Troubleshooting *For* BOATERS

Safety first and electrical maintenance go hand-in-hand to safeguard boating pleasure

VAUGHN D. MARTIN

THIS ARTICLE IS DIRECTED TOWARD boating enthusiasts with an interest in maintaining their craft's electrical and electronic equipment. It will show you how to test and troubleshoot marine electrical systems, outboard motor magneto ignitions, and the integrity of your boat's corrosion protection system.

The marine environment can be especially harsh on the components of your boat's electrical system. When performing preventative maintenance or when trouble occurs, you will want the capability to make accurate and reliable electrical measurements quickly. The basic tool for this job is the digital multimeter.

Work safety

The voltages and currents present in electrical power systems can cause serious injury or death by electrocution. Consequently, when testing or troubleshooting, carefully adhere to all industry standard safety rules that apply to the situation. Read and follow directions and safety warnings provided by the equipment manufacturer. Don't be misled by low potentials of 12 and 24 volts DC. They may not electrocute you but they can set your boat afire or cause an explosion—with you and others on board!

Here are some troubleshooting safety tips you should know:

• Be sure that all electrical power has been turned off, locked out, and tagged in any situation where you will be in direct physical contact with live circuit components. This is especially important when 117-volt AC dockside power is available. Also, be certain that the power can not be turned on by anyone but you!

• Use only well maintained test equipment. Inspect all test leads (especially the probes) for breaks and cracks and check all on-board fuses before use. Repair or replace any test lead or probe with damaged insulation. Replace defective fuses with new units of the same rating as specified for the equipment by the manufacturer.

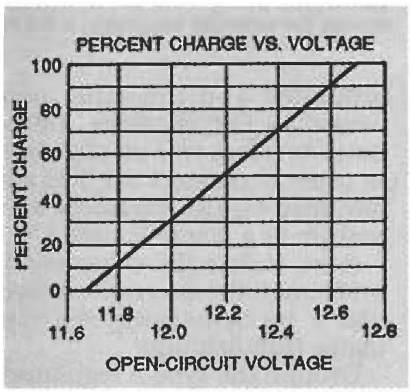

FIG. 1—PERCENT CHARGE vs. lead-acid battery voltage for a common 6-cell battery under no load for 24 hours. Voltage readings will be slightly less for batteries recently used.

• Be very cautious when working on electrical systems when fuel vapors are present. Remember that vapor from gasoline and propane are heavier than air and will collect in the bilge and closed compartments. Sparks generated by making connections with live electrical components can start a fire or cause an explosion when fuel vapors are present. Ventilate completely to eliminate all explosive vapors before proceeding and cease work immediately should you suspect the dangerous vapors are reoccurring.

• Be aware that charging an unsealed lead-acid batteries generates hydrogen gas. This hydrogen can explode if exposed to a spark generated at the battery terminals when connecting or disconnecting a battery charger. Always verify that the power to the battery charger is off before connecting or disconnecting the charger leads at the battery terminals. Also, carefully observe polarity of the battery chargers cables.

Batteries

Very often the first sign of a battery problem occurs when the starter won't turn the engine over. Use your multimeter to get an idea of the battery's charge. To perform a no-load test, set the digital multimeter function switch to measure volts DC and connect the leads across the battery's terminals. Compare your voltage reading to the graph in Fig. 1 to determine percent charge.

The above voltage test indicates only the state of charge, not the battery's condition. For example, a battery may register 100 percent charge but would be unable to crank the engines starter for more than five or six revolutions. To gain additional information about the battery's condition, test the specific gravity of the electrolyte in each cell using a hydrometer calibrated for that purpose. (This test is not possible for sealed batteries.) If the specific gravity is low but relatively the same across all cells, recharging may be able to bring the battery back to good health, unless the plates are sulfated. If they are sulfated, charging the battery will do little to improve its performance—the hydrometer reading would remain low. If one cell shows a specific gravity much lower than the rest, that cell is probably defective and recharging will not help. When you cannot correct the problem by recharging, replace the battery immediately!

Your marina service shop probably has a device that places a load across the battery and provides a voltage reading at the same time. If your battery is sealed and you cannot take a hydrometer reading, see if you can borrow this tool to check out your battery. The meter is usually calibrated Good, Fair, and Bad or Replace.

Sulfated plates can be detected by measuring the output voltage under load after the battery has been fully charged. The sulfate degeneration on the plates of a battery increases its internal resistance. Thus, under load the battery exhibits an internal voltage drop reducing the overall battery voltage to the load (starter), and seriously limiting the amount of current available to start a cold engine. Typical results for a good battery tested under load are given in Fig. 2. Note that the test probe tips must dig into the battery's soft lead terminal post and not the cable clamp-connector.

