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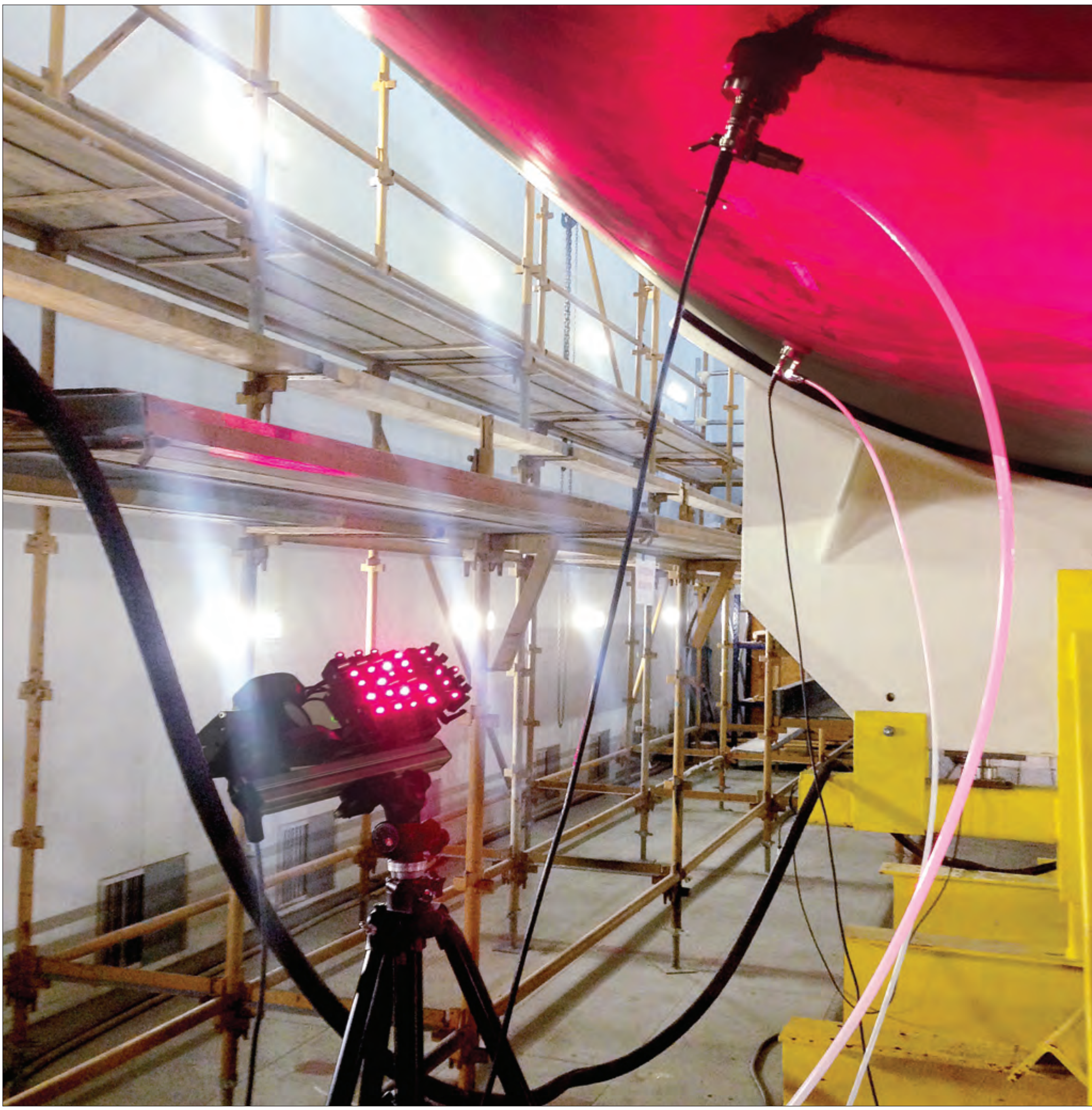

