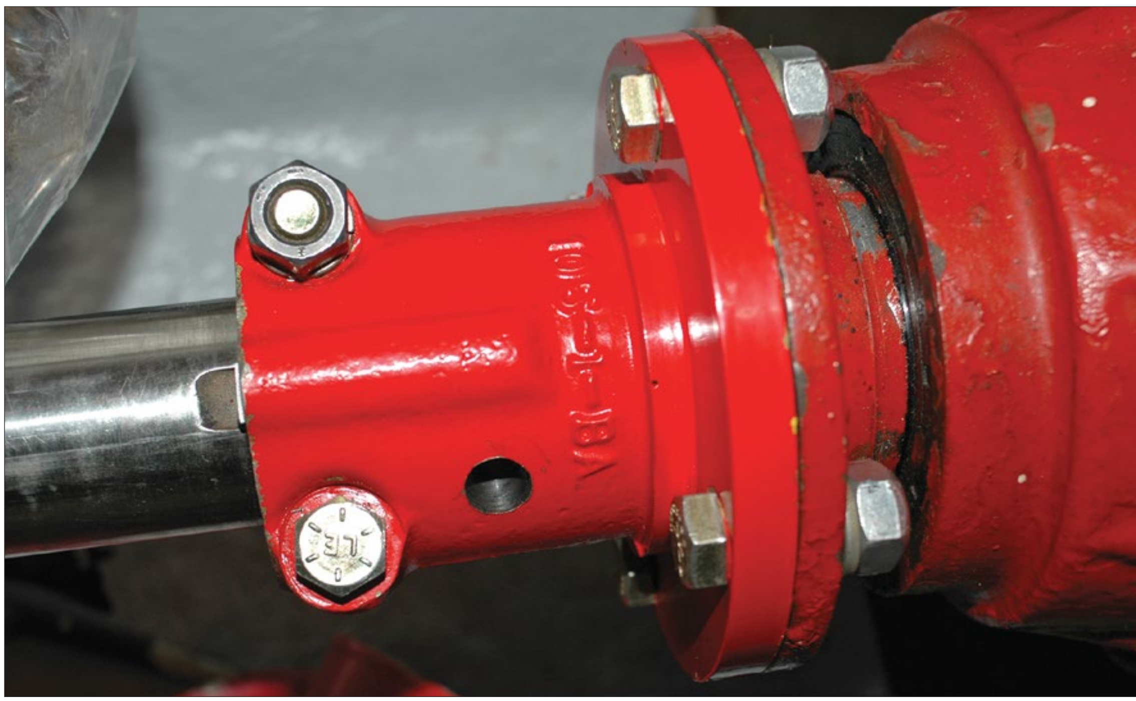
# Shaft Couplings



## The marriage of engine to propeller shaft is the most essential link in the drivetrain. Get it wrong at your peril.

**Text and photographs by Steve D'Antonio**

***Above***—*In this split shaft coupling, grade 8 machine screws fasten the pinch and the flange. The flange cap screws are too short; they should protrude slightly beyond the nut. Note the coupling is designed to be pinned.*

While relatively simple in design and construction, propeller shaft couplings are the sole mechanical tie in the drivetrain between the propeller shaft and the transmission and engine. To fulfill their essential role in a boat's propulsion system, they must be properly selected and installed.

The design of a coupling is simple. It's a wide, flat flange mounted on the end of a driveshaft that interfaces with a mating face on the transmission's output coupling. To keep the two faces centered on each other, the shaft coupling incorporates a male pilot bushing, which stands proud of the face and registers with a corresponding female recess in the transmission coupling. (Note: The bushing is vulnerable to damage when not mated to the transmission.) The two round flanges are secured to each other with multiple common fasteners running through them. While these are the basics, there are variations.

