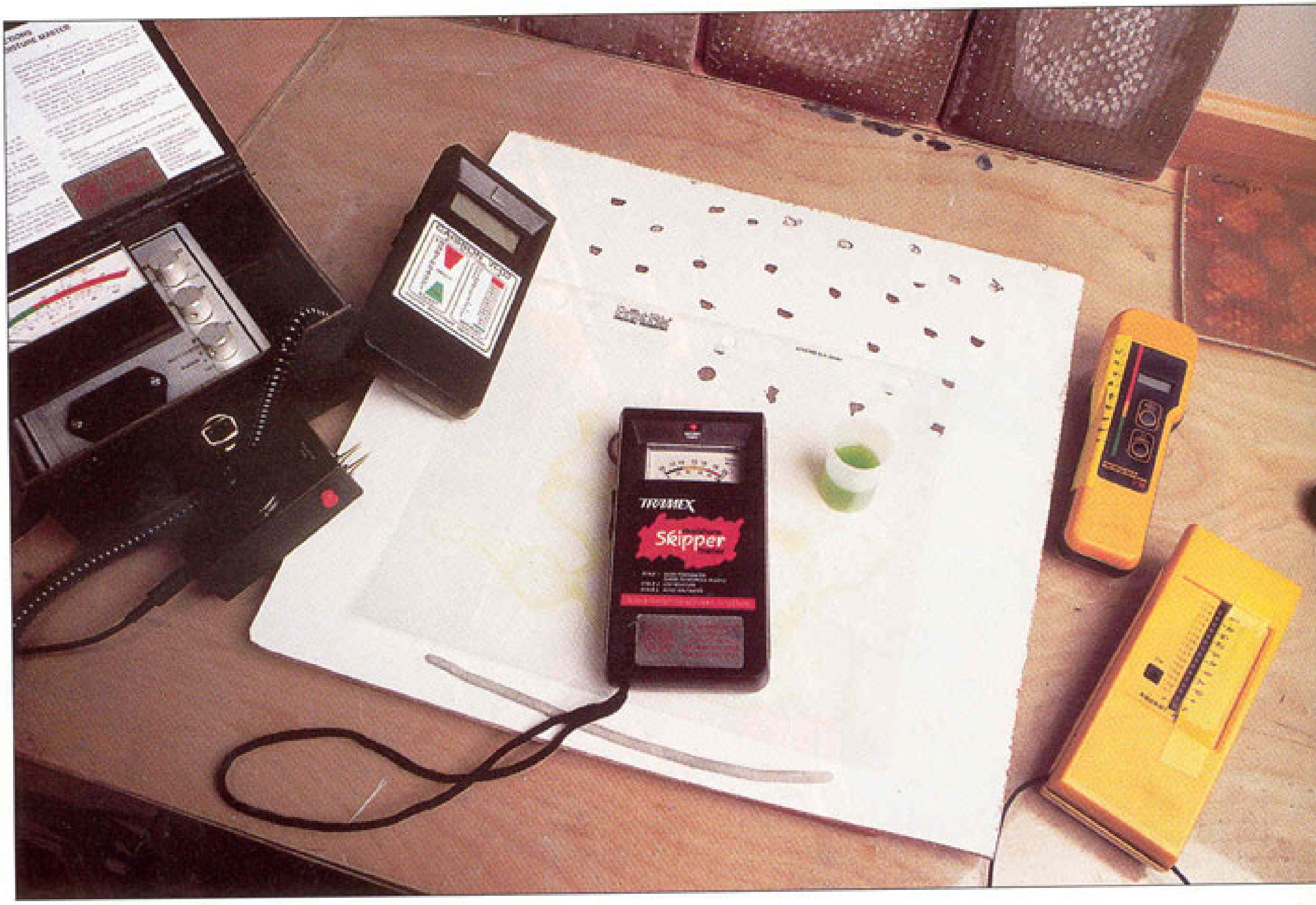


Moisture Meters Revisited

It's been a long time since we looked at these widely used tools. Here's a thorough review of five different units on the market.

Text and photos by Jonathan Klopman

This article is based on an IBEX '99 session entitled "Moisture Meters." The testing described here was done in cooperation with Dan Spurr, editor of *Practical Sailor* magazine. The topic of moisture meters and their ability to reliably read the percentage of water in a laminate has been covered in previous articles by *Professional BoatBuilder*'s technical editor Bruce Pfund (see "Moisture Meters," PBB No. 23, page 42) and in studies by the Southampton (England) Institute of Higher Education. —*Ed.*

Moisture meters have been in wide use in the marine industry for just over 10 years. During this time, these tools have come to be an accepted and expected part of the nondestructive inspection techniques applied by most marine surveyors. Unfortunately, the units have also been purchased by a number of boatyards, brokers, and boat owners.

Many people buy moisture meters without fully understanding how they work, and their limitations. I have always had nagging doubts as to why my meter goes "beep," and many of my colleagues have been plagued by the same questions.

Mode of Operation

The major markets for moisture meters are in the building trades (for assessing wood, concrete, and roofing), agriculture (for monitoring stored grain), and lumber (for determining rate of drying in a kiln). There are even special applications, such as paper production, that use near-infrared scanners to monitor the moisture content of the rolls.

The two most common types of moisture meters operate on one of two principles: resistance or capacitance. Designed as dual-facility instruments, two of the five meters we tested—the Sovereign MkII and the Protimeter Surveymaster—offer both resistance and capacitance in the same unit.

