The Necessity of Straight

A visit to Straight Line Marine, in Fort Lauderdale, Florida, is a refresher course in the practices and precision required to get running-gear alignment right.

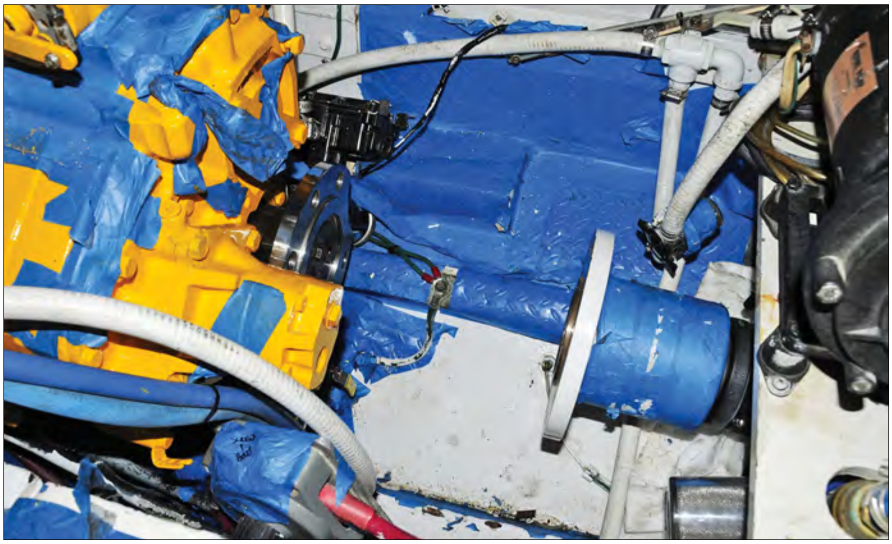
Text and photographs by Steve D'Antonio

Once, after I was asked by a boat owner to correct a misaligned shaft, the boat's builder said to me, "There are many ways to do an alignment, and most of them are right."

I couldn't disagree more; there are very few correct means of carrying out the two primary types of alignment: engine to shaft, and shaft to bearing. Regrettably, these procedures are poorly documented. (While American Boat & Yacht Council Standard P-6, Propeller Shafting Systems, covers running gear, it, like all such standards, isn't a how-to manual; I know of no alignment instruction manual.) I suppose I shouldn't be surprised that I continue to find poorly aligned shafts on new and used vessels alike.

Such a lack of authority makes it easy for misinformation to spread. For instance, it's a popular belief that shaft misalignment can be detected by obvious clues, like vibration. Indeed, while vibration may be an indicator of shaft misalignment, I've run sea trials on many vessels that were smooth and vibration-free, only to learn upon haulout that the running gear was seriously misaligned; and in some cases, I was unable to turn the propeller and shaft even when applying my full body weight to the propeller.

I've heard industry colleagues readily dismiss these episodes as "dry bearings" or, "All boats are like this when hauled; it's different when they're in the water." That's also not true. Rest assured, with "wet" bearings (they can be lubricated with diluted dish detergent but never oil- or petroleum-based lubricants), shafts should turn with no more effort than it takes to lift and carry a suitcase, and in some cases, with only fingertip pressure. While it's true that hulls, particularly wooden ones, distort when hauled, if they distort enough to make a propeller shaft impossible or very difficult to turn, how can one be sure they aren't distorting equally when afloat, in another plane, and thereby imparting just as much or more resistance to shaft motion? While this can be



Facing page—*Altering the shaft alignment typically requires adjusting the location of the struts. This is often accomplished by making customized shims from thickened epoxy. Here, temporary wedges position a strut while the epoxy shim cures.* ***Left***—*In most cases, the term* alignment *refers to the interface between the engine and the shaft couplings, shown here during installation.*

evaluated to some extent by turning a shaft while a vessel is afloat, there's always the possibility that this will change when in a seaway. In my experience, if a shaft is difficult to turn when a vessel is hauled, it's always an indication of a problem related to alignment or, in some cases, bearing-to-shaft clearance.