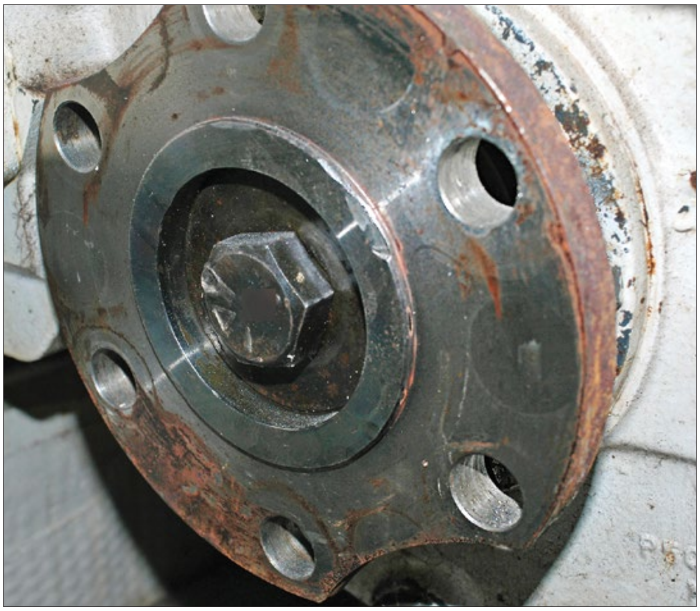
### Coupling Types

For vessels up to about 75′ (22.9m), there are three common styles. The ***solid, or straight-bore, coupling*** relies on a bore the same diameter from end to end, and engages the propeller shaft with a light interference fit. It is typically pushed onto the propeller shaft using a mallet, or a maul and block of wood. A coupling should *never* be struck directly with a metallic hammer or maul, because doing so could damage the finely machined coupling face and pilot bushing. A small hammer mark can create 0.01″–0.02″ (0.25mm–0.51mm) of raised material on the face, causing the shaft to have run-out (deviation from the transmission's center of rotation), which will probably lead to vibration.

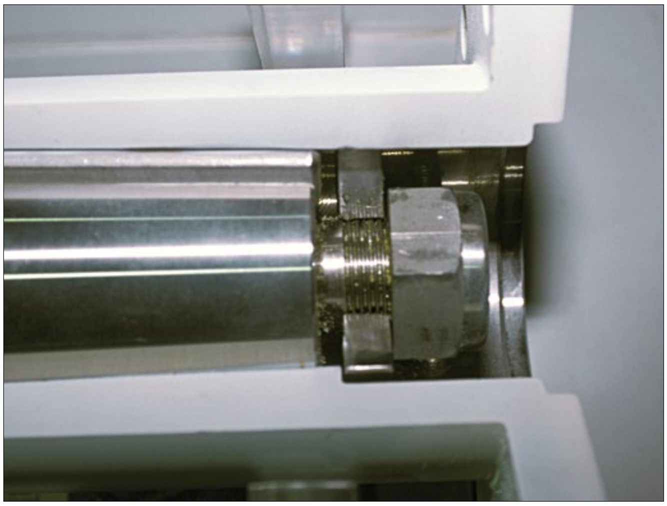
Straight-bore couplings are common in low-horsepower applications, including sail auxiliaries. While they work, they lack the shaft holding power required for larger engines and props, which can place significant strain on the shaft-to-coupling interface. Getting the interference fit between shaft and coupling bore just right is a challenge. If it's too tight, driving the coupling onto the shaft may be difficult if not impossible, especially in confined enginerooms with no space to swing a mallet. If it's too loose, the shaft may begin to work in the coupling with each shift evolution, which in turn will gall the shaft key, allowing for more and more movement with continued wear. It often ends when the key and set screws or roll pins shear off, allowing the shaft and prop to slide out of the shaftlog to strike, and possibly jam, the rudder. The worst-case outcome is that it doesn't jam, and the shaft and prop slide out of the stuffing box altogether, leaving a shaft-sized hole with a geyser of seawater into the bilge, likely overwhelming the pumps.

