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CHAPTER

Electrical Test and Measurement Equipment

CHAPTER OUTLINE

LEARNING OBJECTIVES

After completing this chapter, you will be able to:

- ☐ Discuss test and measurement safety procedures.
- ☐ Identify assembly-level and component-level troubleshooting methods.
- ☐ Explain the use of test lights, continuity testers, and receptacle testers.
- ☐ Understand the capabilities and uses of a digital multimeter.
- ☐ Demonstrate the use of oscilloscope controls and measurement methods.
- ☐ Use a clamp-on ammeter.
- ☐ Interpret oscilloscope calibration waveforms.
- ☐ Explain the use of power supplies and signal generators.
- ☐ Discuss the use of a phase sequence tester.
- ☐ Understand the need for calibration and the calibration process.

TECHNICAL TERMS

arbitrary function generator (AFG)
auto-ranging
clamp-on ammeter
continuity tester
cursor
digital multimeter (DMM)
infrared (IR) thermometer
International Electrotechnical Commission (IEC)
LCR meter
megohmmeter
noncontact voltage tester
oscilloscope
overvoltage
phantom voltage
phase sequence tester
receptacle tester
screwdriver voltage tester
test light
triggering

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It is not possible to see the actual flow of electricity through a circuit—only the effects of it are visible. Electrical test and measurement equipment enables you to "look inside the circuit" and visualize what is happening. After taking electrical measurements, you can use basic electrical calculations to predict other values in that circuit. See **Figure 20-1**.

In this chapter, you will learn about different types of test equipment and the various measurements each is capable of taking. As you become proficient using measurement equipment and techniques, your troubleshooting abilities will continue to grow.

Using testing and measurement, you can identify the faulty component in the circuit and replace it. This approach is far more efficient and affordable than guessing and swapping out part after part until the problem is resolved.

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Figure 20-1. Electrical measurements provide information about how a system or equipment is operating. These measurements can be analyzed as part of the troubleshooting process.

20.1 ELECTRICAL SAFETY

Safety is the most important part of testing and measurement. Be mindful of all safety procedures when making measurements. Anyone who makes their living working with electricity must develop a healthy respect for the potential dangers involved in dealing with live circuits. You should be familiar with the National Electrical Code (NEC), produced by the National Fire Protection Association (NFPA), and OSHA's Code of Federal Regulations (CFR) as it applies to work with electrical circuits.

20.1.1 Physical Condition

Your physical condition can lead to potentially unsafe and dangerous actions. Always be well rested when at work. If you are tired due to lack of sleep, your mind can be "foggy" and your reflexes slowed. This can lead to a poor decision or delayed action, resulting in a dangerous situation and potential injury.

Never work if your body is experiencing the effects of alcohol or drugs. Alcohol and drugs greatly reduce mental and physical abilities, which can lead to unsafe practices. In addition, arriving to work under the influence of alcohol or drugs is cause for immediate dismissal at many companies.

Illness can also lead to unsafe practices. Sickness may reduce mental and physical abilities, not unlike drugs or alcohol. If you do not feel you can do your work safely, call in sick.

Mental stress can also result in unsafe practices. The pressure of needing to get a vital piece of equipment back in operation or the time constraints of completing the job can cause stress. Even experienced technicians can make uncharacteristic mistakes when trying to work too quickly. These mistakes may result in fatal consequences. Never ignore safe practices in order to complete a job more quickly.

20.1.2 Electrical Testing Safety

When preparing to perform electrical tests and measurements, begin by wearing the proper personal protective equipment (PPE). See **Figure 20-2**. Your company or school will have policies regarding what PPE you should use based on the tests being performed, the equipment being tested, and the environment where the test is being conducted. OSHA also has guidelines about what PPE is appropriate. Refer to Chapter 2, *Industrial Safety and OSHA*, for additional information about PPE.

Whenever possible, de-energize the equipment prior to testing. Use proper lockout/tagout procedures, **Figure 20-3**. After disconnecting a device, always test to ensure the equipment is truly de-energized. Working on "live" equipment that has been incorrectly de-energized

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Figure 20-2. Always wear the appropriate personal protective equipment (PPE). This industrial maintenance technician is wearing hearing protection, safety glasses, and a hard hat while taking temperature measurements.

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Figure 20-3. Work on de-energized equipment whenever possible. Always follow proper lockout/tagout procedures.

creates an extremely dangerous situation. Refer to Chapter 2, *Industrial Safety and OSHA*, for additional information about lockout/tagout procedures.

Make sure you review the panel diagrams before you perform an electrical test. Many industrial control panels have multiple sources of electricity, and panels may or may not be labeled to indicate this on the outside of the panel. Panels that contain programmable logic controllers (PLCs), instrumentation, or other controllers may have a low-voltage supply just for those specific systems.

Inspect test equipment before performing a measurement. Test leads are an important part of test equipment safety. Make certain the CAT level (overvoltage category) of the test leads is appropriate for the job. **Figure 20-4** shows a set of test leads with the proper safety features. Look for test leads with double insulation, shrouded input connectors, finger guards, and a nonslip surface. Always inspect test leads and make certain they are not cracked, frayed, or worn. If the test leads are damaged or worn, replace them immediately.

Never exceed the maximum input values of the test equipment you are using. Test equipment is clearly marked with the maximum voltage and current adjacent to the input jacks, **Figure 20-5**. Always know the expected values before applying the test leads, and set the appropriate range before testing.

Check the test equipment setting each time before applying the test leads. See **Figure 20-6**. If, for example, your meter is set to measure resistance and you apply the test leads to an energized circuit, catastrophic results may occur.

Use extra caution when using 1000:1 or 100:1 high-voltage probes. Make sure you have the correct type of probe and the voltage reaching the test equipment will be less than the probe's rated voltage.

Follow the old electrician's rule: "Use only one hand when making a measurement and keep the other hand

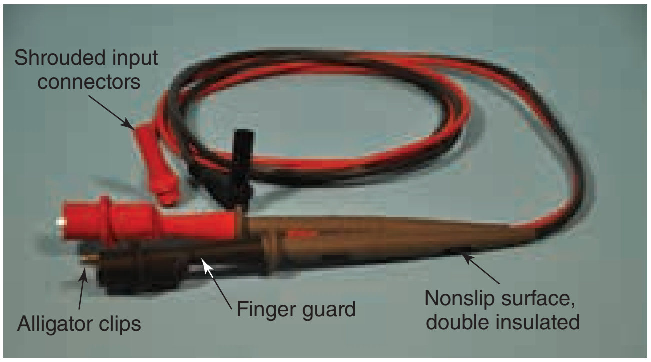

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Figure 20-4. Test leads with finger guards, nonslip surfaces, alligator clips, double insulation, and shrouded input connectors. By using alligator clips, you do not need to hold one or both of the test leads while testing.

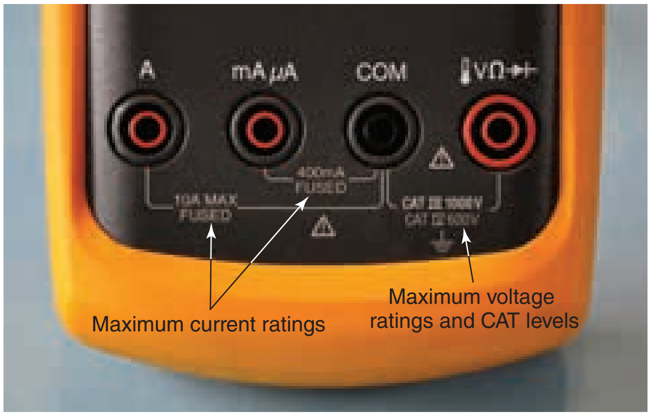

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Figure 20-5. Maximum voltage and current ratings are clearly marked next to the test equipment input connections. Always be sure that the CAT level of the test equipment is appropriate for the measurement.

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Figure 20-6. Always check the test equipment setting before applying the test leads. An incorrect setting can have disastrous results.

in your pocket." This lessens the possibility of a complete circuit being made from one hand to the other, with the current going through your heart.

Be extremely cautious of test lead placement. If the lead slips, it could come in contact with something that could cause a short circuit. Always move carefully and deliberately when performing a test.

