The Trawler & Ocean Motorboat Magazine

PassageMaker

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Shafts: Your Propeller's Other Half

Getting The SHAFT

Propeller Shaft And Alignment Know-How

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PMM's two-part series on propellers discussed the importance of properly selecting and servicing this component of your boat's vital propulsion system. However, a well–cared for and properly chosen propeller is of little use if the object that connects the propeller to your boat's engine–the propeller shaft–is not also properly selected and equally well maintained. In this article, we close the running gear circle by discussing the propeller shaft and some of its related components, and what you need to know to keep them in proper running order.

Because propeller shaft misalignment is a pervasive problem in the recreational-marine industry, a considerable portion of this article will deal with the issue of proper shaft alignment. Well over half the boats that arrive for the first time at the boatyard I manage suffer from some form of propeller shaft misalignment. While many of these boats have been in use for some time, a sizable number are new–fresh from the factories.

In many cases, the symptoms of misalignment are subtle or absent all together; however, the damage continues to occur. Poor alignment leads to, among other things, vibration–sometimes not readily apparent to the owner, particularly if the vessel has vibrated for as long as he or she has owned it. (For more on the causes and effects of vibration, see "Noise And Vibration," Parts One and Two, *PMM* Apr. and June '02, respectively.) During sea trials for vessels just arriving at the yard for maintenance or storage, it's not uncommon for me or one of my technicians to remark, "Holy cow, how could this owner not have noticed such severe vibration?" Yet when I inquire of the owner, he or she will often say, "I never noticed it," or "I thought that was the way it was supposed to feel. It's been like that since I bought the boat."

In some cases, misalignment leads to transmission damage, poor fuel economy, and vessel inefficiency. If the shaft is in contact with the hull or shaft log, or if its alignment is skewed as it passes through the support bearings, then drag and friction are induced. This means some of your engine's horsepower is being wasted. In addition to reducing fuel economy, friction will eventually cause permanent damage to both the shaft and whatever it is rubbing against–shaft log, cutless bearings, or the hull itself. Thus, proper shaft alignment is critical in any power vessel application.

COUPLINGS, KEYS, AND KEYWAYS

Before delving into the details of proper alignment, it's important to understand the basic functions (and associated terminology) of the shaft components. Beginning inside the vessel, the component that connects the shaft to the engine and transmission package is referred to as a

coupling–a precision-machined, flange-like device. This is where much of the measurement of shaft alignment takes place. The coupling is made up of two mating components–the shaft coupling and the transmission output coupling–which are attached to each other using a series of nuts and bolts.

The nuts and bolts used to connect the two couplings should be cadmium rather than zinc-plated–and mild steel, grade 8, and fine thread. Although stainless steel is desirable elsewhere aboard a cruising vessel, in this location, corrosion resistance takes a backseat to brute strength: Mild steel is simply stronger than stainless steel, and grade 8 fasteners (usually identifiable by six hash marks found on their heads) are stronger than the more common grade 5 fastener (with only three hash marks). While many applications do not require more than a grade 5 fastener, if you are purchasing fasteners for this application, it's worth paying a few pennies more for the added strength. Once the couplings are permanently attached, they and hardware securing them should be coated with a rust preventative, such as CRC's Heavy Duty Marine Corrosion Inhibitor.

A conventional I-strut. This is the most commonly used strut assembly; it supports the propeller shaft with the aid of an en-bloc cutless bearing.

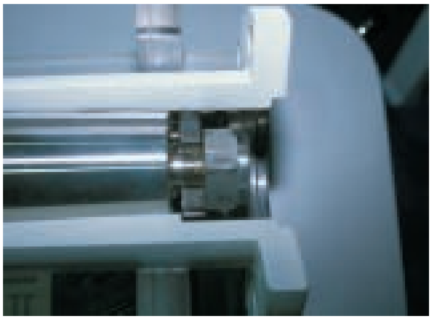
Couplings come in a variety of sizes and configurations, and it is critical that the shaft coupling and output coupling be properly matched. Three types of couplings–conventional, split, and tapered–will be discussed here.