***Split couplings*** are easily identified by their bifurcated design. While this coupling is made up of one part, the aft plate is divided into two sections, which are clamped against the shaft by two or more machine screws (these should be SAE/Society of Automotive Engineers grade 8). With this arrangement the coupling can actually apply clamping action to the shaft. Its main advantage over other coupling types is that it enables easy removal from the shaft (and thus easy shaft removal from the boat) by driving a pair of steel wedges or cold chisels into the gap between the two split halves. Beyond this, I see no other benefit to using a split coupling, and would argue that rather than make it easy to remove, the primary mission of a coupling is to reliably secure the shaft. And, because it is split, it moves or distorts each time the shaft is inserted or removed. When that happens, the coupling face may not remain truly perpendicular to the shaft. That's because it is easy to make an installation mistake—not torqueing pinch bolts in proper sequence, or pinching against a set screw, which leads to the coupler being off perpendicular, resulting in a nasty vibration. So, unless you know you'll want to remove your shaft regularly, there's little to recommend this type.

The third common option is a ***taper coupling***. Its bore is cone-shaped in precisely the same manner as a propeller hub bore, and it engages an identical male cone machined in the forward end of the prop shaft. I prefer to install propellers on a taper engagement because it's extremely reliable: it can never be too tight or too loose;



***Above***—*Pilot bushings are critical to centering the shaft on the transmission output coupling. This coupling's pilot bushing has been damaged by impacts in two locations.* ***Below***—*The primary benefits of a split coupling are its easy removal and, when compared to tapered couplings, the reduced cost of the shaft machining required.*



***Left—**Tapered couplings offer several advantages over straight and split models. The interface between the taper shaft and the bore makes for an exceptionally tight fit. In some cases where locking nuts have loosened, the shaft and coupling must still be separated with a hydraulic puller.* ***Right—**This tapered coupling has the added security of set screws to retain the locking nut.*

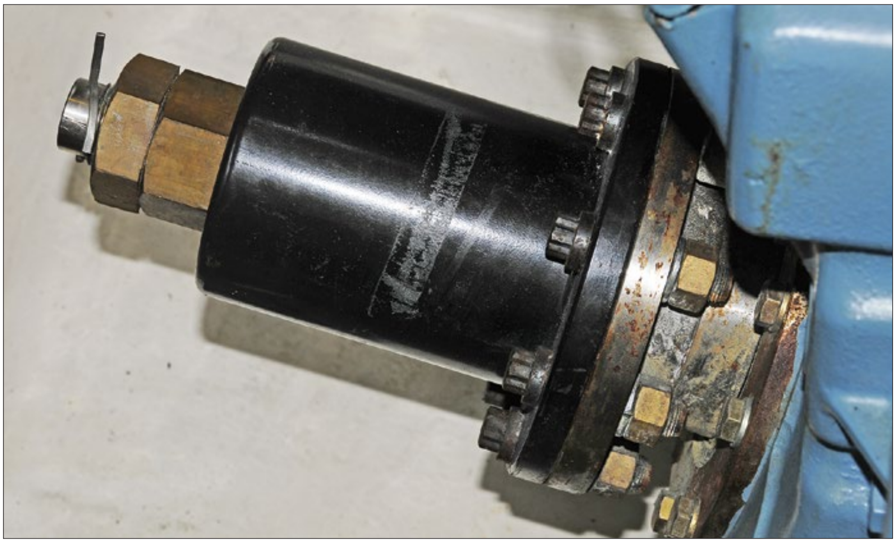
it never compromises the perpendicularity of the shaft and propeller when installed correctly; and once engaged it is highly unlikely to shift or separate. Its primary weakness is the potential for key binding during installation. In short, this is an excellent means of securing the shaft to the coupling, so let's look at some details.

The shaft end fitted to the taper coupling is threaded and retained by a large nut housed in a recess in the coupling face. As on a propeller, the nut is commonly augmented by a cotter pin (sometimes heavy seizing wire) or is replaced with a nylon locking nut. In some cases, set screws installed in the coupling, perpendicular to the shaft and close to the flange end, are tightened against the shaft nut flats, thereby locking it in place.