PROCEDURE

Preparing to Perform an Electrical Test

The following are general steps to take before performing an electrical test or taking an electrical measurement:

1. Wear appropriate PPE based on the test, equipment, and environment.
2. If possible, de-energize the equipment before testing. Follow appropriate lockout/tagout procedures.
3. Select the appropriate test equipment based on the type of test and expected measurement values.
4. Inspect the test equipment for wear and damage.
5. Verify that the test equipment has an adequate voltage rating and CAT level.
6. Check that the leads are connected properly and the test selector switch is set correctly.

There may be an instance when you will need to perform a voltage or current reading using live circuits. OSHA's Code of Federal Regulations (CFR) recommends that taking a reading on a live circuit only occur for the purposes of troubleshooting. Most control cabinets are de-energized by a main disconnect on the panel face. These disconnects can be overridden to allow the opening of the panel while voltage is present. While each disconnect is slightly different, most are overridden by using a screwdriver to turn a latching component of the disconnect while opening the panel.

PROCEDURE

Preparing to Perform a Live Reading

The following are general steps to take before performing a live reading:

1. Review the procedure for overriding the locking safety feature.
2. Let others in the area know that you will be taking live readings.
3. Wear appropriate PPE, including proper electrically insulated gloves.
4. If available, review the circuit diagrams prior to opening the control cabinet. (In some cases, the circuit diagrams are kept inside the panel.)
5. Avoid any potential distractions by turning off your cell phone.

(Continued)

6. Open the control cabinet and perform a general visual inspection of all internal components. This should be done while keeping your hands outside the cabinet. Do not break the front plane of the control cabinet for this initial inspection. Look for evidence of arcing (black marks), shorts, general wiring condition, corrosion on terminals, proper grounding to the backplane of the cabinet, frayed conductors, damaged insulation, moisture, and any noticeable odors.
7. Remove and review any diagrams located within the control cabinet. Some older control cabinets do not have diagrams, or diagrams may have been lost over the years. If you are unable to locate any diagrams, you should not perform live testing unless you have extensive background in electrical troubleshooting.
8. Set up your area by ensuring the panel cover is held open and will not close against you while you are taking readings. Be sure your DMM is clearly visible and you have adequate lighting.
9. Before taking voltage readings, ground one test lead to the main ground connection on the backplane of the panel using a jumper or alligator clip. This enables you to have only one hand holding the "hot" lead of the DMM, while your other hand is outside the panel. Note: The place where you attach your black (ground) lead of the DMM greatly depends on the circuit you are going to test. A 24-volt DC input to a PLC is much different than a 120-volt AC circuit. You must review the circuit diagrams to determine the best course of action. PLC sink and source I/O is covered later in this text.
10. Know what your expected values are before taking a reading.
11. Examine your clamp-on ammeter and compare it to the space inside the control cabinet. If you are taking a reading on 14-gage wires inside a cabinet, a smaller clamp-on ammeter will be more appropriate. If taking a reading on motor leads leaving the cabinet, a larger clamp-on ammeter may be appropriate.

(Continued)

12. Take readings and compare them to known values. This greatly depends on what the initial issue was and what troubleshooting procedure you are performing.
13. Once you have isolated the suspected failure, back out of the control cabinet.
14. Turn off the disconnect and perform a lockout/tagout procedure.
15. Re-enter the cabinet and ensure it is de-energized by performing voltage checks.
16. Replace or correct the suspected malfunction.

20.1.3 Overvoltage Categories (CAT Level)

The ***International Electrotechnical Commission (IEC)*** is a nonprofit, nongovernmental international standards organization that prepares and publishes standards for electrical, electronic, and related technologies. The IEC standards for overvoltage protection categories are used by test equipment manufacturers. These manufacturers certify through testing that their test equipment adheres to IEC standards.

Overvoltages, or *transients*, are undesirable voltage spikes in excess of the intended voltage. If the test equipment you are using is not capable of dealing with the transients that may be present, the test equipment could explode, causing injury or death.

A table with descriptions and examples of the four CAT levels is shown in **Figure 20-7**. Test equipment must be labeled at the required CAT level or at a higher CAT level. For example, if the test requires a CAT II rating, equipment labeled for CAT II, CAT III, or CAT IV can be used safely.

20.1.4 Electrical Testing Safety Rules

Before testing:

- De-energize the circuit whenever possible. Live circuits present additional risks. When de-energizing a circuit, observe the proper lockout/tagout procedures.
- Use the proper PPE.
- Be certain you are using the correct test equipment for the job.
- Check your test equipment settings and connections before each measurement.

Overvoltage Protection Categories		
Category	**Description**	**Examples**
CAT I	Connections to circuits in which measures are taken to limit transient overvoltages to an appropriately low level.	Electronic circuits with overvoltage protection.
CAT II	Energy-consuming equipment to be supplied from a fixed installation.	Appliances, portable tools, and other household and similar loads.
CAT III	In fixed installations and for cases where the reliability and the availability of the equipment is subject to special requirements.	Switchgear and polyphase motors, bus systems and industrial feeders; switches in fixed installation and equipment for industrial use with permanent connection to the fixed installation.
CAT IV	Connections at the utility or origin of installation, and all outside connections.	Outside service entrance and drop from pole to building, wiring run from meter to panel. Electricity meters and primary overcurrent protection equipment.

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Figure 20-7. Standards for measurement categories are published by the IEC. Be sure the testing equipment you are using has the correct CAT level for the test being performed. If the equipment does not have an adequate CAT level, do not use the device—you could be seriously injured by a voltage spike in excess of what the device is capable of withstanding.

- Inspect your test leads for wear and tear before use and do not use any test leads that are damaged or in need of replacement.

During testing:

- Know the expected voltage and current before connecting test equipment to the device. Make sure test equipment is connected properly and set to the correct range.
- Avoid holding the test equipment while making measurements. This minimizes your exposure to an arc flash. Hang or rest the meter if possible. Use the “kickstand” if available.
- Use only one hand when performing the test. Keep one hand in your pocket while making measurements.
- Watch your test lead placement to avoid a short circuit.
- Stay alert and practice safe procedures when making measurements and working on electrical equipment.

20.2 FIELD TESTING AND BENCH TESTING

There are two main types of troubleshooting. Assembly-level troubleshooting is usually accomplished on the plant floor. Component-level troubleshooting is often done at the test bench. A typical test bench has power supplies, signal generators, and test equipment to diagnose the component defect. Assemblies are often brought to the test bench for more in-depth diagnostics.

Many companies keep an inventory of critical assemblies. When an assembly fails, it can be removed from service and immediately replaced with another assembly from inventory. This allows the equipment to continue to operate while the assembly is repaired. Without a spare assembly, the equipment cannot operate until the assembly is repaired. The cost of having the equipment sit idle for an extended period of time can be very expensive.

After the assembly has been replaced and equipment is operating, the defective assembly is brought to the test bench, diagnosed to the component level, and repaired. Often, the repair is replacement of a defective component. The assembly is tested to confirm proper operation and then stored in inventory until needed for replacement.

The time needed to troubleshoot and repair an assembly is a significant factor in determining the cost of the repair. The reliability of the repaired assembly is also a factor. Relatively low-cost assemblies may be recycled rather than repaired.

Some companies outsource their repair work. A good technician who is capable of component-level repair can save a company significant money by completing repair work in-house.

20.3 ELECTRICAL MEASUREMENT TOOLS

Industrial maintenance technicians use many electrical measurement and testing tools. Some measurement equipment can perform multiple types of tests. Other, more specialized equipment performs a single test. Learning both the operation of and uses for each type of measuring equipment is critical.

20.3.1 Test Light

The simplest form of test equipment is a test light, **Figure 20-8**. A ***test light*** is simply a lamp with two wires that is used to test for the presence of electricity. The lamp lights when placed across a voltage source. A test light is a relatively limited electrical testing tool.

20.3.2 Continuity Tester

A ***continuity tester*** is similar to a test light with a power source added to the lamp. See **Figure 20-8**. When the leads of the continuity tester are connected by an electrical path, the lamp lights to indicate a complete circuit. Like a test light, a continuity tester has limited application.

20.3.3 Receptacle Tester

Normal residential 120 VAC wiring consists of three wires. The "hot" wire (black), the "neutral" wire (white), and the "ground" conductor (uninsulated or green). The neutral wire is, by NEC requirements, bonded (connected) to ground at the point where the electrical service enters the building and again at the circuit breaker panel.

