The Complete Lab Manual for Electricity

Fourth Edition

Stephen L. Herman

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The Complete Laboratory Manual for Electricity

Preface

The Complete Laboratory Manual for Electricity, fourth edition, contains hands-on experiments that range from basic electricity through motor control circuits. The components used in the experiments in this manual are readily obtainable from a variety of sources and vendors. The manual assumes that the laboratory has access to 120 volts AC and 208 volts three-phase. Although the manual is written with the assumption of a 208-volt power source, most of the experiments can be performed with a 240-volt power supply. A material list is provided that lists the components necessary to perform all laboratory exercises. A suggested list of vendors is given in the Material List section.

Each unit begins with an explanation of the circuit to be connected in the laboratory. Examples of the calculations necessary to complete the exercise are given in an easy-to-follow, step-by-step procedure. If the power source is 240 volts instead of 208 volts, the student should simply substitute a value of 240 for 208 when doing calculations during the experiment. Students are expected to calculate electrical values and then connect a circuit to make measurements of electrical values.

The Complete Laboratory Manual for Electricity, fourth edition, provides the student with hands-on experience in constructing a multitude of circuits such as series, parallel, combination, RL series and parallel, RC series and parallel, and RLC series and parallel. Section 2 of this manual provides instruction on the basic types of switches that electricians must install whether working in a residential, commercial, or industrial application. Section 3 contains exercises in the basic types of alternating current loads such as resistive, inductive, and capacitive. Section 4 provides experiments with both single-phase and three-phase transformers.

Section 5 provides the student with hands-on experience connecting motor control circuits. This section begins with a simple start-stop push-button circuit and progresses to control circuit design.

The Complete Laboratory Manual for Electricity, fourth edition, is a must-have text for any curriculum dedicated to training electricians to work in a construction or industrial environment. Basic electricity, AC theory, transformers, and motor controls—this text has it all.

New for the Fourth Edition

- Updated graphics.
- The fourth edition revision is the most comprehensive update since the text was first published. In previous editions, incandescent lamps were used as resistive loads because of their availability and cost. In the fourth edition, incandescent lamps have been replaced with fixed high-wattage resistors. The main reason for the change is that Congress has decided to phase out the availability of incandescent lamps over the next few years. Although fixed resistors are more expensive than incandescent lamps, they have the advantage that their resistance value is basically constant over a wide range of temperatures. This permits the student to make Ohm's law calculations before power is applied to the circuit and then make measurements to verify their calculations. The laboratory procedures for many of the units that are associated with Ohm's law have been rewritten to permit the students to make calculation and then measure the results.

Instructor Site

An Instructor Companion website containing supplementary material is available. This site contains an Instructor Guide and an image gallery of text figures.

Contact Cengage Learning or your local sales representative to obtain an instructor account.

Accessing an Instructor
Companion Website from
SSO Front Door

1. Go to http://login.cengage.com and login using the instructor e-mail address and password.
2. Enter author, title, or ISBN in the **Add a title to your bookshelf** search.
3. Click **Add to my bookshelf** to add instructor resources.
4. At the Product page, click the **Instructor Companion site** link.