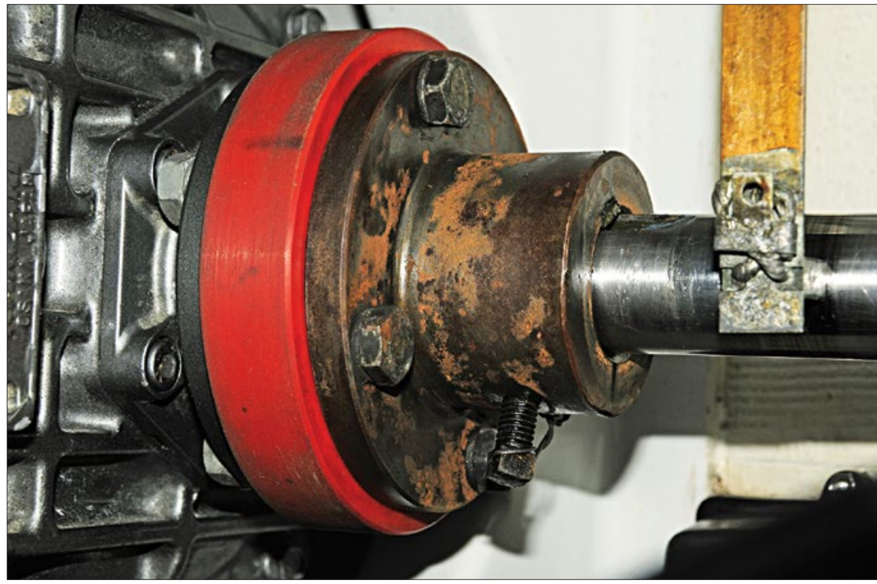
Much like tapered propeller installations, tapered couplings benefit from lapping, wherein the coupling and shaft tapers are custom fit to fine tolerances with the help of valve-grinding compound. The goal is to maximize contact between the surfaces by grinding away small elevations or ridges in the interface. It should be carried out the first time a tapered shaft and coupling are mated, or when it's unknown whether they've ever been lapped. Thereafter it's unnecessary.

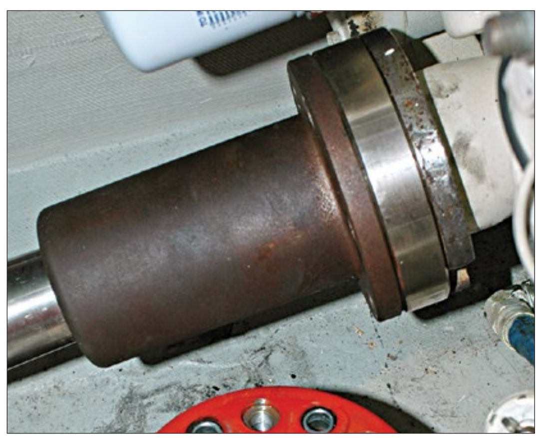
Another tapered-shaft-retention method applies what's referred to as a "three-bolt keeper plate" in place of the large single locking nut. This alternative hardware relies on three recessed Allen-head machine screws threaded into holes parallel to the shaft centerline, located in the coupling end of the shaft. A metal plate located under the heads of the fasteners acts as a retainer. The advantage to this approach, typically found on shafts 4″ (102mm) and larger in diameter, is ease of access. The nut requires a large 1″ (25mm) breaker bar and a 3″ or 4″ (76mm or 102mm) socket for removal and installation, room for which sometimes doesn't exist. The keeper-plate bolts, on the other hand, can use a standard ½″ or ¾″ (13mm or 19mm) ratchet drive, a small Allen socket, and far less torque.

Other than the set screws, none of these retention components are visible after the coupling is bolted to the transmission. I have separated many taper shaft couplings from their transmission flanges, only to find the retaining nut



*Reverse-taper couplings like this one are often used with V-drive transmissions wherein the shaft passes through a "port" in the transmission case.*





***Above***—*This red nonmetallic coupling insert is designed to shatter if the prop strikes a large object. Insert surfaces lack the precision required for accurate alignment measurements. Before an alignment, the insert must be removed and the coupling faces brought together. If shaft length or the insertion of line cutters won't permit that, a precision spacer like the one shown at* ***left*** *can be installed to perform the alignment.*

loose but the shaft still firmly engaged in the coupling bore—evidence of the taper design's effectiveness.