Why is misalignment an issue if the symptoms are often so subtle? Shaft misalignment increases wear on shafts and cutless bearings. It may also lead to wear of other components not designed to support or make contact with the rotating shaft. The primary area of unintentional contact that misalignment affects is the shaftlog, the tube through which the shaft passes as it exits the vessel. This drag increases fuel consumption and can potentially damage both shaft and log. In a few cases, it may cause vibration, but that's not necessarily a given or, as mentioned above, even that common.

Alignment Primer

When I received an e-mail from Chris Brown, a shaft-alignment specialist and the owner of Straight Line Marine, a division of High Seas Yacht Service, in Fort Lauderdale, Florida, I immediately recognized a kindred spirit since I have spent a good part of my professional career studying and honing my understanding of shaft alignment, as well as helping boat owners find a boatyard where repairs can be carried out. During the decade I managed a boatyard and custom boatbuilding shop, the frequency of running-gear-alignment issues seemed to increase with each passing season.

Brown's note was in response to a column I'd written on propeller nuts and the order of their installation (see "Nuts. Bolts. Screws," *Professional BoatBuilder* No. 118). His concern about such an esoteric subject signaled that he was detail oriented and experienced when it came to running gear. It didn't take long for our dialogue to progress to an invitation to tour his shop, which I readily accepted.

Before I share my visit, a primer on alignment may give the reader a better understanding of Straight Line's efforts and accomplishments. As previously noted, there are essentially two types of alignment: that of the engine to the shaft, and that of the shaft to its supporting bearings.

• To align the **engine to the shaft**, the engine is jacked or shifted to align the transmission's output coupling flange with the propeller shaft's flange. The goal is to ensure that the two couplings are centered on each other and parallel to within a few thousandths of an inch, usually somewhere between three- and seven-thousandths of an inch (0.076mm to 0.178mm). It should not exceed one-thousandth of an inch (0.025mm) for every inch (25mm) of coupling diameter, and preferably should be less. By comparison, U.S. paper currency is about four-thousandths of an inch (0.102mm) thick. Savvy alignment technicians pride themselves on their ability to adjust this gap to the lowest possible figure.

Raising and lowering the engine, to bring the flange faces into parallel vertically, is accomplished by turning the jacking nuts on the motor mounts (these are sometimes referred to as isolators, because they help to isolate engine vibrations from the stringers and hulls). To close the gap at the 12 o'clock position on the coupling, for example, the forward end of the engine might be raised or the aft end lowered. To do this while maintaining center orientation between the couplings may require that all mounts be raised or lowered in unison, irrespective of the specific adjustment required to close the gap. That can be tricky, and it gets trickier. The range of motion is

Left—*While misalignment can result in the shaft making contact with the shaftlog, that doesn't necessarily cause vibration, because the misalignment is constant. However, it does create drag, leading to wear on the shaft and log.* ***Right***—*Gaps and compression at bearings—like the large space between the top of this bearing and the shaft—offer clues about alignment and should not be ignored.*

Left—*An adjustable motor mount is shimmed to reduce stud extension. Boatbuilders should ensure that an initial engine installation is properly aligned without relying on excessive extension of motor mount studs, which can lead to stud failure. Instead, motor mounts should be thought of as tools for fine-tuning alignment.* ***Above***—*Alignment between the engine and shaft couplings requires precise measurement, using geometry and feeler gauges, like those shown here. Ultimately, coupling faces must be made parallel and centered with each other to within a few thousandths of an inch.*

limited to as little as ½″ (12.7mm) or less, depending on the motor mounts' installation requirements.

The onus is on the boatbuilder to set up the initial engine bed alignment as close as possible. Failure to do this can cause mounts to be overadjusted. When that happens, too much of the adjustment stud is exposed below the engine bracket, creating significant leverage, which can lead to stud failure. That leverage can be corrected by adding a shim under the mount's base. Overextension of mounts also may require the engine to be lowered beyond the mounts' lowest adjustment, which often can only be achieved by cutting or modifying the engine beds or stringers, or modifying the engine brackets attached to the mounts. However, if the builder does his or her job, it should not be necessary to add shims, cut engine beds, or modify brackets. Motor mount adjustment should be considered fine-tuning rather than gross adjustment.