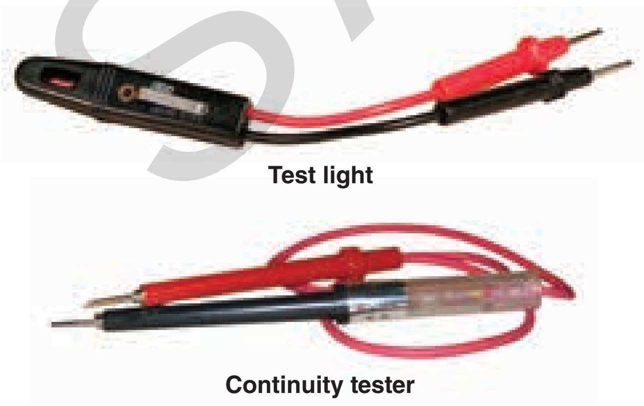
In order for a receptacle (electrical outlet) to be wired correctly, each conductor is connected to a specific terminal. However, in some cases, conductors are attached to incorrect terminals and the receptacle is not properly wired.

A common troubleshooting task for electricians is to check receptacle wiring. One device for testing a receptacle to determine the "hot" slot is a ***screwdriver voltage tester***. This device consists of a pocket screwdriver that has a neon lamp and a current-limiting resistor connected between the screwdriver blade and the metal pocket clip. The electrician inserts the screwdriver into one slot of the receptacle while his hand is in contact with the metal pocket clip. If the screwdriver is inserted into the hot side of the receptacle, the neon lamp lights.

Receptacle testers, **Figure 20-9**, have replaced most screwdriver voltage testers. A receptacle tester has three indicator lamps. It is plugged into a receptacle and if the two yellow lamps illuminate, the outlet is wired correctly. Any other combination of illuminated lamps indicates a wiring error that must be corrected. A legend is included on the device to indicate the type of error encountered.

In addition to the three indicator lights, the receptacle tester has a test button that is used to trip a GFCI (ground-fault circuit interrupter). GFCIs trip almost instantaneously when a miniscule amount of current flows to ground. GFCIs are employed as a safety measure and are required by the *National Electrical Code (NEC)* in certain instances. GFCI protection can be provided by GFCI receptacles or by GFCI circuit breakers.

The modern version of the screwdriver voltage tester is the ***noncontact voltage tester***, **Figure 20-10**. A noncontact voltage tester employs a Hall effect sensor (a semiconductor device that is sensitive to magnetic fields) and operates in a similar fashion to the electrician's screwdriver, except that no direct contact with a live conductor is required. This allows the user to verify the presence of voltage on a conductor even through the conductor insulation.



Klein Tools, Inc.; Goodheart-Willcox Publisher

Figure 20-8. Test lights and continuity testers are simple electrical testing tools with limited application for an industrial maintenance technician.

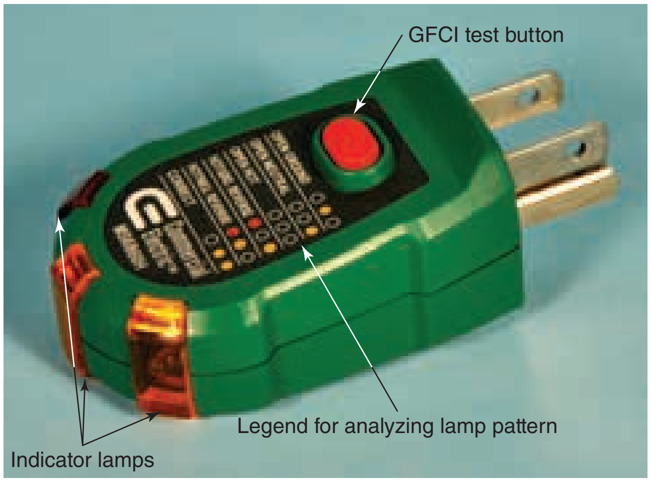


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Figure 20-9. A receptacle tester for analyzing the wiring connected to an electrical outlet.

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Figure 20-10. A noncontact voltage tester lights in the presence of voltage.

Interestingly, if you drag the detector tip of a noncontact voltage tester along a power cord between an electronic device and a receptacle, you will notice that the detector senses the presence of voltage for a certain distance, then senses nothing. This occurs because the conductors in the cord are twisted. The twist places the hot conductor next to the sensor for a certain distance, and then the ground and neutral conductors next to the sensor for the remaining distance.

20.3.4 Digital Multimeter (DMM)

A ***digital multimeter (DMM)*** is an instrument used to measure a variety of electrical properties. A DMM can serve as a voltmeter for measuring electrical potential, an ohmmeter for measuring resistance, and an ammeter for measuring current. Due to its ease-of-use and versatility, a DMM is one of an industrial maintenance technician's most valuable tools.

Before taking a measurement with a DMM, select the appropriate type of measurement and range using the mode selector switch. On many DMMs, the mode selector switch either lacks or has few range values. See **Figure 20-11**. The DMM automatically determines the correct range without operator intervention. This automatic action is referred to as ***auto-ranging***. As a result, you must be careful when reading the value in the display. At first glance, 100 mV might appear to be 100 V. Always check the suffix on the reading to verify that you are interpreting the displayed value correctly.

SAFETY NOTE

DMM Input Jacks

A common and dangerous mistake is to attempt a voltage measurement with the test leads plugged into the current input jacks. When configured for measuring current, the DMM creates a direct short to the voltage source. Always check to ensure that the test leads are connected correctly for the type of measurement being made, **Figure 20-12**.

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Figure 20-11. Most digital multimeters (DMMs) have features similar to those shown here.

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Figure 20-12. A digital multimeter with the test leads appropriately connected to measure voltage or resistance. Note the two current jacks to the left of the test leads.

When using a DMM, first set the mode selector switch to the correct setting for the type of measurement. Note that voltage and current normally have different mode settings for AC and DC. With the mode set, plug the leads into the corresponding input jacks. As mentioned earlier in this chapter, always check the voltage rating, current rating, and CAT level listed on the DMM to ensure that the device is appropriate for the expected measurement. When measuring current, position the test leads so the DMM is connected in series with the load. See **Figure 20-13**.

Many digital multimeters also have a min/max/average memory. With this feature, a DMM holds the minimum value measured, the maximum value measured, and the average value over a period of time. In addition, some advanced DMMs measure frequency and convert the current measurement of a 4–20 mA process control loop to a percentage reading.

TECH TIP
DMM Safety Features

Low-cost DMMs may not include safety features included in some higher-end models. These extra safety features may someday prevent damage to the device or (more importantly) injury to its user. When working in an industrial environment, the extra safety features are worth the extra cost.

Ohmmeter Mode

Before measuring the resistance of a device or component, disconnect the electrical power from the device. The circuit must be de-energized before resistance can be measured. In the ohmmeter (resistance measurement) mode, the DMM provides voltage to the circuit under test. Most DMMs can measure resistance ranging from fractions of an ohm to several megohms.

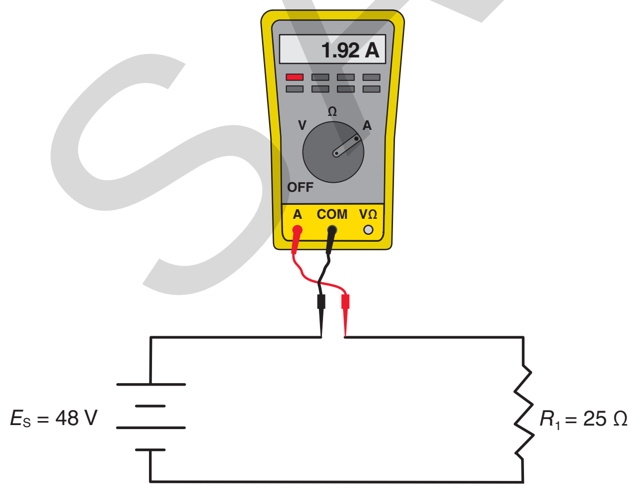

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Figure 20-13. A DMM connected for measuring current. When measuring current, the DMM must be connected in series and set to the proper range. Never attempt to place the meter probes across the voltage source.

