voltage (meter E3) as a function of line current (meter I1).

How does the graph demonstrates Ohm's Law?

____

Sketch the graph here.



☐ 20. Use your vast knowledge of Ohm's law to predict the voltage drops across resistors R_1 and R_2 when a 100 V supply voltage is applied to the circuit.

I_1 = __________ A E_1 = __________ V E_2 = __________ V

☐ 21. Add E_1 and E_2 to measure the voltage drop across resistors R_1 and R_2, as shown in Figure 1.6, and adjust the source voltage to **100 V** with the voltage control knob.

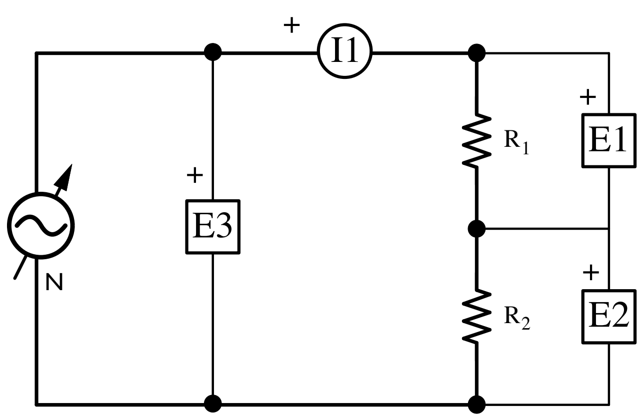


Figure 1.6: Voltage Divider Circuit

☐ 22. Record the voltage drop across the two resistors with voltmeters E1 and E2, and the line current with I1.

I1 = __________ A E1 = __________ V E2 = __________ V

How well do the measured values agree with the predictions that you made?

____

What is the relationship between the source voltage E3, and the values shown on E1 and E2?

____

This circuit is often called a "voltage divider." Why?

____

☐ 23. In a voltage divider circuit like this one, the ratio of the the voltage drops across the two resistors should equal the ratio of their resistances.

E_1/E_2 = __________ R_1/R_2 = __________

Are the ratios approximately equal? ☐ Yes ☐ No

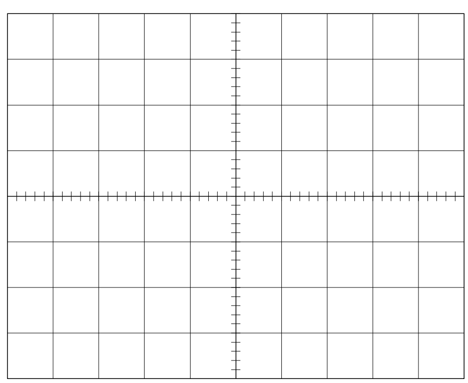
Phasors and Phase Angle

☐ 24. Continuing with the setup from the preceding section, click on the *Oscilloscope* button and display E3 and I1 on channels 1 and 2. Adjust the vertical scales and the time base to show at least one complete cycle of the sine waves.

Is the line current still in phase with the line voltage? ☐ Yes ☐ No

☐ 25. With the power off, switch the 300 □ resistor with a **300 □ inductor**. Turn the power back on when the circuit has been modified.

☐ 26. Observe the oscilloscope display, and sketch what you see.



☐ 27. Are the current and voltage still in phase? ☐ Yes ☐ No

☐ 28. Does the current lead or lag the voltage? ☐ Lead ☐ Lag

☐ 29. Use the cursors to determine the time delay between current and voltage in ms.

T_d = __________ ms

☐ 30. Calculate the phase shift in degrees, using the time delay and the period T you measured earlier.

$\phi = \frac{T_d}{T} \cdot 360°$ = __________

☐ 31. Set the *cursor units* to degrees, and measure the phase shift. Does this number agree with your calculated value?
☐ Yes ☐ No

☐ 32. Turn on the *Phasor Analyzer* and set it up to display E3 and I1. Use E3 as the *reference phasor*. Does the phaser analyzer show the same phase shift between current and voltage as your calculation?

☐ Yes ☐ No

☐ 33. Do the lengths of the phasors represent the *Peak* or *rms* values of the voltage and current?

☐ Peak ☐ rms

☐ 34. Replace the 300 □ inductor with a **300 □ capacitor**, and observe the circuit behavior again.

☐ 35. What does the phase shift between voltage and current tell you about the load?

____

____

☐ 36. **Turn off the power.** Disassemble the circuit.

Line and Phase Voltages

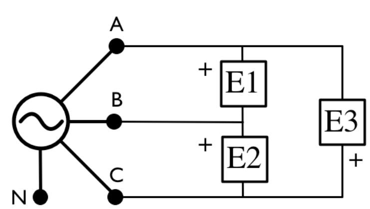


Figure 1.7: Line Voltage Measurement

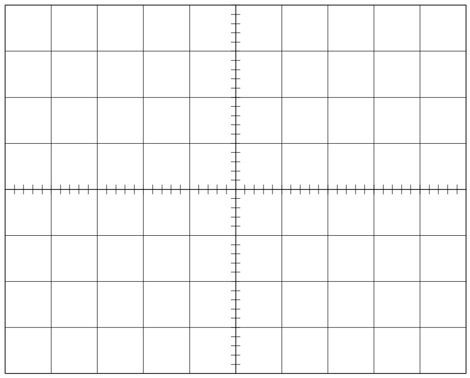
☐ 37. With the power off, connect voltmeters E1, E2, and E3 to simultaneously measure the LINE voltages of the fixed voltage three-phase power supply, as shown in Figure 1.7.

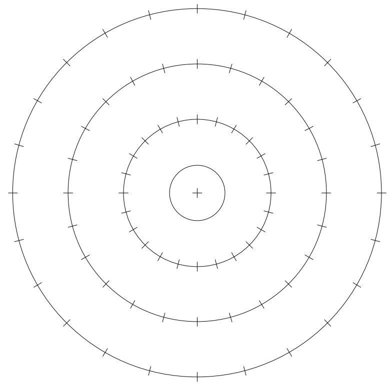
Pay attention to the polarities of the voltmeters.

☐ 38. Turn on the power and record the measured values here.

$E_{A\text{-}B}$ = __________ V $E_{B\text{-}C}$ = __________ V $E_{C\text{-}A}$ = __________ V

☐ 39. Set up the *oscilloscope* and *Phasor Analyzer* to display the three voltages, and sketch below what you see.





☐ 40. Turn off the power and reconnect voltmeters E1, E2, and E3 to simultaneously measure the PHASE voltages of the fixed voltage three-phase power supply, as shown in Figure 1.8.

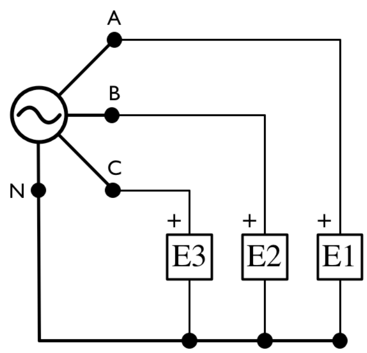


Figure 1.8: Phase Voltage Measurement

☐ 41. Observe the voltages on the *oscilloscope* and *Phasor Analyzer* and record the measured values here

$E_{A\text{-}N}$ = ________ V $E_{B\text{-}N}$ = ________ V $E_{C\text{-}N}$ = ________ V

☐ 42. Answer these questions:

Are all three rms line voltages approximately equal?	☐ Yes	☐ No
Are all three rms phase voltages approximately equal?	☐ Yes	☐ No
Are the line voltages $\sqrt{3}$ times greater than the phase voltages?	☐ Yes	☐ No

☐ 43. What is the angular phase difference the any two voltages?

ϕ = ________ °

☐ 44. What is the time difference between any two voltages?

ΔT = ________ ms

☐ 45. Turn off the power, turn off the computer, and put everything away.

Review Questions

1. Phase angle can be used as

   a) a measurement of the period of a periodic waveform.
   b) an indication of a signal's frequency.
   c) a measurement of the separation between two waveform.
   d) only valid when three-phase signals are considered.

2. A sine wave has a leading phase angle of 72°. Will it reach maximum before or after the reference waveform?
   a) After.
   b) Before.
   c) It depends on the frequency.
   d) None of the above.
3. Three-phase ac power consists of three sine waves separated by 120°.
   a) True in North America only.
   b) False.
   c) True.
   d) False since square waves are sometimes used.
4. A sine wave has a phase angle of -45°. Is the reference waveform leading or lagging this sine wave?
   a) Leading.
   b) Lagging.
   c) Neither, it is in phase.
   d) The reference cannot lead or lag another waveform.
5. The oscilloscope images of the current and voltage waveforms for a circuit shows that a large phase difference exists between the two. What does this indicate about the type of circuit components?
   a) Nothing.
   b) They must be defective.
   c) They are all resistors.
   d) There must be capacitors and/or inductors in the circuit.
6. The peak-to-peak amplitude of a sine wave is 200 V. What is the rms value?
   a) 282 V
   b) 70.7 V
   c) 141 V
   d) 14.1 V
7. The period of a sine wave is 0.02 seconds, What is its frequency?
   a) 5 Hz
   b) 50 Hz
   c) 50 s
   d) 0.02 Hz
8. An ac voltage can be considered as a dc voltage that is continually changing its amplitude and polarity.
   a) False.
   b) True in cases when the current is zero.
   c) True.
   d) None of the above.
9. One complete cycle of a sine wave is the same as one circular rotation of 360 degrees.
   a) True in cases where the frequency is less than 100 Hz.
   b) True.

c) False because a sine wave is not a circle.
d) False.

10. When are two sine waves said to be in phase?
    a) When the current leads the voltage.
    b) When they both attain their maximum values at the same time.
    c) When they both go through zero at the same time.
    d) Both band c together.

Lab 2

Three Phase Transformers

Introduction

Objective

After completing this exercise, you will be familiar with operating characteristics of three-phase transformers. You will be able to connect transformer windings in wye and delta configurations, and verify that windings are connected with the proper phase relationships.

You will make voltage and current measurements and investigate transformer characteristics. You will determine the primary and secondary voltage and current ratios and phase shifts caused by three-phase transformers connected in four configurations, wye-wye, delta-delta, wye-delta, and delta-wye.

Transformers

A *transformer* is an electromagnetic device which uses Faraday's principle of induction to change an ac voltage from one value to another. Transformers are also used to isolate one circuit from another.

Transformers have two coils, the *primary* and the *secondary*, magnetically linked to each other by an iron core. When an alternating voltage is applied to the primary coil, current flow creates an alternating magnetic field. This magnetic field links through the secondary winding, and the changing magnetic field there induces the secondary voltage. The output voltage is dependent on the applied voltage and the number of turns in each coil. In an ideal transformer, the input to output voltage ratio is equal to the turns ratio; if both coils have the same number of turns, a *1:1 turns ratio*, the voltage neither steps up nor steps down.

$$\frac{N_{\text{pri}}}{N_{\text{sec}}} = \frac{E_{\text{pri}}}{E_{\text{sec}}} = \frac{I_{\text{sec}}}{I_{\text{pri}}}$$

In actual transformers, the ratio is only approximate due to voltage drops occurring in the coils, and imperfect linkage of the magnetic flux through the coils.

When line voltage steps up line current steps down, and vice-versa, because their product EI is electrical power, which is conserved by a transformer.

Three phase transfomers

The main features of three-phase transformer circuits that are important to understand are that transformers have two sides: *primary* and *secondary*; there are two types of connections: *wye* and *delta*; and we can measure two different voltages: *line* and *phase*. Since both the primary and secondary windings can be connected in either wye or delta there are four possible types of connections: *wye-wye, delta-delta, delta-wye,* and *wye-delta*. Three-phase transformers can physically be three single-phase units connected together or a single unit containing three transformers.

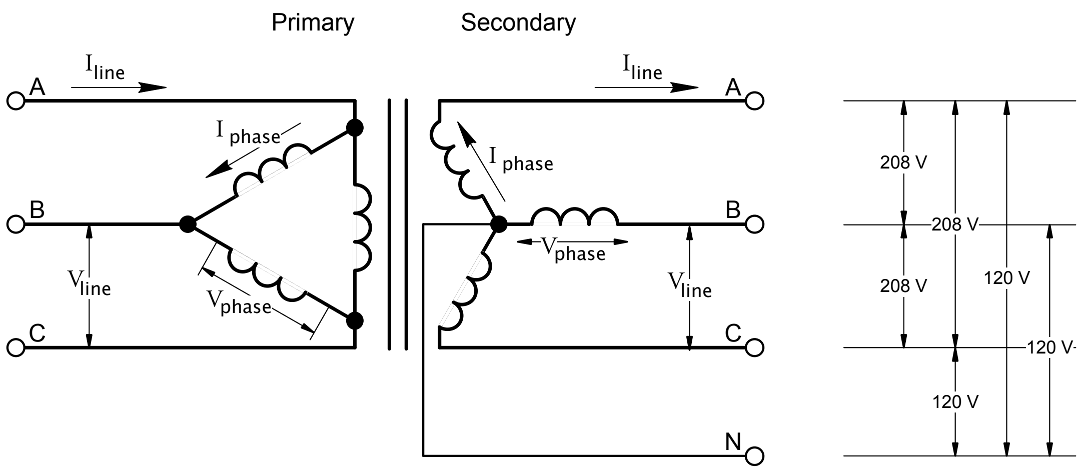


Figure 2.1: Delta Wye Three-phase Transformer

In wye-connected three-phase circuits, *line voltages* are greater than *phase voltages* by the factor $\sqrt{3}$ while the *line current* and *phase currents* are equal. A wye connected transformer can be used to provide two different voltages for different uses simultaneously. For example, in Figure 2.1 when 120 V three-phase power is supplied to the primary of a transformer 208 Volts is available between any two lines on the secondary, while 120 volts can be obtained between a line wire and the neutral wire. Therefore the wye-connected secondary provides three-phase 120/208 V power using 4 wires. The primary side of the transformer may be connected in delta as in the figure or in wye.

In delta-connected three-phase circuits, the situation is just the opposite. Line and phase voltages are equal, while line currents are greater than the phase currents by the factor $\sqrt{3}$. One advantage of using a delta configuration for the primary is that only three wires are needed to distribute the three phases. Another advantage is that two single-phase transformers (instead of three) can be operated in what is known as the *open-delta* configuration in an emergency if one of the three transformers becomes damaged or is removed from service. The open-delta transformer bank still delivers phase voltages and currents in the correct relationship, but the capacity of the bank is reduced to 57.7% ($1/\sqrt{3}$) of the total nominal capacity available with three transformers in service.

When 1:1 transformers are used, the phase voltage on the secondary equals the corresponding phase voltage on the primary. If the turns ratio is not 1:1, the the phase voltages step up or step down accordingly. The situation is more complex when comparing line voltages: in the delta-delta and wye-wye configurations, the line voltage at the secondary is equal to the line voltage at the primary times the inverse of the turns ratio; in the delta-wye configuration, the line voltage at the secondary is equal to the line voltage at the primary times the inverse of the turns ratio times $\sqrt{3}$; and, in the wye-delta configuration, the line voltage at the secondary is equal to the line voltage at the primary times the inverse of the turns ratio times $1/\sqrt{3}$.

	Wye	Delta
Voltage	$V_L = \sqrt{3}V_\phi$	$V_L = V_\phi$
Current	$I_L = I_\phi$	$I_L = \sqrt{3}I_\phi$

Table 2.1: Property relations for three-phase connections

Three phase transformers may also introduce a phase shift between the primary and the secondary line voltages. Primary and secondary line voltages in delta-delta and wye-wye connections are in phase. In delta-wye and wye-delta connections however, there will be a 30° phase difference between the primary and secondary voltages. The 30° phase shift between the primary and secondary does not create any problems for isolated groups of loads connected to the outgoing lines from the secondary. However, if the outgoing lines from the secondary of a three-phase transformer have to be connected in parallel with another source, the phase shift might make such a parallel connection impossible, even if the line voltages are the same. Recall that in order for three-phase circuits and sources to be connected in parallel, line voltages must be equal, have the same phase sequence, and be in phase when the parallel connection is made.

Figure 2.1 shows a three-phase transformer, with a turns ratio equal to 1:1, connected in the delta-wye configuration and feeding a three-phase load. The voltage across each primary winding E_{pri} equals the incoming line voltage, but the outgoing line voltage E_{sec} is $\sqrt{3}$ times that voltage because the voltage across any two secondary windings is $\sqrt{3}$ times greater than the voltage across a single secondary winding. Note that if the three-phase transformer had a turns ratio of 1:10, the line voltage at the secondary would be $10 \times \sqrt{3}$ times greater the line voltage at the primary, because the inverse of the turns ratio is multiplied by the $\sqrt{3}$ factor. The line current in the secondary is the same as the phase current, but the line current in the primary is $\sqrt{3}$ times greater than the corresponding phase current.

Phase relationship

When wiring up transformers, precautions must be taken to ensure that the secondaries are connected with the proper phase relationships. If a transformer winding is installed backwards, high voltages and short circuit currents can be produced.

In order to set up a wye connection, first connect the three components (windings) together at a common point for interconnection with the neutral wire, then connect the other end of each component in turn to the three line wires. To set up a delta connection, connect the first component in series with the second, the second in series with the third, and the third in series with the first to close the delta loop. The three line wires are then separately connected to each of the junction nodes in the delta loop. Before closing the delta or supplying a load check the phase relationships as follows:

For a wye configuration, check that the voltage measured across any two secondary windings (line voltage) is $\sqrt{3}$ times greater than the voltage across either winding by itself (phase voltage). If not, the connections must be reversed before continuing.

For a delta configuration, the voltage measured between the ends of two series connected secondary windings must equal the voltage across either winding individually, and when one end of the third winding is connected, the voltage measured across all three series-connected windings must equal

Meter	Display
E1, E2, E3	AC Volts
I1, I2, I3	AC Amps
Programmable Meter A	Sum(E1,E2,E3)
Programmable Meter B	Ave(E1,E2,E3)

Table 2.2: Meter Configuration

zero before connecting them together to close the delta. If not, the incorrect connection must be reversed. This is particularly important for a delta configuration, because a very high short-circuit current will flow if the voltage within the delta is not equal to zero when it is closed.

Procedure

Single Phase Transformer

☐ 1. Insure that the Power Supply, Three-phase Transformer module, and Data Acquisition Interface are installed in the EMS Workstation. Insure the USB cable connects the DAI to the computer.

☐ 2. Make sure that the **main power switch is off**, and the voltage control knob is turned fully ccw. Set the voltmeter select switch to the 4–5 position.

☐ 3. Use the grey cable to connect the DAI to the 24 V ac power supply, and turn it on. Leave power on the DAI for the entire exercise.

☐ 4. Launch the *Metering* program, and open configuration file *Lab 2 Transformers* and launch the *Phasor Analyzer* and set it up to display E1, E2, and E3, with E1 as the *Reference Phasor*. The meters should display the values shown in Table 2.2.

☐ 5. Construct the circuit shown in Figure 2.2. Note that E1 measures the input (primary side) voltage $E_{1\text{-}2}$, and E2 measures the corresponding output voltage $E_{3\text{-}5}$ on the secondary side of a single-phase transformer.

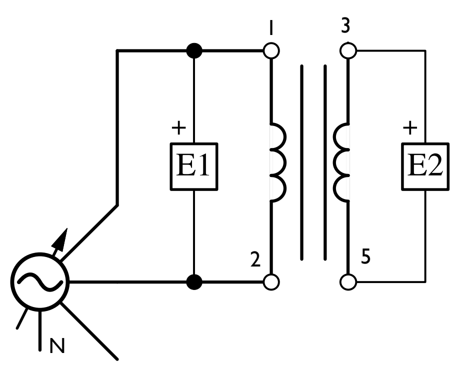


Figure 2.2: Single Phase Transformer

☐ 6. **Turn on the power** and adjust the supply voltage to about **208 V**.

☐ 7. Observe the voltages measured by E1 and E2. Adjust the input (primary) voltage to another value and observe the output (secondary) voltage. Do you see that a 1:1 turns-ratio, single-phase transformer does not step up or step down the voltage? ☐ Yes ☐ No

☐ 8. Observe the *Phasor Analyzer* to compare the voltage phasor $E_{1\text{-}2}$ on the primary side with that of $E_{3\text{-}5}$ on the secondary side. Set the reference phasor to E1, and the voltage scale to 100 V/div.

Does the *Phasor Analyzer* display show that the voltages are equal and in phase, except for possibly a small difference due to transformer reactance? ☐ Yes ☐ No

☐ 9. Move voltmeter E2 to measure the voltage between points 4 and 5. Does the transformer now step down the primary voltage to approximately 120 V. ☐ Yes ☐ No

☐ 10. **Turn off the power**

Wye - Wye

☐ 11. With the power off, connect all three transformers together in the three-phase **Y - Y** configuration shown in Figure 2.3. **Have your circuit checked before turning on the power.**

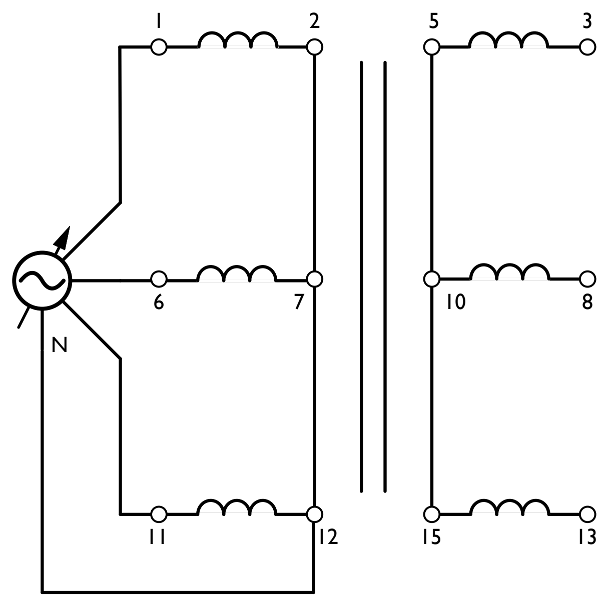


Figure 2.3: Three-Phase Transformer Connected in Wye-Wye

☐ 12. When your circuit has been checked, turn on the power and adjust the supply voltage to **120 V.** Use meter E1 to measure the line and phase voltages on the primary and secondary sides and record the results in Table 2.3. Check each line with *Line*, *Phase*, *Primary*, and *Secondary* as appropriate. After recording the measurements **turn off the power**.

☐ 13. Do your measurements confirm that for a wye connected transformer, the line voltages are $\sqrt{3}$ times greater than the phase (line-to-neutral) values? ☐ Yes ☐ No

☐ 14. Now connect E1, E2, and E3 to measure phase voltages $E_{3\text{-}5}$, $E_{8\text{-}10}$ and $E_{13\text{-}15}$ at the secondary, and and turn the power back on. Observe the voltage phasors on the *Phasor Analyzer*. Does the display confirm that the secondary phase voltages are equal with a 120° phase shift between each of them?

Line	Phase	Pri	Sec	Voltage					
☐	☐	☐	☐	$E_{1\text{-}6}$	______	$E_{6\text{-}11}$	______	$E_{11\text{-}1}$	______
☐	☐	☐	☐	$E_{1\text{-}2}$	______	$E_{6\text{-}7}$	______	$E_{11\text{-}12}$	______
☐	☐	☐	☐	$E_{3\text{-}8}$	______	$E_{8\text{-}13}$	______	$E_{13\text{-}3}$	______
☐	☐	☐	☐	$E_{3\text{-}5}$	______	$E_{8\text{-}10}$	______	$E_{13\text{-}15}$	______

Table 2.3: Line and Phase Voltage Comparison

☐ Yes ☐ No

☐ 15. Does *Programmable Meter A* indicate that the sum of the three secondary phase voltages is approximately equal to zero? ☐ Yes ☐ No

☐ 16. **Turn the power supply off,** and the voltage control knob fully ccw.

Delta - Delta

☐ 17. With the power off, connect the Three-phase Transformer module in the Δ - Δ configuration shown in Figure 2.4. Note that the delta on the *secondary* is left open between points 15–3. **Do not close the delta** until the voltages have been verified to be zero in step 22 below. This is done to insure that the connections have been made properly. Incorrect wiring will produce dangerously high currents, and damage the transformer.

Note that since these transformers are connected in Delta, the phase voltages measured here are also the line voltages.

☐ 18. **Turn on the power** supply and adjust the voltage control knob to obtain 120 V supply (Line) voltage.

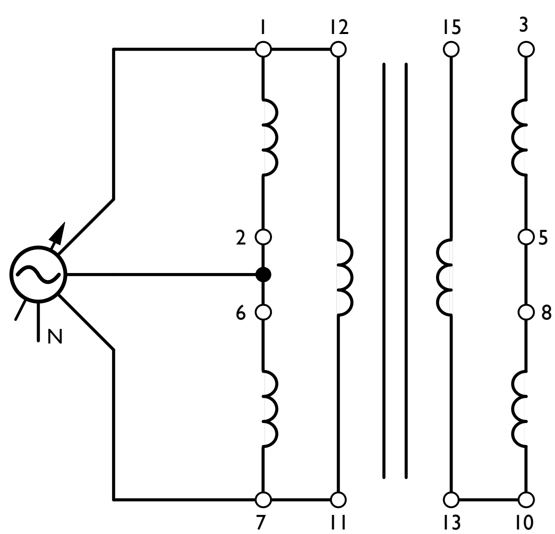


Figure 2.4: Three-Phase Transformer Connected in Delta-Delta

☐ 19. Make the following measurements with voltmeter E1 and record them on the diagram below then **turn off the power.**

Individual windings: $E_{15\text{-}13}$ $E_{10\text{-}8}$ $E_{5\text{-}3}$

Two windings in series: $E_{8\text{-}15}$ $E_{3\text{-}10}$

Three windings in series: $E_{3\text{-}15}$

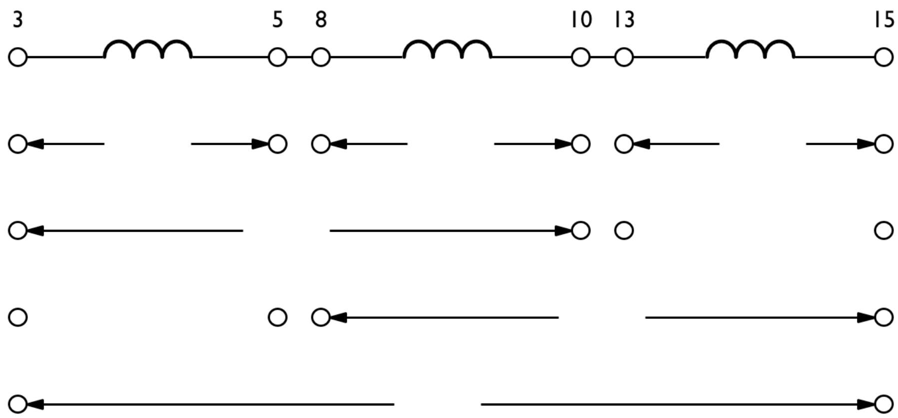


Figure 2.5: Secondary Voltage Measurements

☐ 20. Since these transformers have a 1:1 turns ratio, the values measured on the *secondary* should be the same as the corresponding values measured on the primary. You should see that:

- the voltage across each individual coil is approximately equal to 120 V
- the voltage across two coils in series is also approximately 120 V
- the voltage across three coils in series is nearly zero.

Explain why this is so? (Hint: remember the phase relationships of the three phases.)

____

____

☐ 21. Is the voltage $E_{3\text{-}15}$ nearly equal to zero (≤ 5V), confirming that the transformer is wired correctly, and that it is safe to close the delta? ☐ Yes ☐ No

☐ 22. When the winding connections are confirmed to be correct, **Close the delta** on the secondary side of the transformer.

☐ 23. Connect E1, E2, and E3, to measure the line voltages at the secondary, then **turn on the power**, and adjust the voltage control knob to obtain 120 V line voltage.

☐ 24. Turn on the *Phasor Analyzer* and display the three secondary voltages. Does the display indicate that the secondary voltages are separated by 120° and equal in magnitude to the primary voltages? ☐ Yes ☐ No

☐ 25. Does *programmable meter A* indicate that the sum of the three line voltages is approximately equal to zero? ☐ Yes ☐ No

☐ 26. Draw below the three voltages you see on the *Phasor Analyzer*, then arrange them in tip-to-tail fashion to show that the sum of the three voltages is zero. Then repeat the diagrams assuming that one voltage has reversed polarity.

What would the net voltage be in that case? __________

☐ 27. Connect voltmeter E1 to measure the primary line voltage $E_{1\text{-}2}$, and E2 to measure the corresponding secondary voltage $E_{3\text{-}5}$. Does the *Phasor Analyzer* indicate that the primary and secondary voltages are approximately equal in magnitude, and in phase with each other?

☐ Yes ☐ No

☐ 28. **Turn off the power.**

Wye - Delta

☐ 29. With the power off, connect the Three-phase Transformer module in the **Y -** Δ configuration shown in Figure 2.6. Connect E1, E2, and E3 to measure the line voltages at the primary, $E_{1\text{-}6}$, $E_{11\text{-}1}$, and $E_{6\text{-}11}$.

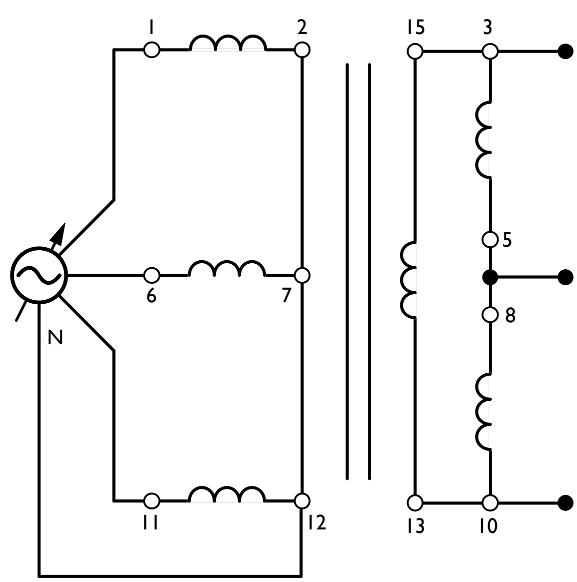


Figure 2.6: Three-Phase Transformer Connected in Wye-Delta

Have your circuit checked before turning on the power.

☐ 30. **Turn on the power** and adjust the voltage control knob to obtain a 120 V line-to-line voltage.

☐ 31. Record the following values.

$E_{1\text{-}6}$ _________ $E_{11\text{-}1}$ _________ $E_{6\text{-}11}$ _________

Sum _________ Average _________

- ☐ 32. Observe the voltage phasors on the *Phasor Analyzer*. Does the display confirm that the primary line voltages are equal with a 120° phase shift between each of them?

  ☐ Yes ☐ No

- ☐ 33. Does *Programmable Meter A* indicate that the sum of the three voltages is approximately equal to zero? ☐ Yes ☐ No

- ☐ 34. **Turn off the power** with out modifying the voltage control setting, and connect E1, E2, and E3 to measure the line voltages at the secondary, $E_{3\text{-}5}$, $E_{8\text{-}10}$, and $E_{13\text{-}15}$.

- ☐ 35. **Turn on the power**, and record the following values.

  $E_{3\text{-}5}$ _________ $E_{8\text{-}10}$ _________ $E_{13\text{-}15}$ _________

  Sum _________ Average _________

- ☐ 36. Observe the voltage phasors on the *Phasor Analyzer*. Does the display confirm that the secondary line voltages are equal with a 120° phase shift between each of them?

  ☐ Yes ☐ No

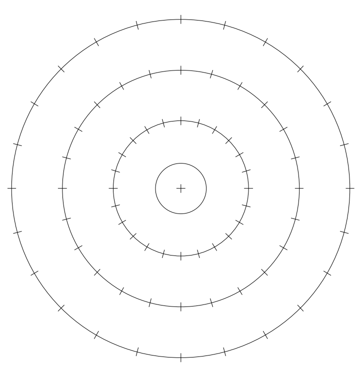
- ☐ 37. Does *Programmable Meter A* indicate that the sum of the three voltages is approximately equal to zero? ☐ Yes ☐ No

- ☐ 38. Calculate the ratio of the average secondary line voltage to the average primary line voltage.

$$\frac{E_{\text{sec}}}{E_{\text{pri}}} = \_\_\_\_\_\_\_\_ = \_\_\_\_\_\_\_\_$$

- ☐ 39. With out modifying the voltage control setting, and connect E1 to measure primary line voltage $E_{1\text{-}6}$, and E2 to measure the corresponding secondary line voltage $E_{3\text{-}5}$. Disconnect meter E3

- ☐ 40. Observe the *Phasor Analyzer* and sketch the voltage phasors below. Make sure that you adjust the scale so that you can see the ends of the phasors.



- ☐ 41. Do your calculations and the *Phasor Analyzer* indicate that a 1:1 turns ratio Y - Δ transformer produces a $1/\sqrt{3}$ step down in voltage, and a 30° phase shift between the primary and secondary? ☐ Yes ☐ No

☐ 42. **Turn off the power supply**

Delta - Wye

Important
Build your circuit without the meters, then have it checked. Install the volt and amp meters after your circuit has been checked.

☐ 43. With the power off, connect the Three-phase Transformer module in the Δ **- Y** configuration shown in Figure 2.7, however do NOT include the voltmeters or ammeters until the instructor has checked your circuit. Set the load resistors to **300** □ each. Since all load resistors have the same resistance, the load is a *three-phase balanced load*. Under these conditions, the rms voltage and current values are the same in all three phases.

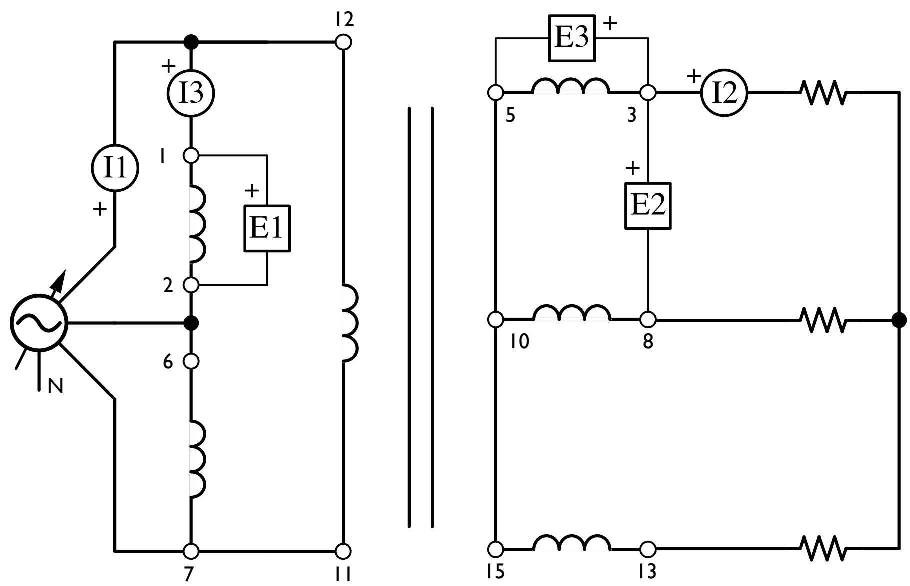


Figure 2.7: Three-Phase Transformer Connected in Delta-Wye. Note: construct circuit without meters.

☐ 44. **Turn on the power** and adjust the voltage control knob to obtain a **70 V** line-to-line voltage.

☐ 45. Determine each of following values:

	Phase Voltage	Line Voltage	Phase Current	Line Current
Primary				
Secondary				

Table 2.4: Data Table for Delta-Wye Transformer

☐ 46. Use the phasor analyzer to compare the phase voltage on the primary side to the phase voltage on the secondary side. Does the phasor analyzer confirm that the primary and secondary phase voltages are equal and in phase? ☐ Yes ☐ No

☐ 47. Use the phasor analyzer to compare the line voltage on the secondary side to the line voltage on the primary side.

$$\frac{E_{\text{sec}}}{E_{\text{pri}}} = \_\_\_\_\_\_\_\_ = \_\_\_\_\_\_\_\_$$

Does your calculation confirm that this configuration produces a $\sqrt{3}$ step up in voltage?

☐ Yes ☐ No

Explain why this is so.

____

____

Does the phasor analyzer confirm that the secondary line voltage leads the primary line voltage by 30°. ☐ Yes ☐ No

☐ 48. Use the phasor analyzer to compare the line current on the primary side to the line current on the secondary side.

$$\frac{I_{\text{sec}}}{I_{\text{pri}}} = \_\_\_\_\_\_\_\_ = \_\_\_\_\_\_\_\_$$

Does your calculation confirm that this configuration produces a $1/\sqrt{3}$ reduction in current?
☐ Yes ☐ No

Does the phasor analyzer confirm that the secondary line current leads the primary line current by 30°. ☐ Yes ☐ No

☐ 49. Use the phasor analyzer to compare the line voltage on the primary side to line current on the secondary side. Does the phasor analyzer confirm that the primary line voltage and the secondary line current are in phase?

☐ Yes ☐ No

☐ 50. Compare the product of primary line voltage and primary line current to the product of secondary line voltage and secondary line current.

$$E_{\text{pri}}I_{\text{pri}} = \_\_\_\_\_\_\_\_ \qquad E_{\text{sec}}I_{\text{sec}} = \_\_\_\_\_\_\_\_$$

Are these products approximately equal? ☐ Yes ☐ No

Explain why.

____

____

☐ 51. Turn off the power, shut down the computer, and put everything away.

Conclusion

You connected transformer windings in three-phase wye-wye, delta-delta wye-delta, and delta-wye configurations. Before energizing, you measured winding voltages to ensure that secondary windings were connected with the proper phase relationships. You confirmed that the voltage within a delta was zero before closing the delta

You confirmed the relations between line and phase voltage for delta and wye connections, and you saw that the delta-delta and wye-wye transformers produced no phase shift between the primary and the secondary voltages. Since 1:1 transformers were used in this exercise, no change in voltage was produced either.

In the wye-delta, and delta-wye configurations, you saw that the line voltage between primary and secondary either increased or decreased by a $\sqrt{3}$ factor. You also confirmed that the outgoing line voltages at the secondary were shifted 30° with respect to the incoming line voltages at the primary, and also that the secondary line currents were shifted 30° with respect to the incoming line currents.

Review Questions

1. Why is it extremely important to confirm that the delta voltage equals zero before the delta is closed?
   a) To ensure that the secondary voltage does not become too high.
   b) To avoid possible damage because of high current.
   c) To avoid a short-circuit at the primary winding.
   d) To maintain the secondary voltage at a constant level.
2. In a delta-delta configuration, the line voltage on the secondary side is
   a) equal to the primary voltage times the inverse of the turns ratio.
   b) $\sqrt{3}$ times the primary voltage.
   c) $\sqrt{3}$ times the primary voltage times the inverse of the turns ratio.
   d) $1/\sqrt{3}$ times the primary voltage.
3. The voltage across two windings In a wye-wye configuration must be
   a) equal to the voltage across each winding.
   b) $\sqrt{3}$ times the voltage across each winding.
   c) less than the voltage across each winding.
   d) $\sqrt{3}$ times less than the voltage across each winding.
4. The voltage across two windings in a delta-delta configuration must be
   a) equal to the voltage across each winding.
   b) $\sqrt{3}$ times the voltage across each winding.
   c) less than the voltage across each winding.
   d) $\sqrt{3}$ times less than the voltage across each winding.
5. A three-phase transformer can be
   a) a single unit with three separate sets of single-phase windings.
   b) three single-phase transformers connected together.
   c) a single unit with one primary and three secondary windings.
   d) either a or b.
6. Delta-wye and wye-delta configurations both produce
   a) increases in the secondary voltages and currents.
   b) decreases in the secondary voltages and currents.

   c) phase shifts between the incoming and outgoing line voltages.
   d) additional $\sqrt{3}$ increases in the secondary voltages and currents.
7. The line voltage at the secondary of a 10:1 wye-delta connected transformer will be
   a) equal to the line voltage at the primary times $1/\sqrt{3}$.
   b) equal to the line voltage at the primary times $\sqrt{3}$.
   c) equal to the line voltage at the primary times 0.1 times $1/\sqrt{3}$.
   d) equal to the line voltage at the primary times 0.1 times $\sqrt{3}$.
8. The line voltage at the secondary of a delta-wye connected transformer is
   a) greater than it is with wye-delta connection.
   b) less than it is with a wye-delta connection.
   c) the same as it is with a wye-delta connection.
   d) only dependent on the turns ratio.
9. The sum of the phase voltages in three-phase transformers
   a) depends on the connection.
   b) equals zero when the transformers are properly connected.
   c) is $\sqrt{3}$ times the turns ratio.
   d) can only be determined when a load is connected to the secondary.
10. Before three-phase transformers are put into service
   a) the phase sequence of the incoming lines must be verified.
   b) the winding connections must be checked to ensure proper phase relationship.
   c) the load must be balanced.
   d) the phase shift must be measured.

Lab 3

DC Generators

Introduction

Objective

When you have completed this exercise, you will understand the factors which affect the output voltage and the main operating characteristics of separately-excited and shunt wound dc generators.

DC Generators

A dc generator is a rotating electrical machine which produces a dc voltage when it is driven by a prime mover. Typical prime movers include steam turbines, diesel engines, wind turbines, etc. The generator consists of three main parts: the *stator*, which creates a stationary magnetic field; the *rotor* or *armature*, which carries a series of windings which produces an alternating voltage as it rotates through the stationary field; and the *commutator and brushes*, which convert the ac voltage produced in the rotor windings to a dc voltage.

The stator may use permanent magnets to create the field, but more commonly, it uses an electromagnet to do the job. The stator consists of pairs field poles wrapped with many turns of a wire known as the *field windings*. The field windings are energized or *excited* with a dc power supply, which may be provided by a separate power supply, or by the output of the generator itself. A *field rheostat* (variable resistor) is usually provided in the field circuit in order to adjust the field current and hence the field strength and generator output voltage. Most generators also include an *voltage regulator* to automatically adjust the field rheostat to maintain the output voltage at the design value; however, the generator in the lab does not include a voltage regulator.

The armature is rotated by the prime mover, and in so doing the armature windings experience a changing magnetic field, which causes a voltage to be induced according to Faraday's principle of magnetic induction. This voltage rises and falls sinusoidally each time the rotor rotates past a pair of field poles, north and south; i.e. the voltage is produced by the rotor is alternating (ac). The commutator, brushes, and armature windings are arranged such that every time the alternating voltage passes through zero, the polarity of the output at the generator terminals is reversed. The result is that the output of the generator is always in the same direction: i.e. the voltage at the generator terminals is direct current. In addition, the brushes provide the connection between the rotating armature and the stationary generator terminals.

When the generator terminals are connected to a load, the output voltage causes current to flow to the load and through the armature. The interaction between the current flowing in the rotor and the magnetic field produces a torque on the rotor which is proportional to the load current, and is in the opposite direction from the driving torque of the prime mover. This *countertorque* opposes the prime mover torque, AND increases as the generator supplies more electrical load. The power required to drive the generator is the product of torque and angular velocity.

$$P = T\omega$$

Field Arrangement

Several arrangement of the generator's field windings are possible, and are shown in figure 3.1. When the field is excited by an external power source, the generator is said to be *separately excited*; when the generator supplies its own field excitation, it is *self excited*. A field winding placed in series with the generator load is called a *series winding*, while a winding in parallel with the load is called a *shunt winding*. The strength of a series winding is proportional to the generator load current and not adjustable, while the strength of a shunt winding is relatively constant, but can be adjusted by means of a field rheostat placed in series with the field winding.

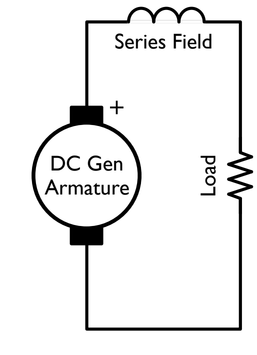
A generator with only a shunt winding is called a *shunt generator*, one with only a series winding is a *series generator*, and one with both is called a *compound generator*. When the windings in a compound generator are with the same polarity, the generator is said to be *cumulatively compounded*; if they oppose each other, *differentially compounded*. The relative strengths of the series and shunt windings determines whether the generator is *over-, under-,* or *flat-* compounded.

The *separately-excited* dc generator provides flexible use because its characteristics can be changed by changing the field current. However, a separate dc power source is required to excite the field electromagnet. Therefore, dc generators that operate without an external dc power source were designed. These are referred to as self-excited dc generators.

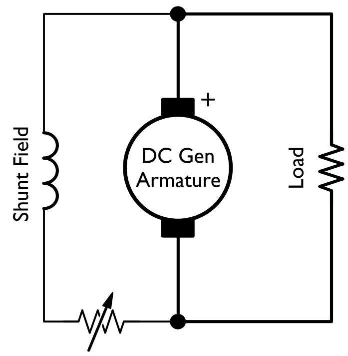
In a self-excited dc generator, the field electromagnet is a shunt winding connected across the generator output (shunt generator) or a combination of a shunt winding connected across the generator output and a series winding connected in series with the generator output (compound generator). The generator output voltage excites the field electromagnet. The way the field electromagnet is implemented (shunt or compound) determines many of the generator's characteristics.

Self-excitation is possible because of the residual magnetism in the stator pole iron. As the armature rotates, a small voltage is induced across its winding and a small current flows in the shunt field winding. If this small field current is flowing in the proper direction, the residual magnetism is reinforced which further increases the armature voltage. Thus, a rapid voltage build-up occurs. If the field current flows in the wrong direction, the residual magnetism is reduced and voltage build-up cannot occur. In this case, reversing the connections of the shunt field winding corrects the situation.

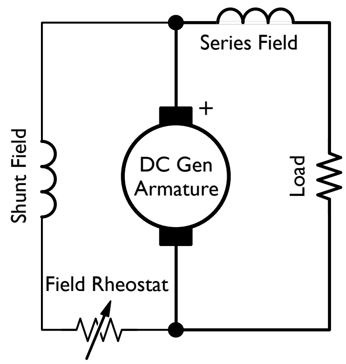
If there is no residual magnetism, a self-excited dc generator will not be able to build up voltage. If the residual magnetism has the wrong polarity, the output voltage after build-up will be of the opposite polarity to that required. These problems can be corrected by stopping the generator and restoring the correct polarity of the residual magnetism. This process is called *flashing the field*. To flash the field, a dc source is connected to the shunt field winding to force a small current flow in the proper direction. When the current stops, residual magnetic of the field poles is established in



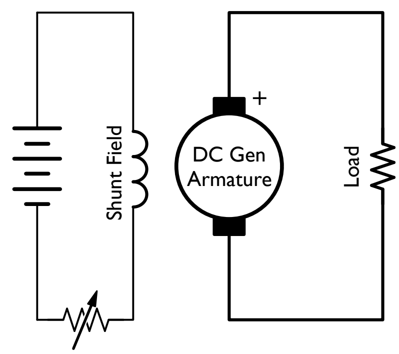
(a) Series: field winding in series with the load.



(b) Shunt: field winding in parallel with the load.



(c) Compound: contains both series and shunt windings.



(d) Separately Excited: shunt winding with external excitation source.

Figure 3.1: Basic DC Generator Field Arrangements

the correct direction, and when the generator is started once again, voltage build-up at the proper polarity occurs.

The field arrangement selected by the generator designer will determine the voltage vs. load behavior of the generator as shown in Figure 3.3. In this lab we will be comparing separately and self excited shunt generators.

Generator Characteristics

DC generators and dc motors are essentially the same device operating in different modes. A motor converts voltage to speed, while a generator converts speed to voltage. Similarly, a motor converts current to torque, while a generator converts torque to current. For separately excited shunt generators, these relations are particularly simple; they are linear. The output voltage of a separately-excited shunt dc generator is equal to the prime mover speed times some constant K_1. The torque required to drive a separately-excited dc generator equals the current supplied to the load times another constant K_2.

Field current I_F of a separately-excited dc generator/motor can be varied to change the strength of the field electromagnet, and thereby, the relative values of constant K_1 and K_2. When the field current is decreased, constant K_1 decreases and constant K_2 increases, as for a separately-excited dc motor. As a result, the slope of the output voltage versus speed relationship decreases, whereas the slope of the output current versus torque relationship increases. Conversely, when the field current is increased, constant K_1 increases and constant K_2 decreases, and thereby, the slope of the output voltage versus speed relationship increases whereas the slope of the output current versus torque relationship decreases. Therefore, the output voltage E_o of a generator operating at a fixed speed can be varied by varying the field current I_F. This produces the equivalent of a dc source whose output voltage can be controlled by the field current I_F.

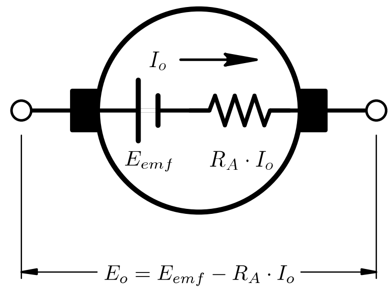


Figure 3.2: Equivalent circuit of a dc armature

The simplified equivalent electric circuit of a separately-excited dc generator is shown in Figure 3.2. It is the same as that for the dc motor, except that the direction of current flow is reversed and voltage E_{cemf} becomes E_{emf} which is the voltage induced across the armature winding as it rotates in the magnetic flux produced by the stator electromagnet. When no load is connected to the dc generator output, the output current I_o is zero and the output voltage E_o equals E_{emf}.

In this lab, we will see that when a generator turns at a fixed speed, armature resistance causes the output voltage E_o to decrease with increasing output current, I_o (electrical load). The output voltage E_o can be calculated using the following equation:

$$E_o = E_{emf} - R_A \cdot I_o$$

where E_o is the dc generator output voltage,
E_{emf} is the voltage induced across the armature winding,
R_A is the armature resistance,
I_o is the dc generator output current.

Figure 3.3 is a graph that shows the voltage versus current characteristics of various types of dc generators. As can be seen, the separately-excited dc generator and the shunt generator have very similar characteristics. The difference is that the output voltage of the shunt generator decreases a little more than that of the separately-excited dc generator as the output current increases. In both cases, the output voltage decreases because the voltage drop across the armature resistor increases as the output current increases. In the shunt generator, the voltage across the shunt field winding, and thereby, the field current, decreases as the output voltage decreases. This causes the output voltage to decrease a little more.

It is possible to compensate the variation in output voltage by automatically changing the magnetic flux produced by the field electromagnet as the output current varies. The shunt and series field windings of a compound generator can be connected so that the magnetic flux increases when the output current increases. Thus the output voltage remains fairly constant and changes very little as

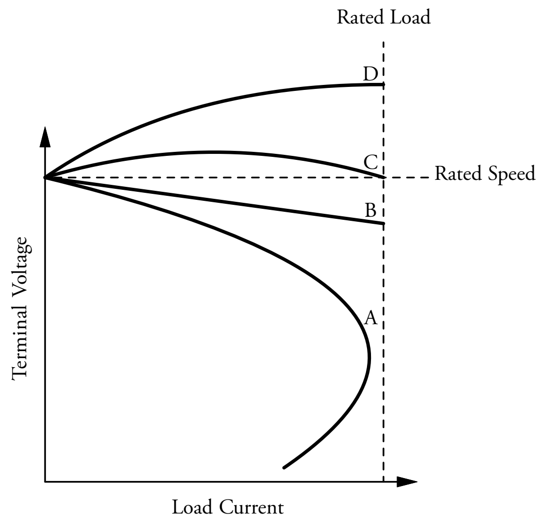


Figure 3.3: Voltage vs. load current: D overcompounded, C Flat Compounded, B, Separately Excited, A – shunt.

the output current increases as shown in Figure 3.3. This type of connection results in a cumulative compound generator because the magnetic fluxes created by the two field windings add together in a cumulative manner. For other applications where the output voltage must decrease rapidly when the output current increases, the shunt and series windings can be connected so the magnetic fluxes subtract from each other, resulting in a differential compound generator.

Procedure

Effect of Prime Mover Speed

- ☐ 1. Insure that the Power Supply, Prime Mover, DC Generator, Resistive Load Module, and Data Acquisition interface modules are installed in the EMS Workstation, and that the Generator is mechanically coupled to the Prime Mover with the timing belt. For this lab, we will be using a dc motor as the prime mover.

- ☐ 2. Make sure that the **main power switch is off**, and the voltage control knob is turned fully ccw. Set the voltmeter select switch to the 7-N position.

- ☐ 3. Insure that the USB cable connects the DAI to the computer. Connect the torque and speed data cables from the Dynamometer to the DAI. Connect the DAI and Dynamometer to the 24 V ac power supply with the grey cables, and turn it on. Leave power on the DAI for the entire exercise.

- ☐ 4. Launch the *Metering* program and open config file *Lab 3 DC Generators* to display:

- ☐ 5. Set the Prime Mover/Dynamometer controls as follows:

  MODE = Prime Mover (P.M.), **DISPLAY** = Speed (N), and **Load Control** = Manual.

Meter	Display
E1	DC Volts
I1, I2	DC Amps
Torque	N-m
Speed	rpm

☐ 6. Build the circuit shown in the Figure 3.4. Notice that the prime mover is supplied from the *Variable DC* source, there is no electrical load on the generator, and that meter E1 measures the generator terminal voltage E_A.

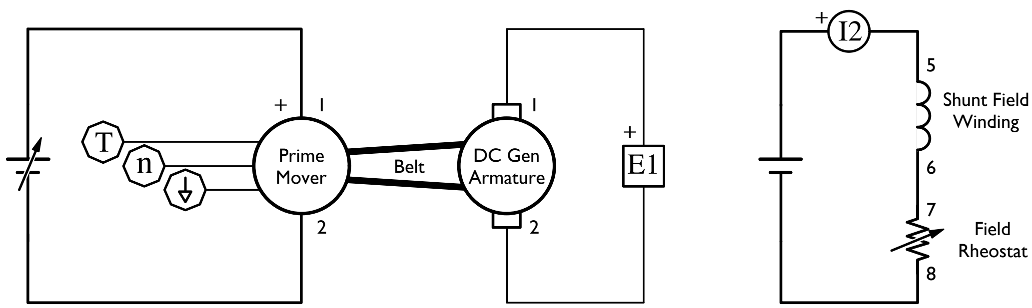


Figure 3.4: Separately Excited DC Generator

☐ 7. Turn on the power and adjust the *field rheostat* to produce 300 mA field current.

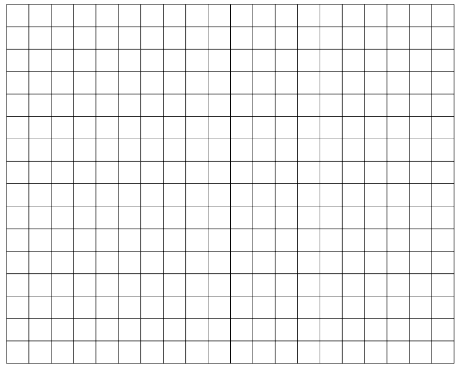
☐ 8. Set up a *data table* to record generator output voltage, E_A, field current I_f, torque T, and speed n. You can just accept the default selection, which will record all these values and others.

☐ 9. Adjust the generator speed from 0 to 1800 rpm in roughly 150 rpm increments with the *voltage control knob*. For each speed setting, record the data in the *data table*.

☐ 10. Click on the *graph* button and make the appropriate settings to produce a graph of generator output voltage as a function of speed.

☐ 11. Describe the relation between voltage and speed mathematically.

☐ 12. Sketch the graph here.



Effect of Field Excitation

☐ 13. Adjust the voltage control knob to bring the prime mover to approximately 1800 rpm.

☐ 14. How much voltage does the generator produce at 1800 rpm?

$E\_A =$ __________ V

☐ 15. Now unplug one of the field circuit connections to bring the excitation current to zero. How much voltage does the generator produce now?

$E\_A =$ __________

☐ 16. Does the generator produce significantly less voltage without field excitation?

☐ Yes ☐ No

Why?

____

How is the generator able to produce *any* voltage with the field circuit disconnected?

____

☐ 17. Reconnect the field circuit and adjust the *field rheostat* so that the field current I_f indicated by meter I2 is around 300 mA, while observing the output voltage. Describe the sequence of events that causes the voltage to change when you change the position of the field rheostat.

____

____

____

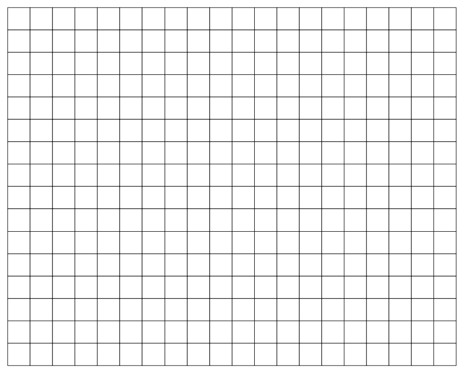
☐ 18. In the metering window, select the *torque correction function* by clicking the lower left corner of *meter T*, until it displays **C**. Meter T now indicates the torque *produced* by the Generator. Since the generator consuming, not producing, torque this value is negative.

☐ 19. Set up a *data table* to record generator output voltage, E_A, field current I_f, torque T, and speed n. You can just accept the default selection, which will record all these values and others.

☐ 20. Record the voltage you measured in Step 15. along with an excitation current of 0 A in the first line of your data table.

☐ 21. While operating at 1800 rpm, move the *field rheostat* from fully ccw to fully clockwise in about 8 steps while taking care not to exceed the field circuit current rating of 400 mA for more than a few seconds. For each setting, record the data in the *data table*. Note that for this part of the experiment the generator is not loaded.

☐ 22. Click on the *graph* button and make the appropriate settings to produce a graph of generator output voltage as a function of field current. Sketch the graph here.



☐ 23. Turn the voltage control knob fully CCW to stop the prime mover.

Behavior under load

☐ 24. With the power off, modify the connections to add a resistive load R_L across the generator output as shown in Figure 3.5. Use all nine resistors of the *resistive load module* connected in parallel to implement resistor R_L. Meter I1 measures the load current I_o.

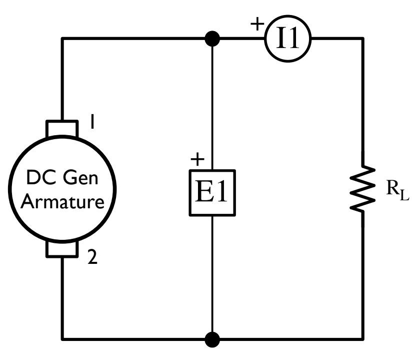


Figure 3.5: DC Generator Armature Circuit, with Load

☐ 25. **Turn on the Power Supply**, and adjust the voltage control knob so that the generator operates at its *nominal speed*, then adjust the field current I_f using the *field rheostat* until the generator is producing its nominal voltage.

Do you know what *nominal* means? If not, look it up!

☐ 26. Set up a *data table* to record generator output voltage E_A, load current I_o, field current I_f, torque T, and speed n, indicated by meters E1, I1, I2, T, and N respectively. You can just accept the default selection, which will record all these values and others.

☐ 27. Set the switches on the *resistive load module* so that the load resistance R_L decreases in steps as indicated in the table. For each step, readjust the *voltage control knob* so that the generator speed remains equal to the nominal speed, then record the data in the data table.

Step	1	2	3	4	5	6	7	8	9
R_L	∞	1200 ☐	600 ☐	300 ☐	171 ☐	120 ☐	86 ☐	71 ☐	57 ☐

Is step 1 the full load or no load? ☐ Full Load ☐ No Load

You can refer to the appendix to find out what combination of switches is needed to produce these resistance settings.

☐ 28. When all the data has been recorded, turn the voltage control fully ccw, and **turn off the power**.

☐ 29. In the graph window make the appropriate settings to obtain a graph of the Torque T required to drive the generator as a function of dc generator load current I_o.

☐ 30. Does the graph show that the absolute value of the torque increases as the load increases?

☐ Yes ☐ No

☐ 31. Why isn't the torque zero when the load is zero?

____

____

Do not delete your data table. You will need it in the next part.

☐ 32. In the graph window make the appropriate settings to obtain a graph of the generator voltage E_A as a function of the separately excited generator load current I_o.

Self Excited Shunt Generator

☐ 33. With the power off, disconnect the field circuit from the dc power supply and plug it in to the armature terminals, while maintaining the same polarity, as shown in Figure 3.6.

You have just turned your *separately-excited* generator into a *shunt* connected *self-excited generator*.

In a self-excited generator, the voltage to excite the field comes from the generator itself.

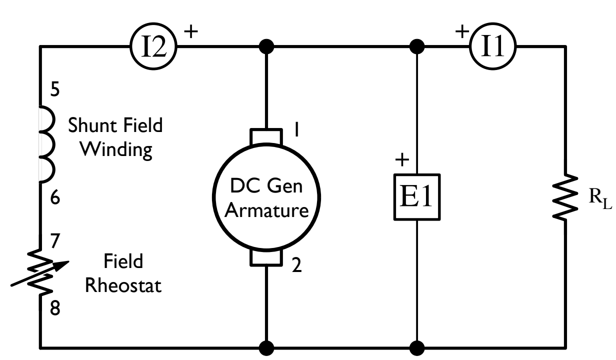


Figure 3.6: Self-excited DC Shunt Generator

☐ 34. *Turn on the power* supply and **adjust the generator speed and terminal voltage** to the values that are in the first line of your data table, so that the initial conditions are approximately the same as the initial conditions you used in step 27.

☐ 35. Repeat step 27 of the previous section. Continue recording your data on the same table. When you have finished, this table will contain data from both the separately-excited and self-excited generators.

☐ 36. Open the graph window again, and it should show the behavior of both the separately-excited and the shunt generator as load is increased while maintaining constant speed.

Compound Generator

☐ 37. A **Compound Generator** is a generator with both *Series* and *Shunt* fields. A shunt field is wired in parallel with the load, while a series field is wired in series with the load. Determine where you could add a series field to your existing shunt generator circuit, and sketch it on your circuit diagram, then show your plan to your instructor.

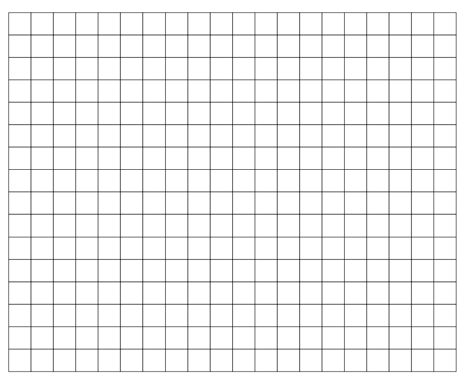
☐ 38. With the power off, add the series winding (terminals 3 and 4 on the DC Motor/Generator) in the position you selected.

☐ 39. *Turn on the power* supply and adjust the generator speed and terminal voltage to the same values as before.

☐ 40. Repeat step 27 of the previous section. Continue recording your data on the same table. When you have finished, this table will contain data from the separately excited, self-excited and compound generators.

☐ 41. Open the graph window again, and it should show the behavior of three different types of DC Generators as load is increased at constant speed.

☐ 42. Sketch and label the graph here.



☐ 43. Which configuration produces the best voltage regulation? ____________

☐ 44. Turn off the power, shut down the computer, and put everything away.

Conclusion

In this exercise, you plotted graphs of the main operating characteristics of a separately-excited dc generator. You observed that the output voltage increases linearly with speed. You also observed that the output current increases linearly with the input torque. You saw that the slopes of these graphs can be adjusted by changing the field current and that this allows the generator's output voltage to be changed. You observed that the output voltage decreases as the load current increases.

You also compared the voltage versus current characteristics of a shunt generator with that of the separately-excited generator and with a compound generator. You observed that the output voltage of the shunt generator decreases more rapidly than that of the separately-excited dc generator when the output current increases, and that the compound generator has flattest voltage behavior.

Review Questions

1. What effect does decreasing the field current have on the output voltage of a separately-excited dc generator operating at fixed speed?
   a) The output voltage increases.
   b) The output voltage decreases.
   c) The output voltage oscillates around its original value.
   d) The value of the field current has no effect on the output voltage.
2. What effect·does increasing·the output current have on the input torque of a separately-excited dc generator?
   a) The torque increases.
   b) The torque decreases.
   c) The torque oscillates around its original value.
   d) The value of output current has no effect on the torque.
3. What is the main characteristic of a cumulative compound generator?
   a) The output voltage becomes unstable when the output current decreases.
   b) The output voltage decreases when the output current increases.
   c) The output voltage increases when the output current increases.
   d) The output voltage varies little when the output current varies.
4. What is the main characteristic of a differential compound generator?
   a) The output voltage becomes unstable when the output current decreases.
   b) The output voltage decreases fairly rapidly when the output load current increases.
   c) The output voltage increases when the output current increases.
   d) The output voltage is made independent of the output current.
5. What happens when the field current of a separately-excited dc generator is increased and the speed is maintained constant?
   a) The output current decreases.
   b) The output voltage increases.
   c) The output voltage decreases.
   d) The output voltage is independent of the field current.

Lab 4

Induction Motors

Introduction

Objective

When you have completed this exercise you will be able to demonstrate the operating characteristics of a three-phase induction motor using the Four-Pole Squirrel-Cage Induction Motor module. You will see how three-phase power is used to create a rotating magnetic field, which is used develop a torque in an induction motor. You will next demonstrate how a capacitor can be used to develop a rotating field when used with single-phase ac supply. Finally you will observe the main operating characteristics of single-phase induction motors using the Capacitor-Start Motor module.

Three-Phase Squirrel Cage Induction Motor

According to Faraday's principle, a voltage is induced between the ends of a wire loop when the magnetic flux linking the loop varies as a function of time. If the ends of the wire loop are connected, a current flows in the loop. When current flows in a circuit, a magnetic field is created. It is the interaction of these two magnetic fields that creates the force which rotates an electric motor.

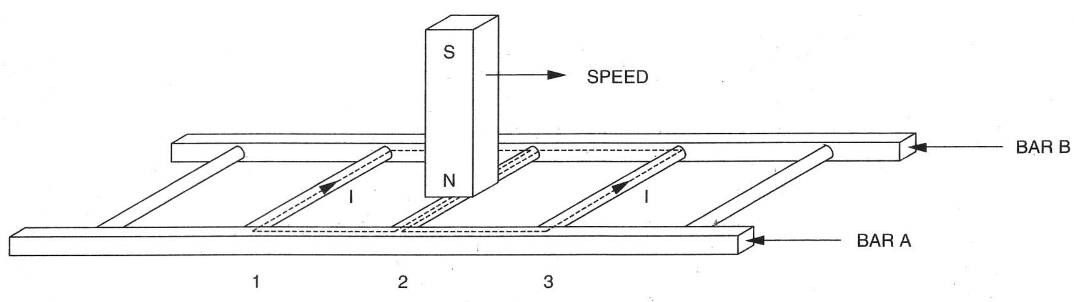


Figure 4.1: Magnet Moving above a Conducting Ladder

To begin this discussion, consider arrangement shown in Figure 4.1, where a magnet is displaced towards the right above a group of conductors shaped like a ladder. The conductors are short-circuited at their extremities by rungs A and B. Induction causes current to flow in the loop formed by conductors 1 and 2, conductors 2 and 3, etc. These currents themselves produce magnetic fields with north and south poles as shown in Figure 4.2. The interaction between the magnetic field of the magnet and the magnetic fields produced by the currents induced in the ladder creates a force that causes the ladder to be pulled along in the direction of the moving magnet.

However, if the ladder moves at the same speed as the magnet, there is no longer a variation in the magnetic flux. Consequently, there is no induced voltage to cause current flow in the wire loops, meaning that there is no longer a magnetic force acting on the ladder. Therefore, the ladder must move at a speed which is lower than that of the moving magnet for a magnetic force to pull the ladder in the direction of the moving magnet. The greater the speed difference between the two, the greater the variation in magnetic flux, and therefore, the greater the magnetic force acting on the conducting ladder.

The rotor of an asynchronous induction motor is made by closing a ladder similar to that shown in Figure 4.1 upon itself to form a shape known as a *squirrel cage* as shown in Figure 4.3. This is where the name squirrel-cage induction motor comes from. To make it easier for the magnetic flux to circulate, the squirrel-cage is embedded inside a laminated iron rotor. The stator of the induction motor is made of three electromagnets A, B, and C, placed at 120° to one another as shown in Figure 4.4. When the stator is connected to a three-phase ac power source, so that the phase currents are shifted by 120° from each other as shown in Figure 4.5, a *rotating magnet field* is created. The rotating field causes a torque which pulls the rotor along in the same direction as the rotating field, in much the same manner as the moving magnet in Figure 4.1 pulls the ladder.