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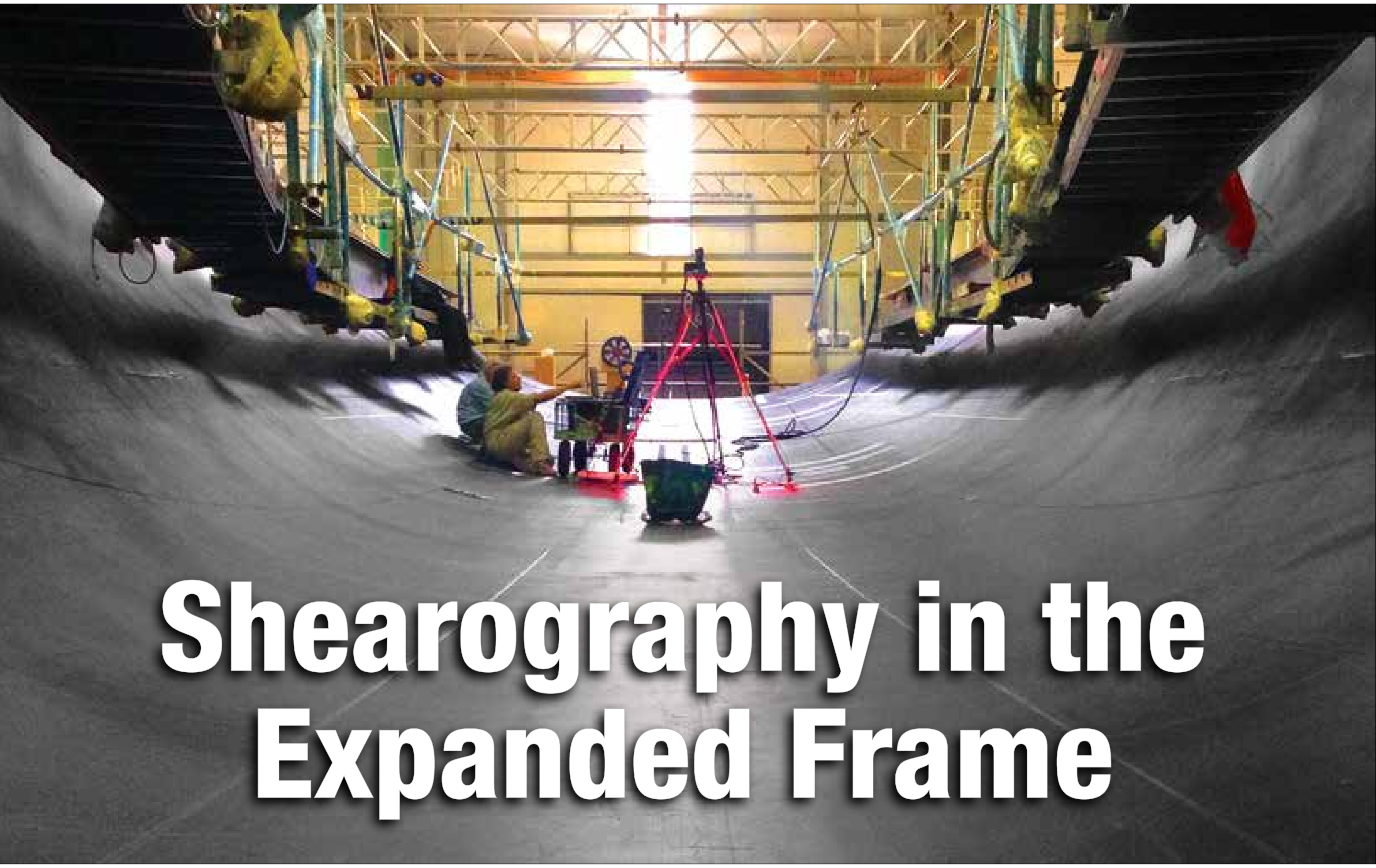
ADVANCES IN LASER SHEAROGRAPHY
OFFSHORE-RACING ROUNDTABLE
A LITHIUM-ION HOUSE BANK
MAINE YACHT CENTER



Shearography in the Expanded Frame

Recent technological advances in laser shearography allow for non-destructive examination (NDE) of large areas in less time and at lower cost than ever before.