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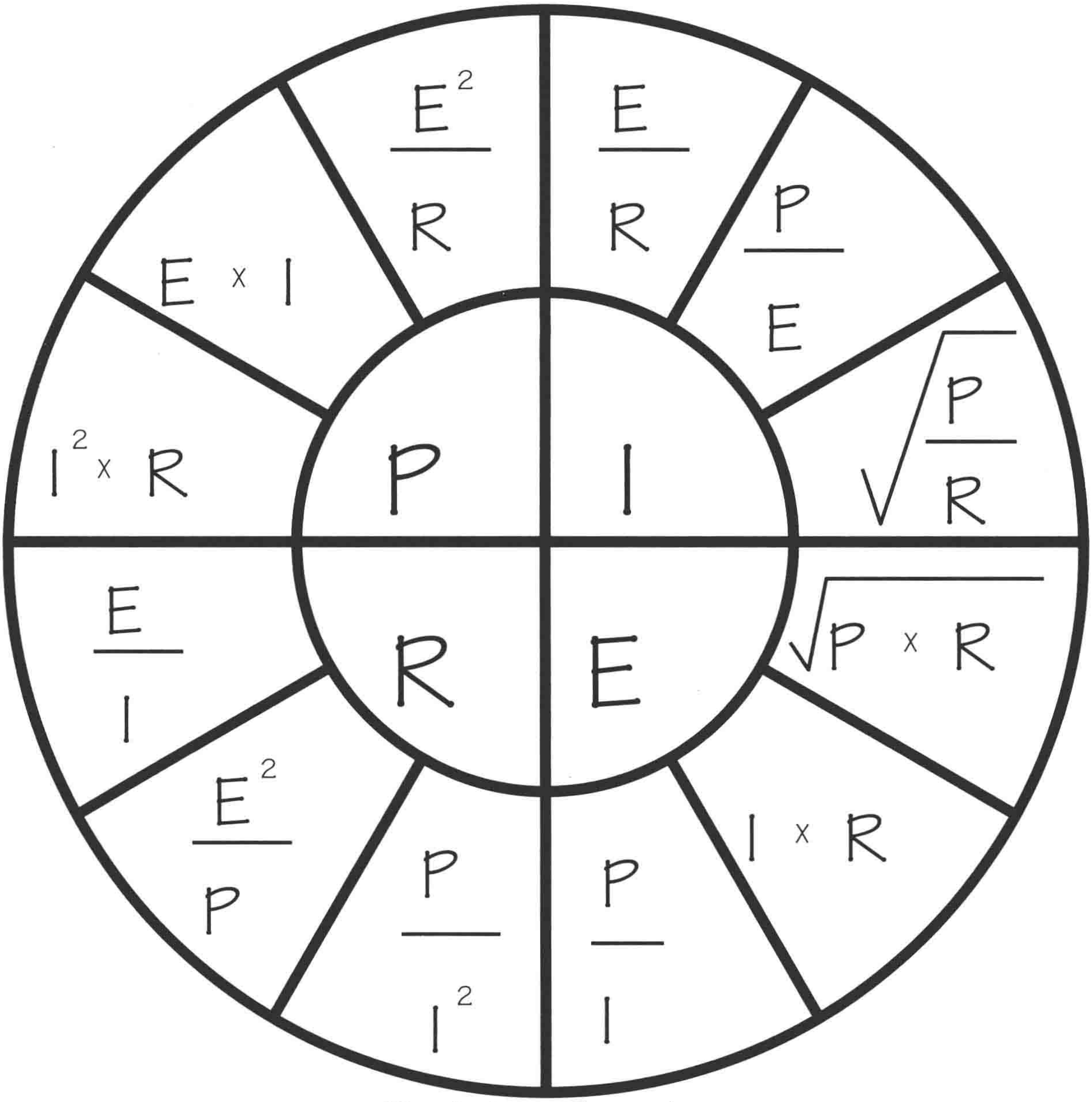


Ohm's Law Formulas

Material List

Quantity	Description
2	250-ohm 60 watt (minimum) resistors
6	150-ohm 100 watt (minimum) resistors
2	100-ohm 144 watt (minimum) resistors
10	Color-coded resistors with different values
3	0.5-kVA control transformers (two windings rated at 240 volts each and one winding rated at 120 volts)
1	7.5-μf AC capacitor with a voltage rating not less than 240 VAC
1	10-μf AC capacitor with a voltage rating not less than 240 VAC
1	25-μf AC capacitor with a voltage rating not less than 240 VAC
1	9-lead dual-voltage, three-phase motor (any horsepower)

