Shafts – a user's guide

As boaters we all have a first hand knowledge of transferring motive power to the propeller in some way or another. However, in the specialist field of racing boats there have been a few refinements to the well-tried methods and these are described in this article. In the main there are two types of power transmission: first by a flexible shaft and second by a rigid shaft, but now there are relatively new hybrid systems which might be of interest to boat builders.

1. Flexible shafts

Flexi-shafts are widely used in racing boats. Such shafts have been around a long time – their routine use for transmitting power go back to at least the 1870s. Over the years since then there has been significant developments in their design, and use of improved materials. The flexi-shafts used in model powerboats are optimised to have excellent torsional stiffness and work in one rotational direction only, this is achieved using several windings of opposing pitches which lock the layers of wires together when torque is applied. The secrets of high-performance flexi-shafts are getting the appropriate mix of the wire gauge of the windings, their pitch, number of layers and choice of materials.

Even when using a high-quality flexi-shaft does not guarantee success of the final drive shaft – because flexi-shafts are almost always operated close to their mechanical limits, shafts they need careful installation and maintenance for best results.

Mounting flexi-shafts

Usually flexi-shafts are used when the line from the engine to the operating angle of the propeller is not quite straight. In general, a flexi-shaft carries a short solid stub shaft at one end which is supported by bearings and the other end of the shaft is either plain circular, or has a square cross section. A plain-ended shaft is often gripped with a collet which is in turn coupled to the engine, although sometimes the shaft is fitted into a cylindrical coupling and gripped with a grub screw. Often a square-ended flexi-shaft is used so that the axial contraction of the flexi-shaft under load is not transferred to the engine bearings. In most model applications the flexi-shaft is surrounded by a casing (stuffing tube) to constrain the flexi-shaft itself and some lubricant. The majority of boats use a high-performance grease to lubricate the shaft and minimise internal friction in the shaft, However, an initial application of dry lubricant and then grease can reduce the running temperature of the shaft compared to just grease – it is worth experimenting with such approaches to see how much improvement can be made. For small (less than 1/4") diameter shafts oil is used as the preferred lubricant, mainly because the rotational speeds are higher in, for example, fast electric boats where the drag between the shaft and the stuffing tube is a more significant factor affecting performance. Teflon liners are sometimes used as a means of reducing friction, however they tend to fail if any localised heating spots exist in the system. Whatever method of lubricating the shaft in use it is wise to store the flexi-shaft in a tube containing oil to use any other method to reduce the risk of corrosion between the wire wraps.

Generally, when mounting the shaft in a model it is best to create a smooth bend in the stuffing tube which surrounds the flexi-shaft. In particular it is important to make sure that there is a reasonably straight path to the solid part of the flexi-shaft near the stub. Not surprisingly a flexi-shaft is weakest at any discontinuity, such as the joint at the stub, it is not wise to introduce an unusually large shaft angle in an attempt to trim the boat. A minor shortcoming of the smooth curve setup is that the speed of the propeller varies slightly during rotation with respect to the rotational speed of the engine; theoretically this can be compensated by setting an "s"- shaped curve into the shaft.

However, this might create greater problems than it solves because of the increase in local shaft curvatures to achieve the desired shape.

Improvements in performance of the flexi-shaft can be achieved by:

- reducing friction as far as possible in the transmission train;
- managing the thrust from the engine;
- striving to achieve perfect alignment of the drive shaft, engine and stuffing tube, and
- reducing vibration.

The propeller end

Probably the most common arrangement is to use a plain-ended flexi-shaft rigidly fixed to the engine coupling. This means that allowance has to be made at the strut for the flexi-shaft to contract under load. With a tuned 26 cc petrol engine, the flexi-shaft will twist up to about 30 degrees, and for a flexi-shaft approximately 500 mm long there will be contraction due to a combination of torque acting on the wire-wraps of the shaft (measured at about 1 mm) and there will be a slight buckling of the shaft due to the end forces under load, estimated about 1 mm. In addition, when the thrust from the propeller is transferred to the engine and thence to the rubber bobbins of the engine mount there will be a further contraction of at least another 1 mm, or so. Therefore, in order that the shaft-dog does not run on the end face of the strut a gap of about 3-4 mm is recommended between the dog and the propeller including any spacing washers.

For square-ended flexi-shafts the thrust of the propeller is taken directly on the end of the stinger, or strut. Washers to provide a relatively friction-free interface comprise either alternating PTFE and phosphor-bronze washers which work well, as do PEEK washers on their own, both approaches achieve a very hard-wearing solution. Some people use ball-bearing thrust-races, but very few commercial bearings are available of a suitable size. Modifications to such bearings are required to reduce drag arising from the motion of the boat through the water. In addition mechanical tolerances of the bearing parts are critical if excessive wear on the propshaft is to be avoided.