SAFETY NOTE
Ohmmeter Mode

When measuring resistance with a DMM, never apply the test probes to an energized circuit. If you do, the DMM may be damaged and you could be injured.

Diode Test Mode

Often, DMMs have a diode test function. This function allows you to measure the voltage drop across the junction of the diode. When in the diode test mode, the DMM supplies voltage to the device under test from its internal batteries.

Depending on the type of diode, you can expect to measure a voltage drop of 0.4 V to 0.7 V on a good rectifier diode. Light-emitting diodes (LEDs) often have a voltage drop of 1.8 V to more than 3 V. Advanced DMMs have sufficient voltage to cause LEDs to illuminate when tested in the forward direction. If a diode is good, it should show no conductivity (infinite voltage drop) in the reverse direction.

TECH TIP
SI Conversions

Capacitors are generally specified in either µF or pF, but the DMM may display the reading in a different unit. Therefore, you may occasionally need to convert from one unit to another. One microfarad is 1000 nanofarads, and one nanofarad is 1000 picofarads. To convert between these units, multiply or divide the number by 1000, which moves the decimal point three places. When converting from a larger unit to a smaller unit, the number increases. When converting from a smaller unit to larger unit, the number decreases. For example, to convert 4700 nF to microfarads (smaller unit to larger unit), move the decimal point three places to make the number smaller: 4.7 µF. To convert 6.8 nF to picofarads (larger unit to smaller unit), move the decimal point three places to make the number larger: 6800 pF.

Capacitor Test Mode

Many DMMs also have a function for measuring capacitance. In the capacitor test mode, the DMM supplies voltage to the capacitor under test. The capacitance displayed on the DMM is typically measured in either microfarads (μF), nanofarads (nF), or picofarads (pF).

Before testing a capacitor, de-energize the circuit. Capacitors that have been in an energized circuit may retain their charge for a certain period of time after the circuit is de-energized. Always discharge a capacitor immediately before testing by shorting it across a resistor. The *NEC* recommends using a resistor of 20–30 kΩ with a rating of 4 W, but your particular needs may vary depending on the capacitor being discharged.

If a capacitor remains in the circuit during testing, the influence of other components and capacitors may affect the DMM measurement. It is best to remove the capacitor to be tested from the circuit and then discharge it before attempting to test it.

PROCEDURE — Alternative Capacitor Testing

Not all DMMs have the ability to test capacitance, but the resistance setting on a DMM can also be used when testing a capacitor. Use the following procedure:

1. Ensure the capacitor is discharged properly and removed from the circuit.
2. Set the DMM to read resistance.
3. Place both leads of the DMM across the capacitor terminals.
4. You should see resistance slowly climbing.
5. Remove one DMM lead from the capacitor while maintaining contact with the other lead. Wait 30 seconds.
6. Reapply the lead that was removed. You should see a resistance value similar to what it was when the DMM lead was removed, and it should continue to climb.

Performing the alternative capacitor test using the resistance setting on a DMM will tell you several things, including whether the capacitor can hold a charge. Your DMM is actually charging the capacitor slowly while reading resistance. If the resistance is low and remains low, the capacitor is internally shorted and will not hold a charge. In this situation, you will need to replace the capacitor. If your resistance value is substantially lower after the 30-second wait in step 5, the capacitor may have a partial internal short, in which case you will also need to replace it. Be aware that even with the best of testing, the capacitor may still have failed. This may only be apparent when operating voltage is applied to the capacitor while in the circuit. When in doubt, replace the capacitor.

In some circuits (variable speed drives, for instance), the capacitor may have a discharge resistor connected across the leads. This may appear to be a short to the untrained technician. This resistor is in place to bleed off charge when the circuit is de-energized. Do not permanently remove this resistor. It can be removed for testing but should then be put back in place to maintain the safe operation of the equipment.

SAFETY NOTE

Capacitor Test Mode

When measuring a capacitor, never apply the test probes to an energized circuit. If you do, the DMM may be damaged and you could be injured. Also, be sure to discharge the capacitor after the circuit has been de-energized. If you fail to discharge the capacitor, it may still hold a charge that can damage the DMM and cause you injury.

Continuity Test Mode

Some multimeters include a continuity test mode where an audible signal indicates the presence of a low resistance. This feature allows checking for continuity without having to look at the multimeter display. In the continuity test mode, the DMM provides voltage to the circuit under test. You should be familiar with the differences between a continuity check and a resistance reading. When placed in continuity mode, the number that appears on the DMM's screen is not a resistance measurement. While some DMMs may indicate continuity at less than 40 ohms, others differ. Make sure you know the specification on your own DMM.

CAUTION

Never connect a DMM in the continuity test mode to an energized circuit or the DMM may be irreparably damaged.

Advanced DMM Functions

Some multimeters are even capable of communicating with a computer, allowing you to plot periodic measurements and determine how the value measured changes over time.

To overcome the problem of slow variations in the value measured, many DMMs include a bar graph in the display. The bar graph simulates the movement of a meter needle so you can get a sense of the rate of change occurring while the display is continuously counting. See **Figure 20-14**. A bar graph typically updates much faster than the digital numerical reading. While a bouncing contact will show on the bar graph, a numerical reading may not have the time to display.

Many multimeters are capable of measuring temperature with the aid of a thermocouple. An example of a DMM and a thermocouple is shown in **Figure 20-15**. Some multimeters even have a thermocouple provided in the accessory package that comes with the meter. The thermocouple is a contact-type temperature device. It measures the temperature of whatever it is contacting. It is capable of measuring the air temperature.

> **TECH TIP**
> **Thermocouples**
>
> A thermocouple is a device that uses the junction of dissimilar metals to generate a voltage proportional to the temperature.

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Figure 20-15. With a thermocouple attached, this DMM can measure temperature.

Most advanced multimeters are labeled *true RMS*. RMS refers to the term "root-mean-square," which is a type of averaging (integration) of a sinusoidal alternating current waveform. In simpler terms, it is the amount of AC voltage that would produce the same amount of power that a DC voltage would.

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Figure 20-14. This DMM display includes a bar graph along the lower portion of the display area. The bar graph provides a visual representation of the fluctuations in the reading.

The RMS value is important because a volt-ohm-milliammeter (VOM) measures in RMS. A DMM can measure in peak voltage if it does not convert to RMS. Without any type of conversion, a DMM would read a voltage much higher than would a VOM.

It is not difficult to convert the peak value of a sine wave to RMS. You simply multiply the peak voltage value by 0.707 to obtain the RMS value. The problem is that with modern industrial electronics, the voltage may not be in a sine wave pattern.

Three-phase variable frequency motor drives do not produce a sine wave output. Switching power supplies and other electronic devices distort the normal sine wave of the AC line power. For this reason, true RMS algorithms (a part of a computer program) are used. With true RMS, the DMM is capable of measuring the RMS value of most any type of waveform.

TECH TIP

True RMS DMMs

If you will be working with industrial electronics, be sure to have a DMM that reads true RMS in order to ensure your readings are correct.

Phantom Voltages

Phantom voltages, also called *ghost voltages*, are DMM readings of electrical potential or voltage between conductors that have no actual voltage difference. These readings are a result of induction or IR drop (resistance) across conductors that are connected to the same point but have different resistances. In addition, the amplifiers inside the DMM are very sensitive, and the DMM will auto-range until it can obtain some sort of reading, even if that reading is so small as to be negligible.

Phantom voltages can range from a few millivolts to hundreds of volts depending on the situation. The DMM inputs have an extremely high impedance (opposition to the flow of alternating current). This high impedance means that, although the phantom voltage might be quite high, its current is extremely low, possibly in the microamp realm. The high impedance of the DMM does not present much of a load, so even these extremely small currents will cause the DMM to display a phantom voltage reading. An example of a phantom voltage reading is shown in **Figure 20-16**. Ghost voltages may also be caused by magnetic fields in the area, even with the DMM disconnected. Fluorescent lighting is a common cause of this.

TECH TIP

Phantom Voltage Readings

Be careful when interpreting voltage readings and pay close attention to the range indication. Does the range show mV or does it indicate V? False interpretation might lead you to believe there is a real voltage present when it is only a result of a phantom voltage.