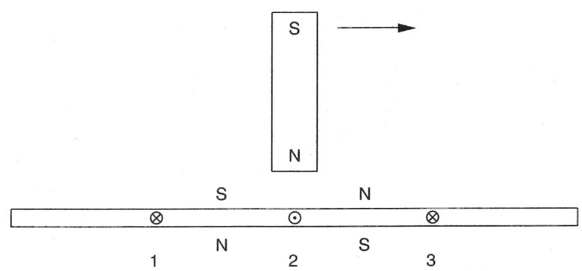


Figure 4.2: Currents in the Conductors Creates Magnetic Fields

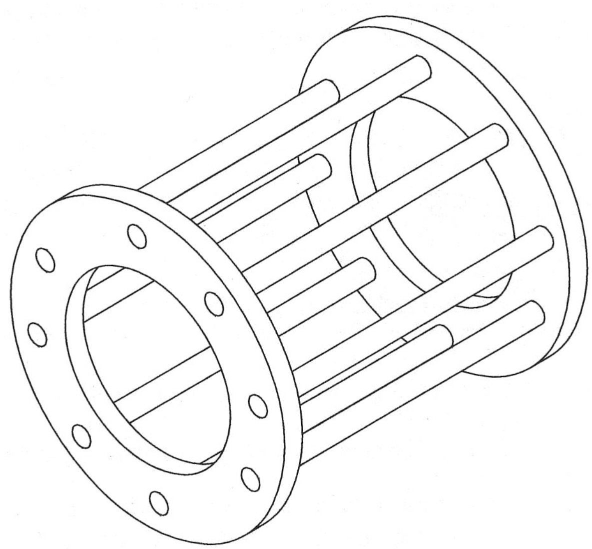


Figure 4.3: Closing the Ladder Upon Itself Forms a Squirrel Cage

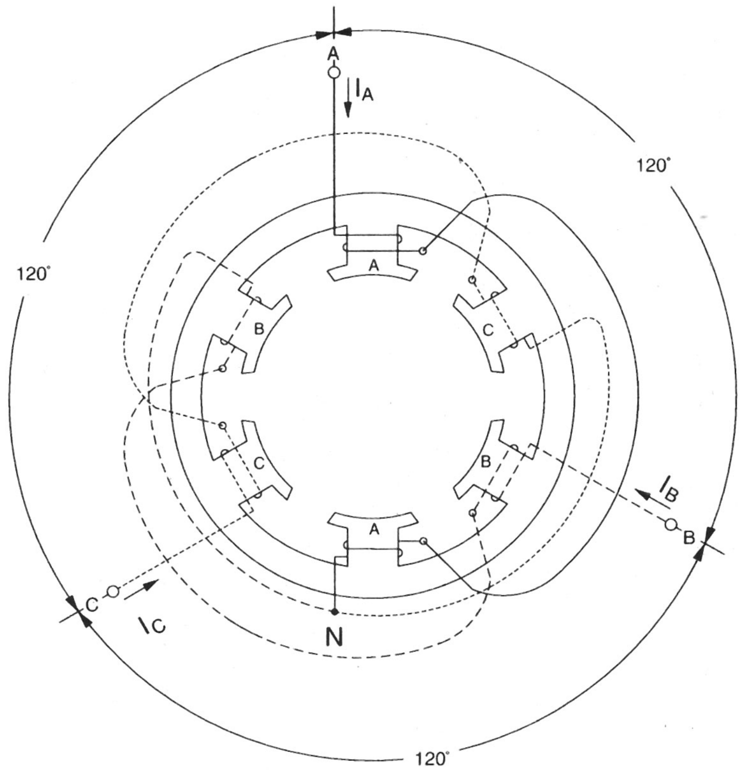


Figure 4.4: Three-phase stator windings

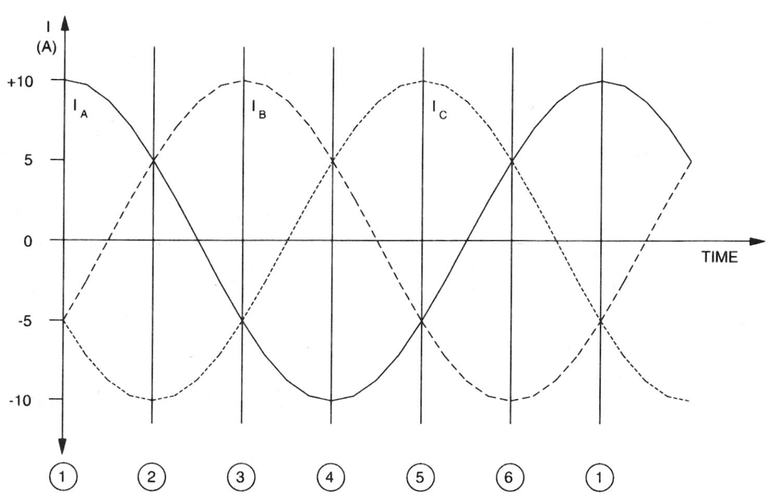


Figure 4.5: Three-phase Sine-Wave Currents Flowing in the Stator Windings

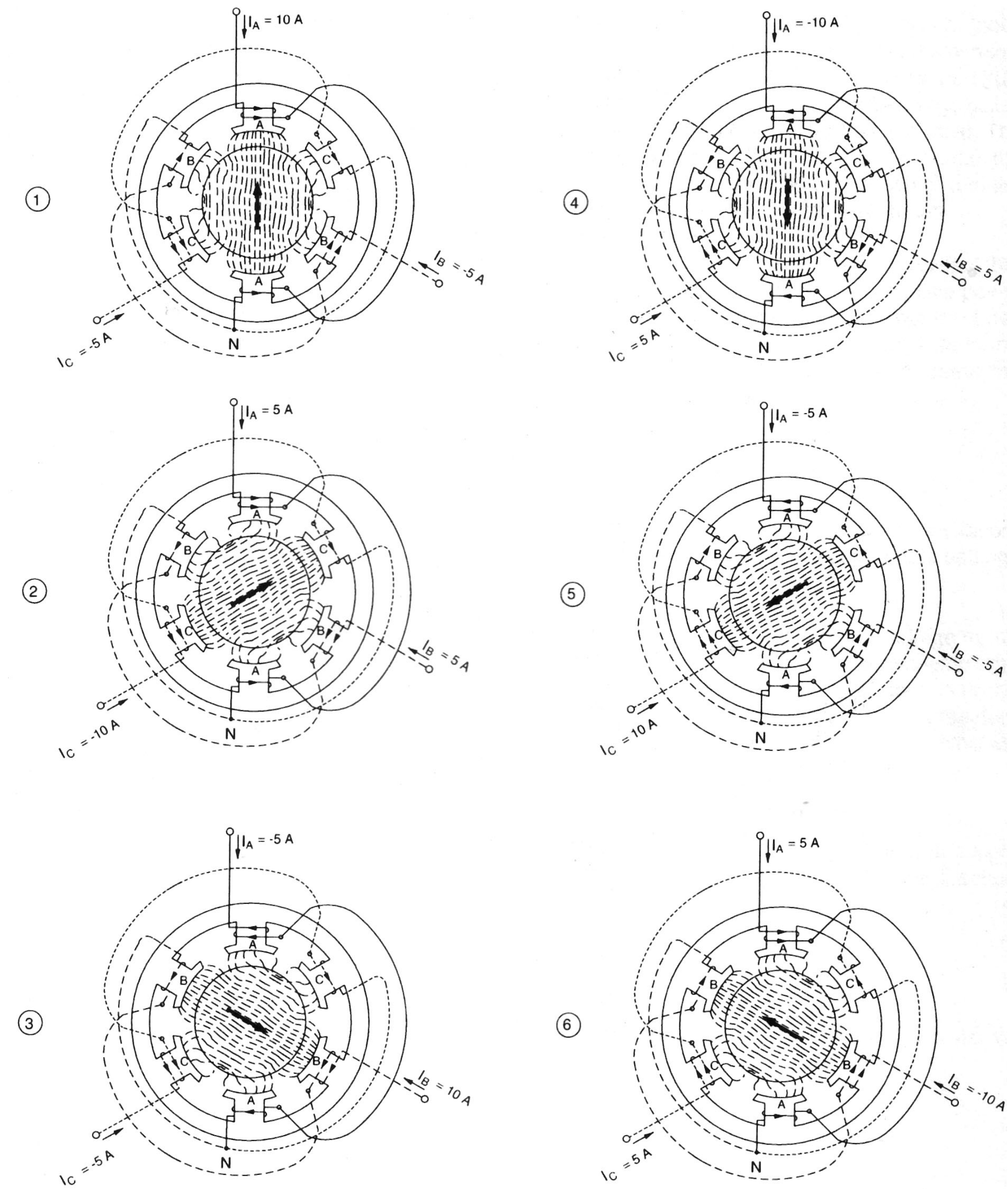


Figure 4.6: Positions of the Rotating Magnetic Field at Various Instants (From *Electrical Machines, Drives, and Power Systems* by Theodore Wildi)

Figure 4.6 illustrates the magnetic field created by stator electromagnets A, B, and C at instants numbered 1 to 6 in Figure 4.5. Notice that the magnetic lines of force exit at the north pole of each electromagnet and enter at the south pole. As can be seen, the magnetic field rotates clockwise. A simulation that can help you visualize the rotating magnetic field is available at `http://www.ipes.ethz.ch/ipes/2002Feldlinien/feld_dreh.html`.

The use of sine-wave currents produces a magnetic field that rotates regularly and whose strength does not vary over time. The speed of the rotating magnetic field is known as the synchronous speed (n_s) and is proportional to the frequency of the ac power source, and inversely proportional to the number of poles (P).

$$n_s = 120f/P$$

A rotating magnetic field can also be obtained using other combinations of sine-wave currents that are phase-shifted with respect to each other, but three-phase sine-wave currents are used more frequently.

When a squirrel-cage rotor is placed inside a rotating magnetic field, it is pulled around in the same direction as the rotating field. Interchanging the power connections to two of the stator windings (interchanging A with B for example) interchanges two of the three currents and reverses the phase sequence. This causes the rotating field to reverse direction, and a result, the direction of rotation of the motor is also reversed.

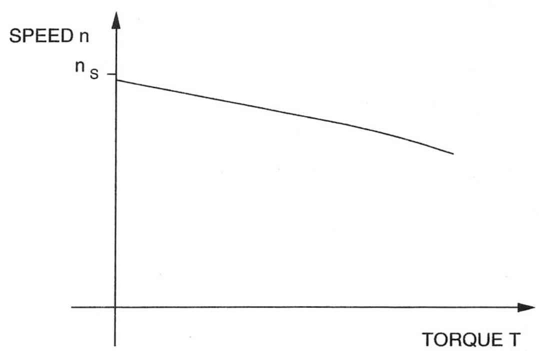


Figure 4.7: Speed vs. torque Characteristic of a Squirrel-Cage Induction Motor, in normal operating range

Based on the discussion of motor action above, one can easily deduce that the torque produced by a squirrel-cage induction motor increases as the difference in speed between the rotating magnetic field and the rotor increases. The difference in speed between the two is called slip. A plot of the speed versus torque characteristic for a squirrel-cage induction motor gives a curve similar to that shown in Figure 4.7. As can be seen, the motor speed n (rotor speed) is always lower than the synchronous speed n_s because slip is necessary for the motor to develop torque. The synchronous speed for the Lab-Volt motors is 1800 r/min for 60-Hz power, and 1500 r/min for 50-Hz power.

The speed versus torque characteristic of the squirrel-cage induction motor is very similar to that of a separately-excited dc motor. However, the currents induced in the squirrel-cage rotor must change direction more and more rapidly as the slip increases. In other words, the frequency of the currents induced in the rotor increases as the slip increases. Since the rotor is made up of iron

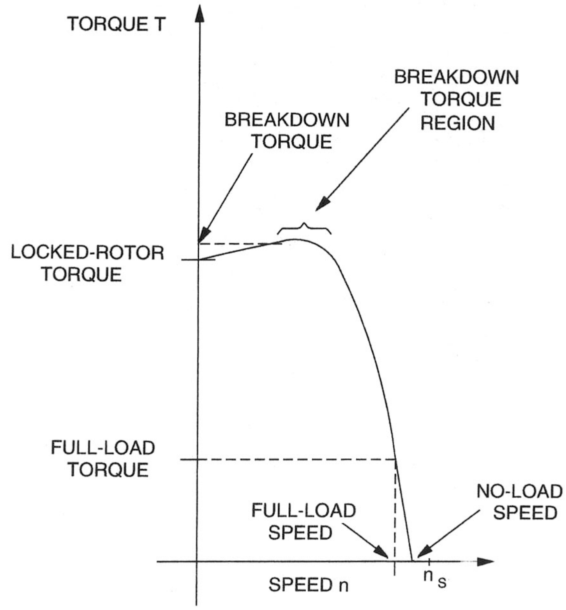


Figure 4.8: Torque vs. Speed Characteristic of a Squirrel-Cage Induction Motor

and coils of wire, it has an inductance that opposes rapid changes in current. At higher slips, the currents induced in the rotor are no longer directly proportional to the slip of the motor, and the torque begins to decrease. The torque vs. speed characteristic of the motor throughout its complete operating range are shown in Figure 4.8.

As the curve shows, the no-load speed is slightly less than the synchronous speed n_s, but as the load torque increases, the motor speed decreases. The motor's *nominal torque* (full-load torque) is the torque produced when the motor is operating at the nominal speed. Further increases in load torque lead cause the motor to slow down slightly, and ultimately lead to a point of instability, called *breakdown torque*, after which both motor speed and output torque decrease rapidly. The torque value at zero speed, called *locked-rotor torque*, is often less than the breakdown torque. At start-up, and at low speed, motor current is very high and the amount of power that is consumed is higher than during normal operation. Motors should not be allowed to be overloaded, because this power consumption leads to high temperatures, which will damage the motor.

Another characteristic of three-phase squirrel-cage induction motors is the fact that they always draw *reactive power* from the ac power source. The reactive power even exceeds the active power when the squirrel-cage induction motor rotates without load. The reactive power is necessary to create the magnetic field in the machine in the same way that an inductor needs reactive power to create the magnetic field surrounding the inductor. Reactive power is reflected by the *power factor* of the operating motor. When a motor is lightly loaded, high reactive power combined with low active power results in a poor power factor.

Single Phase Capacitor Start Motor

It is possible to design a single-phase squirrel-cage induction motor using one electromagnet connected to a single-phase ac power source as shown in Figure 4.9, but one may wonder how this motor can turn since the single field will not be able to produce a rotating magnetic field. It can work, but the operating principle of this type of motor is more complex than that of the three-phase squirrel-cage induction motor. When the rotor of the motor of Figure 4.9 is given an initial start, a torque which acts in the direction of rotation is produced, and the motor continues to turn as long as ac power is supplied to the stator electromagnet. This torque is due to a rotating magnetic field that results from the interaction of the magnetic field produced by the stator electromagnet and the magnetic field produced by the currents induced in the rotor. A graph of speed versus torque for this type of motor, Figure 4.10, shows that the torque is very small at low speeds, and increases to a maximum value as the speed increases, and finally decreases towards zero again when the speed approaches the synchronous speed n_s.

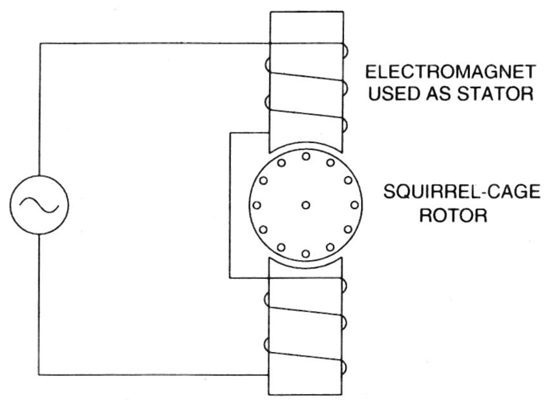


Figure 4.9: Simple Single-Phase Squirrel-Cage Induction Motor

The low torque values at low speeds are due to the fact that the currents induced in the rotor produce magnetic fields that create forces which act on the rotor in various directions. Most of these forces cancel each other and the resulting force acting on the rotor is weak. This explains why the single-phase induction motor shown in Figure 4.9 must be started manually. To obtain starting torque, a rotating magnetic field must be produced in the stator when the motor is starting. It is possible to create a rotating magnetic field using two alternating currents, I_1 and I_2, that are phase shifted 90° from one another, and two electromagnets placed at right angles to each other.

Figure 4.11 shows the simple induction motor of Figure 4.9 with the addition of a second electromagnet placed at right angle to the first electromagnet. The second electromagnet is identical to the first one and is connected to the same ac power source. The currents I_1 and I_2 in the electromagnets (winding currents) are in phase because the coils have the same impedance. However, because of the inductance of the coils of the electromagnets, there is a phase shift between the currents and the ac source voltage as illustrated in the phasor diagram of Figure 4.11.

Since currents I_1 and I_2 are in phase, there is no rotating magnetic field produced in the stator. However, it is possible to phase shift current I_2 by connecting a capacitor in series with the winding of electromagnet 2. The capacitance of the capacitor can be selected so that current I_2 leads current I_1 by 90° when the motor is starting as shown in Figure 4.12. As a result, an actual rotating magnetic field is created when the motor is starting. The capacitor creates the equivalent of a two-phase ac power source and allows the motor to develop starting torque.

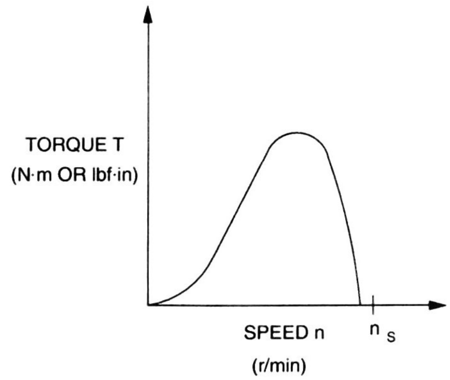


Figure 4.10: Torque vs. Speed Characteristics of a Single-Phase Induction Motor

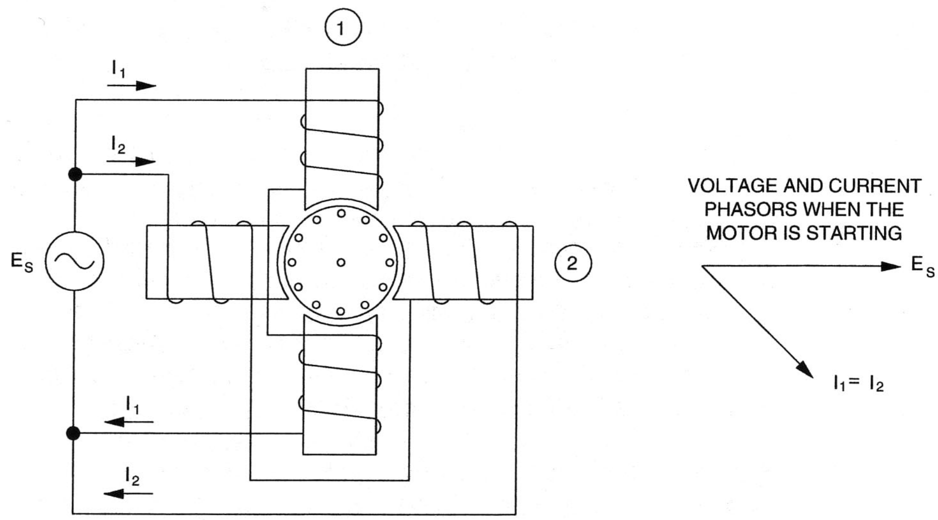


Figure 4.11: Adding a Second Electromagnet to the Simple Induction Motor of Figure 4.9

Another way to create a phase shift between currents I_1 and I_2 is to make a winding with fewer turns of smaller-sized wire. The resulting winding, which is called auxiliary winding, has more resistance and less inductance, and the winding current is almost in phase with the source voltage. Although the phase shift between the two currents is less than 90° when the motor is starting, as shown in Figure 4.13, a rotating magnetic field is created. The torque produced is sufficient for the motor to start rotating in applications not requiring high values of starting torque.

However, the auxiliary winding cannot support high currents for more than a few seconds without being damaged because it is made of fine wire. It is therefore connected through a centrifugal switch which opens and disconnects the winding from the motor circuit when the motor reaches about 75% of the normal speed. After the centrifugal switch opened, the rotating magnetic field is maintained by the interaction of the magnetic fields produced by the stator and the rotor.

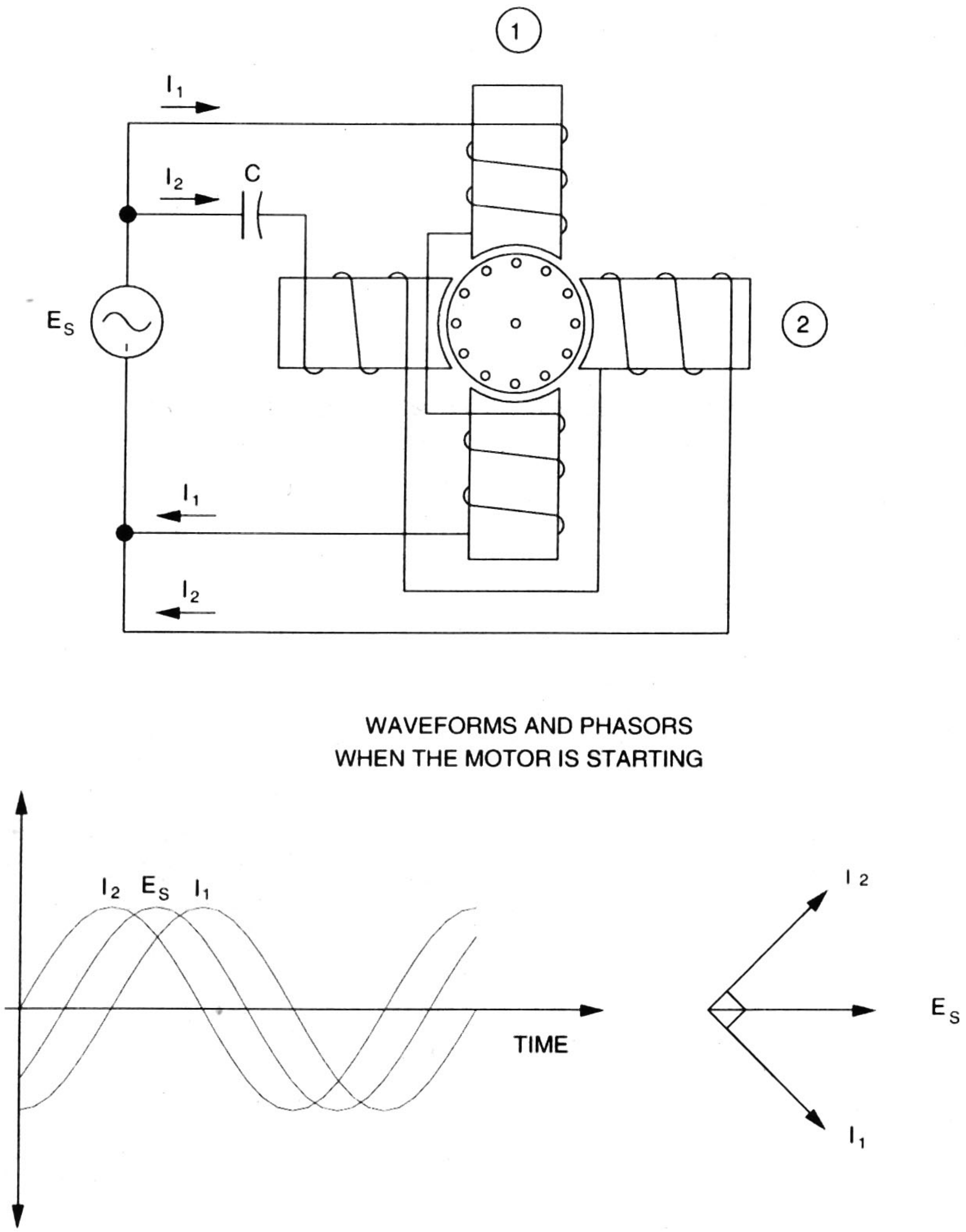


Figure 4.12: Adding a Capacitor allows the Induction Motor to Develop Starting Torque

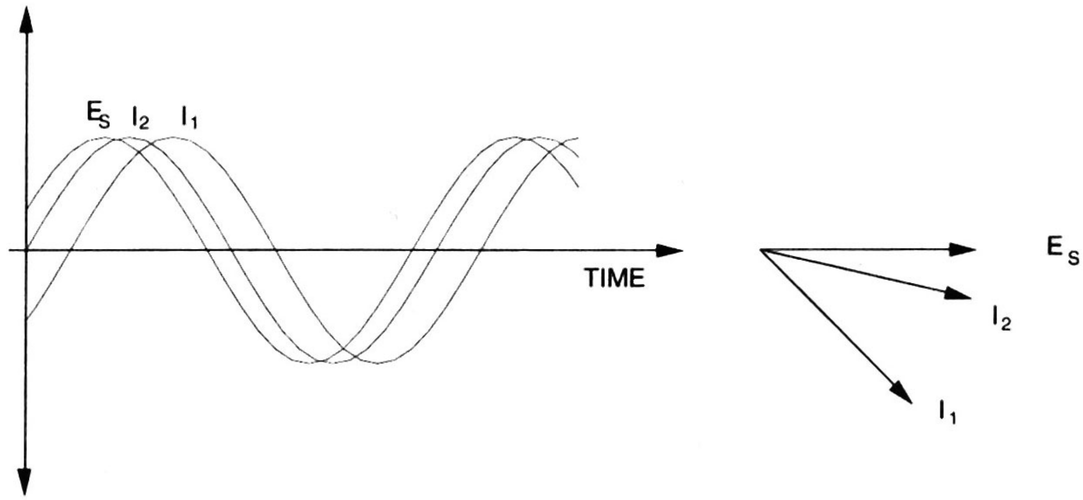


Figure 4.13: Phase Shift Between the Winding Currents when an Auxiliary Winding is Used

Procedure

Three-phase Squirrel Cage Induction Motor

☐ 1. Ensure that the Power Supply, Prime Mover/Dynamometer, Four-pole Squirrel Cage Induction Motor, Capacitor Start Motor, Capacitive Load, and Data Acquisition Interface are installed in the EMS.

☐ 2. Make sure that the main power is off and that the voltage control knob is turned fully ccw.

☐ 3. Connect the DAI to the computer with the USB Cable, and to the 24 V ac power source with the gray cable, and turn on the 24 V power.

☐ 4. Start the metering application and select meter configuration file *Lab 4 AC Motors* to display:

Meter	Display
E1, E2	AC Volts
I1, I2, I3	AC Amps
T	Torque
n	Speed (rpm)
Mechanical Power P_m	
Programmable Meter A	Active Power P
Programmable Meter B	Frequency f
Programmable Meter C	Reactive Power Q
Programmable Meter D	Power Factor

☐ 5. Connect the squirrel cage motor to the variable ac power supply as shown in Figure 4.14. Connect the motor to the dynamometer with the timing belt, and connect the data cables for torque and speed to the the DAI.

Note that the three stator windings must be wye-connected in order for the motor to work!

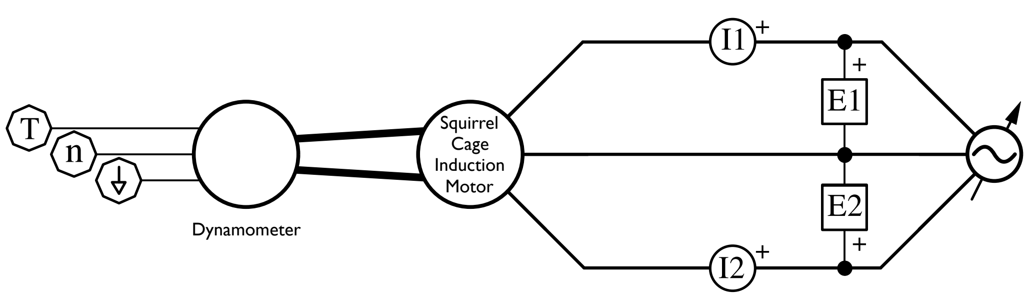


Figure 4.14: Three-Phase Squirrel Cage Induction Motor Circuit

Active and reactive power are calculated by the two wattmeter method using I1, I2, E1, and E2. Mechanical Power is calculated from torque and speed.

$$P_m = T\omega = T\frac{2\pi n}{60}$$

☐ 6. Set the Dynamometer controls as follows:

Control	Position
Mode switch	DYN
Load Control Mode Switch	Manual
Load Control Knob	Minimum (Fully ccw)
Display Switch	Torque (T)

In the metering window, make sure that the *torque correction function* of meter T reads **NC**. Meter T indicates the output torque of the squirrel-cage induction motor.

☐ 7. **Turn on the Power** supply and set the voltage control knob so that the line voltage, E1, is equal to the motor's nominal line voltage, and adjust the load control knob fully CCW.

You can find the nominal ratings of the motor on its name plate on the motor front panel.

Record the no-load speed, current, torque, and direction of the motor, then **turn off the power.**

$n_{nl} =$ ________ $I_{nl} =$ ________ $T_{nl} =$ ________ ☐ cw ☐ ccw

☐ 8. Interchange any two of the three-phase power and **restart the motor** as before. Record the no-load speed and direction, then **turn off the power** and restore the leads to their original positions.

n = ________ rpm ☐ cw ☐ ccw

☐ 9. Does interchanging any two leads of a three-phase motor reverse it? ☐ Yes ☐ No

☐ 10. Calculate the synchronous speed of this motor knowing that it is supplied with 60 Hz three-phase alternating current. This is the speed of the rotating magnetic field.

$$n_s = \frac{120f}{P} = \underline{\hspace{2cm}} \text{ rpm}$$

☐ 11. Is the no-load speed almost equal to the speed of the speed of the rotating magnetic field?

☐ Yes ☐ No

☐ 12. Calculate the % slip when the motor is unloaded.

$$\% \text{ slip} = \frac{n_s - n}{n_s} \cdot 100\% = \underline{\hspace{2cm}}$$

☐ 13. When the motor is supplied with its *nominal voltage* and producing its *nominal power*, it will also, by definition, be running at its *nominal speed*, drawing its *nominal current* and producing its *nominal torque*.

Turn on the motor and adjust the voltage to the nominal value. Then use the *load control knob* of the dynamometer to set the load on the motor to its nominal value and record the nominal speed, current, torque and power below. **Turn off the motor**.

$n_{nom} =$ ________ $I_{nom} =$ ________ $T_{nom} =$ ________ $P_{nom} =$ ________

☐ 14. Do the nominal values just determined generally agree with the values on the motor name-plate? ☐ Yes ☐ No

Loaded Behavior

IMPORTANT
Do not let the motor run in the stalled condition any longer than necessary to record the data. The motor current will be excessively high during this period, which can lead to overheating and damage to the insulation.

☐ 15. Set up a *data table* to record motor line voltage E_l, line current I_l, torque T, and speed n, active power P, reactive power Q, and Power Factor pf, indicated by meters E1, I1, T, N, A, C and D respectively. You can just accept the default selection, which will record all these values and others.

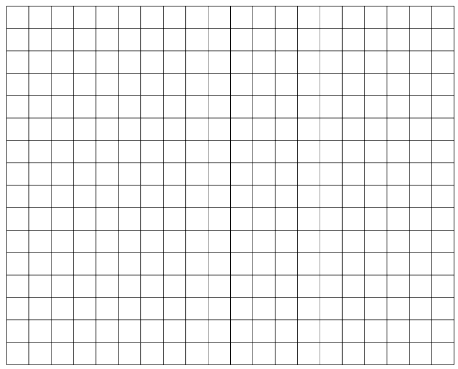
☐ 16. **Turn on the motor** and adjust the voltage to the nominal value. Set the load to zero by turning the *load control knob* fully ccw, then record the data in the data table.

Increase the *load control knob* so that the torque on the motor increases by approximately 0.3 N-m increments up to about 1.8 N-m. For each setting, record the data in the data table.

At this point, continue increasing the load using smaller increments, until the motor passes the *breakdown torque* region, and slows rapidly to its minimum speed, around 300 rpm. For each additional torque setting record the data.

☐ 17. **Turn off the power** and return the *load control knob* to the minimum load position.

☐ 18. In the graph window, make a graph of motor torque T, as a function of motor speed n, and sketch the graph here:



☐ 19. From the graph, determine the following values:

Since this motor never completely stops, use the minimum speed measurements to represent the locked rotor values.

No load Torque	________	No Load Speed	________
Nominal Torque	________	Nominal Speed	________
Breakdown Torque	________	Breakdown Speed	________
Locked Rotor Torque	________	Locked Rotor Speed	________

☐ 20. Describe how the motor speed varies as load is applied to the motor.

☐ 21. Calculate the ratio of the breakdown and locked rotor torques to the nominal torque.

$$\frac{T_{BD}}{T_{Nom}} = \underline{\hspace{3cm}} \qquad \frac{T_{LR}}{T_{Nom}} = \underline{\hspace{3cm}}$$

☐ 22. In the graph window using this same data, make a graph of motor line current I_l as a function of speed n, and sketch the graph here:

☐ 23. Describe how the motor line current varies as load is applied to the motor.

____

____

☐ 24. Calculate the ratio of the locked rotor current to the nominal line current.

$$\frac{I_{LR}}{I_{Nom}} = \underline{\hspace{3cm}}$$

☐ 25. A rule of thumb for induction motors states that *the starting current is 5–7 times greater than the normal running current.* Is that true for this motor? ☐ Yes ☐ No

☐ 26. In the graph window using this same data, make a graph of motor active power P, and reactive power Q as a function of speed n, and sketch the graph here:

☐ 27. Does the graph indicate that the squirrel-cage induction motor always draws reactive power?

☐ Yes ☐ No

☐ 28. Does the graph indicate that the motor draws more electrical power as the load increases?

☐ Yes ☐ No

☐ 29. What does the graph reveal about the power factor of the motor when it is unloaded?

____

Single Phase Motors

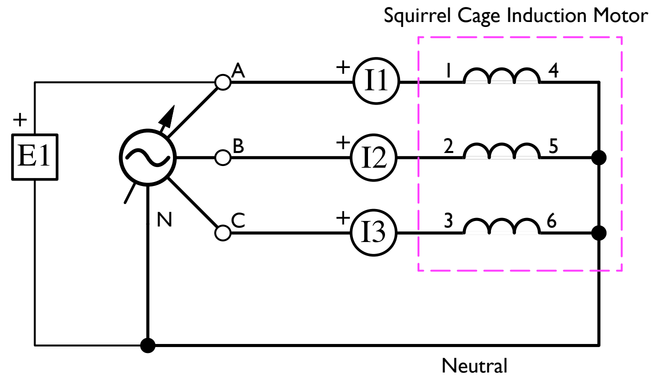


Figure 4.15: Three-Phase Motor – Three Phases

☐ 30. **Remove the belt** that couples the three-phase squirrel cage induction motor to the dynamometer, and construct the circuit shown in Figure 4.15.

☐ 31. **Turn on the power** and quickly raise the voltage to 120 V.

☐ 32. Does the motor start and run normally? ☐ Yes ☐ No

AC motors draw excessive current when operating at reduced voltage, so it's best to turn the rheostat up quickly.

☐ 33. Use the *Phasor Analyzer* to determine the phase angle between the currents measured by meters I1, I2 and I3.

Phase Angle = ________

☐ 34. Without stopping the motor, disconnect one phase by unplugging power line C. Does the motor stop, or continue to run?

☐ Stop ☐ Continue

☐ 35. How does the phase relation between the currents change?

____

☐ 36. Turn the voltage control knob to zero and allow the motor to come to a complete stop, then turn the voltage back up to 120 V. Can the three phase motor motor start on two phases? ☐ Yes ☐ No

☐ 37. While the motor is still running on two phases, disconnect the *Neutral* at the wye connection. Does the motor stop, or does it continue to run?

☐ Stop ☐ Continue

☐ 38. Use the *Phasor Analyzer* to determine the phase angle between the currents measured by I1 and I2.

Phase Angle = ________

Should the two remaining windings be considered one phase, or two?

☐ one ☐ two

☐ 39. Turn the voltage control knob to zero and allow the motor to come to a complete stop. Turn the voltage up to 50%. Does the three phase motor start readily and run normally now? **Turn off the Power**

Don't leave the voltage on for long.

☐ 40. Based on your observations, will a three phase motor start and run on two phases?

Start ☐ Yes ☐ No **Run** ☐ Yes ☐ No

☐ 41. Will it start and run on one phase?

Start ☐ Yes ☐ No **Run** ☐ Yes ☐ No

☐ 42. Turn off the power and disconnect the motor and meters.

Capacitor Start Motor

☐ 43. Construct the capacitor start motor circuit shown in Figure 4.16.

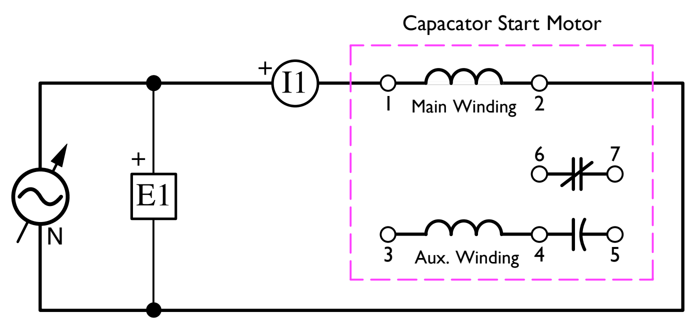


Figure 4.16: Capacitor Start Motor – Main Winding Only

☐ 44. **Turn on the power** and set the voltage control knob to about 10%.

☐ 45. In the *Phasor Analyzer* window, select proper sensitivities to observe voltage phasor E1 and current Phasor I1. Use E1 as the *reference phasor*. Observe that the current phasor I1 lags voltage phasor E1 due to the inductive properties of the main winding.

☐ 46. On the Power Supply, set the voltage control knob to the 50% position. Does the capacitor-start motor start to rotate?

☐ Yes ☐ No

☐ 47. **Turn off the power supply** and set the voltage control knob to zero. Connect the auxiliary winding of the Capacitor-Start Motor as shown in Figure 4.17.

☐ 48. **Turn on the power** and slowly set the voltage control knob to about 10%. Observe current phasors I1 and I2 in the *Phasor Analyzer* window.

Is the phase shift of current phasor I2 (auxiliary winding) with respect to voltage E1 less than that of current phasor I1 (main winding), thus confirming that the impedance of the auxiliary winding is more resistive and less inductive than the main winding when the motor is starting? ☐ Yes ☐ No

Is the phase shift between current phasors I1 and I2 less than 90°? ☐ Yes ☐ No

☐ 49. On the power supply, set the voltage control knob to the 50% position. Does the capacitor-start motor start to rotate? ☐ Yes ☐ No

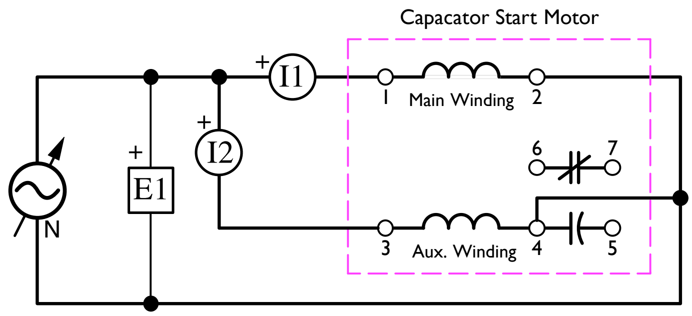


Figure 4.17: Capacitor Start Motor – Main and Auxiliary Winding

☐ 50. **Turn off the power** and turn the voltage control knob fully counterclockwise. Modify the capacitor-start motor circuit by connecting the capacitor on the Capacitor-Start Motor module in series with the auxiliary winding as shown in Figure 4.18.

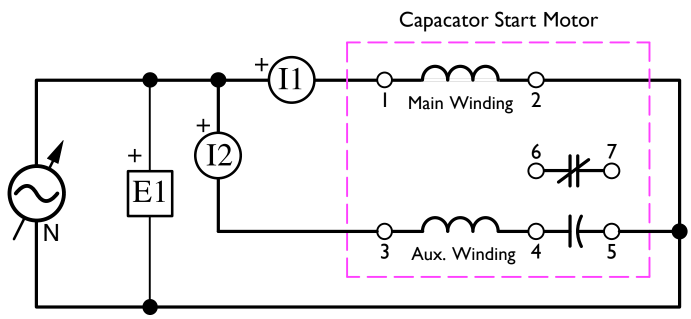


Figure 4.18: Capacitor Start Motor – Main and Auxiliary Windings, and Capacitor

☐ 51. **Turn on the Power** and slowly set the voltage control knob to about 10%.

Observe current phasors I1 and I2 in the phasor analyzer window.

Does connecting a capacitor in series with the auxiliary winding create a phase shift of approximately 90° between current phasors I1 and I2? ☐ Yes ☐ No

☐ 52. On the power supply, set the voltage to knob to the 50% position. Does the capacitor-start motor start to rotate? ☐ Yes ☐ No

☐ 53. Let the motor operate for a few minutes while observing current phasors I1 and I2 in the phasor analyzer window.

I1 = ___________ I2 = ___________

What happens after a few minutes? Why?

____

____

☐ 54. **Turn off the power** and turn the voltage control knob fully counterclockwise. Open the front cover of the capacitor-start motor module and reset the tripped circuit breaker.

Modify the capacitor-start motor circuit by connecting the *centrifugal switch* on the Ca-pac-i-tor-Start motor module in series with the auxiliary winding and the capacitor as shown in Figure 4.19.

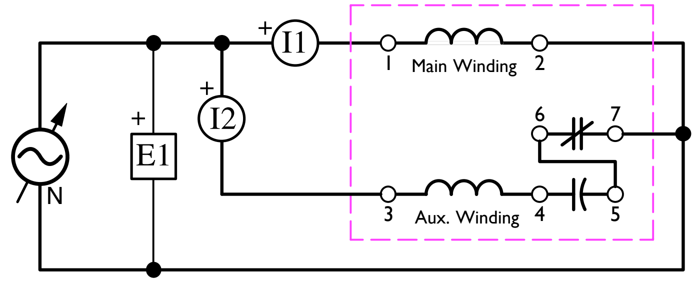


Figure 4.19: Capacitor Start Motor – Main and Auxiliary Windings, Capacitor, and Centrifugal Switch

☐ 55. **Turn on the power** and slowly set the voltage control knob to 100%. While doing this, observe phasors I1 and I2 in the phasor analyzer window as the voltage increases.

Does the capacitor-start motor start and run? ☐ Yes ☐ No

Briefly explain why the current phasor I2 disappears shortly after the motor has started.

☐ 56. Make the necessary wiring changes to operate the motor in the reverse direction.

☐ 57. **Turn off the power** and remove the Capacitor-Start Motor module from the EMS, and inspect the centrifugal switch.

☐ 58. Replace the Capacitor-Start Motor Module, reinstall the timing belt, shut down the computer and put everything away.

Conclusion

In this exercise, you observed a three-phase squirrel cage induction motor and saw that when the nominal line voltage is applied to the stator windings of an unloaded motor, the rotor turns at approximately the same speed as the rotating magnetic field (synchronous speed). You saw that interchanging any two of the three leads supplying power to the stator windings reverses the phase sequence, and thereby, causes the motor to rotate in the opposite direction. You observed that the motor line currents increase as the mechanical load increases, thus showing that the squirrel-cage induction motor requires more electric power to drive heavier loads. You plotted a graph of speed versus torque and used it to determine the nominal, breakdown, and locked-rotor torques of the squirrel-cage induction motor. You also plotted a graph of the motor reactive power versus speed and observed that the squirrel-cage induction motor draws reactive power from the ac power source to create its magnetic field. Finally, you plotted a graph of the motor line current versus speed and observed that the starting current is many times greater than the nominal line current.

Next, you observed that a three-phase squirrel-cage induction motor starts and runs almost normally when powered by only two phases of a three-phase ac power source, because a rotating magnetic field is maintained. However, you saw that when only one phase is connected to the motor, there is no rotating magnetic field and the motor is not able to start rotating. You demonstrated that adding an auxiliary winding and a capacitor to an induction motor allows it to start and run normally when powered by a single-phase ac power source. You saw that this produces two currents (the main- and auxiliary-winding currents) that are phase shifted of approximately 90°, and that these currents produce the necessary rotating magnetic field when the motor is starting. Finally, you observed that a centrifugal switch is used to disconnect the auxiliary winding when the single-phase induction motor reaches sufficient speed to maintain the rotating magnetic field.

Review Questions

1. The speed of the rotating magnetic field created by three-phase power is called the
   a) no-load speed.
   b) synchronous speed.
   c) slip speed.
   d) nominal speed.
2. The difference between the synchronous speed and the rotation speed of a squirrel-cage induction motor is
   a) known as slip.
   b) always greater than 10%.
   c) known as slip torque.
   d) always less than 1%.
3. Reactive power is consumed by a squirrel-cage induction motor because
   a) it uses three-phase power.
   b) it does not require active power.
   c) it requires reactive power to create the rotating magnetic field.
   d) it has a squirrel-cage.
4. Does the speed of a squirrel-cage induction motor increase or decrease when the motor load increases?
   a) It increases.
   b) It decreases.
   c) It stays the same because speed is independent of motor load.
   d) The speed oscillates around the original value.
5. What happens when two of the three leads supplying power to a squirrel-cage induction motor are reversed?
   a) The motor does not start.
   b) Nothing.
   c) The motor reverses its direction of rotation.
   d) The motor consumes more reactive power.
6. When only two phases are connected to a three-phase squirrel-cage induction motor, it
   a) runs almost normally.

   b) turns in the opposite direction.
   c) does not start.
   d) affects the amount of reactive power supplied by the motor.

7. When only one phase is connected to a three-phase squirrel-cage induction motor, it
   a) runs almost normally.
   b) turns in the opposite direction.
   c) does not start or it starts rotating abnormally.
   d) affects the amount of reactive power supplied by the motor.
8. An auxiliary winding and a capacitor are added to a single-phase induction motor to help
   a) it start.
   b) to increase the starting torque.
   c) to produce a phase shift between the winding currents.
   d) All of the above.
9. Single-phase induction motors of the capacitor-start type use a centrifugal switch to
   a) add an auxiliary winding and a capacitor to the motor circuit.
   b) remove an auxiliary winding and a capacitor from the motor circuit.
   c) add resistance only to the starting circuit.
   d) remove resistance only from the starting circuit.
10. The auxiliary winding has fewer turns of finer wire than the main winding and therefore has
   a) lower resistance and higher inductance.
   b) lower resistance and lower inductance.
   c) higher resistance and higher inductance.
   d) higher resistance and lower inductance.

Lab 5

AC Synchronous Generators

Introduction

Objective

After completing this exercise, you will be able to demonstrate and explain the no-load characteristics and the voltage regulation behavior of of three-phase synchronous generator, using the Synchronous Motor/Generator and Prime Mover/Dynamometer modules.

No Load Operation

The *three-phase synchronous generator*, or *alternator*, produces most of the electricity used today. It is found in all electrical-power generating stations, whether they are of the hydroelectric, diesel, coal-fired, wind turbine, or nuclear type. The alternator also generates the electricity used in motor vehicles.

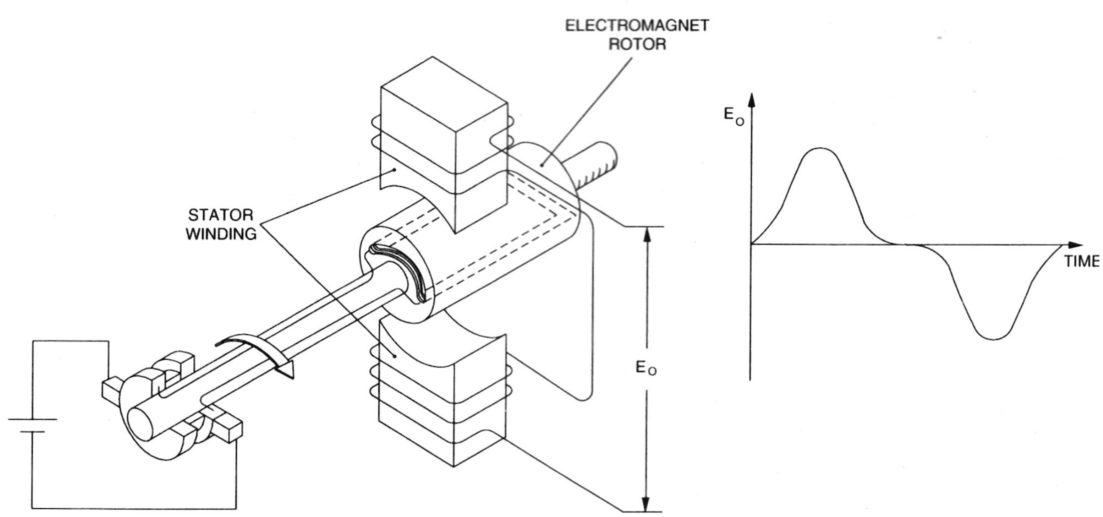


Figure 5.1: An Alternating Voltage is Produced by the Continually-Changing Magnetic Flux Linking the Stator Winding.

The basic principle of operation for alternators is quite simple and can be explained using the simplified single-phase alternator shown in Figure 5.1. An electromagnet creates a magnetic field in the rotor. The electromagnet rotor is coupled to a source of mechanical power, such as a steam turbine, to make it rotate. As a result, a continually-changing magnetic flux links the stator winding and induces an alternating voltage across the stator winding as shown in Figure 5.1.

The way the conductors are wound in the stator of a synchronous generator determines the waveform of the voltage induced across the stator winding. The stator-winding conductors in synchronous generators are usually wound in such a way that the induced voltage has a sinusoidal waveform. The stronger the rotor electromagnet, the greater the magnetic flux linking the stator windings, and the higher the alternating voltages induced across the stator windings. Furthermore, since the induced voltages are proportional to the rate of change of the magnetic flux linking the stator windings, one can easily deduce that the faster the rotor turns, the higher the amplitude of the induced voltages. In brief, the amplitude of the voltages produced by a three-phase synchronous generator is proportional to the strength of the rotor electromagnet and the rotation speed.

The stator in a three-phase synchronous generator is provided with three windings located at 120° from one another. As a result, three sine-wave voltages phase shifted by 120° with respect to each other are induced in the three stator windings. The stator of a three-phase synchronous generator is in fact very similar to the stator of a three-phase squirrel-cage induction motor shown in Figure 4.4.

There is a direct relationship between the speed of the rotor and the frequency of the voltage induced across each stator winding of a synchronous generator. When the rotor of a two-pole synchronous generator like the one shown in Figure 5.1 rotates through one revolution, it produces one voltage cycle. When it rotates at n revolutions per minute, it generates a voltage sinusoid with a frequency of n cycles per minute.

Since rotational speed is usually expressed in revolutions per minute, while frequency is usually expressed in Hz, which are cycles per second, the equation relating the speed of rotation to the frequency of the voltage produced by the synchronous generator shown in Figure 5.1 is as follows.

$$f = \frac{n \text{ [r/min]}}{60 \text{ [sec/min]}} \qquad \text{(for generators with a stator having a single pair of poles)}$$

where

f is the frequency, expressed in Hertz [Hz]
n is the speed, expressed in revolutions per minute [r/min]

However, each stator winding in large synchronous generators usually has several north and south poles instead of just a single pair as illustrated in Figure 5.1. As a result, a higher frequency is obtained for a given speed of rotation. The frequency formula can be adjusted to determine the frequency of synchronous generators, regardless of the number of pairs of north and south poles, by multiplying the speed n in the previous equation by $P/2$, where P is the number of poles per phase of the stator windings. The equation for determining the frequency of the voltage produced by a synchronous generator is thus,

$$f = \frac{P \times n}{120} \qquad \text{(for any type of synchronous generator)}$$

Note that the generator used in this lab has two north poles and two south poles per stator winding, thus it is known as a 4-pole generator, and P equals 4 for the Lab-Volt Synchronous Motor/Generator.

Voltage Regulation

The load on a typical generator will vary throughout the day as equipment is started and stopped. These load changes have an effect on the generator output voltage. Because many devices are sensitive to voltage changes, it is important to maintain the generator output voltage as close as possible to the correct value. The *voltage regulation* of a generator is a measure of how well the generator maintains a constant voltage under load. Voltage regulation is also known as voltage *droop*. Generator percent voltage regulation is determined by the following formula:

$$\%VR = \frac{E_{NL} - E_{FL}}{E_{NL}} \times 100\%$$

where

E_{NL} is the no-load voltage and E_{FL} is the full load voltage.

The result is a percentage value which gives an indication of the generator behavior under load. The smaller the voltage regulation percentage, the less the generator output voltage varies with load. Several factors affect a generators operation. The resistance and inductive reactance of its armature (stator) windings cause internal voltage drops that vary with the amount of current flowing to the load. If the generator is lightly loaded, current through the armature winding resistance and reactance is small, and the resulting voltage drops are also small. As the load increases, the internal voltage drops also increase.

Industrial generators include an electronic device known as a *voltage regulator* which automatically controls the generator output voltage by adjusting the field current, thus producing any desired value of voltage droop.

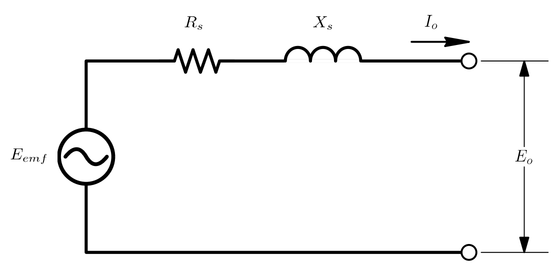


Figure 5.2: Simplified Equivalent Circuit for One Phase of a Three-Phase Synchronous Generator.

As seen in Lab 3 of this manual, a dc generator can be represented by the simplified equivalent circuit shown in Figure 3.2. In this circuit, the voltage E_{emf} depends on the speed at which the generator rotates and the strength of the field electromagnet. Resistor R_A represents the resistance of the armature conductors. A simplified equivalent circuit similar to that of the dc generator can be used to represent each phase of a three-phase synchronous generator. Figure 5.2 shows the simplified equivalent circuit for one phase of a three-phase synchronous generator. To represent a complete three-phase synchronous generator, three circuits like the one shown in Figure 5.2 would be used.

As for a dc generator, the voltage E_{emf} in the simplified circuit of the synchronous generator depends on the rotation speed as well as the strength of the electromagnet. Furthermore, there is a resistor (R_s) in the simplified circuit of the synchronous generator, as in the simplified circuit of the dc generator, that represents the resistance of the stator coil conductors. There is also an additional element in the simplified circuit of the synchronous generator, reactance X_s, which represents the inductive reactance of the stator coil conductors. Reactance X_s is known as the synchronous reactance of the synchronous generator and its value, expressed in ohms, is usually much greater than that of resistor R_s.

When the synchronous generator is operated at constant speed and with a fixed current in the rotor electromagnet (field current I_f), voltage E_{emf} is constant and the equivalent circuit for each phase is very similar to that of a single-phase transformer. Figure 5.3 shows voltage regulation characteristics (curves of the output voltage E_o versus the output current I_o) of a synchronous generator for resistive, inductive, and capacitive loads. These characteristics are very similar to those obtained with a single-phase transformer.

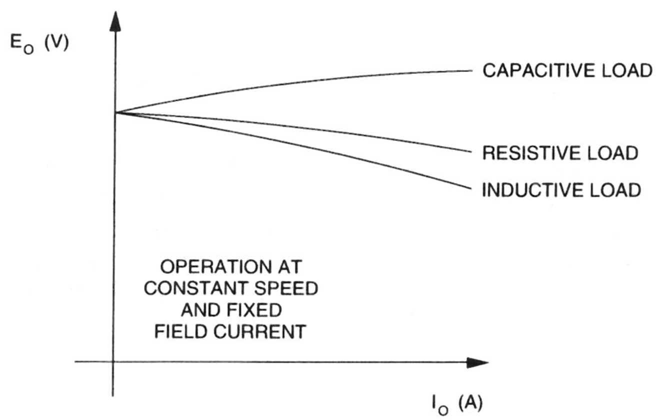


Figure 5.3: Voltage Regulation Characteristics of a Synchronous Generator.

Procedure

No Load Operation

☐ 1. Insure that the Power Supply, Prime Mover/Dynamometer, Synchronous Motor/Generator, Resistive Load Module and Data Acquisition Interface are installed in the EMS Workstation. Insure the USB cable connects the DAI to the computer.

☐ 2. Make sure that the **main power switch is off**, and the voltage control knob is turned fully ccw.

☐ 3. Connect the DAI to the 24 V ac power with the grey cable, and turn it on. Leave power on the DAI for the entire exercise.

☐ 4. Launch the *Metering* program, and open meter config file *Lab 5 AC Generator* to show

☐ 5. Launch the *Phasor Analyzer* and set it up to display E1, E2, and E3, with E1 as the *Reference Phasor*.

☐ 6. Connect the equipment as shown in Figure 5.4.

Meter	Display
E1, E2, E3	AC Volts
I1	AC Amps
I3	DC Amps
T	Torque
N	Speed
Programmable Meter B	Frequency(E1)

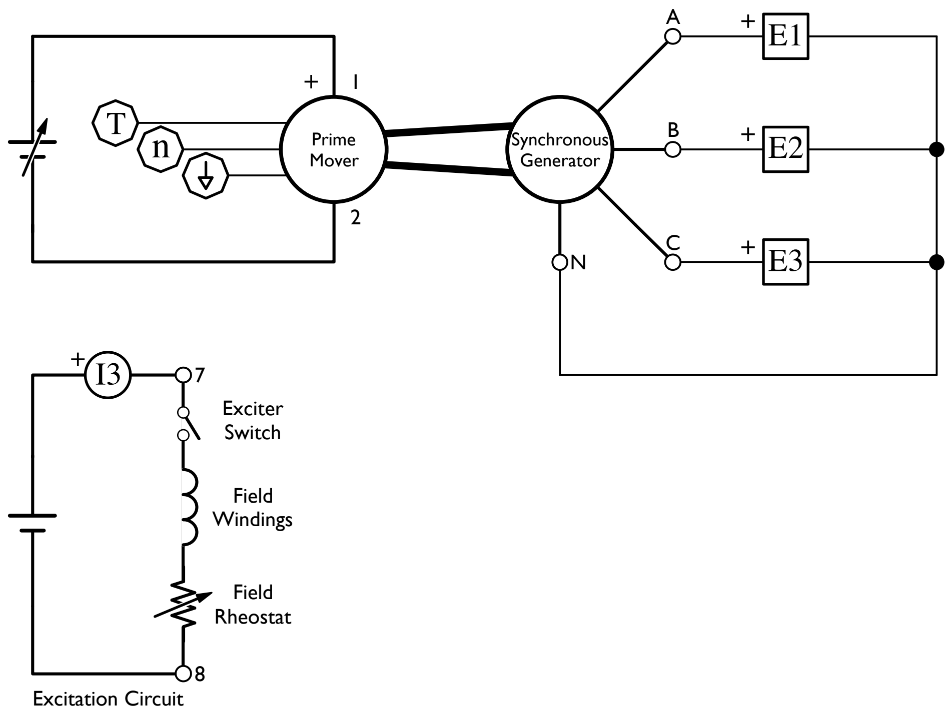


Figure 5.4: Synchronous Generator, No Load, Phase Voltages

☐ 7. Set the Prime Mover/Dynamometer controls as follows:

Control	Position
Mode Switch	Prime Mover (P.M.)
Display Switch	Speed (N.)

☐ 8. **Turn on the power** and set the voltage control knob so that the Prime Mover rotates at the nominal speed of the Synchronous Motor/Generator.

☐ 9. Set the *Field rheostat* to three quarters of maximum and then close the *Exciter switch* on the Generator Module.

☐ 10. In the Oscilloscope window, make the appropriate settings to observe the waveforms of the *phase voltages*E_1, E_2, and E_3 induced across each of the stator windings of the synchronous generator and set the oscilloscope to *continuous refresh*.

Are the waveforms sinusoidal? ☐ Yes ☐ No

What is the approximate phases shift ϕ between each of the voltage waveforms?

ϕ = __________ °

☐ 11. Slowly lower and raise the speed of the prime mover with the voltage control knob. While doing this, observe the waveforms of voltages E_1, E_2, and E_3 in the oscilloscope window.

How do the amplitude and frequency of the voltage waveforms vary when the speed of the the synchronous generator is decreased. Briefly explain why.

____

____

____

The frequency produced by the Synchronous Motor/Generator follows this relationship

$$f = \frac{P \times n}{120} = \_\_\_\_\_\_\_\_\_\_ \text{ Hz}$$

Do your observations agree with this equation? ☐ Yes ☐ No

☐ 12. Toggle the field rheostat switch open and closed and adjust the field rheostat, and while doing this, observe the waveforms of voltages E_1, E_2, and E_3 in the oscilloscope window.

Is the generator output voltage zero when the field current is zero? Briefly explain why.

____

____

How do the amplitude of the voltage waveforms vary when the field current I_f of the the synchronous generator is decreased. Briefly explain why.

____

____

Does varying the field current affect the frequency of the voltage waveforms, or the phase shift between them? Why?

____

____

☐ 13. **Turn off the power** and turn the voltage control knob fully counteclockwise.

Generator Characteristics

☐ 14. Modify the connections so that the modules are connected as shown in Figure 5.5. Note that E1 now measures the generator's line voltage E_o, not its phase voltage as before, and that resistor R_1 is inserted into the field circuit. Connect all nine of the resistors on the resistive load module in parallel to implement resistor R_1.

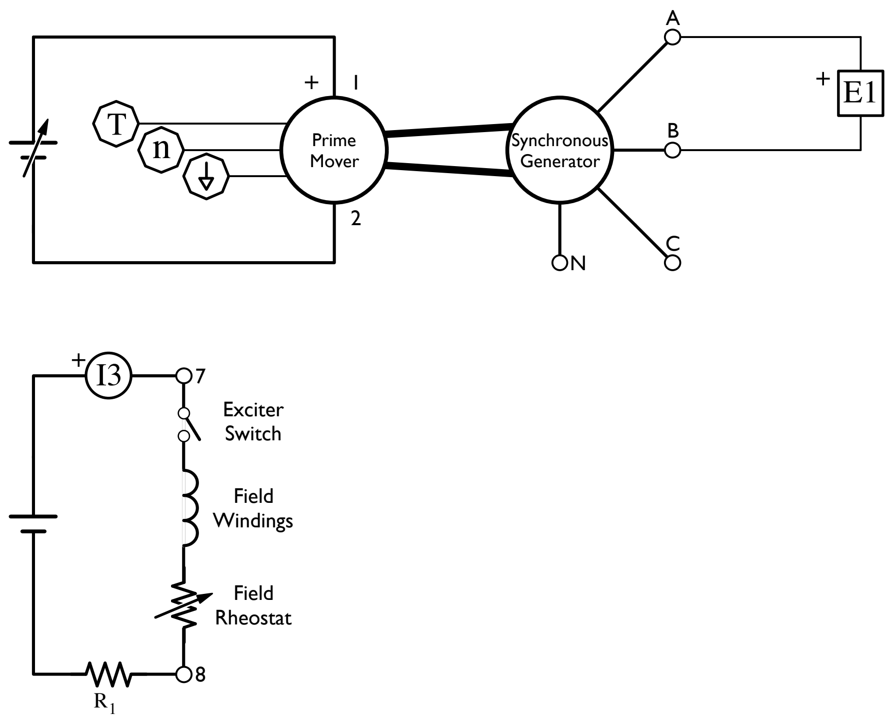


Figure 5.5: Synchronous Generator, No Load, Line Voltages

☐ 15. **Turn on the Power** and set the *field rheostat* so that the field current I_f is 500 mA.

☐ 16. Set up a data table to record the generator output voltage E_o, field current I_f, speed n, and frequency f, indicated by meters E1, I3, N, and B, respectively. You can just accept the default selection, which will record all these values and others.

☐ 17. On the power supply, adjust the voltage control knob so that the prime mover speed increases from 0 to 2400 rpm in 200 rpm increments. For each speed setting, record the data in the data table.

☐ 18. When all the data has been recorded, turn the voltage control knob fully counterclockwise and **turn off the power**.

☐ 19. In the graph window, make the appropriate settings to obtain a graph of the generator output voltage E_o as a function of the speed n.

☐ 20. Sketch the graph here:

☐ 21. **Turn on the Power** and set the voltage control knob so that the Prime Mover rotates at the nominal speed of the Synchronous Motor/Generator.

☐ 22. Set up a data table to record the generator output voltage E_o, line current I_f, speed n, and frequency f, indicated by meters E1, I3, N, and B, respectively.

You will be unable to achieve 50mA, so proceed from 0 to 100 ma, then increase in 50 ma steps to approximately 850 ma. In order to reach the maximum value of field current, it will be necessary to short out resistor R_1. Ask your instructor for help if you need it.

☐ 23. Change the value of resistor R_1 and vary the setting of the *Exciter knob* on the synchronous motor generator to increase the field current I_f from 0 to its maximum value in steps of about 50 mA. For each current setting, readjust the voltage control knob of the power supply so that the Prime Mover speed remains equal to the nominal speed of the motor generator. For each setting, record the data in the data table.

Turn off the power when you have finished.

☐ 24. In the graph window, make appropriate settings to obtain a graph of the synchronous generator's output voltage E_o as a function of field current I_f.

Sketch the graph here:

Briefly explain why the relationship between the synchronous generator output voltage and field current is non-linear for high values of I_f.

___

Resistive, Inductive and Capacitive Loads

☐ 25. Remove resistor R_1 from the field circuit, and add a three-phase y-connected resistive load and ammeter to the output of the generator as shown in Figure 5.6.

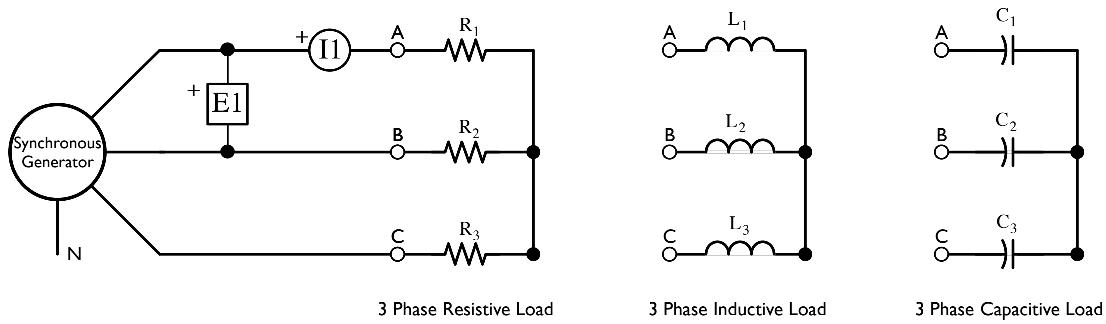


Figure 5.6: Synchronous Generator under Load

☐ 26. **Turn on the power** and set the voltage control knob so that the generator rotates at its nominal speed.

Use the blue cables to connect the generator to the load.

☐ 27. Adjust the excitation current until the generator is producing its nominal voltage.

☐ 28. Set up a data table to record the generator output voltage E_o, line current I_l, speed n, and frequency f, indicated by meters E1, I1, N, and B, respectively. You can just accept the default selection, which will record all these values and others.

☐ 29. Modify the settings on the resistive load module so that the resistance of resistors R_1, R_2, and R_3 decrease in these steps: ∞ Ω, 1200 Ω, 600 Ω, 400 Ω, 300 Ω, 240 Ω, 200 Ω, and 171 Ω.

For each setting, readjust the voltage control knob of the power supply so that the prime move speed remains equal to the nominal speed of the generator, then record the data in the data table.

Refer to the appendix to find out the resistor combinations needed to produce the required resistance values.

☐ 30. **Turn the power off** and replace the resistive load with a three-phase y-connected *inductive* load. Then **turn the power on** and repeat step 29. Continue to collect your data in the same table.

☐ 31. **Turn the power off** and replace the inductive load with a three-phase y-connected *capacitive* load. Then **turn the power on** and repeat step 29. Continue to collect your data in the same table.

☐ 32. **Turn the power off.** In the graph window, make the appropriate settings to obtain a graph of the generator output voltage E_o as a function of the load indicated by I_l. Sketch the graph here:

☐ 33. Calculate *voltage regulation*, VR for each type of load using the following formula:

$$VR = \frac{V_{\text{NL}} - V_{\text{FL}}}{V_{\text{NL}}} \times 100\%$$

Load	V_{NL} No Load Voltage	V_{FL} Full Load Voltage	VR Voltage Regulation
Resistive			
Inductive			
Capacitive			

☐ 34. Put everything away.

Conclusion

In this exercise, you observed that a three-phase synchronous generator produces three sine-wave voltages that are phase shifted by 120° from each other. You saw that decreasing the prime mover speed decreases the amplitude and frequency of the sine-wave voltages, while decreasing the field current decreases the amplitude of the sine-wave voltages. You plotted a graph of the synchronous generator output voltage versus the field current. This graph showed that the synchronous generator starts to saturate when the field current exceeds a certain value. This graph also showed that the synchronous generator produces voltages even when the field current is zero because of the residual magnetism in the rotor. You plotted graphs of the synchronous generator output voltage and frequency versus speed. These graphs showed that the output voltage and frequency are proportional to the synchronous generator speed.

Next, you obtained the voltage regulation characteristics of a three-phase synchronous generator. You observed that the output voltage decreases as the output current increases when the synchronous generator supplies power to either a resistive or inductive load. You saw that the output voltage increases as the output current increases when the synchronous generator supplies power to a capacitive load. The voltage regulation characteristics of the synchronous generator are similar to those of a single-phase transformer because the equivalent circuit is almost the same for both.

Review Questions

1. Most electrical power that is consumed today is produced by
   a) synchronous condensers.
   b) synchronous generators.
   c) alternators.
   d) both b and c.
2. When the speed of a synchronous generator is increased
   a) the output voltage increases and the frequency decreases.
   b) the output voltage decreases and the frequency increases.
   c) both the output voltage and frequency decrease.
   d) both the output voltage and frequency increase.
3. How does the field current affect the frequency of the voltages produced by a three-phase synchronous generator?
   a) Frequency increases as I_F increases.
   b) Frequency decreases as I_F decreases.
   c) Frequency is not affected by changes in field current.
   d) both a and b.
4. Multiplying the speed of an alternator by $P/120$ allows the
   a) frequency to be determined.
   b) output voltage to be determined.
   c) field current to be determined.
   d) number of poles to be determined.
5. Alternator is another name for a
   a) three-phase synchronous motor.
   b) three-phase synchronous generator.
   c) three-phase synchronous condenser.
   d) three-phase ac-to-dc converter.
6. The output voltage of a synchronous generator is a function of the
   a) speed of rotation and polarity of the field current.
   b) speed of rotation and strength of the field electromagnet.
   c) speed of rotation and input torque.
   d) speed of rotation only.
7. The equivalent circuit for one phase of a three-phase synchronous generator operating at constant speed and fixed field current is
   a) identical to that of a dc generator.
   b) very similar to that of a single-phase transformer.
   c) the same as a three-phase balanced circuit.
   d) the same as that of a dc battery.
8. In the equivalent circuit of the synchronous generator, reactance X_s is called
   a) stationary reactance.
   b) steady-state reactance.

   c) simplified reactance.
   d) synchronous reactance.

9. The voltage regulation characteristics of a synchronous generator are
   a) very similar to those of a single-phase transformer.
   b) quite different from those of a single-phase transformer.
   c) identical to those of a single-phase motor.
   d) only useful when the generator operates without load.
10. In the equivalent circuit of the synchronous generator, the value of X_s expressed in ohms,
    a) is much smaller than the value of R_s.
    b) is much greater than the value of R_s.
    c) is the same value as R_s.
    d) depends on the generator output voltage.

Lab 6

Generator Paralleling

Introduction

Objective

When you have completed this exercise, you will be able to synchronize a three-phase synchronous generator with the ac power network using the Lab Volt Synchronous Motor/Generator and the Synchronizing Module. You will see the indications of an incorrect phase sequence, and observe how active and reactive power are controlled and shared. You will motorize a generator, and observe the effects on torque, speed, and power.

You will then use the DAC Paralleling Simulator to parallel two generators and balance the active and reactive loads. This final exercise is an STCW assessment.

Discussion

Most of the electricity consumed today is produced by three-phase synchronous generators. Since a huge amount of electricity is consumed every day, ac power networks are generally made up of a large number of synchronous generators all operating at the same frequency. When the power demand increases, additional generators are connected to the ac power network.

Before connecting a three-phase synchronous generator to an ac power network or another generator, the following conditions are to be observed:

- The *frequency* of the voltages produced by the generator must be equal to the frequency of the ac power network's bus.
- The *voltage* produced by the generator must be equal to the bus voltage.
- The *phase sequence* of the voltages produced by the generator must be the same as the phase sequence of the bus.
- The incoming and bus voltages must be *in phase* at the instant the connection is made.

A generator can only be synchronized when all these conditions are met. A synchronous generator must never be connected to an ac power network before verifying the conditions described above. Connecting generator to an ac power network incorrectly could cause severe damages to the generator, because of the high torque that would be applied to the generator's shaft and the huge currents that would flow in the generator windings at connection. Once a synchronous generator is connected to an ac power network, no current flows between the generator and the ac power network because they produce voltages having the same amplitude and phase. As a result, the generator supplies neither active nor reactive power to the ac power network. In this case, the generator is said to be *floating* on the ac power network. Furthermore, its frequency is determined by the bus frequency, and can no longer be changed by adjusting the torque applied to the generator's shaft. This is because the ac power network is so powerful that it imposes its own frequency. However, adjusting the torque applied to the generator's shaft allows changing the amount of active power that is exchanged between the generator and the ac power network. Increasing the torque increases the amount of active power that is delivered to the ac power network. Conversely, decreasing the torque decreases the amount of active power that is delivered to the ac power network. The generator could even receive active power from the ac power network, and thus operate as a synchronous motor, if the torque applied to the generator's shaft were decreased to zero.

As in three-phase synchronous motors, the amount of reactive power that is exchanged between a synchronous generator and the ac power network can be changed by adjusting the field current. The field current is usually adjusted so that no reactive power is exchanged between the generator and the ac power network, i.e., so that the power factor of the generator is unity. This minimizes the line currents and allows the size of the conductors connecting the generator to the ac power network to be reduced to minimum.

In the first part of the lab a simple circuit used to synchronize and connect a the Lab Volt generator to the utility grid. In this circuit, a three-phase synchronous generator is connected to a three-phase power network (three-phase power source) through three lamps and a three-pole switch set to the open position. A voltmeter and a frequency meter are connected to the generator output to measure its voltage and frequency. A synchroscope is connected to indicate the phase relationship between the generator voltage and the utility network voltage.

The speed and field current of the synchronous generator are first adjusted so that the generator frequency and voltage are approximately equal to the nominal voltage and frequency of the ac power network. The brightness of the lamps will change in synchronism when the *phase sequence* of the generator is the same as that of the ac power network. On the other hand, the lamp brightness will change out of synchronism if the phase sequence of the generator differs from that of the ac power network. In this case, the connections of two of the three line wires of the synchronous generator must be interchanged to reverse its phase sequence.

Once the phase sequence of the synchronous generator is correct, the speed of the generator is adjusted so that the rate at which the lamp brightness changes is as low as possible, and the synchroscope is turning slowly in the fast direction. This adjusts the frequency of the generator to just slightly less than that of the ac power network. The field current of the generator is then adjusted so that the lamps become completely dimmed as their brightness decreases. This adjusts the generator voltage to that of the ac power network. The switch can then be closed at any instant the lamps are dimmed completely (the voltages are in phase at this instant only) to safely connect the synchronous generator to the ac power network.

Procedure

Equipment Setup

☐ 1. Insure that the Power Supply, Prime Mover/Dynamometer, Synchronous Motor/Generator, Synchronizing Module, Synchroscope Module, and Data Acquisition Interface are installed in the EMS Workstation. Insure the USB cable connects the DAI to the computer.

☐ 2. Make sure that the **main power switch is off**, and the voltage control knob is turned fully ccw.

☐ 3. **Important!** Open the *synchronizing switch* on the *Synchronizing Module*.

☐ 4. Connect the DAI to the 24 V ac power with the grey cable, and turn it on. Leave power on the DAI for the entire exercise.