Another variation on this coupling is the reverse taper. In a conventional taper the large end of the bore is farthest from the coupling flange. The shaft is inserted onto this end. In a reverse taper, the large end of the bore is at the flange end. Reverse tapers are most often used in V-drive applications, where the shaft passes through the transmission. In practice it works the same as a conventional taper; however, the retaining nut and cotter pin are exposed after assembly is complete.

On occasion I've recommended that clients specify a tapered coupling for a new or replacement shaft, only to have them report back that the boatbuilder or shaft shop doesn't recommend this approach. When quizzed, they often have no explanation, other than being told, "A split coupling is better." Invariably, when I explore the issue by speaking directly with the shaft shop, I learn that they do not possess the machinery necessary to make a tapered shaft and coupling. In practice, many smaller shaft shops purchase shafts with the prop-shaft-end taper already cut, and then they simply cut the shaft to length and machine the keyway into the coupling end. This is a convenience and cost-saving measure for the shop, but it offers no benefit to the end-user. For all but the smallest shafts, it pays to insist on tapered couplings.

## Flexible Couplings and Inserts

Discussions of the marriage of shafts to transmissions would be incomplete without mentioning flexible couplings. These come in two primary varieties: those that are an integral part of the coupling itself, and those that are inserted between the two coupling halves. True flexible couplings are designed to absorb some limited degree of misalignment between the shaft and engine/transmission. They do so by including a flexible component in the driveline, usually rubber or polyurethane, which converts movement into heat. Consequently, in all cases they eventually wear out. The moment when this occurs can be either insidious, when they simply stop absorbing movement, giving the user no obvious indication, or catastrophic, when they fail completely.

Some flexible-coupling manufacturers *claim* their products reduce vibration in addition to absorbing misalignment, while other manufacturers *claim* theirs shear or shatter in the event the prop strikes a log, rock, etc., thereby preventing or minimizing damage to the transmission. (The only times I've seen them shear is as a result of stresses induced by misalignment, not from striking an object.)

In my experience, there's no substitute for proper alignment, and I have never known a flexible coupling or insert to make a noticeable difference in vibration. I have seen cases where inserts, as a result of their imprecise plastic faces, exacerbate misalignment in otherwise well-installed and -aligned drivelines. Also, they complicate alignment procedures, which, added to their tolerance of misalignment, can lead to acceptance of lower standards for the final installation. Among the most effective means of reducing drivetrain noise and vibrations are combination thrust bearings and universal or CV joints. (For more on thrust bearings, see PBB No. 120, page 42.)

For a coupling alignment, the nonmetallic inserts must be removed and the coupling faces either engaged directly, or, if that's not possible, a precision-machined metal insert installed (these are available from Spurs, the manufacturer of line and net cutters), the alignment checked and corrected,

***Left***—*Set screw tips should be either cupped or pointed, and hardened. Ordinary stainless steel fasteners, shown here, should not take the place of purpose-built screws. On the plus side, these set screws are secured with locking nuts and seizing wire.* ***Above***—*Scallops cut into this shaft indicate that it's designed for use with a split coupling. Pinch bolts interface with the machined dimples to improve shaft-to-coupling engagement.*

and only then should the nonmetallic coupling insert be reinstalled.

In the end, I question whether all this time, trouble, expense, and potential sacrifice in reliability are worthwhile. Other than the precision metallic insert, I'm leery of installing any component into the drivetrain that isn't absolutely necessary, as it simply presents another potential point of failure.

### Fasteners, Set Screws, and Clevis, Taper, and Roll Pins

The grade of fasteners connecting the two couplings should be a minimum of SAE grade 5, identified by three hash marks on the head in a Y pattern (for metric fasteners the head includes the numbers 8.8) and ideally SAE grade 8, with six evenly spaced hash marks on the head (and the numbers 10.9 for the metric equivalent), all mild steel, fine thread. While stainless steel is desirable elsewhere aboard, in this location corrosion resistance takes a backseat to tensile strength, and for like dimensions, mild steel is simply stronger than stainless steel, and SAE grade 8 is stronger than the more common SAE grade 5. Many lower horsepower applications require nothing more than SAE grade 5, but if you are purchasing the fasteners for this application, it's worth paying a little more for the added strength. (For more on fastener selections and grades, see "Nuts. Bolts. Screws." in *Professional BoatBuilder* No. 118.)

