APLUXOR MARINE ELECTRICAL LIBRARY · PART I. YOUR BOAT AND YOUR METER

Chapter 3. Measuring: What the Number Tells You and What the Meter Can’t See

A number you can trust, taken where it means something, without harm to the meter or to you

A meter turns a guess into a number, but only if you know what the number measured, under which current, and what the meter cannot see. This chapter shows you how to get a number you can trust, and how to take it without harming the meter or yourself.

AFTER THIS CHAPTER YOU CAN

- explain why a connection that looks fine can heat like a soldering iron while its fuse notices nothing;
- set a multimeter for the three readings that matter on a boat, and tell whether your meter is good enough for them;
- tell a clamp meter that reads DC from one that reads only AC, and zero it before a DC reading;
- find a bad connection by its voltage drop under the circuit’s own working current, the starter circuit included, with a helper at the key;
- compare a reading with the right yardstick: a battery’s resting voltage, the drop of a whole run, the drop of one connection;
- read a load test and a battery monitor for what they say and what they don’t;

- trust a zero only from a meter you have just proven, and prove the AC side off at the AC panel — the one AC measurement this book leaves to you.

Read first: → 1.7, → 1.8

3.1 Ohm’s law on a boat: a bad terminal is a soldering iron
3.2 Multimeter: the three modes that matter
3.3 Clamp meter: two tools under one name
3.4 Voltage drop under real load — the key measurement of the book
3.5 Thresholds: what to compare the reading with
3.6 Battery load test and reading a shunt
3.7 Measuring safely
3.8 On board

3.1. Ohm’s law on a boat: a bad terminal is a soldering iron

Why does a connection that looks fine get hot enough to melt its insulation, and why does its fuse not notice? Two short rules answer both questions, and the rest of this chapter rests on them. If you want the basics of voltage, current and resistance from the start, they are in → App. F.

The first rule is Ohm’s law: a current that flows through a resistance loses voltage across it, and the voltage lost equals the current times the resistance, $V = I \times R$. The second rule says where that voltage goes. It does not vanish: it turns into heat at that very spot, at a rate equal to the voltage lost times the current, $P = V \times I$. Put the two together, and the heat at a joint grows with the square of the current: twice the current through the same joint makes four times the heat.

This is why a boat is harder on its connections than a house. A lamp of the same power draws ten times the current at 12 V that it draws at 120 V, so a poor joint in its circuit loses ten times the voltage and makes

a hundred times the heat. And the largest currents on a boat flow in the cables of its starter, its windlass, its thruster and its inverter, through every joint on their way.

> **WORKED EXAMPLE: ONE BAD LUG AGAINST A WHOLE CABLE**
>
> Suppose a battery cable lug has a resistance of 0.01 Ω and the starter draws 200 A through it. The lug drops 0.01 × 200 = 2 V and turns 2 × 200 = 400 W into heat — a soldering iron at one connection.
>
> Suppose the same starter sits 5 ft from the battery on 2/0 cable, so the current travels 10 ft there and back. By the book's one base for wire, ABYC's formula (Numbers, below), the cable's resistance is R = 10.75 × 10 ÷ 133,100 = 0.00081 Ω. At 200 A, all 10 ft of cable lose 0.16 V and make 32 W of heat, spread along their length.
>
> What decides the answer is where the heat lands. The one bad lug loses about twelve times the voltage of the whole cable and makes about twelve times its heat, in a spot smaller than a fingertip. The starter turns more slowly because it gets 2 V less, and the lug gets hotter with every crank.

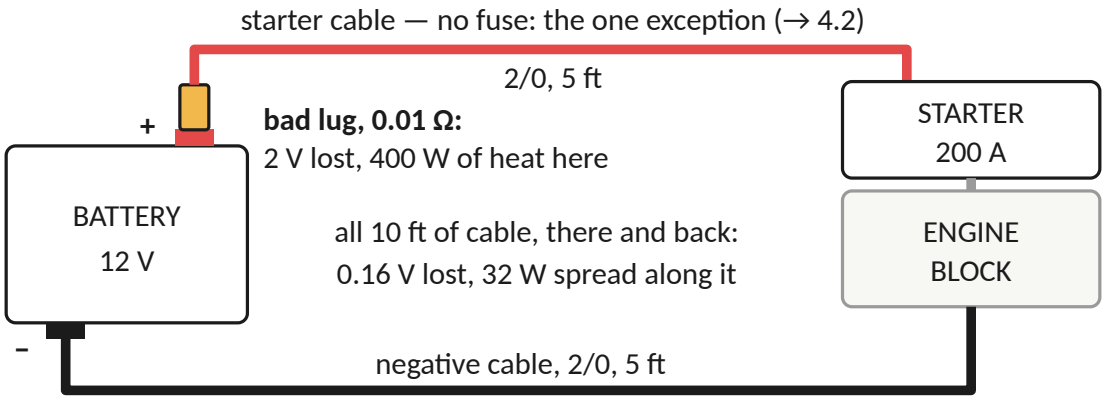


Fig. 3.1. One bad lug against a whole cable, with the teaching numbers of the worked example. The starter cable is the one cable from the battery that may run without a fuse (→ 4.2). The lug loses about twelve times the voltage of the whole cable, in one spot.

NUMBERS

ABYC sizes DC wire with the formula CM = 10.75 × I × L ÷ E. CM is the conductor's area in circular mils, I the current, L the length of the circuit from the source to the device and back in feet, and E the voltage drop allowed, in volts; 10.75 stands for the resistivity of copper. Since a voltage drop is current times resistance, the same formula gives the resistance of a length of wire: R = 10.75 × L ÷ CM, where for one conductor's own resistance L is that conductor's length. ABYC lists 10,380 circular mils for 10 AWG and 133,100 for 2/0. So 0.01 Ω is the resistance of about 9.7 ft of 10 AWG wire, or of about 124 ft of 2/0 cable.

ABYC

Why does the fuse stay silent? A fuse or a breaker responds to the current of its circuit, and a bad joint changes that current only a little. Through a lamp or a motor, the added resistance lowers the current; through an inverter or a DC-DC converter, which draw a set power, the current rises a little, because the device draws more amps to make up for the volts the joint took. Either way the fuse sees an ordinary current while the joint glows. A fuse cannot find a bad connection. A meter finds it, while the current flows (→ 3.4 · p. 11).

The heat lives only while the current flows. With the load off, the bad joint cools, reads well on a multimeter's ohms range and looks fine: that is why a joint is judged under the current that does its work, and not by its look. A joint can also be hot for other reasons. A wire too thin for its current warms along its whole length; a load that draws more than its rating heats every joint in its path (→ 4.3); a joint next to a hot engine takes the engine's heat. A bad joint is the one spot hotter than the wire on both sides of it.

WHY IT WORKS

Heat builds up when it arrives faster than the joint can shed it, so time matters as much as current. The starter's 400 W at a bad lug last only as long as each crank. A joint on an inverter cable carries less current, but for hours.

Suppose the same 0.01 Ω joint carries 100 A to an inverter. It loses 1 V and makes 100 W for as long as the inverter runs. A long run at a moderate current can bring a joint to a higher temperature than a short burst at a large current does. That is why the measurements of this chapter are taken under each circuit's own working current.

3.2. Multimeter: the three modes that matter

Which settings of a multimeter do you need on a boat, and what makes a meter good enough for them? A multimeter is a handheld meter that measures voltage, current and resistance, with a dial to choose the mode. This book uses three of its modes, and current once, by the procedure of → 7.3; it keeps you away from the others, for reasons the meters' own manuals give.

Table 3.1. The multimeter's modes on a boat

Mode, as printed on the dial	What it reads	Where you use it
V ⎓ — DC volts	The DC voltage between the two probes	A battery's voltage, the voltage at a device, the drop of a whole run (→ 3.4 · p. 11, → 3.5 · p. 22)
mV ⎓ — DC millivolts	DC voltages down to 0.1 mV, on the meters that have this range	The drop across one connection, one switch or one fuse holder (→ 3.4 · p. 11)
V ~ — AC volts	AC voltage	The zero check at the AC panel, and nothing else (→ 3.7 · p. 33)

Mode, as printed on the dial	What it reads	Where you use it
Ω and the continuity beep	Resistance, with the circuit's power off	A part out of its circuit and dead: a fuse taken out of its holder as → 1.8 says, or a lamp in your hand. On a live circuit the reading means nothing. It does not judge a connection (→ 3.4 · p. 11)
A, mA — current	The current through the meter, which becomes part of the circuit	Used once in this book: the draw with everything off, with the meter in series (→ 7.3). Other currents are read with a clamp meter (→ 3.3 · p. 9)

The millivolt range is the one that sees a bad joint, so check how your meter reaches it. On some of one maker's meters the dial has its own mV position for DC; on another meter of the same maker, the mV position reads AC and DC together until a button selects DC; on a second maker's meter, the DC volts position switches itself down to a 600.0 mV range. Whatever the meter, its display shows the ⎓ symbol when it reads DC: look for it before you trust a millivolt reading. MFR

The leads decide as much as the dial. Of the jacks at the bottom of the meter, one is marked COM, and the voltage jack is marked V — on some meters V Ω, on others V Ω mA, where the voltage jack also carries milliamps. The jacks marked A, 10A or mA lead into the meter's current path, which is nearly a short circuit; → 3.7 · p. 33 shows what a lead left there does (→ Fig. 3.2 · p. 8).

The current jacks are protected by fuses inside the meter, and the manual names each fuse exactly. One meter's manual asks for an 11 A, 1000 V fast fuse with an interrupting rating of at least 17,000 A. That fuse is a safety part: it must open inside the meter before a fault reaches your hand, so it is replaced only with the fuse the manual names. MFR

On the AC side the meter's category matters. CAT II, CAT III and CAT IV name the measurement category of a meter and its leads: where in an installation they may measure, according to how much energy a voltage spike can carry there — the higher the category, the more energy. The

rating is printed near the input jacks, and the leads carry their own. A higher voltage rating in a lower category does not make up for the category. One meter maker's guide lists the test for each: a CAT III 600 V meter and a CAT II 1000 V meter both meet a 6,000 V spike, but the CAT III test source has a resistance of 2 Ω against 12 Ω for CAT II: 6,000 ÷ 2 = 3,000 A against 6,000 ÷ 12 = 500 A, six times the current the CAT III meter must survive. That maker sets CAT III 600 V as the minimum for measurements in distribution panels, and the boat's AC panel, where the zero check of → 3.7 · p. 33 is made, is such a panel. PRACTICE

A modern meter barely loads what it measures. Its input impedance — the resistance it puts across its probes when it measures voltage — is printed in its manual: 10 MΩ or more on DC volts on two makers' meters, more than 5 MΩ on AC volts on one of them, 1 MΩ on a low-cost meter. That is good for accuracy and bad in one case. A dead AC wire run beside a live one picks up a voltage from it through the capacitance between them, and a meter of such a high impedance shows that voltage although the wire can drive only a tiny current. This is a ghost voltage. MFR

A LoZ (low impedance) setting puts a low input impedance across the probes, so that a ghost from AC wiring side by side collapses and a real voltage remains. Its value is printed in the meter's manual: about 3 kΩ on one meter, 400 kΩ on another. The lower the value, the further a ghost collapses: a 3 kΩ input pulls it much nearer zero than a 400 kΩ input does. You meet it at the AC zero check (→ 3.7 · p. 33). MFR

On the DC side, a voltage on a wire you switched off has another cause. An indicator light or an LED built into a switch, or across a fuse, lets a trickle of current through, and a high-impedance meter reads most of the battery voltage through it; a LoZ setting can still read several volts there. A real feed from a second source reads the same way: a circuit that stays live when its switch is OFF is found on the boat's energy map (→ 1.7). Until you know where the voltage comes from, a wire you believe dead is treated as live. PRACTICE

Two functions matter when a reading lasts only a moment. MIN/MAX records the lowest and highest reading of an event; HOLD freezes the

display when pressed. A held display does not change when the voltage changes, so a HOLD left on can show an old number — or an old zero — over a live circuit. For any reading you will act on, HOLD is off. A MFR drop during a crank rises and falls within seconds, and the figure it is compared with is its highest value, the one MIN/MAX records as MAX (→ 3.4 · p. 11). A meter without MIN/MAX does not take the starter circuit's map in this book.