Resistance meters have two pin

Facing page—The five moisture meters featured in this article were tested for, among other things, sensitivity to unreacted solvents. The fluid seen here is ethylene glycol (engine antifreeze), which delivers a higher reading than the other tested liquids, including water (results on page 59). ***Right****—To test their accuracy when confronted with different variables, in this case low-volt batteries and varying degrees of laminate thickness, the meters scanned six fiberglass samples placed on wet carpet sitting in a pool of fresh water (results on pages 54 and 56-57, respectively).*

These test results are offered in good faith, but they were not performed to ASTM or any other "standard." No warranty, either express or implied, is offered regarding the accuracy or repeatability of readings. In reaching conclusions from the test results, the author assumes no responsibility for the fitness for use, nor the reliability of the meters tested. The tests are based on new sample units randomly selected by manufacturers' representatives. No attempt was made to average readings among numerous units. The conclusions are not based on any consideration from the manufacturers or manufacturers' representatives. The author will not accept liability for the poor interpretation of meter readings or negligence of any individual who cites the details or conclusions of this work as a reference or defense.

Jonathan Klopman, Marine Surveyor

probes that are designed to pierce the surface of the object being measured. This type of instrument is common in the lumber industry. The scale on most of these meters is calibrated for the percentage moisture content in wood—usually 0% to 25%. Although the principle is simple, it takes some training to learn to operate it properly.

The signal can vary depending on whether or not it passes through the growth rings. Therefore, the readings should always be taken with the pins lined up *along the grain* of the sample, not across the grain or into end-grain.

Similarly, the readings tend to fluctuate based on the density, or specific gravity, of the wood sample. The meter is calibrated at the factory for only one species of wood, and should come with a table of compensating factors to allow accurate readings for other species of wood.

The key with resistance meters is that the pins must be buried in the object tested. Consequently, the pins don't give accurate readings for relatively hard surfaces such as gelcoat and catalyzed resin. Measuring the moisture in brightwork, trim, or bulkheads is inefficient at best, and may even be destructive. For these reasons, resistance-type meters have little practical application in assessing marine laminates.

Capacitance meters operate by sending a high-frequency alternating current (AC) between two transmitter plates on the unit. The frequency of this signal is either retarded or attenuated depending upon the dielectric constant, or *permittivity*, of the object being measured. The frequency of this alternating current is monitored and adjusted by a direct current (DC) controller. If the meter is operated on a surface with a very low permittivity (as when the meter is held in the air), the DC circuit will have to expend additional power in order to maintain the same frequency. For this reason, these units are also referred to as "radio frequency power loss" meters. The meter must expend *more* power in order to display a low reading on the scale.

When the meter is placed in contact with a highly conductive material (such as a metal or carbon fiber), the alternating current passes between the plates with little or no resistance. While fresh water has a high permittivity, it is not a conductor, per se. Water molecules are polar. When charged with the AC radio frequency of the meter, the polar water molecules align themselves to pass the charge.

The capacitors in these meters measure *farads*—either millifarads (mF), microfarads (µF), nanofarads (nF), or picofarads (pF)—depending upon the meter's internal components. There's no need to get into the specifics of this circuitry; the size or number of the capacitors doesn't seem to affect performance.

The value of capacitance—meter reading—depends on three factors:

- the area of the plates;
- the distance between the plates;
- the dielectric constant of the material between the plates.

Comparative Testing

We set up a series of tests to highlight the strengths and limitations of five moisture meters marketed to the marine industry. Although we took care to set up a level playing field, the tests do not follow any ASTM standard. We tested new units, randomly selected by manufacturers' representatives, and made no attempt to average the readings among meters.

Our intent was to see how the different meters performed in real-world situations. Under what conditions will a meter fail to pick up moisture trapped beneath the surface of a laminate? Just as importantly, when will a meter "cry wolf" and return a false positive reading?

CAISSON NOVANEX

Strengths

- Light, handy.
- Backlit LCD display easy to read.
- Small footprint: easy to orient head.
- Hard plastic head appears durable.
- Adjustable zero, alarm threshold, upper end of range (0–15).
- Low-battery indicator.

Weaknesses

- Case appears fragile.
- No audio alarm.
- No automatic "off" feature.
- Poor switch.

PROTIMETER AQUANT

Strengths

- Light, handy.
- Small footprint.
- Easy to see readings, except in direct sunlight.
- Will not turn on at low voltage (8V).
- Space to carry spare battery.
- Automatic "off" (but time interval too short).
- Adjustable alarm threshold.

Weaknesses

- Switch not sealed.
- Short, coarse scale (3 flickering lights = +/- 15%).
- No battery-check feature.
- Case appears fragile.
- Head subject to abrasion.
- Must be held 90 degrees to surface, which is sometimes difficult.

TRAMEX SKIPPER

Strengths

- Light, handy.
- Battery "on" light (but no check function).
- Scale evenly graduated and easy to interpret.
- Relative scale included (0–100%).

Weaknesses

- Scale switch inexpensive.
- Three scales not sequential from sensitive to less-sensitive (i.e., #2 scale is most sensitive, #3 least sensitive).
- Alarm nonadjustable.
- Large footprint.
- Case appears fragile.
- No automatic "off" feature.
- Small display can be difficult to read.

Scales and Methods of Measurement

Moisture Content of Wood. Most of the "marine" moisture meters we tested were originally designed and built for the building trades. The two most popular models—the Sovereign MkII and the Tramex Skipper—have analog scales graduated for the percentage of moisture in wood, with roughly 20% to 25% as a maximum on the scale.

At 20% moisture content, most wood species have reached their "fiber saturation point"—that is, the cell walls of the "green" wood can hold no more water. The key point here is that, although the meter may be maxed out, the wood may not even feel wet to the touch, since the *fibers* still retain the moisture.