These fasteners should be mated to split lock washers, or nylon-insert lock nuts when installed, and neither should be reused in a reassembly. For especially hard-working applications, where frequent shifting and throttle work is anticipated (passenger and yacht club launches, for example), consider using cam-style Nord-Lock washers, which are significantly more effective than conventional lock washers or nuts and virtually fracture-proof. Wherever clearance permits, use a torque wrench for installation of *all* coupling fasteners.

When the couplings are permanently connected, they and the securing hardware should be coated with a rust preventative such as CRC's Heavy-Duty Marine Corrosion Inhibitor, or painted. Fasteners available in a plated finish are desirable as it will further inhibit corrosion.

In all the above coupling arrangements, save the taper variety, one or more of several retaining methods are used to further secure the shaft to the coupling, including: one or two set screws (usually installed 90° apart); a clevis pin (a straight, solid, round pin retained by friction alone); a roll pin (a straight, round, hollow pin split and sprung—the spring tension holds it in place); or a taper pin (a cone-shaped pin threaded at the small end, inserted into a cone-shaped bore drilled through the shaft and coupling, and secured with a nut). For split couplings, another retention method may be used, one where scallops or half rounds are cut into the shaft perpendicular to its centerline, which are then engaged by the coupling's clamp bolts.

Unless clevis and taper pins and their matching bores are precisely machined and the pins properly installed, they can cause problems. I've removed clevis and taper pin-equipped couplings only to have the pins fall out in two or three pieces, or to have them seize in the coupling and shaft, requiring tedious drilling, driving out with a drift, or cutting the shaft. Note that ordinary hex-head machine screws should never be used in this through-shaft application, as they lack the necessary precision in sizing and the overall strength required.

Especially after wrestling to disassemble a corroded shaft coupling, it's tempting to apply anti-seizing compounds or grease to facilitate removal, but these should *never* be used on taper fittings, including the shaft taper itself and taper pins. The interference of viscous material can prevent proper


***Far left***—*Grease on this coupling and key was applied to ease installation but will actually prevent full engagement between the shaft and coupling, as it cannot be compressed in the confined coupling bores. Shafts, keys, and couplings may be lightly oiled to prevent binding and ease installation.* ***Left***—*This brass taper coupling relies on set screws to secure the shaft end nut. Note that the seizing wire is correctly tensioned to rotate the screws clockwise.*

engagement of the tapered shaft and the coupling surfaces. The same prohibition on anti-seize is true for other coupling fasteners. A coating of light oil may be applied to prevent binding and inhibit corrosion on all coupling components including the coupling bore, shaft surface that's inserted into the bore, key, keyway, and coupling faces. Do not use it on threaded components where you intend to apply thread-locking compounds. Remember, the torque rating of a fastener whose threads have been oiled is lower than one whose threads are dry. Charts for this are readily available online.

Set screws come in two varieties: square head and recessed Allen-socket-drive heads. (The latter is sometimes referred to as a grub screw.) Ideally, square-head set screws should include a hole through the squared section, which accommodates the added security of stainless or Monel seizing wire to keep the screw from backing out. There is an art to installing seizing wire for this purpose—it must be neat and tight. And always tension the fastener in the clockwise direction. Wire diameter should be selected for the largest size that will fit through the available hole, and because square-head set screws are hardened, those without holes cannot be easily drilled after the fact. If you wish to seize your set screws, order them with holes predrilled. Those that cannot accommodate seizing should be installed with a thread-locking compound. Take the belt-and-suspenders approach and use a locking compound in tandem with seizing wire; in addition to preventing loosening, the compound can also serve as a corrosion inhibitor by preventing water migration into the threads.

For through-shaft applications, ordinary machine screws should *never* be used in place of a hardened set screw, as they lack the necessary tensile strength and proper tip design.