CAUTION: *The wattage rating given for the resistors is a minimum value. Resistors with a higher wattage rating can be used without a problem. The wattage rating indicates the amount of heat that the resistor can dissipate. It should also be noted that the resistors will often become very hot during experiments and they should not be place near objects that can burn or will be damaged by heat. Take care when handling high wattage components because they can cause severe burns.*

2 ea.	3-way switches
1 ea.	4-way switch
	Two-conductor romex wire (number of feet is determined by individual laboratory conditions)
	Three-conductor romex wire (number of feet is determined by individual laboratory conditions)
1 ea.	Octagon metal box or PVC light fixture box
3 ea.	Metal or PVC switch boxes

Motor Controls

1 ea.	Control transformer to step your laboratory line voltage down to 120 VAC
3 ea.	Three-phase motor starter that contains at least 2 normally open and 1 normally closed auxiliary contact
3 ea.	Three-phase contactors (no overload relays) containing one normally open and one normally closed auxiliary contact
3 ea.	Three-phase motors 1/3 to 1/4 hp or simulated motor loads. (*Note*: Assuming a 208-volt three-phase 4-wire system, a simulated motor load can be constructed by connecting three lamp sockets to form a wye connection. These lamps will have a voltage drop of 120 volts each. If a 240-volt three-phase

system in is use, it may be necessary to connect two lamps in series for each phase. If two lamps are connected in series for each phase, these three sets of series lamps can then be connected wye or delta.)

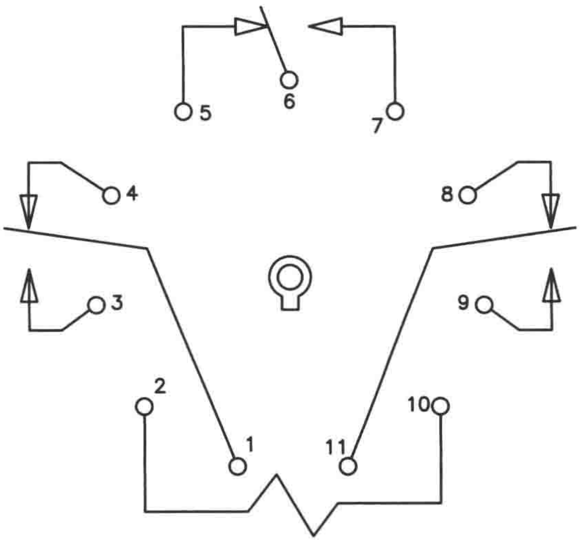
1 ea.	Three-phase overload relay or three single-phase overload relays with the overload contacts connected in series
1 ea.	Reversing starter, or 2 three-phase contactors that contain 1 normally open and 1 normally closed contact, and 1 three-phase overload relay
4 ea.	Double-acting push-buttons
6 ea.	3-way toggle switches to simulate float switches, limit switches, etc.
4 ea.	Electronic timers (Dayton model 6A855 recommended)
3 ea.	11-pin control relays (120-volt coil)
3 ea.	8-pin control relays (120-volt coil)
4 ea.	11-pin tube sockets
3 ea.	8-pin tube sockets
3 ea.	Pilot light indicators
1 ea.	Three-phase power supply (This laboratory manual assumes the use of a 208-volt three-phase system. If an equivalent motor load is employed, the design may have to be modified to compensate for a higher voltage.)