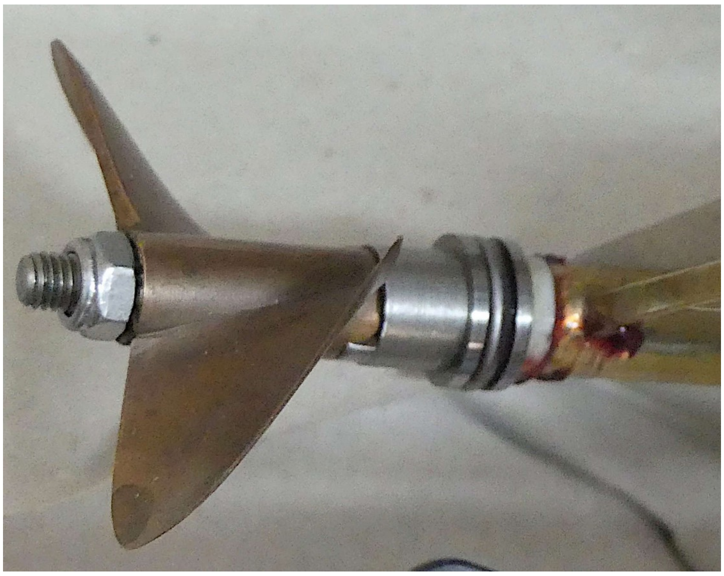

Photo illustrates a thrust race between the shaft dog and a nylon washer. ©GNP

Usually the stub axle itself is mounted in teflon-coated plain bearings. These bearings work very well, but can wear very quickly if the early signs of excessive vibration are ignored. Sometimes there is room to mount the bearings further apart and/or fit extra bearings in the stinger or stub. When modifying the normal bearing arrangement there are trade-offs to be made between potential increases in friction, but a possible reduction in vibration. In early designs miniature roller races were used which did need to be thoroughly lubricated. Some scale Arneson drives use a combination of plain bearings and ball-races which have the advantages of a slender end adjacent to the propeller and a high-performance ball-race close to the transom, but at a price.

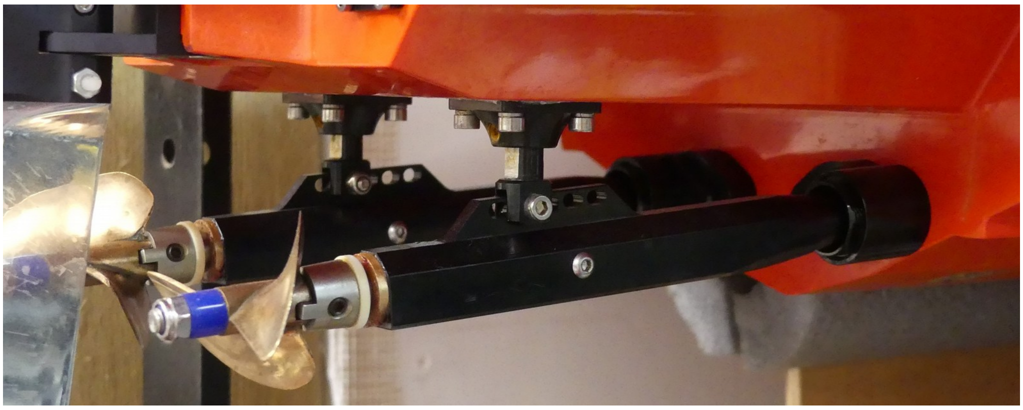

Photo illustrating a pair of Arneson drives fitted to a scale version of Lucas Oil. ©GNP

The engine end

Normally a 1/4” flexi-shaft is used in combination with an 8 mm OD semi-soft brass tube, clearly if the flexi-shaft continuously or intermittently touches the sides of the tube due to bad alignment increased friction will occur and loss of power will result.

There are similarities and essential differences between design options for petrol-engines and electric motors to maintain the flexi-shaft centrally in the stuffing tube.

In the case of electric motors vibration from the motor is not normally a major problem for short racing events, so electric motors are generally, but not exclusively, mounted solidly in the hull and often manually aligned at the construction phase to be in perfect alignment with the flexi-shaft. Acrylic-based adhesives are recommended for engine mounting because they provide some vibration resilience.