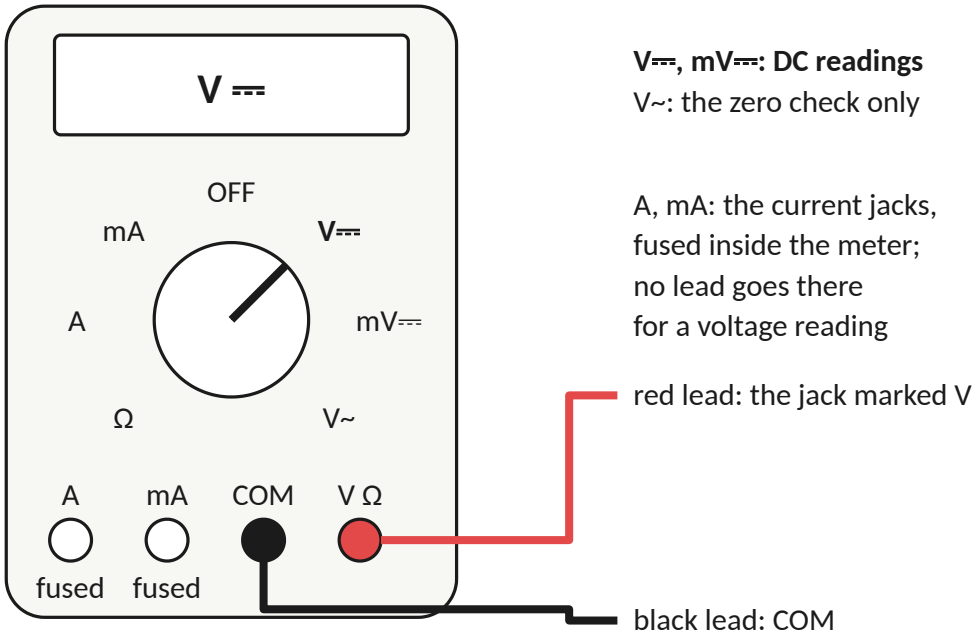


Fig. 3.2. A multimeter's display, dial and jacks, with the leads where a voltage reading has them; the current jacks, fused inside the meter, are empty (→ 3.7 · p. 33).

Four properties decide whether a meter is good enough for everything this book has you measure:

- meter and leads rated CAT III 600 V or a higher category, printed near the jacks and on the leads;
- a DC millivolt range that shows 0.1 mV;
- current jacks protected by the fuses its manual names;
- MIN/MAX, to record the highest drop of a crank.

A LoZ setting is a useful fifth for the AC zero check, not a requirement. A meter without the first property still reads a battery; it does not do the zero check.

3.3. Clamp meter: two tools under one name

How do you read the current in a cable without cutting into it, and why does a clamp meter sometimes read zero on a cable that is plainly working? A clamp meter reads the current in one conductor through jaws closed around it, without breaking the circuit. Under that one name two different tools are sold, and one of them reads zero on every DC cable on your boat.

Current makes a magnetic field around its conductor, and the jaws measure that field. An AC clamp meter senses it with a current transformer, which works only on a field that keeps changing: it responds to AC waveforms only, so on a DC cable it reads zero whatever the current. A DC clamp (Hall effect) is a clamp meter with a Hall-effect sensor in its jaws; it reads DC as well as AC current and is zeroed before a DC reading. The dial tells which tool you hold. A DC current position is marked DC A, or A with the ⎓ symbol; a clamp meter whose current positions show only A~ reads nothing on the DC side of your boat. PRACTICE

A Hall sensor also feels the earth's magnetic field and any other field near the place you measure, so its reading wanders before any conductor is in the jaws. Its makers therefore ask for a zero before each DC reading, made with the meter's own button — REL, ZERO, or the name its manual gives. Zeroing at the place you will measure, with the jaws closed and empty, is accepted practice. MFR PRACTICE

Opposite currents cancel. Around one conductor the clamp meter reads that conductor's current; around a cable that holds both the positive and the negative wire of one load, it reads about zero, because the same current goes out in one wire and comes back in the other. On a boat that means one wire at a time — never a cable with both conductors inside one jacket (→ Fig. 3.3 · p. 10). MFR

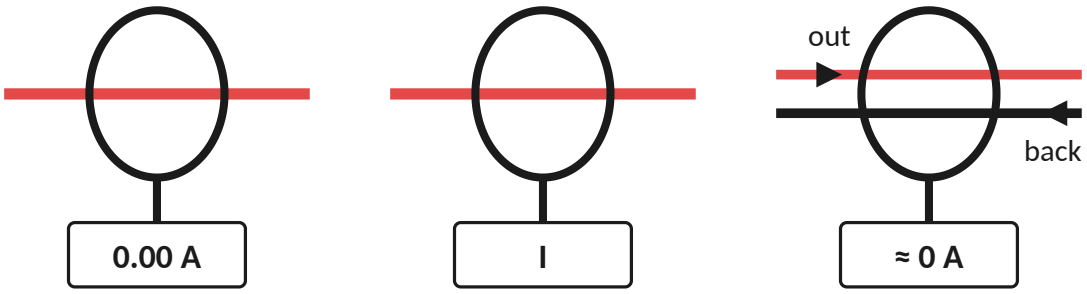


Fig. 3.3. Two tools under one name. An AC-only clamp meter reads nothing on a DC cable; a DC clamp meter reads the current of one wire, and about zero around both wires of one load.

A clamp meter built for tens or hundreds of amps reads a small current poorly. One DC clamp meter's 60 A range is accurate to ±(2.0 % + 8 digits), and its last digit is 0.01 A, so the eight digits add 0.08 A to every reading. At 1.00 A the reading can be off by 0.02 + 0.08 = 0.10 A, which is 10 %; at 0.20 A, by 0.004 + 0.08 = 0.084 A, which is 42 %. The accuracy table in your clamp meter's data sheet tells you the same for your meter. A current of a fraction of an amp, such as a draw that runs while everything seems off and flattens a battery over several days, is therefore not measured with a general-purpose clamp meter (→ 7.3). MFR

An AC clamp meter's work lies on the AC side of the boat. The one AC measurement this book leaves to you is the zero check of → 3.7 · p. 33, made with a multimeter.

Procedure: A DC current with a DC clamp meter

For a device that runs steadily once you switch it on — a light, a fan, a refrigerator — with the jaws around one of its wires. The starter's, the alternator's, a windlass's or a thruster's current flows only while the engine cranks or runs or the machine moves; this book reads those circuits by their drop (→ 3.4 · p. 11).

GASOLINE VAPOR

1. Look at the dial for a current position marked DC A, or A with the ⎓ symbol. With no DC marking, this meter cannot read DC current: stop here.
2. Set that position and the range for the current you expect. With the jaws closed and empty, at the place you will measure, press the zero button its manual names. The display shows zero, or a digit from it.
3. Switch the device on at its own switch or at the panel, and let it run at its normal work. Smoke or a burning smell: go to the card "Smoke, a burning smell, or an overheated wire" (→ emergency card).
4. Open the jaws around one DC conductor only — one wire, or one of the two cables of a pair, where you reach it dry and without opening a panel — and let them close fully. The display shows the current in that conductor.
5. Open the jaws and take the meter away. A minus sign on the display only means the jaws face the other way: compare the number without its sign. Compare the reading with the device's rating, and with its wire and protection (→ 4.3).

PUT THE BOAT BACK IN SERVICE

- The device you switched on in step 3 back as you found it.

3.4. Voltage drop under real load — the key measurement of the book

How do you find the connection that heats before it fails? You measure what it costs the circuit: the voltage it loses while the circuit's own working current flows through it. That cost is the voltage drop — the voltage a cable, connection or switch loses while current flows through it, measured across that part under its working current. This is the key measurement of the book. This section shows how to take it on any

running circuit, on the starter circuit with a helper at the key, and with a windlass or a thruster as the load.

A bad connection is found by its voltage drop under the circuit's real working current: either two readings taken under the same load — one at the source, one at the device — whose difference is the drop of the run between them, or one reading with the probes on the two ends of one section. A voltage read at one point does not show a drop, and the ohms range of a multimeter does not see the hundredths of an ohm that make a joint heat.

WHY IT WORKS

Why not the ohms range? One meter's lowest resistance range reads in steps of 0.1 Ω with an accuracy of ±(1.2 % + 5 digits), which near zero is ±0.5 Ω. MFR

One meter maker's guide puts the test leads themselves at 0.2 to 0.5 Ω, which that maker's meters can subtract. The 0.01 Ω lug of → 3.1 · p. 2 is fifty times smaller than that uncertainty: the meter cannot tell it from a perfect joint. PRACTICE

The continuity beep is coarser still. One meter beeps below 50 Ω, so a lug held by one surviving strand beeps like a good one. MFR

The ohms range also tests with a tiny current. A crack that opens when the joint warms, or a few strands that carry a trickle but not a starting current, read the same as a good joint at that current; under a starting current they do not. A low-resistance ohmmeter, an instrument that drives a known current through the joint, does see such resistances. The voltage drop needs no special instrument: the circuit supplies the current, and the meter's millivolt range reads the result.

A drop is the current times the resistance, so the same joint reads ten times more at ten times the current. A number of millivolts means something only together with the current it was taken at. Two habits keep the number meaningful: compare sections of the same circuit under the same current, and, when you need one joint's own figure, divide the drop by the current measured at the same time — a DC clamp meter's reading (→ 3.3 · p. 9), not a label's rating — to get its

resistance, and multiply the drop by the current to get its heat; a figure worked out this way can show that a joint is bad, never that it is good.

> **WORKED EXAMPLE: A FEW MILLIVOLTS AT A SMALL CURRENT**
>
> Suppose the lug on a battery terminal reads 2 mV while a cabin light that draws 4 A is the only load on it. Its resistance is 0.002 ÷ 4 = 0.0005 Ω, and at 4 A it makes 0.002 × 4 = 0.008 W — nothing. Suppose the same lug also carries the starter's 200 A. Then it drops 0.0005 × 200 = 0.1 V and makes 0.1 × 200 = 20 W at every crank. The 2 mV were not a pass mark; they were a resistance waiting for a larger current.

Two methods take the drop, and → Fig. 3.4 · p. 14 shows both on one circuit.

Two readings under the same load. With the device running, one reading is taken across the battery terminals (C and K) and one across the device's terminals (L and M). The difference is the drop of the whole run between them — the positive wire, the negative wire, and every fuse, switch and joint on the way. The two readings must see the same current and the same battery voltage. A charger or a solar panel that changes the battery's voltage between the two readings makes their difference meaningless; with either of them charging, the second method is the one to use. A second battery reading, taken after the device reading, shows whether the battery's voltage held.