Suppliers

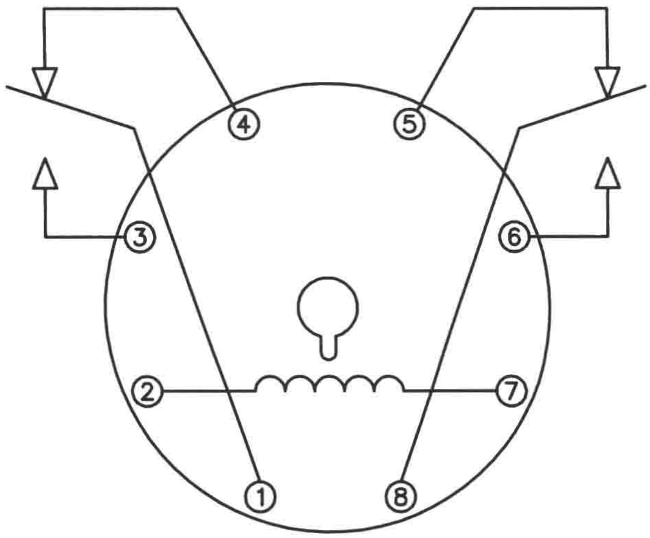
Most of the parts listed can be obtained from Grainger Industrial Supply (www.grainger.com). The Dayton model 6A855 timer is recommended because of its availability and price. Also, it is a multifunction timer and can be used as both an on- and off-delay device. It will also work as a one-shot timer and a pulse timer. Although the Dayton timer is recommended, any 11-pin electronic timer with the same pin configuration can be used. One such timer is available from Magnecraft (model TDR SRXP-120, www.magnecraft.com). This timer as also available from Mouser Electronics (www.mouser.com). Other electronic timers can be employed, but if they have different pin configurations, the wiring connections shown in the text will have to be modified to accommodate the different timer. Mouser Electronics is also a supplier for the wire-wound resistors.

The 8- and 11-pin control relays and sockets can be purchased from Grainger, Mouser Electronics, or Newark Electronics (www.newark.com). The control transformer used in the controls sections can be purchased from Mouser Electronics or Sola/Hevi-duty (www.solaheviduty.com). Model E250JN is recommended because it has primary taps of 208/240/277 volts. The secondary winding is 120/24. It is also recommended that any control transformer used be fuse protected. Another control transformer that can be used is available from Grainger. It is rated at 150 VA and has a 208-volt primary and 120-volt secondary. The 0.5-kVA control transformers are available from Grainger or Newark Electronics. Transformers rated at 0.5 kVA are used because they permit the circuit to be load heavy enough to permit the use of clamp-on type ammeters.

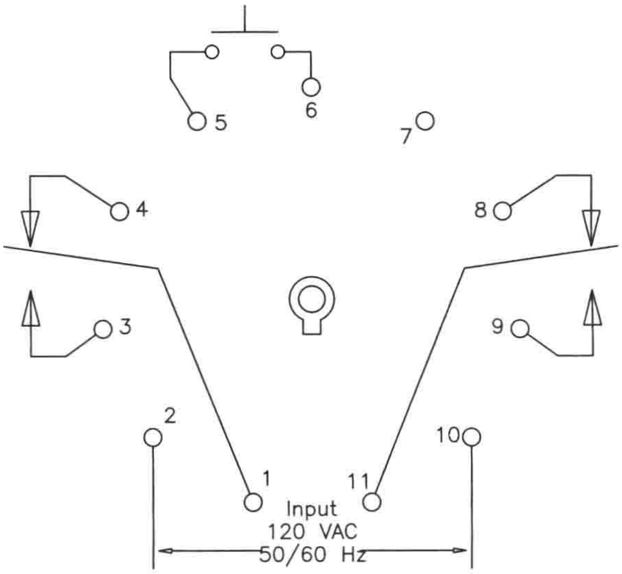
Stackable banana plugs are available from both Grainger and Newark Electronics. The oil-filled capacitors listed are available from Grainger. Color-coded resistors can be obtained from Newark Electronics or Mouser Electronics.