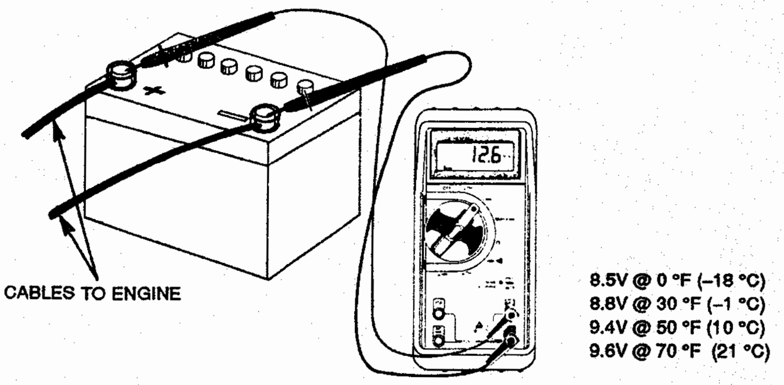

FIG. 2—MEASURING THE BATTERY'S output voltage under load. The chart indicates typical voltage outputs for starter loads at various temperatures.

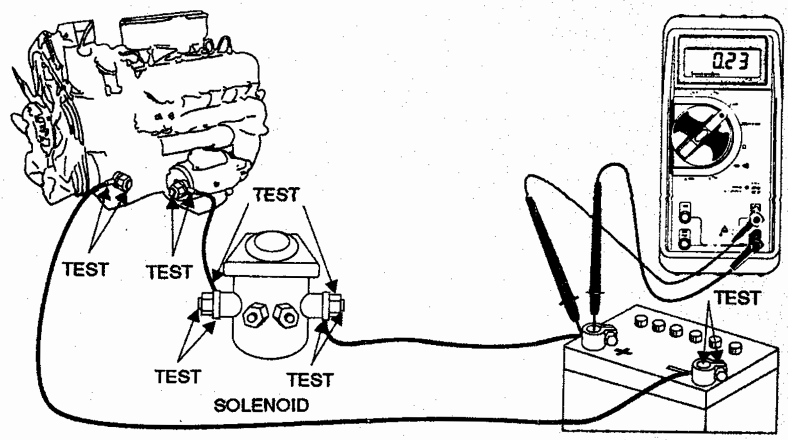

FIG. 3— TO DISCOVER WHERE POWER is being lost when cranking the starter, each connection point in the circuit must be checked for excessive voltage drop. Check across the solenoid assembly; if the resistance is high, replace the unit.

Alternators

A digital multimeter's accuracy and display make diagnosing regulator/alternator troubles easy. First determine if the system has an integral (internal) regulator, then whether it's type A or B. Type A is sometimes referred to as P-Type and type B is sometimes referred to as N-type. A type-A regulator has one brush connected to the battery's + terminal and the other brush grounded through the regulator. The Type-B regulator has one brush directly grounded and the other connected to the regulator. (Alternator brushes ride on slip rings in order to connect the field coil mounted on the alternator's armature to a power source.)

Next, isolate the cause of the problem to the alternator or regulator by by-passing the regulator (full-fielding).

Ground the Type-A regulator's field terminal. Connect the Type-B regulator's field terminal to the battery's + terminal. If the system charges now, the regulator is faulty. Use a rheostat in series with the field connection if possible. Otherwise, just idle the engine (lights on) so the voltage doesn't exceed 15 volts.

Starting systems

Starting system troubles are often confused with charging-system problems. Many dead batteries have been replaced when the real cause was a faulty charging system. Be sure that the charging system is functioning properly before you replace the battery. Make sure the battery is charged and passes a load test, then look for resistance in the starter circuit should the engine still crank slowly.

In a lead-acid battery, each cell produces about 2.1 volts at full charge. Therefore, a 12-volt battery has 6 cells in series and delivers about 12.6 volts when fully charged. If the no-load test on a fully charged battery reads about 10 volts, a dead cell is likely and the battery should be replaced immediately.

Resistance increases in a starting system when high-current cables are frayed, connections are loose, and terminals are corroded or dirty. Investi-

Continued on page 79

TROUBLESHOOTING

continued from page 42

gate an excessive current draw; check for worn-through insulation, a seized or tight engine, and a faulty starter. If the starter turns the engine slowly, the current draw is not high, and the battery is in good condition, check the resistance in the starter circuit. Its brushes may be defective, making poor contact or the commutator of the armature may be dirty.