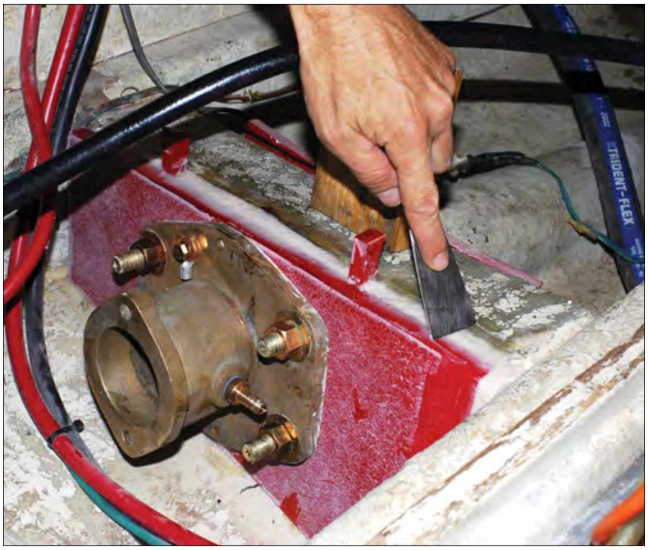
Adjusting the engine laterally to achieve acceptable gaps on the port and starboard sides of the coupling faces can be a bit more challenging; it requires pushing the engine from side to side, often with the assistance of a hydraulic jack for larger engines. Conducting this sort of alignment can be a brainteaser. For instance, to close a gap at the 2 o'clock position on the coupling faces, the front of the engine may have to be raised and moved to the left, while reducing a gap at the 6 o'clock position could require lowering the front of the engine or raising the rear of the engine or varying degrees of both. However, as tricky as this may sound, it should be well within the capabilities of any skilled marine mechanic, and it typically requires only combination wrenches, a lever bar, and/or a hydraulic jack kit.

• The other type of alignment—that of the **shaft to its bearings**—is entirely different. Once installed, shaft support bearings are not designed to be moved or adjusted (not easily at least). Boatbuilders should be getting this alignment correct from the start; however, based on the volume of misaligned shafts I encounter, many builders simply don't spend the necessary time and energy on this task. Ultimately, this can lead to costly trouble for the boat owner, as misalignment may result in pinched cutless bearings; prematurely worn shafts, bearings, and shaftlog (through contact with the shaft); and vibration.

The first step in correcting any of these problems is accurate and quantifiable assessment. The traditional approach involves removing the shaft and then passing a length of string or wire through the bearings up to the center of the transmission. When pulled taut, the wire simulates the shaft's centerline and forms a reference point to measure against using a caliper. It works, but it's primitive. For lengths more than about 12′ (3.6m), the wire will sag no matter how tightly it's stretched (it needs to be glued to the center of the transmission flange, so it can be tensioned only so much), inducing some error. An alternative to the piano wire, and one I've used for much of my career, is to measure against a laser pointed at targets placed in the cutless bearing and at the transmission flange. Optical alignment is another approach, which Straight Line has been using for many years and will be explained below. Both of these newer measurement methods are significantly more accurate and easier on those making the adjustments.

Once you assess the bearings' positions, they and/or the struts and shaftlogs should be corrected by separating them from the hull and then shifting them into a position that ideally brings them into perfect alignment with the centerline of the shaft when it is reinstalled. Typically, struts are "mushed" into a thickened epoxy

Above—*The hull has been ground before an epoxy shim material is applied. Once that's applied, this strut can be moved into position so the epoxy fills the gap between it and the hull.*
Right—*Shaftlogs may also require alignment. This log is shimmed with prefabricated fiberglass sheet, which was then set in thickened epoxy to facilitate final positioning.*



mixture and supported in place until the epoxy cures, forming a custom fit and sturdy foundation. Shaftlogs can be more challenging, as many are an integral part of the hull, meaning their removal can require significant fiberglass or metal work. Yet, I've never found one that couldn't be moved. Entire shaftlogs, or just the bearing in cases where only smaller adjustments are needed, can be repositioned and mushed in place. (For more about proper alignment techniques, see "Running Gear Alignment" on www.ProBoat.com.)