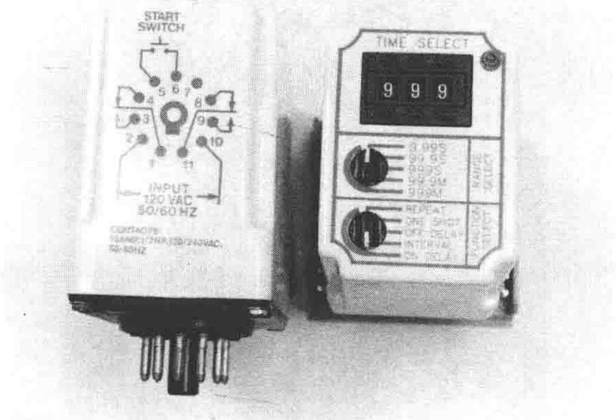
Connection diagram for an 11-pin relay.



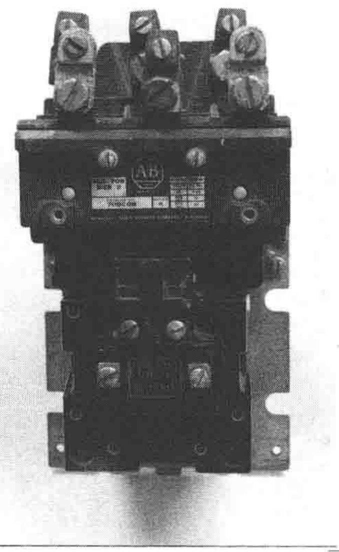
Connection diagram for an 8-pin relay.



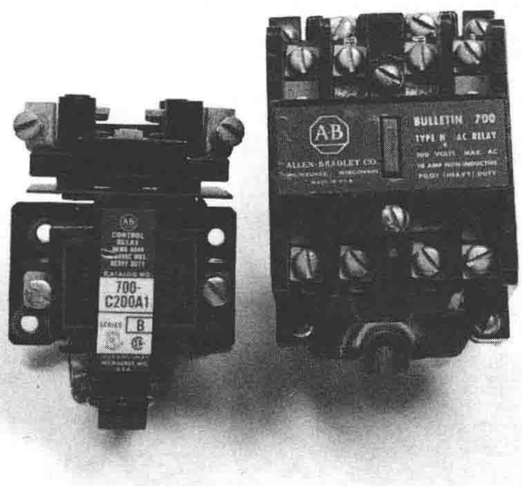
Connection diagram for a Dayton model 6A855 timer.



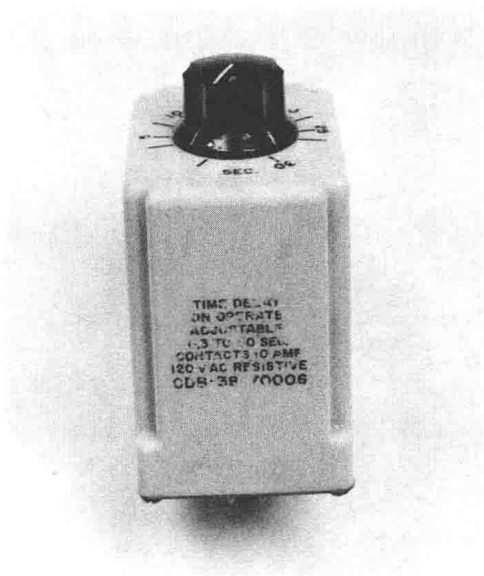
Dayton timer model 6A855. This timer mounts in an 11-pin tube socket and can be set to operate as a repeat timer, a one-shot timer, an interval timer, and an on-delay timer. The thumb-wheel switch sets the time value. Full range times can be set for 9.99 seconds to 999 minutes.



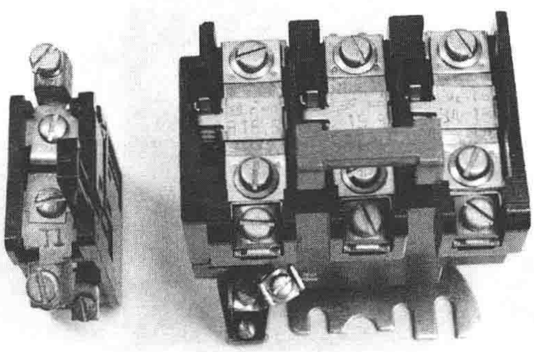
Three-phase contactor. This contactor contains one normally open auxiliary contact and three load contacts. The contactor differs from the motor starter in that the contactor does not contain an overload relay.