One reading across one section. The probes go on the two ends of one section — the two terminals of a switch, a wire and the stud it lands on, the two ends of one cable — and the meter reads that section's drop directly, at the same instant as its current. A charger does not disturb it. The drop of each section of one circuit, measured under the same working current and written side by side, is a drop map: the section whose drop stands out is where the heat is.

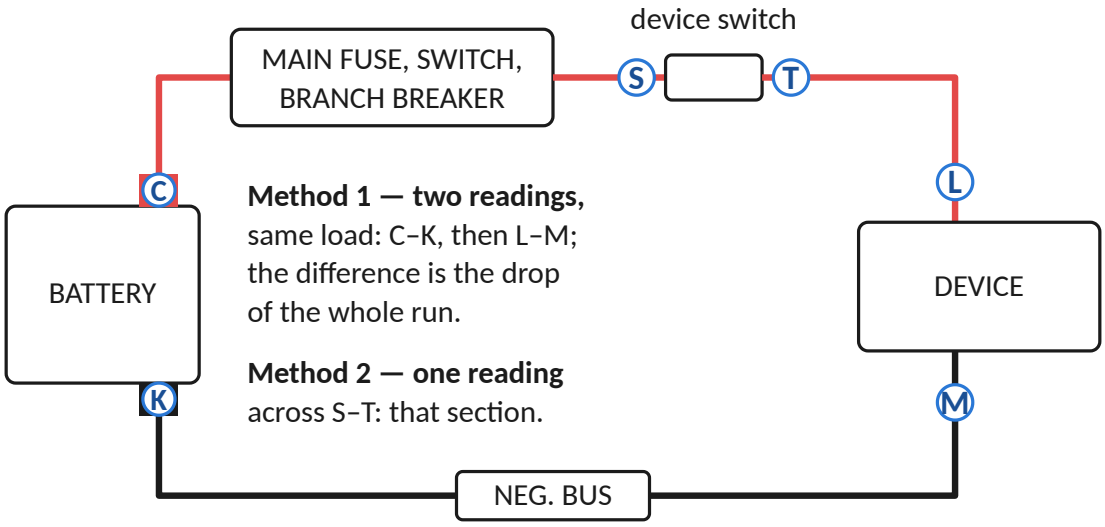


Fig. 3.4. One branch circuit and two ways to read its drop. Points C and K are the battery's terminals, L and M the device's terminals, S and T the two sides of the device's switch.

Procedure: The drop of a running circuit

For a device you switch on at its own switch or at the panel — a light, a fan, a refrigerator, a radio — with the engine stopped: a running engine charges the battery and turns its belts beside the points you probe. Points C, K, L, M, S and T are those of → Fig. 3.4 · p. 14.

GASOLINE VAPOR SHORT CIRCUIT METER LEADS

1. Find on your boat, for the device you chose, its two terminals (L and M) and the sections along its wires you reach dry and without opening a panel: each switch, each fuse holder, each wire end and the terminal it lands on.
2. Switch the device on, and let it run at its normal work: the light lit, the fan turning, the compressor running. Read the voltage across its terminals, L and M: close to the battery's voltage. That reading also proves the meter for the small readings that follow (→ 3.7 · p. 33). Smoke or a burning smell while it runs: go to the card "Smoke, a burning smell, or an overheated wire" (→ emergency card). A device that does not run carries no current and shows no drop: a tripped breaker or a blown fuse → 4.8.

3. The whole run, unless a charger or a solar panel is charging the battery, or you cannot tell which battery feeds the device with the battery switch where it is now. With the device still running, read the voltage across the battery's terminals, C and K; then across the device's terminals, L and M; then across C and K once more. A minus sign on the display only means the leads are the wrong way round: compare the number without its sign. The two battery readings agree to the last digit and the device reading sits below them; otherwise the battery's voltage moved between the readings, and you read all three again. The battery reading minus the device reading is the drop of the whole run: compare it with the 3 % and 10 % rows of → Table 3.2 · p. 28. On a boat with a panel, that run is the panel's feeder and the branch together, each sized for its own 3 % or 10 % (→ 5.4): a drop within the branch's own figure passes the branch, and a larger one is placed by the sections of steps 4 and 5.
4. One section. Put the probes on the two ends of one section — S and T across the device's switch, or a wire end and the terminal it lands on — and read the drop, without its sign. Compare it with → Table 3.2 · p. 28; a switch reads more than a connection.
5. Move section by section along the same circuit, with the same device running, and write each reading beside its section. That is the drop map: the section that stands out is where the heat is. A connection above its yardstick: where it sits decides who repairs it, as step 4 of the route "A connection, a holder or a wire runs hot" says (→ 4.8). A switch above its yardstick, with the connections on its terminals under theirs, is replaced, not remade: where it sits decides who replaces it (→ 1.8), and a battery switch is a pro's. A whole run above its figure with no section above its yardstick: the run is judged and sized by → 5.4, as step 4 of the procedure "The drop across one connection" says (→ 5.8).

A reading above its yardstick fails at any current. One below it passes only when it was taken at the circuit's full working current; at a smaller current, read it again with every load on the circuit at full work. A joint that at other times carries a larger current — a lug on a feeder this

circuit shares with an inverter or a windlass — is judged only at that larger current: with the windlass as the load, by the procedure below, or with the inverter running its largest usual AC load.

PUT THE BOAT BACK IN SERVICE

- The device back as you found it, and any cover you lifted back in place.

The starter circuit

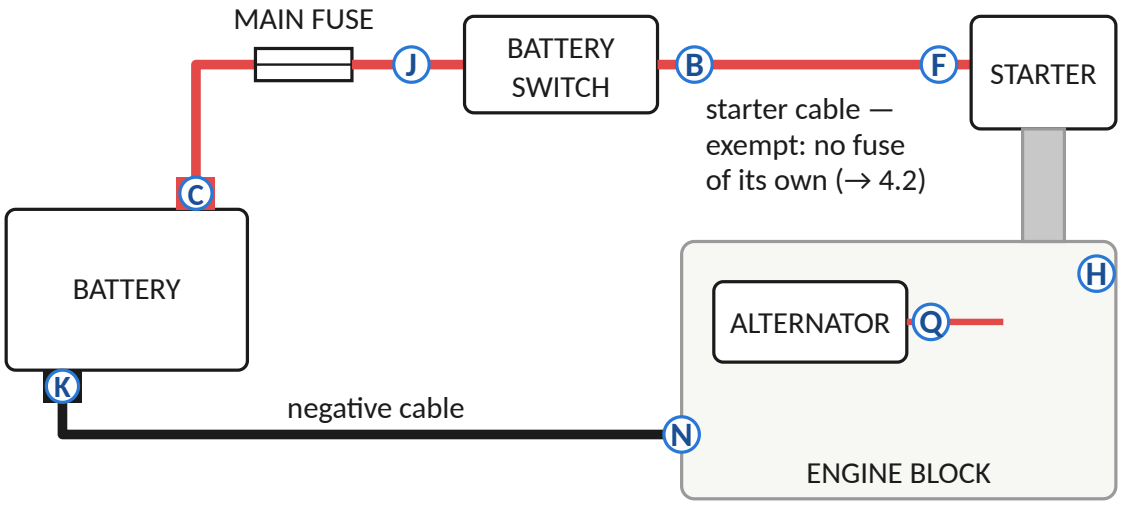
When an engine cranks slowly or only clicks, the cause is a battery that cannot deliver the starting current, a connection that loses volts under it, the starter itself — or the engine, which resists turning: one diesel maker's fault table for an engine that will not crank lists seized parts and water in a cylinder. On an inboard with a water-lift muffler, MFR every crank without a start pumps cooling water into the muffler, and the water can reach the cylinders. The starter circuit's drop map tells a connection from the other causes. → Fig. 3.5 · p. 17 shows the starter circuit of the boat drawn in Fig. 1.4 (→ 1.7): the battery's positive terminal (C), the main fuse, the battery switch with its battery-side terminal (J) and its panel-side terminal (B), the starter cable to the starter's battery stud (F), the starter bolted to the engine block, bare metal of the block next to the starter (H), the negative lug on the block (N), and the negative cable back to the battery's negative terminal (K). Your boat can be wired differently: a starter cable straight from the battery, a negative cable that lands on a negative bus before the engine — one more section — or an outboard whose starter sits under its cover.

A measurement crank takes two people: a helper at the key, and you at the meter, watching the meter and the engine. The engine sets its own limits: its manual gives the longest crank and the rest between cranks — 5 seconds on one outboard, 10 seconds followed by 30 seconds' rest on one diesel. Out of the water, an engine that starts during a MFR measurement crank runs without cooling water.

The meter needs three things for this map: MIN/MAX, because a crank's drop rises and falls within seconds and this book compares its highest value, the MAX, with the figures of → Table 3.2 · p. 28 — their source's own way to catch the peak; test leads with insulated clips, so that they stay on while your hands are clear; and leads long enough to reach from C to F and from H to K. The map is read on the DC volts position, not on millivolts. One maker's manual says its meter stays in the range it showed when MIN/MAX was switched on, and lists its millivolt position as a single 600.0 mV range; another of that maker's manuals says MIN/MAX ignores overloads. On such a meter, a section that drops more than 0.6 V during the crank — the kind the map is there to find — would leave a MAX that is too low.

PRACTICE

MFR



positive side: red lead on C, black lead on F
negative side: red lead on H, black lead on K
sections, red lead on the first letter: C–J, J–B, B–F; H–N, N–K

Fig. 3.5. The starter circuit and its measurement points, on the boat drawn in Fig. 1.4 (→ 1.7); your boat can be wired differently. C and K are the battery's terminals, J and B the two terminals of the battery switch, F the starter's battery stud, H bare metal of the engine block next to the starter, N the negative lug on the block, Q the alternator's output terminal. The starter cable is exempt from a fuse of its own (→ 4.2).

Procedure: The starter circuit's drop map

You need a helper who stays at the key, a meter on DC volts with MIN/MAX, and leads with insulated clips that reach from C to F and

from H to K.



1. Find on your boat the points of → Fig. 3.5 · p. 17: C and K, the terminals of the battery that the battery switch, in its present position, connects to the starter; the starter's battery stud (F) — the stud where the heavy starter cable lands; and bare metal of the engine block next to the starter (H). On an outboard these points are under the engine's cover: take it off as the engine's manual shows. With the switch at BOTH, 1+2, ALL or COMBINE, a parallel switch ON, or a charging link closed between two banks, two batteries share the starting current and the readings at C and K speak for one of them only: take the map with the switch at the start battery's own position, which your Boat Passport records (field 6; → 1.7), and any parallel switch OFF. A point you cannot reach, cannot tell for sure, or reach only by opening a panel or through bilge water stays unmeasured, and so does a pair your leads do not reach.
2. Prove the meter: the red lead on the battery's positive terminal (C), the black lead on its negative terminal (K). It reads the battery's voltage.
3. Clip the red lead to C and the black lead to the starter's battery stud (F), each clip on its own terminal alone. With both clips on, switch MIN/MAX on and check that the display shows ⎓. With the engine at rest the meter reads about 0 V, because both points carry battery voltage, and so does the record's MAX; a MAX well above that is an older record: end MIN/MAX and start it afresh, the way the meter's manual shows. Every reading of this map gets a record of its own, started this way after its clips are on.
   Battery voltage instead, with the black clip on the battery stud and not on the starter's other terminal — the one that carries voltage only while the starter turns: the path between C and F is open now, and the map stops here. A battery switch at OFF: the route of → 3.8 · p. 39 starts at its step 1. A switch at its working position: the main fuse or a connection between C and F is open (→ 4.8; with the

panel dark too, the card "The panel went dark — no lights, no electronics" → emergency card). A steady reading that is neither about 0 V nor battery voltage: check that C and K are the terminals of the battery that feeds the starter; still neither, the points are not the ones of Fig. 3.5, and a pro finds why.