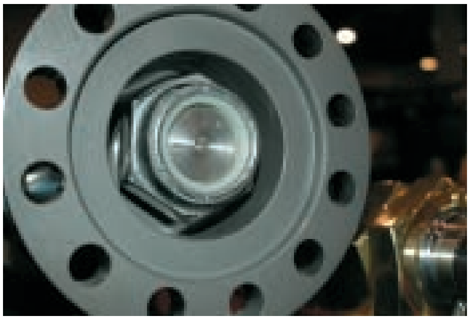
A coupling connects to the shaft by way of a key-and-keyway arrangement, in which matching keyways (or slots) are cut into the shaft and the inside of the coupling. The two keyways then accommodate a key (which is simply a rectangle of precision-machined metal stock) as well as one or more specially hardened set screws. The coupling is tapped and the shaft "dimpled" to accept the set screw. A small hole is usually drilled laterally across the head of most set screws. Set screws drilled in this manner must be seized or held in place with stainless steel or monel seizing wire. (Seizing wire should be tightly and neatly twisted in such a way that it tensions the screw in the clockwise rotation.) Set screws that are not drilled should alternatively be installed with a proprietary thread-locking compound, such as Loctite.

Split couplings are easily identified by their bifurcated design. Although this coupling is really one unit, its aft end is divided into two sections that are clamped against the shaft using two or more machine screws. These couplings are desirable in that the shaft removal is usually easier than with conventional couplings. Shafts are notorious for getting stuck in their couplings. (The coupling, which is ordinary steel, rusts–seizing the shaft in the process.) When this occurs, the labor required to remove the shaft often makes cutting–and thereby destroying–the shaft a less expensive alternative than trying to separate the shaft from the coupling. Thanks to their design, this rarely occurs where split couplings are used.

Tapered couplings can be found on any size shaft, but they are most common on larger sizes, generally 2 inches and above. The tapered design uses the same principles as those found at the other end of the shaft, where the propeller is attached. As long as they've been properly designed and manufactured, tapered assemblies used at either end of the propeller shaft are well known for their strength, security, and reliability. A cone-shaped bore or hole through the center of the tapered coupling provides the interface with a male taper located at the forward end of the shaft. This male taper, sized to

Above: A stress-relieving, ramped keyway and matching key found at the coupling end of a propeller shaft. Top right: A pair of split couplings, fresh off the machinist's lathe after having been "faced." Facing ensures that the face of the coupling, the part shown here, is perpendicular to the shaft. Middle right: During the facing, the shaft and coupling are rotated. In order to maintain proper alignment during this procedure, the other end of the shaft must be properly supported on a roller assembly. Bottom right: A machinist faces a coupling to ensure that it will align properly with the shaft, as well as with the transmission coupling.





Top: A machinist cuts a new taper into a propeller hub so it can be used with a larger shaft. The propeller's taper must match the shaft's taper with absolute precision. Once the taper is cut, the machinist will lap the two components for an ideal fit. Above left: This is a cutaway version of a tapered coupling. Above right: Before it's bolted to a transmission coupling, a tapered coupling is easily identified by the recessed nut. Like the nut that secures a propeller to a shaft, this nut secures the coupling to its shaft.

exactly fit the bore, is threaded at the end of the shaft to accept a nut, which keeps the shaft from separating from the coupling. The nut in turn is held in place by an integral nylon locking ring and a cotter pin or seizing wire inserted into the end of the shaft. Once the shaft coupling is mated up to the output coupling, this nut is no longer visible. Tapered couplings use keys and keyways, much like conventional couplings; however, they are not–and should not be–equipped with set screws. (A tapered coupling may have the same outward appearance of a conventional coupling. The lack of set screws is often a clue that a coupling is of the tapered variety.)

Finally, some couplings may use a roll or drift pin–inserted through the coupling longitudinally–which bisects the shaft at a right angle. This pin is designed to keep the shaft attached to the coupling more positively than a set screw or screws. I have mixed feelings about these pins. Unless they and their matching bores are precisely machined and the pins properly installed, they may prove troublesome. I've removed a number of drift pin–equipped couplings only to have the pins fall out in two or three pieces.

If you are looking for the ultimate in strength and security, a tapered coupling is the preferred approach. If you are seeking ease of removal, split couplings will accomplish the task. Just be certain a split coupling's set screws are secure and properly seized.