Text and photographs by Roby Scalvini

Laser shearography (LS) was developed decades ago for the aerospace industry—B2 stealth bomber, the space shuttle, Airbus, etc.—to detect defects in composite structures (particularly sandwich) not detectable by other, more conventional NDE methods. Later it made a timid appearance in the marine industry but failed to gain the popularity it deserves.

Things have changed.

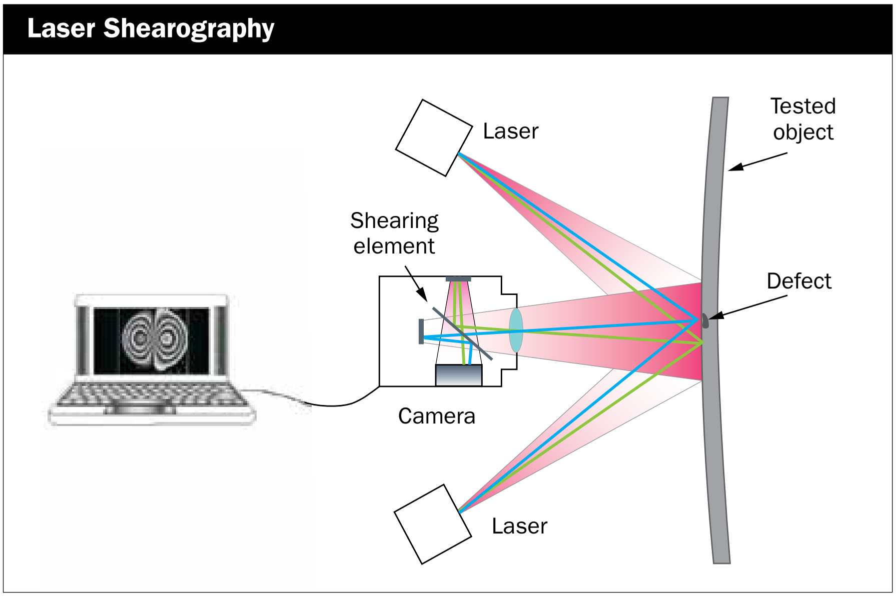
How It Works

Laser shearography is a noncontact optical method of detecting nanometric deformation changes in the surface of an inspected part. Small changes (stress loads) are applied to the part while it is illuminated by a suitable laser light. Stress increments alter the structure's surface, but the change in the surface over a defect imbedded within the composite structure differs from the surrounding sound laminate. These changes are detected and recorded in real time, as "phase shifts" in the reflected laser light. The **diagram** on the facing page shows the basic setup of a shearography system.

The test begins with the recording of a shearogram (an image of the laser-illuminated surface). After an incremental stress load is applied to the object, causing a small, almost imperceptible deformation of the illuminated surface, a second shearogram is recorded. Subsequent subtraction of the two images yields visible interference fringes related to surface strains, indicating the position of underlying defects.

Stress loads can be applied to the part by heat, vacuum, pressure, or as we will see later, by ultrasonic waves (a method called dynamic excitation). Note that due to LS's sensitivity, only very minor stresses are required: 3.6°F (2°C) increase in temperature, or 1 psi (0.007 N/mm^2) of vacuum.

Although LS is widely recognized for detecting a variety of defects in composite structures, it has never become mainstream in the marine industry due to the cost of equipment



Facing page—*Crew from NDE Solutions applies its latest laser shearograpy device to scan the hull of a 100' (30.5m) advanced-composite high-performance sailing yacht in build. The tripod-mounted shearographic camera increased the field of view (FOV) by 4,500% over that of the conventional vacuum hood; testing the entire hull required only 240 shots, reduced from more than 10,000, and was completed in three workdays.*
Left—*In basic shearography, the shearing element and lasers are contained in a single housing. In expanded-FOV shearography, those components are exposed and visible, as shown here.*

and inspections, operational limitations, and limited applicability.