Too few yards are adept at assessment, and fewer still are capable of carrying out the realignment of bearings, struts, and shaftlogs. In the consulting work I've done for boatyards seeking to broaden their expertise, I've encouraged them to take on a specialty that's in demand but uncommon. Shaft alignment falls into this category. When I managed a yard that specialized in this work, there was never a shortage of customers.

The Making of a Technician

Brown grew up in South Florida and was quickly drawn to boating, mostly sailing. Shortly after college he took his first boatyard job as a fiberglass repair apprentice. On his first day, at $3.50/hour, he was handed a grinder and a dust mask and ushered to a boat. This was a test (and one I've used on more than a few occasions) of a new employee's resolve, particularly a young one's: "So, you have this dream about working around boats? Okay, here's a longboard. Go make that wavy hull fair, and don't come back until it's done." I've seen many go to lunch on the first day and never come back. Brown came back. He ultimately gravitated toward building and sailing ultralight offshore racing sailboats. He then worked as a yard manager for a few years.

After acquiring High Seas Yacht Service, Chris Brown successfully secured its position as a shaft alignment specialist, and he added other skill sets, including shaft cladding and hydraulics installation and repair.

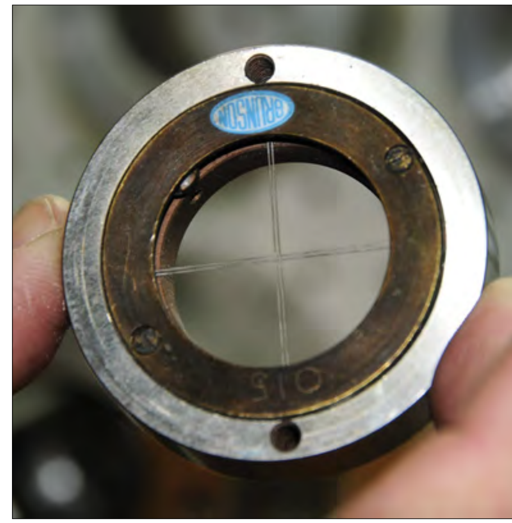
In the late '80s he left boats behind to become a corporate warrior in product development, sales, marketing, and strategic business planning, all heavily focused on customer support. Those offered a superb on-the-job business education and a chance to globe-trot; that's what he did for the next 25 years. As gratifying as the work was, he began longing for a business of his own and to return to his roots in the South Florida marine industry. He found High Seas, or it found him, via a business broker, and he purchased the company in 2008 on the day it went up for sale.

High Seas Yacht Service started life in the 1980s as a mobile marine-repair business, sending trucks and crews around the Fort Lauderdale area, to boatyards and residences, where they carried out all manner of routine service and repair work. By the late 1990s High Seas became running-gear exclusive, opening its Straight Line division in 2003. While alignment has remained its focus, in 2012 the company added High Seas Hydraulics—specializing in steering, winches, thrusters, stabilizers, and passerelles—which occupies one of its four bays. High Seas staff hold certifications from most major hydraulic equipment and stabilizer manufacturers.

Brown knows running gear and alignment intimately. In preparing for this article, I worked with him to solve a persistent vibration on a boat owned by one of my clients. We reviewed running gear that several other people had gone over on multiple occasions with a variety of fixes carried out, none of which had a meaningful effect. When Brown and his crew got their hands on the running gear, they quickly discovered a serious inherent manufacturing flaw: the shaft was not centered in the original shaft coupling.