The meters are calibrated to indicate when the wood is fully cured, *not if it is deteriorated.* In general, wood needs to have a minimum of 20% moisture content in order to support fungal growth (along with some oxygen and a minimum temperature of 50° to 60°F [10° to 15°C]). So, at most, a meter will indicate that the conditions necessary for rot exist in the piece. Confirmation of fungal growth requires destructive testing.

Moisture Content of Fiberglass. As noted above, the meters are calibrated for wood. Converting these readings to apply to fiberglass is tedious at best (the Tramex meter is supplied with a table). The range for moisture in fiberglass is only 0% to 3%—not much room for error.

More importantly, what does the percentage of moisture in the laminate mean? If there is 3% moisture trapped under the gelcoat, does this mean that a degenerative condition exists? While the meters can detect moisture, they cannot discriminate between water and the byproducts of ester hydrolysis in osmotic blistering.

Finding "Common Ground." The Southampton Institute of Higher Education (SHIHE) published a table of the results of a test in which the moisture content of several fiberglass samples was measured by a variety of meters, and then verified by weighing the samples. *[For more on this study, see PBB No. 23, page 42—Ed.]* Though this may seem the best way to compare "apples to apples," I thought it would be impractical and cumbersome

SOVEREIGN

Strengths

- Heavy-duty metal case and dials.
- Instructions for calibration and use.
- Battery check (but no warning) and calibration.
- Remote head is compact (but must be unplugged to fit in case).
- Relative scale included (0–100%).
- Adjustable alarm and zero control.
- Plastic protective cover for head.
- Easy battery access.
- Pins for probe.

Weaknesses

- No power "on" light; easy to drain batteries.
- Two-handed use is awkward.
- Neither of its two scales are calibrated for fiberglass.
- Scales not evenly gradated.
- Pressure on head affects readings.
- Doesn't compensate for low batteries.

PROTIMETER SURVEYMASTER

Strengths

- Light, handy.
- Durable rubber case gasket.
- Remote head and probes.
- Easy battery access; good battery contacts.
- Automatic "off" (but time interval too short).
- Battery indicator.
- Adjustable audio alarm.

Weaknesses

- Head difficult to keep at 90 degrees to surface.
- Because of head location on back, holding hand tends to obscure the LCD lights.
- No numbers on scale.

Moisture Meter Feature Summary

Make/Model:	Sovereign	Tramex Skipper	Caisson Novanex	Protimeter Aquant	Protimeter Surveymaster
Type	Capacitance	Capacitance	Capacitance	Free-field effect	Capacitance
Battery	9V	9V	9V	9V	2 AA
Case	Leather/metal	Black plastic	Black plastic	Yellow plastic	Yellow plastic
Scales	0-25, 0-8 analog	10-20 analog	0-13 LCD	101-115 LEDs	20 LEDs (no numbers), LCD for remote
Battery Check?	Yes	"On" light, no check	Lo bat	No	Yes
Transducer	Remote on cord	Backside	Forward end	Forward end	Backside
Convenience	Clumsy, two-handed operation	Fair	Good	Fair	Fair
Visibility	Good	Good	Good	Fair	Poor
Switches	Good	Poor	Poor	Fair	Good
Other	Scales not calibrated for FRP; includes instructions; remote head is compact	Large footprint; illogical switch/ scale settings	Small footprint; large digital LCD display	Auto-off too fast; clip-on "near-field" attachment	Auto-off too fast; small footprint; remote head and probes

to try to establish a sixth scale to compare the five meters we tested. Realistically, how many surveyors and boatyards would actually use another scale in order to confirm readings?

We determined that the most direct approach was to convert the scale on each meter to a simple 0–100 graduation (the Tramex and Sovereign units provide 0–100 relative scales). It then became fairly easy to compare the relative deflection of one meter to another. Most surveyors—myself included—intuitively tend to look at how far the needle moves on the scale.

How informative are the "green/yellow/red" graduations on the units? Most of us stop and go "Hmm" when we hear the meter "beep" and see the needle peg the scale into the red. When the needle stays in the green, however, don't we tend to relax and think that green means "good"?

We arranged the tests to see how the meters reacted to a series of known anomalies. This is merely a qualitative approach, with no intention of quantitatively determining actual moisture percentages in or beneath the surface of a laminate.

The Tests

Battery Power

Out in the field, it's common enough to run down the batteries in a meter. I have personally killed enough batteries that I regret not having bought stock in Duracell. The point of this test was to see how the meters performed with a battery that was partially drawn down.

We laminated a series of six fiberglass test panels of varied thickness out of alternating layers of 24-oz woven roving and chopped-strand mat, using general-purpose polyester resin. We placed the panels on an 8″ x 20″ section of wet carpet set in a pool of fresh water, and laid a pad of wet paper towel on top of the carpet and under each panel to act as a wick for an even distribution of moisture.

With each meter, we recorded readings on the successively thicker panels. We took the first series of readings with a fresh 9V battery (except for the Protimeter Surveymaster, which runs on two 1.5V AA cells). We made the next series of readings with a battery that had been drawn down to 8V. We then compared the readings to see if the sensitivity of the meters dropped

Battery Test

	Sovereign Scale A		Tramex Scale 2		Tramex Scale 1		Tramex Scale 3		Caisson V–03		Protimeter* Surveymaster	
panel	lo bat	full charge	lo bat	full charge	lo bat	full charge	lo bat	full charge	lo bat	full charge	lo bat	full charge
a .135"	12.5/7.0	12.5/7.0	100/20	100/20	100/20	100/20	20/12.5	20/12.5	4.9	4.58	45/9	40/8
A .150"	12/05	12.5/7.5	100/20	100/20	95/19.5	98/19.8	20/12.5	15/12	4.5	4.58	40/8	45/9
B .313"	08/2.5	09/2.8	100/20	100/20	55/15.5	53/15.25	05/10.5	05/10.5	3.16	3.26	30/6	30/6
C .360"	08/2.5	8.5/2.7	100/20	100/20	50/15.5	50/15	05/10.5	05/10.5	3.13	2.9	30/6	30/6
D .410"	7.5/2.0	8.0/2.25	95/19.5	90/19	35/14.25	30/14	03/10.3	03/10.2	2.75	2.66	25/5	30/6
E .510"	7.5/2.0	7.5/2.0	85/18.5	85/18.5	30/14	25/13.5	03/10.3	2.5/10.2	2.75	2.53	25/5	25/5

Readings are in relative scale (0–100)/indicated scale. *Protimeter Aquant would not turn on with only 8V

The meters probed six FRP panels (labeled a-E for their varying thickness) with a fully charged battery (9V), then with a battery drawn down to 8V.