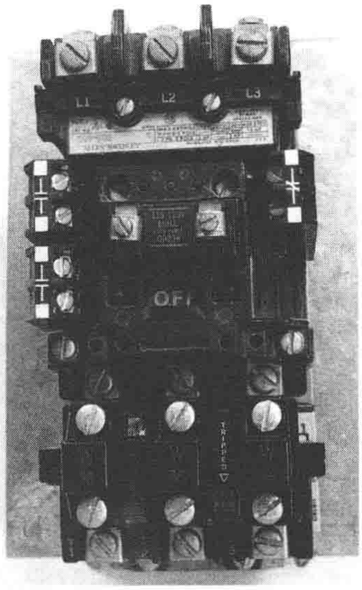
Control relays. These relays contain auxiliary contacts only and are intended to be used as part of the control circuit. They are capable of controlling low-current loads such as solenoid valves, pilot lights, and the like.



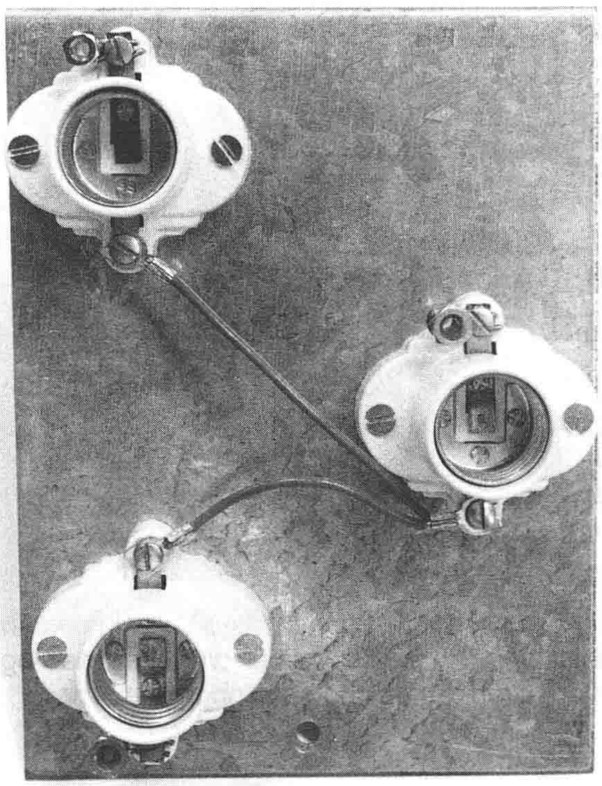
Eight-pin on-delay timing relay. This timer can be used as an on-delay timer only. Time setting is adjusted by the knob on top of the timer.



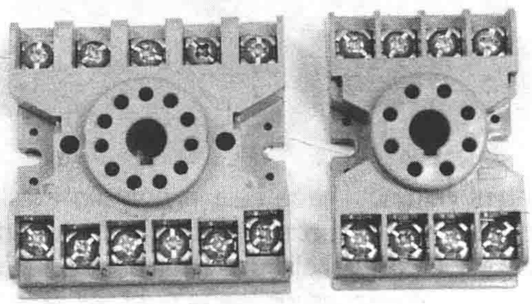
One single-phase and one three-phase overload relay. The three-phase overload relay contains three heaters but only one set of normally closed auxiliary contacts. If an overload should occur on any of the three lines, the contacts will open.



Three-phase motor starter with two normally open and one normally closed set of auxiliary contacts. Notice that a motor starter contains an overload relay as part of the unit.