Added resistance in the starter circuit causes the starter to turn slowly. For example: In a starter system drawing 200 amps, 0.01 ohms of added resistance in the starter cable will cause a 2 volt drop in voltage at the starter's armature. A 0.01 ohm resistance is too small for all but the most expensive and sophisticated ohmmeters to measure. However, you can measure a voltage drop indicating where there is excessive resistance (Fig. 3). Determine if there is resistance in the circuit by measuring the voltage drop across each connection and component in the starter circuit. Do this while cranking the engine. Measure the voltage drop between the battery post and the connecting cable, the solenoid posts and the wires that attach to them, and across the solenoid itself. Also, check the connection on the starter, alternator (feed and ground side) and the ground strap connection to the engine block. A logical test sequence would be to start by first measuring the battery voltage between the + and – terminals when the starter is cranking. Then measure the voltage between the starter terminal and engine block when cranking. If the starter voltage is significantly less, use our just completed procedure to isolate the voltage drop. The corrective action is usually indicated by the fault's location: clean and tighten poor connections, replace defective cables, etc.

Ignition systems

If your engine has breaker points in the distributor, use your multimeter to measure the resistance across the contacts when the points are closed. The reading should be very low, typically 0.1 to 0.3 ohms.

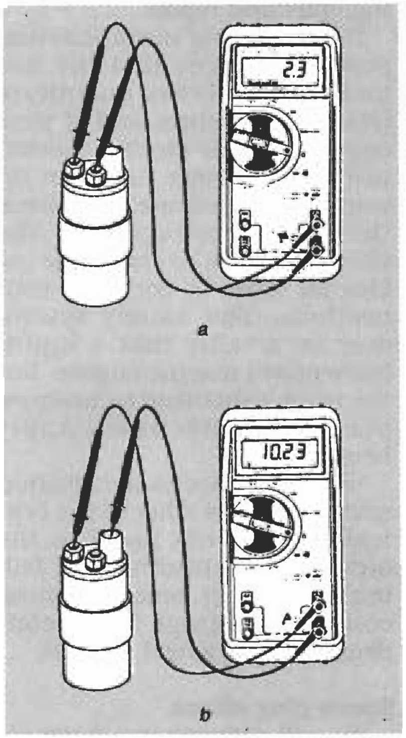

FIG. 4—USING A DIGITAL MULTIMETER to check the continuity of the primary (a) and secondary (b) windings of an ignition coil. Resistive values shown are typical for these coils.

The primary and secondary windings in the ignition coil can also be measured for resistance (see Fig. 4). If your digital multimeter has an automatic ranging feature, use the manual ranging feature on the multimeter to avoid any oscillations between ranges that can sometimes be caused by the inductance of the coil.

Ballast resistors in series with the coils primary winding can be measured. Look for low values in the range of 0.5 ohm. A word of caution: Connecting and disconnecting the battery source in the digital multimeter across the primary winding of the ignition coil will cause a high-voltage surge in the secondary winding. The shock experienced is usually minor. However, an involuntary sudden movement by you might cause a bruising injury or worse.

If you suspect a malfunctioning ignition coil, check the resistance of primary and secondary windings. Do this when the coil is hot, and again when it is cold. Expansion and contraction may open a coil winding. Also measure from the case to each connector. The primary windings should have a very low resistance, typically from a few tenths of an ohm to a few ohms. The secondary windings have a higher resistance, typically in the 10-kilohms to 13-kilohms range. To get the actual figures for a specific coil, check the manufacturer's specifications.

Condensers (capacitors)

Shorted condensers are a common problem. Many experienced boaters replace them at the beginning of every season (or once a year where the boating season is year round) and keep a spare condenser onboard for emergency replacement when away from the dock. Your multimeter is a valuable tool that can check the capacitor's usability. Set the multimeter to the ohms range and observe the meter reading or bar graph indication. The battery in the multimeter will charge the capacitor from zero volt to the battery potential causing the ohms reading to increase from zero to infinity for a good condenser. A leaking condenser will have a finite resistance, indicating that you should replace it.

Be sure to reverse the leads to the meter and check current flow both ways. Also make sure to check condensers, both hot and cold. Leaking condensers do not give an infinity-ohms reading.

Spark plug wires

Most modern gasoline engines have resistance wire for the high-voltage connections from the distributor cap to the spark plugs. The internal resistance within the wire reduces radio interference and produces a cleaner spark. Plug wires should be checked for open circuits if they are more than two years old. A common sense approach is to replace plug wires biannually. Keep a few of the longer old plug wires aboard for emergency replacements when not at dockside. Due to the heat of the spark plug insulator, a spark plug boot may bond to the spark plug. Pulling a spark plug boot straight off the spark plug can damage the delicate conductor inside the insulated wire. Rotate the boot to free it before pulling it off.

If you suspect bad wires, test the resistance of the wire while gently twisting and bending it. Resistance values should be about 10 kilohms per foot depending on the type of wire being tested; some may be considerably less. You should compare readings to other spark plug wires on the engine to provide a relative reference for a typical good reading.