4. Before the first crank, keep the engine from running where it must not. On an inboard with a water-lift muffler, close the raw-water seacock: each crank without a start pumps water into the muffler. While the seacock is closed, keep the engine from starting the way its manual shows — the procedure "A crank without starting" in → 9.5 — until the seacock is open again. Out of the water, supply cooling water as the engine's manual says, or keep the engine from starting the way it shows. A seacock you cannot close, or a manual that shows no way to do what this step needs: no measurement crank — the map is a pro's.
5. Have the helper crank once while you watch the meter and the engine, and let go at your word as soon as the reading has settled. Note the MAX reading: the drop of the positive side during the crank. If the engine starts, the helper stops it at once, as its manual says; the reading is already held.
6. Move the clips to the negative side: the red lead to bare metal of the engine block next to the starter (H), the black lead to the battery's negative terminal (K), each clip on its own point alone. Start a new MIN/MAX record, as in step 3, with its MAX at about 0 V. Have the helper crank once more, and note the MAX: the drop of the negative side.
7. Compare each side with → Table 3.2 · p. 28: about 0.3 V on the positive side, 0.2 V or less on the negative side, and not more than 0.5 V for the two together. A side above its figure is the side to map, one section at a time, with the red lead on the section's first letter: C to J (the main fuse and its connections), J to B (the battery switch), B to F (the starter cable and its two lugs); H to N (the block to its lug), N to K (the negative cable and its lugs). Clip the leads across one section, each clip on its own terminal alone, start a new MIN/MAX record with its MAX at about 0 V, have the helper crank

once, and note the MAX; then move the clips to the next section of that side, one crank per section. A MAX of about 0 V with a MIN below zero means the leads of that section are the wrong way round: swap them, start a new record, and give that section one more crank.

8. With the cranks done, take the clips off, and write the map with the date into the Boat Passport (field 16). Within a side, the section that stands out is where the heat is; who repairs it is in → 3.8 · p. 39.

PUT THE BOAT BACK IN SERVICE

- A raw-water seacock you closed for the cranks: open again before the engine runs. Anything you did to keep the engine from starting, and any cooling-water supply, undone or removed the way the engine's manual shows.
- An outboard's cover back on, as its manual shows.
- If you ran the bilge blower before the cranks, its switch back where you found it.
- If step 1 moved the battery switch or turned a parallel switch OFF: each back to the position you found it in, with the engine stopped; then check that the bilge pump's automatic switch has power (→ the check in 3.8).

The charging circuit

The alternator's current crosses connections too: from its output terminal to the battery's positive terminal, and from its case to the battery's negative terminal. That drop is read at full charging current with the engine running, for as long as the reading takes, with hands and leads beside a turning belt and pulley; this book leaves it to a pro, and → 3.8 · p. 39 says what to ask for. Neither ABYC's sizing rule nor one alternator maker's manual gives a pass mark for a measured charging run; that maker's manual sizes the charging cable for a 3 % drop, a MFR figure for choosing the cable, not for judging a reading.

Procedure: A windlass or a thruster as the load

A windlass or a thruster draws a large current through a long cable to the bow or the stern. When one turns slowly, the question is the one of the starter: a low battery, a feed that loses volts under its current, a worn motor — or, for a windlass, a fouled anchor. The machine itself is the load for the reading, run by a helper at its control while you read the meter. While its breaker or isolator is ON, every station that controls it — a second switch at another helm, a foot switch, a remote — can start it, and both windlass manuals in this chapter's list of documents ask for the windlass to be switched off at its breaker or isolator whenever it is not in use. Neither manual gives a run time, and each reading takes only seconds. MFR



1. Choose the points of the machine's feed you reach dry and without opening a panel: the two terminals of its breaker or isolator, each lug of its feed and the stud it lands on, and the feed's end — the stud where the feed lands at the machine's contactor, and the terminal where the machine's negative cable lands. That last pair shows the voltage the feed delivers. A reversible windlass motor can have three power terminals — one maker marks them F1, F2 and "–" — and its contactor feeds a different one for each direction: a motor's own terminals are read only by the pair its wiring diagram names for a raise.
2. With the machine's breaker or isolator OFF, clip the leads across the feed's end: the red lead on the contactor's feed stud, the black lead on the negative cable's terminal.
3. Breaker or isolator ON. At your word the helper runs the windlass, raising the anchor, or the thruster, and you read the display once the start is over and the machine runs steadily: the start's inrush current reads higher than the run. At your word the helper stops it. The reading is close to the battery's voltage, and it also proves the meter for the small readings of the sections (→ 3.7 · p. 33).
4. Breaker or isolator OFF before the clips move. Clip the leads across one section, breaker or isolator ON, one run, one reading, breaker

or isolator OFF; then the next section. A minus sign on the display only means the leads are the wrong way round: compare the number without its sign.

5. Write each reading beside its section. The readings of one map are compared only when their runs were alike: for a windlass, each a raise with about the same length of rode out, so that it lifts about the same load. The section that stands out is where the heat is; the reading of step 3 shows the voltage the feed delivers.

> **PUT THE BOAT BACK IN SERVICE**
>
> - The windlass or the thruster off at its breaker or isolator; the anchor secured, with the chain stopper on where the windlass has one.

3.5. Thresholds: what to compare the reading with

What do you compare a reading with? A number means something only next to the right yardstick, and each yardstick comes with a condition that decides whether your number can be compared with it. Three cover what this book has you measure: a battery's resting voltage, the drop of a whole run, and the drop of one connection or one switch.

A battery's resting voltage

A battery's voltage depends on what it is doing: under charge it reads high, under load low. Only its resting voltage — a battery's voltage after it has rested with no charge and no load for the time its maker names — says how full it is, and only through that maker's table. One maker asks for at least 6 hours of rest and prefers 24; another reads its batteries at least four hours after a charge ends, or 30 minutes after a discharge ends. A reading taken sooner, or with a charger, a solar panel or a running engine still connected, is not a resting voltage, and no table applies to it. MFR

Table 3.3. Resting voltage of 12 V lead-acid batteries at full and at half charge, from their

makers' tables

Battery	100 %	50 %	The maker's condition
Flooded, one maker	12.73 V	12.10 V	Rested at least 6 h; the maker's first choice is 24 h MFR
AGM, the same maker	12.84 V	12.24 V	No rest time or temperature printed with the table; that maker's user's guide for all its lead-acid types asks for at least 6 h of rest and names 24 h as its first choice MFR
Lead-acid, a second maker; its table names no type	12.65 V	12.24 V	Battery at 80 °F MFR
Thin plate pure lead (TPPL) AGM, a third maker	12.9 V	12.2 V	4 h after a charge ends, 30 min after a discharge ends MFR

The same 12.24 V is half full on two of these batteries and above half on the first. Use your own battery's table, from its maker, for its type; with no table, do not turn volts into percent. → 3.6 · p. 28 shows what a battery monitor adds.

A reading below the 100 % row means the battery needs a charge, and the makers want it soon: one writes that batteries should not be left deeply discharged for any length of time, and another that a discharged battery will freeze even when moderately cold. The charger has to MFR suit the battery. One maker's gel and AGM batteries need a voltage-limited charger; another maker writes that its batteries, once deeply discharged, are not recharged by a maintenance charger, and that some chargers cannot charge a severely over-discharged battery at all. MFR Far below its table, the battery's maker decides what comes next: one maker counts its battery as deeply discharged below 11.6 V and leaves its recovery to a trained technician. MFR

A lithium (LiFePO4) battery's voltage says little about its charge. Its curve stays nearly flat through most of the discharge: one maker writes that a battery at 80 % state of charge (SOC) — how full a battery is, in percent of its capacity — may show nearly the same voltage as one at

30 %, and names a battery monitor as the accurate way to follow it. For a lithium battery, the resting voltage is not a fuel gauge, and a normal-looking voltage does not show that the battery is connected to its loads: one maker writes that its battery reading above 12 V may be in its battery management system's protection mode (procedure below, step 4). PRACTICE

Procedure: A battery's resting voltage

The rest needs hours in which nothing charges the battery and nothing you can switch off draws from it: at a dock, on a trailer, or at anchor by day. Under way, the engine charges the battery and the boat needs its lights and electronics.



1. Nothing charges the battery during the rest: the charger off, at its own switch or at its breaker on the AC panel — an inverter/charger at its own switch; the engine stopped; a wind generator stopped as its manual says; the solar panels off at their disconnect switch, if your boat has one — otherwise the rest runs through the night and you read before the panels see daylight.
2. Nothing draws from it either, beyond what must stay on: every load you can switch off at the panel or at its own switch off, the refrigerator included, and an inverter on this battery off at its own switch (→ 2.2). A CO alarm, a bilge pump's automatic switch and a high-water alarm stay as they are: the makers' tables are for a battery with no load at all, and this book accepts their small draw. Then wait the rest time your battery's maker names (→ Table 3.3 · p. 22). PRACTICE
3. Put the red probe on the battery's positive terminal and the black probe on its negative terminal, read, and check that the display shows ⎓. Compare the number with your battery maker's table:
   - at or above its 100 % row: the battery is full;
   - below its 100 % row: charge it now, fully, with a charger that suits its type, as its maker's manual says — for a deeply

discharged battery too; then let it rest and read it again;

- a charger that will not start on it: a pro, with the battery maker's manual;
- a battery that does not come up to its 100 % row after a full charge and its rest is not holding its charge: a lead-acid battery goes to the procedure "A load test of one lead-acid battery" (→ 3.6 · p. 28), any other to a pro.

With the battery switch at BOTH, 1+2, ALL or COMBINE, a parallel switch ON, a charging relay's own combine control ON, or a charging link closed between two banks, the probes read the banks together: the number speaks for both, not for either one. A bank joined by its own jumpers reads as one. A lithium battery: the number is not a percentage, and a normal-looking number does not show that the battery is connected to its loads — with everything on its bank dark, go on with step 4.

4. If the meter showed 0 V or near it — or the battery is lithium and everything on its bank is dark, whatever it reads: prove the meter on another battery you know is charged — another one aboard that this battery does not feed, a car's, or a flashlight cell — and read this battery again (→ 3.7 · p. 33). With the meter proven and the battery still near 0 V, whatever this battery feeds may be without power — a bilge pump or a high-water alarm on it too, unless you know they are not: watch the water until it has power again. A charger, solar power or another bank can still feed some of it, so nothing on it is treated as dead. A lead-acid battery still near 0 V goes on charge as step 3 says. A lithium battery may have been switched off by its own battery management system (BMS), which cuts the cells from the terminals: on one maker's battery the terminals then read under 10 V, often near 0 V, and another maker's battery can read above 12 V in its protection mode. Its maker's manual says how it reconnects; steps that take cables off the battery are work at a battery terminal (→ 1.8). PRACTICE

PUT THE BOAT BACK IN SERVICE

- The loads you switched off and the inverter at its own switch back as you found them; the charger, the solar disconnect and the wind generator back on, so that a battery below its 100 % row charges now.