Using a discharged power source, the units are able to compensate and return readings similar to full power. The one notable exception is the Sovereign, which must be continually adjusted for "zero" to account for voltage change.

with the weak battery.

Surprisingly enough, the meter readings were essentially identical across the board. Either the meters were able to compensate, or their scales were not calibrated based on the DC voltage.

The results reinforce the capacitance theory of operation; the DC power only monitors and maintains the AC signal that is being transmitted through the part. Which makes sense, because in the operation of capacitors, it only takes 1V to push a bazillion electrons from plate to plate.

It should be noted, however, that the analog display on the Sovereign must be "zeroed in" to adjust for battery strength. This is fairly quick and easy to do, but the operator must be vigilant to see that the meter needle returns to zero. Combined with the fact that it's easy to forget to turn off the Sovereign unit, power loss and constant adjustment could become annoying problems.

The Protimeter Aquant has an internal circuit that senses battery power and shuts the unit down when the DC power drops to 8V. Despite the reassuring correlation we discovered between full-power and low-power readings, this fail-safe mode is a very good design feature. Another good feature—although not as foolproof—is a low-power indicator on the LCD displays of the Caisson and Protimeter Surveymaster.

Thickness Test

The Setup. One of the most important tasks of a moisture meter is to measure water intrusion into a cored laminate. We designed the following test to determine the ability of each meter to punch a signal through an outer skin of fiberglass and assess an underlying wet area.

For this test, we used the same wet-carpet pool and laminate samples from the battery test. The large piece of carpet in a pool of water provided an adequate mass of moisture. Water in the laminate acts as an antenna for the Protimeter Aquant; if there were just a damp pad under the samples, then the return signal would be weak.

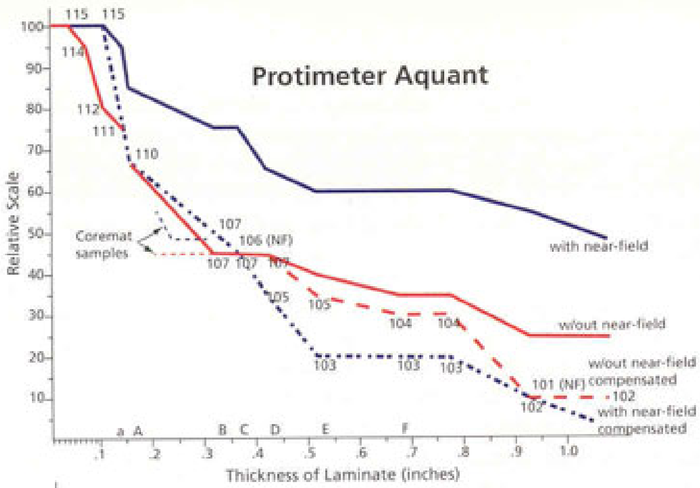
The pool of water simulates extreme water intrusion. This was the only way to assure a consistent baseline. Obviously, a moist pad would have yielded different results. At the other extreme, salt water would have intensified the readings. Due to vagaries of salinity and the relative "moistness" of a partially wet pad, the latter two tests would have been hard to control.

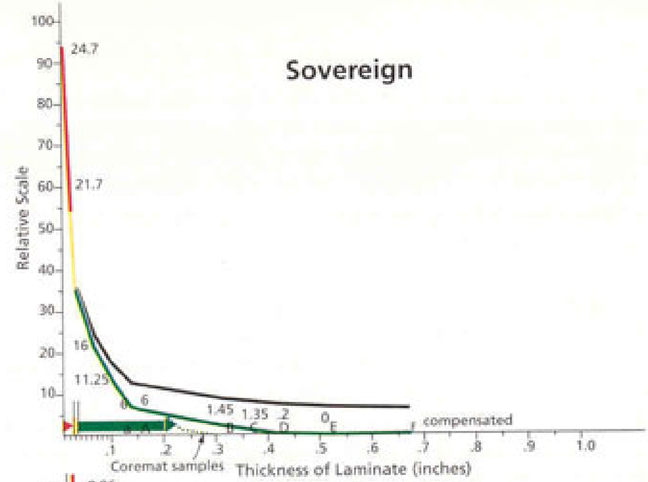
The laminate samples ranged in thickness from .135" to .672". As noted above, we laminated with the same resin, post-cured them all in an oven, and allowed a minimum of one week before testing. We checked the panels with a Barcol durometer to assure that they had reached an adequate level of cure.