☐ 5. Launch the *Metering* program, and open meter configuration file *Lab 6 Synchronizing* to show

Meter	Display
E1, E2	AC Volts
I1, I2	AC Amps
I3	DC Amps
T	Torque
N	Speed
Pm	Mechanical Power P_m
Programmable Meter A	Active Power P
Programmable Meter C	Reactive Power Q
Programmable Meter B	Frequency f

☐ 6. Set the Prime Mover/Dynamometer controls as follows:

Control	Position
Mode Switch	Prime Mover (P.M.)
Display Switch	Speed (N.)

☐ 7. Close the *Exciter switch* on the Generator Module, and set the *field rheostat* to the mid position.

☐ 8. Connect the equipment as shown in the Figure 6.1.

Phase Sequence

☐ 9. **Turn on the power** and adjust the voltage control knob so that the Synchronous Motor/Generator rotates at approximately 1750–1775 rpm. Observe the behavior of the *synchronizing lights* and the *Synchroscope*.

Is the synchroscope rotating slowly in the slow direction? ☐ Yes ☐ No

Are the synchronizing lights blinking together, indicating that the phase sequence of the generator matches the phase sequence of the three-phase power network? ☐ Yes ☐ No

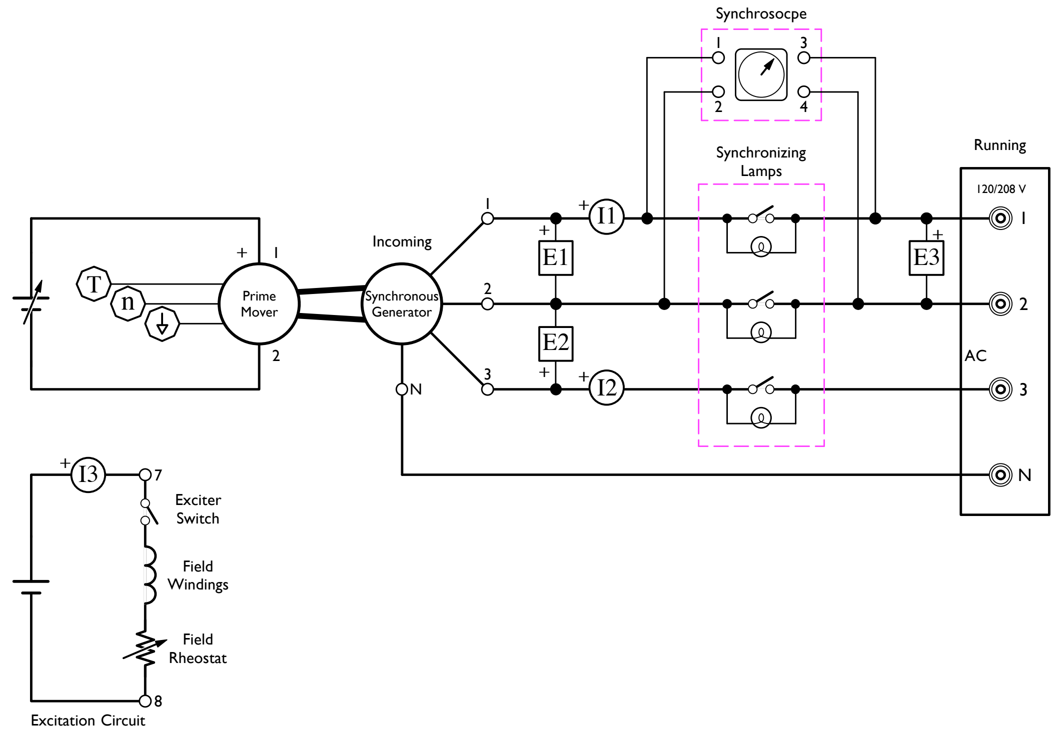


Figure 6.1: Synchronous Generator Paralleled with the AC Power Network

☐ 10. Raise the speed of the generator until it is slightly higher than the nominal speed of the generator. Describe how the behavior of the synchronizing lights and the synchroscope change.

____

____

☐ 11. **Turn off the power** and interchange the power connection leads at terminals 1 and 2 on the power supply.

☐ 12. **Turn on the power** and adjust the generator speed to approximately 1725 rpm. Observe the behavior of the *synchronizing lights* and the *Synchroscope*.

Are the synchronizing lights "twinkling"? ☐ Yes ☐ No

Does the synchroscope display look unusual? ☐ Yes ☐ No

Never attempt to parallel generators when the synchronizing lights are "twinkling".

☐ 13. **Turn off the power** and restore power connection leads 1 and 2 to their original positions.

Synchronization

☐ 14. **Turn on the power** and adjust voltage control knob until the generator rotates at approximately 1700 rpm.

☐ 15. Adjust the *field rheostat* until the generator voltage indicated by meters E1 and E2 is slightly higher than the voltage of the three-phase network.

☐ 16. Adjust the speed of the generator until the synchroscope is turning *slowly in the fast direction*.

Are the synchronizing lights all dark at the moment the synchroscope is at top dead center?

☐ Yes ☐ No

☐ 17. Close the synchronizing switch on the Synchronizing module when the synchroscope is pointing *slightly before top dead center* to parallel the generator with the network.

Is the generator now paralleled with the network? ☐ Yes ☐ No

Is the generator supplying any power to the nework? ☐ Yes ☐ No

How do you know?

____

____

Effect of Driving Torque

In this section you will observe how changing the input mechanical power and driving torque effects a generator paralleled with an infinite bus.

☐ 18. If it isn't already, parallel the lab generator with the bus:

- Adjust the prime mover until the incoming frequency is slightly higher than the bus frequency and the synchroscope is turning slowly in the fast direction
- Adjust excitation until incoming voltage is slightly higher than the bus voltage (2 volts or so)
- Close synchronizing switch when synchroscope is pointing at top dead center.

☐ 19. Adjust the Generator to full load by increasing the prime mover voltage until the torque supplied to the generator to approximately –1.5 N-m.

The negative sign is the result of a sign convention. A quantity like torque or power leaving the device is considered positive. Since the prime mover is supplying torque to the generator, the torque "out" of the generator is negative, and the electrical power "out" is positive. On the other hand, a motor consumes electrical power and produces mechanical power so torque "out" is positive, and electrical power "out" is negative.

☐ 20. Record the following values including units:

T	Torque	________
n	Speed	________
P_m	Mechanical Power	________
P_e	Active Power	________
Q_e	Reactive Power	________

☐ 21. If the shaft speed n is 1800 rpm, what is the shaft angular velocity, ω?

$$\omega = \frac{2\pi n}{60} = \_\_\_\_\_\_\_\_\_\_$$

☐ 22. Mechanical Power is Torque times Angular Velocity. Calculate the input mechanical power. What are the associated units? Does this value agree with the value indicated on the computer?

$$P_m = T\omega = \_\_\_\_\_\_\_\_\_\_$$

☐ 23. Efficiency is the ratio of output power to input power. In this case, the input is mechanical power supplied by the prime mover, while the output is active power. Calculate the generator efficiency at full load.

$$\eta = \frac{P_e}{P_m} = \_\_\_\_\_\_\_\_\_\_$$

☐ 24. Set up a new, blank data table.

☐ 25. Decrease the input torque in about 15 small steps from its present value in small steps by decreasing the prime mover voltage. Record values in a data table after each step. Continue until the until the torque indicated stops changing. Be sure to wait about three seconds after each adjustment before recording to get good results.

☐ 26. Make of graph of active and reactive power as a function of Torque, and sketch it below. If necessary, change the colors to make the curves clearly visible.

☐ 27. Answer the following questions.

Does changing the input torque change the active power produced by the generator?

☐ Yes ☐ No

Does changing the input torque change the reactive power produced by the generator? ☐ Yes ☐ No

Which effect is predominant? __________

Does changing the torque affect the speed of the generator? Explain why or why not.

Can you adjust the torque to zero N-m? ☐ Yes ☐ No

Under these conditions, is the electrical power out positive or negative? ________

If the prime mover is supplying zero torque, where is the torque coming from to keep the generator spinning at 1800 rpm?

What is the greatest positive torque you observed? ________

Under these conditions is the generator motorized? ☐ Yes ☐ No

Did the motor direction change when it became motorized? ☐ Yes ☐ No

Did the torque change direction when the generator became motorized? ☐ Yes ☐ No

What do you think will happen if you disengage the prime mover while the generator is running?

What do you think will happen if you open the sync switch with the prime mover disengaged?

Effect of Field Excitation

In this section you will observe how changing the excitation current effects a generator paralleled with an infinite bus.

☐ 28. Delete your previous data table

☐ 29. Load the generator by increasing increase the prime mover voltage until the driving torque is approximately –1.5 N-m.

☐ 30. Turn the field rheostat fully counterclockwise while observing the generator speed and terminal voltage. Do speed or terminal voltage change? Why or why not.

☐ 31. Starting with the field rheostat fully counterclockwise, adjust the rheostat in small steps until it is fully clockwise, recording data after each step. Be sure to wait about three seconds after making the adjustment before recording the data to get good results.

☐ 32. Make a graph of Active and Reactive Power as a function of field current and sketch and label it below.

☐ 33. Answer the following questions.

Does adjusting the field excitation change the generator terminal voltage? ☐ Yes ☐ No

Does adjusting the field excitation change the generator rpm or frequency? ☐ Yes ☐ No

Does adjusting the field excitation change the generator active power? ☐ Yes ☐ No

Does adjusting the field excitation change the generator reactive power? ☐ Yes ☐ No

Can the generator reactive power be adjusted to zero? ☐ Yes ☐ No

Under these conditions, what is the generator power factor? ___________

Turning the rheostat clockwise causes the resistance to ☐ increase ☐ decrease

Turning the rheostat clockwise causes the excitation current to ☐ increase ☐ decrease

Turning the rheostat clockwise causes the field to get ☐ stronger ☐ weaker

Turning the rheostat clockwise causes the reactive power to ☐ increase ☐ decrease

☐ 34. Change the graph to show line current vs. field current. Can you explain the shape of the graph?

☐ 35. Turn off the power and put everything away.

Paralleling Simulator

In accordance with the requirements of STCW Assessment OICWE–7–1E, each student will demonstrate the Paralleling Procedure using the DAC Paralleling Simulator.

☐ 1. Start Incoming generator

a) Select **Display Function D** to show incoming and running generator parameters
b) Raise Turbine to operating speed to bring the frequency to 60 Hz using the **speed control buttons**.

c) Adjust incoming generator voltage to approximately 22000 Volts using the **voltage control buttons**

☐ 2. Synchronize incoming generator

a) Use **Sync Selector** to turn on the synchroscope for the incoming generator.
b) Make voltage and speed adjustments as necessary in order to match incoming and running voltages while at the same time producing a slow clockwise rotation of the synchroscope.
c) When ready, (think…, then) close the correct **circuit breaker** when the synchroscope is at 5° before 12 o'clock.
d) Turn off the synchroscope using the **sync selector**.

☐ 3. Adjust the load on the generator

a) Use the **speed control buttons** to raise the load to balance the Active Power Load (MW). Use **Display Function A** to see the active-power house diagram.
b) Use the **voltage control buttons** to balance the Reactive Power (MVAR) Use **Display Function B** to see the reactive-power house diagram.
c) Readjust speed and voltage to the nominal values without unbalancing the active and reactive loads.

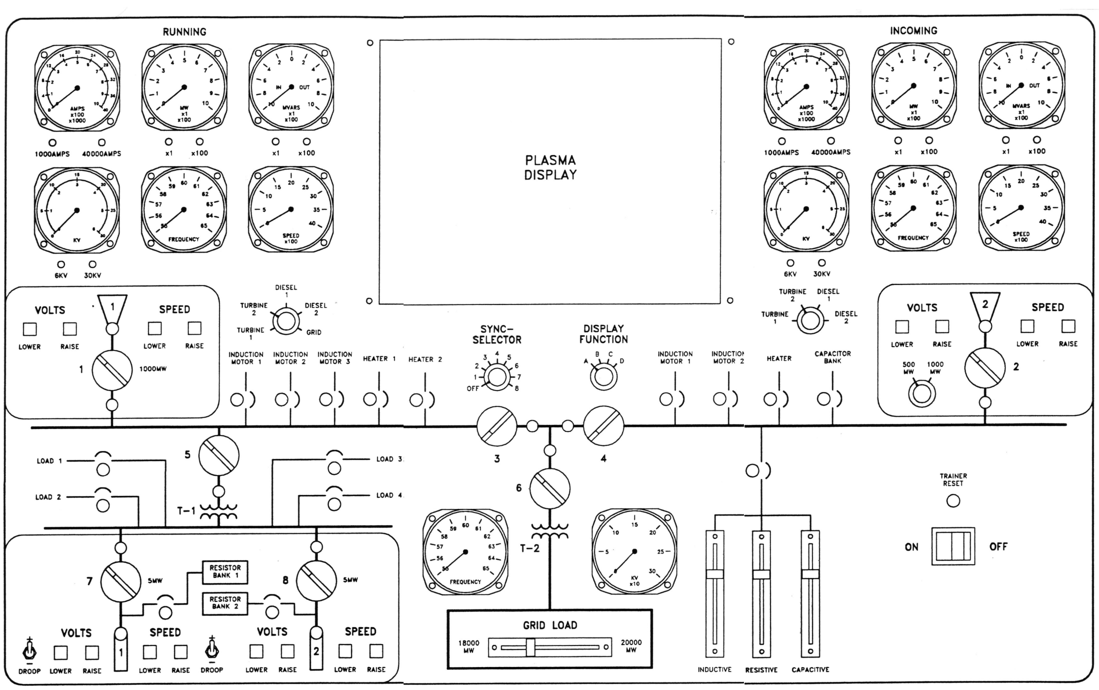


Figure 6.2: Paralleling Simulator

Conclusion

In this lab, you synchronized a three-phase synchronous generator with the ac power network using the lab volt equipment, and then again using the DAC paralleling simulator. You also observed the load sharing behavior of synchronized generators. You observed that varying the torque at the generator's shaft with the prime mover voltage in the case of the Lab Volt generator, or with the governor

	1000 MW TG	500 MW TG	5 MW DG
PF	0.85	0.85	0.8
MVA	1176	588	6.26
Voltage	22 KV	22 KV	4160 V ac
RPM Trips	1800	3600	900

Table 6.1: Generator Ratings

	1000 MW TG	500 MW TG	5 MW DG
Over speed	1980	3960	990
Over current	35 KA	17.5 KA	1000A
NL Volt Hi	24 KV	24 KV	4540 V
NL Volt Low	21 KV	21 KV	3970 V
NL RPM Hi	2000	4000	1000
NL RPM Low	1700	3400	850

Table 6.2: Generator Trip Limits

control on the paralleling simulator, varies the share of active load carried by each generator. You saw that varying the field current of the generator varies the amount of reactive power exchanged between the generator and the ac power network.

Review Questions

1. Before a synchronous generator is synchronized with the ac power network, its phase sequence, frequency, and voltage must be
   a) the same as those of the ac power network.
   b) different from those of the ac power network.
   c) any value depending on the generator and its prime mover.
   d) none of the above.
2. After synchronization with the ac power network, the phase sequence, frequency, and voltage of a synchronous generator will be
   a) the same as those of the ac power network.
   b) different from those of the ac power network.
   c) any value depending on the generator and its prime mover.
   d) none of the above.
3. What parameters of the synchronous generator must be matched before connecting it to an ac power network?
   a) Its phase sequence and frequency only.
   b) Its voltage and frequency only.
   c) Its phase sequence, frequency, and voltage.
   d) Its speed only.
4. When a synchronous generator "floats" on the ac power network, this means
   a) that it will speed up and slow down with network voltage fluctuations.
   b) that neither active nor reactive power is exchanged with the ac power network.
   c) that it is sitting above the water line.
   d) that the output voltage is almost identical to that of the ac power network.

5. Active power to overcome the rotation friction of a synchronous generator that is "floating" on the ac power network comes from
   a) the network.
   b) the ac power supply.
   c) the source of mechanical power coupled to the generator.
   d) the field current.

Lab 7

Residential Wiring

Objective

To enable students in the proper methods of wiring a typical residential circuit, including wire sizing, circuit breaker selection, wire termination, and wiring techniques.

For safety purposes, the wiring system is energized at approximately 15 volts AC, however the design and methods used will be those on a residential 120 volt single phase AC system.

The Lab Setup includes four nearly identical stations. Each station will be wired by a team of 2 students. Lockout and Tagout procedures shall be strictly adhered to.

Each station is fed from a main circuit breaker panel. The student is responsible for correctly locking and tagging out the circuit breaker that feeds his/her workstation. Each station shall then be wired so that the light fixture is operable from either of two three-way switches. Additionally, a receptacle shall be wired in parallel to the light fixture, however the receptacle shall not be switched, though it shall have a common circuit breaker with the light fixture.

Procedure

1. The station shall be Locked Out and Tagged Out.
2. Circuit Breaker. The circuit breaker shall be installed in the station subpanel. The breaker shall be a 15 amp single phase breaker. Care shall be taken with the breaker so that it is installed and removed correctly and without breaking it.
3. The light fixture shall be installed in the 4-inch octagonal box located next to the breaker panel.
4. The receptacle shall be installed directly below the light fixture.
5. The two three-way switches that will control only the light fixture shall be installed to the left and right of the receptacle in the "handy-box" provided.
6. On completion, the student will first (before energizing the circuit) check the continuity of the circuits with a multi-meter. The student shall ascertain that the receptacle is wired correctly, that the switches work, and that the light bulb is in working order.
7. On completion of the continuity test, the student shall request authorization from the instructor to remove the Lockout/Tagout device and energize the circuit.

8. After energizing the circuit, the student shall first test the voltage at the receptacle, then at the light fixture with the multi-meter. If appropriate, the light bulb can be installed, and the switches tested.
9. After successful completion, the student shall return the lab station to its original condition, return all tools, and report any defects or damages found in the system. Care shall be taken to insure that the multi-meters are left in the "off" position so that the batteries do not drain.

National Electric Code Requirements: The lab is to be wired in accordance with the National Electric Code (NEC) regulations as they apply to a residential circuit. The following questions should be considered while wiring the circuit.

Reference Materials

Operating, Testing, and Preventive Maintenance of Electrical Apparatus, by Charles I. Hubert, Prentice Hall 2003. See Chapter 8 for AC circuits in general. There are "Reference Tables in Chapters" listed on page xxvii, which should be useful. Appendices A.1, A.2, A.3 show Allowable Ampacities of Insulated Conductors. This information is from the National Electric Code with permission. Appendix A.4 contains the standard color code for tubular resistors per USAS and RETMA.

Check out the web such as: http://www.make-my-own-house.com/diagram-electrical-wiring.html for additional info on residential wiring.

The National Electric Code has both general and specific information regarding residential wiring. Remember that there are Federal, State, County and City or Town Electric Codes which must be complied with and all wiring installed in a home by anyone should be permitted, inspected and approved by local AUTHORITY HAVING JURISDICTION (AHJ). The National Electric Code(NEC) is the MINIMUM requirements for compliance. It is possible to have requirements which exceed the NEC.

Questions

1. Who is responsible for installing the Lockout/Tagout?
2. Who can remove the Lockout/Tagout?
3. If the circuit breaker is in the "Tripped" position, is it de-energized?
4. Is this circuit acceptable for commercial as well as residential applications?
5. Can this circuit be used in a a. Bedroom b. Bathroom c. Kitchen d. Living Room
6. What do the numbers on the circuit breaker mean?
7. What are the three positions of the circuit breaker switch?
8. What type of wire is being used?
9. What size wire is being used?
10. What parts of this circuit need to be grounded? Why is there a ground wire?
11. Why are the ground wires and neutral wires placed on different busses? They are on the same bus in my house.
12. The receptacle has three screws: silver, gold, and green. Which wire is attached to each?
13. The light fixture has two screws. Does it matter which wire goes to each screw? Why?
14. When wiring the switch, should I interrupt the hot (ungrounded) conductor of the neutral (grounded) conductor?
15. Does it matter what color wires I use?

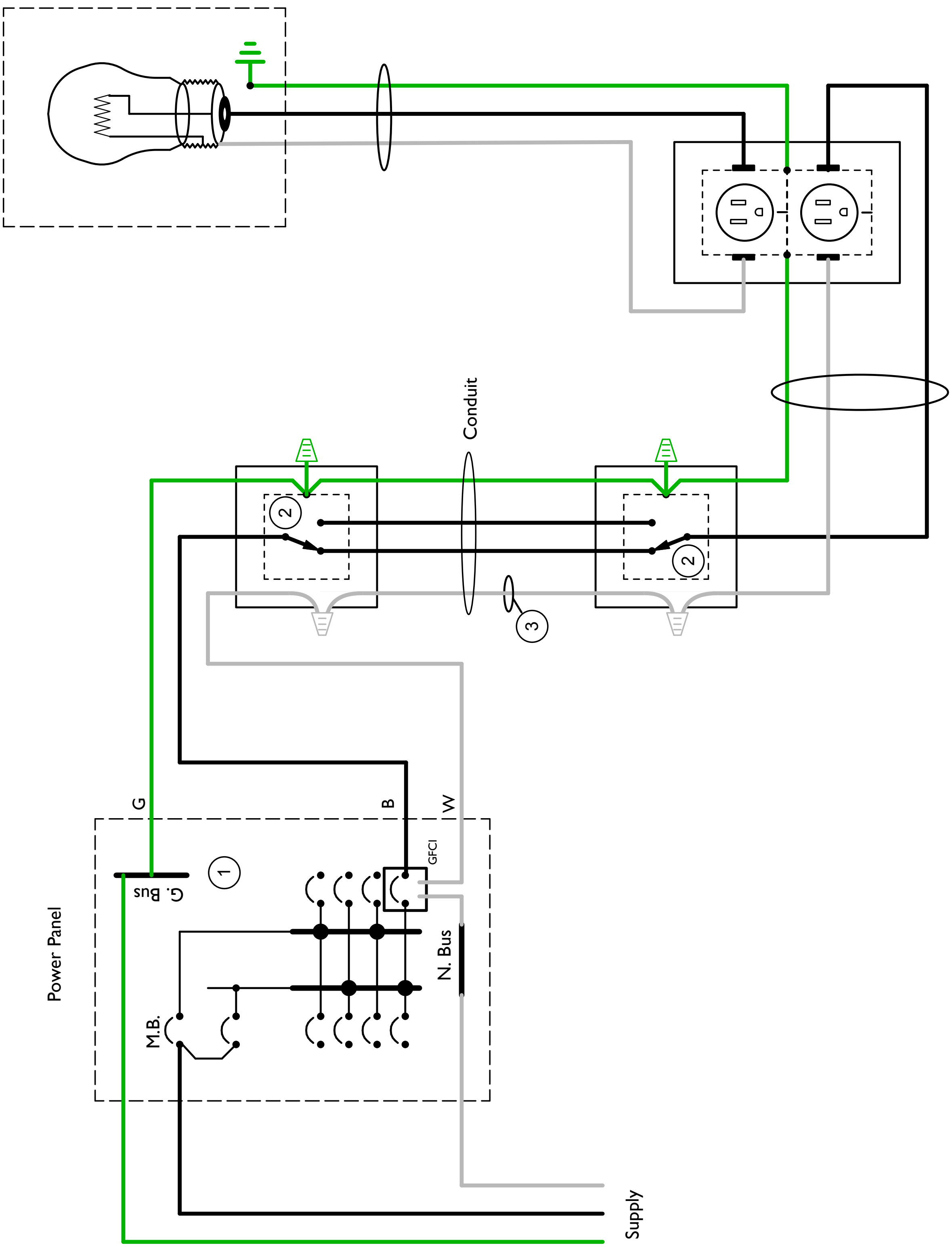


Figure 7.1: Three Way Switch Circuit

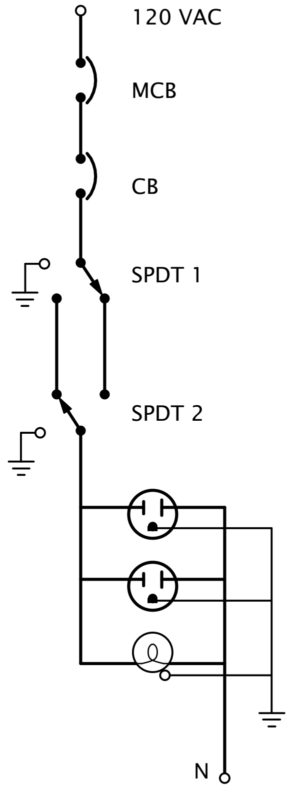


Figure 7.2: Ladder Diagram

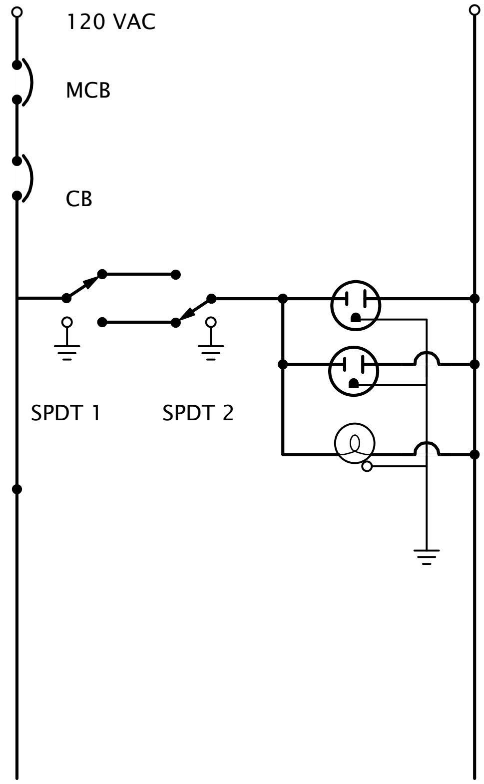


Figure 7.3: One Line Diagram

16. What is a ground clip?
17. Can I "backstab" the wires into the devices?
18. Is there enough room in the electric box for all these wires? How many can I really fir into there?
19. Why are the wire nuts different colors?
20. Does it matter which way I wind the wire around the screw?
21. Should I use stranded wire or solid wire? Does it matter?
22. Why does the conduit have a temperature rating?
23. Can I stuff as many wires as I want into the conduit?

Quiz

1. Who can remove a Lockout/Tagout?

2. When installing a switch in an AC circuit, which wire is attached to the switch?

3. What is the purpose of the ground wire?

4. What color are the three screws on a 120 volt single phase grounded receptacle, and what wire attaches to each screw?

5. Regarding a two wire Edison Base light fixture (as used in the lab), what wire goes to each screw?

6. What are the two ratings shown on a circuit breaker?

7. How do you determine if a circuit is de-energized?

8. How do you use a multi-meter to determine if a switch is operational?

Labs 8 – 11

Lab Volt Industrial Controls

In upstairs labs 8–11 you will be working with the Lab-Volt Industrial Controls Training System to learn about techniques of motor control and circuit wiring. You will complete the exercises in the Lab Volt manual found in Appendix A.

Lab 12

5kV High Voltage Switchgear

In this lab you will familiarize yourself with the following high voltage switchgear

- ITE Metal-Clad Switchgear Circuit Breaker – Model 5HK 250
- 1200A Vertical Section Air Frame Training Circuit Breaker

Objective

When you have completed this lab you will be able to:

- Exercise AC high voltage switchgear
- How to safely energize (close) and de-energize (open) the main circuit breaker by using the main switch handle
- Identify all of the parts in a breaker cubicle section
- Use proper PPE; Safely rack out the breaker
- Open the cubicle; Open the charged springs
- Remove the breaker form the cubicle cell; Install the breaker remote test lead to cycle the breaker while out of the cubicle cell
- Inspect the primary and secondary contacts, Inspect the arc chutes
- Manually pump the breaker springs
- Manually close the breaker
- Inspect the inside of the cubicle cell
- Check linkages
- Ensure the breaker terminations an d bolted connections are tight
- Know how to properly install and remove the circuit breaker from the cell

Safety

Safety Prior to any disassembly or inspection of the circuit breaker, the closing springs should be discharged and the breaker should be open.

Use of PPE When working on any high voltage equipment it is extremely important to ensure that the breaker is de-energized. There are several ways to ensure the breaker is safe to work on.

Remember All circuit breakers connect the line side (hot) to the load side by the movement of spring loaded moveable contacts. There is an enormous amount of energy that is transferred during the contact closing and contact opening process. Many personal injuries and equipment casualties have occurred while performing maintenance of circuit breakers. It is imperative to utilize all PPE and practice all recommended procedures when engaging in this work.

- Use all the required PPE for the task at hand: Insulated safety gloves, insulating matt, helmet and face shield, fire retardant suit and safety shoes.
- Make sure all of the electrical testing equipment is up to date and is rated for the respective load.
- Ensure all of the electrical testing equipment is in working condition. In this lab we will be using a tick tracer and a hot stick.
- Make sure the breaker you plan on working on is the correct breaker to be serviced.
- Try to reduce all load on the affected breaker. The more current flowing through the circuit when the breaker is opened, the bigger the arc.
- Make sure the breaker is in the open position. View the labeled flag on the breaker through the shutter before opening the cell access door.

Procedure

1. Review the circuit breaker information in the equipment manual.
2. **Cell Identification:** Look at the handout and identify all of the parts listed.
3. **Existing Conditions:** Now we will proceed with de-energizing the circuit breaker. You should find the circuit breaker in operation and online with the breaker selector switch in the "closed" position with the "red" indicating light on. Open the shutter on the bottom of the cell access panel and you should see the flag "closed" which denotes the breaker is online.
   Again, the engineer should try to reduce all load on the feeder circuit BEFORE he opens the breaker to de-energize the circuit.
   - Move breaker handle to the open position. You should hear the breaker cycle and the light change from red to green.
   - Open the shutter in the bottom of the cell and you should see the breaker flag also state the breaker is in the "open" position.
   - Once the breaker is de-energized, open the cell access doors. Use the breaker crank out handle and insert it into the rack-out connection. While your left hand is depressing and moving the lock lever to the left, simultaneously rotate the crank handle clockwise to initiate the worm gear thereby allowing the circuit breaker to begin the rack out process. Note the position of the breaker and the labels located on the right base frame of the breaker.
   - You will observe three positions for the breaker. Connected, Test, Disconnected. (Please read the OEM handout).

- Once fully retracted, the breaker can then be removed for observation and discussion.

4. **Discussion:** Class will now discuss components and operation.
5. **Remote Test Station:**
   - Insert remote test station jack. **MAKE SURE SPRINGS CHARGE SWITCH IS OFF**
   - Once jack is inserted, cycle breaker manually.
   - Insert manual hand pump lever to recharge springs and crank until ratchet slips free.
   - Cycle breaker by hand and observe primary and secondary contacts.
   - Remove jack from remote test station
6. **Reinstall Circuit Breaker Into Cell:**
   - Simply perform the same rack-in procedure as was done during the rack-out procedure.
   - Test the breaker for proper operation.

Appendices

Appendix A

Lab Volt Manual

Industrial Controls Training System

Basic Controls

Student Manual

39163-00

Lab-Volt®

INDUSTRIAL CONTROLS TRAINING SYSTEM

BASIC CONTROLS

by
the Staff
of
Lab-Volt Ltd.

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Foreword

Control systems for electric motors are vital to the proper performance and protection of modern equipment. They are essentially the link in every complex industrial process. These systems may range from the simple starting and stopping of an electric motor to directing energy flow in a completely automated factory. Between these extremes, we find semiautomatic controllers in which a human operator must fill some of the required functions.

The Industrial Controls Training System, Model 8036, and the related modules and manuals, provide a thorough understanding of the theory and operation of electric motor controllers. Many genuine industrial components are included in the system to familiarize the student with the way they actually operate and special emphasis is put on safety.

Training starts with the basic fundamentals, and proceeds step by step, through various types of controls encountered in industry. The student manual explains what kinds of controls are available, how they operate, where they are used, and why they are used in a particular application.

The multiplicity of modules makes it possible to implement setups that fit a large number of needs. Control equipment and components are panel mounted with hidden fault insertion switches in each module to develop the troubleshooting skills of the students.

This program is fully compatible with existing modular components from Lab-Volt.

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Bibliography
We Value Your Opinion!

Introduction

The exercises in this manual, *Basic Controls*, provide a foundation for further study in the industrial control branch of knowledge. Additional material is supplied in the following volumes of this series.

The present manual is divided into six units:

- *Unit 1* provides basic safety procedures and presents most modules that will be used in this manual;
- *Unit 2* gives an overview of the data that can be found on industrial control devices. This Unit also introduces graphical tools used to represent industrial control circuits;
- *Unit 3* presents basic motor starter and control circuits;
- *Unit 4* is dedicated to jogging and braking features of a control circuit;
- *Unit 5* shows methods of starting a motor smoothly;
- *Unit 6* introduces time relays.

Each unit contains exercises which provide a systematic and realistic means of learning the subject matter. Every exercise is divided into the following sections:

- A clearly defined *Exercise Objective*;
- A *Discussion* of the theory involved in the exercise;
- A *Procedure Summary* which provides a bridge between the theoretical *Discussion* and the laboratory *Procedure*;
- A step-by-step laboratory *Procedure* in which the student observes and quantifies important principles covered in the *Discussion*;
- A *Conclusion* to summarize the material presented in the exercise;
- *Review Questions* to verify that the material has been well assimilated.

A ten-question test at the end of each unit allows the student's knowledge of the unit material to be assessed.

Safety Considerations

Make sure that you are wearing appropriate protective equipment before performing any of the exercises in this manual. Remember that you should never perform an exercise if you have any reason to think that a manipulation could be dangerous to you or your teammates.

Component Specifications

A CD-ROM containing detailed specifications of the components is supplied in the back cover of this manual.

Unit 1

BASIC PRINCIPLES OF MOTOR CONTROL

UNIT OBJECTIVE

Upon completion of this unit, you will be able to identify and demonstrate the utility of different types of motor control and current protection devices. You will also be able to understand the operation of a lockout/tagout procedure.

DISCUSSION OF FUNDAMENTALS

Motor control is a broad term that can apply to anything from a simple toggle switch to a complex system with components such as **relays**, **contactors**, and **programmable logic controllers** (PLCs). The common function of all these controls is to command the operation of an electric motor.

A complete motor circuit is usually divided into control and power sections. The power circuit includes the motor and therefore, operates under higher voltage. On the other hand, the control part mostly contains switching devices and typically operates under lower voltage.

Control description

Control panel devices, such as push buttons, selectors, or toggle switches, command the operation of electric motors via their open or closed contacts, which relay a control current.

Contactors and **control relays** are devices that use **electromagnetic induction** to open and close contacts. Contactors are often part of the motor starter, being power switching devices. Control relays are rather used as control switching devices, because they are designed to withstand lower electrical currents.

Motor starters are systems comprising switching and overload-protection components. They provide a safe, convenient, and economical means of starting and stopping motors.

Circuit-breakers and fuses protect the motor from very high currents. Overload protection devices are safeguards against prolonged, relatively high current levels. The particular application of each motor and control installation must be considered when determining the protective devices required.

Safety procedures

Lockout/tagout procedures are measures taken to ensure the safety of workers during servicing and/or maintenance operations. When implemented correctly, all **energy sources** are isolated, thus limiting greatly the probability of accidents.

Three-phase distribution systems

Most domestic electrical systems are **single phase**, which means that there is only one live line per power outlet, along with a neutral and a ground wire.

Three-phase is another common electric power transmission method used for motors and many other industrial devices. Three-phase systems may have a neutral wire or not.

Figure 1-1 shows the evolution of the three phases in time. With the help of this graph, it is possible to find the relationship between line–neutral and line–line potentials.

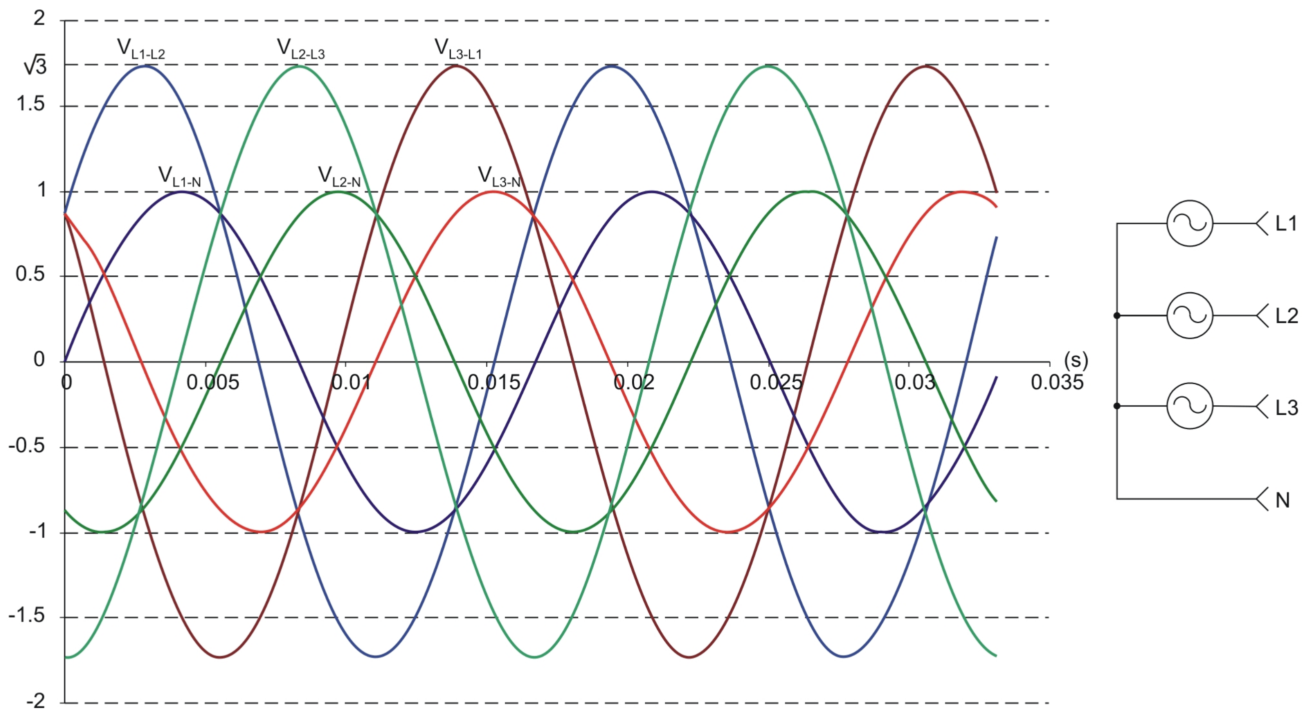


Figure 1-1. Three-phase distribution system.

Say, for instance, that we want to know the voltage between line 1 and line 2. We can subtract, for each time value, the L2–N value from the L1–N value to determine the desired line–line voltage (V_{L1-N} - V_{L2-N} = V_{L1-L2}). We observe that the amplitude of the obtained signal V_{L1-L2} is √3 times that of the V_{L1-N}, V_{L2-N}, or V_{L3-N} signals. The same principle applies to V_{L2-L3} and V_{L3-L1} signals.

As an example, in North America, we find line–neutral voltages of 120 V and line–line voltages of 208 V (√3 × 120 V). That is to say that a single phase load supports a higher voltage when located between two power lines than between a power and a neutral line.

Note also, from Figure 1-1, that there is a 120-degree phase shift between each phase sine wave. This is a very important feature, since electric motors using all three phases can easily produce a rotating magnetic field, hence greatly simplifying the machine design. Moreover, inverting two of the three phases has the effect of reversing the same rotating field, thus making the motor turn in the opposite direction.

LOCKOUT/TAGOUT PROCEDURE

EXERCISE OBJECTIVE

- Become familiar with the Industrial Controls Training System.
- Understand and perform proper lockout/tagout procedures during industrial servicing and/or maintenance operations.

DISCUSSION

Lockout/tagout procedures are measures taken to ensure that a machine or equipment, on which the personnel is working, is safe and cannot be powered unless every employee is done.

Many pieces of machinery are potentially hazardous because of their purpose, the way they are built, or their location. Take, for example, a debarking machine (see Figure 1-2). It is equipped with several moving, sharp, and heavy parts. Servicing this type of equipment requires a number of safety precautions, because its accidental activation may easily be disastrous.

Figure 1-2. Debarking machine. (Image courtesy of USNR)

LOCKOUT/TAGOUT PROCEDURE

Prior to any operation on a machine or equipment, tasks that may expose workers to inadvertent release of hazardous energy must have been identified and proper training provided to the personnel. Sources of hazardous energy may be electrical, but also mechanical, hydraulic, pneumatic, chemical, thermal, gravitational, or others.

To make a machine or equipment safe:

- Notify all the **affected employees** that a procedure is going to be performed on a machine or equipment.
- De-energize the machine or equipment.
- Isolate and block all forms of hazardous energy, using locks and/or tags. In general, lockout devices should be preferred to tags. If more than one person is assigned to a task, all workers must use a personal and identifiable lock and/or tag at each **energy-isolating device**. A group lockout/tagout is also possible, providing that all workers are properly protected. The last hole of a hasp is usually reserved to accommodate an additional hasp.
- Verify that no one is near the machine or equipment and test if it is possible to start the equipment.

  Note: *Special additional procedures may be required in cases where dangerous products like chemicals are involved.*

When energizing a machine:

- Check that the machine or equipment is ready to operate, that the area is clear and secure, and that guards are positioned correctly.
- Notify all affected employees that the machine or equipment is about to be energized, and check that no worker is in reach of the machine or equipment.
- Each worker must remove his own locks and tags. The machine or equipment must not be energized as long as a lock has not been removed by its owner.
- Start the equipment and make sure that it is working properly.

It should be remembered that each situation may require a particular procedure to ensure the safety of all workers. Therefore, please refer to the equipment manufacturer's documentation and to your local safety regulations for additional information.

A lockout/tagout procedure specific to the Industrial Controls Training System, Model 8036, is provided in Appendix D of this manual.

Procedure Summary

In the first part of this exercise, you will link the Lockout Module to the AC Power Supply module and verify that the output voltages are as stated in Unit 1 theory.

You will carry out a lockout/tagout procedure before connecting a first electrical circuit. To help you out with the setup, both a **schematic diagram** and an interconnection diagram will be provided.

In the circuit, a control transformer is connected through fuses between lines 1 and 2 of the Lockout Module module. This transformer provides control voltage that enables powering a pilot light without damage. An emergency button is located between the transformer and the pilot light, to allow the light to be turned off. Fuses inside the Fuse Holder module are deliberately blown, to make you practice fuse replacement.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

PROCEDURE

WARNING!

The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

Basic setup

☐ 1. Perform the Basic Setup procedure described in Appendix D.

Line–neutral voltage

☐ 2. Connect the voltmeter between terminals L1 and N of the Lockout Module to measure the line–neutral voltage.

Turn on the AC Power Supply by setting the individual power switch to the I position.

Note: *Make sure that the main switch is set to the up position.*

Turn on the Lockout Module.

Record the voltage displayed by the voltmeter.

E_{L1-N} = ______

Line–line voltage

☐ 3. Turn off the Lockout Module.

Connect the voltmeter between terminals L2 and L3 of the Lockout Module to measure the line–line voltage.

Turn on the Lockout Module.

Record the voltage displayed by the voltmeter.

E_{L2-L3} = ______

☐ 4. Do the voltage results confirm the theory presented in the Discussion of Fundamentals? Explain why.

____

____

Lockout/Tagout procedure

☐ 5. Perform the Lockout/Tagout procedure described in Appendix D.

Fuse replacement

☐ 6. Connect the circuit shown in Figure 1-3.

> **Note:** *When using the Fuse Holder, indicate the rating of the fuses on the module faceplate. Note the rating on three blank magnetic labels and install them above the fuse terminals. The rating of the fuses supplied with the training system is as follows (1.5 A for 220 and 240 V versions, and 3 A for 120 V version):*

1.5 or 3 A 600 V ac	CLASS CC	TIME DELAY

> *To facilitate the understanding of the circuit shown in the picture, the ground connections are shown with green leads, and the other connections are shown with yellow leads. When setting up your circuit, use leads with appropriate length to connect the components, whatever the color. In the schematic diagrams, however, the red color indicates a low voltage connection.*

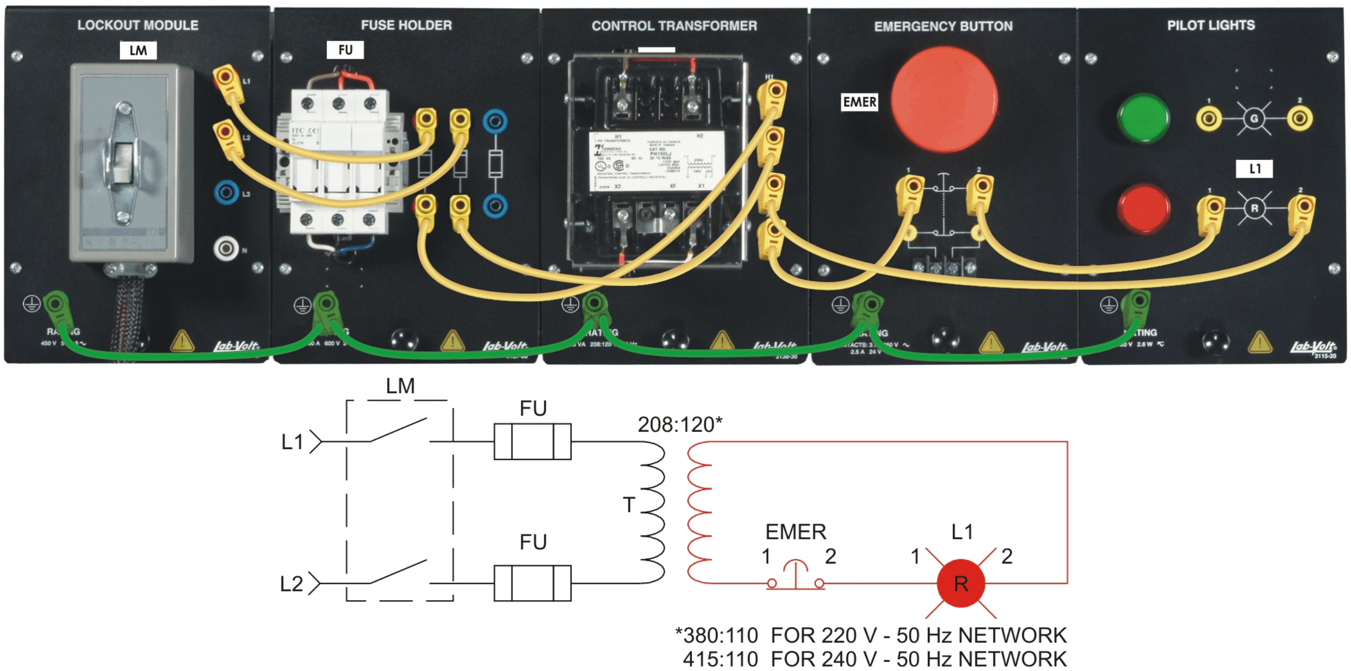
☐ 7. Make sure that the push button of the Emergency Button module is released.

> **Note:** *In case of doubt, press the Emergency Button and turn it in the counterclockwise direction to reset the button in the release position.*

Perform the Energizing procedure described in Appendix D.

After the Lockout Module is turned on, does the L1 pilot light turn on?

☐ Yes ☐ No



LEGEND

EMER = EMERGENCY PUSH BUTTON (MAINTAINED CONTACT)
FU = FUSE
L1 = PILOT LIGHT (RED)
LM = LOCKOUT MODULE
T = CONTROL VOLTAGE TRANSFORMER

Figure 1-3. Basic circuit with the Lockout Module.

☐ 8. Turn off the Lockout Module.

Remove the fuses from the Fuse Holder module and check them with an ohmmeter. Are the fuses blown?

☐ Yes ☐ No

☐ 9. Install new fuses (not blown) in the Fuse Holder module.

Turn on the Lockout Module. Does the L1 pilot light turn on?

☐ Yes ☐ No

☐ 10. Describe what happens when you press the Emergency Button, and then reset it.

____

____

____

☐ 11. Turn the individual power switch of the AC Power Supply off, disconnect the circuit, remove the magnetic labels, and return the equipment to the storage location.

CONCLUSION

Lockout/Tagout procedures are meant to provide maximum security to every worker performing servicing or maintenance on a piece of equipment. These procedures imply isolating all sources of energy with personal locks and tags.

CONTROL PANEL DEVICES

EXERCISE OBJECTIVE

- Verify the operation of selected motor control devices.

DISCUSSION

A motor **controller** is a device or group of devices that commands the operation of an electric motor, using **normally open** (NO) and **normally closed** (NC) contacts. NO contacts are closed only when actuated. NC contacts work in the opposite way, opening when the contact is actuated.

A motor controller has one or more of the following capabilities. It may cause the motor to:

- Start or stop;
- Rotate forward or reverse;
- Have its speed or **torque** limited or regulated;
- Be protected against overloads and faults.

There are many factors to consider when selecting and installing motor control devices for use with particular machines or systems. For example, to start or stop a motor, here are some considerations that may influence the choice of a motor controller:

- Characteristics of the motor;
- Number of starts and stops in a cycle;
- Light or heavy loads when starting or stopping;
- Fast or slow stopping;
- Need for accurate stopping;
- Manual or automatic starting and stopping;
- Installation and operating costs.

Once the conditions are met, the motor may be controlled safely and efficiently.

Push buttons

Push buttons are switches that provide control of a motor by pressing a push button. Push buttons usually have a NO and a NC set of contacts which change state momentarily as the push button is pressed.

Figure 1-4 shows the Push Buttons module, Model 3110-2. The green push button is usually used along with its NO contact as a start push button. The red push button is usually used along with its NC contact as a stop push button. For security reasons, stop push buttons are more easily accessible than start push buttons.

CONTROL PANEL DEVICES

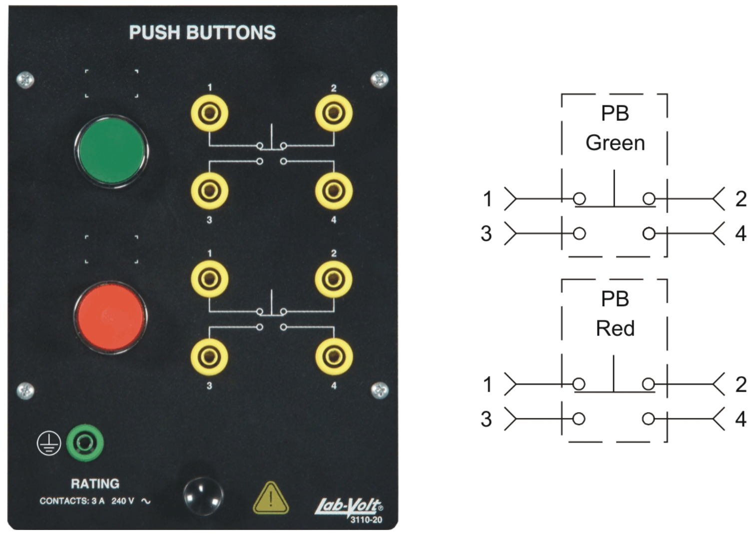


Figure 1-4. Push Buttons, Model 3110

Selector and toggle switches

The Selector Switches module, Model 3111-2, allows one to alternate between two control circuit branches through the selector (at the top) or the toggle (at the bottom) switches. The two switches work independently. Selecting a position activates or deactivates the maintained contacts. Figure 1-5 shows the Selector Switches module and its diagrams.

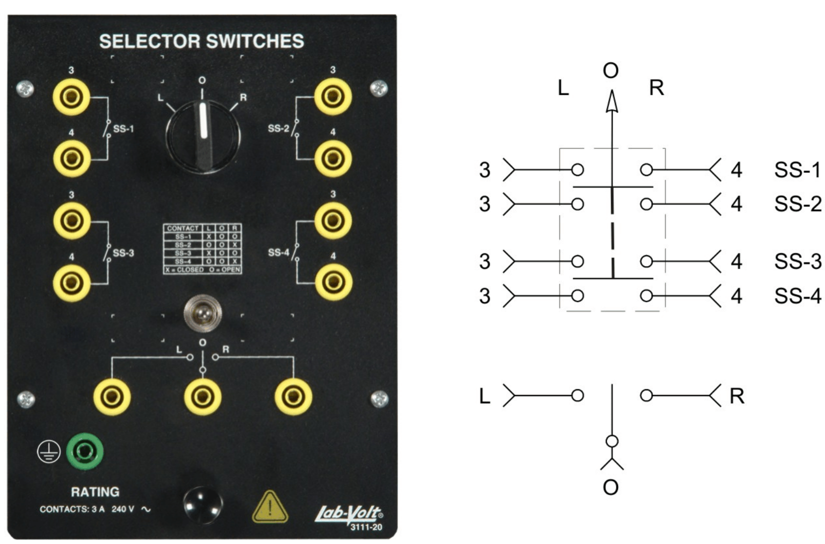


Figure 1-5. Selector Switches, Model 3111.

Pilot lights

Pilot lights, which are usually red or green, are used to indicate if the line is energized, or the motor is running. Figure 1-6 shows the Pilot Lights module, Model 3115-2.

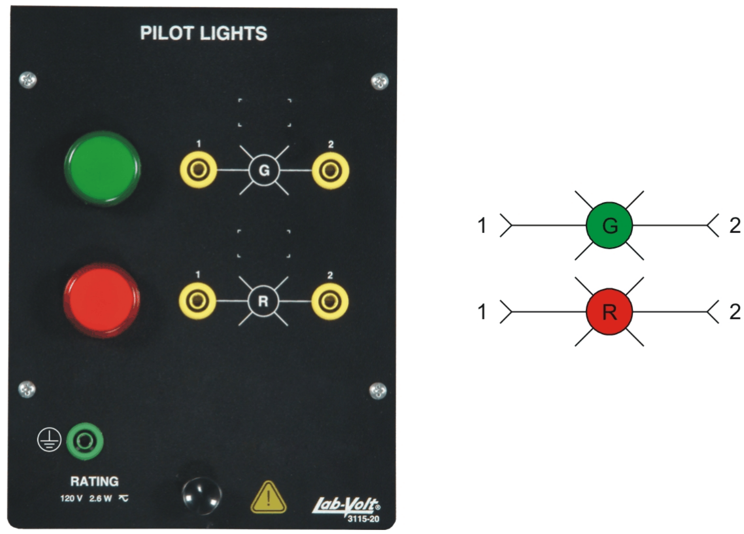


Figure 1-6. Pilot Lights, Model 3115.

Procedure Summary

In the first part of this exercise, you will use one NO and one NC push button contact to power two pilot lights. This procedure will demonstrate that push button contacts are momentary. Once again, it is necessary to use the Control Transformer in order to obtain a voltage compatible with the Pilot Lights module.

In the second part of the exercise, you will use a similar circuit, in which a toggle switch is employed instead of the push buttons. You will observe that the toggle switch differs from the push buttons in the way that it has a maintained contact.

In the third part of the exercise, you will verify, with the help of an ohmmeter, that the behavior of the selector switch corresponds to the indications provided on its module faceplate.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

PROCEDURE

WARNING!

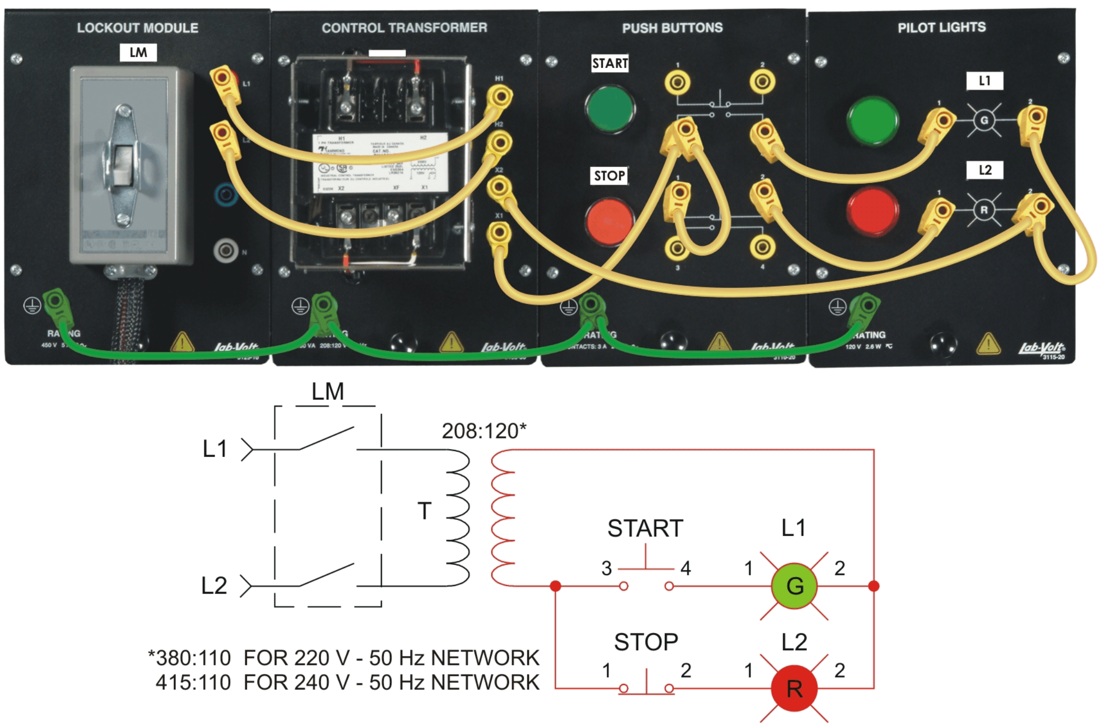
The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

Basic setup

☐ 1. Perform the Basic Setup and Lockout/Tagout procedures.

Momentary contacts

☐ 2. Connect the circuit shown in Figure 1-7.



LEGEND

L1	=	PILOT LIGHT (GREEN)
L2	=	PILOT LIGHT (RED)
LM	=	LOCKOUT MODULE
START	=	START PUSH BUTTON (MOMENTARY CONTACT)
STOP	=	STOP PUSH BUTTON (MOMENTARY CONTACT)
T	=	CONTROL VOLTAGE TRANSFORMER

Figure 1-7. Basic push button circuit.

☐ 3. Perform the Energizing procedure.

☐ 4. After the Lockout Module is turned on, which pilot light(s) illuminate(s) when:

- No push button is pressed?

  ☐ L1 pilot light ☐ L2 pilot light ☐ Both ☐ None

- Only the START push button is pressed?

  ☐ L1 pilot light ☐ L2 pilot light ☐ Both ☐ None

- Only the STOP push button is pressed?

  ☐ L1 pilot light ☐ L2 pilot light ☐ Both ☐ None

- Both push buttons are pressed?

  ☐ L1 pilot light ☐ L2 pilot light ☐ Both ☐ None

☐ 5. Following your last observations, what type of contacts are connected to:

- Push button terminals 1-2?

  ☐ Normally open ☐ Normally closed

- Push button terminals 3-4?

  ☐ Normally open ☐ Normally closed

☐ 6. Does the state of a pilot light associated to a push button change when the button is released?

  ☐ Yes ☐ No

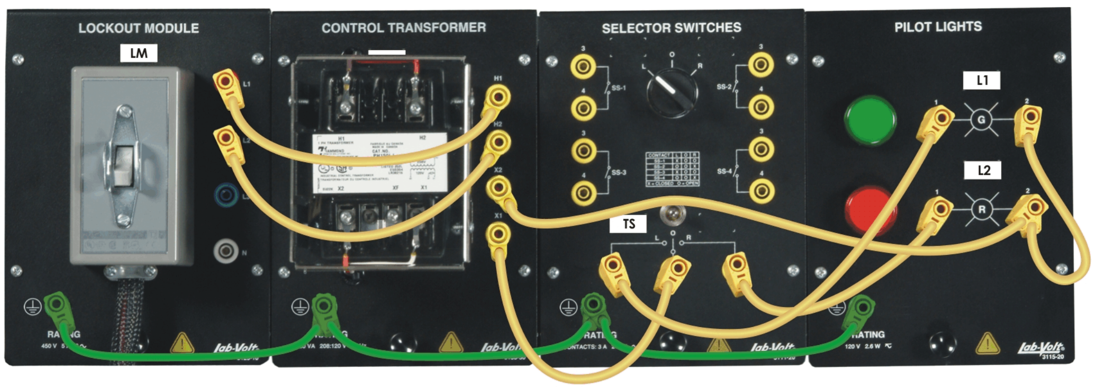
☐ 7. How can we characterize the Push Buttons module contacts?

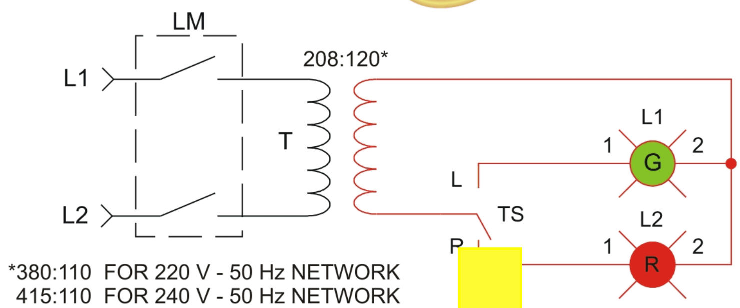
  ☐ Maintained ☐ Momentary

Maintained contacts

☐ 8. Perform the Lockout/Tagout procedure.

Connect the circuit shown in Figure 1-8.





Toggle Switch "TS" feeds from center only to either "L" or "R".

"L" & "R" NEVER connect together.

LEGEND

L1	=	PILOT LIGHT (GREEN)
L2	=	PILOT LIGHT (RED)
LM	=	LOCKOUT MODULE
TS	=	TOGGLE SWITCH (MAINTAINED CONTACT)
T	=	CONTROL VOLTAGE TRANSFORMER

Figure 1-8. Basic toggle switch circuit.

☐ 9. Set the TS toggle switch of the Selector Switches module to the O position.

☐ 10. Perform the Energizing procedure.

After the Lockout Module is turned on, does a pilot light illuminate? Explain why.

____

____

☐ 11. Set the TS toggle switch to the L position.

Which light illuminates?

☐ L1 pilot light ☐ L2 pilot light ☐ Both ☐ None

☐ 12. Set the TS toggle switch to the R position.

Which light illuminates?

☐ L1 pilot light ☐ L2 pilot light ☐ Both ☐ None

☐ 13. Does the toggle switch contact return to its original state after you release it?

☐ Yes ☐ No

☐ 14. How can we characterize the toggle switch contacts?

☐ Maintained ☐ Momentary

☐ 15. Turn off the Lockout Module.

☐ 16. Using an ohmmeter, check what contacts of the Selector Switches module are closed when the selector is at a certain position. Fill out the Table 1-1, marking an "X" when a contact is closed.

Note: *You will learn later in this manual that this type of table, showing the different contact states of a device, is called a target table.*

CONTACT	POSITION		
	L	O	R
SS-1			
SS-2			
SS-3			
SS-4			

Table 1-1. Target table of the Selector Switches module.

☐ 17. Does your table correspond to the one located on the module faceplate?

☐ Yes ☐ No

☐ 18. Turn the individual power switch of the AC Power Supply off, disconnect the circuit, remove the magnetic labels, and return the equipment to the storage location.

CONCLUSION

Motor controllers command the operation of electric motors through normally open (NO) and normally closed (NC) contacts.

Push button, toggle and selector switches are common manual controllers. The state of their contacts change as a push button is pressed, or the position of a toggle or knob is modified.

Pilot lights are used to show the condition of a circuit.

MANUAL STARTERS

EXERCISE OBJECTIVE

- Examine and describe the operation of manual motor starters.

DISCUSSION

Motor starters are made out of power switches and overload protection devices. They can be operated manually or remotely, through a magnetic contactor commanded by a control circuit. Full or reduced voltage can be applied to the motor, depending on the application.

Three-pole starters are used with motors operating on three-phase systems. The number of poles in these starters refers to the number of power contacts and does not include control contacts for control circuit wiring.

Two basic configurations of manual motor starters will be presented in this exercise, namely the **direct-on-line** (DOL), also called **across-the-line** or **full-voltage starter**, and the reversing starter. Magnetic motor starters will be seen in Unit 3, and reduced voltage motor starting methods, in Unit 5 of this manual.

Direct-on-line (DOL) starters

"Direct-on-Line" starters are also known as "Across the Line" starters and utilize full line voltage.

DOL starters are the simplest way of starting a motor. A manual contactor is combined with an overload protection device. Figure 1-9 shows the Manual Starter, Model 3126, which can be used as a motor starter in both single-phase and three-phase operation. This particular module has a manual contactor, an adjustable overload protection, plus a circuit-breaker. This is a DOL-type starter because full voltage is applied directly to the motor.

Reversing starters

Reversing starters are designed to make motors change direction by interchanging two lines to the motor. **Cam switches** can be used for that purpose, with the addition of overload protection.

A cam (or **drum**) switch allows one to change between 2 or 3 operating modes, using a control knob to switch power lines directly. Figure 1-10 shows the Cam Switch module, Model 3140.

MANUAL STARTERS

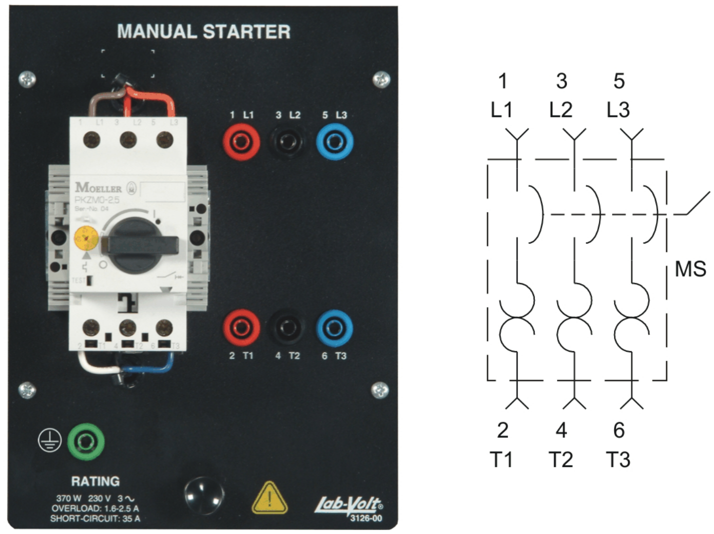
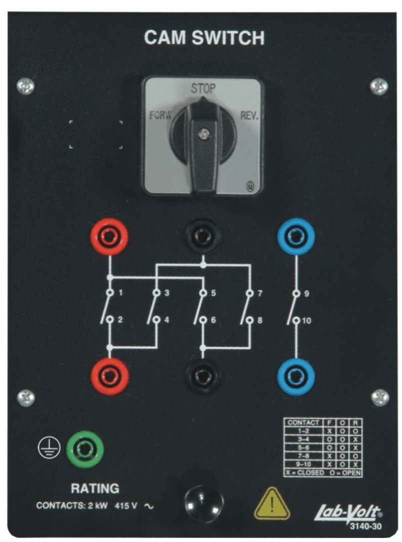
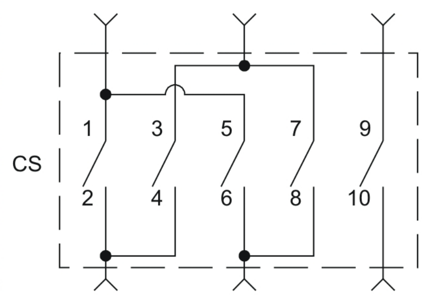


Figure 1-9. Manual Starter, Model 3126.





	POSITION		
CONTACT	F	O	R
1-2	X		
3-4			X
5-6			X
7-8	X		
9-10	X		X
X = CLOSED CONTACT			

Figure 1-10. Cam Switch, Model 3140.

Procedure Summary

In the first part of this exercise, you will examine the Manual Starter and determine that it has both the power contacts and the overload protection necessary to be called a motor starter. You will then test the Manual Starter with push buttons and pilot lights, to see that power lines are not reversed by the device, making it a DOL starter.

In the second part of the exercise, you will inspect the Cam Switch to find out that it does not include an **overload relay**, and hence, cannot be considered as motor starter. After that, you will connect the Cam Switch to push buttons and pilot lights to see that two power lines are inverted between the forward and the reverse modes. You will observe that the Cam Switch can thus be part of a reversing starter.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

PROCEDURE

WARNING!

The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

Basic setup

☐ 1. Perform the Basic Setup and Lockout/Tagout procedures.

Direct-on-line (DOL) starter

☐ 2. Examine the Manual Starter module.

What is the range of the Manual Starter overload (indicated on the module faceplate)?

Overload range: ______

☐ 3. What is the purpose of the black knob on the Manual Starter?

____

____

☐ 4. What is the purpose of the yellow potentiometer on the Manual Starter?

____

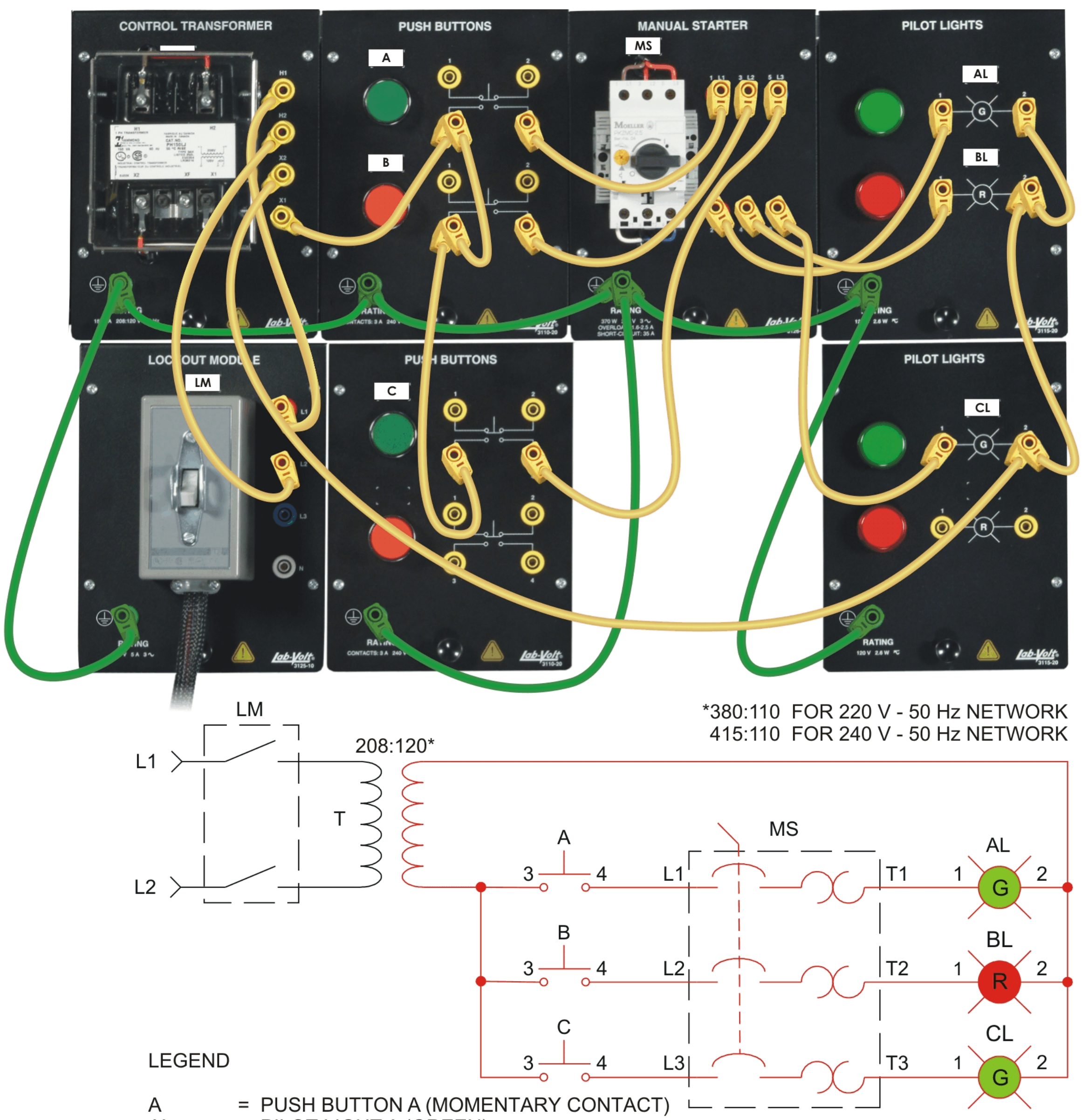
____

☐ 5. Is it appropriate to call this device a motor starter? Explain why.

____

____

☐ 6. Connect the circuit shown in Figure 1-11.