The drop of a whole run

ABYC sizes conductors so that the voltage drop does not exceed 3 % for panelboard main feeders, bilge blowers, electronic equipment, navigation lights and other circuits where the drop must be kept to a minimum, and 10 % for lighting other than navigation lights and other circuits where the drop is not critical. That is a rule for choosing a wire, with the drop calculated at the circuit's full current. On a boat with a panel, the panel's feeder and each branch circuit are sized for their own percentage, each from its own source connection, so a reading from the battery to a device covers two allowances (→ 5.4). ABYC

This book uses it as a pass mark for a drop you measure — a use the standard does not make. A reading above its yardstick fails at any current. One below it passes only when it was taken at the circuit's full working current; at a smaller current, read it again with every load on the circuit at full work. On a 12 V system 3 % is 0.36 V and 10 % is 1.2 V; on a 24 V system, 0.72 V and 2.4 V. PRACTICE

Suppose a run drops 0.30 V with every load on its circuit at full work. That is 0.30 ÷ 12 = 2.5 % of a 12 V system: inside 3 %, and the run passes. The same run read with its fan on low shows less, and that smaller reading passes nothing.

A bilge pump is not on ABYC's 3 % list — the bilge blowers on it are fans — but this book holds a pump circuit to 3 % all the same: it is the circuit you least want weak. PRACTICE

The drop of one connection or one switch

For one kind of connection ABYC gives a number: a friction-type connector — a push-on terminal — may be used on a component only

if, among the standard's other conditions, it drops no more than 50 mV at a current of 20 A. That is 0.05 ÷ 20 = 0.0025 Ω, and 0.05 × 20 = 1 W at that current; the 0.01 Ω lug of → 3.1 · p. 2 has four times that resistance. ABYC

For a lug, a ring terminal, a cable or a switch, the numbers of → Table 3.2 · p. 28 come from one meter maker's guide for cars, which gives them for use when the vehicle's manual lists none: about 0.00 V across a connection, 0.20 V across a wire or cable, 0.30 V across a switch, and 0.10 V across low-current wires and switches. They are read on the volts range, where "0.00 V" means less than 0.005 V — 5 mV. PRACTICE

For the starter circuit during a crank, the same maker's starter guide gives not more than 0.5 V for the whole circuit, about 0.3 V of it on the positive side and 0.2 V or less on the negative side. In the starter map these side figures decide; within a side, the section that stands out is the one to repair. PRACTICE

Like every drop, these figures mean something only at the current they were read at, and this book compares a reading with them at the full working current of its circuit — for one joint, at the largest current that joint carries. As → 3.4 · p. 11 explains: compare sections of one circuit under the same current; a reading at a smaller current passes nothing. PRACTICE

Suppose a joint reads 3 mV at 5 A and carries a starter's 200 A at other times. Its resistance is 0.003 ÷ 5 = 0.0006 Ω; at 200 A it drops 0.0006 × 200 = 0.12 V and makes 0.12 × 200 = 24 W. The 3 mV were under the 5 mV of Table 3.2 only because the current was small; at its real current this is a joint to repair.

Table 3.2. Yardsticks for a measured drop

What you measured	Yardstick	Where it comes from
The whole run of a circuit that must keep its voltage: panel feeder, bilge blower, electronics, navigation lights; in this book also a bilge pump	3 %: 0.36 V at 12 V, 0.72 V at 24 V, at full working current	ABYC's wire-sizing rule, used by this book as a pass mark PRACTICE
The whole run of a circuit where the drop is not critical, such as cabin lighting	10 %: 1.2 V at 12 V, 2.4 V at 24 V, at full working current	The same PRACTICE
The starter circuit during a crank	Not more than 0.5 V in all: about 0.3 V on the positive side, 0.2 V or less on the negative side; within a side, the section that stands out	One meter maker's starter guide for cars PRACTICE
One push-on (friction-type) connector	Not more than 50 mV at 20 A (0.0025 Ω); a reading at a smaller current passes nothing	ABYC's condition for push-on connectors on components ABYC
One connection: a lug, a terminal	About 0.00 V on the volts range: under 5 mV, at the largest current the connection carries	One meter maker's guide for cars PRACTICE
One wire or cable	0.20 V	The same PRACTICE
One switch	0.30 V; a low-current switch, 0.10 V	The same PRACTICE

3.6. Battery load test and reading a shunt

A load tester and a battery monitor each put a number on a battery. What does each number say, and what does it not? The load tester makes the battery deliver a heavy current for seconds and watches its voltage; the monitor counts the current in and out through a shunt. They answer different questions, and each fails in its own way.

The load test

A load test loads a charged lead-acid battery at half its CCA for 15 seconds and reads the voltage at the end, with the load on; its instrument, the load tester, is a load with a voltmeter, clamped to the battery terminals. One battery maker sets the test this way: the load at one-half of the battery's cold cranking amps (CCA) — the rating printed on a start battery's label — for 15 seconds, and the battery passes if it holds at least the voltage of → Table 3.6 · p. 29 for its temperature: 9.60 V at 70 °F or above, less as the battery gets colder. That maker asks you to estimate the battery's internal temperature to the nearest 10 °F. MFR

Table 3.6. Lowest voltage at the end of a load test, 12 V lead-acid battery, by battery temperature (one battery maker)

Battery temperature	Lowest voltage with the load on, at 15 s
70 °F or above	9.60 V MFR
60 °F	9.50 V
50 °F	9.40 V
40 °F	9.30 V
30 °F	9.10 V
20 °F	8.90 V
10 °F	8.70 V
0 °F	8.50 V

The same maker says a discharged battery cannot be load tested: below 12.4 V, it is charged completely first (→ 3.5 · p. 22). MFR

What the test says: whether this battery, charged, can deliver a heavy current now. What it does not say: how many amp-hours it still holds for a night at anchor — that is a separate quantity, and a test of seconds does not measure it. Its numbers also belong to lead-acid batteries, and not to every one of them: two makers of deep-cycle batteries say that CCA testers, which judge a battery by its internal resistance, and carbon-pile testers are not suitable for testing deep-cycle batteries; a deep-cycle battery is tested as its own maker's manual says (→ 6.6).

One conductance tester — an instrument that judges a battery electronically instead of loading it — lists flooded, AGM and gel batteries as the ones it tests. For a lithium battery, the battery maker's manual says what can be tested, and how (→ 11.4). MFR

The tester's own limits come first. One tester with a load switch allows the switch to be held for 10 seconds at most; on that tester the 15-second test cannot be run, and its own instructions and scale decide. A conductance tester has no load switch and is used as its own manual says. For a 24 V system, one such manual has the batteries disconnected and tested one by one. MFR MFR

Batteries joined together share the test. A tester clamped to one battery of a parallel bank loads the whole bank through the jumpers, and the reading belongs to the bank. Testing one battery of a parallel bank means taking it out of its bank and putting it back by the planned job on a battery (→ 6.5); one battery of a bank in series — a 24 V pair, or a 12 V bank of two 6 V batteries — is taken out and put back by a pro.

Procedure: A load test of one lead-acid battery

For one lead-acid battery, with a load tester that has a load switch, such as a carbon pile; a conductance tester follows its own manual.

 GASOLINE VAPOR  SHORT CIRCUIT  HOT BATTERY

1. Check what you test: one lead-acid battery whose label shows its CCA, joined to no other battery — no jumper from its terminals to another battery, its battery switch not at BOTH, 1+2, ALL or COMBINE, no parallel switch ON, and no charging link closed between two banks. A lithium battery is tested as its maker's manual says (→ 11.4), and so is a battery its label calls deep-cycle (→ 6.6); a battery joined to another gives the bank's reading, not its own, until the planned job on a battery (→ 6.5) has taken it out of its bank; a label with no CCA gives no load to set.
2. Nothing charges the battery and nothing else draws from it during the test, as in steps 1 and 2 of the procedure "A battery's resting voltage" (→ 3.5 · p. 22).

3. With the tester's load switched off, clamp it on — the red clamp on the positive terminal, the black clamp on the negative — and read the voltage on the tester's dial. Below the voltage your battery's maker sets for a load test — 12.4 V for one maker's batteries — MFR the battery is not charged enough to test: take the clamps off, load still off, charge it fully (→ 3.5 · p. 22), and start again from step 1. With no load-test figure from your battery's maker, charge it fully before the test in any case.
4. Apply the load — on an adjustable tester, half the battery's CCA — for 15 seconds, or for the time the tester's instructions allow if that is shorter, never longer, and read the tester's dial with the load still on. Then switch the load off, and only then take the clamps off. The tester's case is now hot enough to burn: set it down where it touches nothing until it has cooled as its instructions say.
5. Compare the reading with your battery maker's table for the battery's temperature — → Table 3.6 · p. 29 is one maker's — or with the tester's own scale on a tester that cannot hold 15 seconds. Below the minimum, on a fully charged battery with the clamps on clean metal: one maker asks for the battery to be recharged and tested once more, and, below the minimum again, for it to be replaced. MFR At or above it: the battery delivered the test current, and for a slow crank the next check is the procedure "The starter circuit's drop map" (→ 3.4 · p. 11).

PUT THE BOAT BACK IN SERVICE

- A battery taken out of its bank for the test — it, or a new one in its place — goes back into it by the planned job on a battery (→ 6.5); one from a bank in series, by a pro.
- With every battery back in its bank: the loads you switched off, the charger, the solar disconnect and the wind generator back as you found them.

The battery monitor and its shunt

A battery monitor counts the amp-hours into and out of a battery through a shunt and shows a state of charge calculated from that count.

The shunt is a calibrated resistor in the main negative cable whose small voltage tells the monitor the current. One maker's 500 A shunt gives 50 mV at 500 A — 0.1 mV for each amp, so 2.5 mV means 25 A — and that maker rates it for 66 % of its rated current in continuous use; a second shunt maker recommends no more than two-thirds. MFR

The percentage on the screen is a count, not a measurement. You typed the battery's capacity in, and the monitor adds up current from the moment it was last set to full. Without a regular full charge the count drifts: one maker's monitor shows "---" until a full charge has synchronized it. Another maker's monitor cannot count while it is switched off. MFR MFR

A monitor also counts only the current that passes its shunt. One maker writes that any load or charger connected on the battery side of the shunt, or on the battery's negative terminal, is left out of its state of charge. So a battery with a shunt has one cable on its negative terminal, and it goes to the shunt's battery side; every load and every charger returns through the shunt's other side (→ Fig. 3.6 · p. 33). MFR

Two exceptions are by design. A bank of batteries in parallel has jumpers between the batteries' negative terminals; the shunt sits in the one cable that leaves the bank, and the jumpers stay. And one monitor maker connects the monitor's own negative lead to the battery side of the shunt on purpose — that lead is the monitor's, not a bypass. Anything else on the battery's negative terminal or on the shunt's battery side, such as a charger's negative or a pump's negative, is current the monitor never sees. MFR