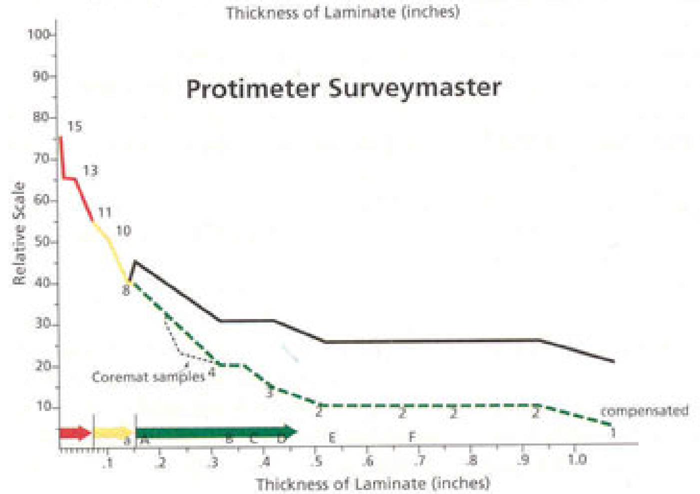
When Dry Laminate Doesn't Read "Dry." We tested all of the panels dry before placing them on the wet pad, assuming that the meters would return baseline readings of "0". Boy, were we wrong. As it turns out, most of the meters *reacted to the dry laminate samples*, giving higher readings as the laminate thickness increased.

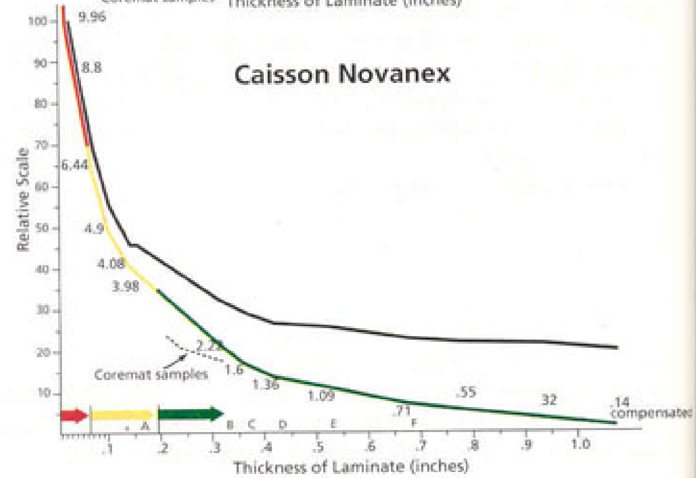
The meter operator, then, must keep in mind that the thicker the laminate, the higher the baseline, but the *lower* the signal from the moisture trapped on the far side of the laminate. So, an accurate reading would require subtracting the false positive for the base thickness of the laminate, and then adding for the loss in sensitivity due to the barrier of the laminate. Obviously, since surveyors in the field will not know the precise laminate thickness of the boat hull, and certainly can't perform accurate compensating calculations, the readings from thick laminate will be skewed.

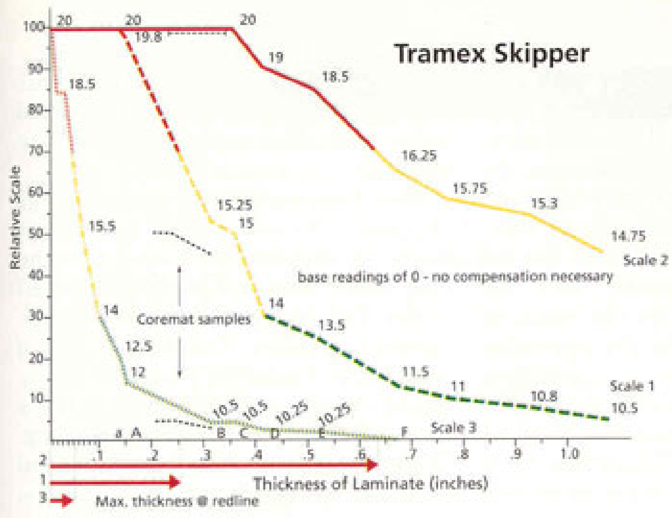
Only the Tramex Skipper remained totally unaffected by the dry samples. The Protimeter Aquant (without the clip-on near-field attachment) did not begin to give false-positive readings until the laminate samples reached .4" in thickness.











Performance curves of the five meters, which were asked to detect wet carpet beneath dry FRP panels of varying thickness. The vertical lines on the graphs are the relative scale (1–100) for each unit, while the plotted numbers are the actual numbers on the meter. (See the Feature Summary chart on page 52 for meter scales.) The red/yellow/green gradations along the bottoms of the graphs indicate where those colors correlate to the laminate thickness. (Protimeter Aquant does not use color coding to indicate moisture.) The top plotted line is the actual reading while the lower plotted line compensates for the false positive readings taken from dry laminate, making it a more accurate curve. The Tramex Skipper was tested once for each of its three scales; it does not need to be adjusted for false readings since it isn't affected by the dry laminate.

Adding the clip-on near-field attachment to the Protimeter Aquant resulted in extremely high readings on dry laminates more than .15″ thick. *This attachment will give wildly inaccurate readings in any thicker laminates.* Though not as dramatic, both the Caisson and the Sovereign readings were skewed by false-positive readings as the laminate thickness increased.

The Performance Curves. After taking baseline readings for the dry samples, we placed the panels on the wet carpet and tested them successively with the five meters. We recorded the results and plotted them on graphs with the horizontal axis as thickness of laminate in inches, and the vertical axis as relative meter reading (0–100). The resulting curve shows how each meter fared in detecting the wet carpet, while still returning a high reading as laminate thickness increased.

After subtracting the previously recorded false-positive readings for dry laminate, we plotted "compensated" curves for each meter. The greater the variation between the original curve and the "true," or compensated curve, the more difficult it is to trust that particular meter with thicker laminates.

Next, we added three panels of Coremat and 1808 bi-ply to simulate the skincoat of a topside laminate. We plotted the test results for the Coremat-covered panels against the corresponding thicknesses of solid laminates to see how the spongy material affected the readings.