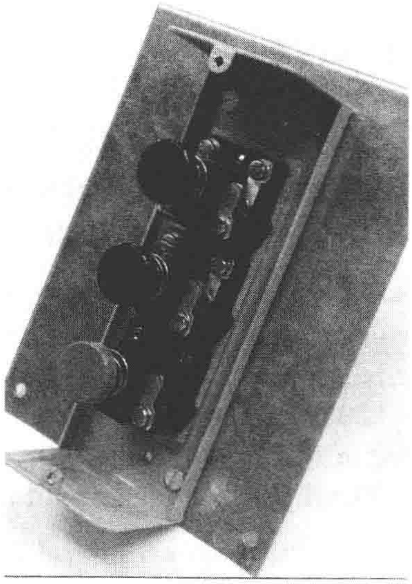


Light sockets mounted on a metal plate. The sockets have been connected to form a wye connection. This can be used to simulate a three-phase motor load.

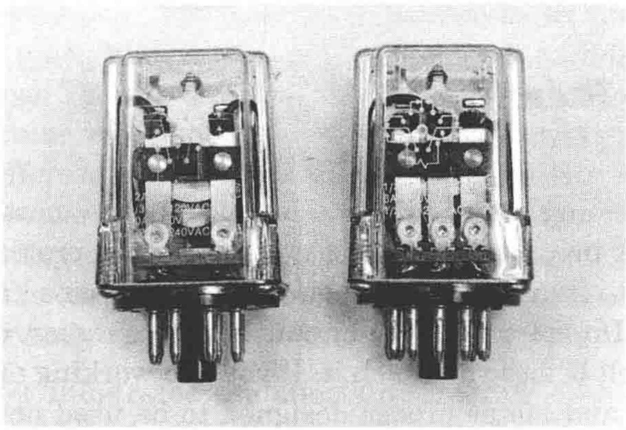


Eight- and 11-pin tube sockets. All wiring is done to the socket and the relay is then plugged into the socket.

Pneumatic off-delay timer. A microswitch has been added to the bottom to supply instantaneous contacts for the timer.



Three push-button station. The bottom push button is normally closed. The two top buttons are double action. Each contains both a normally open and normally closed set of contacts.



Eight- and 11-pin control relays contain two sets of double-acting contacts. Eleven-pin relays contain three sets of double-acting contacts.

Safety

Objectives

After studying this section, you should be able to:

- Discuss basic safety rules.
- Describe the effects of electric current on the body.

The purpose of this laboratory manual is to provide students of electricity with hands-on experience with electric circuits. Electricity is an extremely powerful force and should never be treated in a careless manner. This manual assumes a laboratory equipped with a 208/120 volt three-phase power system. Many of the experiments in this manual involve the use of full line voltage (208 or 120 volts). It is extremely important that you practice safety at all times. Please read and memorize the following safety rules:

- Never work on an energized circuit if it is possible to disconnect the power. When possible use a three-step check to make certain that the power is turned off. The three-step check is as follows:
  1. Test the meter on a known live circuit to make sure the meter is operating.
  2. Test the circuit that is to be de-energized with the meter.
  3. Test the meter on the known live circuit again to make certain that the meter is still operating.
- Install a warning tag at the point of disconnection to warn people not to restore power to the circuit.

General Safety Rules

Think

Of all the rules concerning safety, this one is probably the most important. No amount of safeguarding or "idiot proofing" a piece of equipment can protect a person as well as the person's taking time to think before acting. Many technicians have been killed by supposedly "dead" circuits. Do not depend on circuit breakers, fuses, or someone else to open a circuit. Test it yourself before you touch it. If you are working on high-voltage equipment, use insulated gloves and meter probes designed to be used on the voltage being tested. Your life is your own, so *think* before you touch something that can take it away.

Avoid Horseplay

Jokes and horseplay have a time and place, but the time or place is not when someone is working on an electric circuit or a piece of moving machinery. Do not be the cause of someone's being injured or killed and do not let someone else be the cause of your being injured or killed.