Outboard motors

The ignition troubleshooting procedure for outboard motors given here can be used for any small one- or two-cylinder gasoline engine using a breaker-point magneto ignition. This type of ignition is commonly found in lawn mowers, chainsaws, emergency-power generators, snow throwers, etc.

In order to start, the engine requires three things:
a. The proper amount of fuel/air mixture,
b. A properly timed spark,
c. Some piston compression.

If the engine won't start, chances are that one or more of these items is missing. The troubleshooting logic is straightforward: Find out which critical items are missing, why and repair.

Before getting into the actual procedure, verify that the fuel tank has a sufficient quantity of fresh fuel mixture and if your engine has an electric starter, use the DC volts function on your digital multimeter to check the battery voltage. Use the ohms function to check the cables for loose or corroded connections. The battery system may be smaller that a multi-horsepower marine engine, but the troubleshooting techniques previously discussed apply here.

With reference to the ignition system, here is a list of the critical components listed in the order of their likelihood of failing: spark plug, breaker points, coil, high-voltage wire, condenser and flywheel magnet.

Spark plug check

We will assume you have already tried the normal starting procedure, i.e., turned the engine over a number of times, first with the choke closed and then open. Remove the cowling (if necessary) to gain access to the spark plugs. For a twin cylinder engine, label the spark plug wires so that they can be replaced in the correct order. Pop the wires off and unscrew the spark plug(s). Keep track of which plug came out of which cylinder.

Examine each plug carefully. This is like palm reading; the condition of the plug tip can tell a story about what is going on in each cylinder. If the plugs are wet with gasoline, fuel is undoubtedly reaching the cylinders. If the plugs are dry, the opposite is true. Look for a blockage in the fuel system or a bad fuel pump in a remote tank.

If the plug(s) are fouled with carbon and/or oil, several things could be wrong. The spark to the plug(s) is weak or non-existent. The spark plug heat- range is too cold. (Check the engine's manual to determine the recommended plug type.) Another possibility is the engine has been run for long periods of time at low speeds, maybe with an incorrect fuel or fuel/oil mixture. In the case of multi-cylinder engines, if only one plug shows difficulties, the problem is likely to be a weak spark from the ignition system or a defective plug.

The next step is to check actual spark plug operation. If new plugs are available, use them. If not, clean the old ones as follows: Using a sharp object such as the point of a safety pin or a straightened fish hook, scrape off the deposits on the insulator surrounding the center electrode. Dig down between the insulation and sidewall and remove as much deposited carbon as possible. Now, wash out any remaining oil or carbon particles with a non-conductive solvent such as paint thinner or unmixed gasoline. Allow the plug to air dry; blow on it if necessary.

Next, gap each plug by tapping or bending the outer electrode. If you don't know what the recommended gap is, use 0.025" (a bank credit card is typically .030"). Test each plug and high-voltage wire combination by connecting the wire to the plug and laying the plug on the engine block where the gap can be seen. The plug's outer body needs to make electrical contact to the engine's metallic block, just as it does when it is screwed in place. Now, turn the engine over at normal cranking speed and watch for a spark. If you are in bright sun, you may have to shade the plug to see the spark. If this test shows no spark, or a weak spark, the trouble is with the breaker points or the coil

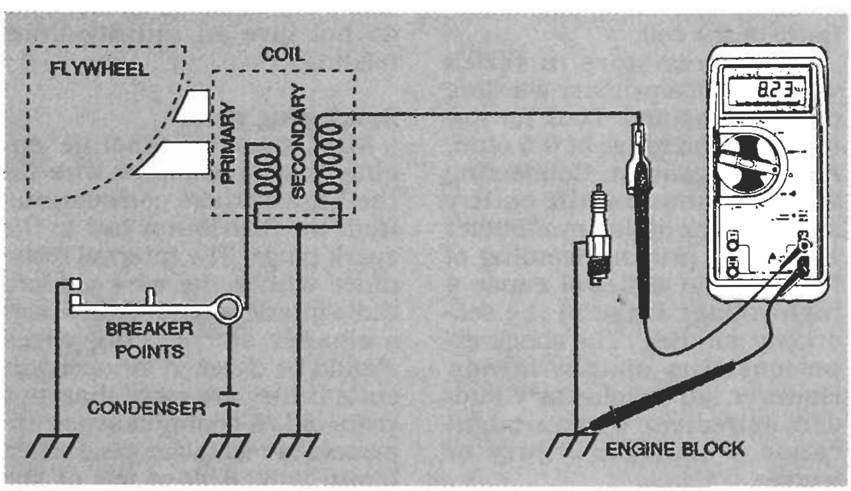

FIG. 5—CONTINUITY TESTS for the high-voltage wire.

inside the magneto. A strong spark indicates that the plugs were fouled and you corrected the problem.