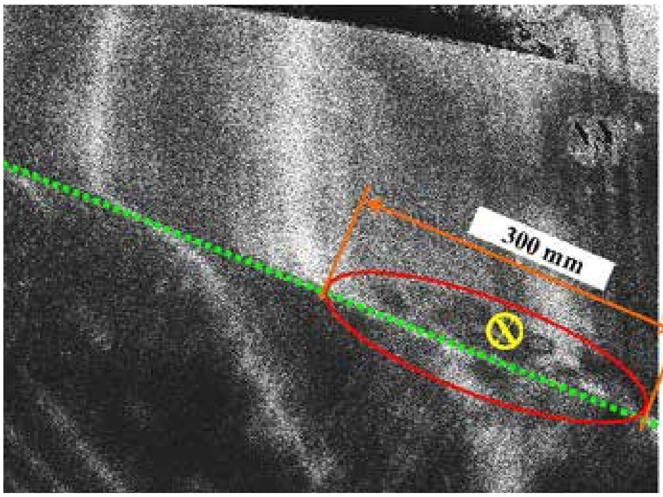
One of the best features of LS is that it is a "full-field" method, meaning that 100% of the inspected area is examined. This is a big advantage over ultrasonic testing (UT), for example, which tends to be limited to "spot-type" inspections; individual readings are taken at specific intervals, typically every 8″–20″ (20cm–50cm) over a grid or pattern, much the same as readings for ultrasonic thickness testing (audio gauging) of a metal hull are taken. The inspector can gauge the quality of the laminate only in the area immediately below the probe, typically ¾″–1″ (20mm–25mm) diameter, leaving potential flaws undetected in the gap to the next reading.

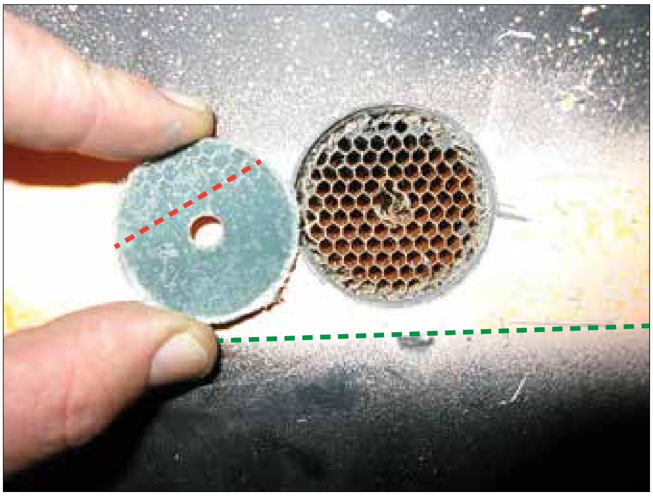
For monolithic laminates, UT grid inspection may be the only option, but for sandwich construction, especially when employing honeycomb cores, LS is clearly a more suitable choice. Particularly after Kevlar honeycomb was introduced as a substitute for Nomex honeycomb, a number of structural failures have been detected, sometimes too late, at the edges of the honeycomb panels. These core-edge disbonds are due to Kevlar's notoriously more difficult adhesion compared to the well-proven Nomex. However, as the structural properties of Kevlar honeycomb are significantly higher than those of Nomex, and Kevlar costs only marginally more, it is becoming a more common choice for high-end yachts.

(For more laser shearography basics and a case study of a carbon fiber mast inspection, see "Carbon and Lightning," *Professional BoatBuilder* No. 128.)

Stressing Techniques

Since 2009 at NDE Solutions (the Marine Survey Bureau's subsidiary for NDE work) we have been using three techniques for stressing the subject laminates. In that time we have developed a good understanding of each method's specific applications and limitations for inspecting boats.





