Moisture Meters

Limitations and Use of an Important Tool

By Dave Gerr, CEng FRINA

In the early years—when fiberglass replaced wood plank-on-frame construction—boaters blithely assumed that their FRP hulls were impervious to degradation from moisture. As time rolled by, however, even supposedly inert fiberglass began to exhibit moisture-related problems. Of these, blistering is the best known, but core debonding and decay, and failure of gelcoat or paint are others. Indeed—even fiberglass—we've now learned can be too wet.

This is somewhat disconcerting. After all, how can you determine if a particular boat's laminate has a water problem? Major blister repairs are expensive and a core failure is worse still. It's just this question that has lead surveyors and boatyards (and even some boat owners) to use moisture meters in an attempt scientifically gauge the percentage of water absorbed in a fiberglass laminate.

Precision Metering

Moisture meters are reassuring gizmos. After all they work by precisely measuring electrical characteristics and displaying the results on a scale which can be read off for seemingly exact findings. Many marine surveyors employ moisture meters, and it certainly can appear to add weight to a report to record, say, that: "The forward port hull bottom reads 18 on the scale, indicating high moisture content in this region."

In fact, you should always specify the make and model of the meter, and the scale used for the reading in your report. There is a large difference between the scales used on dif-

Sovereign Moisture Meter Photo: Ed Sherman

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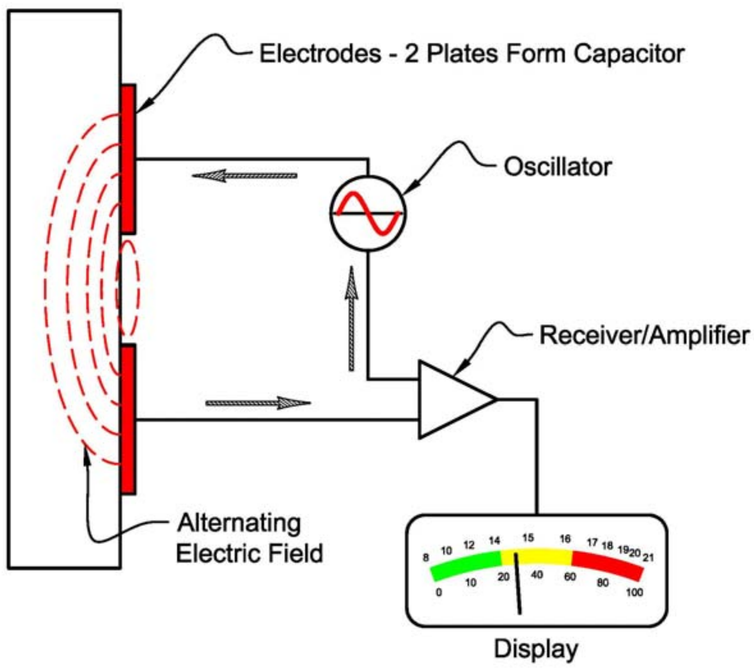
ferent meters (and on different scales on the same meter). A reading of 18 on and a Sovereign A scale would be on the wet side (broadly speaking), but the same reading on a Tramex 2 scale would be quite dry.

Measurement Limitations

Unfortunately, moisture meters have real limitations. First off, most moisture meters were not originally intended for testing fiberglass boat hulls, but rather for testing wood in buildings or in lumber yards, or concrete, or plaster, or grains, and so on. Use on fiberglass boats is an engineering afterthought. In fact, one entire class of moisture meters can't even be applied to fiberglass. These are the 2-pronged-sensor, direct-DC-resistance meters. Designed specifically for lumber, the prongs of these meters cannot penetrate deep enough into the hard FRP of a boat hull to give any sort of usable reading. (There's one important exception, which we'll look at later.)



Moisture Meter Circuit

How Moisture Meters Work

The correct moisture meters for use in testing hull laminates operate by using an oscillator to generate a radio-frequency (RF) signal. This signal's frequency is affected by the resistance or *impedance* (Z) of any nearby material. Unlike DC current, in which resistance is essentially a single straightforward effect, in AC or RF circuits total resistance is *impedance*, and impedance is a combination of four factors: resistance, capacitance, inductance, and frequency. These impedance components are usually divided into two parts:

- Resistance (R), which is the component not affected by frequency
- Reactance (X), which is the component that varies with frequency

It is the reactance that is being measured by moisture meters. Reactance is complex in that the combination of inductance and capacitance causes a "phase shift" between the current and voltage. Accordingly, resistance and reactance can't just be added together. Electrical engineers have to use vector addition to calculate impedance properly.