LEGEND

A = PUSH BUTTON A (MOMENTARY CONTACT)
AL = PILOT LIGHT A (GREEN)
B = PUSH BUTTON B (MOMENTARY CONTACT)
BL = PILOT LIGHT B (RED)
C = PUSH BUTTON C (MOMENTARY CONTACT)
CL = PILOT LIGHT C (GREEN)
LM = LOCKOUT MODULE
MS = MANUAL STARTER (CIRCUIT BREAKER WITH OVERLOAD)
T = CONTROL VOLTAGE TRANSFORMER

Figure 1-11. Basic manual starter circuit.

☐ 7. Set the knob of the Manual Starter to the O position.

Perform the Energizing procedure.

☐ 8. Set the knob of the Manual Starter to the I position.

☐ 9. Find out which lights illuminate when you press the push buttons. Fill out Table 1-2 for all three push buttons.

PUSH BUTTON PRESSED	PILOT LIGHT ILLUMINATED		
	AL	BL	CL
A			
B			
C			

Table 1-2. Target table of a DOL starter.

☐ 10. What type of starter is it?

☐ DOL starter ☐ Reversing starter

☐ 11. Perform the Lockout/Tagout procedure.

Cam switch reversing circuit

☐ 12. Examine the Cam Switch module. Does this module permit on and off switching?

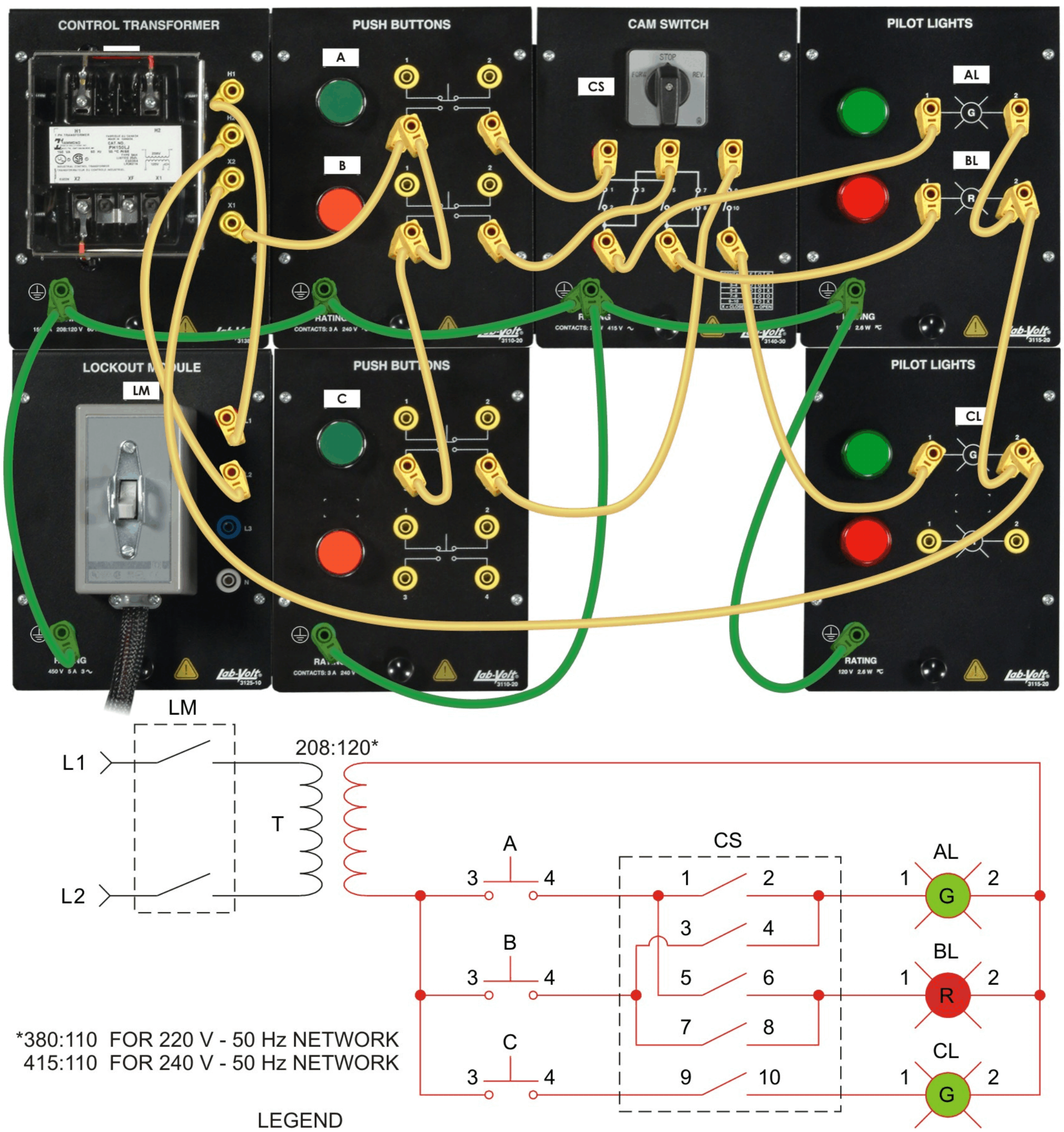
☐ Yes ☐ No

☐ 13. What are the operating modes of this module?

____

☐ 14. Does the Cam Switch incorporate an overload relay?

☐ Yes ☐ No



LEGEND

A	=	PUSH BUTTON A (MOMENTARY CONTACT)
AL	=	PILOT LIGHT A (GREEN)
B	=	PUSH BUTTON B (MOMENTARY CONTACT)
BL	=	PILOT LIGHT B (RED)
C	=	PUSH BUTTON C (MOMENTARY CONTACT)
CL	=	PILOT LIGHT C (GREEN)
CS	=	REVERSING 3-POLE CAM SWITCH
LM	=	LOCKOUT MODULE
T	=	CONTROL VOLTAGE TRANSFORMER

Figure 1-12. Cam Switch reversing circuit.

☐ 15. Is it appropriate to call this device a motor starter? Explain why.

____

____

☐ 16. Connect the circuit shown in Figure 1-12.

☐ 17. Perform the Energizing procedure.

☐ 18. Find out which pilot lights illuminate when you press the push buttons. Fill out Table 1-3 for all three push buttons in FWD, STOP, and REV modes.

PUSH BUTTON ACTUATED	CAM SWITCH POSITION	PILOT LIGHT ILLUMINATED		
		AL	BL	CL
A	FWD			
	STOP			
	REV			
B	FWD			
	STOP			
	REV			
C	FWD			
	STOP			
	REV			

Table 1-3. Target table of the Cam Switch.

☐ 19. Compared to the FWD mode, which lines have been switched in the REV mode?

☐ 1 and 2 ☐ 1 and 3 ☐ 2 and 3 ☐ None

☐ 20. What type of starter can be constructed with the Cam Switch and an appropriate overload relay?

☐ DOL starter ☐ Reversing starter

☐ 21. Turn the individual power switch of the AC Power Supply off, disconnect the circuit, remove the magnetic labels, and return the equipment to the storage location.

CONCLUSION

Contactors and overload protection devices are the essential elements of motor starters.

DOL starters are the simplest method of starting a motor. They provide on/off control for small motors. The Manual Starter module is an example of a DOL starter.

Reversing starters reverse the direction of the motor by inverting two motor power lines. The Cam Switch module, with the addition of an overload relay, can be used for that purpose.

CONTACTORS AND CONTROL RELAYS

EXERCISE OBJECTIVE

- Identify the characteristics of control relays and contactors.

DISCUSSION

Contactors and control relays are switching devices providing electrical isolation between the control signals and the commanded electrical circuits. Different combinations of normally open and normally closed contacts are used to open and close circuits.

Solenoids, such as the one shown in Figure 1-13, are extensively used to operate contactors and control relays. Placing a coil of wire around a soft iron **core** sets up a magnetic flux. When energized, a **magnetic field** is developed around the coil. A north and a south pole are created and the iron core becomes a temporary magnet. As a result, a moveable plunger is attracted to the coil, and contacts attached to the plunger change state.

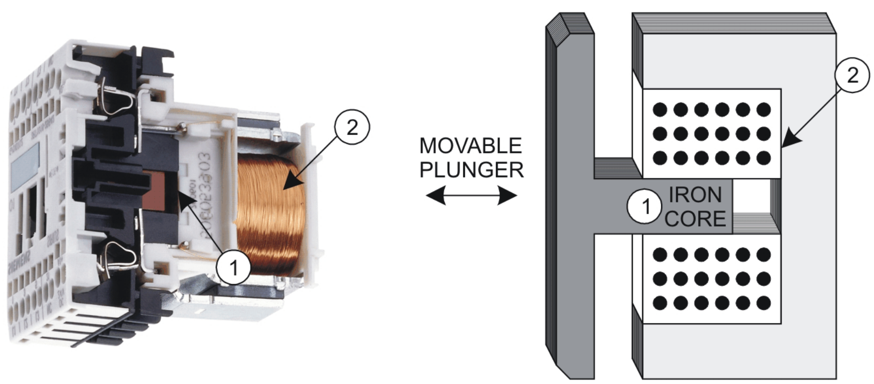


Figure 1-13. Basic magnetic core and coil.

When the coil is de-energized, the force of gravity or spring tension releases the plunger from the magnet body, causing the electrical contacts to return to their original state.

The same principle applies to single- and three-pole circuits. Figure 1-14 shows the motion of a single-pole magnetic contactor.

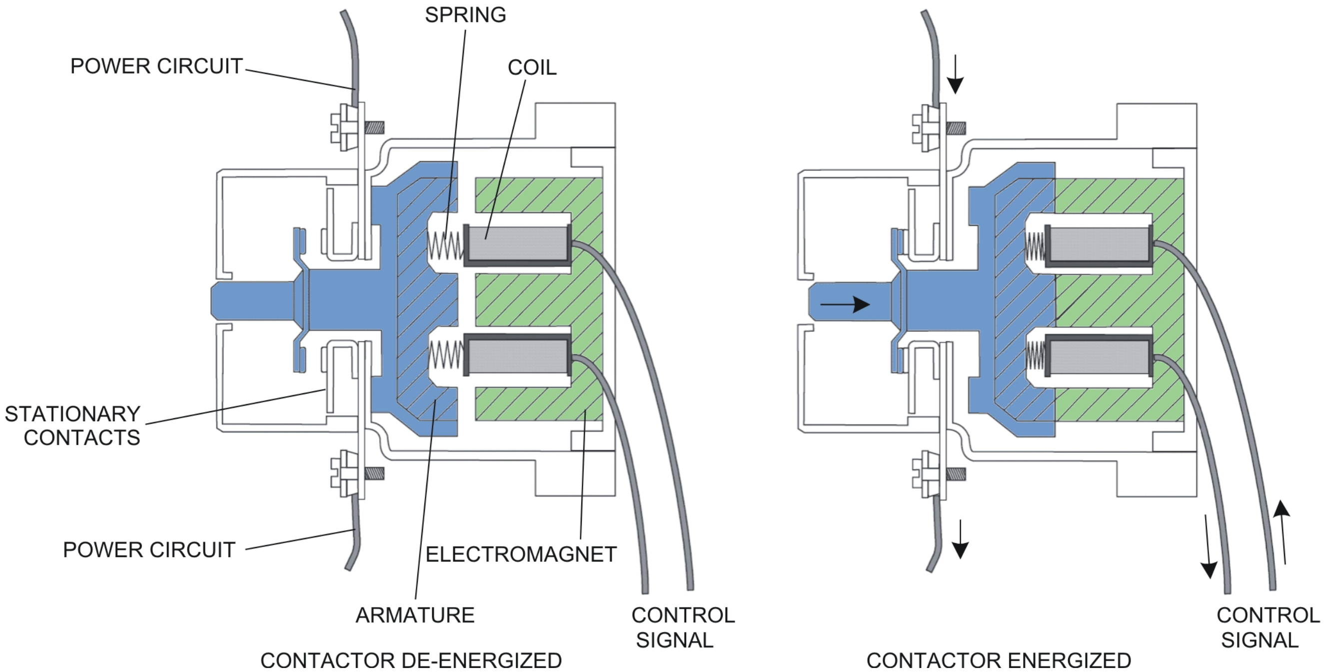


Figure 1-14. Single-pole solenoid-operated magnetic switch.

Contactors

Contactors are heavy-duty and use a small control current or manual switching to command power-consuming loads like motors, lighting and heating. Contactors are similar to motor starters, except that they do not provide overload protection. Figure 1-15 shows the Contactor module, Model 3127. A1–A2 are the coil terminals. L1, L2, L3, T1, T2, T3 are the input and output power terminals. 13–14 is an auxiliary NO contact, used to provide feedback about the contactor state.

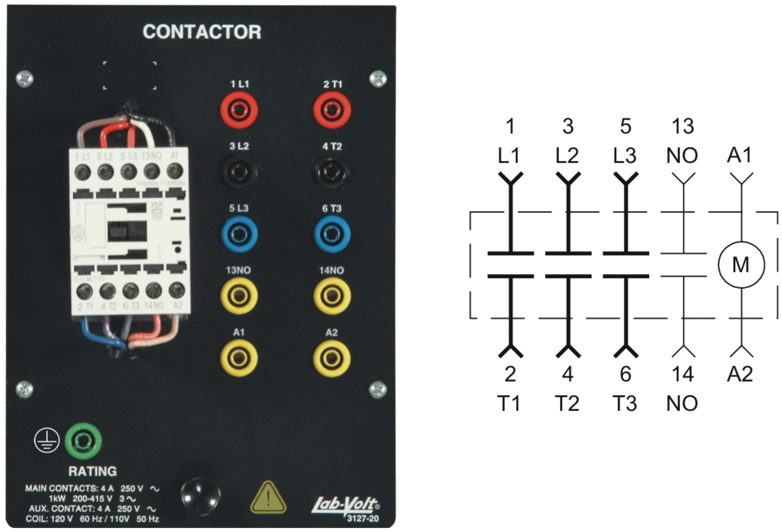


Figure 1-15. Contactor, Model 3127.

To reverse the direction of a motor, an arrangement of two contactors can be made, with each contactor dedicated to either forward or reverse direction. These contactors may then serve the same purpose as the Cam Switch module, except they are operated by way of external circuits.

Figure 1-16 shows the Dual Contactors module, Model 3119, made of two contactors similar to the one of Model 3127. Auxiliary blocks are added on top of the contactors to provide more feedback about the state of the contactors. The Dual Contactors module can be used to reverse the direction of rotation of a three-phase motor. A mechanical interlock is located between the two contactors. It is a safety mechanism, preventing the motor from being powered by the two contactors at the same time, therefore causing a short-circuit. When one of the two contactors is energized, the contacts of the other contactor are mechanically maintained, even if the second coil is energized.

Student must understand that when Coil "M" is energized, ALL Normally Open (NO) contacts will close and all Normally Closed (NC) Contacts will open.

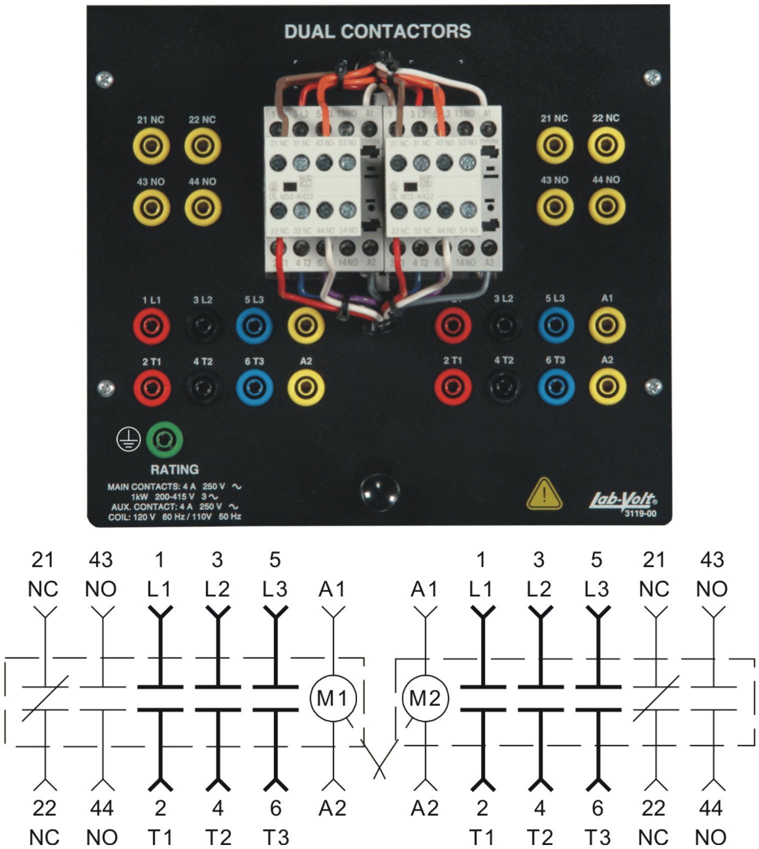


Figure 1-16. Dual Contactors, Model 3119.

Control relays

Control relays are designed to control circuits and small loads like pilot lights, audible alarms, and some small motors. Figure 1-17 shows the Control Relay module, Model 3130. A1–A2 are the coil terminals, 13–14 and 43–44 are NO contacts, while 21–22 and 31–32 are NC contacts.

> **Note:** *Contact terminals ending with 1 or 2 are NC, while terminals ending with 3 or 4 are NO.*

Student must understand that
when Coil "M" is energized,
ALL Normally Open (NO)
contacts will close and all
Normally Closed (NC)
Contacts will open.

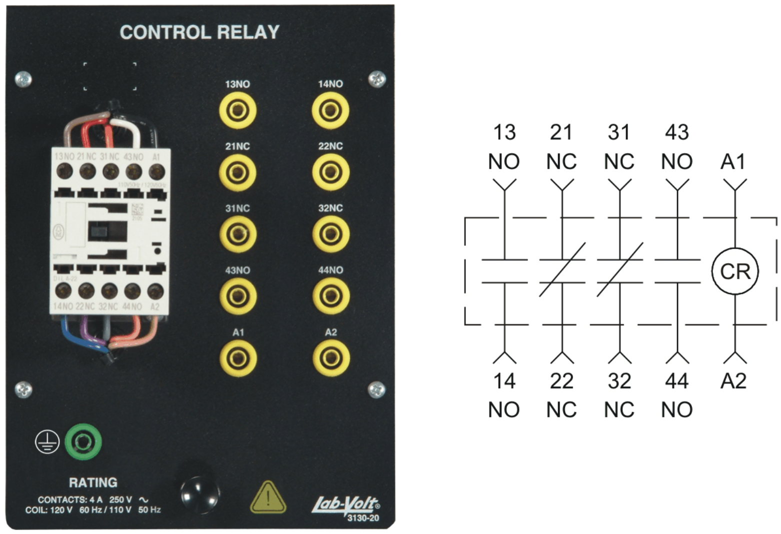


Figure 1-17. Control Relay, Model 3130.

Procedure Summary

In the first part of this exercise, you will inspect the Contactor and the Control Relay to identify their terminals and the voltage required to energize their coils.

In the second part of the exercise, you will connect a circuit involving a toggle switch and the Dual Contactors. This will help you fill out a target table that will show which power lines have been inverted between the two contactors.

In the last part of the exercise, you will set up a simpler dual contactor circuit to observe how the mechanical interlock operates.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

PROCEDURE

WARNING!

The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

Basic setup

☐ 1. Perform the Basic Setup and Lockout/Tagout procedures.

Contactor and Control Relay operation

☐ 2. Examine the Contactor module, Model 3127. Choose from the following list the purpose of each of the different terminals:

Coil – NC Contact – Mechanical Interlock – NO Contact – First Power Contact – Second Power Contact – Third Power Contact

1L1 – 2T1: ___________

3L2 – 4T2: ___________

5L3 – 6T3: ___________

13NO – 14NO: ___________

A1 – A2: ___________

☐ 3. Is the auxiliary contact designed for power or control purposes?

☐ Power ☐ Control

☐ 4. What type of voltage is used to energize the coil?

_____ V ☐ DC ☐ single phase ☐ three-phase

Note: *The black moveable plunger is located on the top of the contactor. You may press it with your finger to get a feel for its motion.*

☐ 5. Examine the Control Relay module. Choose from the following list the purpose of each of the different terminals:

Coil – NC Contact – Mechanical Interlock – NO Contact – First Power Contact – Second Power Contact – Third Power Contact

13NO – 14NO: ___________

21NC – 22NC: ___________

31NC – 32NC: ___________

43NO – 44NO: ___________

A1 – A2: ___________

☐ 6. Does the Control Relay have power contacts?

☐ Yes ☐ No

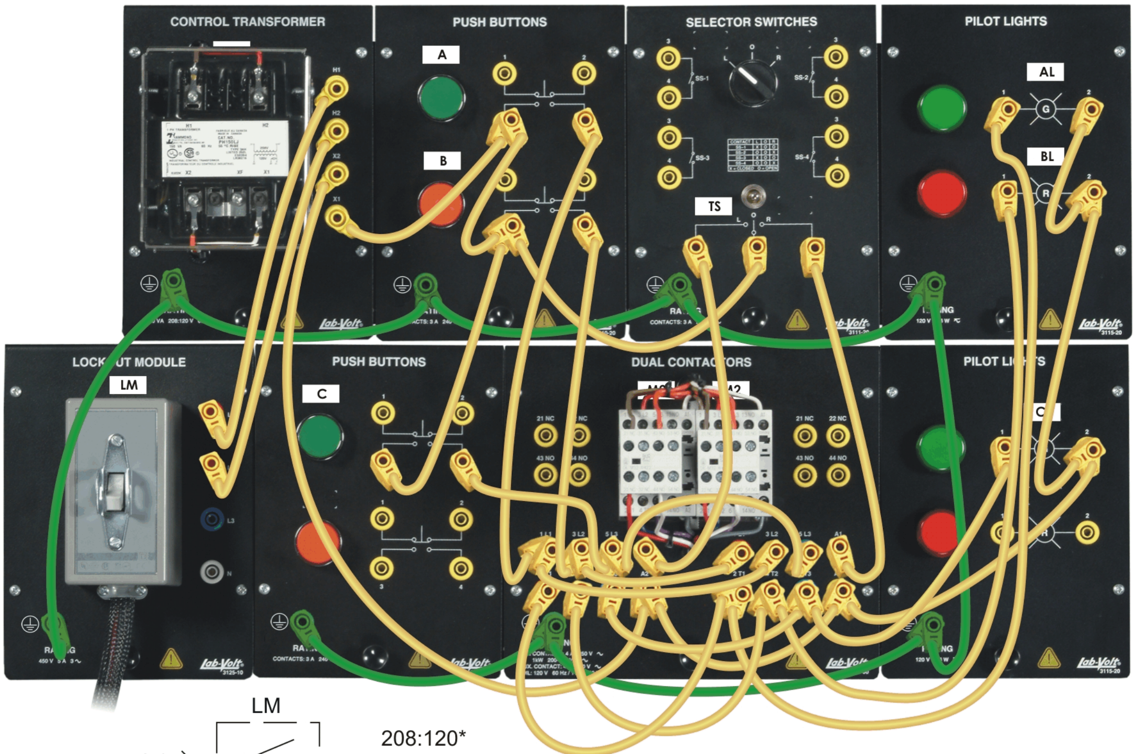
☐ 7. What type of voltage is used to energize the coil?

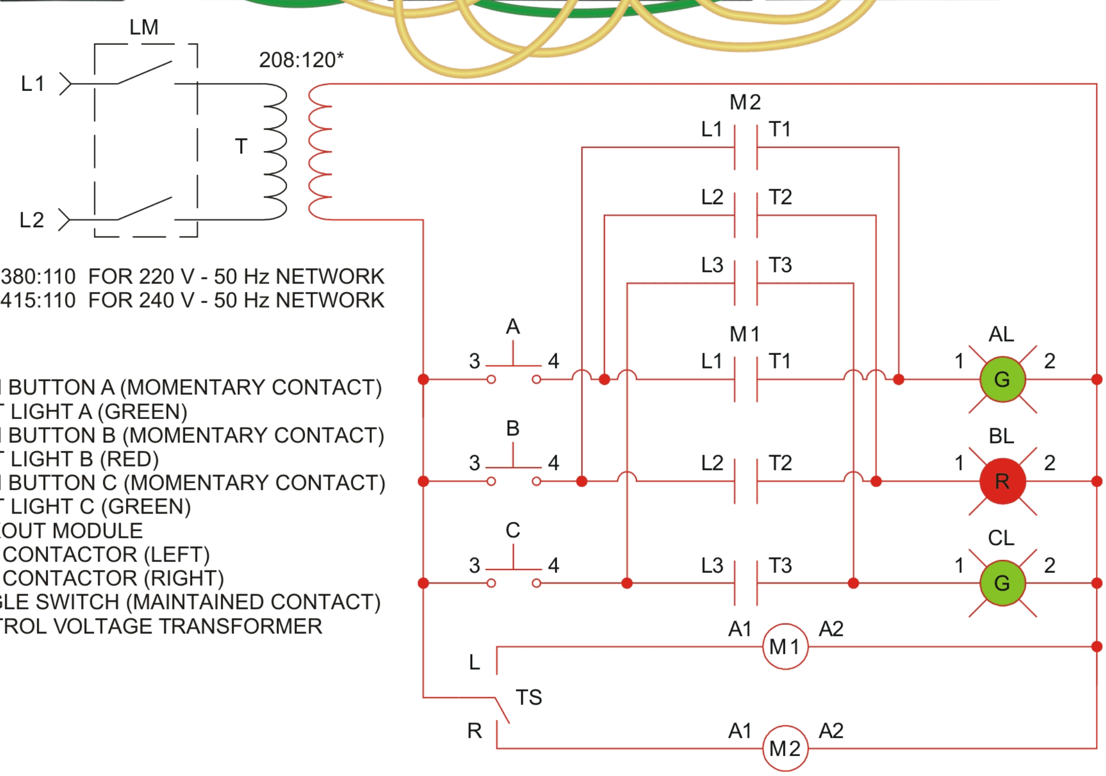
______ V ☐ DC ☐ single phase ☐ three-phase

Note: *The black moveable plunger is located on the top of the control relay. You may press it with your finger to get a feel for its motion.*

Dual Contactors operation

☐ 8. Connect the circuit shown in Figure 1-18.





*380:110 FOR 220 V - 50 Hz NETWORK
415:110 FOR 240 V - 50 Hz NETWORK

LEGEND

A	=	PUSH BUTTON A (MOMENTARY CONTACT)
AL	=	PILOT LIGHT A (GREEN)
B	=	PUSH BUTTON B (MOMENTARY CONTACT)
BL	=	PILOT LIGHT B (RED)
C	=	PUSH BUTTON C (MOMENTARY CONTACT)
CL	=	PILOT LIGHT C (GREEN)
LM	=	LOCKOUT MODULE
M1	=	MAIN CONTACTOR (LEFT)
M2	=	MAIN CONTACTOR (RIGHT)
TS	=	TOGGLE SWITCH (MAINTAINED CONTACT)
T	=	CONTROL VOLTAGE TRANSFORMER

Figure 1-18. Dual contactors reversing circuit.

☐ 9. Set the TS toggle switch of the Selector Switches module to the O position.

☐ 10. Perform the Energizing procedure.

☐ 11. Set the TS toggle switch to the L and R positions to energize the coils M1 and M2 respectively.

Press all push buttons alternately, and fill out Table 1-4.

COIL ENERGIZED	PUSH BUTTON ACTUATED	PILOT LIGHT ILLUMINATED		
		AL	BL	CL
M1	A			
	B			
	C			
M2	A			
	B			
	C			

Table 1-4. Target table of the dual contactors reversing circuit.

☐ 12. According to Table 1-4, which lines have been interchanged?

☐ 1 and 2 ☐ 1 and 3 ☐ 2 and 3 ☐ None

☐ 13. Perform the Lockout/Tagout procedure.

Mechanical interlock

☐ 14. Connect the circuit shown in Figure 1-19.

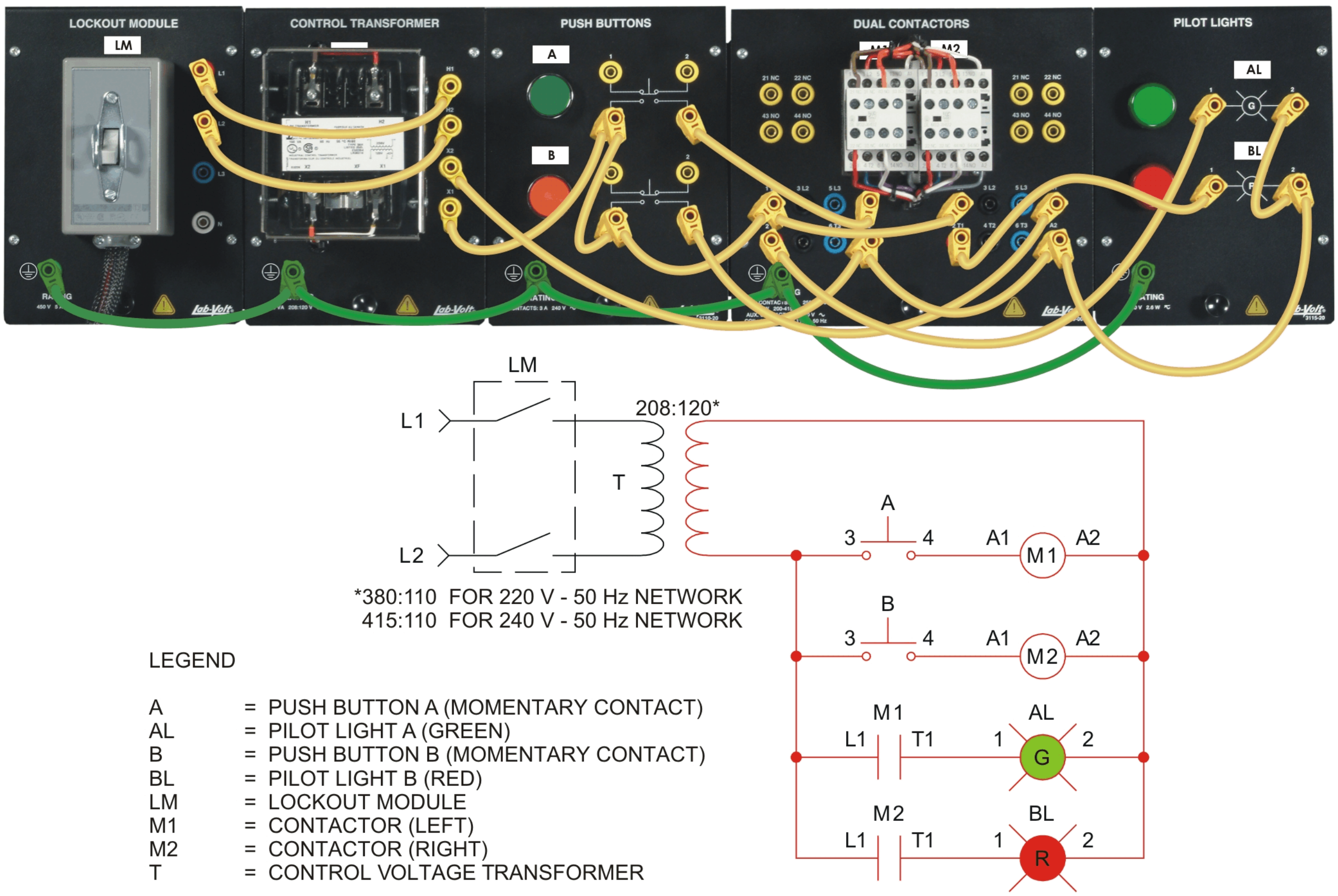


Figure 1-19. Mechanical interlock testing circuit.

☐ 15. Perform the Energizing procedure.

☐ 16. Which pilot light illuminates when you press the A push button?

☐ AL pilot light ☐ BL pilot light

☐ 17. Which pilot light illuminates when you press the B push button?

☐ AL pilot light ☐ BL pilot light

☐ 18. What do you observe and hear when you hold down the A push button and you press the B push button momentarily?

____

____

☐ 19. What do you observe and hear when you hold down the B push button and you press the A push button momentarily?

____

____

☐ 20. What mechanism between the contactors prevents both pilot lights from being powered simultaneously?

____

☐ 21. Turn the individual power switch of the AC Power Supply off, disconnect the circuit, remove the magnetic labels, and return the equipment to the storage location.

CONCLUSION

Solenoids are magnetic devices used to open and close contacts of contactors and control relays.

Contactors are switching devices designed for power circuits, while control relays are built for control circuits and small loads.

Dual contactors with a mechanical interlock enable reversing the rotation direction of a motor, without risking powering both coils at the same time.

CURRENT PROTECTION DEVICES

EXERCISE OBJECTIVE

- Describe and test the operation of circuit-breakers, fuses, and overload relays.

DISCUSSION

Motors can be damaged by excessive currents going through their windings. Protection devices must be added to motor circuits to prevent the machines from burning up.

Circuit-breakers or fuses are necessary to avoid high current levels rushing into the motor windings. Under such conditions, these protection devices open the circuit immediately.

Low levels of excessive current may also cause damage to the motor over a certain period of time. Overload protection devices will open the circuit when the current drawn by the motor is relatively high after a time delay.

When sizing the protection devices, it is important to note that all electric motors suffer from a condition called **inrush current**. When starting the motor, there is a brief spike of current that can be several times the steady-state current. Protection devices must be carefully chosen so that they do not unnecessarily disrupt the system under those normal conditions.

Circuit breakers

Circuit breakers are switches that open the circuit automatically over a predetermined current level. Circuit-breakers can be reset to resume normal operation. Figure 1-20 shows three-phase circuit-breakers.

CURRENT PROTECTION DEVICES

Figure 1-20. Three-phase circuit-breakers.

When electrical contacts open to interrupt a large current, there is a tendency for an arc to form between the contacts, which would allow the flow of current to continue. The maximum short-circuit current that a breaker can interrupt safely is called the **interrupting capacity**.

Fuses

A fuse protects the circuit from an overcurrent condition. Its metal alloy melts when heated by a prescribed electric current, hence opening the circuit. Fuses are classified by types which depend on the application. A fuse also has a rated interrupting capacity, which is the maximum current the fuse can safely interrupt. Figure 1-21 shows the Fuse Holder module, Model 3137.

Compared to circuit-breakers, fuses have the advantage of being cheaper for similar ratings. However, blown fuses must be replaced with new devices, which is less convenient than simply resetting a breaker. In addition, when a single fuse blows in a three-phase system, the two other phases may still be operational, which is possibly hazardous. In comparison, a three-phase circuit-breaker interrupts all phases simultaneously.

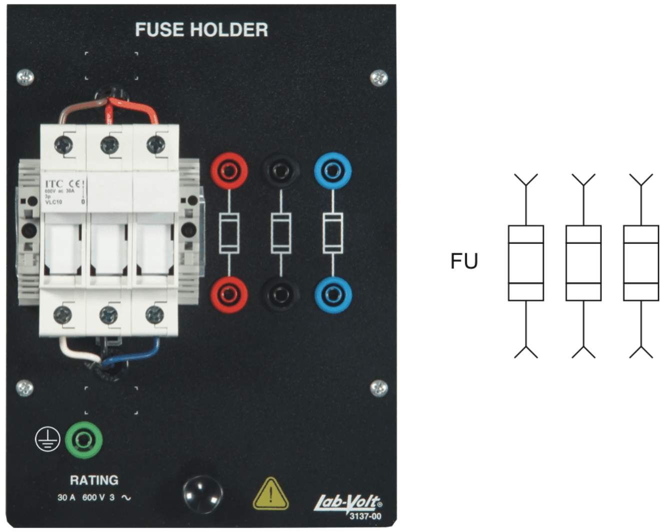


Figure 1-21. Fuse Holder, Model 3137.

Overload protection

Electric motor overload protection is necessary to prevent burnout and ensure maximum operating life of the motor. Motor overloads may be caused by:

- An undersized motor;
- Increased load on the driven machine;
- Low input voltage;
- Numerous start/stop cycles;
- An open phase in a polyphase system.

When an overload occurs, the motor draws excessive current, causing overheating. Since the insulation of a motor breaks down under excessive heat, limits have been established for motor operating temperatures. Overload relays are used to limit the amount of current drawn to a predetermined value. These relays have current sensitive thermal or magnetic elements that de-energize the starter and stop the motor when excessive current is drawn. Local electrical codes determine the size and class of the overload relay.

The class number indicates how long the overload relay takes to trip when carrying a current equal to 6 times its current rating (or the value set when the overload is adjustable):

- Class 10 overload relay will trip in 10 seconds or less at a current equal to 6 times its rating.
- Class 20 overload relay will trip in 20 seconds or less at a current equal to 6 times its rating.
- Class 30 overload relay will trip in 30 seconds or less at a current equal to 6 times its rating.

Class 10 overload relays are usually used with motors that heat faster, such as hermetic motors, or submersible pumps. Class 30 overload relays are mostly used with motors driving high inertia loads, that take more time to accelerate.

Figure 1-22 shows tripping time as a function of the ratio between the circuit actual current and the overload relay setting for different overload relay classes.

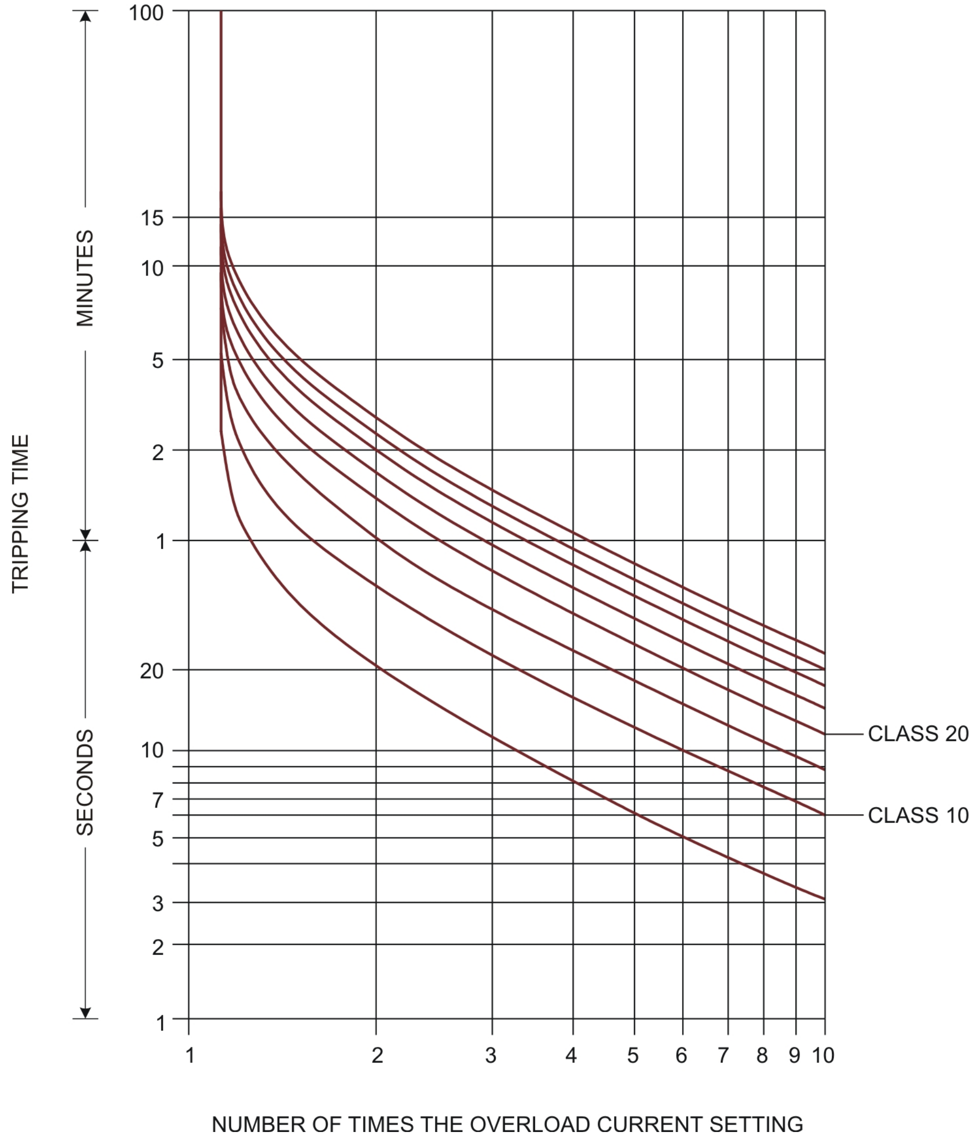


Figure 1-22. Overload classes tripping chart.

Figure 1-23 shows the Overload Relay module, Model 3131. This thermal overload device has adjustable tripping current. Figure 1-24 explains how this thermal overload relay operates. When the current level rises, the bimetal strips heat up and bend to **trigger** the auxiliary contacts. This action is more or less rapid, depending on the ambient temperature.

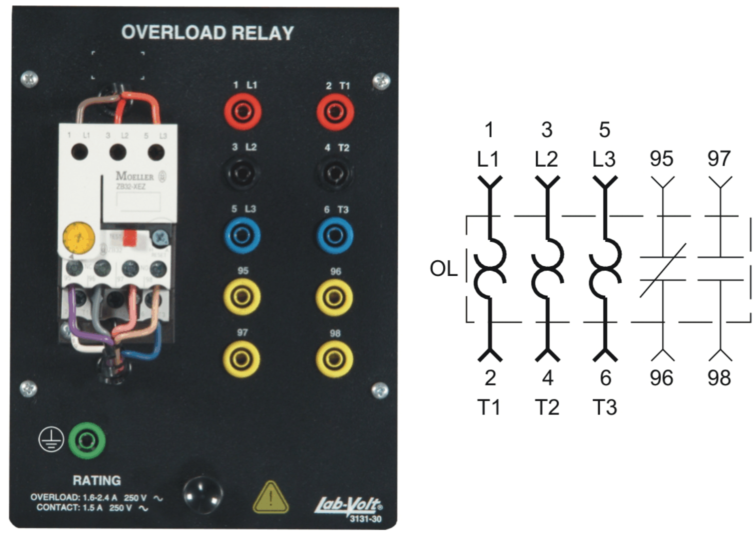


Figure 1-23. Overload Relay, Model 3131.

The auxiliary contacts (95–96 and 97–98) subsequently switch off the load by means of a contactor. The *tripped* status is signaled by means of a switch position indicator. The contactor is either reset manually (position H) or automatically (position A).

> **Note:** *The test button on the Overload Relay module is for contacts testing. Pressing the test button opens the NC contact, and pulling the same test button closes the NO contact.*

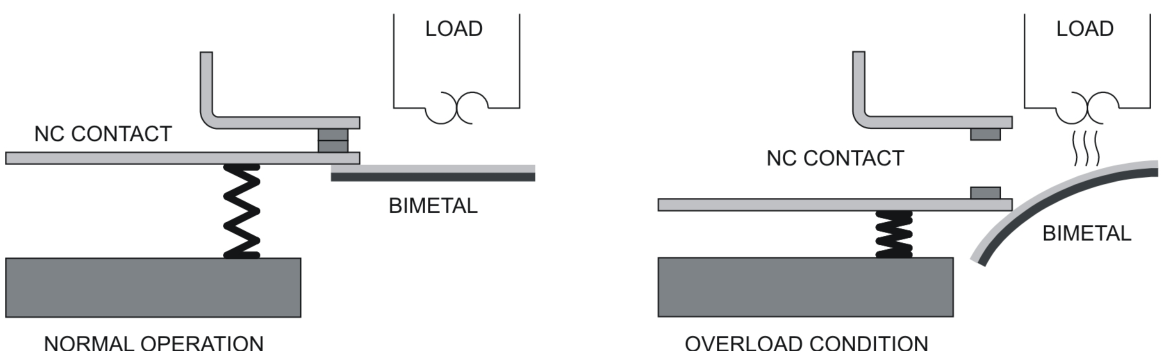


Figure 1-24. Bimetal overload operation.

Procedure Summary

In the first part of this exercise, you will set up a tripping circuit for the Manual Starter. You will first test the circuit-breaker section of the Manual Starter by shorting the circuit. After that, you will intentionally overload the circuit to make the overload relay part trip.

In the second part of the exercise, you will use a tripping chart to identify the Overload Relay module overload class and theoretical tripping time. You will then implement a circuit with the Overload Relay module to verify the theoretical tripping time value. You will also see that heat has an effect on an overload relay tripping time.

Finally, you will compare the Manual Starter and the Overload Relay and observe that the first works directly on the power lines and the latter, on the control circuit.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

PROCEDURE

WARNING!

The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

Basic setup

☐ 1. Perform the Basic Setup and Lockout/Tagout procedures.

Overload protection using the Manual Starter

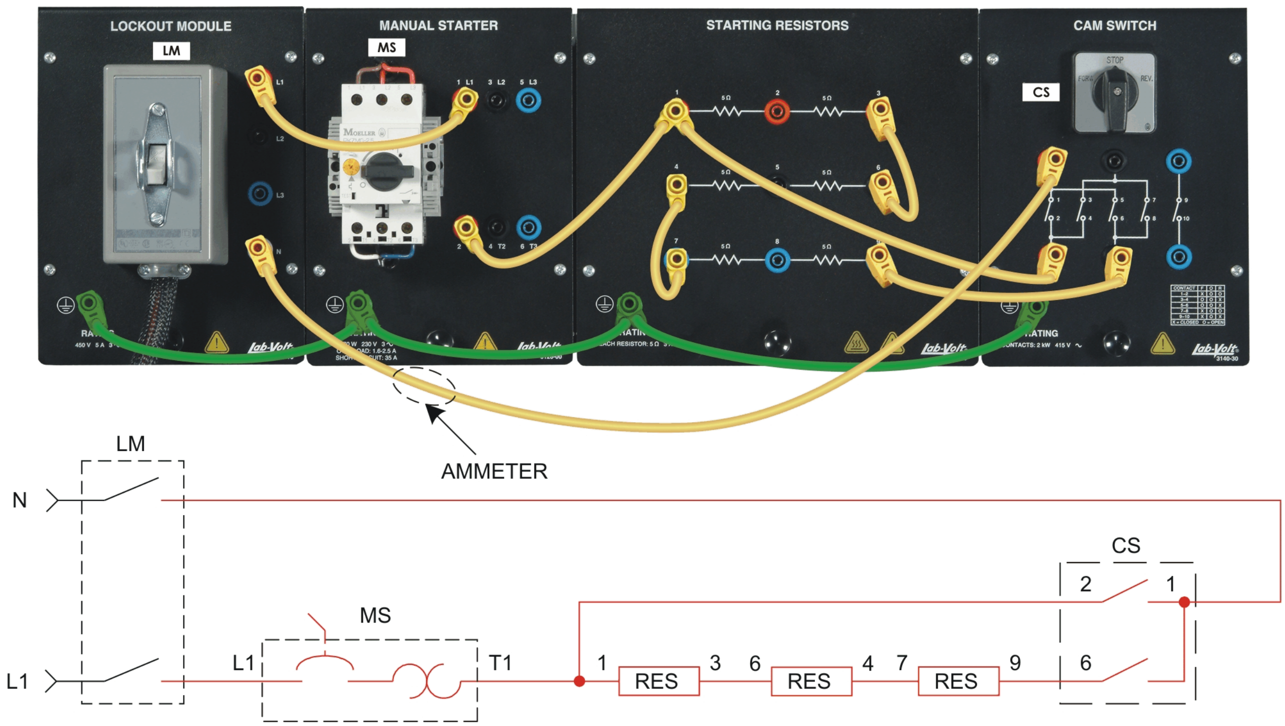
☐ 2. Connect the circuit shown in Figure 1-25.

☐ 3. Set the Cam Switch to the STOP position.

Set the overload potentiometer of the Manual Starter to the lowest value, and the knob to the I position.

Clamp an ammeter around a power lead as shown in Figure 1-25.

Perform the Energizing procedure.



LEGEND

CS	=	CAM SWITCH
LM	=	LOCKOUT MODULE
MS	=	MANUAL STARTER (CIRCUIT BREAKER WITH OVERLOAD)
RES	=	RESISTOR

AC LINE VOLTAGE	VALUE OF R_{EQ} RESISTORS IN SERIES
120 V	R_{EQ} = 10 Ω x 3 = 30 Ω
220 V	R_{EQ} = 40 Ω x 3 = 120 Ω
240 V	R_{EQ} = 40 Ω x 3 = 120 Ω

Figure 1-25. Manual Starter tripping circuit.

☐ 4. Start the chronometer as you set the Cam Switch to the FWD position.

How long does it take for the Manual Starter overload to trip? Explain what happened.

____

____

____

☐ 5. Set the Cam Switch to the STOP position.

Reset the Manual Starter by turning the knob to the **I** position.

Start the chronometer as the Cam Switch is set to the REV position.

Referring to the ammeter display, what current is flowing through the circuit?

Current: ______

☐ 6. How long does it take for the Manual Starter overload to trip?

Tripping time: ______

☐ 7. How many times the Manual Starter overload set current was the measured current?

Number of times: ______

☐ 8. Explain what happened compared to when the Cam Switch is set to the FWD position.

____

____

____

CAUTION!

The Starting Resistors module may be hot. Please be careful when you handle this module after use.

☐ 9. Perform the Lockout/Tagout procedure.

☐ 10. Referring to Figure 1-22, determine the overload class of the Manual Starter by using the tripping time and current ratio determined from the Figure 1-25 circuit.

☐ Class 10 ☐ Class 20 ☐ Class 30

☐ 11. Referring to Figure 1-22, at six times the overload current setting, how long should the Manual Starter take to trip?

Tripping time: ______

Overload protection using the Overload Relay

☐ 12. In the Figure 1-26 circuit, what would happen in case of a short-circuit (if the only short-circuit protection device is the Fuse Holder)?

____

____

☐ 13. Calculate the current that will flow through line L3, using the nominal voltage, resistor value, and Ohm's law (E = RI).

Current: ______

☐ 14. Calculate the ratio of the current calculated in the previous step to the Overload Relay's current setting (lowest value on the potentiometer) ($I_{CALCULATED}$ / $I_{OVERLOAD}$).

Ratio: ______

☐ 15. Referring to Figure 1-22, how long should it take for the overload to trip, when power is applied to the circuit? Use the current ratio calculated in the previous step.

Tripping time: ______

☐ 16. Connect the circuit shown in Figure 1-26.

☐ 17. Set the overload potentiometer of the Overload Relay to the lowest value, and the reset button to the A (automatic reset) position.

Set the TS toggle switch of the Selector Switches module to the O position.

Clamp an ammeter around power line 3 as shown in Figure 1-26.

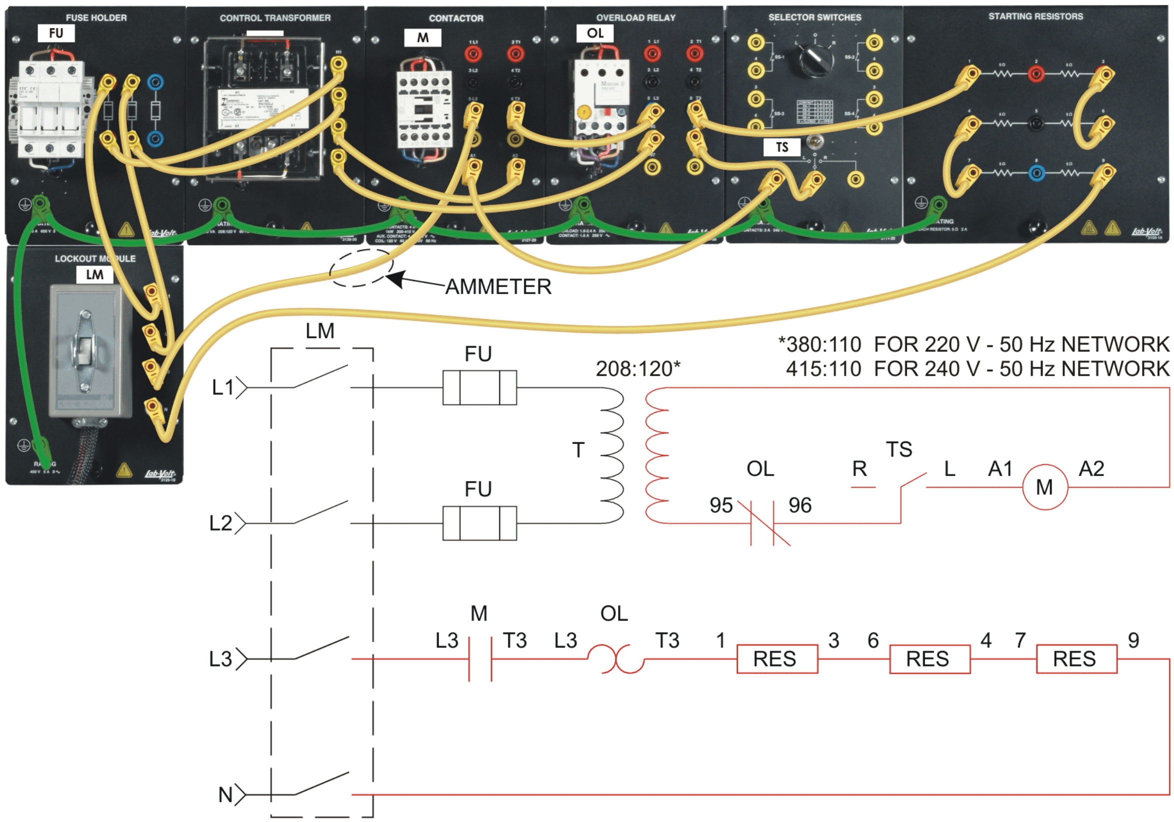
> **Note:** *Before installing the Fuse Holder module, make sure that the fuses inside are not blown.*

Perform the Energizing procedure.

☐ 18. Start the chronometer as you set the TS toggle switch to the L position.

Referring to the ammeter display, what current is flowing through the circuit?

Current: ______



LEGEND

FU = FUSE
LM = LOCKOUT MODULE
M = MAIN CONTACTOR
OL = OVERLOAD RELAY
RES = RESISTOR
TS = TOGGLE SWITCH (MAINTAINED CONTACT)

AC LINE VOLTAGE	VALUE OF R_{EQ} RESISTORS IN SERIES
120 V	R_{EQ} = 10 Ω x 3 = 30 Ω
220 V	R_{EQ} = 40 Ω x 3 = 120 Ω
240 V	R_{EQ} = 40 Ω x 3 = 120 Ω

Figure 1-26. Overload Relay tripping circuit.

☐ 19. How long does it take for the overload to trip?

Tripping time: ______

☐ 20. How long does the Overload Relay take to reset automatically (wait for the current to flow again)?

Reset time: ______

☐ 21. How long does it take for the overload to trip a second time?

Tripping time: ______

☐ 22. How was the tripping time, compared to the first time?

☐ Shorter ☐ Longer ☐ About the same

Note: *The bimetal strip inside the Overload Relay is still hot after the first reset.*

☐ 23. Does the theoretical tripping time obtained with the chart correspond to the value obtained experimentally?

☐ Yes ☐ No

☐ 24. What reasons could explain a difference between calculated and experimental results?

____

____

____

☐ 25. Do the Manual Starter and the Overload Relay take nearly the same time to trip under similar conditions?

☐ Yes ☐ No

☐ 26. Which device works directly on the power lines?

☐ Manual Starter ☐ Overload Relay

☐ 27. Explain how the two devices make the motor stop.

____

____

____

____

☐ 28. Turn the individual power switch of the AC Power Supply off, disconnect the circuit, remove the magnetic labels, and return the equipment to the storage location.

CONCLUSION

Circuit-breakers and fuses protect circuits from high current levels. They open the circuit if the current is between their ampere rating and their interrupting capacity. Circuit-breakers can be reset, while fuses have to be replaced after use.

Overload protection is used to prevent burnout of the motor. Overload relays limit the amount of current drawn to a predetermined value. The higher the current, the less time it takes to de-energize the contactor and stop the motor. Thermal overload relays heat up depending on the motor current.

Unit 2

CIRCUIT LAYOUT AND SPECIFICATIONS

UNIT OBJECTIVE

Upon completion of this unit, you will be familiar with device ratings, symbols, abbreviations, and circuit diagrams used to characterize control circuits.

DISCUSSION OF FUNDAMENTALS

Important information is displayed on labels and nameplates located directly on industrial control components and motors. These ratings are particularly useful for replacing parts during maintenance operations.

To illustrate and define elements and functions easily, electrical diagrams are utilized. They are made of graphic symbols and device designations. Schematic diagrams focus on circuit functions, without taking into account the physical arrangement, whereas **wiring diagrams** include all the devices in the system and show their physical relationships.

EXERCISE OBJECTIVE

- Interpret the information found on motor nameplates and specification labels.

DISCUSSION

When servicing or installing industrial control equipment, it is vital to comprehend the information characterizing the components of the circuits. This exercise gives an overview of the data that can be extracted from nameplates and labels.

Rating labels of control devices

Control devices are marked with information permitting their use under the right conditions. Figure 2-1 is an example of label for a contactor.

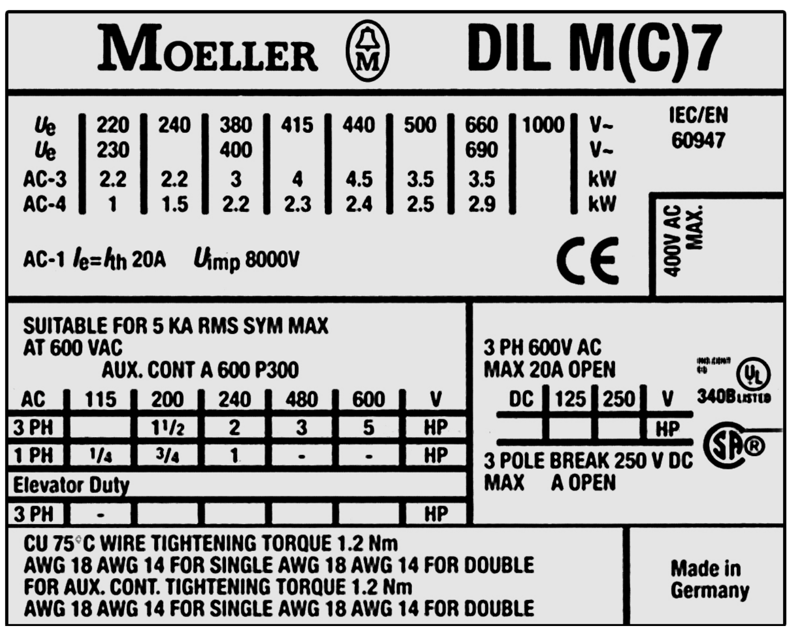


Figure 2-1. Contactor label.

Certification marks indicate that a product has been evaluated for compliance to national and international standards by a formal process, and that it complies with applicable standards for safety and performance. If we refer to the contactor label shown in Figure 2-1, we see that it meets the IEC, UL, CSA, and EN standards.

NEMA and IEC standards

Industrial control device ratings can be provided according to the National Electrical Manufacturers Association (NEMA) and/or the International Electrotechnical Commission (IEC). For example, if we take a motor starter or a contactor, both NEMA and IEC ratings can be specified for that device, but they will be different for a given motor power.

As Table 2-1 shows, NEMA motor starters and contactors are given size ratings, which depend on the continuous current rating, or the motor power and voltage. NEMA components are intended to be interchangeable between same-size devices. Because the exact application is not defined, they are designed to have more reserve capacity than their IEC counterparts. For that reason, NEMA devices are usually bigger and more expensive.

NEMA SIZES FOR MOTOR STARTERS AND CONTACTORS						
NEMA SIZE	Continuous Current Rating (A)	HORSEPOWER				Service-limit Current Rating (A)
		60 Hz		50 Hz		
		200 V	230 V	380 V	460 or 575 V	
00	9	1½	1½	1½	2	11
0	18	3	3	5	5	21
1	27	7½	7½	10	10	32
2	45	10	15	25	25	52
3	90	25	30	50	50	104
4	135	40	50	75	100	156
5	270	75	100	150	200	311
6	540	150	200	300	400	621
7	810	-	300	-	600	932
8	1215	-	450	-	900	1400
9	2250	-	800	-	1600	2590

Table 2-1. NEMA sizes for three-phase single-speed full-voltage starters and contactors (non-plugging and non-jogging duty).

On the other hand, IEC motor starters and contactors do not have standard sizes. Instead, they are described by their utilization category (see Table 2-2), power (hp or kW), thermal current (I_{th}), rated operational current (I_e) and rated operational voltage (U_e). For the same application, IEC devices are usually cheaper and smaller than their NEMA counterparts. However, they are more application sensitive and require greater knowledge from the buyer.

IEC STARTERS AND CONTACTORS UTILIZATION CATEGORIES	
UTILIZATION CATEGORIES	TYPICAL APPLICATIONS
AC-1	Non-inductive or slightly inductive loads, e.g. resistive furnaces.
AC-3	**Squirrel cage motors**, starting and switching off while running at rated speed. Make locked **rotor** current and break **full load current**. Occasionally jog.
AC-4	Squirrel cage motors, starting and switching off while running at less than rated speed. Jogging (inching) and plugging (reversing direction of rotation from other than off condition). Make and break locked rotor current.

Table 2-2 IEC utilization categories.

Pilot and control-circuit device rating

Pilot and control-circuit devices, such as push buttons and control relays, also have ratings. **Contact rating designations**, shown in Tables 2-3 and 2-4, give an indication of the maximum make and break currents. The letter designates the maximum continuous thermal test current of the unit or assembly. Letters A through E are for AC devices, and letters N through R are for DC devices. Numerical suffixes specify voltage design values of 600, 300, and 150 V.

AC CONTROL-CIRCUIT CONTACT RATINGS												
Contact Rating Designation	Thermal Cont. Test Current (A)	Maximum Current (A)								Voltamperes	
		120 V		240 V		480 V		600 V			
		Make	Break	Make	Break	Make	Break	Make	Break	Make	Break
A150	10	60	6	-	-	-	-	-	-	7200	720
A300	10	60	6	30	3	-	-	-	-	7200	720
A600	10	60	6	30	3	15	1.5	12	1.2	7200	720
B150	5	30	3	-	-	-	-	-	-	3600	360
B300	5	30	3	15	1.5	-	-	-	-	3600	360
B600	5	30	3	15	1.5	7.5	0.75	6	0.6	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	0.3	1800	180
D150	1	3.6	0.6	-	-	-	-	-	-	432	72
D300	1	3.6	0.6	0.8	0.3	-	-	-	-	432	72
E150	0.5	1.8	0.3	-	-	-	-	-	-	216	36

Table 2-3. Mechanical switching rating for AC control-circuit contact.

DC CONTROL-CIRCUIT CONTACT RATINGS					
Contact Rating Designation	**Thermal Continuous Test Current (A)**	**Maximum Make or Break Current (A)**			
		125 V	**250 V**	**301 to 600 V**	**Voltamperes**
N150	10	2.2	-	-	275
N300	10	2.2	1.1	-	275
N600	10	2.2	1.1	0.4	275
P150	5	1.1	-	-	138
P300	5	1.1	0.55	-	138
P600	5	1.1	0.55	0.2	138
Q150	2.5	0.55	-	-	69
Q300	2.5	0.55	0.27	-	69
Q600	2.5	0.55	0.27	0.1	69
R150	1	0.22	-	-	28
R300	1	0.22	0.11	-	28

Table 2-4. Mechanical switching rating for DC control-circuit contact.

Pilot and control-circuit elements have utilization categories different from contactors and motor starters, as Tables 2-5 and 2-6 show.

AC SWITCHING ELEMENTS UTILIZATION CATEGORIES	
Category	**Typical Applications**
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. 72 VA closed).
AC-15	Control of electromagnetic loads (greater than 72 VA closed).

Table 2-5. AC switching elements utilization categories.

DC SWITCHING ELEMENTS UTILIZATION CATEGORIES	
Category	**Typical Applications**
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 resistors in circuit.

Table 2-6. DC switching devices utilization categories.

Motor nameplate data and wiring information

A nameplate displays useful information about the motor. The nameplate portrayed in Figure 2-2 is for a standard, three-phase, nine-lead motor.

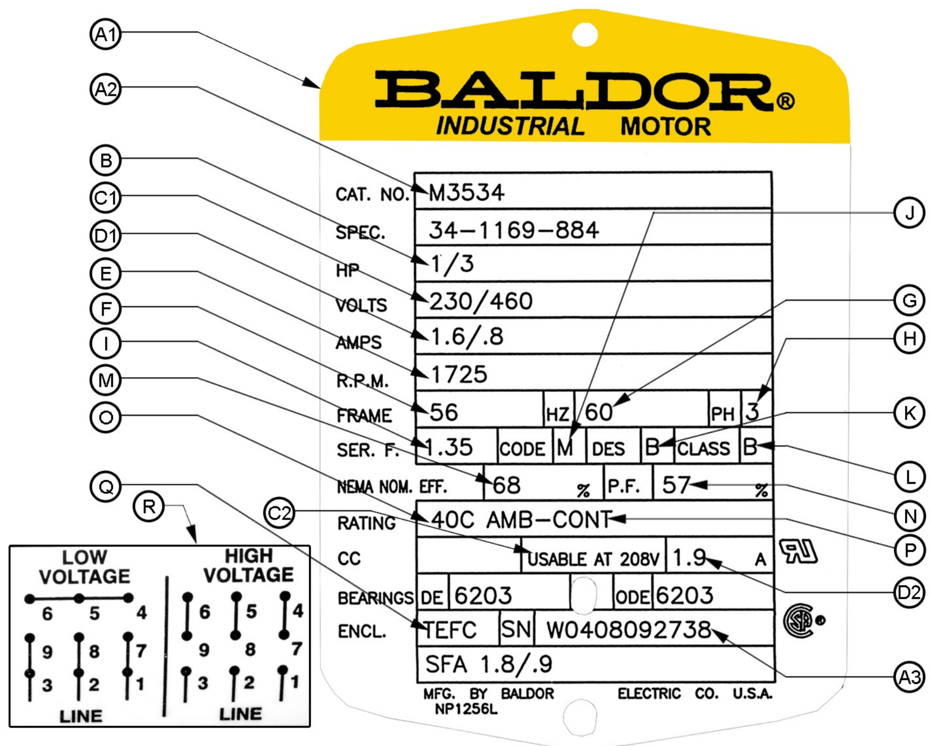


Figure 2-2. Three-phase motor nameplate.

Typically, you will find on a motor nameplate:

A. **Manufacturer's name**, **model**, and **serial number**: This information is invaluable for tracing replacement parts.

B. **Power rating**: The nominal output power at the shaft of the motor is given in horsepower (hp) or kilowatts (kW).

C. **Rated voltage**: Motors are designed to operate at specific voltage(s). So-called dual voltage motors can be used with two different voltages, depending on how they are connected. Table 2-7 shows that the voltages found on AC motors nameplates are often slightly lower than those of corresponding electrical supply systems.

NEMA NOMINAL SYSTEM AND RATED MOTOR VOLTAGES	
NOMINAL SYSTEM VOLTAGE (V)	RATED MOTOR VOLTAGE (V)
120	115
208	200
240	230
480	460
600	575
2400	2300
4160	4000
6900	6600

Table 2-7. NEMA standard nominal and rated 60 Hz polyphase motor voltages.

D. **Current rating(s)**: The motor rated current at full load and rated voltage, also called **full-load ampere** (FLA). When a motor draws more current than its FLA, it is said to be overloaded.

E. **Rotation speed**: The rated operating speed of the motor at full load. Motors can have more than one operating speed.

F. **Frame size**: NEMA and IEC have categorized the frames of motors to make them interchangeable, regardless of the manufacturer. Refer to Appendix C for NEMA and IEC Motor Frames Charts. NEMA motors may have a prefix (specific to the manufacturer) and a suffix (indicating the mounting type) in addition to the size number. A "T" or no suffix indicates current NEMA frame standards.

G. **Frequency**: This refers to the frequency of the power source supplying the motor, which is usually 60 or 50 Hz, depending on the country.

H. **Phase**: AC motors will require one or three phases.

I. **Service factor**: A multiplication factor denoting the amount of continual power overload capacity designed into a motor. A service factor of 1.0 does not permit overcharging, whereas a service factor of 1.15 enables continuous overload of 15 % without overheating the motor.

J. **Locked rotor code letter**: The code letter is a function of the locked kVA per horsepower, as Table 2-8 shows. Since the inrush current approaches the locked-rotor current, the following equation gives an indication of the starting current that is helpful to size motors' circuit protection:

$$\text{Locked rotor current} = \frac{\text{chart kVA/hp x motor hp}}{\text{rated voltage}} \times \begin{matrix}\text{1000 (single phase)} \\ \text{577 (three phases)}\end{matrix}$$

For example, a three-phase motor with a locked rotor code letter M and rated 1/3 hp at 230 V will have approximate locked rotor amps of:

$$(10.6 \times 0.33 \times 577) \div 230 = 8.78 \text{ A}$$

LOCKED ROTOR CODE LETTERS			
CODE LETTER	**kVA/hp**	**CODE LETTER**	**kVA/hp**
A	0.00-3.15	L	9.0-10.0
B	3.15-3.55	M	10.0-11.2
C	3.55-4.0	N	11.2-12.5
D	4.00-4.5	P	12.5-14.0
E	4.5-5.0	R	14.0-16.0
F	5.0-5.6	S	16.0-18.0
G	5.6-6.3	T	18.0-20.0
H	6.3-7.1	U	20.0-22.4
J	7.1-8.0	V	22.4 and up
K	8.0-9.0		

Table 2-8. Locked rotor code letters.

K. **NEMA design code letter**: This letter gives an indication of the torque's behavior depending on the speed. The most common design letters are A, B, C, and D. Design A are specialized motors used for their high pullout torque. Design B are standard industrial duty motors. Design C have higher starting torque than Design B motors. Design D have the highest starting torque, but this drops significantly with speed.

L. **Insulation class**: The type of insulation used in a motor is chosen depending on the expected operating temperature. Figure 2-3 shows the estimated life of different insulation classes, rated with letters. The higher the class letter, the more rugged the insulation.

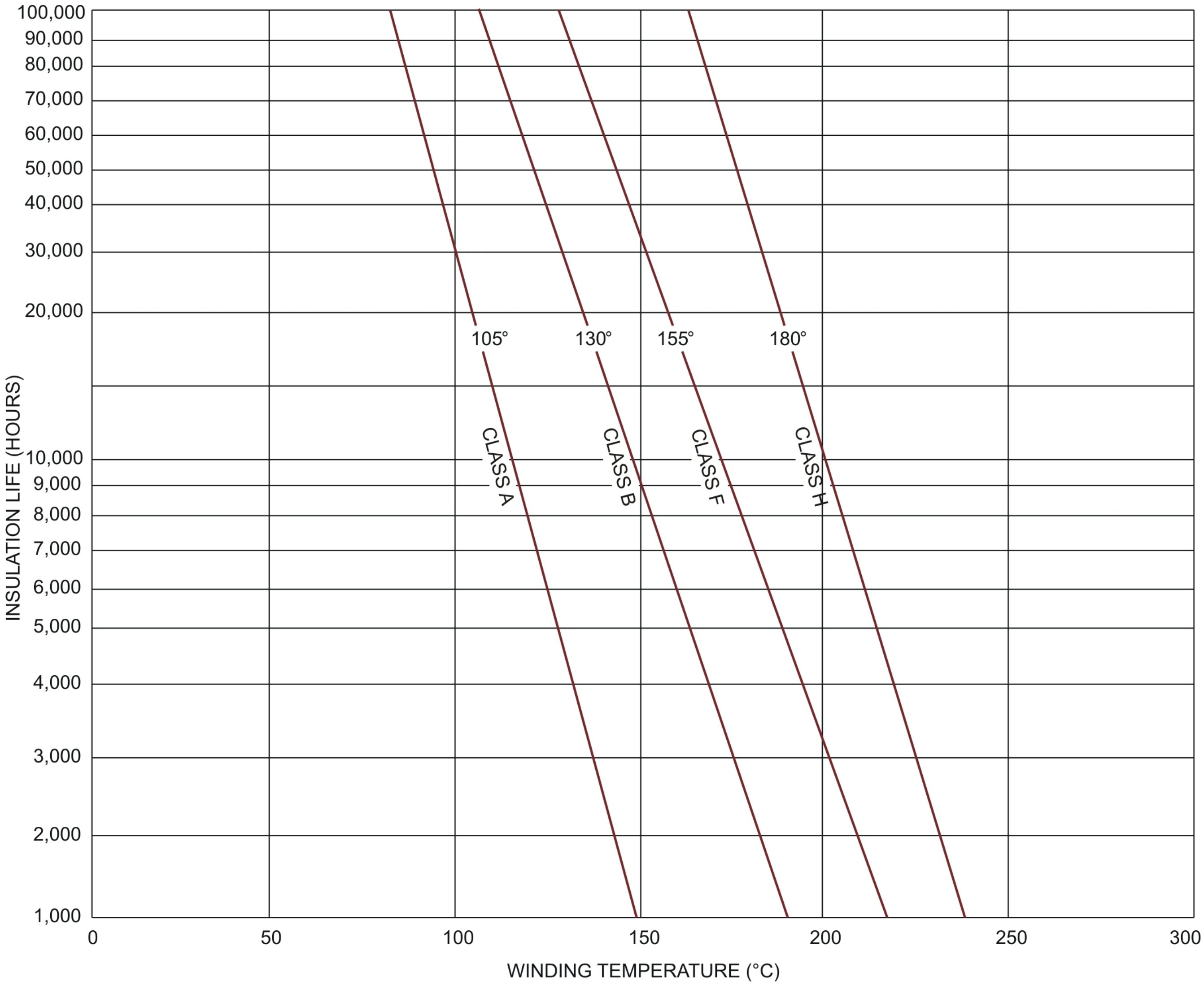


Figure 2-3. Insulation life and winding operating temperature.