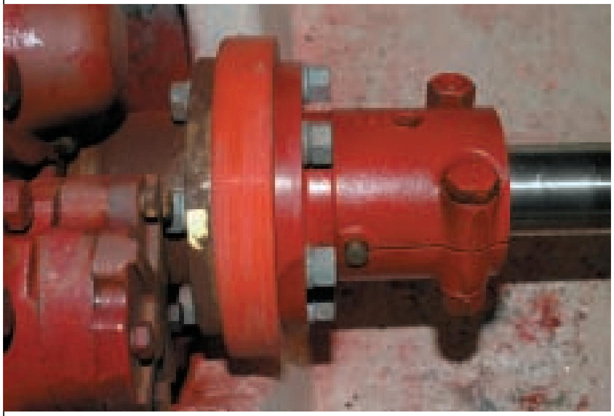
SHAFT LOGS, STRUTS, AND CUTLESS BEARINGS

The remaining shaft components are the shaft log, struts, and cutless bearings. The shaft log is nothing more than a tube–usually made of fiberglass or bronze–that allows the shaft to pass through the hull, from inside to outside. (Stainless shaft logs are less than desirable because of their susceptibility to crevice corrosion.) The stuffing box, a component familiar to most vessel owners, is attached to the forward end of the log.

Struts are appendages that support a shaft or shafts on the outside of the hull after they exit the shaft log. Traditional trawlers with a full-keel design typically are not equipped with a strut. Faster, semi-displacement hull designs and twin-screw vessels, however, often rely on a strut or struts (each shaft may use more than one strut) to support the shaft. Struts may be shaped like an "I" or a "V" and are most often made of bronze.

For vessels that rely on them, struts figure prominently into the shaft alignment equation. It would be an understatement to say that the proper alignment of the shaft and strut(s) is vital. If a strut or struts and shaft are improperly aligned, vibration and rapid wear of cutless bearings (more about these components below) are a veritable certainty. Unfortunately, many new vessel manufacturers fail to take the necessary time and effort to ensure this proper alignment–with predictable results. The fix for this scenario is often time-consuming and costly.

of naval brass but may also be made of a phenolic nonmetallic material. The latter is often used on steel and aluminum vessels to avoid galvanic incompatibility and corrosion. Both types of bearings are lubricated with seawater alone. As a result, an uninterrupted supply of seawater is vital to their longevity. Barnacles, weed, line, or zinc anodes placed directly ahead of a strut-mounted bearing will impede the flow of water and lead to premature wear. Zinc shaft anodes should be placed at least 1 foot ahead of any strut-mounted cutless bearing.



Above left: The clamping bolts on this coupling identify it as one of the split variety. This coupling is also fit with a retaining drift pin, visible at the terminus of the split. These couplings are desirable for their ease of removal from the shaft. Above right: A V-strut whose cutless bearing has been removed. The V configuration is sometimes used for added shaft stability where a longer strut is required. The appendage attached to the left side of the strut in this image is the stationary portion of a Spurs line cutter.

(For gross alignment adjustment, the motor mounts themselves may have to be shimmed, depressed, or moved altogether.)

The final component in the alignment lexicon is the cutless bearing. Cutless bearings are installed in the aft end of the shaft log on full-keel strut-less vessels, and in the strut(s) of strut-equipped vessels. The cutless bearing supports the shaft on water-lubricated rubber cushioning as it passes through the strut and/or shaft log. In vessels with particularly long shafts, cutless bearings may be used in both locations. Many twin-screw Grand Banks trawlers, for instance, use three cutless bearings for each shaft–one in the log and one each in the main and intermediate struts.

Cutless bearings come in a variety of sizes (both fractional/English and metric) and in at least two different outer shell materials. The bearing is made up of two components. The inner–usually octagon-shaped–section is fluted and made of rubber (nitrile is common). The hard outer shell is typically made

ALIGNMENT

Now that we have a complete picture of the shaft and its related components, we can fully discuss proper shaft alignment. As mentioned earlier, the correct alignment of these components is critical to both the figurative and literal smooth running of your vessel.

In simple terms, there are two types of propeller shaft alignment. The first type–often referred to as an "engine alignment"–is relatively common and involves the proper mating of the faces of the shaft and transmission output couplings. The second–shaft alignment–involves the proper alignment of the shaft and its supporting bearings.

Engine alignment uses the engine's adjustable mounts to move the position of the engine in relation to the propeller shaft. For common engine alignment purposes, the shaft and its bearings are considered immovable, and thus the engine is moved to accommodate the shaft.