The style of set screw tip plays an important role in securing the shaft. If the tip is pointed, as some set screws are, then the shaft must be drilled with a matching pointed dimple of the same angle, into which the screw point fits snugly. If, on the other hand, the set screw is cupped, then a dimple is not necessary and should not be used.

Like propellers, all couplings are typically interfaced or "keyed" to the shaft using a rectangular section of precision-machined stainless steel stock known as a key set in a corresponding keyway milled longitudinally into the shaft and coupling. The keyway should be radiused, meaning the interface between its vertical "walls" and "floor" should be slightly rounded, and the aft termination of the shaft keyway should be ramped. These features minimize the formation of stress risers and cracking.

The key-to-keyway fit is critically important for proper engagement between shaft and coupling: too loose and movement may occur; too tight and binding may occur between key, shaft, and coupling. If lightly oiled and installed, the key should move in the keyway with fingertip effort; however, it should not be possible to rock the key or produce any clicking sound. When

***Left***—*A ramped and radiused keyway is more resistant to stress-induced fractures, while the knurling improves the interference fit on this small sail auxiliary straight-bore coupling.* ***Right***—*Keys should fit snugly into a keyway and, when lightly oiled, should slide and be easily removed. Unlike this one, they should not rock or clack when moved from side to side.*

*If left uncoated in a damp bilge, mild steel couplings will rust. Couplings and fasteners should be painted or coated with a corrosion inhibitor that will not be flung off a spinning shaft*

the three components—shaft, coupling, and key—are engaged, all independent movement between them should be entirely eliminated, and all but the smallest fore-and-aft movement of the key would be too much.

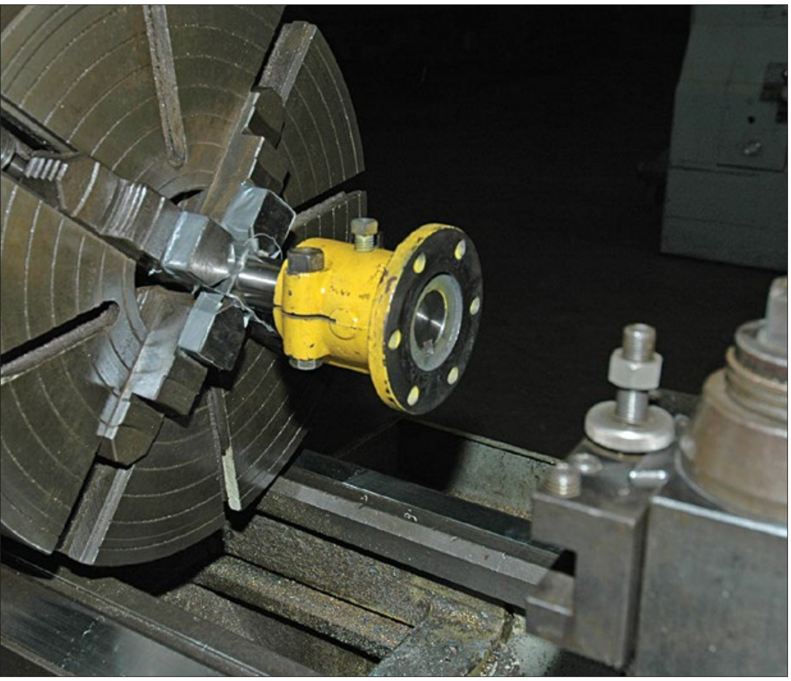
Shafts are notorious for seizing in their couplings. No surprise, as most couplings are made of ordinary ductile iron (though some are brass), which is prone to rust. When the shaft is seized in a rusty coupling, the labor to remove it sometimes makes cutting, and thereby destroying, the shaft a less expensive alternative. This is especially true for smaller diameter (less than 2″/51mm), and short shafts. Keep this in mind if you are removing a shaft from a heavily corroded coupling, and discuss it with crews before the work begins and before they generate an invoice that exceeds the cost of a new shaft.