As it turns out, the Coremat gave substantially lower readings. The air trapped in the layer of foam core soaks up some of the signal, which makes the task of punching through the outer laminate skin of a cored hull even more difficult. Furthermore, metering the topsides as a "baseline" for comparison to the underbody laminate may be misleading. While the topside laminate may be thinner overall, the Coremat will make it read as if it is thicker.

Results. We gauged the curves not only by the 0–100 relative scale, but also according to the arbitrary "green-equals-good, red-equals-bad" cutoff points on each meter's display. That way, it's easy to see how thick a laminate the meter can penetrate and still return a reading in the red zone. It's equally important to see at what thickness the meter will only have enough power to meter in the green—even if the underlying core is dripping wet.

The Tramex Skipper set to scale two was able to punch through more than .4" of laminate and still return a reading of 100. In terms of color code, the Tramex on scale two gave warning signs in the red at up to .63" of laminate thickness. These readings did not have to be "compensated," since this meter is not affected by dry-laminate thickness. Considering the operating principle of the meters, it's interesting to note that the Tramex has the largest pads of all the units, and that the pads are spaced far apart. This seems to be an integral reason for its excellent sensitivity when penetrating laminate.

In contrast, the Sovereign performance curve drops off very sharply. The Sovereign will only give a red "warning" reading if the thickness is *less than .02"*, or roughly the thickness of the gelcoat itself. At depths of only .06", the Sovereign readings drop off into the green/good range. At depths of more than .1", the compensated curve drops well away from the indicated readings (making the readings unreliable). Since the results show that the signal probably won't be able to punch through the skincoat, this means that the Sovereign is of limited value in assessing virtually any core damage.

The Protimeter Aquant readings dropped off fairly steeply to the 50% mark on its LED scale (this was the only meter without a green/yellow/red scale). But, the performance was relatively consistent. The unique way in which the Protimeter Aquant reads, based on the mass of moisture, has a marked effect on the meter reading. While the Aquant may be well suited to detecting significant water intrusion into a core, or a blanket of osmotic damage, it is not effective in tracking a small leak.

The Protimeter Surveymaster gave mixed results. Although an inspection of the unit's innards reveals what appears to be exactly the same transmitter and receiver as the Aquant, the response curve is well below that of the older Protimeter model. At the same time, the Surveymaster was sensitive to laminates thicker than .15", so its compensated curve suggests that it's somewhat unreliable in reading thick laminates.

Sensitivity to Solvents

	Sovereign	Tramex	Caisson	Protimeter Aquant w/o Near-Field	Protimeter Aquant Near-Field	Protimeter SM
Interlux 202 Naphtha Methyl Isobutyl Ketone Cyclohexanone						
Interlux 333 Kerosene			base .35 up to .39		20/103	10/2
Interlux 355 VinyLux Solv Xylene, MIK, Diacetone Alcohol	base 3/.5 up to 6/1.1		base .65 up to .70		105-106	
Lacquer Thinner Toluene Methanol Butoxyethanol						
Stove Alcohol (Methanol)	3 up to 5 (minor)		base .34 up to .56		one light (min.)	two lights (min.)
Acetone	15/10	40/14.5 scale 2 3/10.3 scale 1	base .36 up to .39		103–104	5/1
Diesel						
West 206 Hardener Mod. Aliphatic Polyamine						
MEKP						
Phanol Nontoxic Antifreeze Propylene Glycol	20/13	100/20 scale 2 25/13 scale 1	base 3 up to 1.5			
Engine Antifreeze Ethylene Glycol	100/25	100/20 scale 1 & 2 62/16 scale 3	12.8	35/105	80/112	35/7
Vinegar Acetic Acid	90/24.5	100/20 scale 1 & 2 50/15 scale 3	10.05	25/104	65/110	25/5
Water	57/21.25	100/20 scale 2 82/18 scale 1 10/11 scale 3	base .49 up to 3.39	10/102	104–107	15/3

Readings are in a relative scale (0–100) / indicated scale.
Figures for dielectric constant:
Water, 78.5; Acetone, 20.7; Methanol, 32.6; Ethylene glycol, 37.7 (Note that these numbers do NOT correspond to actual meter readings).

All samples dropped on a .130" FRP panel under a cover shim of .010 poly. The major components are listed below the brand names of the tested fluids. (For example, Interlux 333 is kerosene.) Some solvents did not register on the units, and although they were tested, the readings are too low to be listed.

Due to the small mass of the samples, the readings for the Protimeter Aquant and Surveymaster may be inaccurate.

Sensitivity to Unreacted Solvents

Myriad compounds trapped beneath the surface of a laminate actually may throw off moisture meter readings. Whether the compounds are added intentionally, or are defects in material or workmanship, the mystery of "the goop that lies under the gelcoat" has always been a wild card in moisture meter readings.

As I mentioned early on, one of the key operating principles to capacitance meters is the *permittivity*, or dielectric constant, of the surface between the plates. The following figures are the dielectric constants of some representative liquids:

water	78.5
ethylene glycol (antifreeze)	37.7
methanol	32.6
acetone	20.7

To set up the test, we smeared a series of compounds on a sheet of fiberglass, and then covered it with a sheet of .01"acetate. Our intent was to test the meter's reaction to just the compounds, with as little influence as possible from the film or backing. Since we used only a small volume of fluid in this test, the readings for the Protimeter may be unnaturally low. This is why the readings for the Protimeter Aquant were with the near-field attachment clipped in place. The table on page 59 is condensed from the original data.

Note that most of the volatile solvents and petroleum distillates, including MEKP, do *not* appreciably affect the meters. Apparently, just because the stuff is wet doesn't mean it'll make your meter go "beep." Acetone was the only solvent that caused a jump in the meter readings. Practically speaking, however, acetone flashes off so quickly that it would be unusual to see it trapped in the liquid state.