Left—*A shearogram of the port aft chine (dotted green line) of a contemporary 72' (22m) racing yacht reveals core bonding defects (in red oval). The yellow X marks the location of the core sample shown at* ***right.*** *The destructive test confirms the shearogram's indication that there is a significant never-bond between the Kevlar honeycomb core material and the film adhesive in this area. Such manufacturing defects are generally not detectable with conventional non-destructive examination (NDE) techniques such as ultrasonic or infrared thermography.*

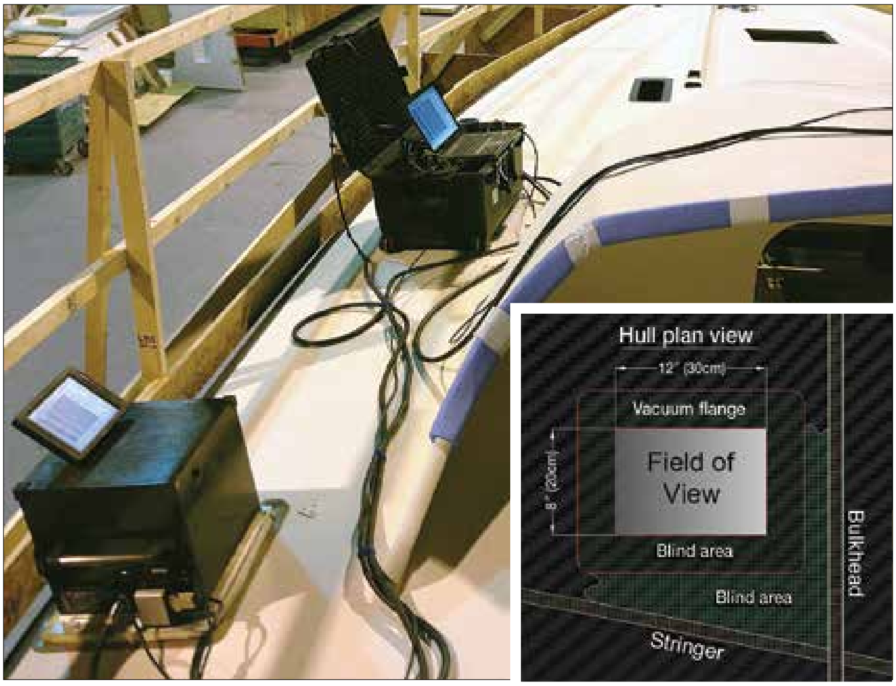
Vacuum is the most common stressing technique, employed mostly in the aerospace industry. The shearographic camera is placed inside a sealed box (known as a vacuum hood, open only on one side), from which air is extracted by a fast vacuum pump. This extremely sensitive system is capable of detecting very small defects in the composite structure.

One of this method's main limitations is its small field of view (FOV). The proximity of the camera to the inspected part limits each shot to a maximum of 12″ x 8″ (30cm x 20cm), so only small areas, rather than complete structures, can be assessed.

Also, the geometric shape of the vacuum hood itself limits this technique to fairly flat panels, excluding complex geometries such as compounded shapes, chine corners, internal reinforcements, and joints, exactly where most of the defects in a sandwich panels are most likely to occur. For these reasons, inspecting complete hulls with a vacuum hood can be impractical and uneconomical.

The ***heat load*** technique (employing heat lamps to stress the part) is somewhat more versatile than the vacuum hood; however, achieving uniform and repetitive heat also limits the FOV.

Dynamic excitation, a more recent introduction, employs ultrasonic waves to induce a stress load, and it was an improvement, as any shape could be inspected. FOV also increased considerably from the 12″ x 8″ of the vacuum hood and the heat load. But at 28″ x 20″ (70cm x 50cm), FOV was still fairly small.