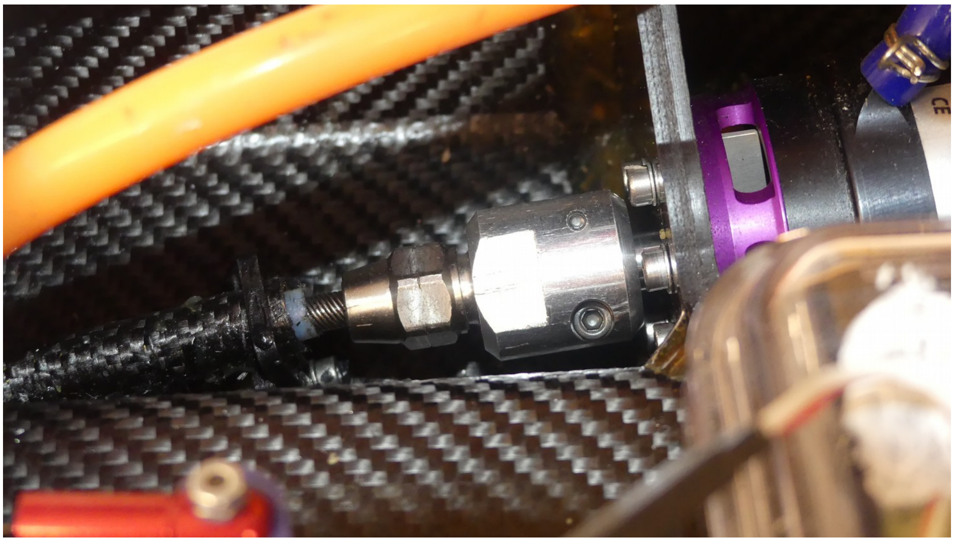

Photo of an Lehner motor closely coupled with a 5 mm diameter flexi-shaft aligned in the construction phase. ©GNP

However, if it is possible because of space constraints within the hull, it is much better to align the motor and shaft with an *in-situ* alignment jig.

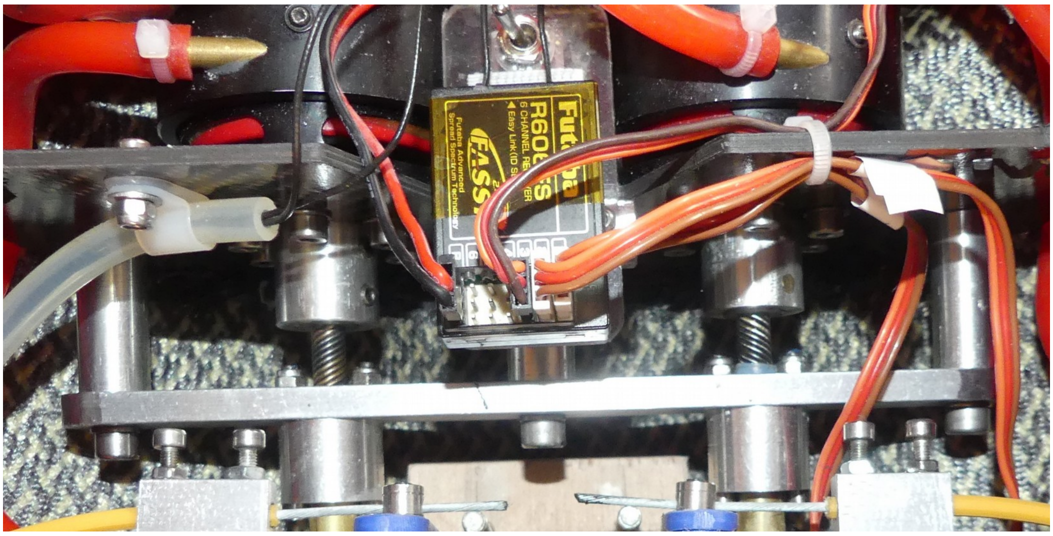

Photo of a twin Plettenburg A30-engined electric boat with plain connections to the motor and alignment bushes bolted to a plate which is in turn bolted to the engine mount. ©GNP