## Fitting and Facing

While shafts and couplings are precision-made and interchangeable, once mated they represent a custom assembly. That's why some element of custom matching is required for shafts and couplings mated for the first time (if either or both parts are new). It's a process known as fitting and facing, which should be carried out by a machine shop that specializes in prop shaft work.

The coupling face and pilot bushing should be carefully inspected to ensure that they are free of dents, gouges, rust, or other irregularities. (Even new couplings should be inspected, as they can be damaged while in storage or during shipment.) Minor blemishes can often be repaired, but severe damage often warrants replacing the coupling.

Next, the shaft is secured in a lathe, and the coupling is installed on the shaft, just as it would be in the vessel.




***Left***—*Fitting and facing involves installing the coupling on its shaft and checking the coupling face's run-out. For correct alignment, the coupling face must be near perfectly perpendicular to the shaft centerline. If it's not, the face is milled on a lathe.* ***Right***—*This coupling has been marked with its after-machining run-out, which does not exceed 0.001" (0.025mm).*

*Loose fasteners, movement between coupling faces, or both frequently lead to fretting, which generates iron dust. That, in turn, rusts very quickly, leaving behind a telltale brown halo. Such clues should be investigated promptly.*

Then you measure the coupling face irregularity, or run-out, with a dial indicator, while turning the coupling and shaft slowly by hand. Ideally, the run-out or lack of perpendicularity between the shaft and coupling face should be as little as possible—no more than 0.001″ or 0.002″ (0.025mm or 0.051mm). The larger this irregularity, the greater the imprecision will be when it comes time to carry out an engine/shaft alignment. (For more on engine and shaft alignment procedure, see "The Necessity of Straight," in PBB No. 159.) If the run-out is found to be too great, the lathe is switched on, and the coupling face is fly-cut, or shaved, to make it truly perpendicular to the shaft.

Because coupling bolts are not designed to hold the coupling in the center, it's essential that during fitting and facing, the coupling pilot bushing should also be checked to make certain it is true, centered relative to the shaft, and free of damage, and to ensure that it meets the proper dimensional requirements for engagement with the female recess in the transmission flange. A heavily rusted pilot bushing, for instance, may make it impossible to properly engage the coupling.

Also beware of undersized pilot bushings. Ideally you want the female pilot to be 0.003″ (0.076mm) larger than the male pilot. This allows a perfect fit during coupling to the engine. If it is tighter, there is a chance of binding during installation. If it is too loose, the coupling will not be centered on the transmission flange, which in turn can lead to run-out and vibration.

More often than not, vibration is caused by eccentric or cam motion, which is the result of an off-center pilot bushing, or coupling bore that is not centered, rather than flange-face misalignment, which induces a constant bow in the shaft. The former is easily identified using a dial indicator, while the latter will show no abnormal run-out, again because it is constant.

Finally, couplings should be periodically inspected. With the engine off (not just in neutral), run your fingers over every fastener and set screw, pin, etc. to make sure none is loose. Any signs of fretting or galling should be investigated, along with obvious flaws such as cracks. Industry professionals should get into the habit of checking couplings for the aforementioned flaws, as well as loose or improper fasteners, or improperly installed seizing wire whenever they are in the vicinity of this component, the engine, transmission, or stuffing box. PBB

***About the Author:** A former full-service yard manager, Steve works with boat builders and owners and others in the industry as Steve D'Antonio Marine Consulting. An ABYC-certified Master Technician, he sits on that organization's Hull and Piping and Engine and Powertrain Project Technical Committees, and is also* Professional BoatBuilder*'s technical editor. He acknowledges assistance from Chris Brown of High Seas Yacht Service, www.highseasyachtservice.com, in Fort Lauderdale, Florida, for reading this article for technical accuracy.*

## PBB Resources

Buck Algonquin: hydrasearch recreational.com

CRC: crcindustries.com/products/heavy-duty-corrosion-inhibitor-10-wt-oz-06026.html

Marine Hardware: marinehard ware.com

Nord-Lock: nord-lock.com

Spurs: spursmarine.com

Walter Machine Company: waltergear.com/psc.htm