It's also interesting to see that methanol has virtually no effect on the meters either, despite its relatively high rating for dielectric constant. Here's another thing: the results for acetone and methanol contradict the permittivity principle.

Both of the glycols gave high readings. In fact, antifreeze routinely registered *higher meter readings than water.* Another surprise was the meters' strong reaction to vinegar. The relevance of both these readings is that maleic acid and glycols are essential components of polyester resin. Both compounds will be released into solution if the laminate suffers ester hydrolysis.

In other words, in a hull with a severe blistering problem, the meter is reacting not just to water, but to the broken-down polyester resin. This also explains why hulls don't "dry out" efficiently on their own. While water may evaporate, the greasy glycols won't. Understanding this fact should help repair-yard crews who are scouring the surface of a laminate in preparation for barrier-coating.

Effectiveness of Meters in Freezing Temperatures

There has been speculation of late that moisture meters become ineffective in cold weather. The manufacturer's literature from Tramex even warns of this problem. The reasoning behind it is unclear, but it must have something to do with the moisture in the laminate going into a solid state.

Effect of Freezing Temperatures on Meter Performance

	Cored Panel Saturated	Cored Panel Moist	Brown Rot Advanced	White Pocket Rot Incipient
Sovereign Room temperature	20/13	12.5/6	100/25	100/25
Frozen (26°F)	22/15	12/6	90/24.5	80/24
Tramex Room temperature	100/20 scale 2 95/19.5 scale 1 15/12 scale 3	100/20 scale 2 70/16.5 scale 1 9/11 scale 3	100/20 scale 2 100/20 scale 1 82/18 scale 3	100/20 scale 2 100/20 scale 1 82/18 scale 3
Frozen (26°F)	100/20 scale 2 82/18 scale 1 10/11 scale 3	100/20 scale 2 42/14.5 scale 1 3/10.3 scale 3	100/20 scale 2 100/20 scale 1 100/20 scale 3	100/20 scale 2 100/20 scale 1 50/15 scale 3
Caisson Room temperature	4.06	2.7	10.5	11.4
Frozen (26°F)	4.3	1.9	9	9.6
Protimeter Aquant Room temperature	25/104	20/102	85/113	65/110
Frozen (26°F)	10/103	5/101	65/110	45/107
Aquant (near-field) Room temperature	65/110	40/106	100/115	100/115
Frozen (26°F)	60/109	35/105	95/114	100/115
Protimeter SM Room temperature	30/6	15/3	65/13	60/12
Frozen (26°F)	30/6	20/4	55/11	55/11

Readings are in a relative scale (0–100) / indicated scale.
The results show that the permittivity of frozen water is *not* lower than room-temperature water.

We set up three test panels. One was a section of balsa-cored panel that had been partially soaked in water. One half of the panel was saturated with water, while the other was moist from water that had wicked up. The next test panel was a piece of oak with advanced brown-rot decay. We covered the pieces of wood with a layer of plastic to isolate them from the meter head.

We froze the test pieces in several different controls: a household freezer, a commercial freezer, outdoors on a dry cold day, and outdoors in snow (but covered). The panels were frozen for a minimum of three hours to overnight. At the time of testing, we confirmed the temperature of the panels with an infrared pyrometer. The lowest extreme was the commercial freezer, which brought the panels down to 9°F.

In short, the readings did not change appreciably. In all, we performed over five tests; the meter readings were consistent through all the panels and all the tests. We even tested the meters on frozen, soaked sponges, as well as

Miscellaneous Tests

	Sovereign	Tramex Scale 2	Caisson	Protimeter Aquant w/o Near-Field	Protimeter Aquant w/ Near-Field	Protimeter Surveymaster
Black Bottom Paint*	100/25+	100/20+	14	101 - 108 *	50/107-8 (35/105)	15-20/4 lights*
High-copper (75%) Bottom Paint	13/08	30/14 scale 2 11/1 scale 1	Negligible	Negligible	Negligible	Negligible
Baltoplate (Teflon Based)	01/03**	15/12 scale 2 10/11 scale 1	1.3 (.89 base)	0	106	15/3 lights
Fire-Retardant Resin (Valiant/Uniflite)	22.5/16	100/20+ scale 2 100/20+ scale 1 40/14.5 scale 3	8.1	55/108	85/113	40/8
Interlux AL-200	Elevated	Elevated	Elevated	Negligible	Negligible	Negligible

Readings are in a relative scale (0–100) / indicated scale on meter. Base readings are in parentheses.

*** Not all black paint gave high readings.** It depends solely on whether the manufacturer uses graphite as pigment. The Protimeter without the near-field attachment at times will register relatively high readings; presumably, because the entire paint film acts as an antenna. When a very small area is scraped away (half the size of the transmitter head, or .75" x 1.25"), the signal is broken and the readings drop dramatically.

** Another boat sample read "10" on a Sovereign and "18" on a Tramex (scale 2). The Tramex readings dropped dramatically ("11") when kicked down to scale 1.

Field samples can vary significantly in sudden changes of weather. Whenever a cool hull is subject to heat differential, sweating can occur.

on blocks of ice. There was no significant evidence that the readings were affected by the cold.

Surface Coatings and Resin Additives

The high metal content of many coatings and additives may cause a meter to deliver a false positive. Do you know when your meter's lying to you? Knowing when to *disregard* the meter reading is an important part of learning its limitations.

Black Bottom Paint. Most (but not all) black bottom paints contain graphite as a pigment. All of the meters gave extremely high readings when used on graphite-filled paints. The Protimeter Aquant without the near-field attachment will register, at times, relatively high readings. This may be because the entire paint film acts as an antenna. When, however, a very small area was scraped away (half the size of the transmitter head, or .75"x 1.25") the signal was broken and the readings dropped dramatically.