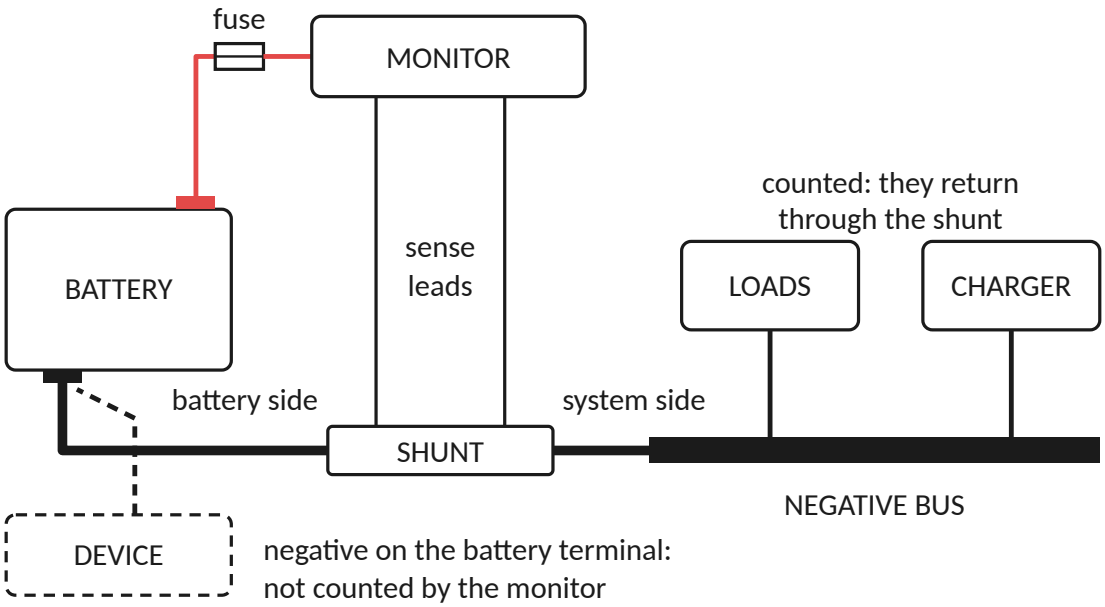


Fig. 3.6. A shunt counts only what passes it. One cable on the battery's negative terminal, to the shunt's battery side; every load and charger returns through the negative bus. The dashed device on the battery's terminal is current the monitor never sees.

When the percentage and the boat disagree, four causes come first: a capacity typed in wrong, a count that has not been synchronized by a full charge, a monitor that was off for a while, and a connection around the shunt. The first three are in the monitor's menu and its manual. The fourth you see by counting the cables on the battery's negative terminal and on the shunt's battery side: counting is looking, without opening a panel, and nothing is touched.

3.7. Measuring safely

What keeps a measurement from hurting you or the meter? Each way a measurement goes wrong has its own physics: a lead in the wrong jack, a zero from a meter that could not have shown anything else, a battery terminal bridged by metal, a measurement that has no place on your list, a source that stays live when its switch is off, and the AC side, where this book leaves you one measurement — the zero check.

Leads and dial

Where the leads sit decides what the meter is. On volts, it puts a megohm or more between its probes and reads without disturbing what it touches (→ 3.2 · p. 5). A lead in an amps jack (A or 10A), or the dial on amps, can turn the meter into a short circuit across whatever the probes touch.

> **WHY IT WORKS**
>
> On a meter with separate current jacks, the dial alone does not make that short, but a lead left in a current jack does. On a meter whose voltage jack also carries milliamps, the dial on a current position is enough. And one low-cost meter has no fuse at all on its 10 A jack, so nothing stops that short but the battery itself. MFR

Prove the meter before you trust a zero

A meter that reads 0 V has told you nothing until you know it could have read a voltage. A flat meter battery, a broken lead, a blown fuse, the dial on the wrong mode or HOLD left on all show 0 V, or no change, over a live circuit. So a zero is trusted only inside a three-point test: proving a meter on a known live source, making the measurement, and proving the meter on the same source again. NFPA 70E, the US standard for electrical safety in the workplace, asks for a check on a known voltage source before and after each test (NFPA 70E 2015, 120.1(5)); one meter maker calls the sequence the three-point test.

On the DC side, the known live source is a point you know carries battery voltage: the terminals of a battery that reads its normal voltage, or the battery-side terminal of a battery switch fed by such a battery, where you reach it without opening a panel. That terminal stays live when the switch is OFF only while its battery, and any fuse between them, are sound, so a meter that read 0 V across a battery is proven on another battery, never on the switch that battery feeds. A source proves only the mode it feeds. A battery proves the meter's DC volts and says nothing about its AC volts. Those are proved on a known live AC source: a source of AC voltage known to be on, used to prove a

meter's AC path before and after a measurement — and a battery is not one.

With the boat's AC side off, the practical known live AC source is a proving unit: a battery-powered pocket source of known voltage for proving a meter before and after a measurement. One maker's unit gives 240 V into a standard meter input and about 60 V, at least 50 V, into a LoZ input; another maker's gives 440 V AC. The meter must MFR show the value the unit's maker states for its input, within the tolerance the maker states where it states one: "some voltage" is not a proof, and a unit that states no value for your meter's input does not prove that input. An outlet or the pedestal also carries a known voltage, but probing either puts the probes on live AC.

At the battery terminals

Why is a battery terminal different from every other point you probe? Nothing limits the current of a short at its terminals except the battery, so a ring, a watch band or a loose wrench that bridges a terminal and a part connected to the negative heats at once with the battery's full current through it, and a lead-acid battery gives off explosive gas in normal operation, as one tester maker prints in capitals on its manual. A meter on DC volts is not that bridge: on volts it puts a megohm MFR or more between its probes, by the manuals in this chapter's list of documents. With a lead in an amps jack, or the dial on a current position of a meter whose voltage jack also carries milliamps, the meter itself can be that bridge.

What you never measure

Two measurements stay off your list, and a third is made only one way, each for its own reason. Probes in an outlet, in the shore inlet or at the pedestal, a clamp meter on an AC conductor, or any AC voltage beyond the zero check below put your hand at a live AC connection. Resistance or continuity on a live circuit reads nothing you can use. And current with the meter in series puts the meter's current path — nearly a short circuit (→ 3.2 · p. 5) — into the circuit; this book reads current that way only for the draw with everything off, by the procedure of → 7.3.

Insulation testing

Insulation testing with a megger is a pro's job, and only on a cable disconnected at both ends, with no electronics, sensors or pumps attached. Never on an assembled circuit.

> **WHY IT WORKS**
>
> An insulation tester (megger) is an instrument that tests insulation by applying a high DC voltage and measuring the current that leaks through it. One generator maker's guide puts that voltage at some 500 V, or more with some instruments, and says that electronic components connected to the circuit under test could be damaged and must be disconnected. On an assembled circuit — wiring still connected at either end to a panel, a device, a bus or a battery — the test voltage reaches every device on it, and the reading mixes the wire's insulation with the devices'. The full treatment is in → 16.3.

PRACTICE

The inverter is a source

An inverter makes 120 V AC from a bank, and its own switch does not take it off the boat's energy map. That switch turns its output off but leaves its DC input connected: its terminals and DC cable stay live until the DC breaker or isolation switch that feeds it is opened, the cable from the battery to that breaker or switch stays live even then, and until then a remote panel can switch the inverter back on. An inverter fed only through a fuse has no such breaker or switch.

The one AC measurement you make: proving the AC side off

Before a hand goes behind the AC panel, the AC side is proved dead, at the right points. Fig. 1.5 names them (→ 1.7): point A on the supply side of the shore power breaker, D on the supply side of the generator breaker, E on the supply side of the inverter breaker, each between its source and its breaker. Only there does a zero prove that the source itself is off. A zero after a breaker you turned OFF proves nothing: it shows the breaker's position, not the source's. A boat with two shore inlets has a point A for each.

Each source has its trap. An inverter that is searching can read 0 V and wake up when a load appears; an inverter/charger — one unit with an AC input, an AC output and heavy DC cables — is an inverter too, and a unit you cannot tell from a plain charger is treated as one (→ 2.2). A stopped generator starts again whenever anything closes its start circuit — its automatic start, or a start switch at the set or at a remote panel. A second shore cord can still be plugged in. That is why the zero counts only after each source is off at its own control.

Shore power has a sign you can see, for each shore cord: its plug is out of the pedestal and out of the boat's inlet. That sign covers shore power only; the order in which shore power is switched off, unplugged and plugged back in is in → 17.2. The inverter and the generator are separate sources, and the batteries are never off.

The check is made one-handed. A current that enters one hand and leaves through the other crosses the chest; with both probes in one hand and the other away from the panel, that path is less likely.

PRACTICE

Table 3.4. The pairs of wires read at each point of the zero check

The wiring at the point	The pairs, one at a time
120 V: one hot, a neutral and a ground	Hot to neutral; hot to ground; neutral to ground
120/240 V: two hots, a neutral and a ground	Each hot to neutral; each hot to ground; neutral to ground; hot to hot

Every pair reads under 1 V. If you cannot tell which wire is which at a point, read every pair of wires you find there.

Procedure: Proving the AC side off at the AC panel

With a meter and leads rated CAT III 600 V or a higher category (→ 3.2 · p. 5), a proving unit made for that purpose, and → Table 3.4 · p. 37. The DC side stays live behind the panel throughout.

 **AC — PRO**  **METER LEADS**  **SHORT CIRCUIT**  **GASOLINE VAPOR**
 **SHOCK IN WATER**

1. Switch every AC source off at its own control. Shore power: the shore power breaker on the AC panel and the pedestal breaker OFF, and every shore cord unplugged. The inverter: OFF at its own switch, and its DC supply cut at the DC breaker or isolation switch that feeds it. The generator: stopped, its automatic start OFF, and no one at any of its start switches until the panel is closed again. An inverter with no such breaker or switch, or a source you cannot confirm off this way: the zero would prove nothing — stop here; the check is a pro's.
2. Set the meter to AC volts with HOLD off, the red lead in V and the black lead in COM. Prove it on the proving unit, switched to AC and used dry, at that same setting: it shows the value the unit's maker states for that input. No proving unit, or another value: stop here; the check is a pro's.
3. Open the AC panel the way it is built to open: take its cover off, or swing it open.
4. Both probes in one hand, the other hand away from metal, read each pair of → Table 3.4 · p. 37 on the supply side of each source's breaker: point A at each shore power breaker (one per shore inlet), then D and E. Every pair reads under 1 V. A reading after a breaker you turned OFF does not count, and the shore inlet itself is never probed. A point you cannot find, or a pair at 1 V or more: the AC side is not proven off — hands out, panel closed, and the job goes to a pro.
5. Prove the meter again on the proving unit at the same setting: the same stated value, and the zeros stand. If it does not show that value, the zeros proved nothing: hands out, panel closed, and the job goes to a pro.

PUT THE BOAT BACK IN SERVICE

- Your hands out of the panel, and the cover back on or the panel closed.
- With an inverter aboard, the DC breaker or isolation switch that feeds it back ON, and the inverter at its own switch as you found it; the generator's automatic start as you found it, and anyone you kept from its start switches told that it may be started again.
- Shore power back last, in the order of → 17.2.

3.8. On board

Your boat gives you a symptom: a slow crank, electronics that reboot as the engine starts, a battery that dies overnight, a hot terminal. Where do the probes go first, and what does the first reading tell you? This section sends each symptom to its first check, follows a slow crank from what changed to the section that loses the volts, and ends with the one repair this chapter leaves in your hands: the negative lug on the engine block.

ON BOARD: GOLDEN RULE

Trust a number only when you know the current it was taken at, and the meter has just shown that it can read. A drop means something only at its current, and a zero only between two good readings on a known live source.

What it means

Each first check below names the procedure that takes it; the signs at the start of that procedure go with it.