Note: *Locked rotor codes, NEMA design codes, and insulation classes are all given by letters, which may lead to some confusion.*

M. **Efficiency**: The ratio of mechanical power produced to the electrical power input required by the motor. Unused energy is converted into heat.

N. **Power factor**: Motors are inductive loads and require reactive power. A higher power factor means that the motor consumes proportionally more real power, thus drawing less apparent power. In general, motors developing more power have a superior power factor.

O. **Ambient temperature**: Indicates the maximum recommended temperature of the air surrounding the motor. Usually 40 °C or 104 °F.

P. **Duty rating**: Motors are classified as either continuous or intermittent duty. The latter can be run continuously only for a given period of time, after which it must be allowed to cool down before restarting. An example of an intermittent duty motor is an air compressor.

Q. **Enclosure type**: Motors have enclosures of two different types: open and enclosed. Table 2-9 lists some of the more common designs for specific operating conditions.

TYPICAL MOTOR ENCLOSURES	
TYPES	**CHARACTERISTICS**
Open drip-proof (ODP)	Protection effective against liquids of entry angles up to 15 degrees from vertical.
Splash-proof (Open)	Protection effective against liquids of entry angles up to 100 degrees from vertical.
Guarded (Open)	Guarded by limited size openings.
Weather protected type 1 (WPI) (Open)	Openings minimize entrance of rain, snow, and airborne particles.
Weather protected type 2 (WPII) (Open)	Like WPI with additional passages to eject high-velocity particles blown into motors.
Waterproof (Enclosed)	Exclude leakage except around shaft.
Totally enclosed fan-cooled (TEFC)	Constructed with a small fan on the rear shaft to cool motors.
Totally enclosed air over (TEAO)	Rely upon the strong air flow of the fan or blower which they are driving to cool them.
Totally enclosed non-ventilated (TENV)	Have no fan. Dissipate their heat by radiation through enclosure.
Totally enclosed water-cooled (TEWC)	Cooled by circulating water.
Totally enclosed blower-cooled (TEBC)	Used for variable speed motors. Constant speed blowers pull air to keep motors cool at all operating speeds.
Totally enclosed explosion-proof (TEXP)	Withstand internal gas explosion and prevent ignition of external gas.

Table 2-9. Typical motor enclosures.

R. **Motor connection diagram**: The indications for proper wiring may be located on the nameplate, in the conduit box, or on a separate plate.

S. **Motor type**: (not shown in Figure 2-2) Manufacturers classify motors by their electrical and mechanical characteristics (squirrel-cage, induction, split-phase, permanent magnet, etc.).

SPECIFICATIONS READING

Procedure Summary

In this exercise, you will examine data on a motor nameplate, a contactor, and a control relay to extract some useful information.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

PROCEDURE

Brake Motor

☐ 1. Examine the nameplate of the Brake Motor, Model 3176-A, and fill out Table 2-10:

RATINGS	208 V	380 V	415 V [1]
Power rating (hp)			
Full-load current (A)			
Number of phases			
Service factor			
Enclosure type			
Duty rating			
Maximum ambient temperature (˚C)			
Rotation speed (r/min)			
Power source frequency (Hz)			
Design code letter NEMA			
Locked rotor code letter			
Insulation class			

(1) If the nameplate of the Brake Motor, Model 3176-A, does not indicate the characteristics of the 415-V version, refer to Appendix F.

Table 2-10. Brake Motor nameplate.

☐ 2. Referring to the locked rotor code letter, determine the maximum starting current at a 230-V rated motor voltage. Show your calculations.

____

____

____

☐ 3. What is the estimated insulation life, in hours, of this motor if it is used continuously with windings at a temperature of 150°C?

Insulation life: ______

Contactor

☐ 4. Examine carefully the enclosure and rating label of the Contactor, Model 3127. What voltages can be used to control the coil?

50 Hz: ______

60 Hz: ______

☐ 5. On the rating label, what is the recommended power rating for 220/230/240 V, AC-3 utilization?

Recommended power rating: ______

☐ 6. What certification marks appear on the rating label?

____

Control Relay

☐ 7. Examine carefully the enclosure and rating label of the Control Relay, Model 3130. What voltages can be used to control the coil?

50 Hz: ______

60 Hz: ______

☐ 8. On the rating label, what is the rated operational current for 400 V, AC-15 utilization?

Rated operational current: ______

☐ 9. What certification marks appear on the rating label?

____

CONCLUSION

Nameplates are installed on motors to help the purchaser for maintenance purposes and the manufacturer with customer service. These plates display useful information concerning the motor ratings, model and connection.

Industrial control devices, including motor starters, contactors, pilot devices, and control relays, are rated by the NEMA and/or the IEC. Those specifications are usually located on rating labels. NEMA devices tend to be interchangeable, whereas IEC devices are more specific to the application, and thus require more knowledge.

SYMBOLS, DESIGNATIONS, AND DIAGRAMS

EXERCISE OBJECTIVE

- Identify symbols and designations used on electrical diagrams.
- Become familiar with schematic and wiring diagrams.

DISCUSSION

Electricians, technicians, and engineers use diagrams when working on electrical circuits. Schematic and wiring diagrams show the electrical relationships of the components. They are a form of shorthand in which the components are shown by symbols rather than actual scale drawings.

The width of lines does not affect the meaning of symbols. However, wider lines may be used for power wiring in contrast to control wiring. The angle at which a connecting line is brought to a symbol usually has no particular significance.

Wiring diagrams

Wiring diagrams are useful in building circuits, since the connections can be made exactly as they appear on the diagram. A wiring diagram provides a means of tracing the wires for troubleshooting or during normal preventive maintenance. Wiring diagrams are also called **connection diagrams**.

Figure 2-4 shows the wiring diagram of a motor control system. This diagram represents the station physically, the relative position of each device, and the different connections. The main parts of the motor starter are labeled on the diagram, so that a comparison can be made with the actual starter.

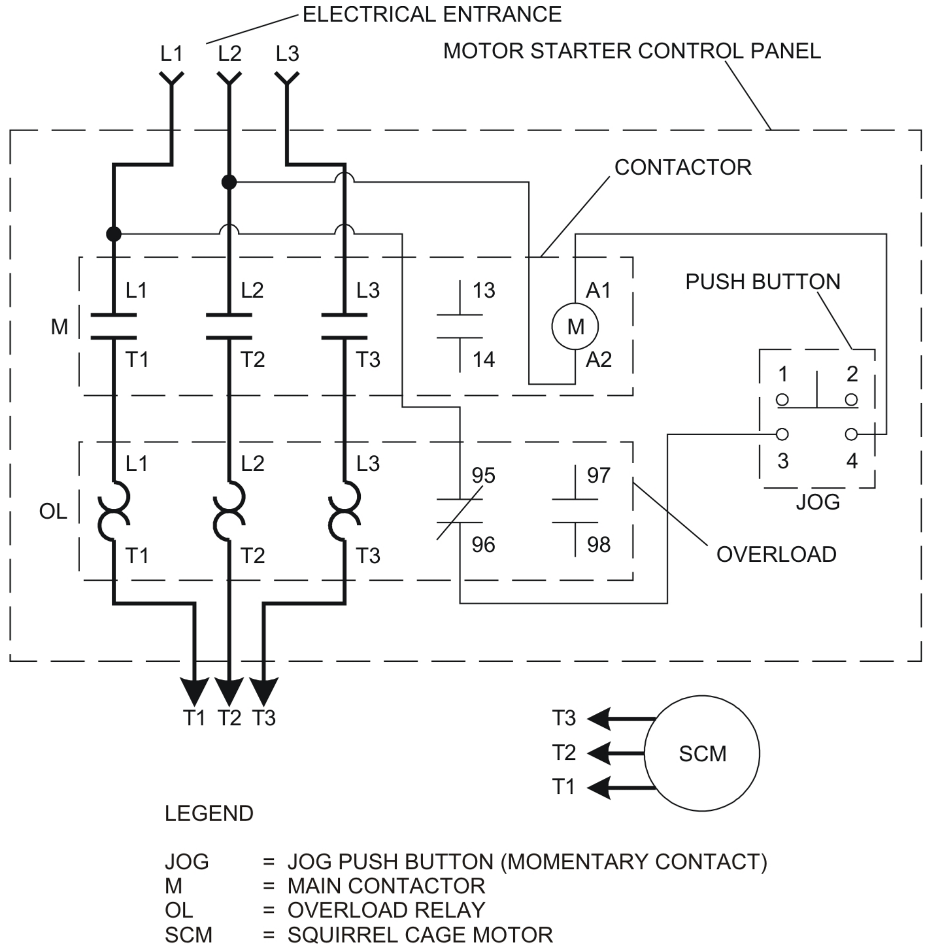
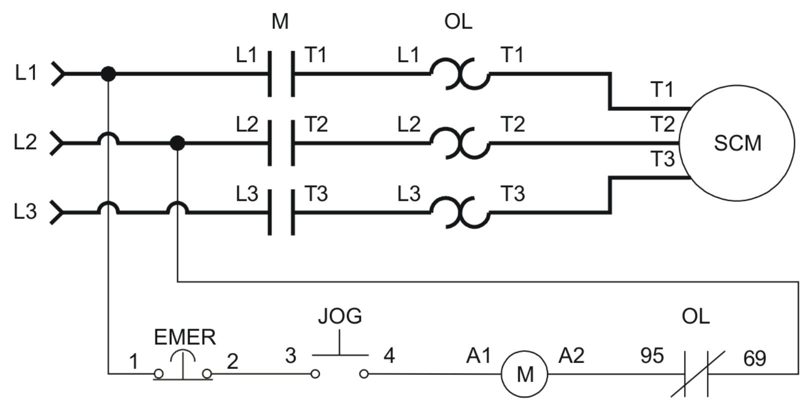


Figure 2-4. Wiring diagram of a motor control system.

Schematic diagrams

Schematic diagrams show the electrical connections and functions of a specific circuit arrangement. These drawings facilitate tracing the circuit, as they do not take account of the device's physical position, size, or shape. Schematic diagrams are sometimes referred to as **elementary diagrams**.

Figure 2-5 represents the schematic diagram of the same motor control system as in Figure 2-4. Symbols and functions of each device are indicated on this diagram.



LEGEND

EMER = EMERGENCY PUSH BUTTON
JOG = JOG PUSH BUTTON (MOMENTARY CONTACT)
M = MAIN CONTACTOR
OL = OVERLOAD RELAY
SCM = SQUIRREL CAGE MOTOR

Figure 2-5. Schematic Diagram of a basic motor control system.

Graphic symbols

Symbols are graphic representations employed in diagrams to represent the different circuit components. Appendix B shows NEMA standard symbols in general use for industrial control circuit diagrams. A table comparing NEMA and IEC symbols is also presented in Appendix B.

Terminal symbols can be added to each attachment point of the represented devices. Typically, control system terminals are marked with numbers and/or letters for identification. Figure 2-6 shows the differences between NEMA and IEC terminal markings.

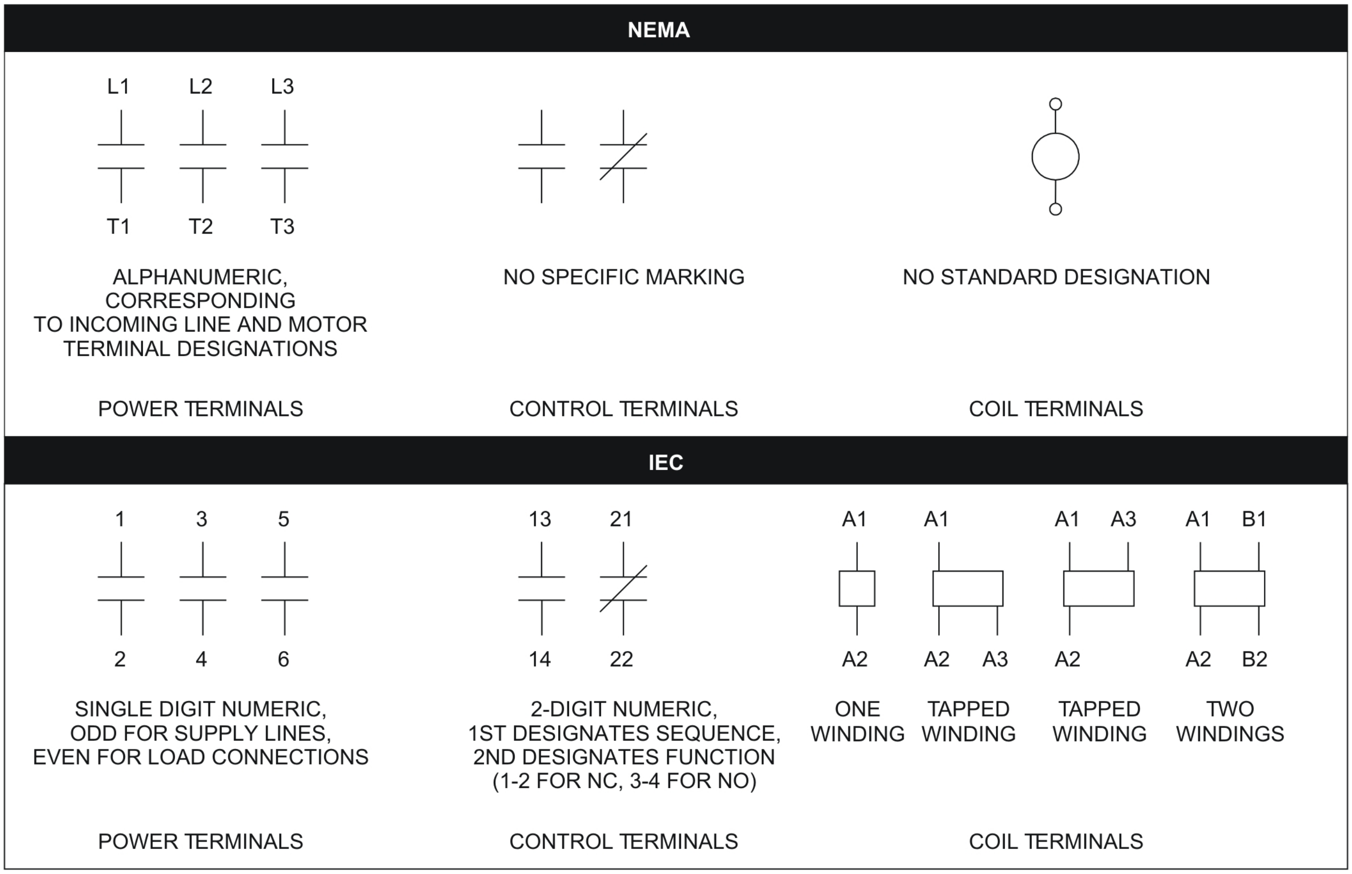


Figure 2-6. NEMA and IEC Terminal Markings.

Note: *Although NEMA diagrams do not show terminals which are not accessible, all terminals in this manual are detailed for better comprehension.*

Designations

Device designations (abbreviations), listed in Appendix B, are used jointly with graphic symbols to indicate the functions of particular devices on diagrams. If we take a look at Figure 2-5, "OL" stands for "Overload" and "M" for "Main contactor."

Two or more designations can be combined to describe a single device. Numbers or letters may be added to the basic device designations to distinguish devices performing similar functions. For example, the first control relay initiating a jog function can be designated "1JCR."

Target tables

A **target table** is used to indicate the contacts condition of a device, depending on its state.

The diagram in Figure 2-7 indicates how the lines and the load are connected to the Cam Switch. Table 2-11 is a target table showing which contacts close to reverse a three-phase motor, and which contacts close to run the motor forward. Each "X" represents a closed contact.

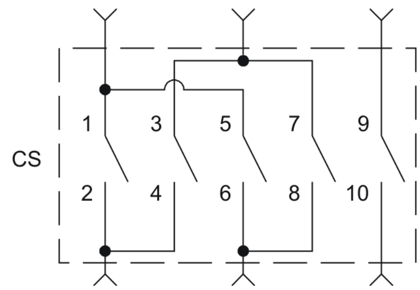


Figure 2-7. Cam Switch motor connections.

CONTACT	POSITION		
	F	O	R
1–2	X		
3–4			X
5–6			X
7–8	X		
9–10	X		X
X = Contact closed			

Table 2-11. Target table of the Cam Switch.

Procedure Summary

In this exercise, you will draw and identify different symbols and designations used on electrical diagrams. You will also draw a complete schematic diagram from a corresponding wiring diagram.

SYMBOLS, DESIGNATIONS, AND DIAGRAMS

EQUIPMENT REQUIRED

No equipment is required for this exercise.

PROCEDURE

Note: *Refer to Appendix B for symbols and designations.*

☐ 1. Draw the following symbols, according to Appendix B. Assume NEMA standard if not specified:

ITEMS	SYMBOLS
Normally open contact	
Single throw toggle switch	
Diode	
Normally closed contact (IEC)	
Fixed resistor	
Relay operating coil	
Three-phase induction motor	
Earth ground	
Red indicating light	
3-pole manual circuit breaker	

☐ 2. Write the following designation letters, according to Appendix B:

a. Time-delay opening contacts: ______

b. Overload: ______

c. Diode: ______

d. Circuit-breaker: ______

e. Push button: ______

f. Ammeter: ______

g. Fuse: ______

h. Capacitor: ______

i. Pressure switch: ______

j. Transistor: ______

☐ 3. In the Figure 2-8 schematic diagram, identify each circled letter with the appropriate device name (see NEMA symbols table in Appendix B).

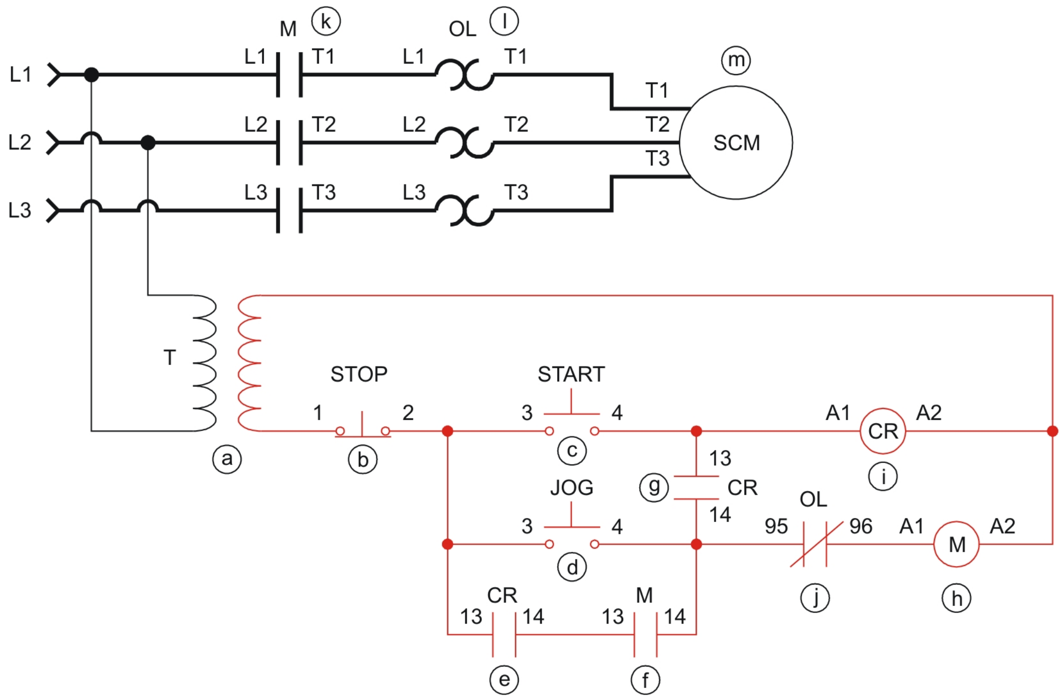


Figure 2-8. Schematic diagram.

a. ______________________________ h. ______________________________

b. ______________________________ i. ______________________________

c. ______________________________ j. ______________________________

d. ______________________________ k. ______________________________

e. ______________________________ l. ______________________________

f. ______________________________ m. ______________________________

g. ______________________________

☐ 4. Draw, in Figure 2-9, the schematic diagram of the wiring diagram shown in Figure 2-10.

Figure 2-9. Schematic diagram of the Figure 2-10 wiring diagram.

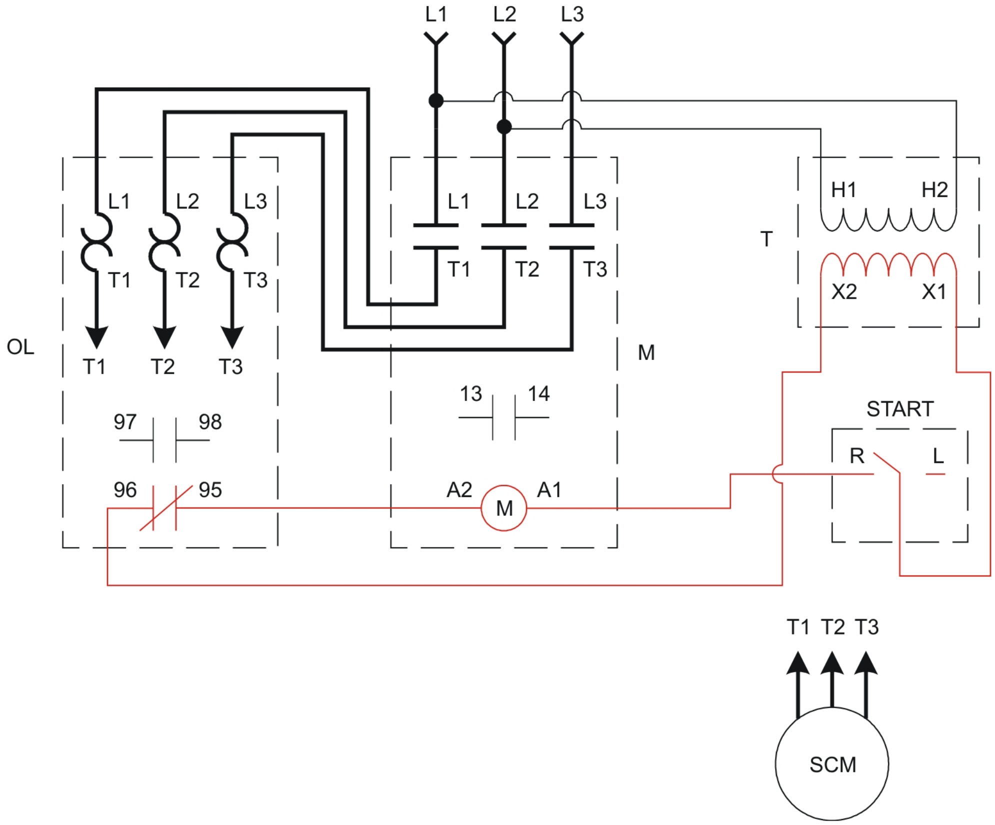


Figure 2-10. Wiring diagram.

CONCLUSION

Symbols are used in diagrams as a shorthand means of illustrating and defining elements and functions of electric circuits. Symbol functions can be defined with abbreviations (designations).

Schematic diagrams show simplified circuit connections and functions and are useful for troubleshooting purposes. Wiring diagrams show the circuits as they physically appear, making circuit construction easier.

Target tables are used to show the state of contacts on control devices.

Unit 3

BASIC CONTROL CIRCUITS

UNIT OBJECTIVE

Upon completion of this unit, you will be able to construct and analyze simple control circuits with various control devices.

DISCUSSION OF FUNDAMENTALS

Different motor control circuits are chosen to suit particular needs. They can be simple, offering only manual on/off control. But they can also be more complex, permitting direction reversal, braking, or offering protection against sudden restarts or short-circuits.

When a motor needs to be operated from more than one location, multiple control stations can be used. Multiple push button stations, for instance, permit the starting and stopping of machinery at different places along a production line.

Each control circuit can be wired to restart automatically or not, following a voltage failure. **Two-wire control** allows a machine to restart automatically following a power outage, whereas **three-wire control** keeps the motor at rest until an operator accomplishes a restart procedure.

Motor reversal

To reverse the rotation direction of a motor, a cam switch can be employed to manually invert two power lines. Reversing the power lines can also be accomplished by using two magnetic contactors, one per motor rotation direction.

But when two reversing contactors are used, there is a risk of energizing both of them simultaneously, thus creating a short-circuit. To safely reverse the direction of a motor, interlocking means are employed. Mechanical interlock and push button interlock are two of these methods.

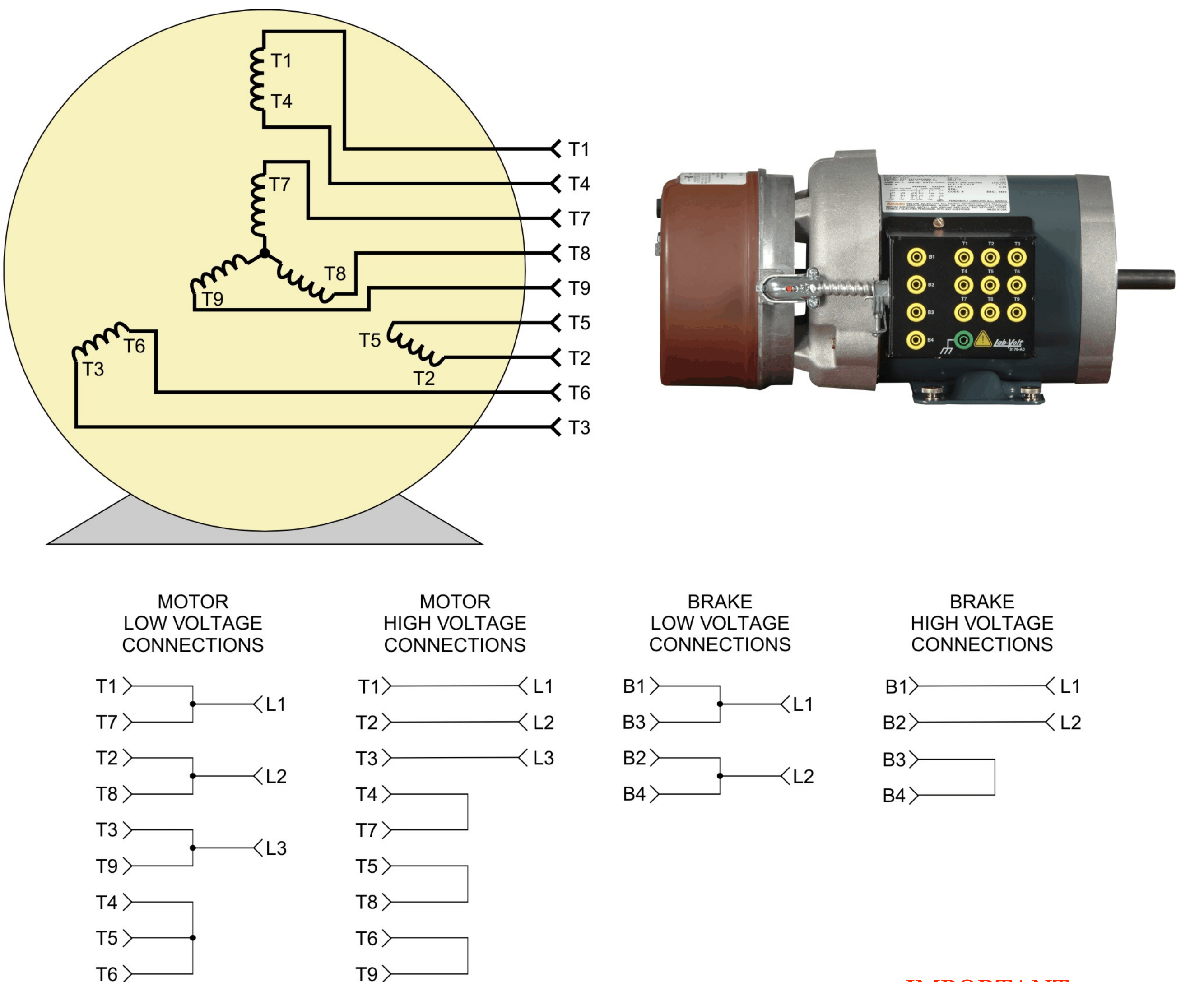
Control voltage

When control circuits are simple enough, the system designer may decide to use controls connected directly to power lines, or between a power line and the neutral. This approach proves to be less expensive because no voltage conversion device is required. Control elements must, however, be built to sustain higher voltages.

In many cases, though, motor control circuits are powered with a different voltage than that of the power circuit. In this manual, the technique used to provide suitable low AC voltage for control devices is utilizing a control transformer. This method also has the advantage of providing electrical isolation between power and control circuits.

Brake Motor

In this unit, you will make use of the Brake Motor, Model 3176-A, portrayed in Figure 3-1. This is a general purpose, three-phase motor, coupled to a **friction disc brake**. The characteristics of the Brake Motor are shown on the motor nameplate and in Appendix F.



IMPORTANT
Read This

Figure 3-1. Brake Motor, Model 3176-A.

The labels on the motor, and on the brake, indicate how to make the connections depending on the supplied voltage and frequency. Table 3-1 indicates the low and high voltage values for different network voltages and frequencies.

LOW AND HIGH VOLTAGE VALUES			
AC LINE VOLTAGE (V)	FREQUENCY (Hz)	LOW VOLTAGE (V)	HIGH VOLTAGE (V)
120	60	208-230	460
220	50	190	380
240	50	208	415

Table 3-1. Low and high voltage values for different network voltages and frequencies.

To manually disengage the friction brake, set the knob on the brake cover to the RELEASE position as shown in Figure 3-2. The operation of the friction brake will be covered in Unit 4.

Figure 3-2. Release of friction brake on the Brake Motor.

MOTOR STARTERS

EXERCISE OBJECTIVE

- Set up and verify the operation of basic motor starters.
- Understand the purpose of a separate control circuit.

DISCUSSION

Motor starters are made out of contactors and overload protection devices. Full voltage can be applied directly to the motor, although this produces rather high inrush current.

The overload relay is chosen so as to protect the motor against a sustained, low level of excessive current. The contactor coil de-energizes when the overload relay trips.

Inertia Wheel

Figure 3-3 shows the Inertia Wheel, Model 3147. This metal wheel can be coupled to a motor to increase its acceleration and deceleration time. In the following exercises, we will utilize the Inertia Wheel to observe the phenomena occurring while motors start and stop.

Figure 3-3. Inertia Wheel, Model 3147.

Separate control

It is sometimes possible to control motor circuits with the voltage between a power and the neutral line, or between two power lines. However, there may be no neutral line available, or the provided potential may not be desirable.

There is a considerable hazard in using high voltages for control circuits. Although push buttons and other pilot devices are often designed to withstand higher voltages, breaks in insulation and careless wiring may subject the operator to a serious shock. Therefore, it is common practice to use a control voltage transformer to provide suitable low AC voltage for control circuits. Figure 3-4 shows the Control Transformer, Model 3138 (208:120 version), used to provide AC control voltage compatible with coils and indicating lights of the Industrial Controls Training System.

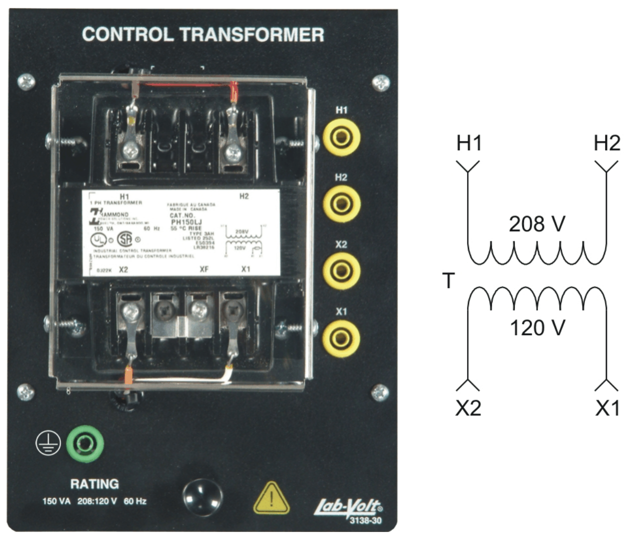
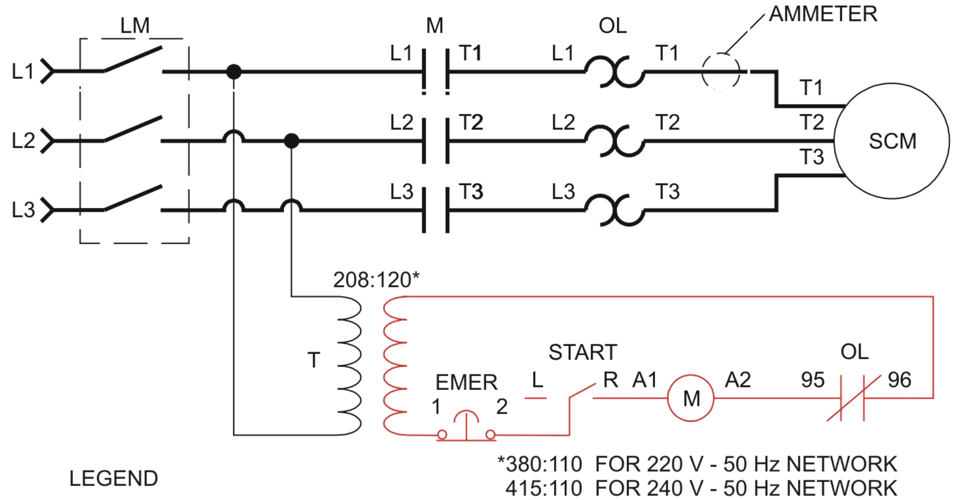


Figure 3-4. Control Transformer, Model 3138 (208:120 version).

Installing a DC power supply is another means of providing a safe control voltage. This method will be seen later in the Industrial Controls Training System student manuals.

Figure 3-5 is the schematic diagram of a separate motor control system. In this diagram, the control circuit is isolated from the power lines because of the control transformer, which takes voltage between two power lines to provide low control voltage. When power is applied to the circuit and the toggle switch is set to the START position, the contactor coil (M) is energized, actuating power contacts. If the NC overload contacts or the toggle switch opens, the contactor coil (M) is de-energized and the power contacts are opened.

WARNING: Ammeter MUST be a Clamp-on ammeter ONLY. DO not connect multimeter as an ammeter!



LEGEND

EMER	=	EMERGENCY PUSH BUTTON (MAINTAINED CONTACT)
M	=	MAIN CONTACTOR
OL	=	OVERLOAD RELAY
SCM	=	SQUIRREL CAGE MOTOR
START	=	START TOGGLE SWITCH (MAINTAINED CONTACT)
T	=	CONTROL VOLTAGE TRANSFORMER
LM	=	LOCKOUT MODULE

Figure 3-5. Motor circuit with Control Transformer.

Procedure Summary

In this exercise, you will verify that the control transformer converts line-line voltage from the power distribution system to a potential compatible with the control pilot lights and coils.

You will then implement a basic motor starter circuit from a schematic diagram. This setup will use a control transformer and a toggle switch to activate a contactor. The instructor will be invited to verify your connections before power is applied to the circuit. When starting the motor, you will observe through the ammeter the inrush current phenomenon that was discussed in Exercise 1-5.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

PROCEDURE

WARNING!

The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

MOTOR STARTERS

Basic setup

☐ 1. Perform the Basic Setup and Lockout/Tagout procedures.

Control Transformer output voltage measurement

☐ 2. Connect the Control Transformer to the Lockout Module as shown in Figure 3-5. Do not connect the other components at this moment.

Connect the voltmeter between terminals X1 and X2 of the Control Transformer.

Perform the Energizing procedure.

What is the voltage provided by the Control Transformer?

Voltage: ______

☐ 3. Is this voltage compatible with the pilot light rating of the Pilot Lights module?

☐ Yes ☐ No

☐ 4. Is this voltage compatible with the coil rating of the Contactor module?

☐ Yes ☐ No

☐ 5. Perform the Lockout/Tagout procedure.

Inrush current measurement

Note: This step is already completed.

☐ 6. Install the Brake Motor, Inertia Wheel, and Safety Guard as described in Appendix E.

Connect the circuit shown in Figure 3-5. Use the toggle switch O-R contact of the Selector Switches module.

Note: *Make sure that the motor is connected according to your distribution voltage.*

Important!

☐ 7. Manually disengage the friction brake by setting the knob, on the brake cover, to the RELEASE position.

Set the START toggle switch of the Selector Switches to the O position.

Clamp an ammeter around a motor power lead.

Perform the Energizing procedure.

☐ 8. Observe the ammeter display as you set the START toggle switch to the R position. Repeat your observation if necessary.

How does the motor current level evolve, when the motor is started?

☐ Current is maximum upon starting and decreases to become stable.
☐ Current is minimum upon starting and increases to become stable.
☐ Current level increases continuously.

☐ 9. Explain what happens in the circuit when the START toggle switch is reset to the O position?

____

☐ 10. Turn the individual power switch of the AC Power Supply off, disconnect the circuit, remove the magnetic labels, and return the equipment to the storage location.

CONCLUSION

The use of a control voltage transformer is a way to isolate control and power circuits. It provides suitable low voltage for the control circuit.

Motor starters are made of contactors and overload protection devices. When loads are coupled to the motor shaft, the motor accelerates and decelerates slower.

The current level is higher upon starting than during normal operation. This phenomenon, discussed in Exercise 1-5, is called inrush current.

TWO-WIRE AND THREE-WIRE CONTROLS

EXERCISE OBJECTIVE

- Construct two-wire and three-wire control circuits and understand their principles.

DISCUSSION

Electrical motor controls can be wired so that they restart the motor automatically or not, after power is removed from and returned to the circuit.

Two-wire control

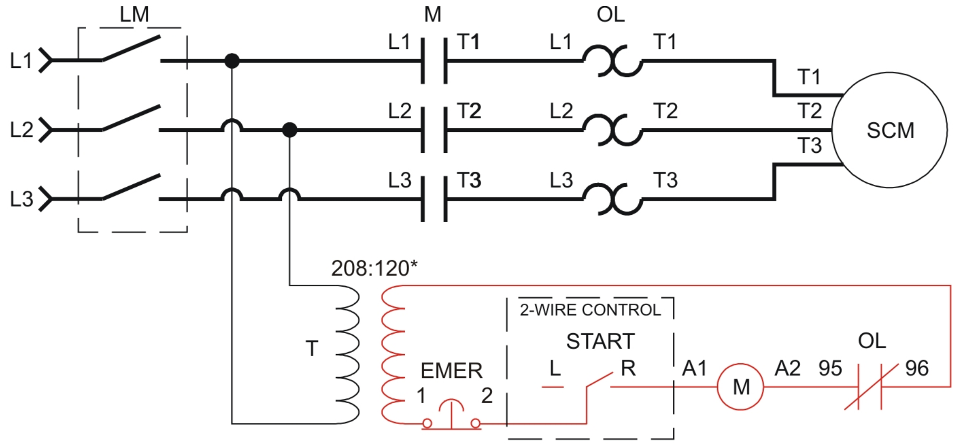
Two-wire control of a starter means the starter drops out when there is a voltage failure and starts up by itself when the voltage returns. This type of control is often used on fans or exhaust blowers.

The two-wire control circuit is so named because only two wires are connected to the pilot device used to energize the magnetic controller. Pilot devices used can hold their contacts closed, even if there is a power failure. These controls may be thermostats, float, pressure, toggle, or **selector switches**. Two-wire control is also called **no-voltage release** or **low-voltage release**.

Two-wire control does not require an operator to be present to restart a machine following a voltage failure. However, this can be hazardous to personnel and machinery, due to the sudden restart of equipment.

Figure 3-6 shows a two-wire control circuit. When the control contact closes, the coil (M) is energized. The power contacts close, causing the motor to start. When the control contact opens, or power is removed from the circuit, the coil (M) de-energizes, opening the power contacts and stopping the motor. When power returns, if the control contact is closed, the motor restarts automatically.

TWO-WIRE AND THREE-WIRE CONTROLS



*380:110 FOR 220 V - 50 Hz NETWORK
415:110 FOR 240 V - 50 Hz NETWORK

LEGEND

EMER = EMERGENCY PUSH BUTTON (MAINTAINED CONTACT)
M = MAIN CONTACTOR
OL = OVERLOAD RELAY
SCM = SQUIRREL CAGE MOTOR
START = START TOGGLE SWITCH (MAINTAINED CONTACT)
T = CONTROL VOLTAGE TRANSFORMER
LM = LOCKOUT MODULE

Figure 3-6. Two-wire control circuit.

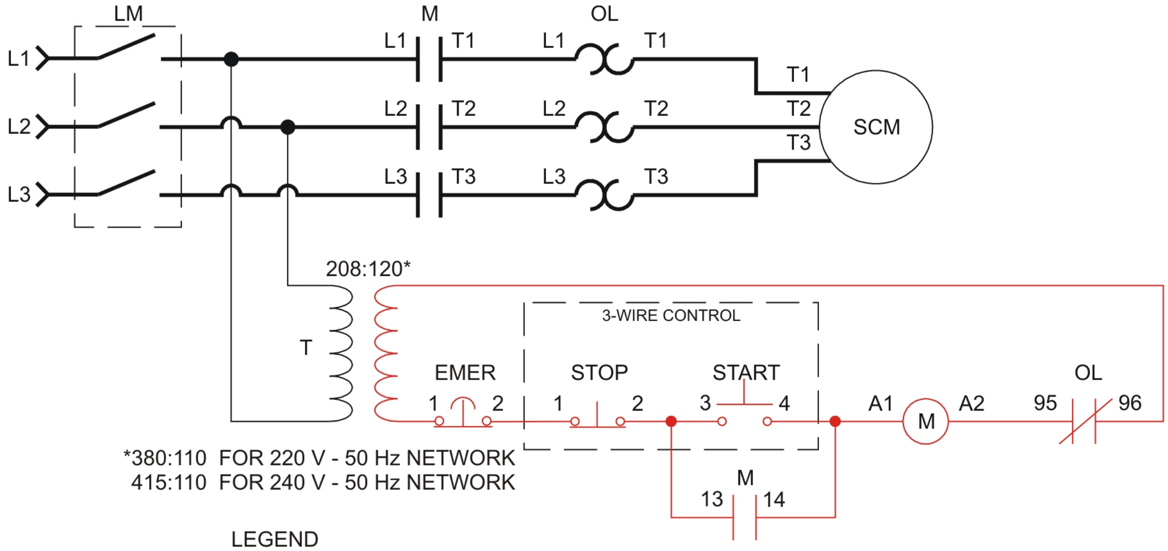
Three-wire control

Three-wire control of a starter means the starter drops out when a voltage failure occurs, but does not restart when the voltage returns, therefore not constituting the same hazard as the two-wire control.

The three-wire control circuit gets its name from the three wires that must be connected to the pilot device. A holding contact must be used in addition to control devices that do not hold their state, like momentary contact push buttons. This method is also called **no-voltage protection** or **low-voltage protection**.

The circuit of Figure 3-7 is an example of three-wire control. It functions in the following manner:

- When the START push button is pressed, the coil (M) energizes and the holding contact (M) closes to keep the coil energized.
- When the STOP push button is pressed or power is removed, the circuit is broken, causing coil (M) to de-energize, and opening the holding contact.
- The START push button must be pressed again to energize the coil.



LEGEND

EMER = EMERGENCY PUSH BUTTON (MAINTAINED CONTACT)
M = MAIN CONTACTOR
OL = OVERLOAD RELAY
SCM = SQUIRREL CAGE MOTOR
START = START PUSH BUTTON (MOMENTARY CONTACT)
STOP = STOP PUSH BUTTON (MOMENTARY CONTACT)
T = CONTROL VOLTAGE TRANSFORMER
LM = LOCKOUT MODULE

Figure 3-7. Three-wire control circuit.

Procedure Summary

In this exercise, you will implement a two-wire control circuit and verify that this circuit restarts automatically, after power is removed and restored.

After that, you will set up a three-wire control circuit to see that such a circuit does not restart by itself, after power is restored following a disruption.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

PROCEDURE

WARNING!

The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

TWO-WIRE AND THREE-WIRE CONTROLS

Basic setup

☐ 1. Perform the Basic Setup and Lockout/Tagout procedures.

Two-wire control circuit

☐ 2. Install the Brake Motor, Inertia Wheel, and Safety Guard.

Connect the circuit shown in Figure 3-6.

☐ 3. Manually disengage the friction brake.

Set the START toggle switch of the Selector Switches to the O position.

How many leads (minimum) are connected to the Selector Switches module?

Number of leads: ______

☐ 4. What type of control is this?

☐ No-voltage protection ☐ No-voltage release

☐ 5. Perform the Energizing procedure.

Explain what happens as you turn on the Lockout Module.

____

____

____

☐ 6. Explain what happens as you set the START toggle switch to the R position.

____

____

____

☐ 7. While the Brake Motor is running, turn off the Lockout Module, then turn it on. Explain what happens.

____

____

____

☐ 8. Perform the Lockout/Tagout procedure.

Three-wire control circuit

☐ 9. Connect the circuit shown in Figure 3-7.

☐ 10. What type of control is this?

☐ No-voltage protection ☐ No-voltage release

☐ 11. Perform the Energizing procedure.

Explain what happens as you turn on the Lockout Module.

____

____

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☐ 12. Press the START push button briefly. Explain what happens.

____

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☐ 13. While the Brake Motor is running, turn off the Lockout Module, then turn it on. Explain what happens.

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☐ 14. What do you have to do to restart the motor?

____

☐ 15. What happens if you press the STOP push button while the motor is running?

____

____

____

☐ 16. Turn the individual power switch of the AC Power Supply off, disconnect the circuit, remove the magnetic labels, and return the equipment to the storage location.

CONCLUSION

Two-wire control circuits restart a motor automatically when voltage returns, following a power failure. A two-wire controller can be a toggle switch, **float switch**, **limit switch**, or any other device with maintained on-off positions.

Three-wire control circuits require an operator present to restart the machine following a power failure. Three-wire controls can be, for example, momentary contact push buttons.

MANUAL REVERSING STARTERS

EXERCISE OBJECTIVE

- Build manual reversing starters and understand how they work.

DISCUSSION

Reversing motor rotation direction is a common operation in industrial controls. For three-phase motors, this is done by interchanging any two power lines. Swapping two lines has the effect of shifting from a line sequence to another. Each sequence makes the motor turn in a specific direction, because the motor revolves according to the rotating magnetic field created by the voltages applied to the motor windings. There are two possible line sequences in a three-phase system:

- 1-2-3-1-2-3 (which can be expressed as 1-2-3, 2-3-1 or 3-1-2)
- 3-2-1-3-2-1 (which can be expressed as 3-2-1, 2-1-3 or 1-3-2)

The phase switching can be accomplished manually, with the help of a cam switch, or with magnetic devices, as will be seen later in this manual.

When the Cam Switch, shown in Figure 3-8, is set to the FWD position, lines are connected in the usual order (L1 to T1, L2 to T2, and L3 to T3), so that the motor runs in the forward direction.

In the REV position, lines 1 and 2 are interchanged (L2 to T1, L1 to T2, and L3 to T3) to reverse the motor rotation direction. Placing the Cam Switch in the STOP position simply opens the three lines and shuts off the motor.

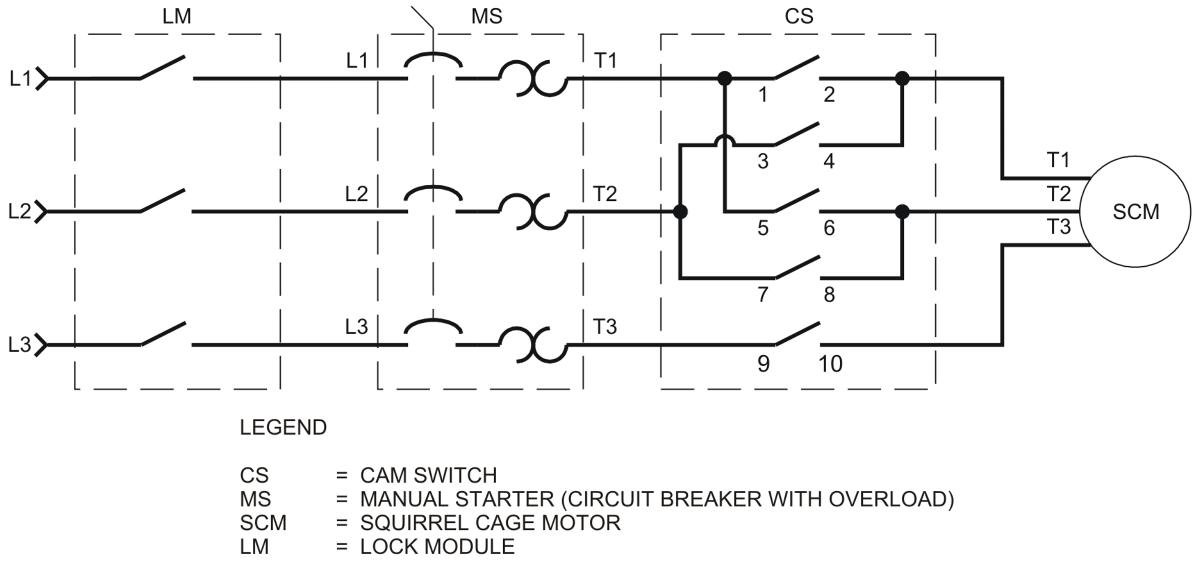


Figure 3-8. Manual reversing starter circuit with a cam switch.

Procedure Summary

In this exercise, you will manually change the motor terminal connections to observe the relationship between line sequence and motor rotation direction.

You will then use a cam switch to reverse the motor rotation direction without having to disconnect power leads.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

PROCEDURE

WARNING!

The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

Basic setup

☐ 1. Perform the Basic Setup and Lockout/Tagout procedures.

Reversing the rotation direction by manually changing the line sequence

☐ 2. Install the Brake Motor, Inertia Wheel, and Safety Guard.

Connect the circuit shown in Figure 3-8.

☐ 3. Manually disengage the friction brake.

Set the Cam Switch to the FWD position.

Set the knob of the Manual Starter to the O position.

Perform the Energizing procedure.

☐ 4. Observe the rotation direction of the motor shaft (facing the end of the motor shaft) as you set the knob of the Manual Starter to the **I** position.

Enter the rotation direction and the line sequence in the appropriate row of Table 3-2.

Set the knob of the Manual Starter to the O position.

☐ 5. Repeat the previous step for all the configurations shown in the Connections column of Table 3-2. Change configuration by modifying the connections at the Brake Motor terminals.

> **Note:** *Turn off the Lockout Module while you modify the connections.*

CONNECTIONS	MOTOR ROTATION DIRECTIONS		LINE SEQUENCES	
	CW	CCW	1-2-3-1-2-3	3-2-1-3-2-1
L1 - T1 L2 - T2 L3 - T3 (M)				
L2 - T1 L1 - T2 L3 - T3 (M)				
L3 - T1 L2 - T2 L1 - T3 (M)				
L1 - T1 L3 - T2 L2 - T3 (M)				
L3 - T1 L1 - T2 L2 - T3 (M)				
L2 - T1 L3 - T2 L1 - T3 (M)				

Table 3-2. Motor rotation directions and line sequences.

☐ 6. Does the line sequence relate to the motor rotation direction?

☐ Yes ☐ No

Reversing the rotation direction using a cam switch to change the line sequence

☐ 7. Turn off the Lockout Module.

Set the knob of the Manual Starter to the I position.

Set the Cam Switch to the STOP position.

Connect the motor in the usual manner (L1 to T1, L2 to T2, and L3 to T3).

Turn on the Lockout Module.

Determine the motor rotation direction as you set the Cam Switch to the FWD position.

☐ Clockwise ☐ Counterclockwise

☐ 8. Set the Cam Switch to the STOP position.

CAUTION!

The Cam Switch module is AC-3 rated. Therefore, it is not recommended to reverse power lines while the motor is still rotating. Wait for the motor to come to a complete stop before changing switch direction.

☐ 9. Determine the motor rotation direction as you set the Cam Switch to the REV position.

☐ Clockwise ☐ Counterclockwise

☐ 10. Compared to the FWD operation, does the motor turn in the other direction?

☐ Yes ☐ No

☐ 11. Does using the Cam Switch have the same effect as manually inverting motor connections of lines 1 and 2.

☐ Yes ☐ No

☐ 12. Turn the individual power switch of the AC Power Supply off, disconnect the circuit, remove the magnetic labels, and return the equipment to the storage location.

CONCLUSION

Changing the motor terminal's line sequence inverts the motor rotation direction. There are only two possible sequences in a three-phase system: one for the forward and one for the reverse direction.

Instead of manually modifying the line sequence, a cam switch may be used to simplify the reversal of motor rotation direction.

REVERSING STARTERS

EXERCISE OBJECTIVE

- Implement magnetic reversing starters.
- Understand the principles of mechanical and electrical interlocking.

DISCUSSION

As you have seen in the previous exercise, reversing rotation direction of a three-phase motor is usually done by interchanging any two power lines. When the equipment is sufficiently rugged, motor line reversal can be accomplished while the motor is running at full speed. This has a major advantage: a counter torque is developed and the motor stops faster. This motor braking method is called **plugging**.

When phase reversal is executed in magnetic circuits, one contactor is used for each direction. But a short-circuit can occur if the two contactors are energized at the same time. Look at the Figure 3-9 power circuit, for example. If all contacts of the F and R contactors close, lines 1 and 2 will be short-circuited. That is the reason why forward and reverse contactors are usually electrically and/or mechanically interlocked together.

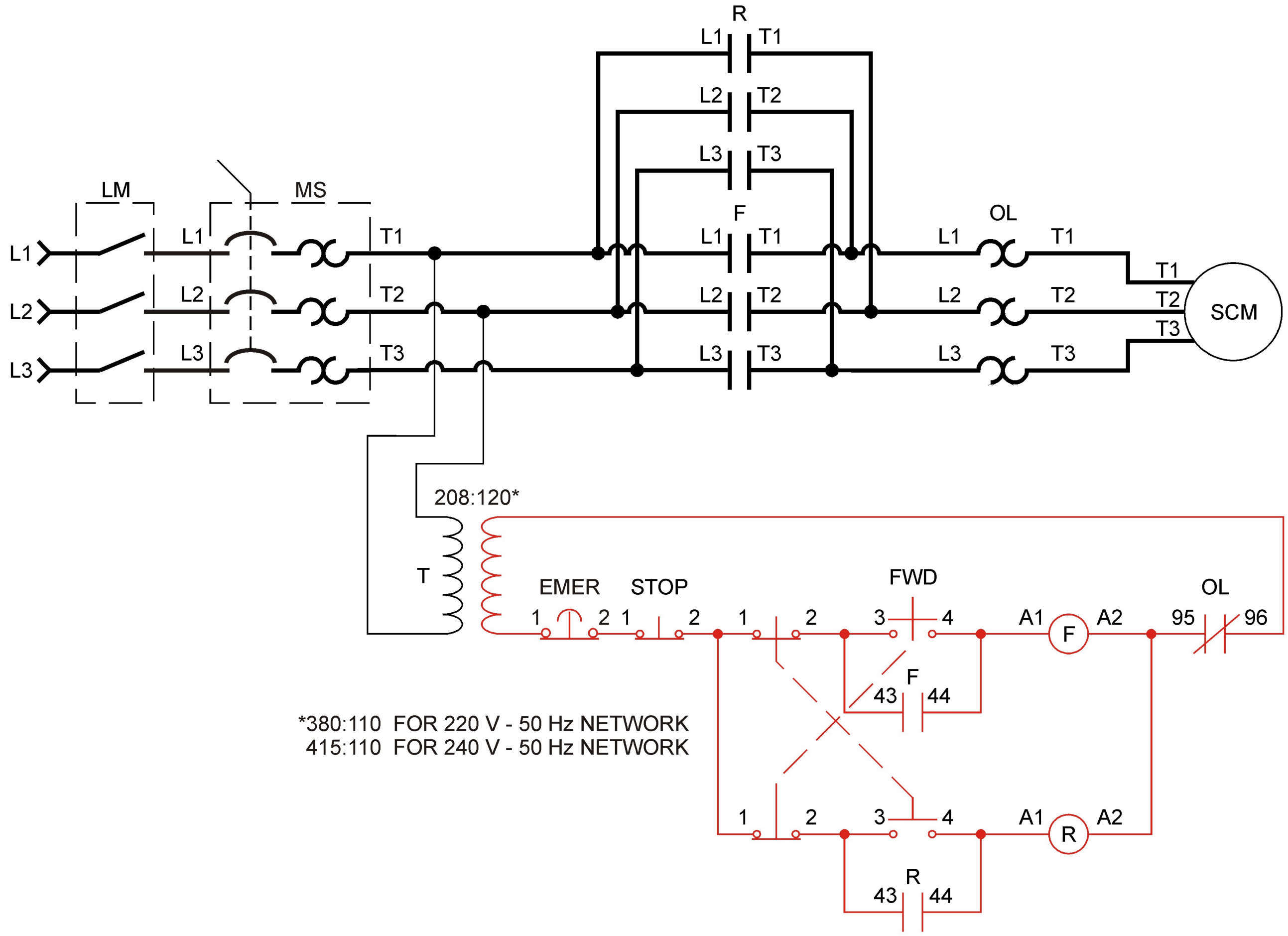
Push button interlocking

Avoiding simultaneous actuation of two contactors can be done electrically, by way of push button interlocking.

When the FWD push button in Figure 3-9 is pressed, the coil (F) is energized and the related holding contact closes. If the REV push button is pressed while the motor is running in the forward direction, the forward control circuit de-energizes. At the same time, the reverse contactor (R) is energized and held closed, making the motor run in the reverse direction. Note that it is not necessary to press the STOP push button to reverse direction. This fact facilitates plugging.

If the FWD and REV push buttons are simultaneously activated, both contactors will stay open. That is because push button NC contacts open the control circuit completely, thereby forcing contactor coils to de-energize.

However, if a contactor coil is stuck closed or does not open fast enough, there can still be a short-circuit when the other coil is activated.



LEGEND

F	=	FORWARD DIRECTION CONTACTOR
FWD	=	FORWARD PUSH BUTTON (MOMENTARY CONTACT)
OL	=	OVERLOAD RELAY
R	=	REVERSE DIRECTION CONTACTOR
REV	=	REVERSE PUSH BUTTON (MOMENTARY CONTACT)
SCM	=	SQUIRREL CAGE MOTOR
STOP	=	STOP PUSH BUTTON (MOMENTARY CONTACT)
T	=	CONTROL VOLTAGE TRANSFORMER
EMER	=	EMERGENCY PUSH BUTTON (MAINTAINED CONTACT)
LM	=	LOCKOUT MODULE
MS	=	MANUAL STARTER

Figure 3-9. Push button interlocking circuit.

Mechanical Interlocking

A mechanical lever is another manner of preventing both starter coils from being energized simultaneously. Figure 3-10 displays the mechanical interlock located between the two contactors of the Dual Contactors, Model 3119.

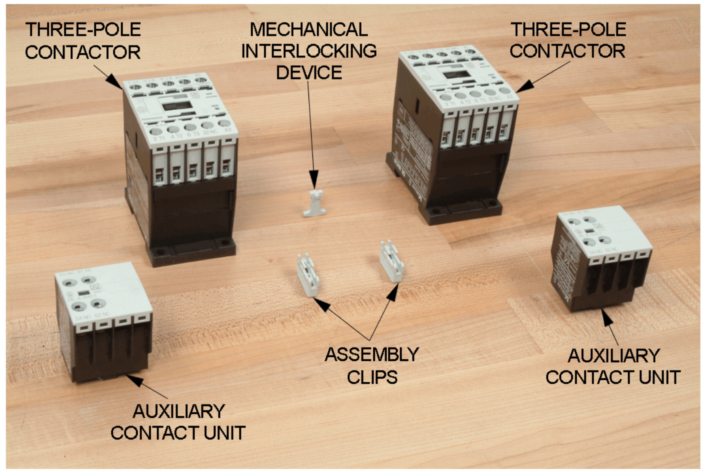
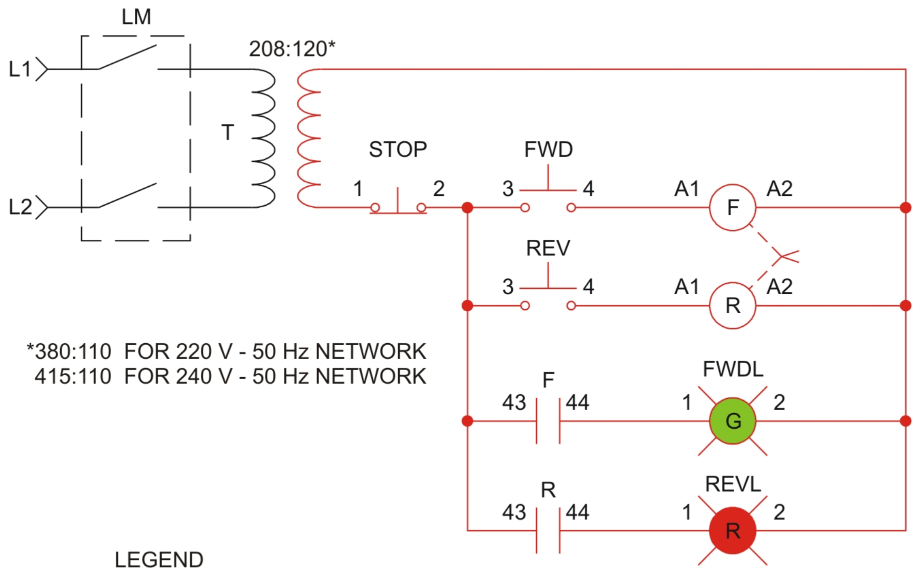


Figure 3-10. Mechanical interlocking.

If you refer to the Figure 3-11 circuit, a mechanical interlock (in dashed lines) is located between the two contactor coils. When one of the two contactors is energized, the contacts of the other contactor are mechanically maintained, even if the second coil is energized. This method provides a level of security against short-circuits resulting from stuck contactors. This explains why mechanical interlocks are so common in the industry.



LEGEND

F	=	FORWARD DIRECTION CONTACTOR
FWD	=	FORWARD PUSH BUTTON (MOMENTARY CONTACT)
FWDL	=	FORWARD PILOT LIGHT
R	=	REVERSE DIRECTION CONTACTOR
REV	=	REVERSE PUSH BUTTON (MOMENTARY CONTACT)
REVL	=	REVERSE PILOT LIGHT
STOP	=	STOP PUSH BUTTON (MOMENTARY CONTACT)
T	=	CONTROL VOLTAGE TRANSFORMER
LM	=	LOCKOUT MODULE

Figure 3-11. Dual contactors testing circuit.

Procedure Summary

In the first part of this exercise, you will set up a reversible starter circuit with push button interlocking and verify that this circuit enables changing of motor direction. You will also observe that motor direction reversing can be accomplished without having to press the STOP push button, to stop the motor faster. You will then verify that both contactors remain de-energized if the operator accidentally presses the two push buttons. Finally, you will simulate a stuck contactor to see that push button interlocking does not protect against short-circuits resulting from that type of trouble.

In the second part of this exercise, you will study, with the assistance of pilot lights, how a mechanical interlock operates. By manually applying pressure on the dual contactors plungers, you will check that it is not possible to activate both contactors at the same time. You will then visualize that, when both coils are powered, only the first contactor has its related contacts closed.

In the last part of this exercise, you will connect a reversing starter with push button and mechanical interlocks. You will see that this circuit, like the push button interlock circuit, enables motor direction reversal and opens completely when both push buttons are pressed. You will also discover that the mechanical interlock included adds protection against stuck contactors.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

PROCEDURE

WARNING!

The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

Basic setup

☐ 1. Perform the Basic Setup and Lockout/Tagout procedures.

Push button interlocking

☐ 2. Install the Brake Motor, Inertia Wheel, and Safety Guard.

Connect the circuit shown in Figure 3-9.

> **Note:** *Use one of the two contactors from the Dual Contactors, Model 3119, as the forward direction contactor, and the Contactor, Model 3127, as the reverse direction contactor, to make sure that there is no mechanical link between contactors.*

☐ 3. On the Manual Starter, set the overload potentiometer according to the motor FLA, and the O/I button to the I position.

Manually disengage the friction brake.

Perform the Energizing procedure.

Determine the motor rotation direction as you press the FWD push button.

☐ Clockwise ☐ Counterclockwise

☐ 4. Press the STOP push button and observe the time taken by the motor to stop.

☐ 5. Determine the motor rotation direction as you press the REV push button.

☐ Clockwise ☐ Counterclockwise

☐ 6. Compared to the forward operation, does the motor turn in the other direction?

☐ Yes ☐ No

Note: *The contactors are all AC-4 rated. This class allows for plugging operation (reversing direction of rotation from other than off condition).*

☐ 7. While the motor is running in the reverse direction, press the FWD push button until the motor halts. Press the STOP push button before the motor starts rotating in the opposite (forward) direction. Repeat if necessary.

Note: *Repeated motor starts and stops may cause the Overload Relay to trip.*

Did the motor stop slower or faster than with the STOP push button only?

☐ Slower ☐ Faster

☐ 8. When the FWD push button was pressed, why were both contactors (F and R) not activated at the same time, thereby causing a short-circuit?

____

____

____

☐ 9. What happens when you keep the FWD and REV push buttons pressed simultaneously?

____

____

☐ 10. Describe how the circuit operates while you simultaneously keep the FWD and REV push buttons pressed.

____

____

☐ 11. What happens if you do not release both push buttons simultaneously? Explain why.

____

____

☐ 12. Press the FWD push button to start the motor.

To simulate a stuck contactor, manually hold the forward contactor plunger down (using the tip of a pen), then press the REV push button. What happens?

____

____

☐ 13. Describe how the circuit operates while you simultaneously hold the forward contactor plunger down and press the REV push button.

____

____

☐ 14. Does push button interlocking offer a good protection against stuck contactors?

☐ Yes ☐ No

☐ 15. Perform the Lockout/Tagout procedure.

Mechanical interlocking

☐ 16. Connect the circuit shown in Figure 3-11.

Note: *Use the two contactors from the Dual Contactors module.*

☐ 17. Perform the Energizing procedure.

☐ 18. Can you (manually) hold down completely the two contactor plungers simultaneously? Explain why.

____

____

☐ 19. When you press the FWD push button alone, which contactor coil is energized? (refer to the respective pilot lights)

☐ F ☐ R

☐ 20. When you press the REV push button alone, which contactor coil is energized? (refer to the respective pilot lights)

☐ F ☐ R

☐ 21. Does pressing the FWD and REV push buttons energize both contactor coils simultaneously?

☐ Yes ☐ No

☐ 22. When both push buttons are pressed, which contactor coil(s) energize(s), in regard to the order in which the corresponding push buttons were pressed?

☐ The first ☐ The second ☐ Both ☐ None

☐ 23. Perform the Lockout/Tagout procedure.

Reversing starter with push button and mechanical interlock

☐ 24. Connect the circuit shown in Figure 3-9, this time using the two contactors from the Dual Contactors module.

☐ 25. Perform the Energizing procedure.

Determine the motor rotation direction as you press the FWD push button.

☐ Clockwise ☐ Counterclockwise

☐ 26. Press the STOP push button and wait for the motor to stop.

☐ 27. Determine the motor rotation direction as you press the REV push button.

☐ Clockwise ☐ Counterclockwise

☐ 28. While the motor is running in the reverse direction, press the FWD push button. Does the motor direction change? Explain what happens, considering that the circuit now contains a mechanical interlock.

____

____

____

☐ 29. Press both push buttons simultaneously, and determine which contactor(s) energize(s), in regards to the order in which the corresponding push buttons were pressed.

☐ The first ☐ The second ☐ Both ☐ None

☐ 30. Press the FWD push button to start the motor. To simulate a stuck contactor, manually hold the forward contactor plunger down (using the tip of a pen). Press the REV push button.

Does the motor still run in the forward direction? Explain why.

____

____

☐ 31. Does mechanical interlocking offer protection against stuck contactors?

☐ Yes ☐ No

☐ 32. Turn the individual power switch of the AC Power Supply off, disconnect the circuit, remove the magnetic labels, and return the equipment to the storage location.

CONCLUSION

Reversing magnetic starters are built with two contactors, one per rotation direction. If both contactors are actuated at the same time, a short-circuit can occur. This is why electrical and/or mechanical interlocks are used.

Push button interlocking is an electrical means of disabling two contactors actuation. When a push button is pressed, the circuit controlling the other motor direction is automatically opened.

Mechanical interlocking uses a lever to artificially keep the second contactor de-energized, while the first coil is actuated. This method is more rugged in the way that it prevents short-circuits resulting from a stuck contactor.

Plugging is a method of making the motor brake faster. It is accomplished by reversing phases while the motor is running.

MULTIPLE PUSH BUTTONS

EXERCISE OBJECTIVE

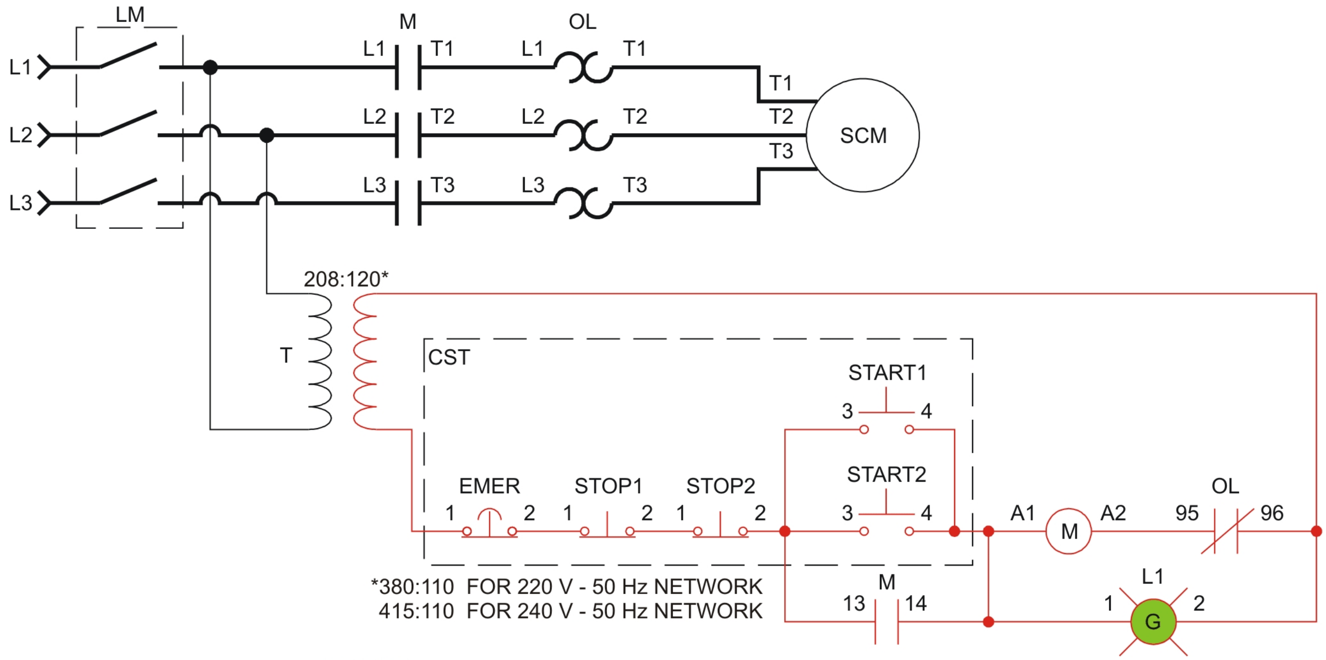
- Implement multiple push button control circuits.
- Understand the differences between stop push button and emergency button.