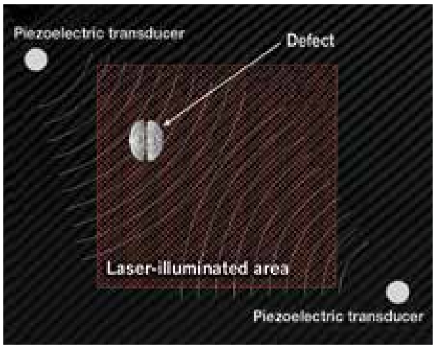


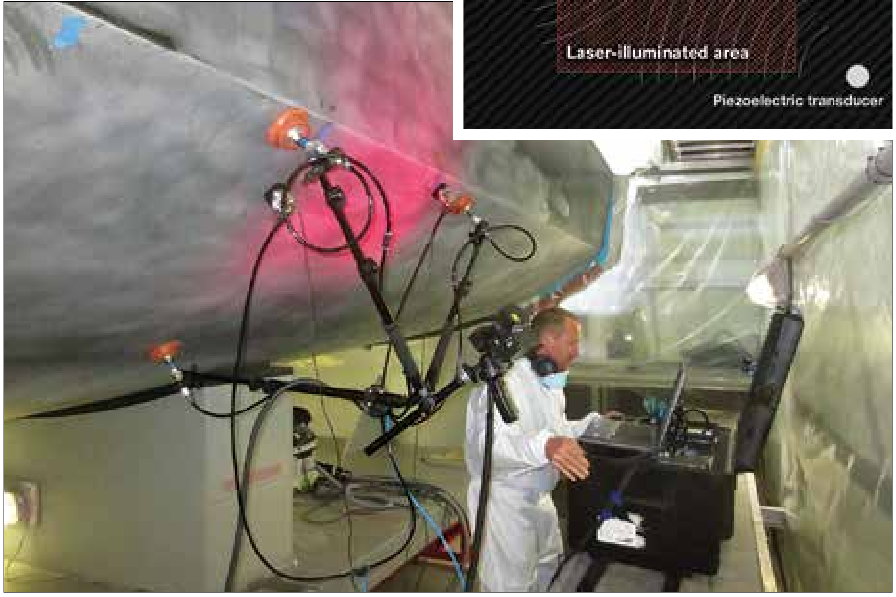
A conventional shearography setup includes the vacuum hood, foreground, and attached computer. The FOV, ***inset,*** *is limited to 12" x 8" (30cm x 20cm), and the shape of the hood prohibits this setup's use on complex shapes such as chine corners and internal reinforcements, exactly where flaws in cored panels most likely occur.*

While we will continue employing each of the techniques for specific applications, we have concentrated our efforts on dynamic excitation. We have found it to be the most versatile, especially for inspecting large areas, and now—thanks to a recent upgrade—that area has increased significantly.

Dynamic-Excitation Upgrade

With dynamic excitation, one or more piezoelectric transducers (piezo-shakers) propagate ultrasound waves at different frequencies 360° into the part. At certain frequencies, objects start to resonate in a homogeneous way, known as their "natural frequency." Discontinuities or defects embedded in the part resonate at different frequencies, which are detected and recorded. The **image** at left shows the basic principle of this technique, employing two piezo-shakers.





Expanded-FOV shearography utilizing dynamic excitation, rather than a vacuum, to stress the test surface can shoot a larger area (28" x 20"/70cm x 50cm), including complex forms such as chines. ***Inset***—*With this method, piezoelectric transducers send ultrasound waves through the structure at different frequencies to reveal discontinuities or defects, which resonate at frequencies different from those in the surrounding sound laminate.*

One of the obvious advantages of the dynamic-excitation method is its ability to test for damage or initial laminate quality of complex shapes such as this carbon fiber bowsprit.

This technique took on a new dimension when a regular client recently asked us to carry out a comprehensive quality assessment of the laminate structure of an advanced-composite 100′ (30.5m) high-performance sailing yacht. It was built with the intermediate-modulus prepreg carbon fiber reinforced plastic and extensive use of Kevlar honeycomb. Saving weight was clearly the number one goal, which meant pushing composites engineering to the limits.