Ideally, the engine mounts are in the center of their adjustment range because the vessel's builder has arranged the engine so that it is in perfect alignment with the shaft. If so arranged, future alignment, fine tuning, and vessel movement (many vessels move or distort slightly as they age; for wood vessels, this movement is often more pronounced) can be accommodated. All too often, however, the builder adjusts the motor's mounts to the limit of their travel in an attempt to achieve proper alignment. Mounts at the limits of travel often

Top left: The hard marine growth fouling this shaft will accelerate cutless bearing wear; the turbulence created by this growth will prevent a smooth flow of cooling, lubricating water into the bearing. Above left: Laser alignment allows the boatyard to go the next step in the alignment process, ensuring that the shaft is properly aligned with the engine as well as the strut(s) and shaft log. The laser landing in the center of this coupling indicates a near-perfect alignment of the shaft. Above: Engine alignment requires a thorough understanding of engine-mount geometry. Here, a 0.005-inch feeler gauge will not fit into the gap between these coupling faces, indicating proper alignment.

indicate incorrect installation of the engine beds and/or the shaft log or struts. When you observe mounts at the top or bottom of their adjustment, chances are very good that the alignment is incorrect.

For a proper engine alignment measurement–that is, the alignment of the transmission output coupling and the shaft coupling–the two coupling faces may be out of parallel by at most one-thousandth of an inch for every inch of coupling diameter. Thus, a 6-inch coupling may accept no more than a 0.006-inch feeler gauge–a tool used for measuring this and other paper-thin gaps–between the two coupling faces. However, this measurement assumes that the centers of the two couplings are already perfectly aligned, which brings us to the details of the other half of the alignment story–shaft alignment.

Until a few years ago, shaft alignment was measured using a piece of string and a divider. With the shaft removed, the string would be glued to the center of the transmission output coupling and then stretched out through the shaft log, cutless bearing(s), and strut(s). A caliper would then be used to measure the gap between the string and the inside surface of the component. If any discrepancy in the measurements was found, something had to be moved–the shaft log, struts, or engine–whichever required the least amount of effort.

Today, the same process is used, except that instead of using a string and dividers, graduated targets (translucent cylinders about 6 inches long, marked with crosshairs at both ends) are installed on the output coupling and in the cutless bearing(s). To assess the shaft alignment, a laser is then attached to the transmission output coupling and shot aft through "shaft alley"–passing through the log, struts, and the target(s) in cutless bearing(s). Notes concerning alignment are made and then the process is reversed. The laser is installed in the aft-most cutless bearing and shot forward, through the targets once again and on toward the output coupling. If the engine and shaft alignment are correct, the laser will land in the center of the coupling and in the center of both ends of the transparent target(s) placed within the bearing(s). If movement or alignment of struts and shaft logs are required, epoxy shims or wedges must be cast, a time-consuming but necessary process that calls for experience and considerable skill.

Once the installation passes the laser test, the shafts should be checked for straightness and roundness. A boatyard with a high-quality dial indicator and dial caliper–and staff who know how to use them–can make some of these determinations on site. The area of the shaft that normally rides on the cutless bearing should be checked for wear. For shafts up to 4 inches in diameter, the shaft is condemnable if it measures as little as 0.001 inch under its rated size.

A bent shaft, on the other hand, can be detected by placing a dial indicator at several locations along the shaft and rotating the shaft within a coupling and bearing set that have already been laser aligned. A bent shaft will make proper coupling alignment impossible. If the shaft is suspect, a machine shop with experience in marine shafting can go to the next step. A machinist will place the shaft on specially designed rollers to check its tolerances. In most cases, minor bends can be straightened.

At this time, the machinist should also "fit and face" the coupling; that is, ensure that the coupling fits on the shaft and engages the key properly, and that its face is perpendicular to the shaft centerline. This process is mandatory whenever a new shaft is being manufactured; the machinist must be given the old coupling (if it is to be reused), as well as the propeller so that the propeller-to-shaft fit and the key-and-taper engagement can be checked. Any time a shaft is sent to a shaft shop, these components should accompany it.

It's worth noting that any alignment performed on land is considered "rough." As mentioned previously, even fiberglass, steel, and aluminum boats settle and move once launched. After the boat has been afloat and loaded with fuel and water for a minimum of 24 hours, another alignment check must be performed. (Of course the shaft/laser alignment cannot be carried out once the boat is launched, so the in-water alignment involves only the engine and couplings.)