DISCUSSION

A standard three-wire push button control circuit may be expanded by adding one or more push button stations. With start push buttons connected in parallel and stop push buttons in series, the motor may be started or stopped from a number of separate locations. Figure 3-12 represents a multiple push button station.

Although they are both designed to stop a motor, stop push buttons and emergency buttons have one major difference. Contrary to the stop push button, the emergency button maintains its contact open after it has been pressed. It is also more accessible, with a larger contact surface.

MULTIPLE PUSH BUTTONS



LEGEND

CST	=	CONTROL STATION
EMER	=	EMERGENCY PUSH BUTTON (MAINTAINED CONTACT)
L1	=	MOTOR STARTED PILOT LIGHT (GREEN)
M	=	MAIN CONTACTOR
OL	=	OVERLOAD RELAY
SCM	=	SQUIRREL CAGE MOTOR
START1	=	START PUSH BUTTON #1 (MOMENTARY CONTACT)
START2	=	START PUSH BUTTON #2 (MOMENTARY CONTACT)
STOP1	=	STOP PUSH BUTTON #1 (MOMENTARY CONTACT)
STOP2	=	STOP PUSH BUTTON #2 (MOMENTARY CONTACT)
T	=	CONTROL VOLTAGE TRANSFORMER
LM	=	LOCKOUT MODULE

Figure 3-12. Multiple push button, three-wire control circuit.

Procedure Summary

In this Exercise, you will implement a multiple push button circuit including an emergency button. You will apply power to the circuit to verify that any start or stop push button can make the motor run or come to a halt.

You will then short-circuit the start push buttons to make the motor run inadvertently. This will help you discover how useful an emergency button can be in this type of situation.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

PROCEDURE

WARNING!

The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

Basic setup

☐ 1. Perform the Basic Setup and Lockout/Tagout procedures.

Multiple push button circuit

☐ 2. Install the Brake Motor, Inertia Wheel, and Safety Guard.

Connect the circuit shown in Figure 3-12.

☐ 3. Manually disengage the friction brake.

Perform the Energizing procedure.

☐ 4. Determine the motor operation for the following conditions:

- The motor starts when the START1 push button is pressed.

  ☐ Yes ☐ No

- The motor stops when the STOP1 push button is pressed.

  ☐ Yes ☐ No

- The motor starts when the START2 push button is pressed.

  ☐ Yes ☐ No

- The motor stops when the STOP2 push button is pressed.

  ☐ Yes ☐ No

☐ 5. What conclusion about start and stop controls in a multiple push button circuit can you draw from the preceding manipulations?

____

____

WARNING!

In the next procedure step, a fault will be added to the circuit, making the motor start automatically as power is turned on.

☐ 6. Turn off the Lockout Module.

Emergency Button

☐ 7. Install a lead linking terminals 13NO and 14NO of the Contactor module.

Stay alert as you turn on the Lockout Module. Describe and explain what happens.

____

____

____

☐ 8. What happens when you press and release a stop push button?

____

____

☐ 9. What happens when you press the Emergency Button?

____

____

☐ 10. Turn the individual power switch of the AC Power Supply off, disconnect the circuit, remove the magnetic labels, and return the equipment to the storage location.

CONCLUSION

A motor can be started or stopped from more than one location by using multiple push buttons. To implement such a circuit, the stop push buttons are connected in series and the start push buttons in parallel.

Emergency buttons are easily accessible and maintain their contact open after it has been pressed.

Unit 4

JOGGING CONTROL CIRCUITS

UNIT OBJECTIVE

Upon completion of this unit, you will be able to understand how friction brakes work, and connect selected jogging control circuits.

DISCUSSION OF FUNDAMENTALS

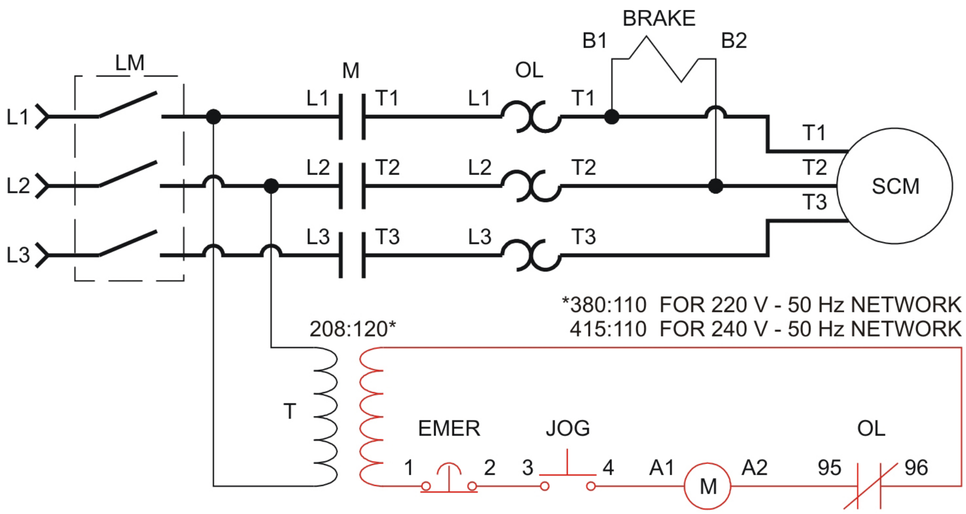
Jogging, or **inching**, is defined as the quickly repeated closure of a circuit to start a motor, for the purpose of accomplishing small movements of the driven machine. Compared to the running mode, the jogging mode has no holding circuit.

Jogging can be used to accomplish precise positioning in machine tools. It may also be used in lifting appliances (see Figure 4-1), where the operator is required to be present to make the machine accomplish a movement, hence improving the security level. Additionally, jogging can be practical to perform checks during maintenance operations.

Figure 4-1. Overhead traveling crane.

JOGGING CONTROL CIRCUITS

Figure 4-2 is a diagram of a simple jogging control circuit. Pressing the JOG push button momentarily closes the power contacts of the contactor. The motor then runs only as long as the JOG push button is pressed, because no holding contact is present to keep the contactor energized.



LEGEND

BRAKE = SOLENOID ACTUATED BRAKE COIL
M = MAIN CONTACTOR
OL = OVERLOAD RELAY
SCM = SQUIRREL CAGE MOTOR
JOG = JOG PUSH BUTTON (MOMENTARY CONTACT)
T = CONTROL VOLTAGE TRANSFORMER
EMER = EMERGENCY PUSH BUTTON (MAINTAINED CONTACT)
LM = LOCKOUT MODULE

Figure 4-2. Simple jogging circuit.

Many other configurations of jogging control circuits can be implemented. For example, many circuits will include a reversing starter for running and jogging operations, in both forward and reverse directions. For that purpose, arrangements of push buttons, control relays, and selector switches can be made. Exercise 4-3 presents some reversing circuits with jogging.

Friction brakes

Friction brakes are a common way of holding a position, in applications where the load is subject to a force such as gravity. For instance, they can be utilized in lifting appliances to prevent objects from falling in case of power losses. Friction brakes provide a faster and more precise means of stopping a motor than simply disconnecting power from the motor. That is why they are often used in jogging circuits. Friction brakes are also called **magnetic brakes**.

FRICTION BRAKES

EXERCISE OBJECTIVE

- Understand the construction and operation of friction brakes.

DISCUSSION

Friction brakes, or magnetic brakes, are used to secure (hold) the position of a motor in lifting appliances. They are also used to shorten motor stopping time and execute precise control.

Friction brakes operate in a manner similar to automobile brakes. Braking is accomplished by friction surfaces (shoes or pads), which come in contact with a disk mounted on the motor shaft. A solenoid usually controls the brake shoes or pads.

The action of friction brakes is smooth in either direction. This can be very useful when working with high inertia loads. As a result, they are often found on cranes, hoists, elevators, and other machines where soft braking is desirable.

Friction brakes can operate in two different ways:

- **Fail-safe**: Power is required to disengage the brake. Otherwise, the brake is set by default. Also called spring set, power off, electrically released, or safety brakes.

- **Non-fail-safe**: A braking force is applied when the brake solenoid is energized. Also called spring return, power on, or electrically set.

Friction brakes are rated according to their braking torque, which should be equal to or greater than full-load motor torque. The latter can be calculated from the following formula:

$$T = \frac{K \times P}{N} \times SF$$

where
- T is the motor full-load torque in N•m (lbf•ft)
- P is the power rating kW (hp)
- N is the motor rotation speed (r/min)
- SF is the service factor
- K is a constant 9549 (5252)

Note: *1 N·m = 0.738 lbf·ft*

FRICTION BRAKES

Brake maintenance primarily consists of shoe and pad replacements. To avoid inadvertent brake activation, the brake solenoid should be connected directly into the motor circuit, and not into the control circuit.

Figure 4-3 shows the friction brake, which is coupled to the end bell of the Brake Motor, Model 3176-A. The brake is released as long as its solenoid is actuated. But as soon as the solenoid de-energizes, the pads are pressed against the braking disk, forcing the motor to stop and hold its position. A label on the end bell of the Brake Motor shows how to wire the brake depending on the supplied voltage.

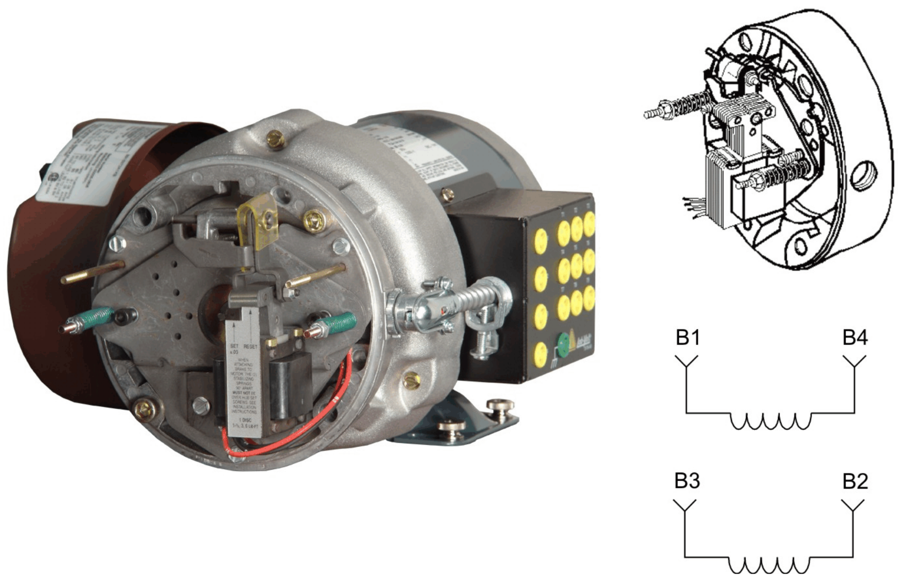


Figure 4-3. Friction brake.

The circuit shown in Figure 4-4 is a simplified motor circuit with a brake coil. When the motor is powered, the brake solenoid energizes. The friction brake then releases the pressure off the motor shaft, and the motor runs normally. Once power to the motor is removed, the brake coil de-energizes, pressure is applied to the shaft, and the motor stops smoothly. It is important to be aware that friction brakes will apply instantly in case of a power failure.

Note: Use the Brake Schematic found on the Brake Nameplate, not the above drawing!

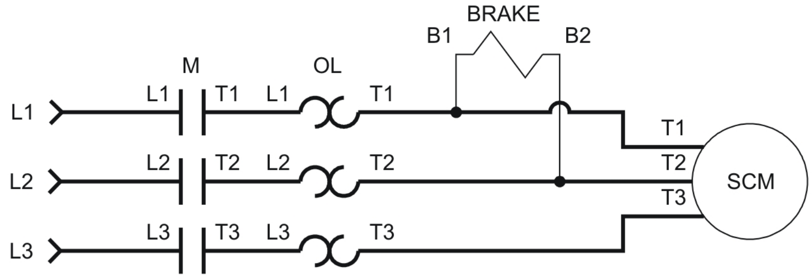


Figure 4-4. Friction brake in a motor circuit.

Procedure Summary

In the first part of this exercise, you will examine a friction brake label to determine its braking torque. You will then verify that this value is greater than the full-load motor torque, calculated from the ratings of the motor nameplate.

In the second part of the exercise, you will release and apply the brake manually. You will subsequently do the same via the Manual Starter, to make sure that the shaft turns freely when the brake is released and is blocked otherwise.

Finally, you will set up a simple motor starter circuit to test how the friction brake reduces the motor stopping time.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

PROCEDURE

WARNING!

The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

Basic setup

☐ 1. Perform the Basic Setup and Lockout/Tagout procedures.

Brake torque calculation

☐ 2. Install the Brake Motor, and the Inertia Wheel.

☐ 3. What is the braking torque rating indicated on the brake label?

> **Note:** *The braking torque rating is the same for the 208/380/415 V versions. If the SI values are not shown on the brake label, use the Imperial units for your calculations.*

Braking torque: ______

☐ 4. Enter the rating of the following parameters shown in the motor nameplate.

Power rating (hp): ______

Service factor: ______

Rotation speed (r/min): ______

☐ 5. Determine the full-load torque (T) of the motor using the formula of the DISCUSSION section and the ratings shown in the motor nameplate.

Full-load torque: ______

☐ 6. Is the braking torque greater than the motor full-load torque?

☐ Yes ☐ No

☐ 7. Set the friction brake knob to the RELEASE position.

Does the motor Inertia Wheel turn freely (no lead is connected to the motor terminals)?

☐ Yes, in both ways ☐ Yes, but in one direction only ☐ No

☐ 8. Explain what happens inside the friction brake.

____

____

☐ 9. Turn the friction brake knob to the normal position (applied). Does the motor Inertia Wheel turn freely?

☐ Yes, in both ways ☐ Yes, but in one direction only ☐ No

☐ 10. Explain what happens inside the friction brake.

____

____

Brake coil testing

CAUTION!

The friction brake is dual voltage. Be careful to use the appropriate connection for your system power supply, as indicated on the brake label.

☐ 11. Connect the circuit shown in Figure 4-5.

Note: *No lead is connected to the motor power terminals.*

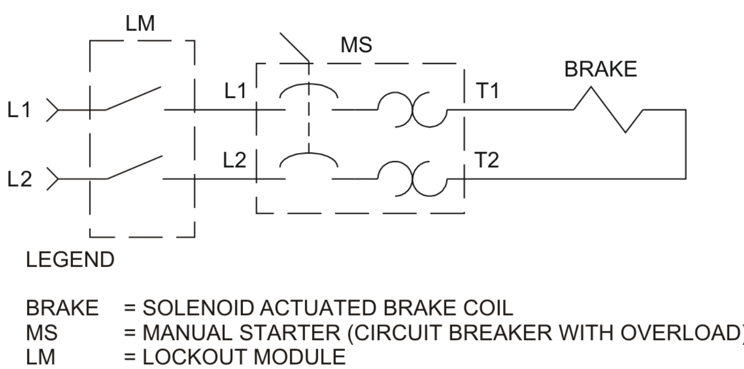


Figure 4-5. Brake coil testing circuit.

☐ 12. Set the overload potentiometer of the Manual Starter to the lowest value, and the knob to the O position.

Perform the Energizing procedure.

Set the knob of the Manual Starter to the I position.

A sound should come from the friction brake enclosure. Does the motor Inertia Wheel turn freely?

☐ Yes, in both ways ☐ Yes, but in one direction only ☐ No

☐ 13. Return the knob of the Manual Starter to the O position. Does the motor Inertia Wheel turn freely?

☐ Yes, in both ways ☐ Yes, but in one direction only ☐ No

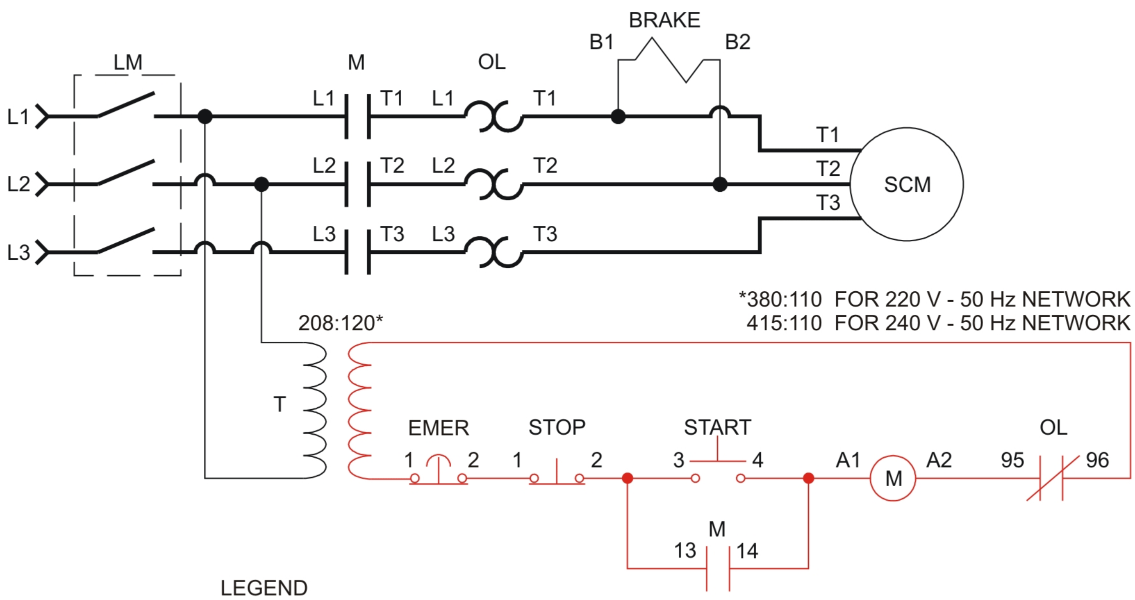
☐ 14. Following your last observations, in what manner does the brake operate?

☐ Fail-safe ☐ Non-fail-safe

☐ 15. Perform the Lockout/Tagout procedure.

Motor stopping with and without friction brake

☐ 16. Connect the circuit shown in Figure 4-6.



LEGEND

BRAKE = SOLENOID ACTUATED BRAKE COIL
M = MAIN CONTACTOR
OL = OVERLOAD RELAY
SCM = SQUIRREL CAGE MOTOR
START = START PUSH BUTTON (MOMENTARY CONTACT)
STOP = STOP PUSH BUTTON (MOMENTARY CONTACT)
T = CONTROL VOLTAGE TRANSFORMER
EMER = EMERGENCY PUSH BUTTON (MAINTAINED CONTACT)
LM = LOCKOUT MODULE

Figure 4-6. Motor starter circuit with friction brake.

☐ 17. Apply the friction brake.

Install the Safety Guard.

Perform the Energizing procedure.

Press the START push button to start the motor.

Start the chronometer as you press the STOP push button. How long does it take for the motor to come to a complete stop?

Complete stop time: ______

☐ 18. Turn off the Lockout Module.

Disconnect the friction brake from the power lines.

Manually disengage the friction brake.

Turn on the Lockout Module.

Press the START push button to start the motor.

Start the chronometer as you press the STOP push button. How long does it take for the motor to come to a complete stop?

Complete stop time: ______

☐ 19. Did the motor stop faster or slower with the help of the friction brake?

☐ Faster ☐ Slower

☐ 20. Turn the individual power switch of the AC Power Supply off, disconnect the circuit, remove the magnetic labels, and return the equipment to the storage location.

CONCLUSION

In friction brakes, the movement of a solenoid makes shoes or pads come in contact with a disk mounted on the motor shaft. Fail-safe brakes, which apply automatically when power is turned off, provide an extra level of security to weight-lifting equipment.

Friction brakes are used in applications where a motor has to hold a certain position, and when quick and precise stops are required. Additionally, they provide a smooth braking action that can be useful with high inertia loads.

FRICTION BRAKES

To stop a motor, the braking torque must be greater than the motor torque. Therefore, friction brakes usually provide a braking torque greater than the full-load motor torque.

MOTOR STARTERS WITH JOGGING

EXERCISE OBJECTIVE

- Connect and test motor starter circuits with jogging capabilities.
- See the effect of friction brakes on position control.

DISCUSSION

Jogging (also called inching) is used when an operator desires to make a motor accomplish small movements, without having to press the stop button every time. With jogging control circuits, the starter is energized only as long as the jog button is pressed.

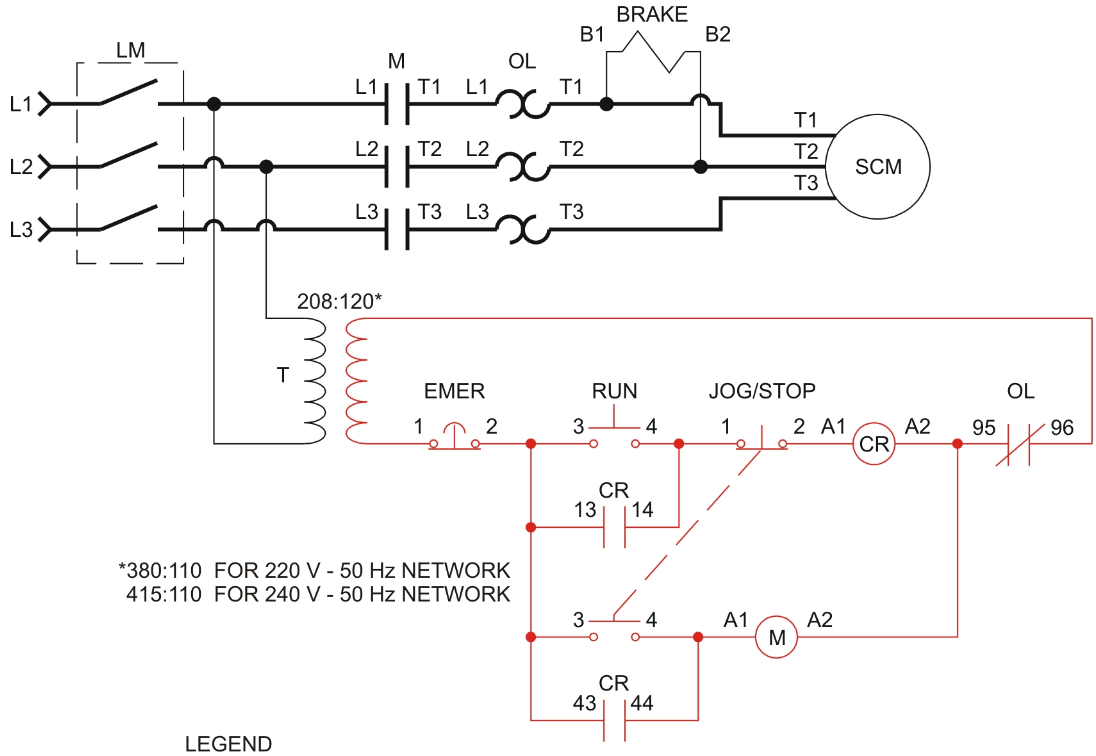
In jogging applications where precision is an important factor, the use of a friction brake greatly improves position control by stopping the motor rapidly. Repeated stops, however, reduce the life expectancy of brakes. Jogging operation is also tough for power contacts, the rapid and repeated switching of inrush currents considerably diminishing contactors' life.

Jog/Run circuits

Figure 4-7 shows a jog/run circuit using a control relay. When the RUN push button is pressed on, the control relay (CR) is energized and holding circuits are formed for both the control relay (CR) and the main contactor (M). The motor then starts and keeps running until the JOG/STOP push button is pushed, causing the control relay (CR) to de-energize.

Pressing the JOG/STOP push button when the system is at rest causes the motor to start and run normally until the JOG/STOP push button is released.

The friction brake applies when the motor stops.



LEGEND

BRAKE	=	SOLENOID ACTUATED BRAKE COIL
CR	=	CONTROL RELAY
EMER	=	EMERGENCY PUSHBUTTON (MAINTAINED CONTACT)
M	=	MAIN CONTACTOR
OL	=	OVERLOAD RELAY
SCM	=	SQUIRREL CAGE MOTOR
RUN	=	START PUSH BUTTON (MOMENTARY CONTACT)
JOG/STOP	=	STOP PUSH BUTTON (MOMENTARY CONTACT)
T	=	CONTROL VOLTAGE TRANSFORMER
LM	=	LOCKOUT MODULE

Figure 4-7. Jogging circuit with control relay.

Many other jogging circuits can be implemented. For example, a selector switch can be employed to switch between run and jog modes, the jog mode simply disabling the holding contacts.

Procedure Summary

In the first part of this exercise, you will set up a simple jogging circuit. You will make it work to verify that the motor only works when the JOG push button is pressed. You will also see that using a friction brake adds precision to the stop.

In the second part of the exercise, you will implement a jog/run circuit that uses a selector switch to change between jog and run modes.

In an additional exercise, you will be asked to replace the preceding circuit with one that includes three push buttons and a control relay.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

PROCEDURE

WARNING!

The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

Basic setup

☐ 1. Perform the Basic Setup and Lockout/Tagout procedures.

Simple jogging circuit

☐ 2. Install the Brake Motor, Inertia Wheel, and Safety Guard.

Connect the circuit shown in Figure 4-2.

Do not connect the friction brake coil at this moment.

☐ 3. Manually disengage the friction brake.

Perform the Energizing procedure.

Press the JOG push button. Does the motor start to run?

☐ Yes ☐ No

☐ 4. Release the JOG push button. Does the motor keep running?

☐ Yes ☐ No

☐ 5. Turn off the Lockout Module.

Connect the friction brake to the power lines.

Turn on the Lockout Module.

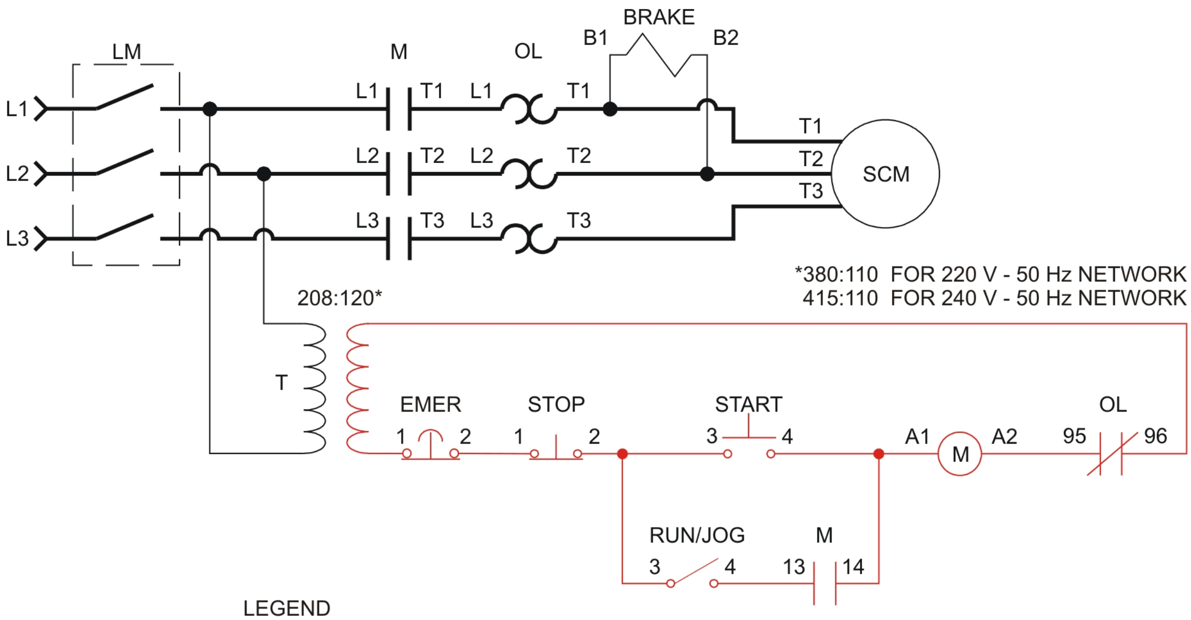
Press and release the JOG push button. Is stopping more precise when the friction brake is connected?

☐ Yes ☐ No

☐ 6. Perform the Lockout/Tagout procedure.

Jog/Run circuit with selector switch

☐ 7. Connect the circuit shown in Figure 4-8. Use the SS-1 contact of the Selector Switches module.



LEGEND

BRAKE = SOLENOID ACTUATED BRAKE COIL
M = MAIN CONTACTOR
OL = OVERLOAD RELAY
RUN/JOG = RUN/JOG SELECTOR SWITCH (MAINTAINED CONTACT)
SCM = SQUIRREL CAGE MOTOR
START = START PUSH BUTTON (MOMENTARY CONTACT)
STOP = STOP PUSH BUTTON (MOMENTARY CONTACT)
T = CONTROL VOLTAGE TRANSFORMER
EMER = EMERGENCY PUSH BUTTON (MAINTAINED CONTACT)
LM = LOCKOUT MODULE

Figure 4-8. Jog/Run circuit with selector switch.

☐ 8. Set the RUN/JOG selector switch of the Selector Switches to the O position (open contact).

Perform the Energizing procedure.

Press and release the START push button. What happens to the motor?

☐ The motor starts and stops.
☐ The motor stays off.
☐ The motor starts and keeps running.

☐ 9. Does the START push button work like a normal jog push button?

☐ Yes ☐ No

☐ 10. Set the RUN/JOG selector switch of the Selector Switches to the L position (closed contact).

Press and release the START push button. What happens to the motor?

☐ The motor starts and stops.
☐ The motor stays off.
☐ The motor starts and keeps running.

☐ 11. Does the START push button work like a normal start/stop motor starter circuit?

☐ Yes ☐ No

☐ 12. Do your observations confirm that a selector switch can be adequately used to select between jog and run modes?

☐ Yes ☐ No

☐ 13. Turn the individual power switch of the AC Power Supply off, disconnect the circuit, remove the magnetic labels, and return the equipment to the storage location.

ADDITIONAL EXERCISE

Jog/Run circuit using a control relay

Your client wants you to change the control circuit of Figure 4-8 to include three different push buttons: one for jogging, one for starting, and one for stopping.

To implement the new circuit, you decide to set up a jogging circuit with a control relay. Implement the Figure 4-7 circuit and verify that it corresponds to what the client wants.

CONCLUSION

In jogging control circuits, the motor starter remains energized only as long as the jog push button is pressed. No holding circuit is operating. Because of the repeated switching of high currents, jogging greatly reduces the life expectancy of contactors.

Various jogging circuits can be implemented, depending on the requirements of the application:

- Start and stop push buttons can be used along with a jogging circuit to enable continuous motor operation.
- Selector switches enable the choice between run and jog operating modes for the same start push button.
- Control relays make it possible for more specialized circuits. For example, in a jog/run circuit, they can make jogging independent of normal (run) operation.

Friction brakes improve control in jogging operations by reducing stopping time.

REVERSING STARTERS WITH JOGGING

EXERCISE OBJECTIVE

- Connect reversing starter circuits with jogging capabilities.

DISCUSSION

Some machine tool processes require both forward and reverse jog controls. When repeated clockwise and counterclockwise inching is necessary, a jogging control circuit with a reversing starter can be implemented.

Figure 4-9 is a schematic diagram of a jogging control circuit made of a reversing starter and a control relay. This circuit can be jogged while the motor is at a standstill or is rotating in either direction.

Pressing the FWD push button starts and runs the motor in the forward direction. Pressing the REV push button runs the motor in the reverse direction. The FJOG/STOP, or RJOG/STOP, push button must be pressed to stop the motor before changing direction, due to the mechanical interlock between the two contactors.

Pressing the FJOG/STOP push button runs the motor in the forward direction. Once the push button is released, the motor stops. The RJOG/STOP push button operates in the same manner, only in the reverse direction.

Note: A Control Relay (CR) AND a Dual Controller (F & R) must be used!

REVERSING STARTERS WITH JOGGING

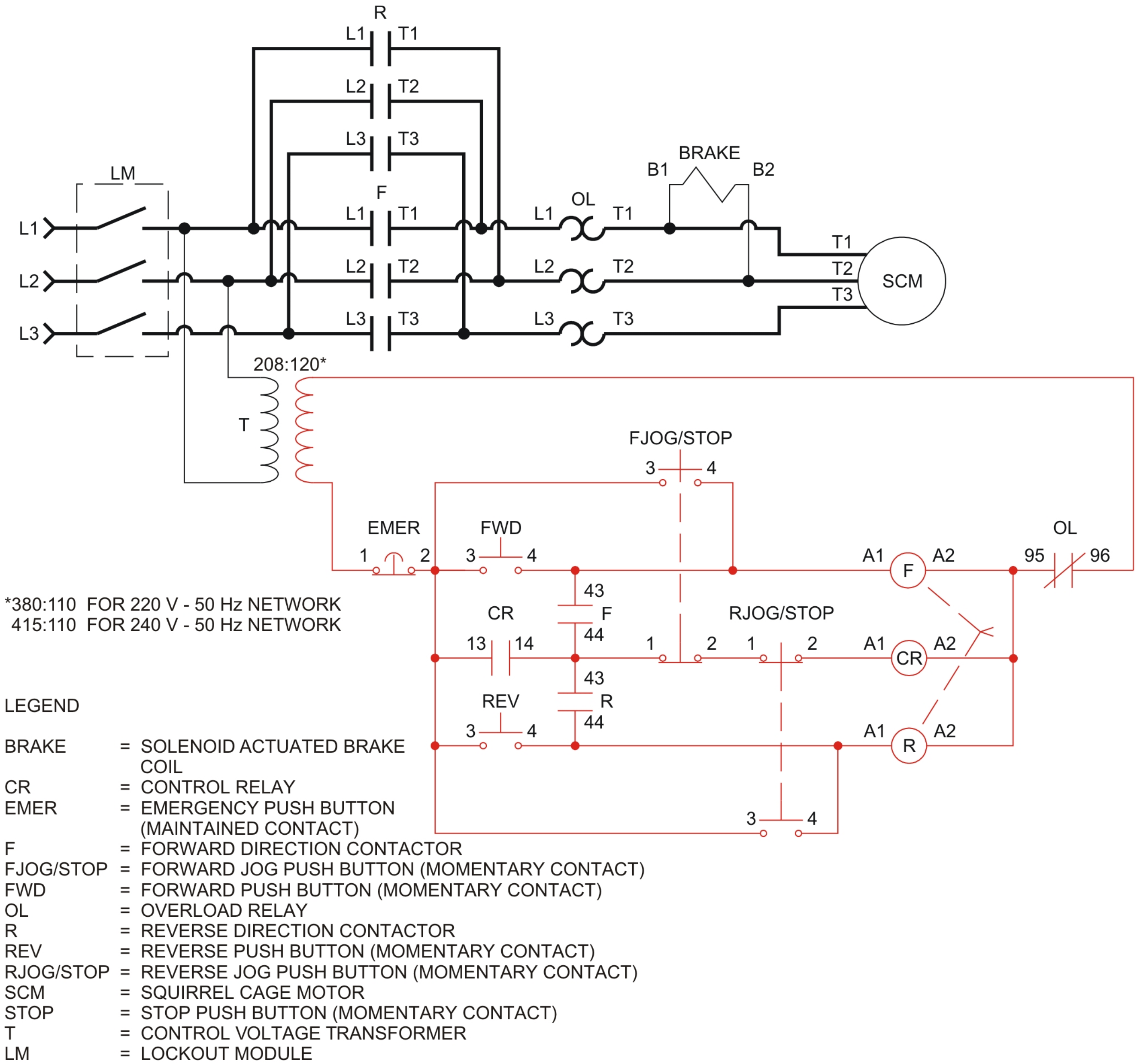
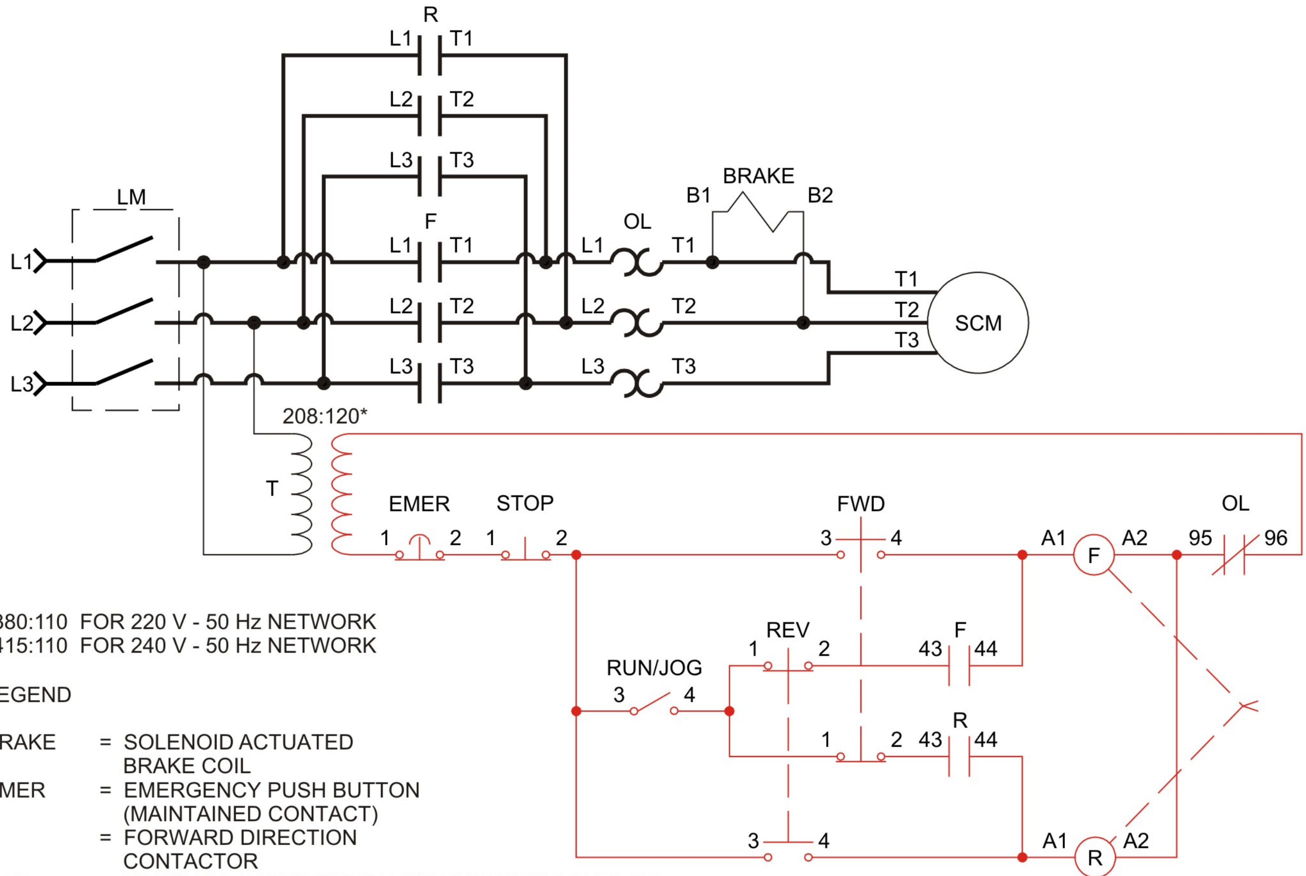


Figure 4-9. Reversing starter circuit with push button jogging.

Many other configurations of reversing circuits with jogging can be implemented. For example, a selector switch may be utilized to switch between jogging and running modes. Such a circuit is shown in Figure 4-10 and is proposed as an additional exercise.



*380:110 FOR 220 V - 50 Hz NETWORK
415:110 FOR 240 V - 50 Hz NETWORK

LEGEND

BRAKE	=	SOLENOID ACTUATED BRAKE COIL
EMER	=	EMERGENCY PUSH BUTTON (MAINTAINED CONTACT)
F	=	FORWARD DIRECTION CONTACTOR
FWD	=	FORWARD PUSH BUTTON (MOMENTARY CONTACT)
OL	=	OVERLOAD RELAY
R	=	REVERSE DIRECTION CONTACTOR
REV	=	REVERSE PUSH BUTTON (MOMENTARY CONTACT)
RUN/JOG	=	RUN/JOG SELECTOR SWITCH (MAINTAINED CONTACT)
SCM	=	SQUIRREL CAGE MOTOR
STOP	=	STOP PUSH BUTTON (MOMENTARY CONTACT)
T	=	CONTROL VOLTAGE TRANSFORMER
LM	=	LOCKOUT MODULE

Figure 4-10. Reversing starter circuit with selector switch jogging.

Procedure Summary

In the first part of this exercise, you will implement a reversing starter having jogging and running capabilities in both motor rotation directions. The circuit will use push buttons, as well as a control relay and a dual contactor with mechanical interlock to provide the aforementioned features. You will subsequently test the different push button combinations to verify that the circuit functions correctly.

An additional exercise is also proposed, in which you are asked to set up a comparable circuit that uses a selector switch to enable and disable jogging.

REVERSING STARTERS WITH JOGGING

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

PROCEDURE

WARNING!

The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

Basic setup

☐ 1. Perform the Basic Setup and Lockout/Tagout procedures.

Reversing starter with jogging circuit using push buttons and a control relay

☐ 2. Install the Brake Motor, Inertia Wheel, and Safety Guard.

Connect the circuit shown in Figure 4-9.

☐ 3. Perform the Energizing procedure.

Press the FWD push button. Does the motor start and keep running?

☐ Yes ☐ No

☐ 4. Which NO contact(s) is(are) kept closed?

☐ F (forward contactor)
☐ CR (control relay)
☐ R (reverse contactor)
☐ None

☐ 5. What happens when you momentarily press the FJOG/STOP push button?

☐ The motor keeps running.
☐ The motor stops and restarts.
☐ The motor stops completely.

☐ 6. Does the FJOG/STOP push button act as a stop push button?

☐ Yes ☐ No

☐ 7. Press the FJOG/STOP push button. What happens to the motor while you keep the FJOG/STOP push button pressed?

☐ The motor starts and stops.
☐ The motor stays off.
☐ The motor starts and keeps running.

☐ 8. What happens when the FJOG/STOP push button is released?

☐ The motor stops.
☐ The motor stays off.
☐ The motor keeps running.

☐ 9. Does the FJOG/STOP push button act as a jog push button?

☐ Yes ☐ No

☐ 10. Which contact(s) is(are) closed while you keep the FJOG/STOP push button pressed?

☐ F (forward contactor)
☐ CR (control relay)
☐ R (reverse contactor)
☐ None

☐ 11. Explain how the control circuit operates while you keep the FJOG/STOP push button pressed?

____

____

____

☐ 12. Repeat your observations in the reverse direction.

☐ 13. Make the motor run in the forward direction.

Press and hold the RJOG/STOP push button.

What happens to the motor when the RJOG/STOP push button is pressed?

☐ The motor keeps running in the same direction.
☐ The motor stops completely.
☐ The motor stops rapidly and starts in the reverse rotation direction.

☐ 14. What happens to the motor when the RJOG/STOP push button is released?

☐ The motor keeps running in the same direction.
☐ The motor comes to a stop.
☐ The motor stops rapidly and starts in the reverse rotation direction.

☐ 15. Do your observations confirm that the control circuit acts as a reversing starter having jogging and running capabilities in both motor rotation directions?

☐ Yes ☐ No

☐ 16. Turn the individual power switch of the AC Power Supply off, disconnect the circuit, remove the magnetic labels, and return the equipment to the storage location.

ADDITIONAL EXERCISE

Jog/Run reversing circuit using a selector switch

Your client wants you to change the control circuit of Figure 4-9 to incorporate a selector switch. He does not like the idea of having a control relay and wants the circuit to be simpler. He also wants a push button interlock permitting immediate reversal of motor rotation direction.

Finally, he would like to have a selector switch that, when turned to the JOG position, permits switching off a motor running continuously.

To fulfill the demands of the client, implement the Figure 4-10 circuit and verify that it corresponds to what the client wants.

CONCLUSION

A jogging control circuit using a reversing starter can be implemented when repeated clockwise and counterclockwise inching is necessary.

Push buttons and control relays can be utilized to set up a reversing control circuit with jogging. Using a selector switch permits employing the same push buttons for jogging and running modes.

REDUCED AC VOLTAGE STARTERS

UNIT OBJECTIVE

Upon completion of this unit, you will be able to utilize a primary resistor starter and a soft starter. You will also understand the underlying principles of reduced AC voltage starters.

DISCUSSION OF FUNDAMENTALS

The need for reduced current starting

Induction motors started with full voltage draw high inrush currents from power lines. When large motors are started, this phenomenon can result in power line disturbances and spikes in the electrical power demand (often leading to higher utility bills). Sudden starts are also tougher on the mechanical elements of the system, because the acceleration is more abrupt.

Figure 5-1 shows the current used by an induction motor at various speeds. Note how the starting current is high compared to the running current, until the motor reaches its fully rated speed.

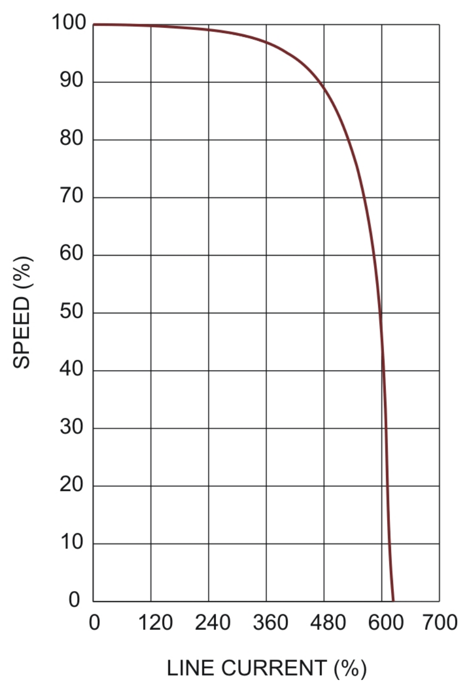


Figure 5-1. Induction motor current at various speeds.

Typical starting methods

Reduced voltage and current methods are often employed to limit the negative consequences of direct-on-line starting. Common alternate motor starting techniques are:

- **Primary resistor starters**: A resistive device is connected in series with the motor to produce a voltage drop for starting. The resistive device is shorted after the motor has accelerated to a certain point.

- **Autotransformer starters**: A tapped autotransformer is included in the circuit to provide specified reduced voltage for starting the motor.

- **Part-winding starters**: This starting method requires the **stator** windings of the motor to be divided into two or more equal parts. During starting, only a part of the winding is powered by full voltage, thus limiting the current and torque. All parts of the windings are later connected in parallel for normal operation.

- **Wye-delta starters**: The stator is **wye** connected for starting and **delta** connected for running. This method requires a motor designed for this purpose, in which no internal connection is made.

- **Solid-state starters**: A soft starter provides gradually increased voltage to the motor. The device is shorted once in running operation.

- **Variable frequency drive**: AC drives initially apply low frequency and voltage to the motor. This avoids high inrush current, while producing high starting torque.

In the following Unit, you will experiment with two reduced AC voltage methods, namely the primary resistor and the solid-state starters.

PRIMARY RESISTOR STARTERS

EXERCISE OBJECTIVE

- Understand how primary resistor starters operate.

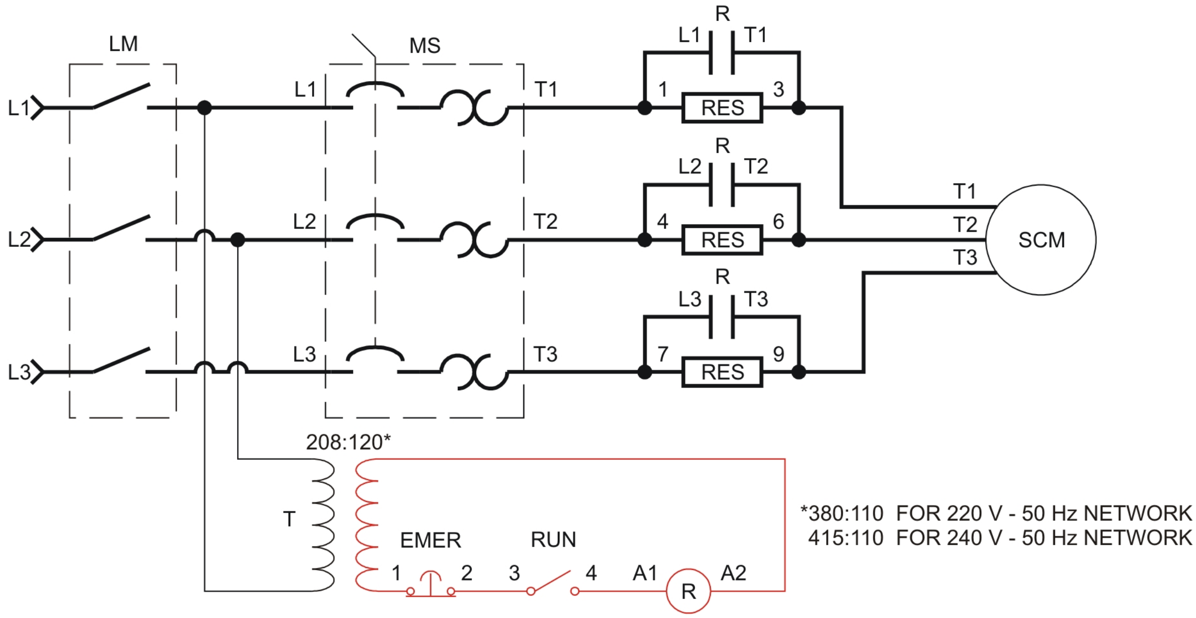
DISCUSSION

High starting torque can result in sudden acceleration and damage to the driven machinery. Excessive current inrush is likely to provoke unwanted power line disturbances. Primary resistor starters can be used to start motors where limited torque or inrush current is required. This type of starter provides smooth acceleration without the line current surges usually experienced with other reduced voltage methods.

Primary resistor starters have resistors connected in series, between each line and the motor. The presence of resistors reduces the voltage applied to the motor, but they produce heat. The lesser potential results in minimized motor starting current. But since motor torque is proportional to the square of the potential, the starting torque is low. As a result, this solution is impractical for systems such as conveyors, which require high torque upon starting.

One or more stages of resistors can be implemented, depending upon the motor size and the desired starting smoothness. More steps provide a more gradual acceleration. The resistors are bypassed by contactors when the motor reaches a certain speed, so that the motor eventually runs on full line voltage.

A typical resistor starter circuit is shown in Figure 5-2. When the Manual Starter is turned on, the resistors are connected in series with the motor. A voltage drop occurs across the resistors and the motor starts on reduced voltage. Once the motor has reached a sufficient speed, the operator shorts the resistors by closing the selector switch commanding the run contactor. The motor is then connected across full line voltage.



LEGEND

MS	=	MANUAL STARTER (CIRCUIT BREAKER WITH OVERLOAD)
R	=	FULL VOLTAGE RUNNING CONTACTOR
RES	=	STARTING RESISTOR
RUN	=	RUN SELECTOR SWITCH (MAINTAINED CONTACT)
SCM	=	SQUIRREL CAGE MOTOR
T	=	CONTROL VOLTAGE TRANSFORMER
EMER	=	EMERGENCY PUSH BUTTON (MAINTAINED CONTACT)
LM	=	LOCKOUT MODULE

Figure 5-2. Primary resistor circuit.

Procedure Summary

In the first part of this exercise, you will set up a circuit to measure the Brake Motor locked rotor current. You will then compare this value with the motor full-load current (FLA) to see that it is many times higher.

In the second part of the exercise, you will implement a circuit including resistors in series with the motor. You will observe that the presence of the resistors diminishes the motor locked rotor current, and consequently, the motor starting current.

Finally, you will start the motor with primary resistors. You will discover that resistors are bypassed during normal operation to avoid making the motor run under lower voltage and lose power through resistors.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

PROCEDURE

WARNING!

The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

Basic setup

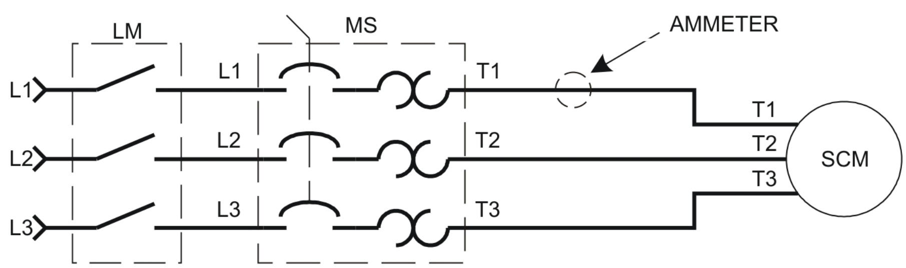
☐ 1. Perform the Basic Setup and Lockout/Tagout procedures.

Brake Motor locked rotor current without resistors

☐ 2. Install the Brake Motor, Inertia Wheel, and Safety Guard.

Connect the circuit shown in Figure 5-3.

WARNING: Ammeter MUST be a Clamp-on ammeter ONLY. DO not connect multimeter as an ammeter!



LEGEND

MS = MANUAL STARTER (CIRCUIT BREAKER WITH OVERLOAD)
SCM = SQUIRREL CAGE MOTOR
LM = LOCKOUT MODULE

Figure 5-3. Manual Starter circuit.

☐ 3. Apply the friction brake.

Clamp an ammeter around a motor power lead.

Set the knob of the Manual Starter to the O position.

Perform the Energizing procedure.

CAUTION!

Turn off power after a maximum of 3 seconds to prevent damage to the equipment.

☐ 4. Observe the ammeter display as you set the knob of the Manual Starter to the I position for three seconds.

Note the locked rotor current going through the power line. Repeat for a better result.

Locked rotor current: ______

☐ 5. What prevents the motor from rotating?

____

☐ 6. Set the knob of the Manual Starter to the O position.

What is the full-load ampere rating (FLA) indicated on the nameplate of the Brake Motor?

Full-load ampere rating: ______

☐ 7. How many times the full-load ampere rating (FLA) is the locked rotor current?

Number of times: ______

☐ 8. Perform the Lockout/Tagout procedure.

Brake Motor locked rotor current with resistors

☐ 9. Connect the circuit shown in Figure 5-2. Use the SS-1 contact of the Selector Switches module.

☐ 10. Apply the friction brake.

Set the RUN selector switch of the Selector Switches to the O position (open contact).

Clamp an ammeter around a motor power lead.

Perform the Energizing procedure.

Note: *The resistors must be connected by their extremities and not by the intermediate taps, to obtain maximum resistance.*

CAUTION!

Turn off power after a maximum of 3 seconds to prevent damage to the equipment.

☐ 11. Observe the ammeter display as you set the knob of the Manual Starter to the I position for three seconds.

Note the locked rotor current going through the power line. Repeat for a better result.

Locked rotor current: ______

☐ 12. Set the knob of the Manual Starter to the O position.

How many times the full-load ampere rating (FLA) is the locked rotor current measured with resistors?

Number of times: ______

☐ 13. Does the presence of primary resistors diminish the motor locked rotor current? Explain why.

____

____

Motor power line voltage with primary resistors

☐ 14. Remove the ammeter and install a voltmeter between two motor power lines.

Manually disengage the friction brake.

Set the knob of the Manual Starter to the I position, and wait for the motor to reach full speed.

What is the voltage between the power lines?

Voltage between the lines with primary resistors: ______

Motor power line voltage without primary resistors

☐ 15. Set the RUN selector switch of the Selector Switches to the L position (closed contact) to bypass the resistors via the R contactor. Note the voltage between the two lines.

Voltage between the lines without primary resistors: ______

☐ 16. Is motor input voltage higher or lower, if resistors are not bypassed during motor operation?

☐ Higher ☐ Lower

☐ 17. Do resistors dissipate power if they are not bypassed?

☐ Yes ☐ No

CAUTION!

The Starting Resistors module may be hot. Be careful when you handle this module after use.

☐ 18. Turn the individual power switch of the AC Power Supply off, disconnect the circuit, remove the magnetic labels, and return the equipment to the storage location.

CONCLUSION

Primary resistor starters can be used for starting motors at a reduced voltage. Resistors are inserted in series with the motor terminals and power lines to create a drop in the input voltage.

Reduced voltage is utilized to protect machinery from the shock of sudden acceleration and prevent power line disturbances resulting from high inrush currents. Once the motor reaches a sufficient speed, the starting resistors are bypassed by a set of contactors, allowing the motor to operate at full line voltage.

SOFT STARTERS

EXERCISE OBJECTIVE

- Understand how soft starters operate.

DISCUSSION

Soft starters are solid-state devices providing gradual voltage increase, for the purpose of starting a motor smoothly. Most soft starters also perform soft stops, to make the motor run-down longer than if the motor were merely to coast to a stop. Compared to primary resistor starters, soft starters present major benefits:

- No wearing parts
- Easy adjustments
- Less space needed
- Gradual voltage increase (no steps)
- Reduced power losses

By lowering the input voltage, a soft starter diminishes the motor current. The motor torque, which is proportional to the square of motor voltage, is also lessened. This explains why a soft started motor does not accelerate suddenly. However, if the starting voltage is too low, the motor will not start immediately, but will nevertheless heat up during that time.

For example, if the starting voltage is at 30%, the torque produced will only be about 9 % of the normal value. This might not be enough to start the motor. A soft starter is correctly set when the motor starts smoothly and runs up rapidly to its rated speed.

Figure 5-4 shows the Soft Starter, Model 3186. This device has three adjustment potentiometers, which are controlling:

- Ramp-up time, in the range from 0 to 20 seconds
- Starting voltage, in the range from approximately 40 to 100% of motor full voltage
- Ramp-down time, in the range from 0 to 20 seconds

Terminals of the Soft Starter are as follows:

- A2-A1: supply voltage
- IN1-A1: auxiliary control voltage
- 1L1, 3L2, and 5L3 connect to three-phase power supply
- 2T1, 4T2, and 6T3 connect to motor terminals

CAUTION!

Supply voltage must be provided to the Soft Starter before power is applied to terminals 1L1, 3L2, and 5L3, in order for the Soft Starter to work properly.

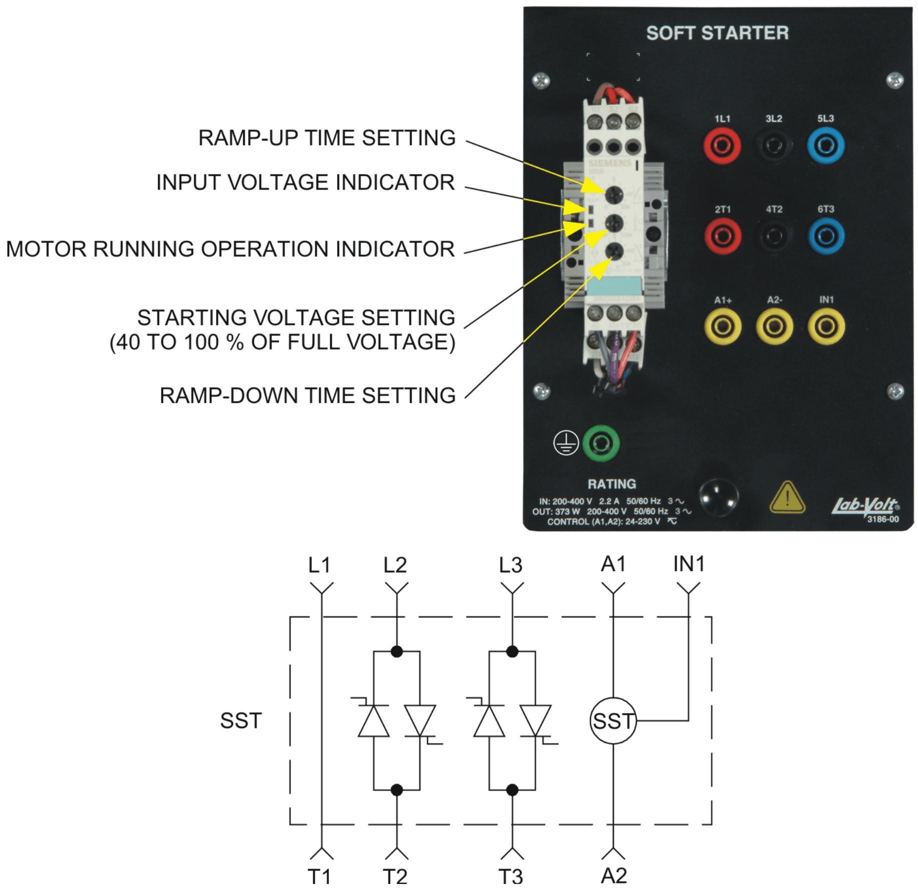
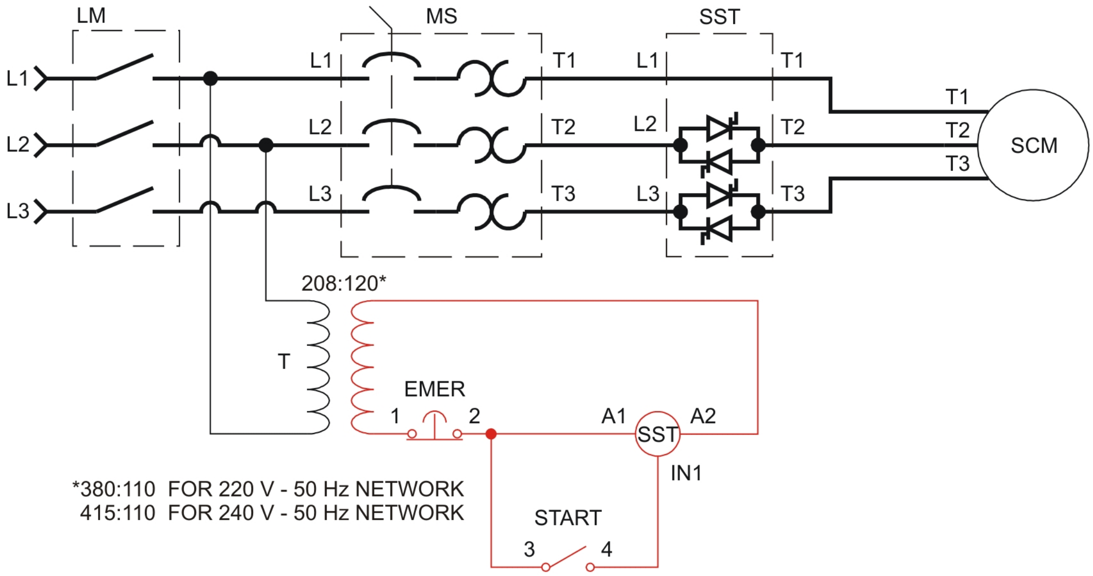


Figure 5-4. Soft Starter, Model 3186.

Note: *Settings of the three potentiometers are scanned before each auxiliary voltage switching operation. If, for example, the starting time setting is changed while the motor is running up, the change does not come into effect until the next start.*



LEGEND

MS	=	MANUAL STARTER (CIRCUIT BREAKER WITH OVERLOAD)
SCM	=	SQUIRREL CAGE INDUCTION MOTOR
SST	=	SOFT STARTER
START	=	START SELECTOR SWITCH (MAINTAINED CONTACT)
T	=	CONTROL VOLTAGE TRANSFORMER
EMER	=	EMERGENCY PUSH BUTTON (MAINTAINED CONTACT)
LM	=	LOCKOUT MODULE

Figure 5-5. Soft Starter circuit.

A simple soft starter control circuit is presented in Figure 5-5. When power is applied to the circuit, supply voltage is applied to the Soft Starter, as shown by the READY indicator on the device. When the Manual Starter is turned on, the Soft Starter input terminals are energized. When the START selector switch actuates, the *Ramp-up* function begins, and the READY indicator begins flashing. The motor is then gradually energized. Once the READY light turns off and the RUN indicator turns on, it is a sign that the device has switched to normal (full voltage) running operation. When the selector switch is turned off, the *Ramp-down* function starts, the RUN light turns off, and the READY indicator begins flashing. When the READY indicator lights up continuously, the *Ramp-down* function is over.

Note: *Like other control devices, soft starters have their own IEC utilization categories. AC-53a are starters that are not bypassed and AC-53b are starters that are bypassed during run to cool them down. The Soft Starter, Model 3186, is AC-53a rated.*

Figure 5-6 is an example of the Soft Starter behavior. The ramp-up time is set to 10 s, the starting voltage to 50%, and the ramp-down time to 15 s. Power is applied to the circuit at t = 0 s. At t = 5 s, the selector switch is turned on and starting voltage is applied to the motor. The voltage is gradually increased to its nominal value over the next 10 s (ramp-up time). The motor then runs under normal conditions until the selector switch is turned off at t = 40 s. During the following 15 seconds (ramp-down time), the motor voltage is gradually reduced to zero.

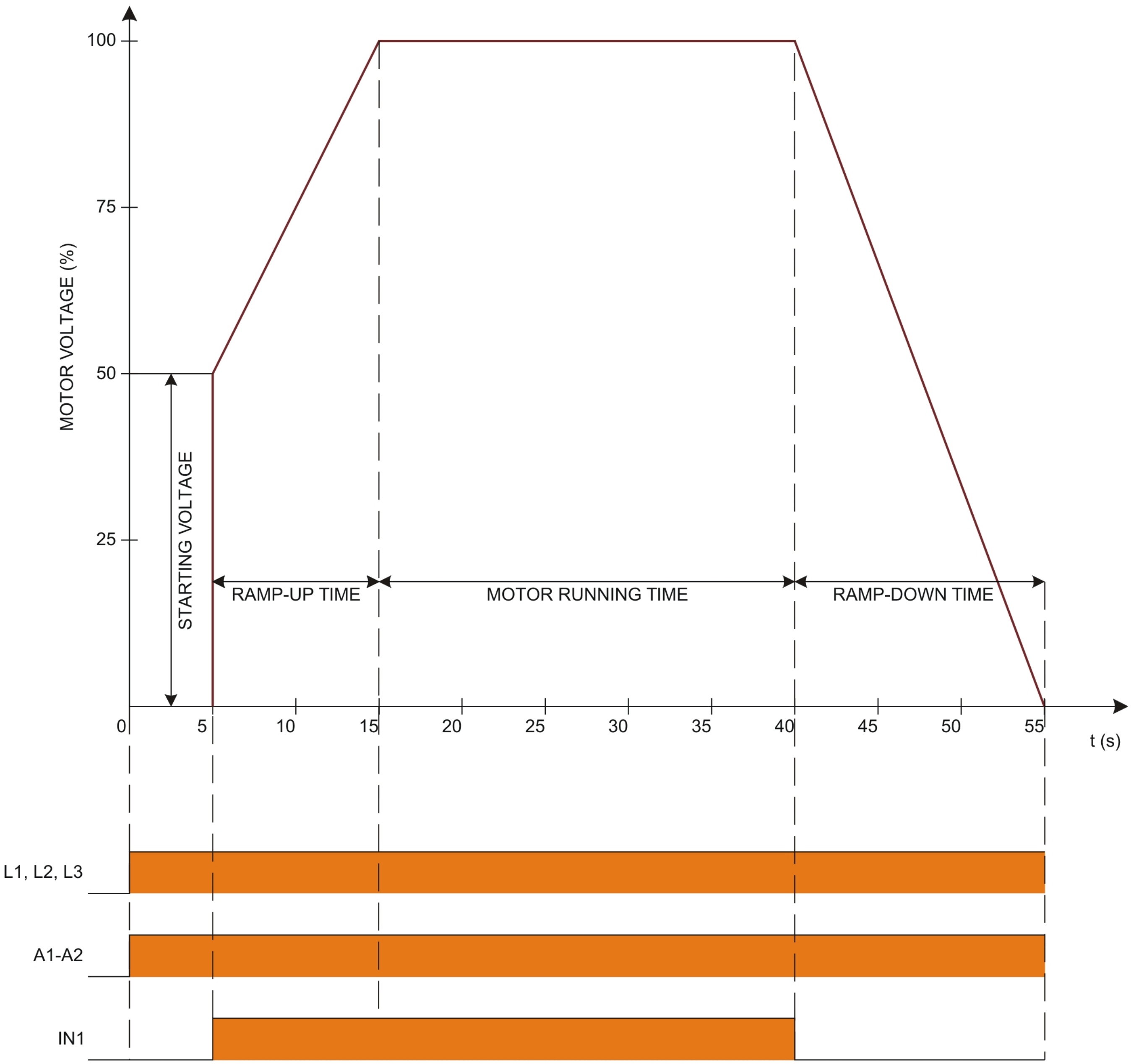


Figure 5-6. Example of Soft Starter behavior.

Procedure Summary

In the first part of this exercise, you will observe the influence of low starting voltage values. You will see that a starting voltage that is too low is not effective, because the motor does not start promptly.

In the second and third parts of the exercise, you will test the influence of different ramp-up and ramp-down time settings on accelerating and decelerating times. You will observe how voltage is gradually increased and decreased with the help of a voltmeter.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

PROCEDURE

WARNING!

The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

Basic setup

☐ 1. Perform the Basic Setup and Lockout/Tagout procedures.

must be provided to the Soft Starter before power is applied to terminals 1L1, 3L2, and 5L3, in order for

Starting voltage setting

☐ 2. Install the Brake Motor, Inertia Wheel, and Safety Guard.

Connect the circuit shown in Figure 5-5. Use the SS-1 contact of the Selector Switches module.

☐ 3. Manually disengage the friction brake.

Set the knob of the Manual Starter to the I position.

Set the START selector switch of the Selector Switches to the O position (open contact).

Set the Soft Starter with the following parameter values:

- Ramp-up time: 10 s
- Starting voltage: min position
- Ramp-down time: 0 s.

Perform the Energizing procedure.

☐ 4. Set the START selector switch to the L position (closed contact) for three seconds, then return the knob to the O position.

Does the motor start easily (during these three seconds)? Describe the motor acceleration.

____

____

☐ 5. Set the starting voltage potentiometer of the Soft Starter to the 12-o'clock position.

Set the START selector switch to the L position for three seconds, then return the knob to the O position.

Does the motor start more easily when the starting voltage is higher? Describe the motor acceleration.

____

____

Ramp-up time setting

☐ 6. Install a voltmeter between the motor's terminals T1 and T2.

Set the Soft Starter with the following parameter values:

- Ramp-up time: 20 s
- Starting voltage: 12-o'clock position
- Ramp-down time: 0 s.

☐ 7. Start the chronometer as you set the START selector switch to the L position. Observe the gradual increase of motor voltage.

How long does the Soft Starter take to supply full voltage to the motor?

Time: ______

☐ 8. Set the START selector switch to the O position.

Set the ramp-up time to 10 seconds.

Start the chronometer as you set the START selector switch to the L position. Observe the gradual increase of motor voltage.

How long does the Soft Starter take to supply full voltage to the motor?

Time: ______

Ramp-down time setting

☐ 9. Start the chronometer as you set the START selector switch to the O position. Observe the decrease of motor voltage.

How long does the Soft Starter take to stop supplying voltage to the motor (less than 2 V)?

Time: ______

☐ 10. Set the ramp-down time to 20 seconds.

Set the START selector switch to the L position, and wait for the RUN indicator of the Soft Starter to turn on.

Start the chronometer as you set the START selector switch to the O position. Observe the decrease of motor voltage.

How long does the Soft Starter take to stop supplying voltage to the motor (less than 2 V)?

Time: ______

☐ 11. Does increasing the ramp-down time make the motor stop more softly?

☐ Yes ☐ No

☐ 12. Turn the individual power switch of the AC Power Supply off, disconnect the circuit, remove the magnetic labels, and return the equipment to the storage location.

CONCLUSION

Soft starters enable smoother starting than direct-on-line starters. Besides, they offer many advantages compared to primary resistor starters: they have no wearing parts, are easy to adjust, need less space, provide gradual voltage changes, and do not dissipate much power.

Soft starters usually have three adjustments: starting voltage, ramp-up time, and ramp-down time.

A lower starting voltage reduces the inrush current upon starting. However, when the starting voltage is too, the motor produces heat and does not start immediately.

The ramp-up time is the time the soft starter takes to reach the rated motor voltage. The longer the time, the softer the start.

Ramp-down time is used to gradually reduce the motor voltage to zero for slower stop. Ramp-down is useful in applications where a controlled stop is needed.

TIME RELAY CIRCUITS

UNIT OBJECTIVE

Upon completion of this unit, you will understand how time relays work. You will also be able to utilize solid-state time relays in applications requiring time delays.