Advanced composites are ever-evolving, and their recent optimized applications leave little margin for error or defects. Assessing the quality of these composites requires ever-evolving advanced NDE techniques as well. With the support of our equipment manufacturer, Isi-sys, in Germany, we upgraded our equipment into an LS system with dynamic excitation capable of covering a much larger FOV for each shot, making it possible to inspect larger areas in less time.

This included increasing the laser illumination, modifying the optical lens, employing a faster computer processor, and upgrading the generators and amplifiers controlling the piezo-shakers to a full digital system. To increase the FOV we had to

Equipment for performing laser shearography with dynamic excitation includes multiple piezoelectric transducers, ***far left,*** *and larger laser illumination arrays,* ***left.***

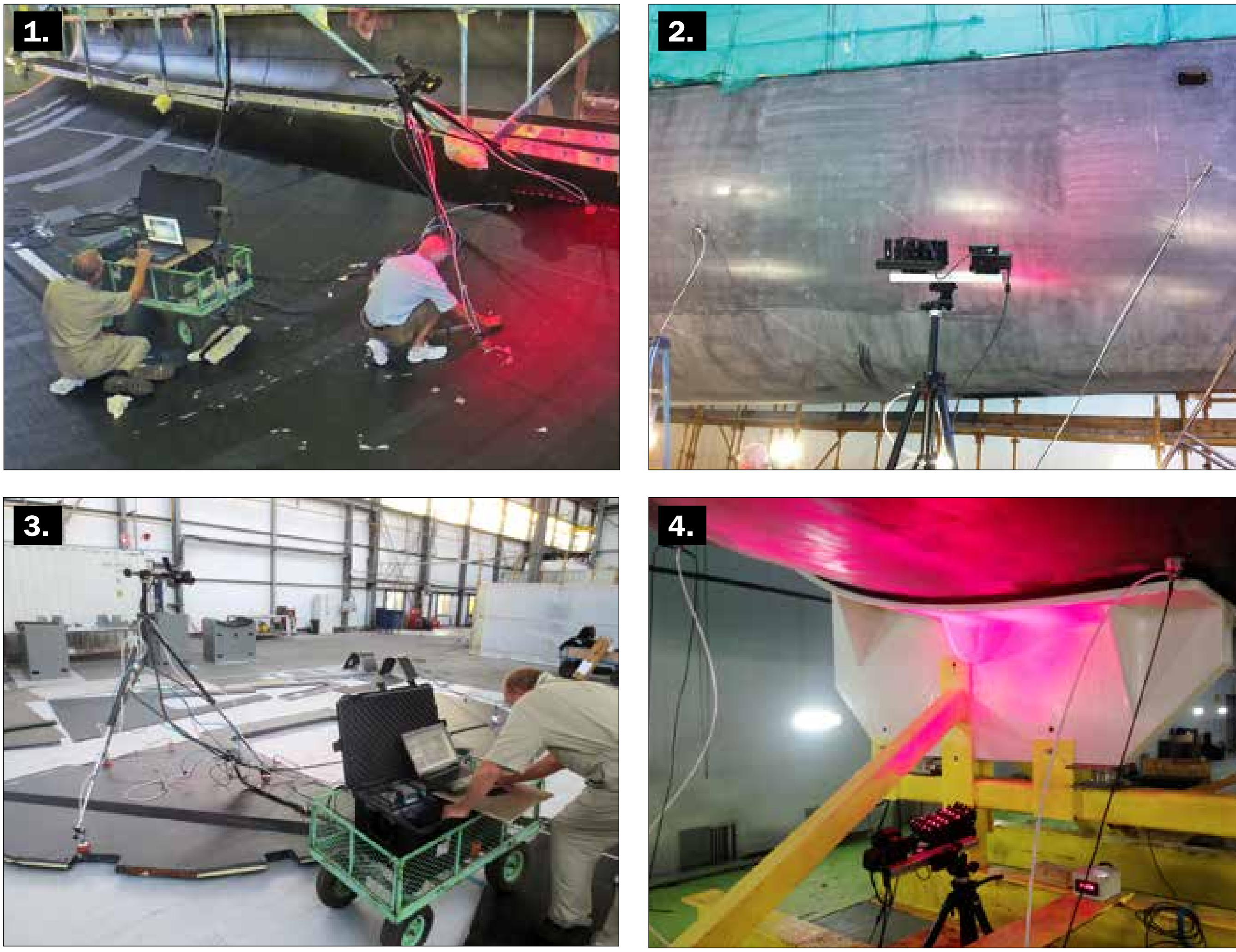
acquire a much larger, sturdier tripod to firmly hold the shearographic camera farther away from the part.