Carrying out the assessment and adjustment of a coupling alignment is not a task for the inexperienced; it requires a thorough understanding of engine installation and coupling geometry. The assessment involves inserting the feeler gauge between the coupling faces when they are pressed, but not bolted, together. To properly measure alignment using this method, the coupling faces must be clean and free of all paint. (Additionally, both the shaft coupling and the transmission output coupling must be perpendicular to the propeller and output shaft centerlines, respectively. The propeller shaft coupling may, as mentioned previously, be checked by the shaft shop for nonperpendicularity, or "run out." The transmission output coupling's run out can be checked in the field by using a dial indicator.) The faces and edges of these couplings must also be absolutely free of dents, nicks, and scratches. Any signs to the contrary will require a careful analysis and possible machine shop work or replacement. Never strike a coupling with a hammer as this may affect its engagement and alignment.

Above left: The tolerance for shaft wear or undersizing is 0.001 inch; any wear beyond that amount condemns the shaft. This shaft is heavily worn where it rode in the cutless bearing, the result of severe misalignment. Right: A dial indicator offers a precision method of determining several shaft faults, including a poor coupling fit or a bent or out-of-round shaft.

Once it has been determined that the couplings are free of all irregularities, and the faces are engaged with one another (a pilot bushing inside one coupling should engage a recess in the opposing coupling), the feeler gauge can be used. The process begins by inserting the largest feeler gauge possible between the two coupling faces at the 12, 3, 6, and 9 o'clock positions. If any disparity is found, the shaft is rotated 180 degrees. If the disparity follows the rotation, the shaft is bent or the coupling is not perpendicular to the shaft.

Ideally, the gap will not move with rotation of the shaft, indicating a straight shaft and true coupling, and will measure something under 0.100 inch (1/10 of an inch). By manipulating the engine's adjustable mounts, this gap should be closed at all of the measurement positions to a maximum of 0.006 inch for a 6-inch diameter coupling, 0.005 inch for a 5-inch diameter coupling, and so on–preferably less. Where possible, zero alignment clearance is ideal.

Engine alignment in some installations requires the mechanic to engage in contortionist-like efforts. This adjustment, however difficult, is critical for proper shaft-to-engine operation.

ALIGNMENT CAVEAT

If your coupling is fit with a nonmetallic, sandwich-type device designed to absorb minor irregularities (most manufacturers of these devices limit them to 0.01 inch) in alignment and shock loads that result from the propeller striking submerged objects, the device should be removed to properly assess the engine alignment. Because the surfaces of these shock-absorbing devices are not machined to the same tolerance as the coupling faces, accurate feeler gauge alignment is not possible with the device in position.

Removal is usually easy enough: Simply unscrew the fasteners, remove the shock absorber, and slide the shaft coupling forward to re-engage the output coupling. The shock absorbers are usually 1–1/2 inches thick, meaning the shaft will have to move forward this distance. Provided there is that much clearance between the propeller hub and the strut or cutless bearing, this isn't a problem. If there isn't this much clearance, or if your shaft is fit with line cutters such as the popular Spurs, then this process cannot be carried out. In that case, many owners and mechanics simply forgo accurate alignment, incorrectly treating the shock absorber as a proper alignment face.

The proper solution is to instead use a coupling shim–a precisely machined steel sandwich that will temporarily take the place of the shock absorber–for the purpose of checking and adjusting engine alignment. These shims or spacers can be custom manufactured by a machine shop or purchased off the shelf for most transmission/shaft coupling configurations from Spurs Marine (spursmarine.com/spacer).

Finally, if your shaft is equipped with line cutters, when the shaft is slid back, to remove the shock-absorbing device or for any other reason, the engagement of the stator-and-rotor assembly will almost certainly be upset. Re-engagement is straightforward enough, but it will require either a haulout or a trip over the side with mask and fins to correct this problem.

Installation of either a coupling-mounted shock absorber or line cutters should not cause the distance between the forward end of the propeller hub and the aft end of the cutless bearing or strut to exceed one shaft diameter (one-and-a-half at the most). Thus, for a vessel equipped with a 2-inch shaft, this clearance must not exceed 2–3 inches, and preferably 2 inches.

Propeller shafts are simple devices that perform admirably under stressful conditions. However, if you fail to keep them properly aligned with the engine and hull, you can count on frequent and costly problems.

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