DISCUSSION OF FUNDAMENTALS

Time relays are used in control, starting, and protective circuits for all switching operations involving time delays. Different pilot devices are employed to control the process of energizing or de-energizing timing relays.

Four main categories of time relays are:

- **Dashpot**: Old technology in which a time delay results from air or liquid going through a valve opening at a variable speed.

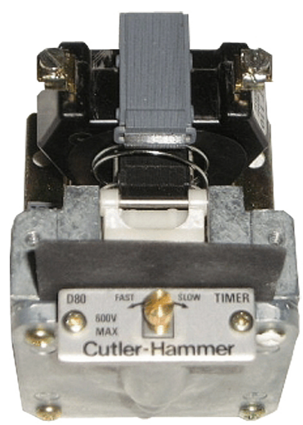


Figure 6-1. Dashpot time relay.

- **Synchronous clock (sequence timer)**: Contacts open and close at intervals depending on the position of the moving hands on a clock dial.

Figure 6-2. Synchronous Clock.

- **Solid-state**: The time delay is supplied by enclosed electronic devices. The Time Relay module, Model 3132, is of this type.

- **Programmable**: More complex control devices, such as programmable logic controllers (PLCs), often include timing functions.

Exercise 6-1

TIME RELAYS

EXERCISE OBJECTIVE

- Become familiar with time relay features and applications.

DISCUSSION

Lab-Volt's Time Relay, Model 3132, is a solid-state category time relay. This device, shown on Figure 6-3, has three adjustment potentiometers, which are controlling:

- Time delay value, in the range from 0 to 20 s
- Time delay adjustment, in the range from approximately 30 to 100% of the set time
- Function code, in the range from A to H

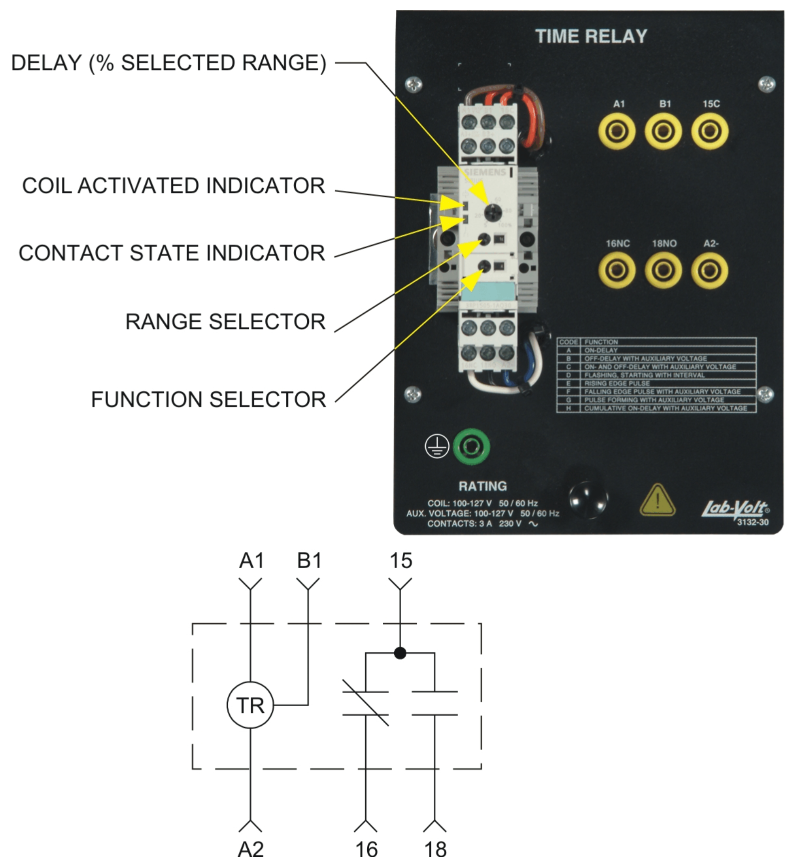


Figure 6-3. Time Relay, Model 3132.

Two indicator lights provide information about the Time Relay status. The one at the top indicates the coil state. The one at the bottom indicates the contact state.

Terminals of the Time Relay are as follows:

- A1–A2: supply voltage
- B1–A2: auxiliary voltage
- 15–16: NC contact
- 15–18: NO contact

Table 6-1 describes the different functions of this module with their associated code. The function codes are also indicated on the module faceplates.

FUNCTION	CODE	DESCRIPTION
On-delay	A	NO contact closes t seconds after the supply coil is energized, providing that the coil remains energized that long. No auxiliary voltage is needed.
Off-delay	B	NO contact closes as soon as the auxiliary voltage is turned on but opens t seconds after it is removed. The supply voltage is always on.
On- and Off-delay	C	Combination of on-delay and off-delay functions, with the same time delay t for on and off switching. The supply voltage is always on.
Flashing	D	NO contact opens and closes at equal intervals of t seconds, after the supply coil is energized. No auxiliary voltage is needed.
Rising edge pulse	E	NO contact closes for t seconds as soon as the supply coil is switched on. No auxiliary voltage is needed.
Falling edge pulse	F	NO contact closes for t seconds as soon as the auxiliary coil is switched off. The supply voltage is always on.
Auxiliary rising edge pulse	G	NO contact closes for t seconds as soon as the auxiliary coil is switched on. The supply voltage is always on.
Cumulative on-delay	H	NO contact closes once the auxiliary coil has been energized for a total of t seconds and opens next time the auxiliary coil de-energizes. The supply voltage is always on.

Table 6-1. Time relay functions.

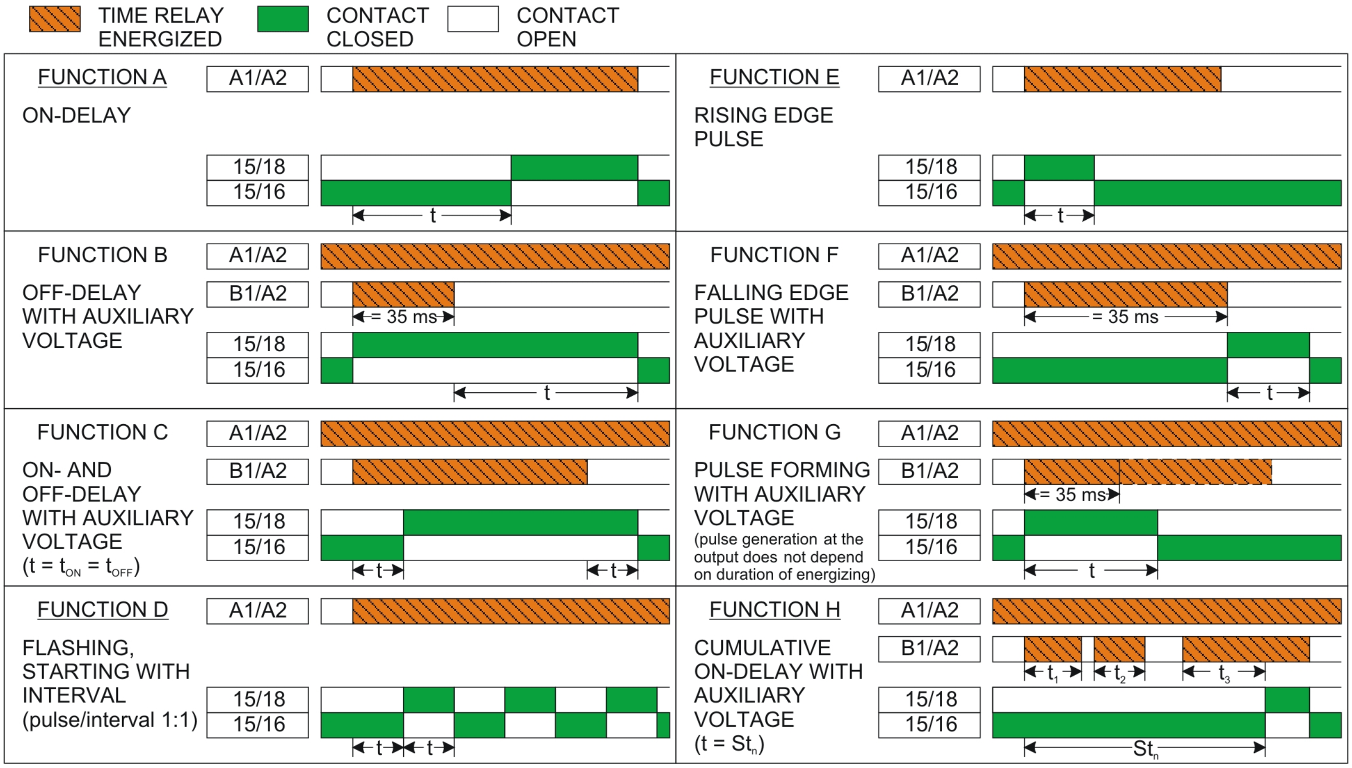


Figure 6-4. Time diagram.

Figure 6-5 shows a time-delay circuit. When the selector switch closes, the time relay coil is energized. If an on-delay is set, the NO contact closes after the preset time t, turning on the green light. Opening the selector switch de-energizes the circuit, turning off the green light.

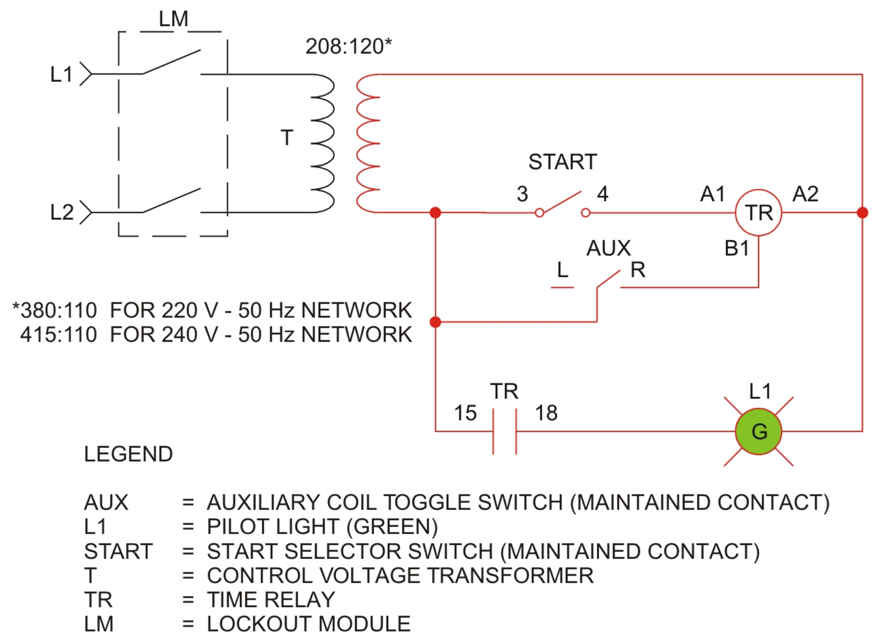


Figure 6-5. Basic time-delay circuit.

Procedure Summary

In the first part of this exercise, you will implement an *On-delay* function in a pilot light circuit. You will observe that this function works with supply voltage only and that a delay is produced before the NO contact closes. You will then modify the time adjustment potentiometer to change the set time delay.

In the second part of the exercise, you will change the time function for *Off-delay*. You will observe that this function works with supply and auxiliary voltages. A delay is produced after auxiliary voltage is lost, before the NO contact opens. The supply voltage must be provided at all times to make this function work.

In the third part of the exercise, you will try the *On- and Off-delay* function. You will discover that a delay is produced before the NO contact opens or closes, following a change in the auxiliary voltage. The supply voltage must be provided at all times to make this function work.

In the last part of the exercise, you will be asked to make a pilot light flash at a given rate. To do so, you will set the function code and time-delay value potentiometers to appropriate values.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

PROCEDURE

WARNING!

The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

Basic setup

☐ 1. Perform the Basic Setup and Lockout/Tagout procedures.

On-delay function

☐ 2. Connect the circuit shown in Figure 6-5. Use the SS-1 contact of the Selector Switches module.

☐ 3. Set the Time Relay with the following parameter values:

- Function code: A (On-delay)
- Time-delay value: 10 s
- Time-delay adjustment: 100%

Set the START selector switch of the Selector Switches to the O position (open contact).

☐ 4. Perform the Energizing procedure.

Start the chronometer as you set the START selector switch of the Selector Switches to the L position (closed contact).

Does the L1 pilot light turn on?

☐ Yes, immediately ☐ Yes, after a delay of ___ s ☐ No

☐ 5. Start the chronometer as you set the START selector switch to the O position (open contact).

Does the L1 pilot light turn off?

☐ Yes, immediately ☐ Yes, after a delay of ___ s ☐ No

☐ 6. Change the time-delay adjustment to 50%.

Start the chronometer as you set the START selector switch to the L position.

Does the L1 pilot light turn on?

☐ Yes, immediately ☐ Yes, after a delay of ___ s ☐ No

☐ 7. Set the START selector and the AUX toggle switches of the Selector Switches to the O position.

Off-delay function

☐ 8. Set the Time Relay with the following parameter values:

- Function code: B (Off-delay)
- Time-delay value: 10 s
- Time-delay adjustment: 100%

☐ 9. Start the chronometer as you set the START selector switch to the L position.

Does the L1 pilot light turn on?

☐ Yes, immediately ☐ Yes, after a delay of ___ s ☐ No

☐ 10. Explain what happens (refer to the Figure 6-4 time diagram if necessary).

____

____

____

☐ 11. Start the chronometer as you set the AUX toggle switch to the R position.

Does the L1 pilot light turn on?

☐ Yes, immediately ☐ Yes, after a delay of ___ s ☐ No

☐ 12. Explain what happens (refer to the Figure 6-4 time diagram if necessary).

____

____

____

☐ 13. Start the chronometer as you set the AUX toggle switch to the O position.

Does the L1 pilot light turn off?

☐ Yes, immediately ☐ Yes, after a delay of ___ s ☐ No

☐ 14. Explain what happens (refer to the Figure 6-4 time diagram if necessary).

____

____

____

☐ 15. Set the START selector and the AUX toggle switches to the O position.

On- and Off-delay function

☐ 16. Set the Time Relay with the following parameter values:

- Function code: C (On- and Off-delay)
- Time-delay value: 10 s
- Time-delay adjustment: 100%

☐ 17. Start the chronometer as you set the START selector switch to the L position.

Does the L1 pilot light turn on?

☐ Yes, immediately ☐ Yes, after a delay of ___ s ☐ No

☐ 18. Explain what happens (refer to the Figure 6-4 time diagram if necessary).

____

____

____

☐ 19. Start the chronometer as you set the AUX toggle switch to the R position.

Does the L1 pilot light turn on?

☐ Yes, immediately ☐ Yes, after a delay of ___ s ☐ No

☐ 20. Explain what happens (refer to the Figure 6-4 time diagram if necessary).

____

____

____

☐ 21. Start the chronometer as you set the AUX toggle switch to the O position.

Does the L1 pilot light turn off?

☐ Yes, immediately ☐ Yes, after a delay of ___ s ☐ No

☐ 22. Explain what happens (refer to the Figure 6-4 time diagram if necessary).

____

____

____

☐ 23. Set the START selector and the AUX toggle switches to the O position.

Flashing

☐ 24. Using the same circuit, set the time relay so that the L1 pilot light turns on or off every 1.5 seconds with a time-delay adjustment potentiometer set to 50%.

What function code and time-delay value have you set on the Time Relay?

Function code: ______

Time-delay value: ______

☐ 25. Confirm your settings by testing the circuit operation.

☐ 26. Turn the individual power switch of the AC Power Supply off, disconnect the circuit, remove the magnetic labels, and return the equipment to the storage location.

CONCLUSION

Time relays enable delaying an action in a control, starting, or protective circuit. Dashpot and synchronous clock time relays are the oldest and most simple types of time relays. They are operated by mechanical means.

Solid-state and programmable time relays are electronically piloted and permit more functions. On-delay, off-delay, flashing, rising edge pulse, and falling edge pulse are some common time functions.

Exercise 6-2

PLUGGING WITH TIME RELAYS

EXERCISE OBJECTIVE

- Understand how a time relay can be used for plugging.

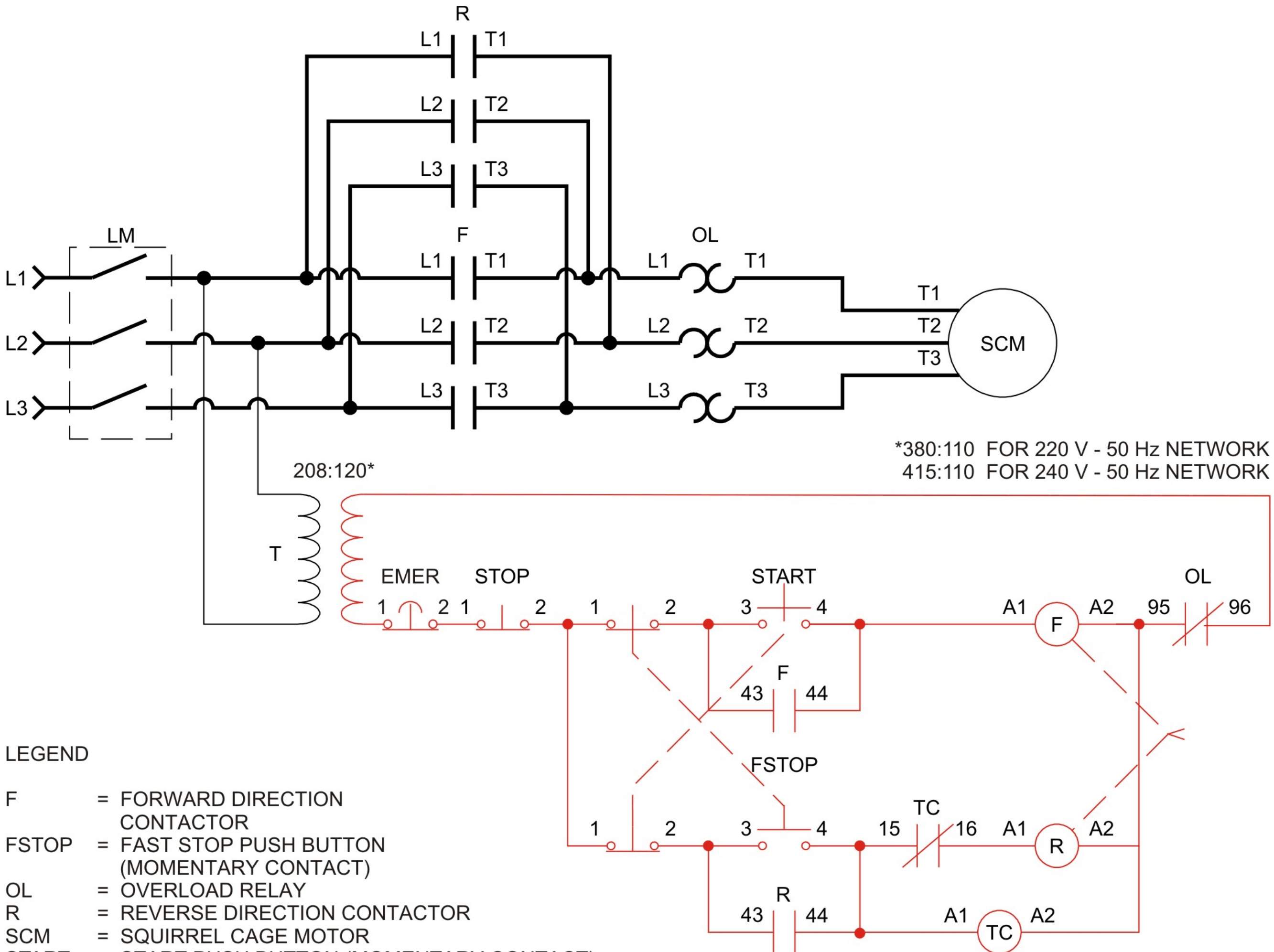
DISCUSSION

Plugging is a motor braking method that uses the counter torque produced by reversing two power lines. In Exercise 3-4, you started a plugging operation by pressing the forward push button while the motor was running in reverse direction. As the motor stopped, you had to press the stop push button to prevent the motor from rotating in the opposing direction.

When it is not possible for an operator to check when the motor is stopped, an automatic means of stopping the motor power supply must be found. A time relay can be utilized for this purpose, provided that the time the motor needs to stop is known in advance. If the stopping time is variable because of a changing load, it could be preferable to use a plugging switch. This method will be seen later in the Industrial Controls Training System student manuals.

Figure 6-6 is a plugging circuit using a time relay to stop the motor before it rotates backwards. To make the motor turn in the forward direction, the START push button is pressed. The STOP push button makes the motor coast to a stop. The FSTOP (fast stop) push button opens the forward contactor and activates the reverse contactor, making the motor stop rapidly. The *On-delay* function of the time relay opens the reverse contactor a preset time t after the forward contactor is de-energized. If t is chosen properly, the motor stops exactly when the reverse contactor is de-energized.

PLUGGING WITH TIME RELAYS



LEGEND

F = FORWARD DIRECTION CONTACTOR
FSTOP = FAST STOP PUSH BUTTON (MOMENTARY CONTACT)
OL = OVERLOAD RELAY
R = REVERSE DIRECTION CONTACTOR
SCM = SQUIRREL CAGE MOTOR
START = START PUSH BUTTON (MOMENTARY CONTACT)
STOP = STOP PUSH BUTTON (MOMENTARY CONTACT)
T = CONTROL VOLTAGE TRANSFORMER
TC = TIME RELAY
EMER = EMERGENCY PUSH BUTTON (MAINTAINED CONTACT)
LM = LOCKOUT MODULE

Figure 6-6. Plugging circuit with time relay.

Procedure Summary

In the first part of this exercise, you will set up a reversing circuit that enables plugging. You will do plugging with the Inertia Wheel on the motor shaft and stop the circuit manually, before it rotates backwards. You will observe that it is difficult to stop the circuit on time, every time.

You will then plug a time relay and adjust the delay to make the motor stop perfectly, each time the FSTOP push button is pressed.

In the last part of the exercise, you will remove the Inertia Wheel and observe that the R contactor is now energized too long, making the motor rotate in the opposite direction.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

PROCEDURE

WARNING!

The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

Basic setup

☐ 1. Perform the Basic Setup and Lockout/Tagout procedures.

Manual plugging

☐ 2. Install the Brake Motor, Inertia Wheel, and Safety Guard.

Connect the circuit shown in Figure 6-6.

☐ 3. Manually disengage the friction brake.

Connect a lead between the Time Relay terminals 15 and 16 to disable the Time Relay.

Perform the Energizing procedure.

Press the START push button to start the motor, and wait for the motor to rotate at full speed.

☐ 4. Press the FSTOP push button and, when the motor comes to a stop, press the STOP push button to de-energize the motor.

Repeat the START - FSTOP - STOP sequence to measure the plugging time required to stop the motor.

Plugging time: ______

Note: *You should notice that it is not easy to manually stop the motor right on time, with consistency.*

☐ 5. Turn off the Lockout Module.

Disconnect the lead between the Time Relay terminals 15 and 16.

Plugging using a time relay

☐ 6. Set the Time Relay with the following parameter values:

- Function code: A (On-delay)
- Time-delay value: 1 s
- Time-delay adjustment: 20%

☐ 7. Turn on the Lockout Module.

Press the START push button to start the motor.

Press the FSTOP push button to start the plugging operation.

Does the motor keep on turning as the circuit is switched off by the Time Relay? If yes, does the motor turn in forward or reverse direction?

____

____

☐ 8. Is the time delay too long or too short?

☐ Too long ☐ Too short

☐ 9. Adjust the time delay to de-energize the motor exactly as it switches off. Repeat the START - FSTOP sequence as often as necessary.

Note the time delay value required to stop the motor exactly as it switches off.

Time delay value: ______

☐ 10. Perform the Lockout/Tagout procedure.

Remove the Inertia Wheel.

☐ 11. Perform the Energizing procedure.

Press the START push button.

Does the motor keep on turning, as the circuit is switched off by the Time Relay? If yes, does the motor turn in a forward or reverse direction?

____

____

☐ 12. Is the time delay too long or too short?

☐ Too long ☐ Too short

☐ 13. Why would this control circuit not be used with variable loads?

____

____

____

☐ 14. Turn the individual power switch of the AC Power Supply off, disconnect the circuit, remove the magnetic labels, and return the equipment to the storage location.

CONCLUSION

A motor can be plugged with a time relay to make it stop rapidly and perfectly each time. If the motor is not stopped completely by the plugging, it is a sign that the time delay is too short. But if it turns in the opposite direction after stopping, the time delay is too long.

If the motor is connected to a variable load, using a time relay is not a good option; the time delay has to be readjusted upon every change in load to obtain perfect plugging stops. Plugging switches, which sense changes in motor speed, can be a good alternative to time relays under those circumstances. They are, however, more expensive.

REVIEW QUESTIONS

1. Which control device sees its NO and NC contacts states change following preset time delays?

   a. Plugging switch
   b. Time relay
   c. Contactor
   d. None of the answers above is correct.

2. In the Figure 6-6 circuit, what happens if time relay terminals 15 and 16 are short-circuited?

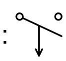
   a. The motor will only run in the reverse direction.
   b. The motor will only run in the forward direction.
   c. The motor will function in both directions.
   d. The motor will not turn at all.

3. In the Figure 6-6 circuit, what happens when the STOP push button is pressed while the motor is running in the forward direction?

   a. Two line phases are inverted to make the motor stop rapidly.
   b. The motor slows down until it stops.
   c. The friction brake is automatically applied.
   d. None of the answers above are correct.

4. In the Figure 6-6 circuit, how can you keep the time relay well set, if the load increases significantly?

   a. Increasing the time delay
   b. Changing the time relay function code
   c. Shortening the time delay
   d. Increasing the overload relay current setting

5. What is the meaning of this symbol: 

   a. NC contact with time delay opening
   b. NC contact with time delay closing
   c. NO contact with time delay opening
   d. NO contact with time delay closing

PRIMARY RESISTOR STARTERS WITH TIME RELAYS

EXERCISE OBJECTIVE

- Understand how a time relay can be used jointly with primary resistor starters.

DISCUSSION

Primary resistor starters are used to reduce the voltage to the motor upon starting, causing starting torque and current to diminish. When the motor is started, a voltage drop is produced by resistors placed in series with the motor terminals. Resistors are bypassed after a while to make the motor run under full voltage and avoid heat dissipation through the resistors.

In Exercise 5-1, you completed such a circuit in which you bypassed the resistors using a selector switch and a contactor. But it is also possible to automatically bypass the resistors by using a time relay. This enables the resistors to be switched off at an appropriate time and prevents the resistors from being left on inadvertently.

Figure 6-7 is a primary resistor circuit using a time relay. Once the power and the Manual Starter are turned on, the motor is started under reduced voltage, because resistors are placed in series with its terminals. The Time Relay coil is also energized and the on delay starts. Once the preset delay has been reached, the Time Relay NO contact closes. This energizes the running contactor, hence bypassing the resistors and making the motor run under full voltage.

PRIMARY RESISTOR STARTERS WITH TIME RELAYS

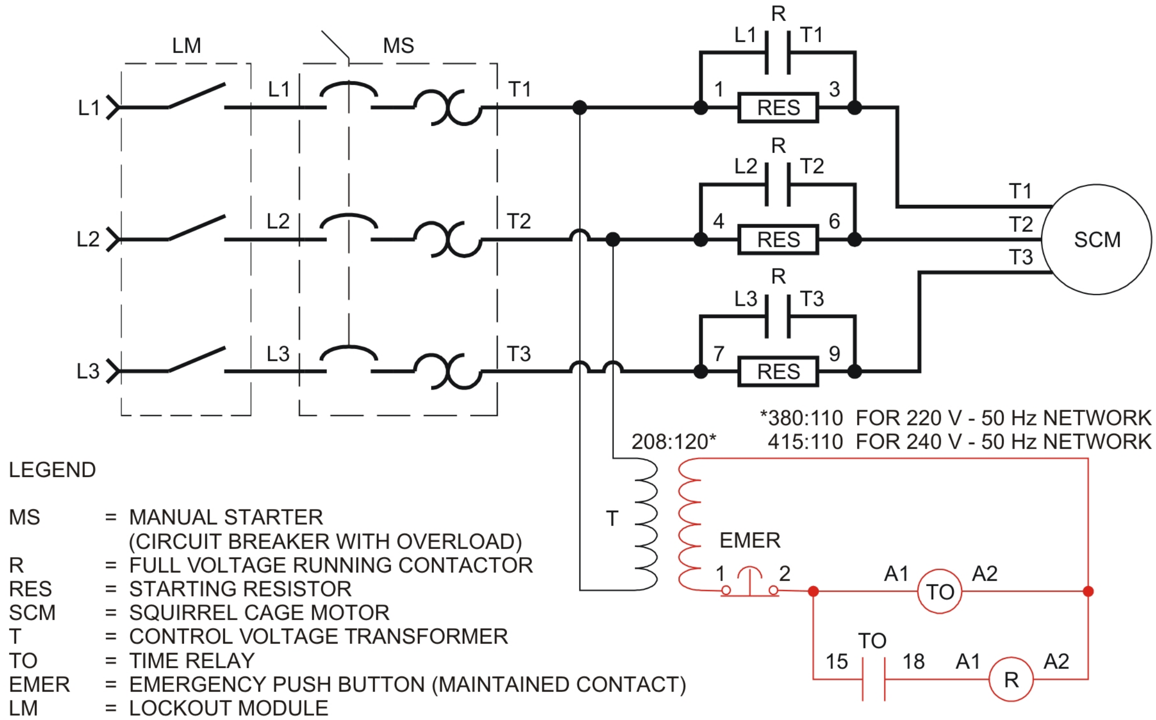


Figure 6-7. Primary resistor starter with time relay circuit.

Procedure Summary

In this exercise, you will put together a primary resistor starter circuit and the Time Relay module. This setup will utilize the On-delay function of the Time Relay to delay the actuation of a contactor that bypasses the resistors. You will modify the delay time to see the influence it has on motor acceleration.

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required for this exercise.

PROCEDURE

WARNING!

The AC Power Supply provides high voltages. Do not change any AC connection with the power on.

Basic setup

☐ 1. Perform the Basic Setup and Lockout/Tagout procedures.

Primary resistor starter with time relay circuit

☐ 2. Install the Brake Motor, Inertia Wheel, and Safety Guard.

Connect the circuit shown in Figure 6-7.

Note: *Resistors must be connected by their extremities and not by the intermediate taps, in order to obtain maximum resistance.*

☐ 3. Manually disengage the friction brake.

Set the knob of the Manual Starter to the O position.

Set the Time Relay with the following parameter values:

- Function code: A (On-delay)
- Time-delay value: 1 s
- Time-delay adjustment: 50%

☐ 4. Perform the Energizing procedure.

Set the knob of the Manual Starter to the I position.

Does the motor acceleration increase when the contactor is energized (after 0.5 s)?

☐ Yes ☐ No

☐ 5. Set the knob of the Manual Starter to the O position.

Set the time delay value to 10 s.

Set the knob of the Manual Starter to the I position.

Does the motor acceleration increase when the contactor is energized (after 5 s)?

☐ Yes ☐ No

CAUTION!

The Starting Resistors module may be hot. Please be careful when you handle this module after use.

☐ 6. Turn the individual power switch of the AC Power Supply off, disconnect the circuit, remove the magnetic labels, and return the equipment to the storage location.

CONCLUSION

Primary resistor starters are used to start motors at a lower voltage, produced by resistors inserted in series with motor terminals. After a time delay, starting resistors are bypassed to let motors operate at full line voltage. This bypass procedure can be controlled manually, by an operator, or automatically, with the help of a time relay.

Equipment Utilization Chart

The following Lab-Volt equipment is required to perform the exercises in this manual.

EQUIPMENT		EXERCISE																			
MODEL	**DESCRIPTION**	**1-1**	**1-2**	**1-3**	**1-4**	**1-5**	**2-1**	**2-2**	**3-1**	**3-2**	**3-3**	**3-4**	**3-5**	**4-1**	**4-2**	**4-3**	**5-1**	**5-2**	**6-1**	**6-2**	**6-3**
3103	Mobile Workstation	1	1	1	1	1			1	1	1	1	1	1	1	1	1	1	1	1	1
3110	Push Buttons		1	2	2					1		2	2	1	1	2				2	
3111	Selector Switches		1		1	1			1	1					1	1	1	1	1		
3114	Emergency Button	1							1	1		1	1	1	1	1	1	1		1	1
3115	Pilot Lights	1	1	2	2							1	1						1		
3119	Dual Contactors				1							1				1				1	
3125	Lockout Module	1	1	1	1	1			1	1	1	1	1	1	1	1	1	1	1	1	1
3126	Manual Starter			1		1					1	1		1			1	1			1
3127	Contactor				1	1	1		1	1		1	1	1	1		1				1
3130	Control Relay				1		1								1	1					
3131	Overload Relay					1			1	1		1	1	1	1	1				1	
3132	Time Relay																		1	1	1
3137	Fuse Holder	1				1															
3138	Control Transformer	1	1	1	1	1			1	1		1	1	1	1	1	1	1	1	1	1
3140	Cam Switch			1		1					1										
3147	Inertia Wheel								1	1	1	1	1	1	1	1				1	1
3150	Starting Resistors					1											1				1
3176-A	Brake Motor						1		1	1	1	1	1	1	1	1	1	1		1	1
3186	Soft Starter																	1			
3196	AC Power Supply	1	1	1	1	1			1	1	1	1	1	1	1	1	1	1	1	1	1
8951	Connection Leads	1	1	1	1	1			1	1	1	1	1	1	1	1	1	1	1	1	1
N/A	AC Voltmeter[1]	1							1								1	1			
N/A	AC Clamp Ammeter[1]					1			1								1				
N/A	Ohmmeter[1]	1	1																		
N/A	Chronometer					1								1				1	1	1	
N/A	Fuses	1				1															

[1] Lab-Volt model 70-38707 multimeter can be used in all exercises involving a voltmeter, a clamp ammeter, or an ohmmeter.

Diagram Symbols

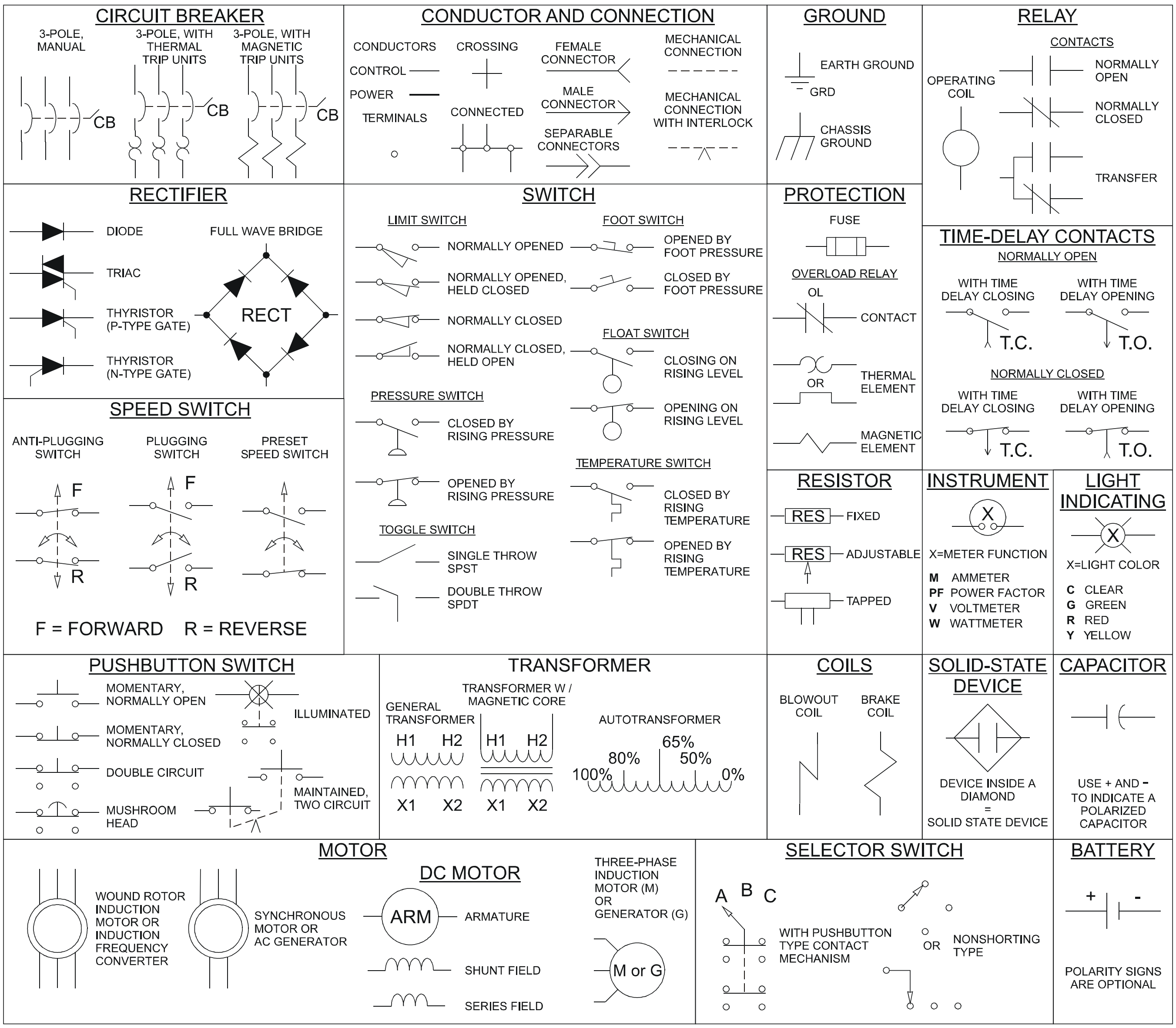


Figure B-1. NEMA symbols.

Diagram Symbols

FUNCTION OR DEVICE	DESIGNATION	FUNCTION OR DEVICE	DESIGNATION
Accelerating	A	Overload	OL
Ammeter	AM	Overvoltage	OV
Braking	B	Plugging or Potentiometer	P
Capacitor, Capacitance	C or CAP	Power Factor Meter	PFM
Circuit Breaker	CB	Pressure Switch	PS
Closing Coil	CC	Push Button	PB
Control Relay	CR	Reactor, Reactance	X
Current Transformer	CT	Rectifier	REC
Demand Meter	DM	Resistor, Resistance	R or RES
Diode	D	Reverse	R or REV
Disconnect Switch	DS or DISC	Rheostat	RH
Dynamic Braking	DB	Selector Switch	SS
Field Accelerating	FA	Silicon Controlled Rectifier	SCR
Field Contactor	FC	Solenoid Valve	SV
Field Decelerating	FD	Squirrel Cage	SC
Field-Loss	FL	Starting Contactor	S
Forward	F or FWD	Suppressor	SU
Frequency Meter	FM	Tachometer Generator	TACH
Fuse	FU	Terminal Block or Board	TB
Ground Protective	GP	Time-Delay Closing Contact	TC or TDC
Holding Coil	HC	Time-Delay Opening Contact	TO or TDO
Hoist	H	Time Relay	TR
Jog	J	Transformer	T
Latch Coil	LC	Transistor	Q
Limit Switch	LS	Trip Coil	TC
Lower	L	Unlatch Coil	ULC
Main Contactor	M	Undervoltage	UV
Master Control Relay	MCR	Voltmeter	VM
Master Switch	MS	Watthour Meter	WHM
Overcurrent	OC	Wattmeter	WM

Figure B-2. Device designations.

Diagram Symbols

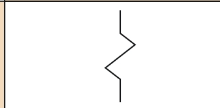
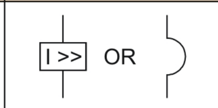
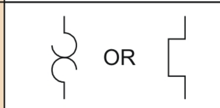
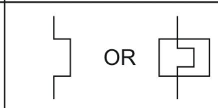
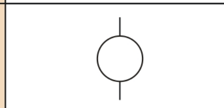
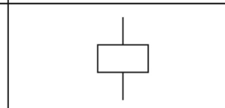
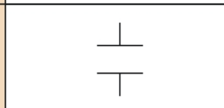
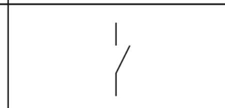
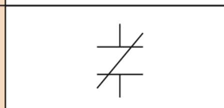
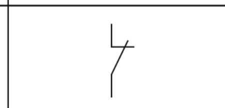
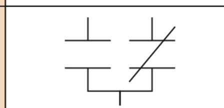
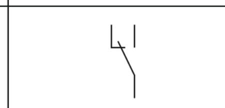
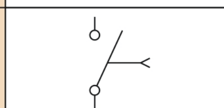
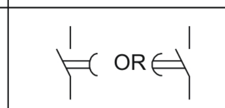
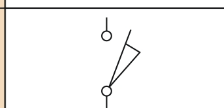
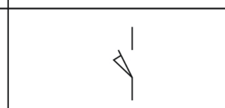
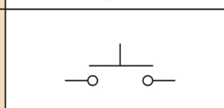
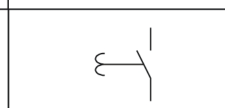
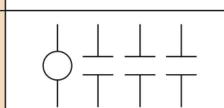
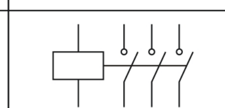
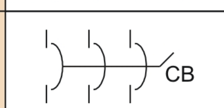
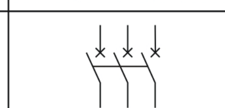
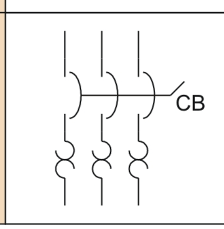
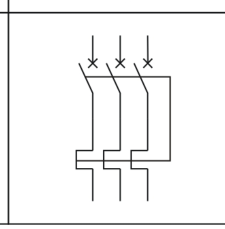
	NEMA	IEC
MAGNETIC OVERLOAD ELEMENT (SHORT-CIRCUIT)		
THERMAL OVERLOAD ELEMENT		
RELAY COIL		
NORMALLY OPEN CONTACT		
NORMALLY CLOSED CONTACT		
TRANSFER CONTACTS		
NORMALLY OPEN CONTACT DELAYED WHEN CLOSING		
NORMALLY OPEN CONTACT (LIMIT SWITCH)		
NORMALLY OPEN PUSHBUTTON CONTACT		
CONTACTOR		
THREE-POLE SWITCH-DISCONNECTOR		
THREE-POLE CIRCUIT-BREAKER WITH THERMAL OVERLOAD RELEASES		

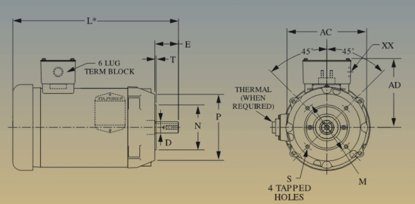
Figure B-3. Comparison of NEMA and IEC symbols.

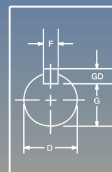
Appendix C

Motor Frames Charts

BALDOR®
MOTORS • DRIVES • GENERATORS

Leader in Energy Efficient
Industrial Electric Motors and Drives

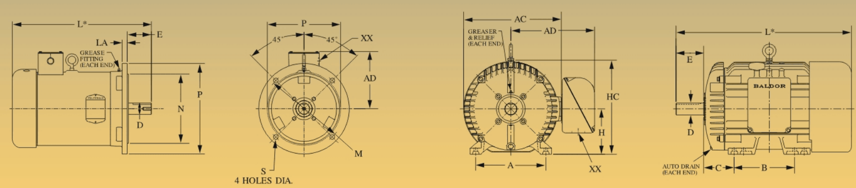




Key and Keyseat Dimensions									
Frame	D	G	F	GD	Frame	D	G	F	GD
63	11	8.5	4	4	180	48	42.5	14	9
71	14	11	5	5	200	55	49	16	10
80	19	15.5	6	6	225	60	53	18	11
90	24	20	8	7	250	70	67.5	20	12
100	28	24	8	7	280	80	71	22	14
112	28	24	8	7	315	85	76	22	14
132	38	33	10	8	355	85	76	22	14
160	37	42	12	8					

Drawings represent standard TEFC general purpose motors.

*Dimensions are for reference only.



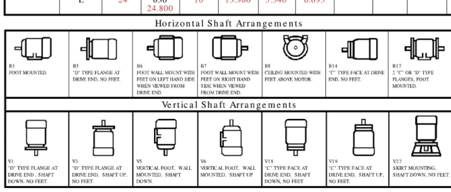
*Contact your local Baldor office for "L" Dimensions.

IEC QUICK REFERENCE CHART

IEC Frame	Type	Foot Mounting				Shaft		B5 Flange						B14 Face					General				
		A	B	C	H	D	E	LA	M	N	P	S	T	M	N	P	S	T	L	AC	AD	HC	XX
63	300	100 3.937	80 3.150	40 1.570	63 2.480	11 .433	23 .906	8 .313	115 4.528	95 3.740	140 5.512	9 .354	3 .118	75 2.953	60 2.362	90 3.540	M5	2.5 0.98	*	119 4.690	102 4 116d 4.567d	121 4.760 136d 5.375d	13 .500 22d .880d
71	300 400	112 4.409	90 3.543	45 1.770	71 2.800	14 .551	30 1.181	8 .313	130 5.118	110 4.331	160 6.299	10 .393	3.5 .138	85 3.347	70 2.756	105 4.130	M6	2.5 .098	*	119 4.690 145d 5.690d	102 4	131 5.140 149d 5.880d	18 .690 21d .844d
80	400 500	125 4.921	100 3.937	50 1.969	80 3.150	19 .748	40 1.575	13 .500	165 6.496	130 5.118	200 7.874	11 .430	3.5 .138	100 3.937	80 3.150	120 4.724	M6	3 .118	*	145 5.690 168d 6.614d	116 4.510 130 5.120	152 6 162d 6.380d	22 .880 21d .844d
90	S L	140 5.511	100 3.937 125 4.921	56 2.205	90 3.543	24 .945	50 1.969	13 .500	165 6.496	130 5.118	200 7.874	12 .472	3.5 .138	115 4.530	95 3.740	140 5.512	M8	3 .118	*	168 6.614 144d 5.687d	130 5.120 107d 4.250d	173 6.810 165d 6.531d	22 .880 21d .844d
100	S L	160 6.300	112 4.409 140 5.512	63 2.480	100 3.937	28 1.102	60 2.362	14 .562	215 8.465	180 7.087	250 9.840	14 .560	4 .160	130 5.108	110 4.331	160 6.299	M8	3.5 .138	*	200 7.875	149 5.875 153d 6.060d	180 7.906 239d 9.440d	27 1.062
112	S M	190 7.480	114 4.488 140 5.512	70 2.760	112 4.409	28 1.102	60 2.362	14 .562	215 8.465	180 7.087	250 9.840	14 .560	4 .160	130 5.108	110 4.331	160 6.299	M8	3.5 .138	*	243 7.875	149 5.875	214 8.437	27 1.062
132	S M	216 8.504	140 5.512 178 7.008	89 3.504	132 5.197	38 1.496	80 3.150	14 .562	265 10.433	230 9.055	300 11.811	14 .560	4 .160	165 6.496	130 5.118	200 7.874	M8	3.5 .138	*	243 9.562	187 7.375	256 10.062	27 1.062
160	M L	254 10	210 8.268 254 10	108 4.252	160 6.299	42 1.654	110 4.331	20 .787	300 11.811	250 9.842	350 13.780	19 .748	5 .200	215 8.465	180 7.087	250 9.840	M12	4 .160	*	329 12.940	242 9.510	329 12.940	35 1.375
180	M L	279 10.984	241 9.488 279 10.984	121 4.764	180 7.087	48 1.890	110 4.331	20 .787	300 11.811	250 9.842	350 13.780	19 .748	5 .200		*					395 15.560	333 13.120	372 14.640	51 2.008
200	L M	318 12.520	267 10.512 305 12.008	133 5.236	200 7.874	55 2.165	110 4.331	27 1.062	350 13.780	300 11.811	400 15.748	19 .748	5 .200		*					441 17.375	359 14.125	416 16.375	63 2.500
225	S M	356 14.016	286 11.260 311 12.244	149 5.866	225 8.858	60 2.362	140 5.512	19 .748	400 15.748	350 13.780	450 17.716	19 .748	6 .236		*					495 19.488	383 15.079	483 19.016	63 2.500
250	S M	406 15.984	311 12.244 349 13.740	168 6.614	250 9.843	70 2.756	140 5.512												*	520 20.472	457 17.992	513 20.197	63 2.500
280	S M	457 17.992	368 14.488 419 16.496	190 7.485	280 11.025	80 3.150	170 6.693												*	616 24.252	497 19.567	581 22.874	63 2.500
315	S M	508 20	406 16 457 18	216 8.500	315 12.400	85 3.346	170 6.693												*	759 29.900	683 26.880	682 26.840	102 4
355	S L	610 24	500 19.690 630 24.800	254 10	355 13.980	85 3.346	170 6.693												*	759 29.900	683 26.880	719 28.320	102 4

LEGEND

Metric (MM) Dimensions in Black
Inch Dimensions in Red
d = DC Motors
1 mm = .03937"   1" = 25.40 mm



IP Protection - Baldor Enclosures

IP22 = Open Drip Proof AC or DC Motors.

IP54 = All standard TEFC AC and DC Motors.

IP55 = All TEFC Chemical Processing, Dirty Duty, and Washdown Duty Motors

BALDOR ELECTRIC COMPANY
P.O. BOX 2400
FORT SMITH, ARKANSAS
72902-2400 U.S.A.

SUMMARY OF IP PROTECTION NUMBERS

First #
Protection Against Solid Objects

IP TESTS
- O NO PROTECTION
- 1 Protection against solid objects up to 50 mm. (E.G. Accidental touch by hands.)
- 2 Protection against solid objects up to 12 mm. (E.G. Fingers)
- 3 Protection against solid objects over 2.5 mm. (E.G. Tools,Wires)
- 4 Protection against solid objects over 1 mm. (E.G. Tools, Wires, and Small Wires)
- 5 Protection against dust - limited ingress (No harmful deposits)
- 6 Totally protected against all dust.

Second #
Protection Against Liquids

- O NO PROTECTION
- 1 Protection against vertical drops of water. (E.G. Condensation.)
- 2 Protection against falling water up to 15 degrees from the vertical.
- 3 Protection against falling water up to 60 degrees from the vertical.
- 4 Protection against splashing water from all directions, limited ingress.
- 5 Protection against low pressure jets of water from all directions, limited ingress.
- 6 Protection against strong jets of water. (E.G. Use on ship decks, limited ingress.)
- 7 Protection against immersion.
- 8 Protection against submersion.

Figure C-1. IEC motor dimension chart (Courtesy of Baldor Electric Company).

Motor Frames Charts

BALDOR

MOTORS • DRIVES • GENERATORS

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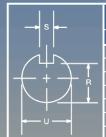
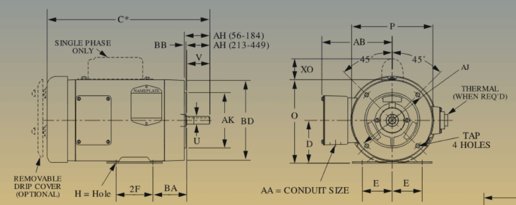
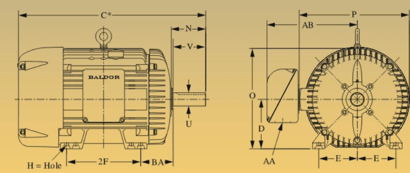


NEMA Shaft	Keyseat Dimensions		NEMA Shaft	Keyseat Dimensions	
(U)	(R)	(S)	(U)	(R)	(S)
3/8	21/64	FLAT	1-7/8	1-19/32	1/2
1/2	29/64	FLAT	2-1/8	1-27/32	1/2
5/8	33/64	3/16	2-3/8	2-1/64	5/8
7/8	49/64	3/16	2-1/2	2-3/16	5/8
1-1/8	63/64	1/4	2-7/8	2-29/64	3/4
1-3/8	1-13/64	5/16	3-3/8	2-7/8	7/8
1-5/8	1-13/32	3/8	3-7/8	3-5/16	1





Drawings represent standard TEFC general purpose motors

Refer Data Section 502 for various models, OPEN or TEFC

*Dimensions are for reference only.

*Contact your local Baldor office for "C" Dimensions.

Dimensions - N, O, P, AB and XO are specific to Baldor.

NEMA QUICK REFERENCE CHART

NEMA FRAME	D	E	2F	H	N	O	P	U	V	AA	AB	AH	AJ	AK	BA	BB	BD	XO	TAP
42	2-5/8	1-3/4	1-11/16	9/32 SLOT	1-1/2	5	4-11/16	3/8	1-1/8	3/8	4-1/32	1-5/16	3-3/4	3	2-1/16	1/8	4-5/8	1-9/16	1/4-20
48	3	2-1/8	2-3/4	11/32 SLOT	1-7/8	5-7/8	5-11/16	1/2	1-1/2	1/2	4-3/8	1-11/16	3-3/4	3	2-1/2	1/8	5-5/8	2-1/4	1/4-20
56 56H	3-1/2	2-7/16	3 5	11/32 SLOT	2-7/16 2-1/8	6-7/8	6-5/8	5/8	1-7/8	1/2	5	2-1/16	5-7/8	4-1/2	2-3/4	1/8	6-1/2	2-1/4	3/8-16
143T 145T	3-1/2	2-3/4	4 5	11/32	2-1/2	6-7/8	6-5/8	7/8	2-1/4	3/4	5-1/4	2-1/8	5-7/8	4-1/2	2-1/4	1/8	6-1/2	2-1/4	3/8-16
182 184 182T 184T	4-1/2	3-3/4	4-1/2 5-1/2 4-1/2 5-1/2	13/32	2-11/16 2-11/16 3-9/16 3-9/16	8-11/16	7 7-7/8	/8 7/8 1-1/8 1-1/8	2-1/4 2-1/4 2-3/4 2-3/4	3/4	5-7/8	2-1/8 2-1/8 2-5/8 2-5/8	5-7/8 5-7/8 7-1/4 7-1/4	4-1/2 4-1/2 8-1/2 8-1/2	2-3/4	1/8 1/8 1/4 1/4	6-1/2 6-1/2 9 9	2-3/8	3/8-16 3/8-16 1/2-13 1/2-13
213 215 213T 215T	5-1/4	4-1/4	5-1/2 7 5-1/2 7	13/32	3-1/2 3-1/2 3-7/8 3-7/8	10-1/4	9-9/16	1-1/8 1-1/8 1-3/8 1-3/8	3 3 3-3/8 3-3/8	3/4	2 7-3/8	-3/4 2-3/4 3-1/8 3-1/8	7-1/4	8-1/2	3-1/2	1/4	9	2-3/4	1/2-13
254U 256U 254T 256T	6-1/4	5	8-1/4 10 8-1/4 10	17/32	4-1/16 4-1/16 4-5/16 4-5/16	12-7/8	12-15/16	1-3/8 1-3/8 1-5/8 1-5/8	3-3/4 3-3/4 4 4	1	9-5/8 3 3	3-1/2 3-1/2 -3/4 -3/4	7-1/4	8-1/2	4-1/4	1/4	10	—	1/2-13
284U 286U 284T 286T 284TS 286TS	7	5-1/2	9-1/2 11 9-1/2 11 9-1/2 11	17/32	5-1/8 5-1/8 4-7/8 4-7/8 3-3/8 3-3/8	14-5/8	14-5/8	1-5/8 1-5/8 1-7/8 1-7/8 1-5/8 1-5/8	4-7/8 4-7/8 4-5/8 4-5/8 3-1/4 3-1/4	1-1/2	13-1/8	4-5/8 4-5/8 4-3/8 4-3/8 3 3	9	10-1/2	4-3/4	1/4	11-1/4	—	1/2-13
324U 326U 324T 326T 324TS 326TS	8	6-1/4	10-1/2 12 10-1/2 12 10-1/2 12	21/32	5-7/8 5-7/8 5-1/2 5-1/2 3-15/16 3-15/16	16-1/2	16-1/2	1-7/8 1-7/8 2-1/8 2-1/8 1-7/8 1-7/8	5-5/8 5-5/8 5-1/4 5-1/4 3-3/4 3-3/4	2	14-1/8	5-3/8 5-3/8 5 5 3-1/2 3-1/2	11	12-1/2	5-1/4	1/4	13-3/8	—	5/8-11
364U 365U 364T 365T 364TS 365TS	9	7	11-1/4 12-1/4 11-1/4 12-1/4 11-1/4 12-1/4	21/32	6-3/4 6-3/4 6-1/4 6-1/4 4 4	18-1/2	18-1/4	2-1/8 2-1/8 2-3/8 2-3/8 1-7/8 1-7/8	6-3/8 6-3/8 5-7/8 5-7/8 3-3/4 3-3/4	2-1/2	15-1/16	6-1/8 6-1/8 5-5/8 5-5/8 3-1/2 3-1/2	11	12-1/2	5-7/8	1/4	13-3/8	—	5/8-11
404U 405U 404T 405T 404TS 405TS	10	8	12-1/4 13-3/4 12-1/4 13-3/4 12-1/4 13-3/4	13/16	7-3/16 7-3/16 7-5/16 7-5/16 4-1/2 4-1/2	20-5/16	20-1/8	2-3/8 2-3/8 2-7/8 2-7/8 2-1/8 2-1/8	7-1/8 7-1/8 7-1/4 7-1/4 4-1/4 4-1/4	3	18	6-7/8 6-7/8 7 7 4 4	11	12-1/2	6-5/8	1/4	13-7/8	—	5/8-11
444U 445U 444T 445T 447T 449T 444TS 445TS 447TS 449TS	11	9	14-1/2 16-1/2 14-1/2 16-1/2 20 25 14-1/2 16-1/2 20 25	13/16	8-5/8 8-5/8 8-1/2 8-1/2 8-15/16 8-15/16 5-3/16 5-3/16 4-15/16 4-15/16	22-7/8 22-7/8 22-7/8 22-7/8 22-15/16 22-15/16 22-7/8 22-7/8 22-15/16 22-15/16	22-3/8 22-3/8 22-3/8 22-3/8 23-3/4 23-3/4 22-3/8 22-3/8 23-3/4 23-3/4	2-7/8 2-7/8 3-3/8 3-3/8 3-3/8 3-3/8 2-3/8 2-3/8 2-3/8 2-3/8	8-5/8 8-5/8 8-1/2 8-1/2 8-1/2 8-1/2 4-3/4 4-3/4 4-3/4 4-3/4	3 4NPT 4NPT	19-9/16 19-9/16 19-9/16 19-9/16 21-11/16 21-11/16 19-9/16 19-9/16 21-11/16 21-11/16	8-3/8 8-3/8 8-1/4 8-1/4 8-1/4 8-1/4 4-1/2 4-1/2 4-1/2 4-1/2	14	16	7-1/2	1/4	16-3/4	—	5/8-11

5000 FRAME	D	E	2F	H	O	P	U	V	AA	AB	BA
5007S	12-1/2	10	22	15/16	26-27/32	30	2-1/2	6-1/2	4-NPT	26-7/8	8-1/2
5007L	12-1/2	10	22	15/16	26-27/32	30	3-7/8	11-1/8	4-NPT	26-7/8	8-1/2
5009S	12-1/2	10	28	15/16	26-27/32	30	2-1/2	6-1/2	4-NPT	26-7/8	8-1/2
5009L	12-1/2	10	28	15/16	26-27/32	30	3-7/8	11-1/8	4-NPT	26-7/8	8-1/2
5011S	12-1/2	10	36	15/16	26-27/32	30	2-1/2	6-1/2	4-NPT	26-7/8	8-1/2
5011L	12-1/2	10	36	15/16	26-27/32	30	3-7/8	11-1/8	4-NPT	26-7/8	8-1/2

NEMA C-Face	BA Dimensions
143-5TC	2-3/4
182-4TC	3-1/2
213-5TC	4-1/4
254-6TC	4-3/4

BALDOR ELECTRIC COMPANY
P.O. BOX 2400
FORT SMITH, ARKANSAS
72902-2400 U.S.A.

Frame	NEMA FRAMES PRIOR TO 1953						
	D	E	F	N	U	V	BA
66	4-1/8	2-15/16	2-1/2	2-1/4	3/4	2-1/4	3-1/8
203	5	4	2-3/4	2-7/16	3/4	2	3-1/8
204			3-1/4				
224	5-1/2	4-1/2	3-3/8	3-1/4	1	3	3-1/2
225			3-3/4				
254	6-1/4	5	4-1/8	3-7/16	1-1/8	3-3/8	4-1/4
284	7	5-1/2	4-3/4	4-1/4	1-1/4	3-3/4	4-3/4
324	8	6-1/4	5-1/4	5-3/8	1-5/8	4-7/8	5-1/4
326			6				
364	9	7	5-5/8	5-5/8	1-7/8	5-3/8	5-7/8
365			6-1/8				
404	10	8	6-1/8	6-3/8	2-1/8	6-1/8	6-5/8
405			6-7/8				
444	11	9	7-1/4	7-1/8	2-3/8	6-7/8	7-1/2
445			8-1/4				
504	12-1/2	10	8	8-5/8	2-7/8	8-3/8	8-1/2
505			9				

Figure C-2. NEMA motor dimension chart (Courtesy of Baldor Electric Company).

Appendix D

Basic Setup and Lockout/Tagout Procedures

This appendix contains the Basic Setup and Lockout/Tagout procedures specific to the Industrial Controls Training System from Lab-Volt. It is divided into four sections:

- *Basic Setup procedure*, explains the basic operations that must be performed at the beginning of the exercise procedures.

- *Lockout/Tagout procedure (de-energizing procedure)*, describes the lockout/tagout procedure used to de-energize the training system before setting up a circuit.

- *Energizing procedure*, gives details on how to end a lockout/tagout procedure and energize the training system.

- *Module identification*, gives instructions on how to use the magnetic labels to identify the modules.

Basic Setup procedure

This procedure is recommended at the beginning of every experiment involving the modules of the training system. It ensures that the system is safe prior to cabling specific circuits.

Basic Setup and Lockout/Tagout Procedures

Figure D-1. AC Power Supply, Model 3196.

☐ 1. Make sure that the power switch located on your side of the AC Power Supply is set to the O position.

> **Note:** *The AC Power Supply should already be installed in the Mobile Workstation.*

☐ 2. Install the Lockout module into the Mobile Workstation.

> **Note:** *Each time you install a module in the Mobile Workstation, make sure that the fault switches located behind the module faceplate are set to the O position as shown in Figure D-2.*

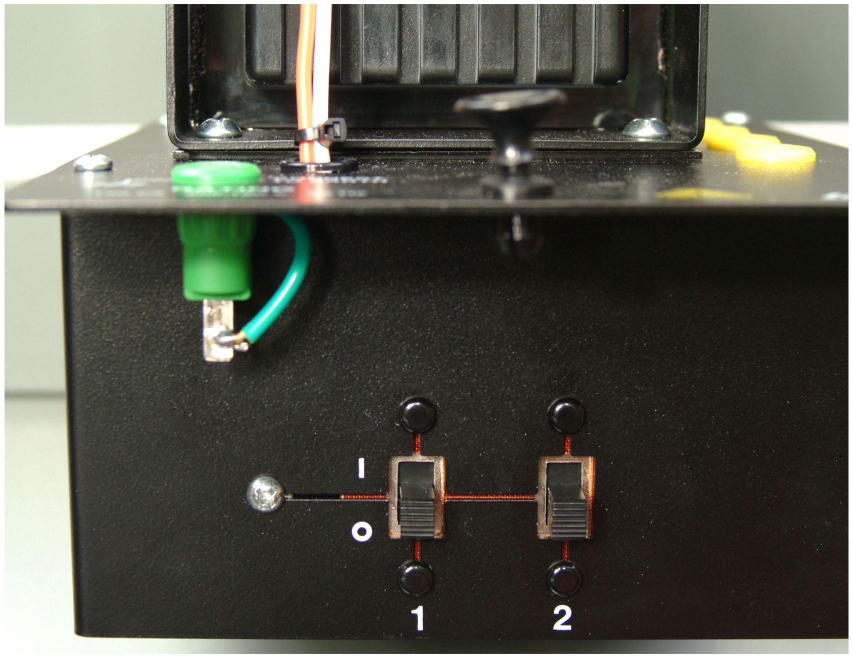


Figure D-2. Make sure that the fault switches are set to the O position.

☐ 3. Turn off the Lockout Module.

☐ 4. Connect the Lockout Module leads to the AC Power Supply module terminals, noting the phase sequence. See Figure D-3.

Figure D-3. Lockout Module connected to the AC Power Supply module.

Lockout/Tagout procedure (de-energizing procedure)

☐ 1. Turn off the Lockout Module.

☐ 2. Install the lockout hasp and the student padlocks and tags on the Lockout Module. Ask the instructor to install the lab padlock and tag as well. Refer to Figure D-4 for details.

Figure D-4. Installation of padlocks and hasps.

☐ 3. Check that the Lockout Module switch cannot be opened. With a voltmeter, verify that no voltage is present between the Lockout Module output terminals to confirm that the circuit is de-energized. You may now set up your circuit.

Energizing procedure

☐ 1. Interconnect the ground terminal (green) of all AC modules with the ground terminal of the Lockout Module.

Note: *DC modules do not incorporate ground terminals.*

☐ 2. Make sure the Security Guard is installed if you are using a motor.

☐ 3. Identify the modules with labels as described in the Module Identification section of this Appendix.

☐ 4. Once the connections have been made, ask for the instructor to check the circuit. When the circuit is correctly wired, notify all the people working around the Mobile Workstation that the system will be energized.

☐ 5. Remove the lockout hasp, padlocks and tags.

☐ 6. Turn on the AC Power Supply and Lockout Module, and return to your exercise.

Module identification

☐ 1. Once the setup is completed, identify all buttons, pilot lights, switches, etc, in accordance with the circuit schematic diagram. Place the magnetic labels on the module faceplates as shown in Figure D-5.

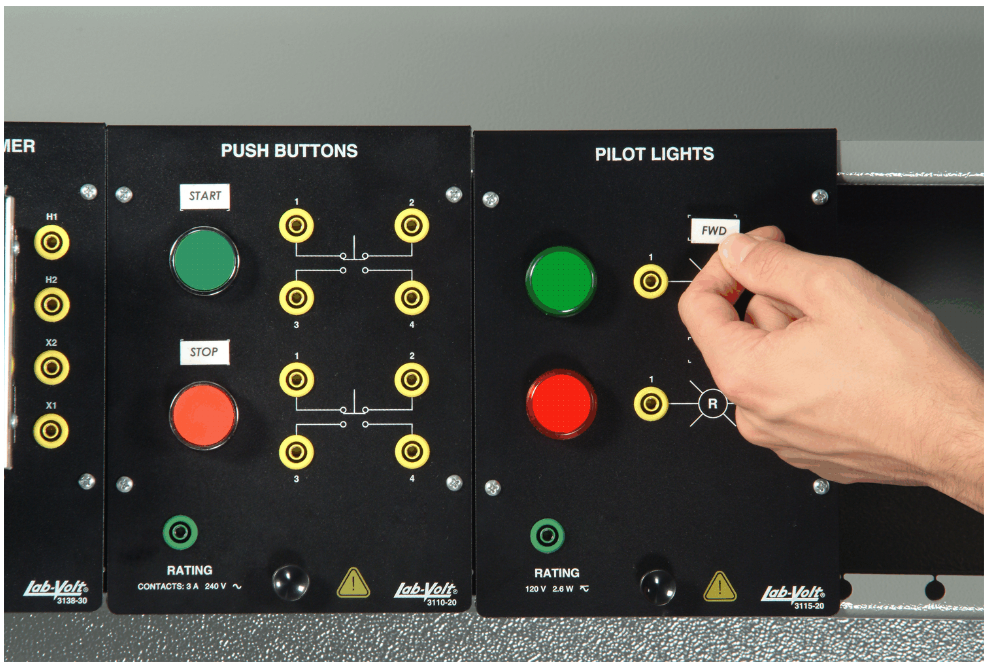


Figure D-5. Module identification.

Note: *For storing purposes, arrange the magnetic labels in alphabetic order on the vertical surface of the Mobile Workstation as shown in Figure D-6.*

Figure D-6. Store the magnetic labels on the vertical surface of the Mobile Workstation.

Appendix E

Brake Motor, Inertia Wheel, and Safety Guard Installation

Installation of the Brake Motor on the mounting plate

Note: *To facilitate electrical connections, the Brake Motor should be installed at your left when facing the motors.*

- Position and align the mounting plate over the four holes at the left of the Mobile Workstation.
- Place the Brake Motor over the mounting plate.
- Fix the Brake Motor to the mounting plate of the Mobile Workstation using hexagonal head screws with knurled nuts or with washers when placing the head of the screw on top. Figure E-1 shows the two fixing methods.

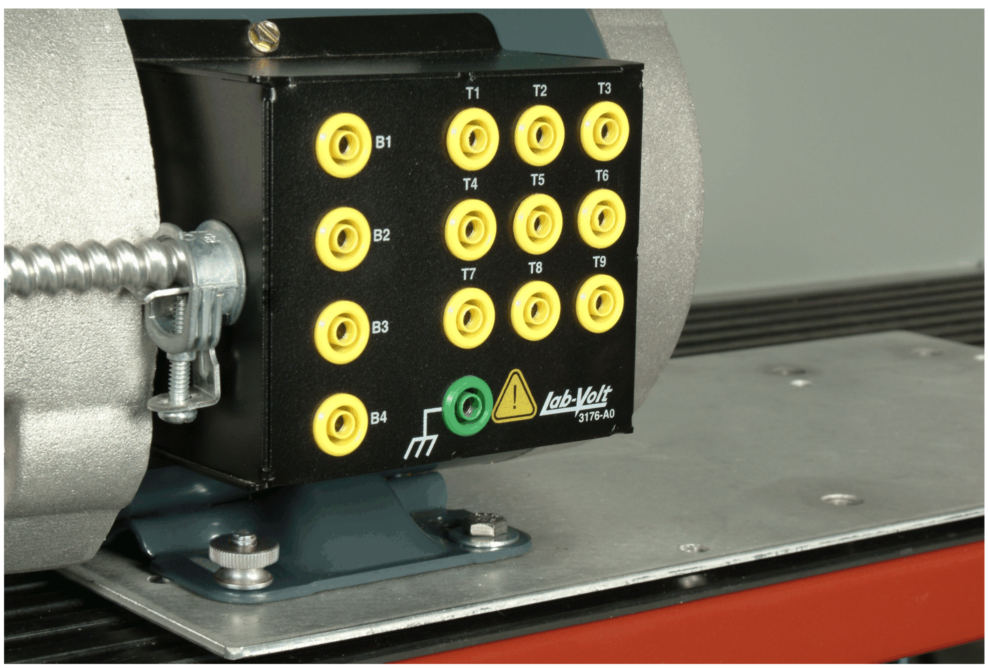


Figure E-1. Install the Brake Motor on the mounting plate.

Brake Motor, Inertia Wheel, and Safety Guard Installation

Installation of the Inertia Wheel on the Brake Motor shaft

- Install a 3/16 x 3/16 key in the shaft keyseat (at the extremity of the shaft).
- Slide the Inertia Wheel over the Brake Motor shaft taking care of aligning the Inertia Wheel keyway with the key (see Figure E-2).

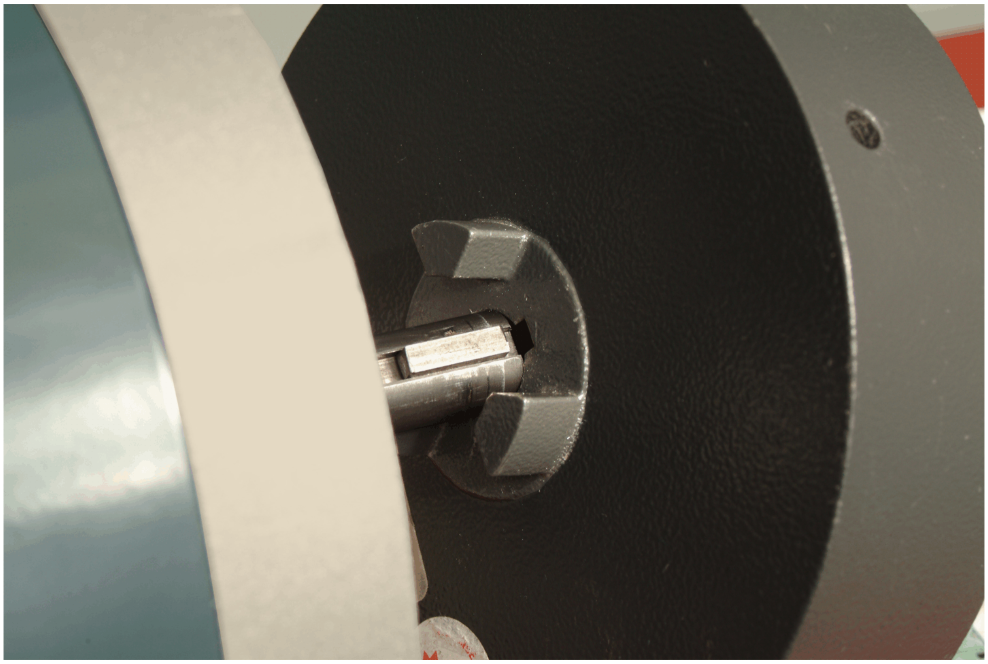


Figure E-2. Align the Inertia Wheel keyway with the key.