Do Not Work Alone

This is especially applicable when working in a hazardous location or on a live circuit. Have someone with you to turn off the power or give artificial respiration and/or cardiopulmonary resuscitation (CPR). One of the effects of severe electrical shock is that it causes breathing difficulties and can cause the heart to go into fibrillation.

Work with One Hand When Possible

The worst case of electrical shock is when the current path is from one hand to the other. This causes the current to pass directly through the heart. A person can survive a severe shock between the hand and one foot that would otherwise cause death if the current path was from one hand to the other. Working with one hand can sometimes be an unsafe practice by itself. The best procedure is to turn off the power. If it is not possible to disconnect the power, wear insulated gloves when handling "hot" circuits. Also wear shoes that have insulated soles and use rubber mats to cover energized conductors and components when possible.

Learn First Aid

Anyone working on electrical equipment should make an effort to learn first aid. This is especially true for anyone who must work with voltages above 50 volts. A knowledge of first aid, especially CPR, may save your life or someone else's.

Effects of Electric Current on the Body

Most people have heard that it's not the voltage that kills but the current. Although this is a true statement, do not be misled into thinking voltage cannot harm you. Voltage is the force that pushes the current through the circuit. Voltage can be compared to the pressure that pushes water through a pipe. The more pressure available, the greater the volume of water flowing through a pipe. Students often ask how much current will flow through the body at a particular voltage. There is no easy answer to this question. The amount of current that can flow at a particular voltage is determined by the resistance of the current path. Different people have different resistances. A body will have less resistance on a hot day when sweating because salt water is a very good conductor. What a person ate and drank for lunch can have an effect on a body's resistance. The length of the current path can affect the resistance. Is the current path between two hands or from one hand to one foot? All of these factors affect body resistance.

The chart in Figure SF-1 illustrates the effects of different amounts of current on the body. This chart is general; electricity affects most people in this way. Some people may have less tolerance to electricity and others may have a greater tolerance.

A current of 2 to 3 milliamperes will generally cause a slight tingling sensation. The tingling sensation will increase as current increases and becomes very noticeable at about 10 milliamperes. The tingling sensation is very painful at about 20 milliamperes. Currents between 20 and 30 milliamperes generally cause a person to seize the line and not be able to let go of the circuit. Currents between 30 and 40 milliamperes cause muscular paralysis, and currents between 40 and 60 milliamperes cause breathing difficulty. By the time the current increases to about 100 milliamperes breathing is extremely difficult. Currents from 100 to 200 milliamperes generally cause death because the heart goes into fibrillation. Fibrillation is a condition in which the heart begins to "quiver" and the pumping action stops. Currents above 200 milliamperes generally cause the heart to squeeze shut. When the current is removed, the heart will generally return to a normal pumping action. This is the principle of operation of a defibrillator. It is often said that 120 volts is the most

0.002–0.003 amp	Sensation (a slight tingling)
0.004–0.010 amp	Moderate sensation
0.010–0.020 amp	Very painful
0.020–0.030 amp	Unable to let go of the circuit
0.030–0.040 amp	Muscular paralysis
0.040–0.060 amp	Breathing difficulty
0.060–0.100 amp	Extreme breathing difficulty
0.100–0.200 amp	Death (fibrillation of the heart)

Figure SF-1 Effects of electric current on the body.

dangerous voltage to work with. The reason is that 120 volts generally causes a current flow between 100 and 200 milliamperes through the bodies of most people. Large amounts of current can cause severe electrical burns. Electrical burns are generally very serious because the burn occurs on the inside of the body. The exterior of the body may not look seriously burned, but the inside may be severely burned.

Review Questions

1. What is the most important rule of electrical safety?

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2. Why should a person work with only one hand when possible?

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3. What range of electric current generally causes death?

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4. What is fibrillation of the heart?

5. What is the principle of operation of a defibrillator?