Table 3.5. What it means

What you notice	What is happening	First check	Yourself or a pro
The engine cranks slowly, or you hear one click and nothing turns	The battery cannot deliver the starting current; a connection loses volts under it; on a cold morning, both; the starter itself; or the engine resists turning	The route "The engine cranks slowly or only clicks" below, from its first step	**Do it yourself, if... you can take each procedure the route names, with its signs**
Electronics reboot or go dark while the engine cranks	The voltage at the electronics falls below what they need while the starter draws its current: a low battery, a feed that loses volts, or a feed that shares a cable or a connection with the starter	The procedure "A battery's resting voltage" for the start battery (→ 3.5 · p. 22), then "The starter circuit's drop map" (→ 3.4 · p. 11); your one-line diagram shows where the electronics take their power (→ 2.3)	**Do it yourself, if... you can take both procedures, with their signs**
The battery seems dead in the morning	A draw at night, a battery never fully charged, or a battery that no longer holds its charge	The procedure "A battery's resting voltage" (→ 3.5 · p. 22); the draw itself → 7.3	**Do it yourself, if... you can take that procedure, with its signs**
The monitor shows a full battery that dies, or it shows "---"	A count that drifted, a capacity typed in wrong, a monitor that was off, or a connection around the shunt	The capacity in the monitor's menu; the cables on the battery's negative terminal and on the shunt's battery side, counted by eye (→ 3.6 · p. 28)	**Do it yourself, without opening a panel**

What you notice	What is happening	First check	Yourself or a pro
The meter shows a voltage on a wire you switched off	On the AC side, a ghost from a live wire beside it; on the DC side, a trickle through an indicator light or LED; on either side, a real feed from a second source	Until you know which, the wire is treated as live. On the AC side, the procedure “Proving the AC side off at the AC panel” (→ 3.7 · p. 33); on the DC side, a second source is found on the energy map (→ 1.7)	**AC: Do it yourself, if... you can take that procedure, with its signs. DC: Do it yourself — looking and tracing without opening a panel**
The meter reads 0 V across a battery	The meter, a lead or the mode at fault; a lead-acid battery deeply discharged; a lithium battery cut from its own terminals by its own electronics	Steps 3 and 4 of the procedure “A battery’s resting voltage” (→ 3.5 · p. 22)	**Do it yourself, if... you can take that procedure, with its signs; a reconnection that takes cables off the battery: Hire a pro (→ 1.8)**
A terminal, a lug or a wire is warm or hot, and nothing trips	Heat at a bad connection at normal current, or a wire too thin for its current	Smoke, a burning smell, or soft or discolored insulation: the card “Smoke, a burning smell, or an overheated wire” (→ emergency card). **HOT BATTERY** A battery that is itself hot, swollen or hissing: the card “Battery smells, is swollen, or is hot” (→ emergency card). Only warm, with none of these signs: the procedure “The drop of a running circuit” (→ 3.4 · p. 11) finds the joint; who repairs it → 4.8	**Do it yourself, if... you can take that procedure, with its signs; the repair → 4.8**

What you notice	What is happening	First check	Yourself or a pro
The windlass or the thruster is slow	A low battery, a feed that loses volts under the machine's current, a worn motor; for a windlass, a fouled anchor	The procedure "A windlass or a thruster as the load" (→ 3.4 · p. 11)	**Do it yourself, if... you can take that procedure, with its signs**
The clamp meter reads 0 A on a DC cable that carries current	An AC-only clamp meter; both conductors inside the jaws; a DC clamp meter not zeroed	The dial's marking; then the procedure "A DC current with a DC clamp meter" (→ 3.3 · p. 9)	**Do it yourself, if... you can take that procedure, with its signs**

Route: the engine cranks slowly or only clicks

WHAT CHANGED BEFORE THE PROBLEM?

- after you installed or changed a device → the connections you touched while installing it: the drop map of step 3 includes them
- after charging → whether the charge reached the start battery: step 2
- after rain or washing the boat → the connections the water reaches: the drop map of step 3
- after the boat sat unused → the start battery's resting voltage: step 2
- after switching sources (shore power, generator, inverter) → the battery switch's position: step 1
- nothing you noticed → step 1

ROUTE: THE ENGINE CRANKS SLOWLY OR ONLY CLICKS — POINTS C, F, H AND K ON → FIG. 3.5 · P. 17

GASOLINE VAPOR **HOT BATTERY** **BILGE PUMP**

1. Look at two things you set by hand: the shift lever — one outboard's manual lists a lever in gear among the causes when the starter will not operate — and the battery switch. MFR
   You will see: A lever in gear: put it in neutral. A battery switch away from the working position your Boat Passport records (field 6) is a change in itself: put it back as → 1.7 shows. The start battery of steps 2 and 3 is the battery the switch connects to the starter in that position. On an inboard with a water-lift muffler that was cranked many times without starting, its raw-water seacock open, before it slowed, water may have reached a cylinder (→ 3.4 · p. 11): no measurement crank — a pro looks at the engine first. Otherwise, go on with step 2.

2. The start battery, by the procedure "A battery's resting voltage" (→ 3.5 · p. 22).
   You will see: At or above its maker's 100 % row: step 3. Below it: charged fully first, as that procedure says, then step 3 — a starter circuit read on a flat battery says nothing about its cables; a lithium start battery is charged as its maker's manual says. Nothing aboard can charge it — at anchor with no solar panel, wind generator or generator: where your battery switch has a position that puts another lead-acid bank alone on the starter (Boat Passport field 6), start from that bank, turning the switch as → 1.7 shows; on an inboard with a water-lift muffler, the crank time and seacock of "How long to crank, and what a low battery stops" in → 9.5 come with every try; with no such bank, call for a tow or for help to a place where the battery can be charged. A lead-acid battery that will not come up to its 100 % row after a full charge and its rest: the procedure "A load test of one lead-acid battery" (→ 3.6 · p. 28).

3. With the battery charged, the procedure "The starter circuit's drop map" (→ 3.4 · p. 11).
   You will see: A side above its figure in → Table 3.2 · p. 28: the section that stands out on that side is where the volts are lost — step 4. Both sides within their figures and the crank still slow: the battery under load (→ 3.6 · p. 28) — and, with the battery passing, the starter itself or the engine, a pro's work.

4. **Who repairs the section that stands out depends on where it is.**
   You will see: The negative lug on the engine block (H to N): yours, by the procedure at the end of this section. A lug on a battery terminal: on a 12 V lead-acid battery, on its own or in a bank joined in parallel, the route ends here — do the planned job on a battery (→ 6.5), then take this route again from step 1; otherwise, work at a battery terminal (→ 1.8). The main fuse, the battery switch, a cable, the starter, or a lug on a battery terminal that still stands out after that job: a pro, with your map in hand (What to tell the pro, below).

5. **Write the readings, the date and what was repaired into the Boat Passport (field 16).**
   You will see: The record a pro needs, and your baseline for next season.

PUT THE BOAT BACK IN SERVICE

- The procedures of steps 2 and 3 end with their own restore blocks.
- If you turned the battery switch in step 1 or 2, check that the bilge pump's automatic switch — a float, a sensor or one built into the pump — has power, by the check your pump allows. A pump that checks for water by itself: stay by it and listen — one maker's pumps run for about a second every two and a half minutes, and one of its models every 20 seconds. MFR A float switch with a test lever at its back: press the lever, which lifts the float, where the switch is dry, or with a dry non-conductive stick from above the water; the pump runs. Your Boat Passport records that the pump starts by itself with every battery switch OFF (field 11): the switch never cut it. Pressing MAN for a moment runs the pump, which shows the pump and its MAN feed, not that its automatic switch has power. Afterwards no pump runs by hand: a three-position switch back in AUTO, never OFF — check it when you let go of a spring-return switch — and a separate manual switch OFF. None of these fits, you cannot tell which kind your pump has, or you cannot reach the pump: someone stays with the boat and watches the water until one of these checks shows the pump runs, or a pro checks it.

LOOKS LIKE THE FIX	FIND OUT FIRST	WHAT FIXES IT
A new battery, because the engine cranks slowly.	Whether the old battery, read at rest by the procedure "A battery's resting voltage" (→ 3.5 · p. 22) and charged fully, comes up to its maker's 100 % row after its rest, and passes the procedure "A load test of one lead-acid battery" (→ 3.6 · p. 28); then the procedure "The starter circuit's drop map" (→ 3.4 · p. 11).	The part that loses the volts. A new battery on a circuit whose drop map shows one section far above its figure cranks as slowly as the old one did; that section, repaired, gives the starter back its volts.

Do it yourself or hire a pro

DO IT YOURSELF OR HIRE A PRO · MEASURING

STOP · ⚠ **AC — PRO** An insulation tester on an assembled circuit (→ 3.7 · p. 33), or probes in an outlet, the shore inlet or the pedestal. The first puts hundreds of volts into every device on the circuit; the second puts your hand at a live AC connection.
What to do this minute: Put the probes away and leave the circuit as it is.

HIRE A PRO · Every AC reading beyond the zero check (a voltage at an outlet, a current with a clamp meter, a leakage current); the charging circuit's drop, taken with the engine running; a measurement crank where the engine must be kept from starting — out of the water, or with its raw-water seacock closed — and its manual shows no way to do it, or to supply cooling water out of the water; a load test of one battery that is joined to others, unless the planned job on a battery (→ 6.5) takes it out of the bank first; and repairs at a battery terminal beyond that job (→ 1.8). Ask for the readings in writing, section by section, with the current each was taken at (What to tell the pro, below).

If no pro is available:  **SHORT CIRCUIT**  **CARBON MONOXIDE**  **BLOWN FUSE**  **BILGE PUMP** The measurement waits, and the boat goes on as before. Write the symptom and the readings you have into the Boat Passport (field 15). A circuit you suspect of heating stays off and labeled — at its breaker or its fuse; a fuse at the battery comes out as step 3 of the procedure in → 4.6 takes it out. A bilge pump on it is off with it, and the boat is watched as the entry of the BILGE PUMP sign says. A circuit that feeds a CO alarm or a high-water alarm stays on instead, with every other load on it — a bilge pump included — off at its own switch and labeled, so that the circuit carries only the alarm's own current. Where the alarm cannot stay on without another load, that circuit goes off too, and the entries of the CARBON MONOXIDE and BILGE PUMP signs say what you do while the alarm has no power. Under way, or at anchor after dark, the circuit that feeds the navigation or anchor lights or what steers the boat stays on, as the entry of the BLOWN FUSE sign says. Smoke or a burning smell at the suspect joint: the card "Smoke, a burning smell, or an overheated wire" (→ emergency card).

When a pro may do it differently: A pro may measure live AC, measure with the engine running, judge a joint with a low-resistance ohmmeter instead of its drop, or test insulation on a cable disconnected at both ends. You see it in the instrument named and the numbers written in the pro's report.

DO IT YOURSELF, IF…

The procedures of this chapter, each with the signs at its start: "A DC current with a DC clamp meter" (→ 3.3 · p. 9); "The drop of a running circuit", "The starter circuit's drop map" and "A windlass or a thruster as the load" (→ 3.4 · p. 11); "A battery's resting voltage" (→ 3.5 · p. 22); "A load test of one lead-acid battery" (→ 3.6 · p. 28); "Proving the AC side off at the AC panel" (→ 3.7 · p. 33). And one repair, by the procedure "The negative lug on the engine block" below; at a battery terminal, the planned job on a battery (→ 6.5).