Brake Motor, Inertia Wheel, and Safety Guard Installation

- Tighten the setscrew with a hexagonal key as shown in Figure E-3.

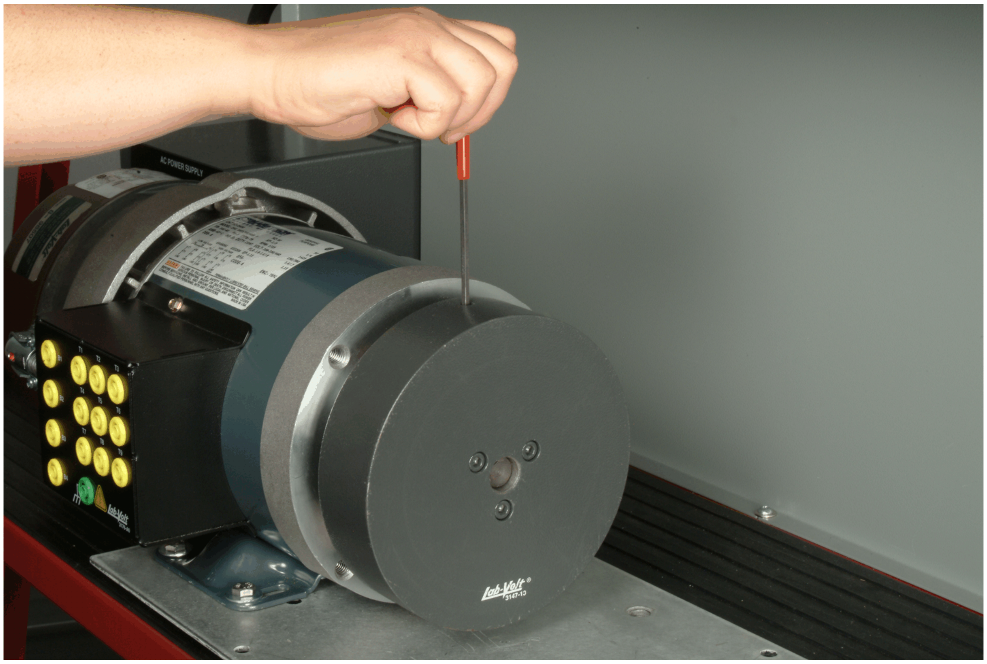


Figure E-3. Tighten the setscrew with a hexagonal key.

Brake Motor, Inertia Wheel, and Safety Guard Installation

Installation of the Safety Guard

- Install the Safety Guard over the Inertia Wheel as shown in Figure E-4. Press the push-locks (4) once the Safety Guard is placed.

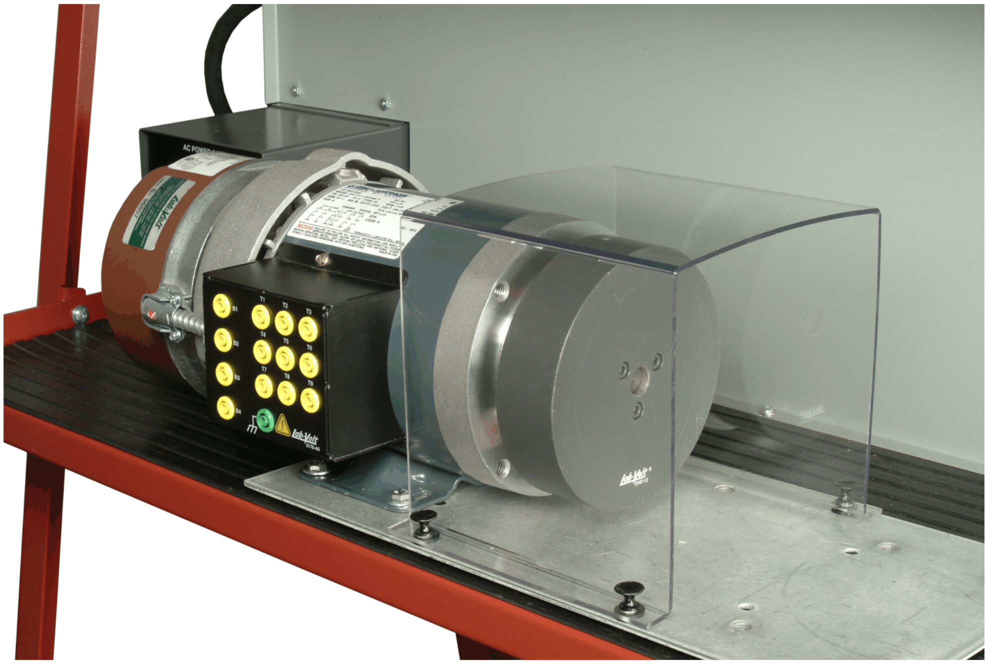


Figure E-4. Installation of the Safety Guard.

Brake Motor Characteristics

The characteristics of the Brake Motor are:

RATINGS	208 V	380 V	415 V
Power rating (hp)	1/3	1/4	1/4
Full-load current (A)	1.8	0.7	0.8
Number of phases	3		
Service factor	1.15		
Enclosure type	TEFC		
Duty rating	CONT.		
Maximum ambient temperature (˚C)	40		
Rotation speed (r/min)	1725	1425	1455
Power source frequency (Hz)	60	50	50
Design code letter NEMA	B		
Locked rotor code letter	R		
Insulation class	B		

Glossary

across-the-line starting	See DOL Starting.
affected employee	An employee whose duties are related to the machine or equipment in question but who is not performing the servicing or maintenance operations.
ambient temperature	The temperature of a medium such as air, water or earth into which the heat of the equipment is dissipated.
autotransformer	A single-winding transformer in which the primary coil is a fraction of the entire winding for voltage step up, or the secondary coil is a fraction of the entire winding for voltage step down.
cam switch	A type of contact switch that closes certain electrical contacts or combination of contacts at various positions of a cam.
connection diagram	See Wiring Diagram.
contact rating designations	Ratings (for example A600 or P300) giving an indication of the make and brake currents under a specified voltage.
contactor	A heavy-duty switching device used to establish and repeatedly interrupt an electrical power circuit.
control relay	An auxiliary relay that controls the operation of motor starters, contactors, switching solenoids, and other relays.
controller	A device or group of devices that governs, in a predetermined manner, the delivery of electric power to apparatus connected to it. (IEEE)
core (magnetic core)	The part of the magnetic structure around which the magnetizing winding is placed. (IEEE)
delta-connected circuit	A three-phase circuit that is mesh connected.
DOL (direct-on-line) starting	The process of starting a motor by connecting it directly to the supply at a rated voltage. (IEEE)
drum switch	A type of contact switch that closes certain electrical contacts or combination of contacts at various positions of a rotating cylinder or sector.
electromagnetic induction	The production of an electromotive force in a circuit by a change in the magnetic flux linking with that circuit. (IEEE)
electromechanical device	A device that is electrically operated and has mechanical motion such as relays, servos, etc. (IEEE)

Glossary

elementary diagram	See Schematic Diagram.
energy source	Any source of electrical, mechanical, hydraulic, pneumatic, chemical, thermal, or other energy.
energy-isolating device	A mechanism that prevents the transmission or release of energy and to which all locks or tags are attached.
float switch	A switch in which actuation of the contacts is affected when a float reaches a predetermined level. (IEC)
friction brake	Motor stopping method where shoes or pads come in contact with a wheel mounted on the motor shaft.
full-load ampere rating (FLA)	See Full-Load Current Rating (FLC).
full-load current rating (FLC)	The current required to produce full-load torque at the motor's rated voltage and speed.
full-voltage starting	See DOL Starting.
inching	See Jogging.
induction motor	An ac motor in which a primary winding on one member is connected to the power source and a polyphase secondary winding or a squirrel-cage secondary winding on the other member carries induced current. (IEEE)
inrush current	Initial surge of a current into a load before it attains normal operating condition.
interrupting capacity	The highest current at rated voltage that the device can interrupt. (IEEE)
jogging	Quickly repeated closure of a circuit to start a motor from rest for the purpose of accomplishing small movements of the driven machine.
limit switch	A switch that is operated by some part or motion of a power driven machine or equipment to alter the electric current associated with the machine or equipment. (ANSI)
lockout procedure	The placement of a lock on an energy-isolating device, in accordance with an established procedure, ensuring that the energy-isolating device and the equipment being controlled cannot be operated until the lock is removed.
low-voltage protection	See Three-Wire Protection.
low-voltage release	See Two-Wire Control.
magnetic brake	See Friction Brake.
magnetic field	The space around a magnetic pole or magnetized body in which the magnetic force has an effect.

motor starter	Electric controller (comprising a contactor and an overload protection device) used to accelerate a motor from rest to normal speed and for stopping the motor.
normally closed (NC) contact	Contact that is in a closed position when the operating magnet is de-energized.
normally open (NO) contact	Contact that is in an open position when the operating magnet is de-energized.
no-voltage protection	See Three-Wire Protection.
no-voltage release	See Two-Wire Control.
overload relay	A relay that responds to electric load and operates at a preset value of overload. (ANSI). Overload relays are usually current relays but they may be power, temperature, or other relays.
part-winding starting	Motor starting method where power is applied first to part of the motor coil windings. During normal operation, power is applied to all coil windings.
PLC (programmable logic controller)	A small computer that is programmed and reprogrammed to automatically control an industrial process or machine.
plugging	Motor braking method that uses the counter torque produced by connections reversal.
pressure switch	A switch in which actuation of the contacts is affected at a predetermined liquid or gas pressure. (IEC)
r/min (revolutions per minute)	The number of full rotations something makes in one minute.
relay	An electrical switch that opens and closes under the control of another electrical circuit.
rotor	The rotating member of a machine, including the shaft.
schematic diagram	A diagram that shows all circuit connections between components, by means of graphic symbols, without taking into account physical sizes, shapes, or locations of the items.
selector switch	A device that can provide several different contact arrangements by rotating a single switch.
service factor	Multiplier that is applied to the rated power to indicate the permissible power loading capacity designed into a motor.
solenoid	A tubular, current carrying coil that provides magnetic action to perform various work functions.

Glossary

solid-state	Circuitry designed using integrated circuits (transistors, diodes, etc.), without any electromechanical devices, such as relays.
squirrel-cage induction motor	An induction motor in which a primary winding on one member (usually the stator) is connected to an alternating-current power source and a secondary cage winding on the other member (usually the rotor) carries alternating current produced by electromagnetic induction.
star-connected circuit	See Wye-Connected Circuit.
stator	The portion of a motor that includes and supports the stationary portion of the magnetic circuit and the associated winding and leads.
tagout procedure	The placement of a tag on an energy-isolating device, in accordance with an established procedure, to indicate that the energy-isolating device and the equipment being controlled may not be operated until the tag is removed.
target table	Table used to indicate the contact condition of a device, depending on its states.
three-phase circuit	A combination of circuits energized by alternating electromotive forces that differ in phase by one third of a cycle; that is 120˚. (ANSI)
three-wire control	A control function that utilizes a momentary-contact pilot device and a holding-circuit contact to provide undervoltage protection. (IEEE)
torque	The twisting or turning force which tends to produce rotation in a motor.
trigger	A pulse used to start or stop the operation of a circuit or device.
two-wire control	A control function that utilizes a maintained-contact type of pilot device to provide undervoltage release. (IEEE)
undervoltage protection	The effect of a device, dependant on the reduction or failure of voltage, to cause and maintain the interruption of power to the main circuit. (IEEE)
undervoltage release	The effect of a device, dependant on the reduction or failure of voltage, to cause the interruption of power to the main circuit, but not to prevent the reestablishment of the main circuit on return of voltage. (IEEE)
wiring diagram	A diagram that locates and identifies electrical devices, terminals, and interconnecting wiring in an assembly. (NEMA)
wye-connected circuit	A polyphase circuit in which all the current paths extend from a terminal or conductor.

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Appendix B

5 kV Breaker Manual

.5 OF 5

IB-8.2.7-2

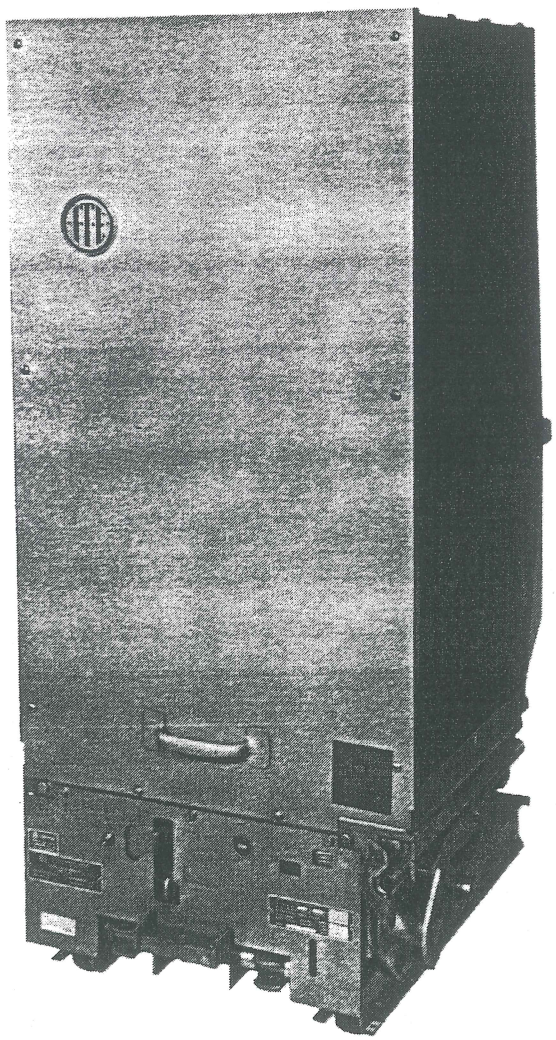
ISSUE F

CIRCUIT BREAKS

I-T-E METAL-CLAD SWITCHGEAR

INSTRUCTIONS

5 KV POWER CIRCUIT BREAKERS
TYPE 5HK75, 5HK150, 5HK250 AND 5HK350



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COVER H45277

INSTRUCTIONS FOR 5 KV POWER CIRCUIT BREAKERS TYPE 5HK75, 5HK150, 5HK250 AND 5HK350

INTRODUCTION

These instructions for installation, operation and maintenance of HK circuit breakers shoud be read carefully and used as a guide during installation and initial operation.

The specific ratings of each model circuit breaker are listed on the individual nameplates.

File these instructions in a readily accessible place together with drawings and descriptive data of the switchgear. These instructions will be a guide to proper maintenance of the equipment and prolong its life and usefulness.

RECEIVING AND STORAGE

Immediately upon receipt of the circuit breakers, examine the cartons to determine if any damage or loss was sustained during transit. If injury or rough handling is evident, file a damage claim at once with the carrier and promptly notify Gould Inc. Gould Inc. is not responsible for damage of goods after delivery to the carrier. However Gould Inc. will lend assistance if notified of claims.

Unpack the circuit breakers as soon as possible after receipt. If unpacking is delayed, difficulty may be experienced in making a claim for damages not evident upon receipt. Use care in unpacking in order to avoid damaging any of the circuit breaker parts. Check the contents of each carton against the packing list before discarding any packing material. If any shortage of material is discovered, promptly notify the nearest sales representative of Gould Inc. Information specifying the purchase order number, Gould sales order number, carton number and part numbers of the damaged or missing parts should accompany the claim.

Circuit breakers should be installed in their permanent location as soon as possible. If the breakers are not to be placed in service for some time, it is advisable to provide adequate means of protection. This may be done by keeping the breaker in its original shipping carton and storing in a warm, dry and uncontaminated atmosphere. If the circuit breaker cannot be stored properly due to circumstances, it must be thoroughly checked before going into service to insure it has not absorbed moisture, rusted or become generally contaminated in any way.

CIRCUIT BREAKER INSTALLATION

GENERAL

Prior to the initial installation of the circuit breaker into switchboard, certain preliminary inspections should be made to insure proper operation. The inspection procedures for this are given in this section.

FOR SAFETY: Prior to any disassembly or inspection of the circuit breaker, the closing springs should be discharged, and the breaker should be open.

If it is necessary to raise or move the breaker, attach a lifting yoke at points 4 (Fig. 1) or a fifth wheel at point 5 (Fig. 2) to transport the breaker as required.

INSTALLATION INSPECTION

Inspect condition of circuit breaker arc chutes, contacts and electrical connections prior to installing the circuit breaker into the switchboard. Even though each circuit breaker is completely adjusted and tested at the factory, shipping and handling conditions could cause defects.

REMOVING INTERPHASE BARRIER

For 5HK75, 150 and 250, remove two lower front sheet screws, lift straight up above arc chutes by grasping front handle and top sheet at rear, then draw barrier forward and away from circuit breaker.

For 5HK350, remove two lower front sheet screws, and lift front sheet up and away from the breaker. Remove arc chute tie bar at upper front of arc chutes. Pivot rear brace at rear of each barrier upward and slide the separate barriers forward and away from the circuit breaker.

CAUTION: The 5HK350 barriers will not stand unsupported and must be braced.

These instructions do not purport to cover all details or variations in equipment nor to provide for every possible contingency to be met in connection with installation, operation, or maintenance. Should further information be desired or should particular problems arise which are not covered sufficiently for the purchaser's purposes the matter should be referred to Gould Inc.

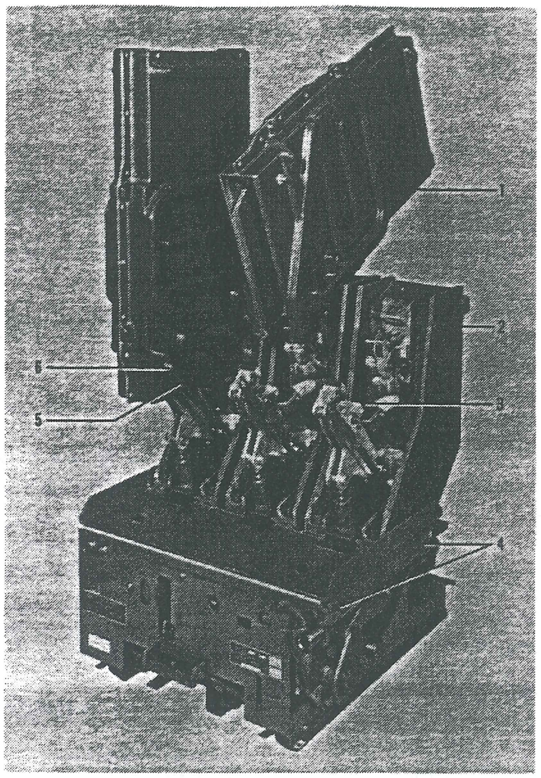

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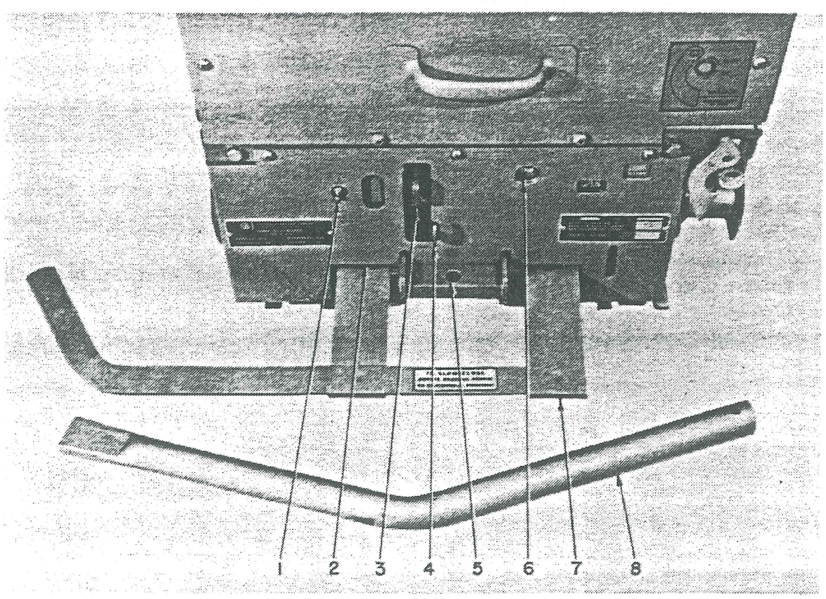
Fig. 1 — View Showing Arc Chute and Contact Structure



E40250-A

Fig. 2 — Front View of Control Panel

REMOVING ARC CHUTES (See Fig. 1)

For 5HK75, 150 and 250, remove nut (6) and gently disconnect return connection (5). Grasp the arc chute (1) at the front and top and gently tilt on its pivot towards the rear until it rests on the lead support molding (2). If other than visual inspection is to be done, the arc chute, in the tilted position, should be lifted straight out of the pivot guide slots and fingers and removed from the circuit breaker.

For 5HK350, remove nut (6) and gently disconnect return connection (5). Remove bolt connecting the front leg of the arc chute to the block on the base sheet of the circuit breaker. Attach the accessory lifting bracket to the tie bar bushing at the top front of the arc chute and slowly raise the arc chute as required by means of a hoist. It will pivot at its terminal connection and then should be guided straight out of the pivot guide slot and fingers and removed away from the circuit breaker. If only a visual examination is to be made, each arc chute may be tilted back gently, hand held and then slowly lowered.

CAUTION: Be sure return connection is clear and does not catch on the arc chute. Also block wheels to prevent breaker from rolling.

ARC CHUTE EXAMINATION

Examine arc chutes carefully before placing into service. Look for any breakage to liner plates and arc chute plates. Check for presence of any foreign particles such as chips of ceramic and metal. Inspect exterior for any damage or deformation. The polyester glass moldings occasionally have some small cracks develop in resin rich areas but these cracks do not indicate defective material and should not cause concern.

INSULATION STRUCTURE

All insulated parts should be checked for damage. Any dust or dirt should be removed by air or wiped with a clean lintless cloth saturated with an oil-free solvent. This is important because the soot or dirt can accumulate and, with moisture, can place the circuit breaker in jeopardy, dielectrically. The lead support moldings are polyester glass and occasionally have some resin rich cracks or crazing develop but these do not indicate defective material and should not cause concern.

MANUAL SLOW CLOSE TO CHECK CONTACT PRESSURE (See Fig. 2)

NOTE: Insure that accessories that affect electrical/mechanical operation are set in their operating position: i.e., undervoltage devices should be energized or mechanically closed; mechanical interlocks, key or other, should be properly set; etc.

Turn racking screw clockwise approximately two to three turns until the racking-unlocking lever snaps into the first position corresponding to the "DISCONNECT" position.

Engage manual charge handle (8) with charging lever (3). Pump charging lever until breaker closing springs snap into charge position, then remove handle.

Insert BOTH tangs of spring retainer bracket (7) into holes of closing spring guides (2).

Pull manual close lever (4) to discharge closing springs onto tangs of spring retainer bracket (7). At this time the contacts will partially close.

Re-engage manual charge handle (8) with charging lever (3), then slowly pump to slow close breaker contacts. Check contact pressure as listed in Adjustment Section, using the manual trip button (6) to open the breaker.

To remove spring retainer bracket (7) from circuit breaker, continue pumping until closing springs are again heard to snap into charged position. Spring retainer bracket can now be removed.

Discharge closing springs by pulling manual close lever (4) and pushing manual trip button (6) at the same time to effect a trip free operation. (Or the breaker can be closed first and then tripped.)

INSTALLING ARC CHUTES (See Fig. 1)

Position arc chute (1) in tilted position, squarely down into its rear pivot guide slots and fingers (avoid bumping and chipping of all moldings), then lower slowly into position.

CAUTION: Be sure return connection is clear and does not catch on the arc chute.

Securely fasten return connection (5) by its nut (6). Also, on 5HK350 breakers the front arc chute support leg must be secured to its hold down block.

INSTALLING INTERPHASE BARRIER

For 5HK75, 150 and 250, lift barrier and slide it approximately halfway on the breaker. Then, after aligning the vertical sheets of the barrier properly between the lead support moldings and inside the clips on the outside moldings, slide the barrier as far to the rear as possible. Lift the barrier slightly by its handle at the lower front (Fig. 2) to permit the rear brace of the barrier to drop down behind the arc chutes. Then, push firmly down and back on the barrier handle to properly position the interphase barrier in place. Secure the barrier in place with the two lower front sheet screws.

For the 5HK350, slide the right and left interphase barriers, as marked, in place between the lead support moldings and inside of the clips on the outside moldings, and pivot the rear brace downward behind the arc chutes. Install the arc chute tie bar at the upper front on the arc chutes. Then, left front sheet in place so that it hooks over the arc chute tie bar. Secure the barrier front sheet in place with the two lower front sheet screws.

CAUTION: On 5HK350, for older unmarked barriers, ensure that the flux shunt pad is installed between poles.

INSTALLING CIRCUIT BREAKER INTO COMPARTMENT (See Figs. 2 & 3)

NOTE: CLOCKWISE ROTATION of racking crank for inserting breaker. COUNTERCLOCKWISE rotation of racking crank for removal of breaker.

Turn motor disconnect switch (if supplied) (1, Fig. 2) to "OFF" position.

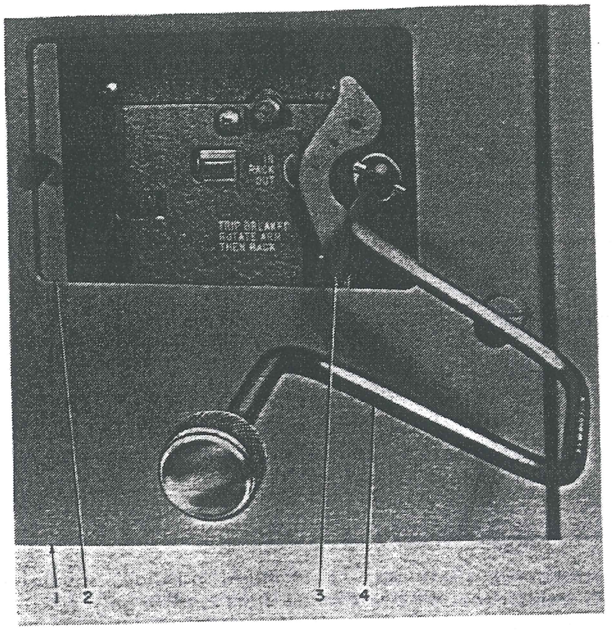


Fig. 3 — Method of Racking Circuit Breaker

Engage racking crank (4, Fig. 3) and push racking unlocking lever (3) to left, then rotate racking crank counterclockwise only until resistance to motion is felt. (DO NOT FORCE.)

Engage the fifth wheel with hole (5, Fig. 2); guide and push circuit breaker into compartment until stopped. (If closing springs were left in charged condition, they will automatically discharge.) Again engage racking crank and rotate clockwise until racking mechanism automatically stops at "DISCONNECT" position. (Breaker is now held captive in compartment.)

To rack circuit breaker to "TEST" position, push racking unlocking lever (3, Fig. 3) to left, rotate racking crank approximately ¼ turn clockwise, then release unlocking lever. Continue cranking until racking mechanism automatically stops at "TEST" position.

With the circuit breaker racked to "TEST" position, it should be checked for proper operation by operating all possible means of opening and closing, this includes control switches, relays, etc. Turn motor disconnect switch (1, Fig. 2) to "ON" position to charge the closing springs, and operate the breaker as required. (If motor disconnect switch (1, Fig. 2) is not provided, springs will automatically charge when approaching "TEST" position.)

FOR SAFETY: When racking circuit breaker to "CONNECTED" position, close compartment door (1, Fig. 3) and insert racking crank (4, Fig. 3) through sliding panel (2, Fig. 3).

Push unlocking lever (3) to left and turn racking crank (4) approximately ¼ turn clockwise, then release unlocking lever. Continue cranking until racking mechanism automatically stops at "CONNECTED" position.

CAUTION: Do not attempt to rack any further.

The circuit breaker now may be put in service and be operated as required.

CIRCUIT BREAKER REMOVAL
(See Fig. 3)

To remove circuit breaker from "CONNECTED" position, open the breaker as required.

Open sliding door (2) in front compartment door (1). Engage racking crank (4) and push racking unlocking lever (3) to left. Rotate racking crank (4) counterclockwise approximately ¼ turn, then release unlocking lever. Continue cranking counterclockwise until racking mechanism automatically stops at "TEST" position.

Repeat same operation for "DISCONNECT" position.

To position the racking mechanism for withdrawal of the circuit breaker from the switchboard, again push the racking unlocking lever to the left and turn the racking crank counterclockwise only until resistance to motion is felt. (Approximately 2-3 turns—DO NOT FORCE.) The circuit breaker can now be removed from the compartment by pulling on the handle located at the bottom of the front barrier, or by pulling at lower edge of front barrier sheet on the 1200 or 2000 Ampere 5HK350.

NOTE: The closing springs, if charged, will automatically discharge when the circuit breaker is withdrawn from the switchboard.

SAFE OPERATION RECOMMENDATIONS

1. It is recommended that any circuit breaker be withdrawn and stored in the test position whenever it is to be maintained in the open position with no planned switching.

2. It is recommended that a ground and test device be connected in the proper compartment when any work is to be done on any bus or feeder circuit.

MAINTENANCE AND ADJUSTMENTS

GENERAL INFORMATION

The HK circuit breakers are designed for minimum maintenance and tested to insure that minimum maintenance will be required. There is only one basic adjustment normally required and that is contact adjustment. This should be checked to the dimensional values required as described elsewhere. The few other adjustments that are noted are required only when an operational check indicates a problem. Of course, during the maintenance checks, all accessible bolts, nuts and screws should be routinely checked to insure that they are tight.

It is recommended that the 5HK75, 5HK150 and 5HK250 circuit breakers be normally inspected after 2000 operations and that the 5HK350 circuit breakers be normally inspected after 1000 operations. These operations can be either no-load mechanical or load current switching where the power factor is relatively high. When the circuit breakers are used for direct bulk capacitor or reactor switching operations or for motor starting aplications, it is recommended that the

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5HK75, 5HK150 and 5HK250 circuit breakers be inspected after 1000 operations and that the 5HK350 circuit breakers be inspected after 500 operations because of the switching severity.

If however, after the first inspection period, there is no indication of any problems, actual operating experience can then dictate the inspection cycle.

Regarding maintenance recommendations following fault duty, reference is made to ANSI Standard C37.04 to which the circuit breakers have been tested. In accordance with this standard, a total of 400% asymmetrical fault duty can be accumulated. This is to be ten or less close-open operations at less than 85% of full fault duty, but it can be an accumulation over a long time period of lower currents. The condition of the breaker should be such that after this duty it is capable of one more close-open operation at full fault current. Inspection is to be made at this time to insure this and then the final operation can be made if everything is satisfactory. At this time, maintenance should be performed and reconditioning done and replacements made as indicated.

Further, in accordance with the same standard, it is recommended that after a major fault duty cycle (CO-15 SEC. -CO) which is known to be between 85 and 100% of the circuit breaker rated asymmetrical short circuit current that the circuit breaker be inspected regardless of any time period or number of operations. Also, when the circuit breaker is applied on reclosing duty, it should be inspected immediately after the series of fault operations in the same range of currents.

The condition of the circuit breaker after interruption depends on the circuit conditions regarding such things as power factor, X/R ratio and relay delay times. Experience with specific circuits will indicate the future amount of maintenance that will be required for the various breakers and then modification in procedure can follow.

Of course, where unusual service conditions, as covered by ANSI Standard C37.04, exist, it must be assumed that these conditions were considered at the time of order; that the equipment supplied was designed for the special application; and that an appropriate supplemental maintenance program has been developed. These maintenance instructions only cover circuit breakers used under the standard usual service conditions.

After normal service without major fault interruption, the following tests and adjustments should be made:

NOTE: The following tabulated tests and adjustments are all that are normally necessary for proper maintenance and operation of the HK circuit breaker. The remaining portions of the breaker — close coil assembly, shunt trip device, control relay, auxiliary switch and motor — require no maintenance during the standard life of the circuit breaker regardless of the operating duty.

MILLIVOLT DROP TEST

During normal maintenance periods, the condition of the circuit breaker can easily be determined by performing a millivolt drop test. This test should be performed regardless of whether the circuit breaker had interrupted low or high currents or has minimum operations.

The following table lists the millivolt drop and resistance values for the circuit breakers covered by this instruction book, from terminal to terminal, exclusive of the primary disconnects.

CIRCUIT BREAKER	MAXIMUM MV DROP*	MAXIMUM MICRO-OHMS
5HK75, 5HK150, 5HK250 5HK350 1200 Ampere	9	45
5HK150, 5HK250, 5HK350 2000 Ampere	7	35
5HK350 3000 Ampere	4	20
* Millivolt drop with 200 amperes flowing.		

If the millivolt drop does not exceed 150% of the above values, on breakers with normal loading, no maintenance is necessary. If the millivolt drop does exceed 150% of the above values, the main and arcing contacts should be dressed with a fine file, cleaned and be adjusted for proper contact pressure and then rechecked. If the values are still in excess of the 150% value, the bridge pivot pressure should be readjusted as outlined elsewhere.

However, for optimum performance of the circuit breakers during periods of increased loading, it is recommended that the listed values be met.

After all above steps have been taken and the millivolt drop is still excessive, contact Gould for recommendations.

CONTACT AND INSULATION CLEANING

Any dirt, soot or grease should be removed from the circuit breaker contacts and surface of entire current carrying structure, as well as all insulation surfaces, with a cloth saturated with an oil-free solvent. Cleaning of the insulation is important because the soot and dirt can accumulate and, with moisture, can place the circuit breaker in jeopardy, dielectrically.

A degree of burning and pitting on the circuit breaker arcing contacts is to be expected from normal operation; also, on highly inductive or capacitive circuits and after major interruptions, some pitting may occur on the main contacts. A moderate amount of pitting will not interfere with the operation of the contacts. When necessary to dress the contacts, cover the puffer nozzle (3, Fig. 1) with a cloth, then follow the contour of the contacts with a fine file. Do not attempt to eliminate pitting entirely. After this maintenance, the contact pressure and millivolt drop should be checked.

NOTE: Replacement of contacts need only be considered when: after repeated dressing of any contacts, less than 50% of the original contact material thickness is left; the tips of the stationary arcing contacts have been eroded away; any contact has been broken or cracked.

CONTACT PRESSURE (See Fig. 4)

A. With the circuit breaker withdrawn from the switchboard, the following step-by-step procedure should be followed for properly checking and/or adjusting the contact pressure on an "HK" type circuit breaker.

1. Remove interphase barrier assembly and remove arc chutes as described previously.

2. Turn racking screw clockwise approximately two to three turns until the racking-unlocking lever snaps into the first position corresponding to the "DISCONNECT" position.

3. Manually slow-close the circuit breaker as described on page 5, but only to the point that the arc contacts just touch. All arcing contacts should touch within 1/32".

4. Continue the slow-close operation to fully close the breaker. Each pole should have between 7/64" minimum and 3/16" maximum main contact compression measured at "A" between the EDGE of the metal stop plate and the main contact stop. (This dimension measured on either side is sufficient.) A rod or drill of these sizes can be used for measuring.

At this point, if the adjustments are correct, complete steps B6, B7, B8 and B9 following.

B. If any adjustment is incorrect, use the following procedure to readjust contact pressure or to initially adjust when changes are made:

1. Completely slow-close the circuit breaker and set each pole for 7/64" main contact compression at "A". (A 7/64" rod or drill should fit tightly between the EDGE of the metal stop plate and the main contact stop.)

2. Open the circuit breaker, manually recharge the closing springs, and partially slow-close the circuit breaker until the arcing contacts of any pole or poles just touch.

3. Advance the adjustment of the lagging pole or poles so that the three arcing contacts touch simultaneously within 1/32". This adjustment is made by loosening locking bolt or set screw (depending on model) (2) and rotating adjusting stud (3).

4. Complete slow-close operation to fully closed position and check that the main contact compression of the pole or poles that were advanced does not exceed 3/16". Also, the arcing contact springs on these poles should not be fully compressed. If the 3/16" dimension is exceeded, the entire procedure should be repeated to obtain the correct gap at "A".

NOTE: Occasionally, the center pole contact pressure may slightly exceed 3/16". However, if the outer poles are within the 3/16" dimension and the arcing contact springs of the center pole are not fully compressed no readjustment need be made. When this condition exists, the center pole parts before the outer poles on opening.

5. Open the circuit breaker, recharge the closing springs, remove the slow-close bracket, fast-close the breaker, recheck adjustments and trip open.

NOTE: Fast-closing the circuit breaker results in a slight increase in contact pressure over slow-closing.

6. Tighten the locking bolt (2) on each adjusting stud (3) to lock the contact pressure adjustment stud in place.

7. The arc chutes can now be replaced, and the interphase barrier assembly can now be reinstalled.

8. Return the racking screw to its original position by turning it counterclockwise approximately two to three turns until it stops.

9. The circuit breaker can now be replaced in its compartment and returned to service.

PUFFERS (3, Fig. 1)

The performance of the puffers can be readily checked during a maintenance interval. Each puffer should provide a moderate blast of air at the breaker contacts, on opening of the circuit breaker. This can be detected by holding the hands or arm over the top of the contacts and opening the circuit breaker. All three poles must have puffing action or else the circuit breaker must not be placed in service.

FOR SAFETY: Keep clear of all moving parts.

CLOSING AND OPENING TIMES

After the operation intervals noted previously or a change in bridge pivot adjustment, the closing and opening times are recommended to be checked by use of a cycle counter, time-travel analyzer*, oscillograph etc. to monitor the time from energizing to arcing contact touch or part.

*Analyzer mounting support and instructions available on special order.

The circuit breaker closing and opening times should be within the following time ranges for normal operation.

CIRCUIT BREAKER	CLOSING TIME RANGE - MS *	OPENING TIME RANGE - MS *
5HK75, 5HK150, 5HK250 1200 Ampere	50 - 90	23 - 35
5HK150 & 5HK250 2000 Ampere	60 - 95	23 - 35
5HK350 1200 & 2000 Ampere	50 - 90	23 - 35
3000 Ampere	65 - 95	23 - 35

* At 125Vdc - Times at other voltages may vary slightly.
NOTE: 5HK250, 80kA high momentary, same as 5HK350, 1200 & 2000 Ampere, in table above.

NOTES:

1. Below 0° C., the closing times will increase (but with no reduction in closing force); and opening times will be within the limits.

2. Adjustments to correct times, if found to be outside limits, are critical and Gould Inc. should be contacted for recommendations.

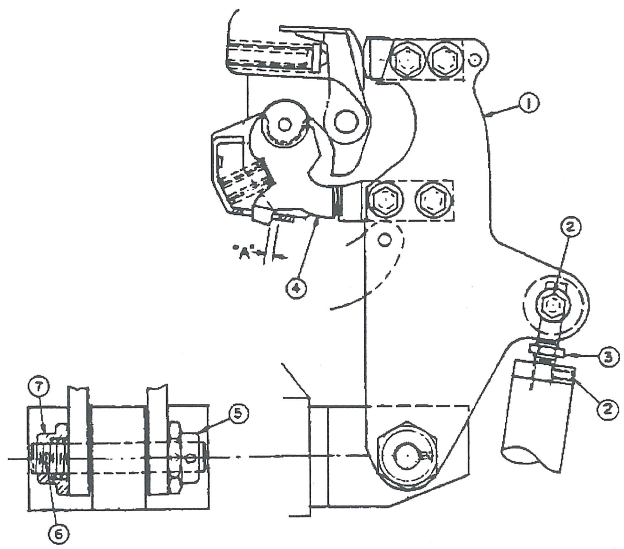


Fig. 4 — Contact Pressure and Bridge Pivot Pressure

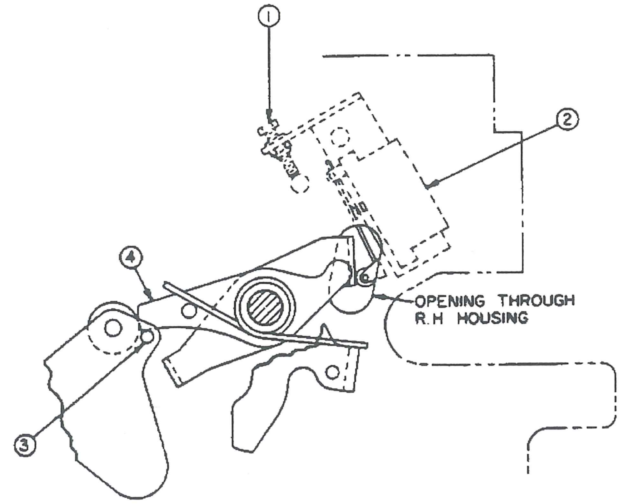


Fig. 5 — Latch Check Switch Adjustment

ARC CHUTES

The arc chutes should be inspected internally to insure that no breakage occurred to the liner plates or arc plates. Further, there may be a crust formed on the liner plates if the load current interruptions were close to the continuous current rating of the breaker or moderate faults were interrupted. This crust should be removed by carefully using a carborundum stone or scraper. Then the arc chute should be blown out with air to remove the resultant dust and particles.

After 400% accumulated current or major interruptions occur, the circuit breaker should be inspected immediately afterwards, as stated previously. All maintenance checks or tests noted above should be carried out plus the arc chutes should be looked at closely. Arc plate and liner plate breakage should be carefully looked for, along with excessive erosion of the arc plates. The arc plates are made of ceramic material and perform the function of extracting heat from the arc as it is being forced into and elongated by them. The leading edges become coated with glass that comes to the surface from the extreme heat. The direct measure of use is the amount of glass beads evident.

When the entire leading edge and portions of the flat arc plate are noted to be heavily encrusted with glass beads, the arc chute should be replaced. It should be noted that this condition will vary between arc chutes on the same breaker because of single-phase fault and asymmetrical current incidences. If there are any questions, contact Gould Inc. for recommendations.

BRIDGE PIVOT PRESSURE (See Fig. 4)

Bridge pivot pressure should be adjusted only when the millivolt drop test indicates a problem.

When this adjustment is necessary, the following steps should be done.

1. Locking bolt (2) should be loosened on solid pushrod models. Spring-loaded pushrod models do not require disconnecting.

2. Bridge (1) should be disconnected from adjusting stud (3) on solid pushrod models.

3. Loosen one set screw (6) in one pivot nut — either side.

4. Tighten bridge pivot nut (5 or 7) securely (approximately 75 ft. lbs.). Then gradually back up pivot nut (approximately ½-1½ flats) until bridge motion is just free when bridge is moved by hand. On spring-loaded pushrod models, lift bridge against spring and then slowly release, insuring that it resets freely.

5. Tighten set screw (6) in nut that was loosened, reconnect adjusting stud, if disconnected, and readjust contact pressure as described elsewhere.

OPERATING MECHANISM (See Fig. 5)

The operating mechanism is adjusted at the factory for proper operation and should not be disturbed unless the circuit breaker does not close electrically on reclosing duty.

This condition is caused when the latch check switch (when used) is not actuated. Circuit breaker should not close before trip latch (4) has reset.

Adjustments should be made with latch (4) against reset stop pin (3). Turn in adjusting screw (1) until contacts of switch (2) "break" (as indicated by an audible click or check with bell ringer). Retract adjusting screw until switch contacts "make", then rotate adjusting screw one turn more. (Adjusting screw is self-locking.)

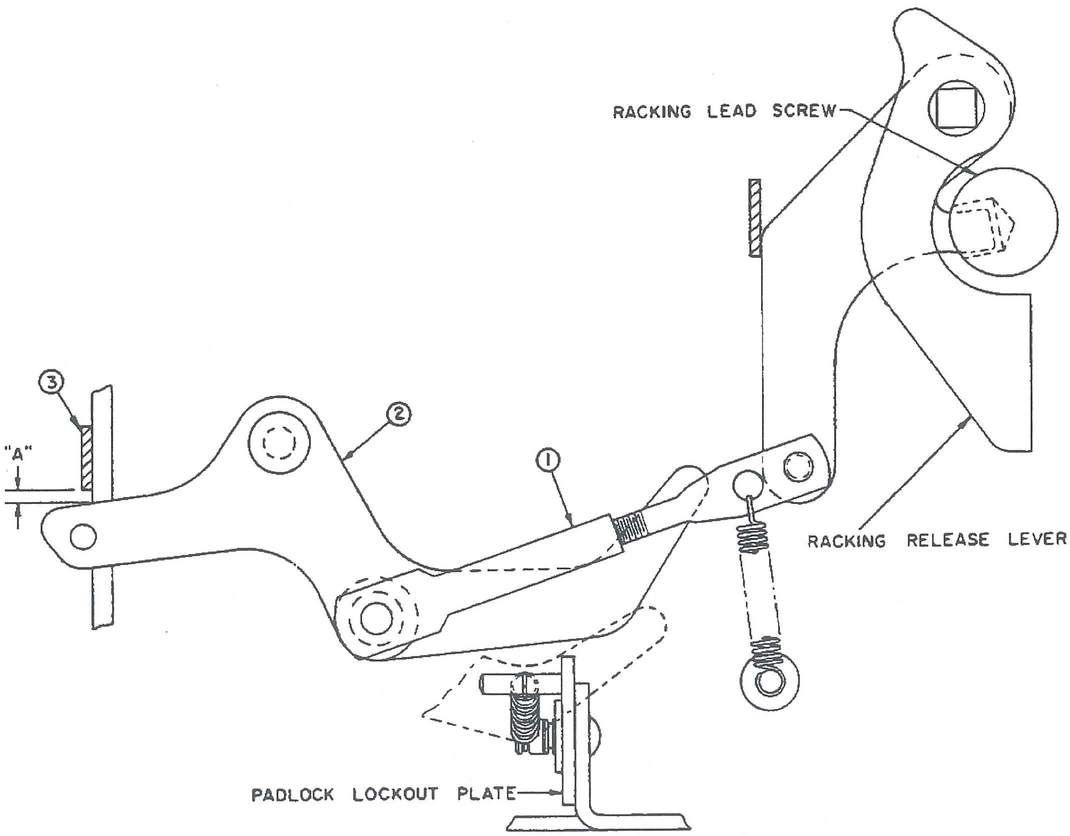


Fig. 6 — Racking Mechanism

TABLE 1 - OPERATING VOLTAGE RANGE

NOMINAL CONTROL VOLTAGE	SPRING CHARGING MOTOR	CLOSE COIL	TRIP COIL	UNDERVOLTAGE	
				PICK-UP MAXIMUM	DROP-OUT
24 V dc	-	18-28	14-30	21	7-14
48 V dc	35-50	35-50	28-60	41	15-29
125 V dc	90-130	90-130	70-140	106	38-75
250 V dc	180-260	180-260	140-280	212	75-150
115 V ac	95-125	95-125	95-125	97	34-69
230 V ac	190-250	190-250	190-250	195	69-138

TABLE 2 - AVERAGE CURRENT VALUES

NOMINAL CONTROL VOLTAGE	SPRING CHARGING MOTOR	CLOSE COIL	TRIP COIL	LOCKOUT COIL	UNDER-VOLTAGE	N.E.C. FUSE
24 V dc	-	22.0	22.0	0.30	0.9	30
48 V dc	25.0	10.7	10.7	0.15	0.5	30
125 V dc	10.0	5.0	5.0	0.06	0.2	30
250 V dc	5.0	2.2	2.2	0.03	0.1	30
115 V ac	10.0	4.5	4.5	0.40	0.2	30
230 V ac	5.0	2.3	2.3	0.20	0.1	30

RACKING MECHANISM (See Fig. 6)

The circuit breaker racking mechanism is adjusted for proper operation and should not be disturbed unless it becomes possible to close the breaker during a racking operation.

It may be possible that interlocked blocking members are not positioned properly, which should be corrected as follows:

Remove the lower front mechanism coverplate and with the circuit breaker closed, make adjustments by regulating the length of connecting rod (1) for 1/8 inch minimum to 3/16 inch maximum clearance at "A" between trip link (3) and blocking lever (2).

LUBRICATION

The HK circuit breakers are lubricated during factory assembly as follows:

1. All mating surfaces of moving current-carrying joints have been lubricated with NO-OX-ID special grade "A" grease manufactured by Dearborn Chemical Company.

2. All other mechanism parts, bearings, pins, etc. have been lubricated with ANDEROL L757 manufactured by Tenneco Chemical, Inc., Intermediate Division.

The circuit breaker requires no lubrication during its normal service life. However, if the grease should become contaminated or if parts are replaced, any re-lubrication should be done with NO-OX-ID or ANDEROL grease as applicable.

NOTES:

1. Do not use NO-OX-ID grease on any main and arcing contact surfaces.

2. It is recommended that the primary disconnects be maintained by renewing the NO-OX-ID grease during maintenance periods.

3. Do not use light oil to lubricate any mechanism parts.

4. The charging motor is sealed and no lubrication is required.

DIELECTRIC TESTS

If it is desired to make dielectric tests during maintenance periods, the following test values should be used and are to be applied for a one minute period.

CIRCUIT	60HZ	DC
PRIMARY	11.5kV	16kV
*SECONDARY (CONTROL)	1100V	1500V

*It is necessary that the charging motor be disconnected for this test by turning the motor disconnect switch to the "OFF" position. If a test is desired on the motor, then the motor disconnect switch should be turned to the "ON" position and the circuit re-tested at 540V, 60Hz or 760V DC.

ELECTRICAL CHARACTERISTICS OF CONTROL DEVICES

For operating voltage ranges for various nominal control voltages refer to Table 1.

For average current values at various nominal control voltages, refer to Table 2. The current values given in this table are average, steady state values and momentary inrush currents for all charging motors and AC coils are approximately six to eight times these values.

ELECTRICAL OPERATING SEQUENCE

Please refer to the specific schematic diagrams and other operational information furnished with your order.

Fig. 7 is provided as a typical schematic for general information on electrical operation.

The operation of accessories, when installed as ordered, can affect the electrical/mechanical operations of the circuit breaker. When the circuit breaker is being tested electrically or mechanically, undervoltage devices should be energized or otherwise mechanically closed and mechanical interlocks, key or other, should be set in the operate position.

GROUND AND TEST DEVICES

These devices are supplied when ordered and are basically three design types, with certain component variations such as test ports and interlocks.

— Simple, three terminal, non-automatic.

— Simple, three terminal, electrically operated.

— Complex, six terminal, electrically operated with manual selector switch.

These devices are basically maintenance free for their normal operating life. Racking procedure is the same as for the basic circuit breaker as outlined previously, and all detailed operational instructions are attached to the individual devices and need not be repeated here.

RENEWAL PARTS

We recommend only those renewal parts be stocked that will be required to insure proper and timely maintenance for normal operation of the HK circuit breakers. Copies of the applicable Renewal Parts Bulletin for specific circuit breakers will be furnished on request to our nearest sales office.

The minimum quantity of assemblies and items recommended in these bulletins are predicated on infrequent replacement of parts based on accumulated tests and operating experience. Total assemblies are recommended for fast replacement, when necessary, to return the breaker to service as quickly as possible. Then certain replaced assemblies, such as the stationary upper terminals, can be returned to the factory for nominal reconditioning. The bulletins contain specific part ordering instructions; and if desired, specific instructions regarding replacement of those part assemblies recommended, that are not obvious, are also available if ordered.

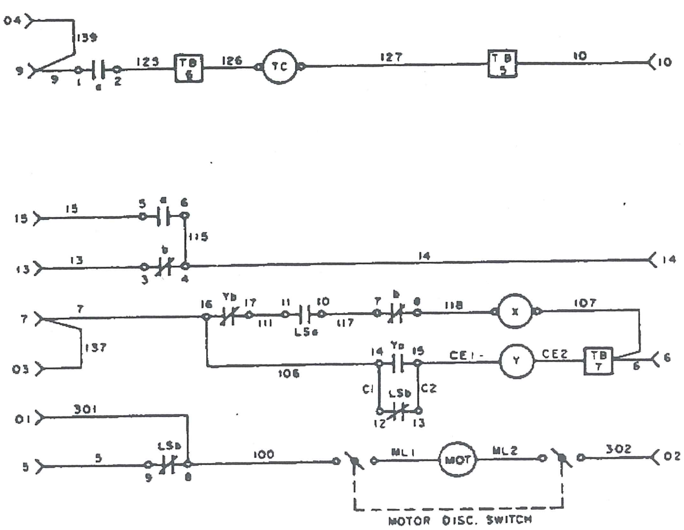
a open when open . . .
B closed when open

A closed when closed
B open when closed

AA -

6 >	< 5
9 >	< 7
10 >	< 13
15 >	< 14
04 >	< 03
02 >	< 01

REAR VIEW OF
SECONDARY
DISCONNECTS



LEGEND

a - Auxiliary Switch Contact Closed When Breaker Is Closed.
b - Auxiliary Switch Contact Open When Breaker Is Closed.
LCb - Latch Check Switch Contact Closed When Breaker Operating Mechanism Is Reset.
LSa - Limit Switch Contact Open When Springs Are Discharged, Closed When Springs Are Charged.
LSb - Limit Switch Contact Closed When Springs Are Discharged, Open When Springs Are Charged.
TC - Shunt Trip Coil.
X - Closing Latch Release Coil.
Y - Control Relay Lockout Coil.
Ya - Normally Open Control Relay Contact.
Yb - Normally Closed Control Relay Contact.
TB - Terminal Block Point.
ML - Motor Lead.
CE - Coil Lead End.
C1, C2 - Terminal Jumper (Control Device).
>- - Female Secondary Disconnect Contact.
UV - Undervoltage Trip Device.
UVb - Normally Closed Undervoltage Trip Device Contact.
69 - Permissive Control Switch.
BL - Blocking Lever Switch (Open When Ground Switch Is Locked In Ground Position).

188556, Sheet 1, REV 0
188571, Sheet 1, REV 2

Fig. 7—Typical DC Schematic Diagram of Control Circuit

Appendix C

EMS Workstation Reference

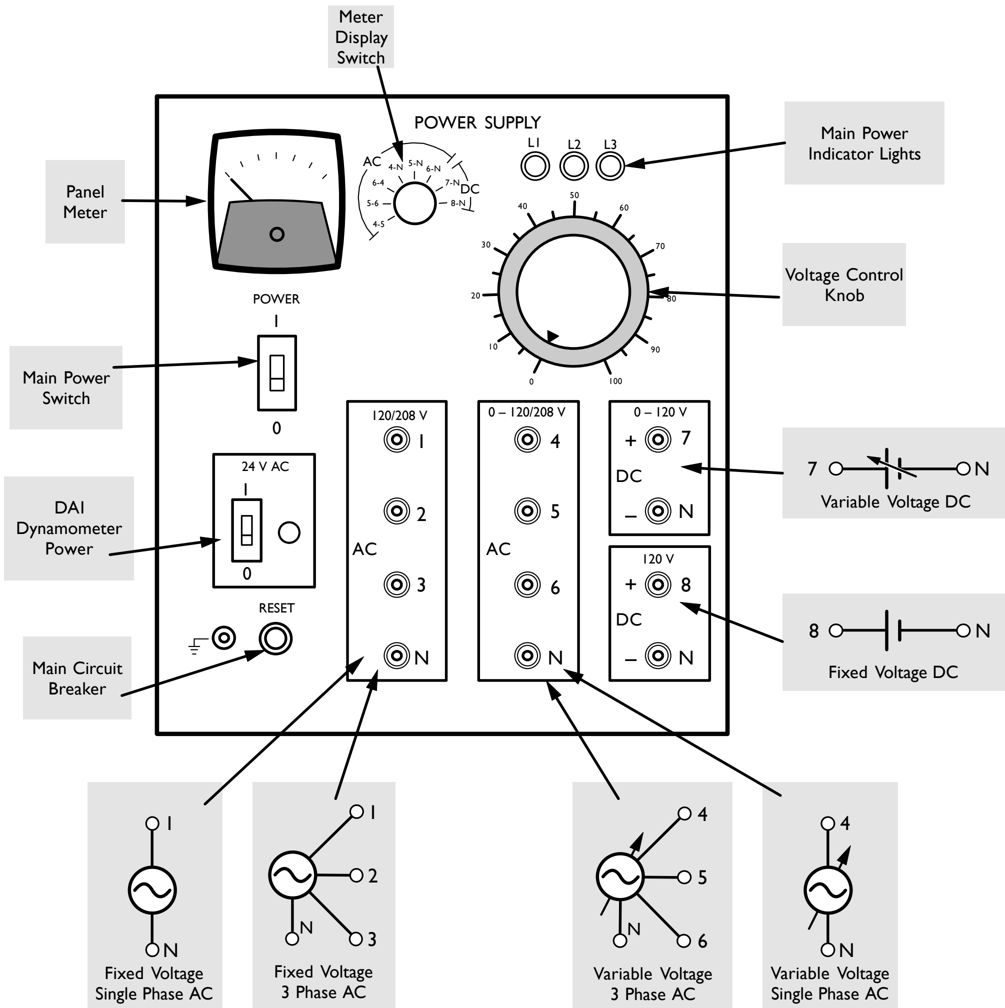


Figure A-1: Lab-Volt Power Supply

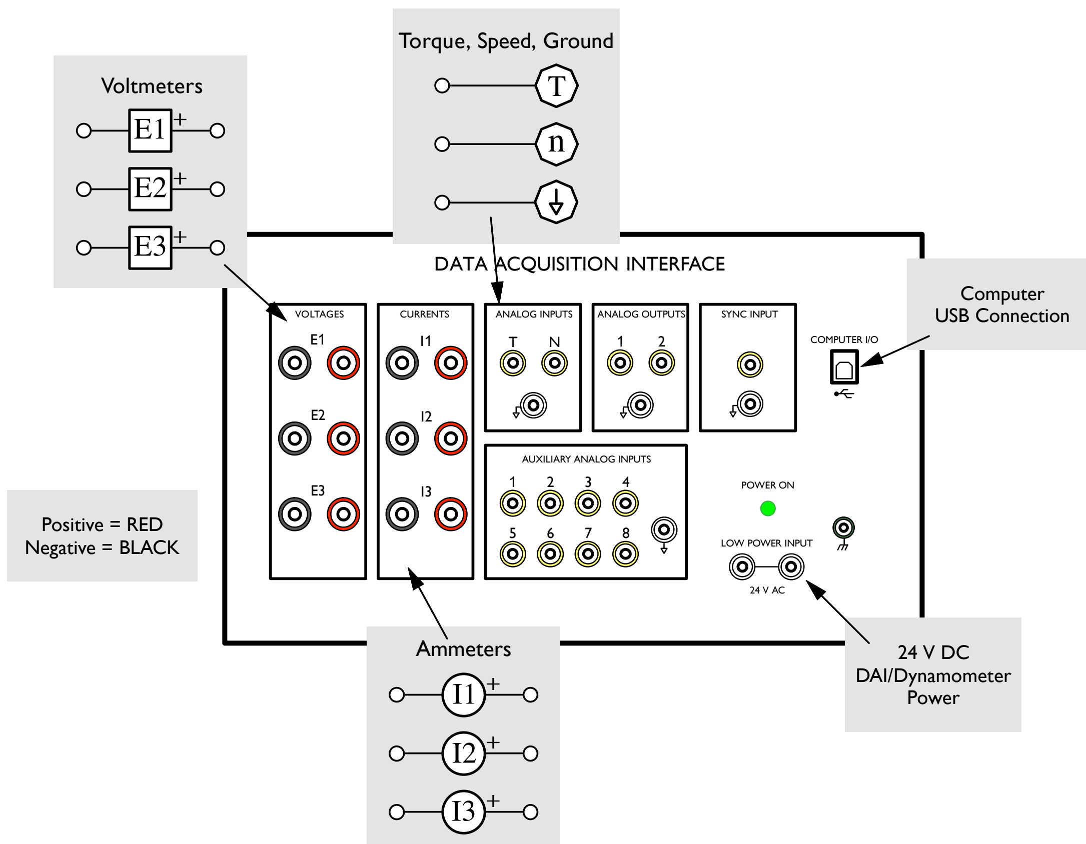


Figure A-2: Data Acquisition Interface

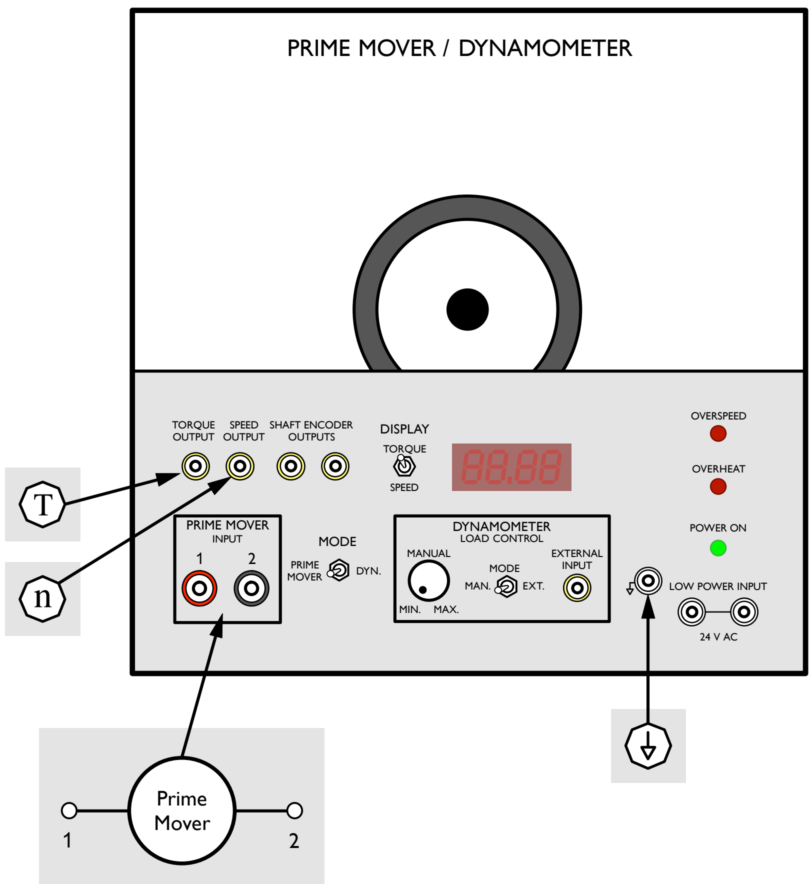


Figure A-3: Prime Mover/Dynomometer

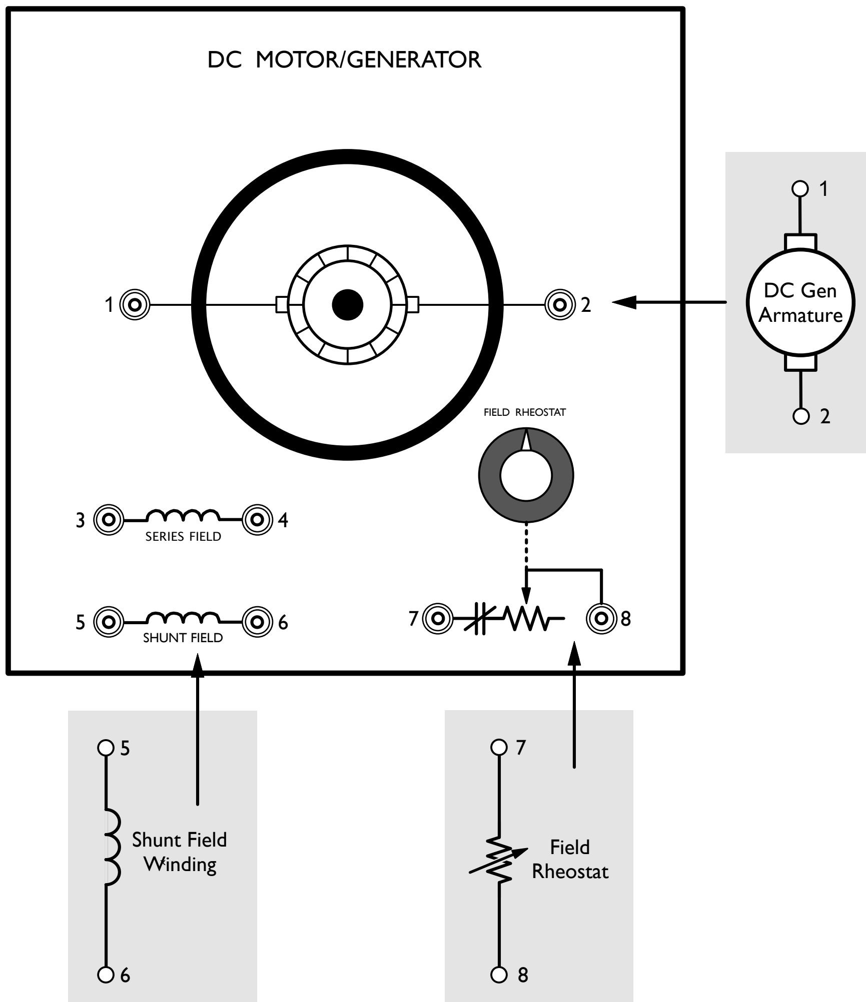


Figure A-4: DC Motor Generator

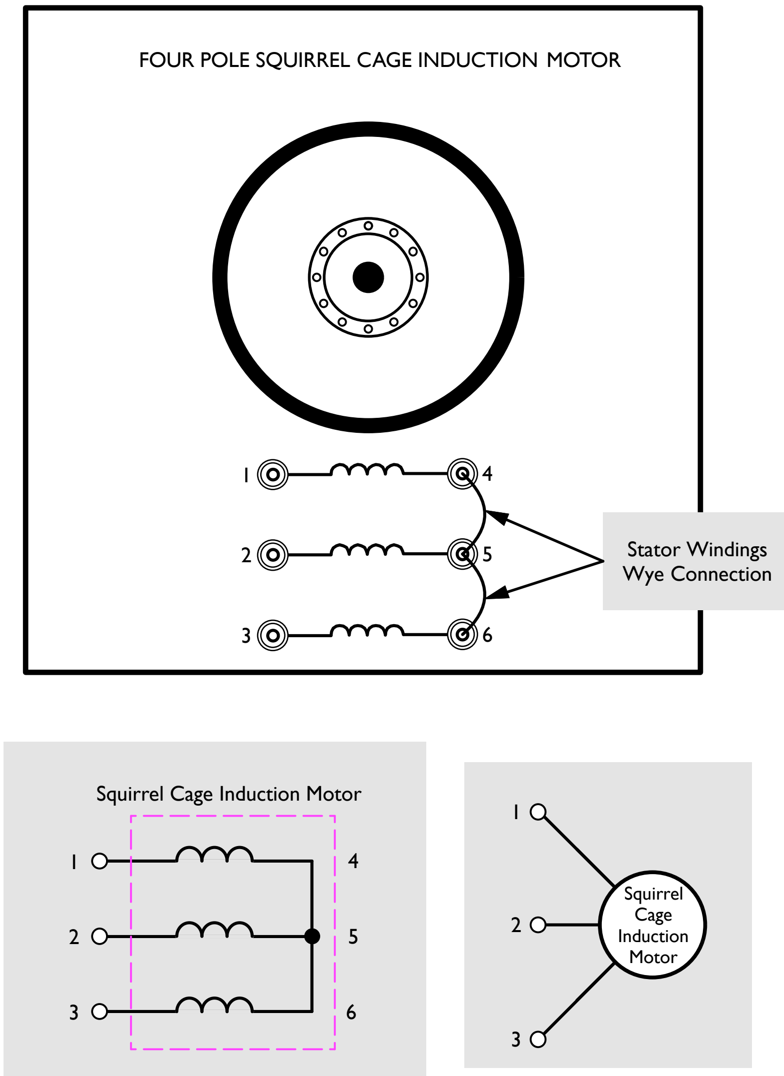


Figure A-5: Three-phase Induction Motor

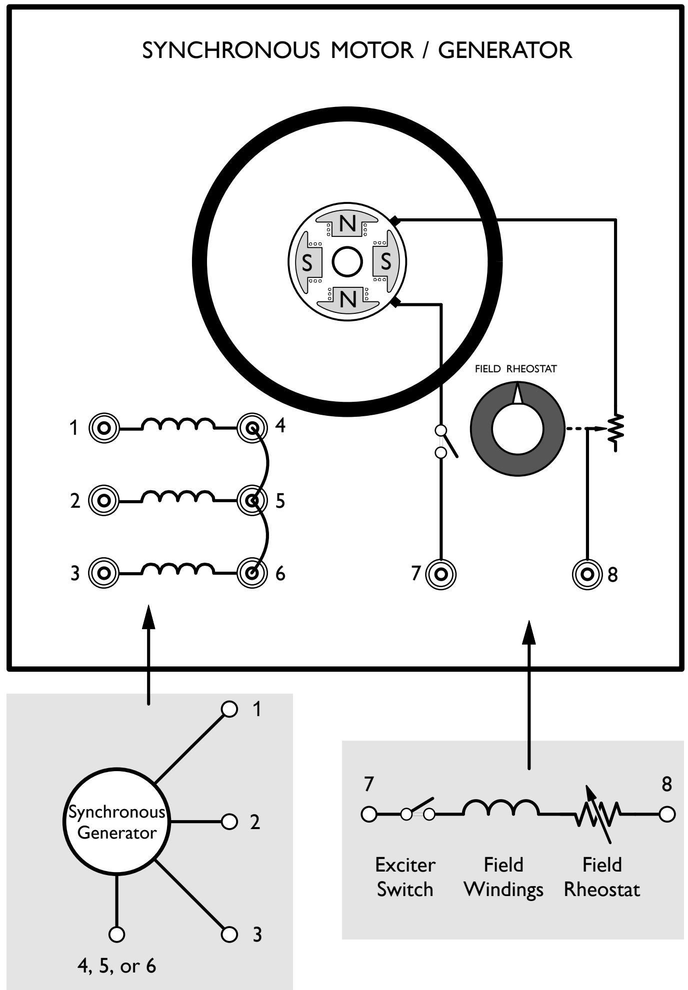


Figure A-6: Synchronous Motor/Generator

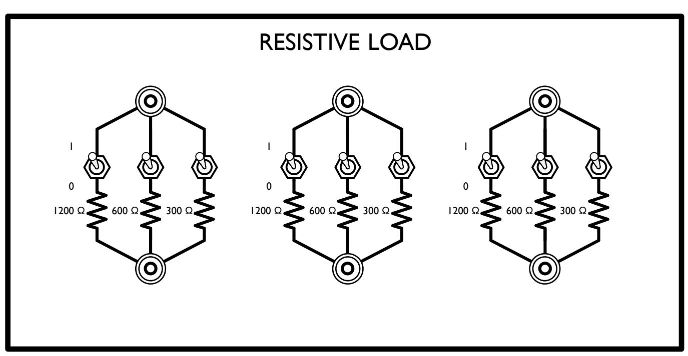


Figure A-7: Resistive Load Module

R_t	Switch Positions								
	1 1200 □	**2** 600 □	**3** 300 □	**4** 1200 □	**5** 600 □	**6** 300 □	**7** 1200 □	**8** 600 □	**9** 300 □
1200 □	1								
600 □		1							
400 □	1	1							
300 □			1						
240 □	1		1						
200 □		1	1						
171 □	1	1	1						
150 □	1			1	1	1			
133 □		1		1	1	1			
120 □			1		1	1			
109 □			1	1	1	1			
100 □	1		1	1	1	1			
92 □		1	1	1	1	1			
86 □	1	1	1	1	1	1			
80 □	1			1	1	1	1	1	1
75 □		1		1	1	1	1	1	1
71 □			1		1	1	1	1	1
67 □			1	1	1	1	1	1	1
63 □	1		1	1	1	1	1	1	1
60 □		1	1	1	1	1	1	1	1
57 □	1	1	1	1	1	1	1	1	1

Table A-1: Resistive Load Module Resistance Combinations