As Brown took me into Straight Line's shop, I felt right at home. Located in four large bays, it had all the requisite sights, sounds, and smells of a busy shaft and machine shop: a huge lathe with a large shaft chucked up (the one I saw could accept shafts up to 4″/102mm in diameter, while a recently acquired second, larger lathe increases capacity to 9″/229mm shafts); the hum of operating machinery; and the unmistakable aroma of cutting oil. I glanced at a wall posted with technical articles and bulletins, primarily for visiting customers and boat captains ("new" techniques can be a tough sell to the latter). It was clear Brown understood two of the most essential aspects of this business: knowledge and its dissemination to those making decisions about vessel upkeep, service, and repair.

We walked to the back of the shop, to what I call the tool crib, where Brown showed me Straight Line's series of precision optical scopes. Typically, these are used for land surveying and setting up alignment on industrial equipment and inside large ship engines. They are essentially telescopes with a set of crosshairs—similar to a scope for a spotter or rifle. The scope is pointed at targets: 2″-diameter (51mm) pieces of glass with microline crosshairs in the center. In the hands of a pro, the optical scope can deliver accuracy that, if you're an alignment junkie, is sublime. Now I wanted to see it in action.



Crosshairs center an optical alignment target. High Seas prefers optical over laser alignment for a variety of reasons, with accuracy over greater distances being chief among them.

How the Optical Scope Works

When I peered through it I could see just how sharp the scope was. It allowed me to focus on different targets, each representing a bearing location (you can't do that with a laser). Typically, three glass targets are used in an alignment. The first two are set up to create a straight line, which is done by placing one optical target in the center of the aft strut and the second in the center of the shaftlog. With the optical scope on a tripod 1′–2′ (305mm–610mm) aft of the strut, the technician then focuses the scope's crosshairs to the crosshairs of both targets (the clear glass of the first target allows the scope to see the next in line). After many careful adjustments and constant focusing and refocusing, the technician eventually aligns both targets, creating a straight line to work from. Then the third target is placed in the center of the transmission output flange, and the technician focuses the scope through the first two perfectly aligned targets to the third one on the transmission. If the scope does not align with the crosshairs of the target on the transmission, the engine is out of alignment.

An optical scope is set up to analyze the alignment on a vessel undergoing engine repositioning.

PBB To watch a video of High Seas performing an optical alignment, go to ProBoat.com.

I asked Brown which is more accurate: optical or laser?

Accuracy, he said, is indeed lower for lasers, which use the same principles—optical targets creating a line. (For more on this, read the technical article on the company's website, www.highseasyachtservice.com.) On large yachts, where the stretch distance could be 20′ (6m) or more, there's a small difference between optical and laser. Those distances mean the technician has to be able to spot the center of a dancing laser spot about ⅛″ (3.175mm) in diameter, which results in laser error rates of 0.05″ to 0.1″ (1.27mm to 2.54mm). In comparison,

Left—*Chris Brown checks alignment with an optical scope, a precise method involving three glass targets.* ***Right***—*While High Seas primarily measures alignment with optical scopes, it also employs lasers for a process called deck spotting, which measures changes in vessel shape before and after hauling. This laser is attached to a heavy steel plate for stability.*

optical alignment will get within 0.003″ to 0.005″ (0.076mm to 0.127mm). Brown cautioned that lasers require careful handling to avoid eye damage.

While I still believe lasers are an effective alignment tool, especially for shorter shaft lengths (and they are comparatively inexpensive), the advantages of optical alignment are evident.

High Seas has other uses for lasers. When a boat is hauled, particularly one built of fiberglass or wood, it distorts. The problem is that it's nearly impossible to haul and block a boat and know whether it has hogged (the bow and stern droop) or if the center of the hull is sagging. If the alignment is carried out with the vessel in a shape that it won't be in when launched, the alignment, no matter how precise, will be flawed. Brown's team can "deck sight" a boat using a trio of lasers that enable it to reproduce the floating shape of the boat when it's blocked. This is most commonly done when working on shaft alignment on larger, longer, and more flexible vessels; however, it may be employed for any boat to ensure absolute shaft-alignment accuracy. In any case, all final alignment adjustments between engine and shaft are carried out with the boat afloat. (For more on blocking techniques, see "Blocking Drill," PBB No. 142.)