Luckily—as marine surveyors—you don't have to calculate any of this. As we've seen, one component of impedance is called *capacitance* and is measured in *farads* (F). It is capacitance that most moisture meters are measuring. Depending on a meter's circuitry, it may be measuring in millifarads (mF), microfarads (uF), nonaofarads (nF), or picofarads (pF). Two plates on the moisture meter form either end of a capacitor, and the meter is measuring the varying capacitance between these plates as affected by the material in-between—the laminate you're testing. Some meters' contact "pad" electrodes also measure the overall AC impedance as well.

Regardless, capacitance is governed by the *dielectric* constant of a material. The presence of water changes the dielectric constant. (Water has roughly 75 times the dielectric constant of air for example). The presence of water thus changes the frequency (RF or AC). Moisture meters sense this change. One approach to this is for the meter to maintain constant frequency and detect the changes in internal power required to accomplish this.

Because of the above, moisture meters used for testing hulls are often called capacitance meters, but are also sometimes referred to as radio-frequency power-loss meters, or impedance meters. The RF/oscillator type meter is generally somewhat less likely than the contact-pad type to be affected by surface moisture and surface contamination problems.

The Problem With Gauging Moisture

With all this science behind them, it's no wonder that surveyors and their clients tend to treat moisture meter results very respectfully. Unfortunately, there are many variables and practical limitations that can leave moisture-meter readings suspect. This is unsettling because it tends to put you back in the position of not knowing if a particular boat is too wet or not. This is also a bit controversial because so many surveyors and yards have come to rely on moisture meters (at least to some degree) to answer just this question.

The first problem with moisture meters is that various laminate materials can give divergent readings. CoreMat, for example, indicates quite differently than the ordinary mat/roving laminate which makes up most "traditional" or standard laminates. Indeed, surveyors who understand moisture

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meters' limitations often use them as comparison tools, not as absolute measures. For instance, a surveyor will, say, take a series of readings along the upper topsides. In the absence of other indications, this region is assumed to be relatively dry, and gives a "baseline" by which to gauge areas elsewhere. (Usually, and ideally, the baseline reading should about correspond with the dry or fairly dry region of the meter's scale.) With the baseline established, the surveyor can now move to, perhaps, the hull bottom and see how the readings compare with the topsides baseline.

This sounds sensible and it is, but there are still difficulties. A typical example: It's fairly common for some production builders to use CoreMat in the outer layer of the topsides to reduce print-through, but do not use CoreMat in the hull bottom, where print-through is less of a consideration. (This not my favorite practice, incidentally, but it's acceptable and not unusual.) CoreMat, though, reads direr than mat/roving (even if they actually both have the same moisture content). The supposedly dry baseline readings may (or may not) reflect the presence of CoreMat. As a surveyor you can't know if CoreMat has been used in a particular hull without either getting this information directly from the builder, or by taking a core sample. (Yes, drilling holes in the hull.) Following this scenario through, the hull-bottom will read wet compared the supposedly "dry" baseline number, even though both areas may have the same moisture content and both may, in fact, be dry. This, then, could cause a surveyor to conclude that there was a moisture problem in the hull bottom when no such problem existed.

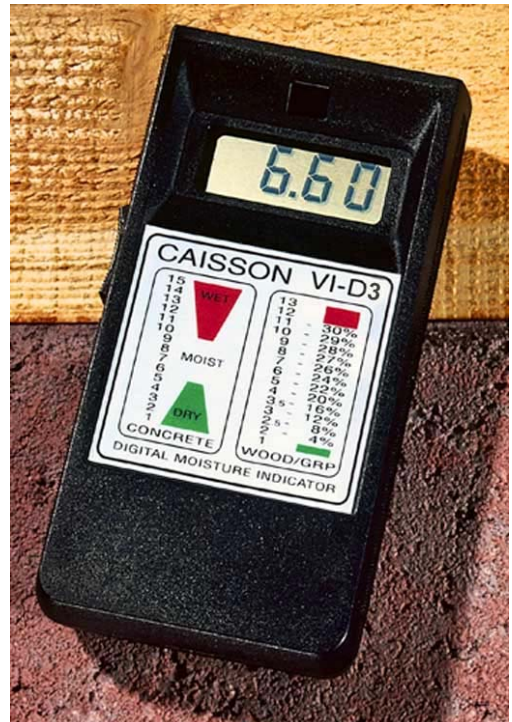
Unknowns and Variables

Many similar unknowns can throw off readings or the baseline itself. Here's a brief list of just the most common factors that can (and do) confuse moisture meters:

- high metal content in antifouling paint
- titanium dioxide (common pigment in white paint)
- high humidity
- condensation
- nearby pipes or wires
- nearby tanks
- metallic filler or putties
- embedded metal
- metal ballast
- bilge water
- carbon fiber
- frozen water may read low in some instances
- deep/aggressive nonskid can reduce effective contact
- static electricity
- how hard the meter is pressed against the surface

This is quite a list of very common items, all of which can pay havoc with results.

Most of the above are obvious, but you wouldn't think pressing harder would change readings. A test done by the University of Rhode Island, however, showed a Sovereign meter A scale varied as much as reading 5.5 with light pressure to 11 with hard pressure on a water-saturated fiberglass panel. A Novanex meter varied from 8 light down to just 3.5 hard (which is contrary to what you'd expect).



Novanex Caisson Moisture Meter

More amusing, is a larger British survey company, who had a woman surveyor. No matter what moisture meter she used, she always got significantly higher readings then anyone else—using the same meters on the same boat. You might conclude she had an electric personality, but it turned out that the clothes she wore collected and held a static charge. If she removed her shoes and thus grounded herself, her readings were identical to everyone else's. It is thus possible that the clothes you wear and the static charge they build up can affect your meter readings.

The Problem With Blister Juice

More subtle chemical effects can also scramble the readings. Osmotic blisters—one of the things moisture meters are most frequently used to predict—are really caused by the chemical interaction of the salts (see sidebar) in seawater with poorly cured or poor quality regions in the resin. The chemical by-products (imaginatively termed *blister juice)* are largely not water, yet their differing dielectric constant can cause a moisture meter to read wet. This would hardly seem to be much of a problem. After all, you want to detect potential blister juice. However, if you are trying to dry out a hull for blister repair, these regions can continue to give false wet readings, long after they've dried enough for repair and refinishing to begin.

About Salts

The "salts" we're referring to are not simple table salt (Sodium Chloride) found in sea water. Chemically, salts are a vast array of ionic compounds created during the total or partial neutralization of acids. Salts can also be created by

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the direct combination of elements—reactions of salts and acids, or reactions between different salts. Salts created during complete neutralization are termed "normal salts," while salts created in an incomplete neutralization are termed "acid salts." That salts are ionic means that they have an imbalance in the electrons they contain. As a result salts cause or enhance chemical reactions. Salts do this by facilitating the transfer of electrons—the basis of chemical reactions. Sometimes these reactions are desirable. In the case of creating blister juice, such chemical reactions are undesirable. Sea water is more conducive than fresh to the interactions that result in the creation of salts and thus blister juice; however, the chemical compounds contained in various resin systems—particularly poor-quality systems or poorly cured resin—can create undesirable salts (ionic or chemically active compounds) in fresh water as well.

A Problem In Depth

A serious consideration in using moisture meters is that fact that—contrary to some claims—they generally cannot give reliable readings deep into the laminate. My feeling is that readings beyond a depth of 0.20 inches (5 mm) are not fully trustworthy, say, 1/4 inch (6.4 mm) maximum. Most average boats—over 30 feet (9 m)—will have bottoms at least 0.27 inches (6.8 mm) thick. Vessels in the 40- to 50-foot (12 to 16 m) range will have bottom laminates in excess of 3/8 to 7/16 inch (9.5 to 11 mm), and as much as twice this or more at the keel. Moisture meters, simply don't give dependable indications that far in.

Protimeter Aquant

The Protimeter Aquant is a bit different. It measures the overall affect on a larger area electromagnetic field, with the "head" of the meter acting something like an antenna. In fact, the operator's body is part of the "receiver." You are not supposed to wear gloves or touch the object being measured with your hand or body. The Aquant does seem to measure in more depth, but then it's providing gross average readings over a larger volume. This can be useful, but it can also easily include more of the potential problem sources causing false readings.