The whole system still fits in a 31.5″ x 20.5″ x 16″ (80cm x 52cm x 40cm) Pelican Storm Case and weighs less than 55 lbs (25 kg). It is easy to transport as checked luggage and easy to handle on site.

With these modifications, the new FOV increased to 71″ x 59″ (180cm x 150cm) for each shot, 4,500% larger than the FOV of a vacuum hood. In practical terms, the number of shots required to inspect 100% of the 100′ yacht's hull and deck structure was reduced from a staggering 10,000+ (totally impractical) to a mere 240, which can be done in three workdays.

By increasing the FOV, the equipment's sensitivity had to be turned down dramatically, with the size of the smallest detectable flaw increasing from the few microns detectable by a vacuum hood to a few millimetres in the broader FOV. However, you can still zoom in on critical, stressed areas for closer inspection.

Before the inspection at the yard, we tested the new system on representative sandwich panels with purpose-built defects and found it could reliably detect flaws as small as 0.6″–0.8″ (15mm–20mm). Then we staged the inspection in three visits. Completely examining the yacht's 7,000 sq ft (650m²) of composite surface area took less than 30 hours.



In just 30 hours, NDE technicians, working primarily at night so they wouldn't interfere with the build crew, inspected the complete 7,000-sq-ft ($650m^2$) composite surface area of a 100' high-performance sailing yacht. ***1****—The project started with the inner skins of the hull and deck parts while they were still in their female tooling.* ***2****—Next, the outer skins were tested when the parts were released from the tooling. Note how far apart the two piezoelectric transducers (at the ends of the white cables) are on the hull surface.* ***3****—Bulkheads were inspected flat on the shop floor before installation.* ***4****—Here, the curved hull bottom is bathed in red laser light during testing. The full project revealed mostly common defects in bondlines between prepregs and the Kevlar core. The tests enabled the builder to correct those flaws before the vessel went into service.*

Inspection and Results

First, we assessed the inner skins of the hull and deck while the parts were still in their female tooling, and then their outer skins after they were released from their tooling and assembled. All bulkheads were inspected. All inspections took place at night, which had the double advantage of not interfering with the yard's daytime production schedule, while providing the quiet conditions necessary for an LS inspection. (A dozen boatbuilders thumping on deck while we try to measure nanometric deformation changes in the surface of the inspected part does not really work.)

As expected, we found a number of inevitable manufacturing defects, mostly related to the bondline between prepreg skins and Kevlar honeycomb. This thorough quality assessment gave the yard the option of rectifying the defects under optimum shop-floor conditions, rather than letting them go undetected and possibly causing much greater havoc once the vessel was in service.

Another advantage of a recordable full-field optical technique versus ultrasonic spot inspection is the ability to document images. Ultrasonic testing readings are sparse and generally not recorded unless they are abnormal, but images produced during an LS inspection can be recorded and stored long term for reference, the same way as are X-ray shots of the welds in a metal hull. Such documentation is certainly a bonus and a safeguard in an increasingly litigious world.

While the cost of the LS equipment remains fairly high for the average yard, I'm sure that this upgrade to dynamic-excitation will open the door to testing more and more advanced-composite yachts with laser shearography. PBB

About the Author: *Roby Scalvini, the principal surveyor at the Marine Survey Bureau, in Palma de Mallorca, Spain, is a specialist in advanced nondestructive testing, and a contributing editor of* Professional BoatBuilder.