Other Specialties

In addition to carrying out alignments, the crew at Straight Line removes, installs, and laps propellers; repairs and replaces stabilizer fin bearings and seals; replaces and balances motor mounts (mount loads need to be balanced, a task far too many mechanics neglect); and installs and services torsional dampeners. As mentioned earlier, Straight Line also has a full hydraulics shop, with the capability to make high-pressure hoses up to 1¼″ (32mm).

The machine shop crew's repertoire includes straightening shafts up to 6″ (0.15m) diameter and 35′ (10.7m) long; repairing and fabricating couplings; cutting shaft tapers, coupling bores, and keyways (keyways cut by Straight Line on all shafts over 2″ include a stress-dissipating "spoon" design); repairing and replacing coupling pilots (the fit of the shaft coupling's recess to the transmission coupling's protrusion is an overlooked aspect of alignment); and repairing struts and rudders.

"We also dial-indicate the pilot and face of the transmission flange," added Brown. "Every once in a while we read unusual run-outs. If the pilot on the transmission is running out 0.005″, then the mechanics know that the shaft run-out behind the coupling will not be better than 0.005″. Checking shaft run-out after installing shafts and prior [to] launch and sea trial is [yet another] important quality-control step." (A dial indicator is a precision instrument that measures irregularities in the surface of the coupling face. Run-out refers to the amount of irregularity, or the amount it causes the dial indicator's needle to move.)

Straight Line is also American Bureau of Shipping (ABS)–approved in a technique called cladding, or weld-over, which allows worn, pitted, or otherwise damaged shafts to be repaired rather than replaced; the damaged area is built up with weld metal and then cut back down on a lathe (see the **sidebar**, page 46). When a shaft is properly repaired by cladding, the results are undetectable.

Straight Line technicians conduct Class II crack testing. Required for meeting *Lloyd's Register* non-destructive testing standards on propeller shafts and propeller hubs, the testing is also a requirement for ABS-classed vessels after propeller installation and torquing are complete. With a staff of 20, there isn't much in the way of alignment, machining, or hydraulic work that Straight Line can't handle on vessels up 210′ (64m).

While in the tool crib I noticed a series of curious-looking mandrels and was told they are shaft-bearing jigs. Shaft bearings are typically made up of a metal bearing shell and a rubber-like liner. The shell slides into a strut or shaftlog bore with little effort; it's referred to as a light interference fit (bearings should never be hammered into place, and Brown winces when that technique is even mentioned). In practice, however, the shell or the strut often needs to be cut or modified. When the bearing shell is designated to be cut, it's placed in a lathe, and some of its material—usually a few thousandths of an inch—is removed. However, if the bearing is chucked into the lathe without any support, it can distort. Cutting will often compensate for the distortion, making the shell perfectly round once again, until it's removed from the chuck, whereupon it will often be oval. The jig supports the bearing and prevents it from distorting during this process.

A few best practices I observed in the shop: All running-gear assemblies include lapping couplings to shafts; dry-fitting complete shaft assemblies in the shop for precision checking, and then stamping the parts to ensure that they are reassembled in precisely the same orientation; and use of torque wrenches and grade 8 fasteners where called for.

As I nodded approvingly at a torque wrench, Brown said, "We always use torque wrenches and thread-locking compound, even on shaft-bearing setscrews. If you overtighten those, the shafts will sing." In fact, to reduce the pressure that's necessary to ensure that the bearing won't move, they dimple the bearing shell where the set-screw lands. Loose or loosening fasteners simply aren't tolerated in

The Cladding Solution

Propeller and rudder shafts are routinely condemned due to surface damage caused by misalignment, crevice corrosion, and unavoidable everyday wear. Defects of this sort seldom threaten a shaft's structural integrity, so when I told a customer that a shaft needed to be replaced, the conversation usually went like this:

Steve: "Your shaft is heavily pitted at the stuffing box and worn at the bearing. I'm afraid it will need to be replaced. It'll cost about $4,000, and since we don't stock your shaft size, it will take about a week. Plan on two to be safe."