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Figure 20-16. A DMM displaying a phantom voltage. Be careful in interpreting the reading. Notice the mV indication in the display. The reading is 6.3 mV, not 6.3 V.

20.3.5 Clamp-On Ammeter

DMMs have a limited range for measuring AC current. Most DMMs are capable of safely measuring a maximum current of 10 A. Another drawback of using a DMM to measure current is that the DMM must be series-connected. This requires disconnecting a current-carrying conductor and placing the DMM into the circuit.

A ***clamp-on ammeter*** eliminates these shortcomings by providing a noncontact method of measuring current. See **Figure 20-17**. To accomplish this, some clamp-on ammeters use a current transformer that can be opened to insert the conductor to be measured. No disconnection or physical contact with a live connection is required. The magnetic field around the conductor to be measured is coupled into the clamp-on ammeter's current transformer.

Because older clamp-on ammeters use a current transformer, they are limited to measuring only AC currents. Modern clamp-on ammeters use a Hall effect sensor instead of a current transformer. A Hall effect sensor is a semiconductor device that is sensitive to magnetic fields. Hall effect sensors allow a clamp-on ammeter to measure both AC and DC current.

In general, low-cost models use a current transformer and more expensive models use a Hall effect sensor. When purchasing a clamp-on ammeter, consider whether the capability to measure DC current is needed.

Many models have a built-in clamp-on ammeter to save the technician time and bother switching from one test instrument to another in the middle of troubleshooting a problem.

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Figure 20-17. This clamp-on ammeter is capable of measuring AC or DC current. In addition, it has a DMM for measuring resistance, AC voltages, and DC voltages; a diode test function; a capacitor test function; and a noncontact voltage detector.

20.3.6 Megohmmeter

A ***megohmmeter*** is an ohmmeter that uses high voltage to make resistance measurements. An example of a megohmmeter is shown in **Figure 20-18**. Megohmmeters are also called *meggers* or *insulation testers*.

Most DMMs can measure resistance in the megohm range. However, DMMs use a low voltage to accomplish this task. In some cases, shorts may not be readily apparent when tested at a low voltage.

The insulation in coil, transformer, and motor windings is relatively thin in order to conserve space. For this reason, the insulation rating is only marginally greater than the working voltage. In an overvoltage situation, the overvoltage present is greater than the insulation voltage rating of the wire and an arc-over may occur.

When an arc-over occurs, a carbon path is formed. This carbon path presents a relatively high resistance,

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Figure 20-18. Megohmmeters are also known as *meggers* or *insulation testers*. The range switch is set to the proper range, test leads are connected to the device under test, and then the test button is pressed to energize the high voltage and make the measurement.

TECH TIP
Low-Current Measurements

Clamp-on ammeters suffer from poor accuracy when measuring low-current values. This problem can be minimized by placing a second turn of the conductor being measured through the clamp-on core. When this is done, the reading obtained will be twice the actual current in the conductor, so you must divide the reading by two. Higher currents do not present this accuracy problem. Do not use a standard DMM for process control measurements that will be used to calibrate instrumentation (such as 4–20 mA signals), unless that DMM is specifically designed (calibrated) for this purpose. Clamp-on ammeters designed exactly for this purpose are available. If you perform calibration, you may want to consider buying one of these specialty clamp-on ammeters.

which is unaffected by the low voltage of a DMM. However, the carbon path presents a significant problem at normal operating voltages.

Another scenario occurs when insulated wire comes in contact with the bare metal of the stator of a motor. Vibration eventually wears through the insulation of the winding and causes a high resistance circuit to ground. Again, this is relatively unaffected by the lower-voltage output of the DMM in the ohmmeter mode.

In either scenario, when measured at operating voltage, substantial current flow may occur. By testing with the higher output voltage of a megohmmeter, you can identify high-resistance shorts such as those described. Note: Testing of motor insulation should be performed at twice the operating voltage of the motor.

20.3.7 LCR Meter

An ***LCR meter*** measures inductance (L), capacitance (C), and resistance (R). While a DMM is capable of making both resistance and capacitance measurements, an LCR meter is much more accurate. An LCR meter is also capable of making inductance measurements, which a DMM cannot. An example of an LCR meter is shown in **Figure 20-19**.

An LCR meter is more accurate than a DMM because an LCR meter has a higher measurement resolution and a variable frequency source. Taking capacitance and inductance measurements using a frequency at or near the operating frequency provides a more accurate measurement.

Inductance measurements are quite valuable when trying to diagnose a transformer, coil, or motor winding if a shorted turn is suspected. When a coil has a shorted turn, it will exhibit a substantially lower inductance than that of a coil without a shorted turn.

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Figure 20-19. An LCR meter. Notice there are various probes to make component measurements more easily. This unit comes with a probe that resembles a pair of tweezers for measuring tiny surface mount components. In place of a mode selector switch, this model uses buttons to navigate on-screen menus.

20.3.8 Oscilloscope

An ***oscilloscope*** is a device that is capable of graphically representing a voltage waveform. This device is extremely valuable in troubleshooting problems that are otherwise invisible. A modern digital oscilloscope is shown in **Figure 20-20**.

TECH TIP

Oscilloscopes

Some industrial maintenance technicians say, “I don’t need an oscilloscope.” This is often the case when the technician does not know how to use one. The more you learn about using an oscilloscope, the more indispensable this diagnostic tool becomes.

Divisions

The oscilloscope screen is divided into a grid. Refer to **Figure 20-21**. The Y (vertical) axis depicts voltage or amplitude of the incoming signal. If the trace deflects upward, it depicts a positive input voltage. If the trace

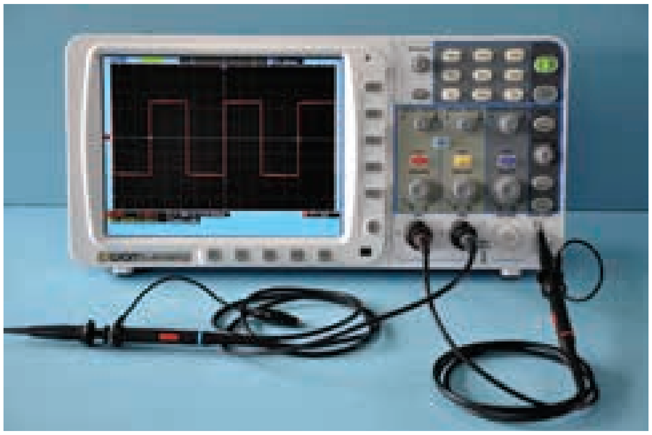

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Figure 20-20. A modern digital oscilloscope with probes. The probe for channel 1 is connected to the scope calibrator output. The scope screen displays the waveform output of the scope calibrator.

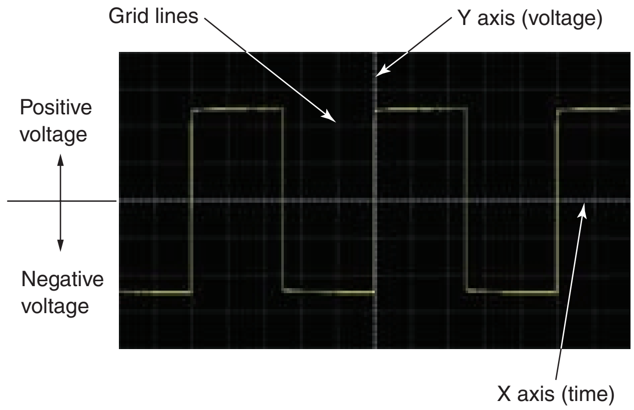

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Figure 20-21. A square waveform as shown on the oscilloscope screen.

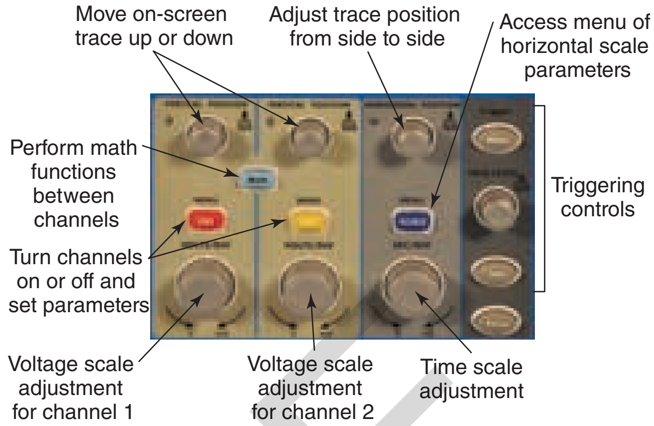

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Figure 20-22. Typical controls of a digital oscilloscope.

deflects downward, it depicts a negative value. The X (horizontal) axis depicts time.