The Question Of Wet Cores

If you think about it, a boat with a soggy wet core, poses a real conundrum for a moisture meter. If a boat has been


Water shooting out of the core of a 34-foot foam-core boat

hauled out and kept dry for several days or longer. The core will still be wet but the surface dry. Indeed, the surface could well dry to a 0.8% moisture content (not too bad). The moisture content will continue to increase as you drill or grind down into the hull. It's almost a straight-line increase, and could well be as high as 1.75% moisture content 0.1 inches in from the gelcoat surface.

What is a moisture meter reading is such a situation? It's effectively taking a rough average (weighted somewhat toward the surface layer) of the moisture content in this surface 0.1 inch (or somewhat more). An exact average between 0.8% and 1.75% would be 1.275%, but—since this is weighted toward the surface—you could expect a reading based on an average dielectric constant (moisture content) indicating around 1.1% moisture content. Some meters aren't even good at getting a rough average, and will read heavily weighted to the surface moisture only.

In fact, detecting wet cores is one of the other common uses for moisture meters. In my experience—being so deep in the laminate—the best moisture meters can hope to do is signify this indirectly. If the core is truly soggy with water and the moisture from the core saturates the skin laminate, it may

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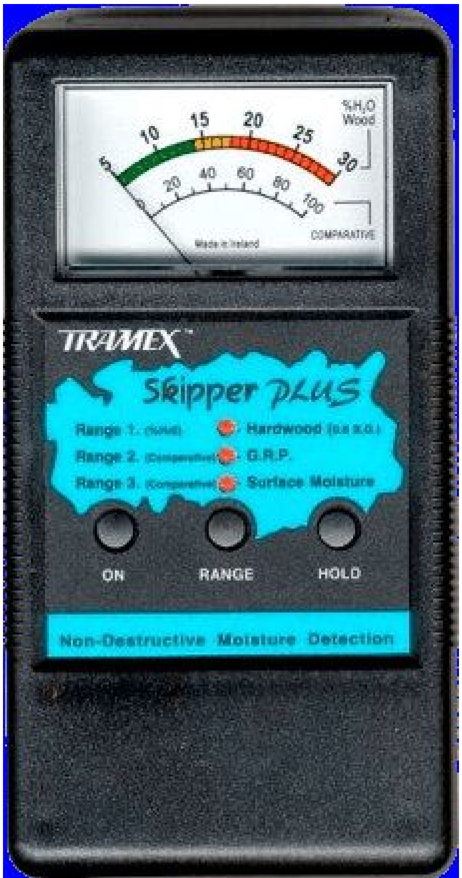
well read wet. Unfortunately, it seldom works this way.



Tramex Skipper Moisture Meter

A foam-cored 34-footer (10.4 m) was brought in to one of my builders for repairs. Water had migrated remarkably efficiently through fastening holes and along improper open channels left by unfilled kerfs in the core. Nearly the entire hull shell—from keel to sheer—was flooded with water. Hauled out, water literally shot out of test holes we drilled in its bottom. One hole alone filled a 1-gallon (3.2 l) coffee can three-quarters full in just a few minutes.

My feeling was that no guaranteed satisfactory repair could be made as there'd be no way to tell that the hull was ever fully dry. After all, any small quantity of water left would freeze in the winter; potentially bursting a bit more of the core away from the laminate; which in turn would create more area for condensation to occur; which would then lead to a spread of the water and subsequent freeze damage—a vicious cycle. How could you expect to see what was going on throughout the interior of the cored surface of this entire hull—some 600 square feet (56 m^2) in all?

What Dry Hull Readings Really Indicated

In fact, the original builder took the boat back and asserted that they could use moisture meters to confirm when the hull was completely dry. The vessel was trucked up for repairs; the entire exterior skin was drilled full of drainage holes at closely spaced regular intervals; and the boat was dried in a heated shed with powerful blowers going for over four months. At this time, it was pronounced dry by moisture-meter testing. (Two different kinds of meters were used.) The boat was then refinished. After the exterior laminate had been completely repaired (and it did look good), the hull was tested again with moisture meters. Once more, it was pronounced dry. Just a few weeks later, the refinished vessel was trucked back down to its owner's marina for preparation for launching. Before launch; however, a hole was drilled in the topsides to install a fitting. Sure enough, water spurted out! So much for reliable readings through to the depth of the core.