Customer: "Oh no! What does this mean? Is it going to break or fall out of the boat if I don't fix it?"

Steve: "No."

Customer: "So what's the problem?"

Cladding, or weld-over, can save some defective shafts. Here, a bead of weld metal has been built up over a previously pitted shaft. After it cools and has been turned down in a lathe to match the shaft diameter, the repair will be imperceptible.

Pitted, *worn*, and *scored* are words no boat owner wants to hear describing his or her propeller or rudder shafts, because these defects nearly always lead to unexpected cost and downtime. To make matters worse, because there's no sense of urgency, the expense is even tougher to justify.

Even though they're often surface phenomena, more often than not these occur at critical areas, including bearing supports and stuffing box packing. Irregularities, particularly pitting, make it virtually impossible to achieve a reliable, long-term seal between the shaft and packing material or lip seals. Pitted shaft surfaces will quickly devour shaft bearings and lip seals, while worn shafts may make it impossible to achieve even the maximum allowable clearance between the shaft and a new, much less a used, bearing.

There is an alternative to replacement. Cladding, or "weld-over," is a process that can repair surface defects in an otherwise sound propeller or rudder shaft, saving boat owners significant time and expense.

Cladding begins with placing the shaft in a lathe to cut away, or turn down, damaged areas, typically to a depth of ⅛″ (3.2mm). Then the technician builds up the areas using a semi-automatic MIG (metal inert gas) welder feeding helium/argon/carbon dioxide gas–shielded ER316L wire, which adds metal while the shaft is slowly turned. Then the shaft cools overnight. The heat from welding nearly always causes distortion, which can be corrected the next day by employing a hydraulic press. After it's straightened, the shaft is turned once again in the lathe, cutting back the excess weld metal and ensuring the repairs are indistinguishable—visually and tactilely—from the parent shaft.

High Seas Yacht Service, in Fort Lauderdale, routinely clads larger shafts (typically, High Seas polishes defects in the bearing area to smooth them out, and reserves cladding for areas where seals and packing ride). According to owner Chris Brown, it is the only facility in Florida certified for American Bureau of Shipping (ABS) AQ22/ER316L cladding (a goal the company achieved in 2011). While almost any propeller or rudder shaft can be clad, it typically makes economic sense for those over 3″ (7.6cm) in diameter. By cladding, the cost savings over replacement varies, of course; for large-diameter shafts it routinely represents an 80% savings for vessel owners.

—Steve D'Antonio

Though it's untrue, there is a pervasive myth among boat owners that some shaft misalignment is good—or even necessary. This recently realigned shaft for a 55' (16.8m) motor vessel required repositioning both struts, and it can now be turned with the pressure of just one finger.

this shop; all fasteners remain as they were installed, period. Finally, sea trials are mandatory for all Straight Line's completed projects.

Finally, Brown took me on a quick tour of some projects they were working on, from classic wooden commuters and sailing catamarans to modern superyachts and trawlers. He commented that 20% of Straight Line's work is on new boats. That's good for Straight Line, but it reinforces my observation that many new builders simply aren't spending the time and effort needed to ensure proper alignment.

As mentioned at the outset of this article, alignment is often overlooked or simply given cursory attention. The next time you haul a vessel or walk by one in the yard, take a close look at the shaft and bearings, and turn the shaft—if you can. If the effort is excessive, well, you know the rest of the story. PBB

About the Author: *For many years a full-service yard manager, Steve now works with boat builders and owners and others in the industry as "Steve D'Antonio Marine Consulting." He is the technical editor of* Professional BoatBuilder*, and is writing a book on marine systems, to be published by McGraw-Hill/International Marine.*