The next test checks for a continuous path for the spark through the high-voltage wire and the ignition coil (see Fig. 5). For a one-cylinder engine, there is a direct electrical path from the plug cap through the high-voltage wire and ignition coil to the engine block. This can be checked without taking the magneto apart as follows: Set the multimeter to the ohms function. Use the range button to manually select the 40 kilohm range.

Now, touch one probe tip to the engine block and the other to the metal connector inside the plug wire cap. The meter should read the resistance of the coil and high-voltage wire in series. Good readings will range from 3 kilohms to 15 kilohms. Higher readings mean a poor connection or cable. A poor connection typically occurs either where the high-voltage wire connects to the coil or at the other end where the high-voltage wire connects to the spark plug clip inside the cap. An infinite resistance reading means that there is an open circuit or break in the electrical path. If you get a bad reading, check again and make sure you are making a good connection with both test leads.

Continuity test

If you are testing a 2-cylinder, 2-cycle engine (mixed fuel), perform this test for each cylinder individually. Look for a correlation between a bad reading and a fouled spark plug on the same cylinder.

If the engine is a 4-cycle model (unmixed fuel), such as a Honda or Onan, the test is performed slightly differently, as shown in Fig. 6. You should expect continuity from one spark plug clip to the next since there is only one secondary winding. The secondary winding is not connected to the engine block. However, an open spark path will kill the spark to both cylinders.

A break in the high-voltage

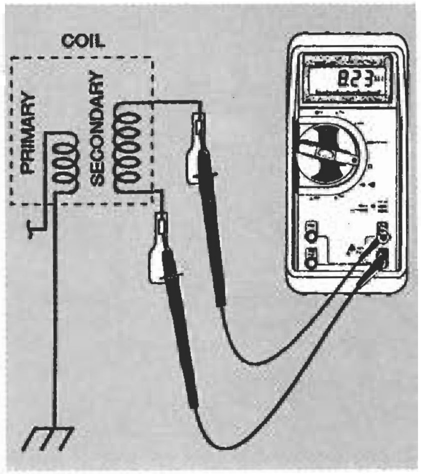

FIG. 6—RESISTANCE/CONTINUITY TEST for 2-cylinder, 4-cycle engines. Note that there is no distributor and that both plugs fire at the same time.

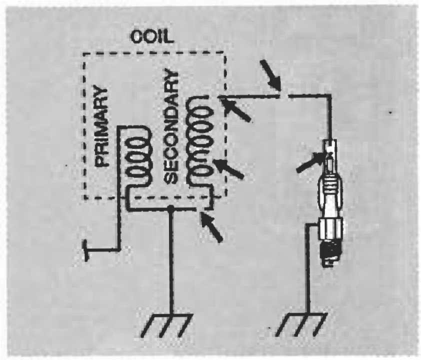

FIG. 7—LOCATION OF possible circuit interruptions in the secondary winding, high-voltage circuit.

circuit can occur in several places as shown in Fig. 7. If the poor connection or open circuit occurs at the spark plug clip, you may be able to repair it without taking anything else apart. If the problem is located inside the magneto, it will probably be necessary to remove the flywheel.

Breaker point test

The breaker points on a magneto ignition are often located under the flywheel. Remove any parts obstructing the flywheel's removal. Hold the flywheel in a stationary position with a strap wrench and remove the large nut that holds the flywheel to the crankshaft. Use a puller to loosen the flywheel and lift it off the crankshaft. Locate the breaker points and examine the contact surfaces. Caution here: when rotating the crankshaft, turn it in the forward direction only to prevent damage to the water-pump impeller.

For proper operation, the breaker-point contact surfaces should be clean and shinning. Make an electrical resistance test with your digital multimeter before attempting to clean the contact surfaces. This provides a before and after indication. Refer to the diagram in Fig. 8. Note the points are in parallel with the primary winding of the ignition coil and condenser. When the points are open, the resistance across the coil will be about 1 ohm (the winding's wire resistance). When the points (with clean contacts) are closed, the resistance falls to 0.1 to 0.2 ohms. Any oil or corrosion on the point contact surfaces increases the resistance and reduces the primary winding current. This subsequently weakens or kills the spark.

Measure the contact resistance as follows: Place the multimeter in the ohms function. Hold the probe tips tightly together to obtain a reference reading with the tips shorted. The reading should show zero (0.0) ohms. If not, note the value. This is the reference reading.