Each little "box" on the oscilloscope grid is referred to as a division. On the Y axis, the value of each division is in volts (volts/division). On the X axis, the value of each division is in time (time/division). Two controls on the oscilloscope set these values. The V/div (volts per division) control knob sets the value of a division on the Y axis, and the t/div (time per division) control knob sets the value of each division on the X axis. These controls are adjusted until the waveform can be conveniently measured.

For the waveform shown in **Figure 20-21**, the scales are set to 1 V/div and 200 µs/div. Count the number of divisions vertically from the positive peak of the waveform to the negative peak to arrive at the peak-to-peak value of 5 V. Count the number of divisions between any point on a cycle, such as where the wave begins to go positive starting from the centerline to the same point on the next cycle, to find 5 divisions. Multiply the number of divisions by the time/div (5 div × 200 µs/div) to calculate 1000 µs, or 1 ms.

Vertical and Horizontal Adjustments

Many digital oscilloscopes have several knobs to adjust various parameters of the device. The most important are the V/div knobs, which set the voltage scale. Refer to **Figure 20-22**. Most oscilloscopes have two or four input channels. Each channel has a voltage scale (V/div) adjustment.

The math button allows you to perform math functions between the two channels. Unfortunately, unknowledgeable technicians press this button and receive a display they are unable to interpret. This is one of the most common mistakes an operator can make. If you are unsure of the results of a setting or adjustment, ask for guidance from your instructor or a knowledgeable operator before using it.

Turning the vertical position or vertical offset knobs moves the trace higher or lower on the screen. For example, you may want to view channel 1 on the top half of the screen and channel 2 on the bottom half. On some oscilloscopes, pressing this knob centers the trace on the screen.

Horizontal controls include a time/division adjustment knob used to set the horizontal scale. A horizontal position adjustment knob allows you to shift the trace from side to side.

Triggering

Triggering allows the waveform shown on the screen to remain stationary without moving horizontally. Without triggering, the waveform drifts or rolls either right or left.

Triggering is the point in time at which the oscilloscope begins sweeping the displayed waveform from

> **TECH TIP**
> **Triggering Options**
>
> Most digital oscilloscopes have a plethora of triggering events to choose from. Read the user's manual for your oscilloscope and become familiar with what triggering options are available to you. Many oscilloscopes provide a button to set the trigger level to 50% of the value of the waveform. This method allows you to get into the "ballpark" quickly. For most waveforms, the 50% setting works with no further adjustment of the trigger level control. More complicated waveforms may require more manipulation in order to lock the trace on the screen.

left to right. You can set the scope to trigger at a specific voltage. You can also specify if the trigger happens on the leading or trailing (rising or falling) edge of the waveform.

Additional Oscilloscope Functions

Oscilloscope controls typically include additional buttons. Button names may vary, but the functions are similar. Always refer to the user's manual of your specific oscilloscope for a complete explanation of available functions. The following are general descriptions of the functions of common buttons:

- **Run/Stop button.** Allows you to stop the sweep on the oscilloscope, "freezing" the waveform for closer examination. This feature is helpful when the waveform is changing too quickly to get a good look at what is happening. This button is not available on analog oscilloscopes.
- **Single (Sweep) button.** Takes a "snapshot" of the waveform. If the waveform frozen by the Run/Stop button is not useful, pressing the Single button takes another snapshot. This button is not available on analog oscilloscopes.
- **Autoscale button.** Allows the oscilloscope to automatically change the voltage scale (v/div). In some instances, it is beneficial to allow the scope to set this parameter.
- **Autoset (Auto Setup) button.** Measures the incoming signal, adjusts the vertical and horizontal scales, and sets the triggering to display a waveform. This option works most of the time on simple waveforms. However, more complex waveforms require additional adjustment. This button is not a substitute for the technician becoming proficient with oscilloscope setup and operation.
- **Save button.** Stores waveforms as a file that can be reloaded to the oscilloscope screen or as an image that can be printed. Most digital oscilloscopes have a USB port, so you can save waveforms to a flash drive.
- **Display button.** Allows you to set and control various aspects of the display.
- **Help button.** Provides general information on how to set up a function. The Help button is not a substitute for reading the user's manual.
- **Measure button.** Accesses a menu that allows you to set the scope to make voltage, time, frequency, pulse length, duty cycle, RMS value, and many other measurements. As many as two or three dozen measurement options may be available, depending on the model of the oscilloscope.
- **Multipurpose knob.** Allows menu-specific adjustments and selections.

Oscilloscopes may include buttons in addition to those described here. Always refer to the user's manual for your specific oscilloscope to learn about the available functions.

Cursors

With regard to oscilloscopes, ***cursors*** are a pair of lines, either horizontal or vertical, whose position may be changed in order to take measurements. Examples of cursor measurements are shown in **Figure 20-23**. Normally, a digital oscilloscope displays the absolute

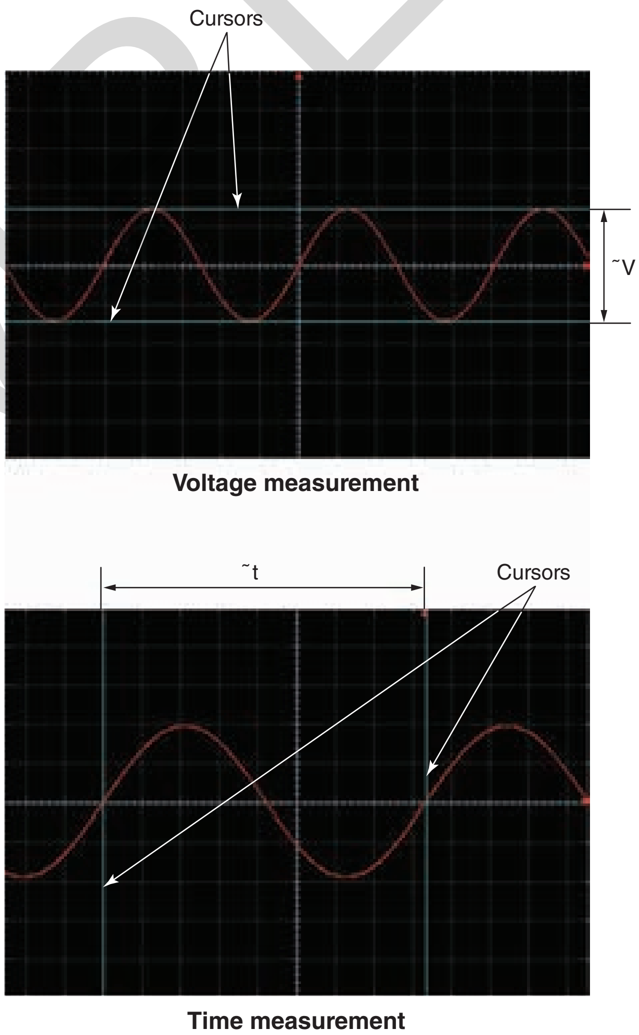

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Figure 20-23. Oscilloscope cursors serve as reference points for measuring voltage and time.

position of each cursor as well as the Δ value (difference) between the two cursors.

Portable Oscilloscopes

Many digital oscilloscopes are portable (handheld) models powered by batteries. See **Figure 20-24**. They either come with a rechargeable battery or in some cases a battery may be added as an option.

The primary benefit of a portable oscilloscope is the ability to use the device on the plant floor without being tethered to a 120 V receptacle. This makes the scope more versatile and allows you to measure grounded circuits without the scope being connected to ground. This isolation is an important safety feature.

Oscilloscope Inputs and Probes

Oscilloscope inputs commonly have an impedance of 1 MΩ. For low frequency signals, the 1 MΩ input is often used with a 10:1 probe, resulting in circuit loading of 10 MΩ. Some oscilloscopes may also select an impedance of 50 Ω to match equipment with a coaxial cable output. With a direct coax cable connection between the scope and the equipment being measured, the impedance is matched and the scope should read accurately. **Figure 20-25** shows the input channel connections and the scope calibrator connection of a digital oscilloscope.