DO IT YOURSELF · Without opening a panel: look, trace and read labels; read the battery monitor and its menu; count the cables on a battery's negative terminal and on the shunt by eye. Set up your meter and read its manual. What lies behind a panel is in → 4.5.

On someone else's boat there are three levels, not four: switches and buttons — yes; tools — no; the gray zone — only with the permission of the charter base or the owner, by phone (→ 2.6). A meter is a tool: there you read the panel's own meters and the battery monitor, and tell the base or the owner what you saw.

Procedure: The negative lug on the engine block

The negative cable from the battery lands on the engine block at a lug (N on → Fig. 3.5 · p. 17). When the negative side of the drop map stands out at H to N, this joint is where the volts are lost, and it is the one repair this chapter leaves to you. It does not apply where the negative cable lands on a negative bus and no cable from that bus lands on the block, or where it goes into an outboard's harness under its cover. You need a torque wrench that covers the torque the engine's manual gives for this bolt, and a wire brush or an abrasive pad.



1. Find on your boat the points of → Fig. 3.5 · p. 17: the negative lug on the engine block (N), the starter's battery stud (F), the alternator's output terminal (Q), any other positive terminal on the engine block next to the lug, and the battery-side terminal of the battery switch (J), which stays live when the switch is OFF while its battery, and any fuse between them, are sound. You only look; nothing is touched yet. A lug that shares its bolt with other terminals, a bolt that also holds the starter or another part, a lug you reach only through bilge water, or an engine manual that gives no torque for this bolt: this repair is a pro's. A lead on the negative terminal of the battery, or of any battery in its bank, other than the cable to this lug and the jumpers between those batteries, or leads there you cannot count by eye: this repair is a pro's too — while the lug is off, such a lead can carry the current of other loads back to the battery by a path not sized for it (→ 7.3). With a battery monitor's shunt, count at the shunt instead: the battery's negative terminal carries only the cable to the shunt and those jumpers; the shunt's battery-side stud only that cable and, where the monitor's maker puts it

there, the monitor's own lead; and the shunt's SYSTEM stud only one cable — the cable to this lug, or the cable to the negative bus from which this lug's cable comes; any other lead at any of these places, or leads you cannot count by eye: this repair is a pro's.

2. Nothing may push current through the lug while it is off: the charger off at its own switch or at its breaker on the AC panel, an inverter/charger at its own switch, a wind generator stopped as its manual says, and the solar panels off at their disconnect switch, or the work done after dark. The engine stays stopped from here to the end of step 7.
3. Meter on DC volts, the black lead clipped to the negative lug (N). With the battery switch still at its working position, put an insulated clip or a probe tip on the starter's battery stud (F) alone, touching neither another terminal nor the block: the meter reads battery voltage. This proves the meter and the leads.
4. Every battery switch OFF — on a boat with two or more, all of them: only what is wired around the switches (→ 1.7) still returns through the lug, and that has no power while the lug is off. Then read, from the lug, every positive terminal within reach of the wrench, one at a time: the starter's battery stud, the alternator's output terminal and any other. Each reads 0 V. Any voltage there, or a terminal you cannot identify: stop here — the repair is a pro's.
5. Prove the meter again before the wrench goes on: J read against the lug, where the leads reach it without opening a panel, or else the battery's own two terminals, shows battery voltage. If it does not, the zeros of step 4 proved nothing: find why the meter failed (→ 3.7 · p. 33) and take steps 3 and 4 again.
6. Wait until no bilge pump is running; then undo the lug's nut or bolt with one wrench and take the lug off the engine block. Clean the lug's face and the block's face to bright metal, with no paint, rust or crust left, put the lug back, and tighten it with the torque wrench to the torque in the engine's manual.
7. Turn the battery switches back to their working positions.
8. With the battery charged, take the procedure "The starter circuit's drop map" (→ 3.4 · p. 11) for the negative side. The negative side now

reads within its figure in → Table 3.2 · p. 28, and H to N no longer stands out from N to K. If it does not, the lug was not where the volts were lost: a pro, with both maps.

PUT THE BOAT BACK IN SERVICE

- If the lug cannot go back on tight — a thread that will not hold, a bolt that will not reach its torque — the battery switches stay OFF and what step 2 switched off stays off, and a pro puts the lug back: the engine's main negative is open, and everything that returns through it has no power until then — where they are wired that way, the bilge pump's automatic switch, the high-water alarm and the CO alarm among them; the entries of the BILGE PUMP and CARBON MONOXIDE signs say what you do meanwhile.
- With the lug back and tightened, or never taken off: the battery switches at their working positions, and the charger, the inverter/charger, the wind generator and the solar disconnect back as you found them.
- The leads off the engine, and the meter's dial at OFF.
- A CO alarm fed from this battery's bank lost its power while the lug was off, and any CO alarm wired after a battery switch also while the switches were OFF; the entry of the CARBON MONOXIDE sign says how you see that it is working again.
- The bilge pump's automatic switch checked as the route above shows (→ its last block).

What to tell the pro

WHAT TO TELL THE PRO

Ask for this: "the voltage drop of the starter circuit while the starter turns the engine — positive side and negative side, then section by section — and of the charging circuit at full charging current, from the alternator's output terminal to the battery's positive terminal and from the alternator's case to the battery's negative terminal; each reading written with the current it was taken at." Accept the work by two signs. You get the readings in writing, section by section, each with its current, and you write them into the Boat Passport. Every connection the pro

repaired reads within its figure in → Table 3.2 · p. 28, at the full working current of its circuit.

REMEMBER

- A bad connection is found by its voltage drop under the circuit's working current; the ohms range of a multimeter does not see the hundredths of an ohm that make it heat.
- A drop means something only at the current it was taken at: compare sections under the same current, and pass a reading only at full working current.
- In the starter map, the side figures decide; within a side, the section that stands out is the one to repair.
- A zero counts only between two good readings on a known live source: a battery proves the meter's DC volts — another battery, when the zero is a battery's own — and a proving unit its AC volts.
- A battery's voltage tells how full it is only after its maker's rest, and only by its maker's table; a lithium battery's voltage tells little at all.
- A battery below its 100 % row needs a full charge soon, from a charger that suits its type.
- A monitor's percentage is a count: it misses every current that does not pass its shunt.

Self-check

1. **Before you measure.** Suppose the positive side of a starter circuit reads 0.9 V during a crank at 200 A, and the negative side 0.1 V. Which side do you map, and how much heat does the positive side make?

   Answer: the positive side: 0.9 V is three times its figure of about 0.3 V in Table 3.2. It makes 0.9 × 200 = 180 W, shared among its sections; the map C to J, J to B, B to F finds the one that makes most of it (→ 3.4 · p. 11).

2. **Before you measure.** Suppose a lug reads 3 mV while 5 A runs through it. What will it read during a 150 A crank if its resistance stays the same, and how much heat will it make?
   Answer: its resistance is 0.003 ÷ 5 = 0.0006 Ω; at 150 A it drops 0.0006 × 150 = 0.09 V, which is 90 mV, and makes 0.09 × 150 = 13.5 W (→ 3.4 · p. 11).
3. **Not yet a number.** Suppose a 12 V AGM battery reads 12.5 V an hour after its charger switched off. Is it about three-quarters full?
   Answer: you cannot tell yet. It has not rested for its maker's time, and only its maker's table turns a rested voltage into a percentage (→ 3.5 · p. 22).
4. **Zero on a working cable.** A clamp meter reads 0.0 A around the cable of a running cabin light. Name three causes.
   Answer: an AC-only clamp meter; both conductors of the cable inside the jaws; a DC clamp meter not zeroed (→ 3.3 · p. 9).
5. **A zero that counts.** At point A — the supply side of the shore power breaker on the panel — your meter reads under 1 V on every pair. What else must be true before that zero counts?
   Answer: the meter showed the proving unit's stated value before the reading and shows it again after, on AC volts with HOLD off, and every source was off at its own control, as the steps of the procedure say (→ 3.7 · p. 33).
6. **On your boat.** Find your meter's CAT rating and its leads' rating, the jack its manual names for voltage, and whether it has a DC millivolt range and MIN/MAX. Is it good enough for everything in this chapter?
   Answer: it is when it has the four properties of → 3.2 · p. 5; without the CAT rating it still reads a battery, but it does not do the zero check.
7. **On your boat.** Count by eye, without opening a panel, the cables on each battery's negative terminal and on the shunt's battery side, and write the count into the Boat Passport (field 5).
   Answer: one cable to the shunt's battery side, the jumpers of a parallel bank, and the monitor's own lead where its maker puts it there; anything else is current the monitor does not count (→ 3.6 · p. 28).
8. **On your boat.** Find the points C, J, B, F, H, N and K of → Fig. 3.5 · p. 17 on your battery, switch and engine, without touching them or opening a panel, and mark which you can reach.

Answer: each point you can reach opens a section you can map; a section whose point you cannot reach stays unmeasured.

Terms

Ohm's law
The rule that the voltage across a resistance equals the current through it times the resistance: V = I × R.

voltage drop
The voltage a cable, connection or switch loses while current flows through it, measured across that part under its working current.

multimeter
A handheld meter that measures voltage, current and resistance, with a dial to choose the mode.

input impedance
The resistance a meter puts across its probes when it measures voltage; it sets how much current the meter draws from what it measures.

ghost voltage
A voltage that a high-impedance meter reads on a wire that can drive only a tiny current, picked up from a live neighbor or through an indicator lamp.

LoZ (low impedance)
A meter mode that puts a low input impedance across the probes, so that a ghost from AC wiring side by side collapses and a real voltage remains; its value is printed in the meter's manual.

CAT III / CAT IV
The measurement category of a meter and its leads: where in an installation they may measure, according to how much energy a voltage spike can carry there.

MIN/MAX, HOLD, AutoHOLD, REL
Meter functions as printed: MIN/MAX records the lowest and highest reading of an event; HOLD freezes the display when pressed; AutoHOLD, on the meters that have it, captures a reading once it is stable; REL subtracts a starting value, such as the offset of a DC clamp.

clamp meter
A meter that reads the current in one conductor through jaws closed around it, without breaking the circuit.

DC clamp (Hall effect)
A clamp meter with a Hall-effect sensor in its jaws; it reads DC as well as AC current and is zeroed before a DC reading.

measurement point (A, B, C…)
A named place where a probe goes; the letter means the same point in the figure, the step and the answer.

drop map
The voltage drop of each section of one circuit, measured under the same working current and written side by side.

water-lift muffler (waterlock)
The muffler of an inboard engine whose cooling water leaves with the exhaust; the water collects in it and the exhaust gas of the running engine pushes it out.

resting voltage (battery)
A battery's voltage after it has rested with no charge and no load for the time its maker names.

state of charge (SOC)
How full a battery is, in percent of its capacity.

load test
A test that loads a charged lead-acid battery at half its CCA for 15 seconds and reads the voltage at the end, with the load on.

load tester
The instrument for a load test: a load with a voltmeter, clamped to the battery terminals.

battery monitor
An instrument that counts the amp-hours into and out of a battery through a shunt and shows a state of charge calculated from that count.

three-point test
Proving a meter on a known live source, making the measurement, and proving the meter on the same source again.

known live AC source
A source of AC voltage known to be on, used to prove a meter's AC path before and after a measurement; a battery is not one.

proving unit
A battery-powered pocket source of known voltage for proving a meter before and after a measurement.

insulation tester (megger)
An instrument that tests insulation by applying a high DC voltage and measuring the current that leaks through it.

assembled circuit
Wiring still connected at either end to a panel, a device, a bus or a battery.

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