Now place the probe tips on opposite sides of the point contacts when the points are in the closed position. The meter should now read no more than 0.1 ohm greater than the reference reading. Higher readings indicate contamination on the contact surfaces. If the contact surfaces are pitted, the best choice would be to replace the points. If you can't install new ones, then carefully clean the ones you've got. The object here is to remove all contamination without damaging the underlying metal.

A small plastic block on the breaker points rides a rotating cam that opens and closes the points. If this block shows signs of wear, or is shortened by wear, replace the breaker points to avoid future problems.

The preferred cleaning method is to remove the contaminants from the points'

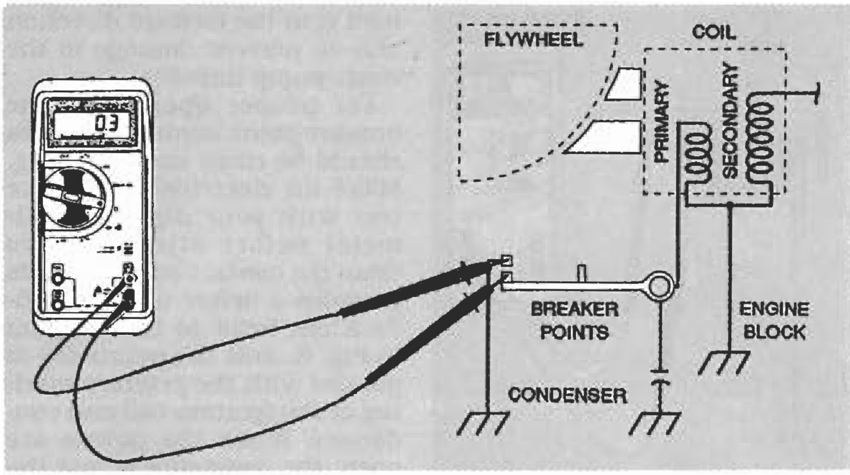

FIG. 8—TEST METHOD for determining breaker point contact resistance.

surfaces as well as metallic oxides that build up. A fine burnisher (a very fine, paper-thin file) is slid over the points' surfaces as the points are gently held closed.

Emergency cleaning methods must be used at times. Scrape the contact surfaces with a sharp carpet-layer's knife. You could file the surfaces with the abrasive surface of a matchbook striking surface—it functions like a fine file. Next, wipe the contacts with solvent on a clean cloth. Away from the dock use ordinary gin or vodka. Filing sometimes work, but there is a risk of damaging the underlying metal. This shortens the life of the contacts. Never use course sandpaper! The grit imbeds itself in the contact metal, rendering the points useless. If you have any doubt about the perfect condition of the points, replace them!

If you want a quick fix to get the engine running in an emergency situation, try the following: With the crank shaft positioned so that the points are closed, gently pry the breaker arm open. Next, insert a clean business card between the contact surfaces. Release the breaker arm so that the points grip the card through its width. This wipes the contacts in the process. The card has two beneficial properties. It is absorbent enough to remove oil and is just gently abrasive enough to remove surface contamination.

When you think the cleaning is complete, verify the results by repeating the electrical resistance test. Before leaving the points, make a visual inspection of the gap in the open position. A typical specification would be 0.020 inches.

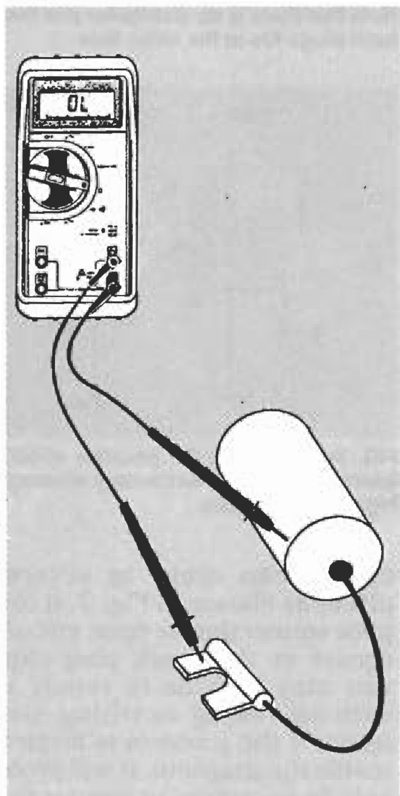

FIG. 9—CHECKING THE IGNITION condenser for leakage.

Condenser test

As before, check the condenser as follows: Disconnect the condenser lead, then place the multimeter in the capacitance function and hold one test lead to the capacitor case and the other to the terminal. (See Fig. 9).

Do not touch both leads with your fingers simultaneously because it causes reading errors. A typical range of good readings would be .015 µF to .030 µF. If the DMM indicates an overload in the capacitance function, the condenser is shorted. A very low capacitance reading probably means the condenser is open. Condensers are not repairable so a bad reading will likely mean a trip to the parts store.