Often, oscilloscope probes have a switch labeled X1/X10 on the probe body. X1 is considered direct, and in this position the probe impedance is the same as the input impedance of the scope.

In order not to load a high impedance circuit under test, switch the probe to the X10 position. This position allows the probe to present a high impedance and not load the circuit under test. When in the X10 position, multiply the reading on the oscilloscope screen by 10 to obtain the actual voltage measured. Some oscilloscopes have a menu option that allows you to specify which probe is connected, such as X1, X10, X100, or X1000.

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Figure 20-24. A portable oscilloscope. Notice that this oscilloscope does not have any knobs. Instead, settings are accessed through the use of on-screen menus and navigation buttons. This portable oscilloscope also makes automatic measurements and functions as a multimeter.

TECH TIP

Oscilloscope Probes

The X100 probe is a good accessory to have when measuring higher voltages. Always be careful to make certain the multiplier or switch position of the probe you are using is set appropriately. Check the menu setting for the probe multiplier as well.

Oscilloscope Calibrator

Most oscilloscopes have a built-in calibration source. This is a useful tool for checking the oscilloscope and probes to ensure that everything is in order. The calibrator output is commonly located next to the channel inputs on the scope.

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Figure 20-25. Oscilloscope inputs and calibrator output.

The most common calibration signal is a 5 V peak-to-peak square wave at a frequency of 1 kHz. The probes are coaxial in design and have a compensation adjustment on them. In a perfect scenario, the coaxial cable inductance is equal to its capacitance and the two cancel each other out.

A probe compensation variable capacitor is built into the probe to allow you to zero out any inductance or capacitance. Connecting the probe to the calibrator and observing the square wave on the scope screen indicates if you need to make any adjustments to the compensation capacitor. On X1/X10 probes, the compensator is applied to only the X10 side of the probe, so be certain to check the switch.

20.3.9 Power Supplies

Assemblies require various AC and DC voltages at different levels. To bench test an assembly, you must provide it with the same type of power it receives in its usual operation.

There are many types of power supplies. Single-voltage DC power supplies provide one level of voltage. Variable DC power supplies can be adjusted among a range of voltage levels. AC power supplies include transformers and variable autotransformers.

20.3.10 Arbitrary Function Generators

An ***arbitrary function generator (AFG)*** is a digital electronic device capable of generating analog and digital signals. See **Figure 20-26**. An AFG, sometimes also called an *arb*, can generate almost any imaginable analog or digital signal. AFGs can be physical devices or may be circuit cards controlled by software on a USB-connected computer, **Figure 20-27**.

An AFG is capable of producing many different waveforms, including operator-specified waveforms. For example, you can save an oscilloscope waveform as a data file, load it into the AFG software, and output the waveform. An AFG is also capable of outputting digital signals and bit patterns.

20.3.11 Phase Sequence Tester

When connecting three-phase power to most equipment, especially electric motors, the three phase conductors must be in the correct relationship to each other. If you were to label each phase A, B, and C, respectively, phase B would start 120° after phase A starts, phase C would start 120° after phase B starts, and phase A would start once again 120° after phase C starts. This phase relationship ensures all the phases are

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Figure 20-26. This arbitrary function generator (AFG) has an analog output and multiple digital outputs. This AFG is completely software controlled, so there are no controls on the unit. A USB port allows the AFG to connect to a computer.

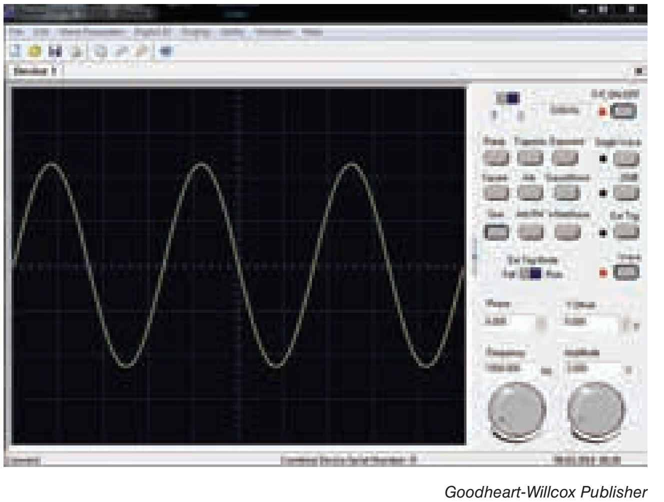

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Figure 20-27. This AFG control software provides all the controls to modify various waveform parameters of an AFG.

in the correct sequence. Note that each phase is 120° apart from the others.

If a three-phase motor is connected with all phases in the correct sequence, the motor rotates clockwise as viewed from the shaft end. If any one of the phases is out of sequence, the motor rotates counterclockwise. The phase sequence can be corrected by switching any two of the three phase conductors. Common practice is to switch L1 with L3 inside the control cabinet at the output to the motor.

According to convention, phase conductors should be labeled L1, L2, and L3. The motor connections should be labeled T1, T2, and T3. Unfortunately, these conductors are often unlabeled or mislabeled. This situation can be corrected using the process of elimination by connecting the motor and seeing which direction it turns when energized. If the motor runs backward, reversing any two phases will correct the situation.

A ***phase sequence tester*** can be used to label or verify the labeling of the phase conductors. A typical phase sequence tester, **Figure 20-28**, has three inputs, three voltage-present indicators, two rotation indicators, and a test button. Simply connect the three input leads to the three phase conductors. The voltage-present indicators verify that voltage is present in each phase. The phase relationship is indicated by one of the two rotation indicators.

For phase sequence testing, some testers have a button that must be pressed to read the rotation. Some high-end units have a motor rotation test capability to identify the proper sequence of the motor leads.

For motor rotation testing, the tester has three input/output jacks, a power indicator, two rotation indicators, and a test button. To test, connect the three motor leads to the three input/output jacks. Press and hold the test button and observe that the power indicator is illuminated. Looking at the shaft end of the motor, rotate the motor shaft and observe the rotation indicator. Verify that the rotation indicator shows the direction the motor is rotating. Rotate the motor in the opposite direction and observe the direction of rotation indicator that is illuminated. If the rotation indication is opposite the direction the shaft is rotating, reverse any two of the three conductors.

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Figure 20-28. A phase sequence and motor rotation tester is a relatively simple and valuable testing device.

TECH TIP

Phase Sequence Tester Applications

A phase sequence tester is an extremely useful tool when working with conveying systems, pumps, compressors, and other rotating machinery using three motors.

20.3.12 Infrared Thermometer

An ***infrared (IR) thermometer***, **Figure 20-29**, is a noncontact electronic device that measures infrared radiation emitted from a surface or object to determine its temperature. The infrared thermometer does not measure the temperature of the air, only the matter it is aimed at.

Most IR thermometers have an aiming laser to make it easy to determine the surface being measured. The area of measurement sensitivity is in the shape of a cone. The farther the IR thermometer is from the surface being measured, the larger the area that is measured. The closer the IR thermometer is to the surface, the smaller the measured area. Most IR thermometers are marked with the distance versus area.

This device proves useful in measuring the temperature of bearings to determine imminent failure. If the bearing on one end of a motor shaft is warmer than that on the other, watch out for a failure in the near future.

High temperature of an electrical connection is a good indication that it is potentially loose and may soon fail. Transformer and motor temperatures may be checked to determine if they are within the manufacturer's specifications. Such devices may fail if they overheat.

20.4 CALIBRATION

Calibration is an important part of test and measurement equipment maintenance. Test equipment should be calibrated on a periodic basis to ensure its accuracy. Many companies are certified to various quality standards, such as ISO 9001. These quality system standards require that all test and measurement equipment be calibrated.

Calibration involves verifying that the test or measurement device measures within the manufacturer's specifications. Calibration does not necessarily mean that the test or measurement equipment must be corrected or recalibrated. Rather, the difference between the measurements the test equipment makes and the standard it is compared against is known and documented. Differences outside the manufacturer's specifications indicate that the equipment needs to be recalibrated and should not be used or relied on.