Two-Pin Resistance Meters on Cores and on Wood Boats?

There is another option beside drilling out cores to see what's really going on. This is a method I first learned of from marine surveyor Jonathan Klopman. Instead of drilling core samples and sending them to a lab, drill a pair of tiny (5/32") holes and use a two-pin, DC-resistance meter in the holes. Such tiny holes can be drilled from the inside, in out-of-the-way corners, and sealed with 5-minute epoxy. Sticking in the long pins from a wall-type DC-resistance moisture meter will enable you to get accurate, true readings of the core. In fact, balsa or wood cores can be contain over 90% moisture, if highly degraded and fully saturated and these meters will read this quite accurately. You'll also get more reliable readings on foam cores, by actually drilling and measuring through a pair of such small holes with a DC-resistance meter.

For the same reason, you could drill such holes in wooden boat hulls and components. If you suspect rot or moisture penetration below an otherwise good surface. using a DC-resistance meter through a few well selected small holes can give you quite reliable results.

The Protimeter Mini and the Protimeter Surveymaster SM are two small hand units that can plug in long-pin, wall-type resistance pin probes.

Protimeter Deep-Wall Probes

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How Much Moisture Is Bad?

More complicated still is determining how much moisture is too much. Specifically, how much water in the laminate makes a particular boat too wet? There isn't even a clear answer to this basic questions. In fact, fiberglass is (obviously) very different from wood. Wood can have a moisture content as high as 20 percent by weight. (Over 90% if severely decayed and water saturated.) This is quite a bit of water. Fiberglass, by contrast, can't contain more than 3 percent water by weight. Half a percent or less is truly dry or low moisture content. Up to one percent is a reasonably dry laminate. (Under 0.5% is considered truly dry.) Blistering, is not caused directly by the presence of water, but—as we've seen—by complex chemical interactions with the salts in seawater. High-quality laminates can have very high (3%) moisture content and never experience the chemical reactions that cause blistering. On the other hand, poor-quality laminates can experience blistering even at modest moisture content, say, 1%. What then is the moisture meter reading telling you, even if you can compensate for all the variables and unknowns?

FRP laminates are also weaker when wet then when dry. You might expect, in this case, that a wet (3-percent-moisture-content) laminate would be more prone to structural failure. This isn't the case; however, or shouldn't be. The boat's designer and builder should have engineered the structure with sufficient safety factor to allow for the lower wet strength of the laminate. In fact, almost all fiberglass hulls (even rather low-quality ones) have more than enough beef built in to allow for the loss of strength from high moisture content.

Protimeter Mini

Moisture Meters As Useful Tools

So are moisture meters good for anything? The answer is yes, most definitely. Moisture meters are one of many tools in the survey equipment bag. Like any tool, moisture meters can give useful information if they are used carefully and with understanding of their limitations. A good surveyor will diligently calibrate his or her particular meter against various sample laminates to compile a tabulated reference record of how it reads in varying conditions and on various material combinations. (Some surveyors like to use two different types of moisture meters during a survey, cross checking their results as further confirmation.) The surveyor will then get baseline readings during each survey, as described earlier and equate these readings with other regions of the hull. If some area appears to indicate wet compared to the hull's baseline readings (and compared with the surveyor's own tabulated test records), then there is some—but only some—cause for concern. Sounding (tapping) and visual examination of the suspect area must be evaluated along the moisture meter results.

When all these factors combined indicate a potential moisture problem, it may then be time to take the next steps in testing. What are they? Drill out plug samples or drill for a resistance pin-probe test of the core. The only way to conclusively know whether a laminate is too wet and suffering from chemical degradation is to remove plugs and send them to a lab. The lab fees are not high (though repairing the holes can add up in cost, if there are many). Further the only way to really know what is going on deep in a core is to bore in and have a look. Moisture meters, combined with a surveyor's other inspection procedures, can help indicate where and when such intrusive testing might be required.

If you ever read a survey report that condemns a hull (or gives it a totally clean bill of health) based on moisture meter readings alone, be suspicions. No moisture meter yet made can make that sort of judgment, only humans can, and—in the case of boat surveys—this takes experience and close attention to a broad range of other tests and clues as well.