High-Copper Bottom Paint. Both the Sovereign and the Tramex (scale

Epoxy Panels & Additives

	Sovereign	Tramex Scale 2	Caisson	Protimeter Aquant w/o Near-Field	Protimeter Aquant Near-Field	Protimeter Surveymaster
Graphite Powder	20/15+ (1/6)	55/15.5 (5/10.5)	2.19 (.93)	102/3 lights (101/2 lights)	50/107–8 (35/105)	15–20/4 lights (2–3 lights)
Aluminum Powder	11/6	15/11.75	1.83	102/3 lights	45/106–7	15/3 lights
Copper Powder	.75/4	11.5/10.5	1.52	102/3 lights	45/106–7	15/3 lights
422 Barrier Coat Additive	.75/4	8/10.75	1.45	101/2 lights	40/105	15/3 lights
Carbon Fiber Tow	100/25	100+	16.75	65/110	100/115	75/15 lights

Readings are in a relative scale (0–100) / indicated scale. Base readings of the bare Masonite backing panel are in parentheses.

The surface of the panels was abraded to expose the additives. The meters in general *did* respond to the additive in the epoxy. With the powders mixed in solution, however, the resin appears to have inhibited the signal significantly. The raw carbon tow is used as a reference. Even if the carbon fibers are impregnated in an epoxy laminate, the signal is typically "off the scale." Note that the Protimeter Aquant did *not* react significantly to the additives, as its signal begins to read just beneath the surface film. With those meters that can read reliably at deeper than .040", the use of additives in a surface layer may be factored into resultant readings. Therefore, if the meter "pegs," then a portion of the high reading is due to the barrier coat, but the remainder is reading subcutaneous moisture. On the other hand, if the hull has been coated with a very thick layer of barrier coat/repair laminate, other meters may have a difficult time punching through this layer to give an accurate read of the underlying laminate (especially the Sovereign).

two) gave slightly elevated readings, though nothing alarming. The Tramex reading dropped when it was switched down to scale one. The Sovereign seemed to be more sensitive to hydrophilic paints, especially on a boat just hauled out of the water. The other meters gave fairly stable bottom readings when the surface of the bottom was washed and dried.

Teflon Racing Paint (VC Baltoplate). There were some cases where the Tramex on scale two and the Aquant with the near-field attachment gave high readings. The Tramex readings dropped dramatically when switched down to scale one.

Aluminum-based Primers (Interlux AL-200). The Sovereign, Tramex, and Caisson tended to give elevated readings. The Protimeter Aquant was unaffected.

Fire-Retardant Resins. Old Valiants and Uniflites were notorious for the fire-retardant resins in their laminates that led to severe blistering. All of the meters showed elevated readings when placed on an old Valiant hull that had been peeled and kept out of the water for several years. Both of the Protimeters gave elevated (40–55) readings, though neither "pegged." Since the resin itself gives high readings, it's difficult to monitor a blister-repair job on one of these boats. How will you know when the boat is "dry"?

Epoxy Additives. Some barrier-coat systems employ powdered fillers such as aluminum, copper, or graphite. The graphite filler definitely caused higher readings. The Protimeter Aquant did not give a significant reading (though the area of the sample panel may have been too small to return an accurate signal). As with the black bottom paint, the best way to "rule out" the barrier coat as a factor in a high reading may be to grind off a very small area and retest with the Aquant.

Condensation. Given the right conditions and a temperature gradient, a boat hull will sweat a significant amount of moisture. Meters that are particularly sensitive, such as the Tramex set to scale two, will give extremely high readings. The Protimeter Aquant without the near-field attachment, though, should not be affected as significantly by a nominal condition on the surface of the hull.

Conclusions

Bruce Pfund's original work on moisture meters pointed out the shortcomings of these tools in trying to divine the onset of osmotic blistering. The units are not calibrated specifically for use with FRP. At the same time, it would be misleading to think that they can provide an accurate "percentage" reading of moisture.

On the other hand, moisture meters can be crucial nondestructive aids in detecting water migration into core material. The keys to performance in this respect seem to be sheer sensitivity and the meter's ability to read through the fiberglass outer skin. The Tramex Skipper, set to scale two, was the clear favorite in the thickness test. In contrast, the Sovereign's failure to penetrate all but the thinnest laminates is a severe shortcoming.

False positive readings can be a significant hindrance in the field. In this regard, the sensitivity of the Tramex is also its greatest liability. The tests seemed to prove that the unique operating principle of the Protimeter Aquant allows it to discriminate between a significant mass of moisture and a surface anomaly. Sometimes it's just as important to pay attention to what a meter doesn't tell you.

No single meter performed flawlessly in all the tests. With some input to the manufacturers and a willingness on the part of surveyors to invest more money for a quality instrument, I think we might eventually see the introduction of a multifunction "uber-meter."

Until that time, the best approach is to use two meters with different operating principles. This isn't unreasonable, especially considering that meters haven't increased in cost for the past 10 years. I've been trying this "two-gun" approach in the field and find that it's a handy way to either confirm or rule out abnormal readings.

Above all, setting up and running this series of tests has taught me to be more objective in interpreting readings and not to place blind faith in the little black box. We cannot expect to be considered experts in our field merely by buying the toys. Don't just trust these results; go out and perform your own tests with several different units. Invest some time and "become one with your meter." PBB

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Some Moisture Meter Sources

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Tramex Ltd.
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Product: Skipper Moisture Meter

Caisson Audio Produas B.V.
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Product: Novanex V1/D3 Moisture Indicator

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