Some large companies have their own calibration laboratory. Others employ calibration firms. Most calibration can be done on-site, but specialized test equipment may need to be shipped to a calibration lab.

Calibration labs are accredited by various organizations. They have calibration standards that must periodically be calibrated against standards maintained by the National Institute of Standards and Technology (NIST). The calibration standards used by a calibration lab, when so calibrated, are considered to be traceable to NIST.

When a piece of test equipment has been calibrated, the company receives a certificate of calibration. Additionally, each device that has been calibrated receives a sticker indicating the date it was calibrated, who calibrated it, and when it is next due for calibration.

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Figure 20-29. Infrared (IR) thermometers determine temperature by measuring the amount of infrared radiation emitted from an object.

Always check the calibration date before using test equipment. Do not use equipment that is past due for calibration. The measurements provided by the equipment could be inaccurate.

CHAPTER WRAP-UP

Whether you are field testing or bench testing, safe practices are critically important when working with electricity. Safety should be a top priority for any electrical technician or responsible employer. Take time to familiarize yourself with the safety standards and practices required for a particular system before you start working on it.

Electrical technicians must be able to use many electrical measurement and testing tools. Learning how to use a variety of testing equipment in a careful and correct manner makes you invaluable for in-house troubleshooting. Keep your tools properly calibrated to ensure you are taking accurate measurements.

Chapter 20 Review

SUMMARY

- Safety first! Always follow all safety procedures and use appropriate PPE before and while performing electrical testing.
- Check the settings on test equipment before connecting to ensure it can handle the voltages and transients present.
- Always de-energize a circuit before testing for resistance.
- A receptacle tester indicates if a receptacle has been properly wired and grounded.
- A digital multimeter (DMM) is one of the most versatile tools in the electrical technician's toolbox. Modes, inputs, safety features, and any advanced functions will vary based on your device.
- Always discharge a capacitor before testing.
- Connect a DMM in series with the source and the load when making current measurements.
- Clamp-on ammeters allow you to measure current without needing to disconnect conductors.
- A megohmmeter uses high voltage to make insulation resistance measurements.
- An oscilloscope shows voltage on the Y axis and time on the X axis.
- Triggering on an oscilloscope provides a way to lock the waveform in a stationary position on the scope screen so that waveforms may be observed and measured.
- The oscilloscope calibrator output allows you to verify proper operation of an oscilloscope and set the probe compensation of multiplier probes.
- An arbitrary function generator (AFG) can be used to produce various types of signals when bench testing an assembly.
- A phase sequence tester verifies that the phase conductors in a three-phase circuit are in the proper order. If the tester shows the phases to be reversed, switch the position of any two conductors. If a motor runs backward, switch the position of any two of the three motor leads.
- Infrared (IR) thermometers measure the infrared radiation being emitted from an object.
- Electrical testing equipment must be calibrated periodically to ensure accurate measurements.

REVIEW QUESTIONS

Answer the following questions using the information provided in this chapter.

Know and Understand

1. *True or False?* Electrical equipment should be energized before testing.
2. Undesirable voltage spikes in excess of the intended voltage are known as _____ or _____.
   A. ghost voltage, voltage spikes
   B. overvoltages, transients
   C. stray voltages, ghost voltage
   D. None are correct.
3. Switchgear and three-phase motors are considered _____.
   A. CAT 1
   B. CAT II
   C. CAT III
   D. CAT IV
4. A receptacle tester indicates a properly wired receptacle when _____.
   A. one yellow lamp is lit
   B. two yellow lamps are lit
   C. one green lamp is lit
   D. both green lamps are lit
5. A noncontact voltage tester uses _____.
   A. a capacitive sensor
   B. a Hall effect sensor
   C. resistance measurements
   D. None are correct.
6. *True or False?* DMMs can measure resistance in a live circuit.
7. For measuring current, a DMM is wired in _____.
   A. series
   B. parallel
   C. series-parallel
   D. None are correct.

8. For a good diode, a DMM would read _____.
   A. 2.5–3.5 V
   B. 1.5–2.0 V
   C. 1.0–3.0 V
   D. 0.4–0.7 V
9. *True or False?* Capacitors are generally specified in either µF or pF, but a DMM may display the reading in a different unit.
10. Most advanced multimeters measure the amount of AC voltage that would produce the same amount of power that a DC voltage would. This is labeled _____ on multimeters.
    A. average
    B. peak
    C. max
    D. true RMS
11. *True or False?* Voltage readings on DMMs between conductors that have no actual voltage difference are called ghost voltages.
12. *True or False?* A megohmmeter uses low voltage to make resistance measurements.
13. If you need to measure the inductance of a motor, which test instrument could you use?
    A. LCR meter
    B. DMM
    C. Clamp-on ammeter
    D. Megohmmeter
14. What does an oscilloscope depict on the X axis?
    A. Voltage
    B. Current
    C. Resistance
    D. Time
15. The X10 position allows the oscilloscope probe to present a high impedance and not load the circuit under test. What would you need to do when interpreting the measurement?
    A. Multiply readings by 10
    B. Divide readings by 10
    C. Multiply Hz by 10
    D. None are correct.
16. If you need to simulate a signal while bench testing an assembly, which test instrument would you most likely use?
    A. Oscilloscope
    B. AFG
    C. DMM
    D. Phase sequence tester
17. An infrared (IR) thermometer is a noncontact electronic device that measures _____ emitted from a surface or object to determine its temperature.
    A. temperature
    B. magnetic field
    C. infrared radiation
    D. resistance
18. *True or False?* Test or measurement equipment that is not identical to the calibration standard does not necessarily need to be recalibrated, but rather it must be documented and acknowledged.

Apply and Analyze

1. Briefly describe which two controls on the oscilloscope you would use to set the X and Y values.
2. If you want to measure the voltage of a three-phase transformer, which test instrument would you use and how would you connect it?
3. What does a receptacle tester tell a technician?
4. What is the modern version of the screwdriver voltage tester or receptacle tester and how does it operate?
5. List five measurements that a typical DMM can make.
6. What does the diode test mode of a test instrument measure?
7. Convert 5800 nF to microfarads.
8. What is a phantom voltage?
9. What are the two main types of troubleshooting?
10. What is triggering?

Critical Thinking

1. What advantages does a clamp-on ammeter have compared to a DMM?
2. What test instrument replaces continuity testers with a continuity test mode? What does the continuity test measure, and how does it let the technician know the circuit has continuity?
3. If you want to measure the resistance of a circuit, what test instrument would you likely use? What would your first step be before taking the measurement?

Questions for Class Discussion

1. Research and price a DMM that you would use on the job. Discuss why you chose this particular model.
2. Research and price a portable digital oscilloscope.
3. Discuss the most common capacitors tested in an industrial setting and how to test them.

NIMS CREDENTIALING PREP QUESTIONS

The following questions will help you prepare for the NIMS Industrial Technology Maintenance (ITM) Electrical Systems Smart Credential exam.

1. Which of the following ratings identifies a test equipment's tolerance for voltage spikes and transients?
   A. Current rating
   B. CAT level
   C. RMS voltage
   D. PPE rating
2. A receptacle tester can determine _____.
   A. if a receptacle is grounded properly
   B. the amount of voltage available from a receptacle
   C. the current rating of a receptacle
   D. if a receptacle is weatherproof
3. A Hall effect sensor is likely to be found in _____.
   A. an oscilloscope
   B. calibration certificates
   C. noncontact test equipment
   D. motor windings
4. The auto-ranging feature on a DMM may eliminate _____.
   A. the need to use test leads
   B. the need to recharge the DMM battery
   C. voltage ratings
   D. selection options on the mode selector switch
5. Convert 4600 pF to nanofarads.
   A. 0.046 nF
   B. 4.6 nF
   C. 4600 nF
   D. 4600000 nF
6. Which of the following is the correct abbreviation for microfarad?
   A. mF
   B. miF
   C. µF
   D. MF
7. A clamp-on ammeter provides a noncontact method for measuring what quantity?
   A. AC current
   B. Resistance
   C. Capacitance
   D. Voltage
8. Which of the following devices is also referred to as an insulation tester?
   A. Clamp-on ammeter
   B. DMM
   C. Megohmmeter
   D. VOM