If your multimeter does not have a capacitance function, use ohms instead. This test is best performed with the ignition condenser removed from the engine. Start by shorting the condenser by touching the lead to the case. Now, touch one probe to the lead and one to the case. Don't touch the probe tips or exposed condenser parts with your fingers. Watch the meter reading as the condenser is charging for indications that it is leaking or shorted. Now reverse the test leads and repeat the test. The results should be the same. If the results are negative (no bad indication), the condenser is good.

Flywheel magnet test

Flywheel magnet failures are rare but sometimes do occur. You can verify the strength of the magnet with a simple test. Locate the inside surface of the flywheel that travels near the pole pieces of the coil. You will find some magnetic material (typically laminated steel) in two places. It's separated by a gap of non-magnetic material (typically aluminum). Lay a hacksaw blade on the laminations near the gap. If the magnet is good, it provides a strong pull on the hacksaw blade. If not, refer to the engine's manual for replacement parts.

Reassembly and final check

Once you've checked out and repaired the ignition system, reassemble the engine and repeat the spark plug test. If the spark looks good, install the plug(s) and try again to start the engine. If troubles persist, inspect the fuel system. Carburetor

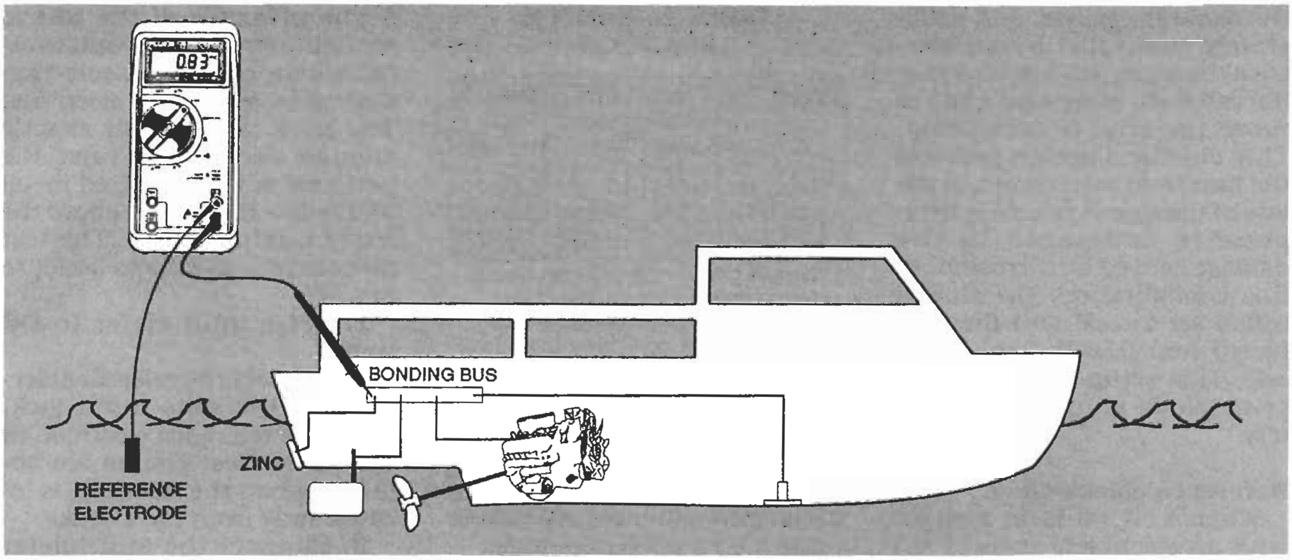

FIG. 10—TESTING THE CORROSION protection on your boat using a reference electrode.

cleaning may be required. Remember, most engine manufacturers recommend the addition of fuel stabilizer for long periods of storage.

Corrosion control

The corrosion protection system on your boat should be checked at regular intervals. Neglect leads to costly and time-consuming repairs. In order to perform the checks detailed here, your digital multimeter should be accurate, rugged and reliable; and, most important, it should have a 10-megohm input impedance in the DC-volts function. The high-input impedance allows you to test your boat in either fresh water or salt water, with repeatable results.

In general, the term corrosion refers to the unwanted loss of metal from the hull and/or underwater metal fittings of the vessel. There are two main types of corrosion—mechanical and electrical. Mechanical rust is common everywhere; a piece of metal rusts because it oxidizes. Under the electrical category, there are three common subcategories: galvanic corrosion, stray current corrosion, and crevice corrosion.

Galvanic corrosion occurs when two dissimilar metals are connected together electrically in the presence of a conductive electrolyte. The water about the hull, either fresh or saline, is the electrolyte. Atoms in the less noble metal give up their electrons to the more noble metal and the atoms with one or more electrons missing are released to flow (corrode) into the electrolyte in the form of positively charged ions.

Stray current corrosion occurs when a voltage source *pulls* electrons out of the metal. The voltage source might be the boat's lighting system, charging system or even elements of the communications system. In fact, some or all of the electrical system provides the stray current through ground loops commonly associated with audio systems. This corrosion allows the positively charged ions to flow into the electrolyte as previously described.

Crevice corrosion is actually a form of galvanic corrosion. However, it involves only one metal. A portion of the metal (in the crevice) becomes active (less noble) due to a loss of oxygen while the remainder stays passive. If an electrolyte is present, a galvanic couple is formed and the active metal is converted to ions and enters the electrolyte solution.

Materials used in the construction of marine vessels are chosen using various criteria. These include cost, mechanical strength, workability and corrosion resistance. When you want to compare metals according to their corrosion resistance, you refer to a ranking list called the Galvanic Series of Metals first learned in high school chemistry. This is often referred to as the "noble scale." This scale indicates the relative boundlessness each metal has for its electrons, i.e., it ranks the metals according to their electron bonding strength.

Metals at the active (less noble) end of the scale yield electrons and corrode more easily than metals on the passive (more noble) end of the scale (see Table 1).

Underwater metals can be protected if they are supplied with sufficient extra electrons. Active metals like zinc protect the more noble metal, iron. If the two metals are immersed in

TABLE 1—GALVANIC SERIES OF METALS

Active (least noble)	Magnesium
	Zinc
	Aluminum
	Cadmium
	Steel
	Iron
	Brass
	Tin
	Copper
	Bronze
	Lead
	Titanium
	Silver
	Platinum
Passive (most noble)	Gold

Alloys may vary according to composition the same electrolyte, and deliberately connected by an electrical bonding system, the zinc liberates its electrons and, in time, the zinc is dissipated. This chemical action protects the iron from corroding and the loss of the zinc is relatively inexpensive compared to the damage caused by corrosion. In this configuration, the zinc is called an *anode* and the protected iron is called the *cathode*. This setup is the familiar principle of an operating battery.

Reference electrode

When a metal is in contact with an electrolyte such as sea water, the metal establishes a natural potential or voltage with respect to the electrolyte. This natural potential (or "freely existing" potential) exists when no extra electrons are being supplied or removed by an outside voltage source. You can measure this potential with a digital multimeter and a reference electrode. The reference electrode allows you to make an electrical connection to the sea water with a known, repeatable value, i.e., a reference value.

Reference electrodes are often called half cells because they contain a metal and a metal compound. Popular types are copper-copper sulfate and silver-silver chloride. Marine system tests are often conducted with a silver- silver chloride electrode (see description in Reference 1).

TABLE 2—SAMPLE READINGS

Metal	Free Unprotected*	Protected*	Over Protected*
Steel	0.05V	0.75V	1.00V
Bronze	0.30V	0.55V	0.80V
Aluminum	0.65V	0.90V	1.05V

* Voltages given in this table are typical values obtained using a silver/silver-chloride reference electrode. Values may vary according to alloy and type of coating.

The principle of the test is straightforward: You want to establish the corrosion protection system by supplying electrons. The trick is to supply exactly enough electrons to raise the potential of the protected metal 250 millivolt (1/4 volt) above the freely existing value. The test procedure is as follows (Refer to Fig. 10):

1. Set a multimeter to DC volts.

2. Connect the reference electrode to the volts input jack. Place the reference electrode in the water. Best results are obtained when the electrode is located away from the anode.

3. Connect the multimeter common jack to a probe that will be used to contact each piece of underwater metal.

4. Touch the common probe to each underwater metal fitting and record the millivolt value as displayed on the meter. If all underwater metal fittings are connected together with a bonding system, as shown in Fig. 10, then all readings should be identical. Some typical values for several metals are listed in Table 2.

Over-protection causes paint to peel from a metal hull, or chemical damage to a wooden hull. References 1 and 2 explain the dangers of over protection and details about bonding systems. In all probability you might be able to borrow a reference electrode from your marina's electrical shop.

Boating is a pleasure sport that can have serious consequences should preventative maintenance be avoided and minor problems ignored. Your boat is the only thing between you and Davy Jones locker. Keep it in excellent condition with a power plant that delivers every time you crank the motor over. Ω

References for Additional Information

1. *Boat and Yacht Corrosion Control*; by Yacht Corrosion Consultants, 2970 Seaborg Avenue, Ventura, CA 93003.
2. *Boatowner's Illustrated Handbook of Wiring*; by Charlie Wing, International Marine, Camden, Maine.
3. *Your Boat's Electrical System*; by C. Miller and E.S. Maloney, Hearst Marine Books.