In the case of petrol engines, glow engines and electric motors used for endurance events, vibration has to be addressed in a more in-depth way. In order to isolate the hull from vibration engines are almost always mounted on rubber bobbins and then, in turn, to assemblies (side rails) which are rigidly fixed to the hull. Most commonly, a so-called “t-bar” is used to locate the end of the stuffing tube solidly in front of the engine, in this case the flexi-shaft is free to vibrate with the engine within the constraint of the stuffing tube. There are many variations on t-bar design, the most important feature is that sufficient adjustment is available to lock the stuffing tube in the correct position and orientation. Sometimes the hole through which the stuffing tube is held is 8 mm in diameter to take the stuffing tube directly, sometimes it is 9 mm when a sleeve needs to be added to grip the tube and sometimes the hole is 5/16” (7.94 mm), so for t-bars of unknown origin it is worth checking. The stuffing tube is most commonly 8 mm diameter, with 9 mm being used when a teflon liner is fitted. In some cases 9 mm tube with 1 mm wall is used when extra rigidity is required. As an alternative the stuffing tube can be mounted directly into the hull with some sort of solid support. It is usually a good idea to use a sleeve around the end of the stuffing tube so that the stuffing tube can be taken out without having to destroy the fixture.

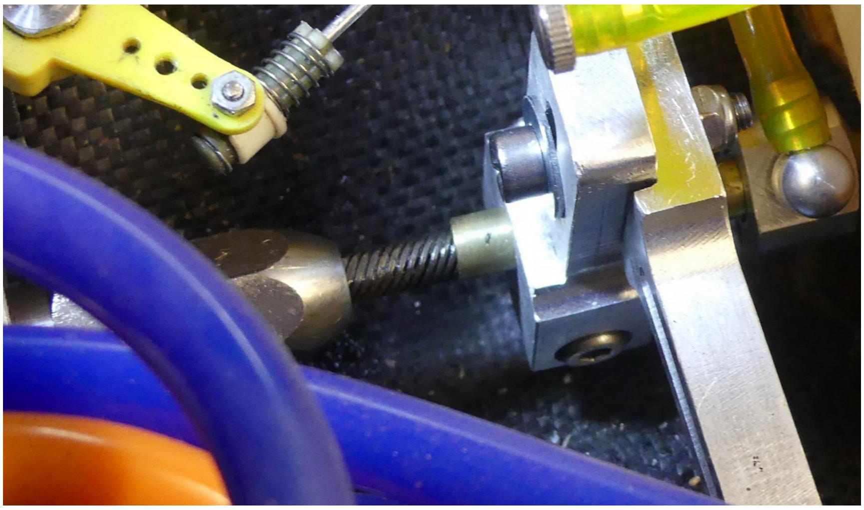

Photo of a bespoke design of t-bar ©GNP

As a next step in control vibrations, the stuffing tube could be rigidly connected to the engine which would fix the relationship between the inner and outer parts of the propeller shaft. This is an improvement as far as the shaft alignment is concerned, but the vibrations of the engine and shaft assembly would have to be vibration isolated. A slightly less perfect solution is to fix a coupling arrangement solidly in the hull and couple to the engine via a Kalistratov coupling offer a compromise and are used successfully in competition, see photograph below. The Kalistratov coupling is optimised to provide isolation from rotational vibrations and shocks, so it might be expected that the bearing at the centre of the assembly might be subject to some shock loading.

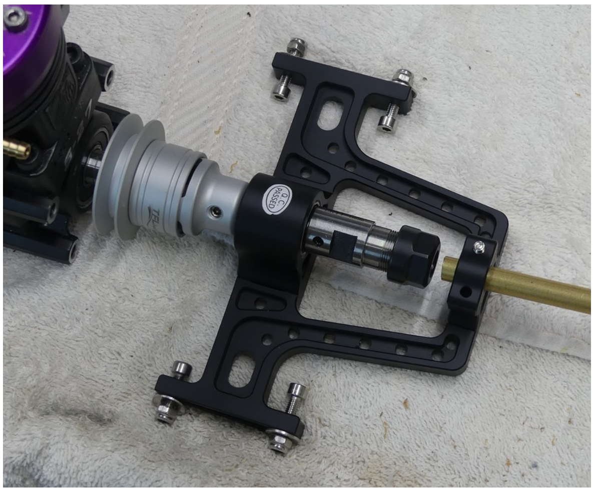

Photo of a mock-up of the TFL drive coupling with a Kalistratov coupling that interfaces with the engine (petrol engine versuin). ©GNP

In between

In the early stages of setting up the trim of a boat the angle of the strut might need to be changed as well as the shaft height, in order optimise the way the boat rides in the water. Normally the t-bar has sufficient grip to safely locate the stuffing tube to allow such adjustments to be made. However, sometimes the grip of the t-bar in not enough and the stuffing tube might rotate slightly with vibration – using small blocks on the hull to restrain the stuffing tube is probably the simplest solution. Some racers prefer to solidly locate the end of the stuffing tube one the optimum set up has been achieved.

2. Solid shafts

Solid shafts have been used for many years, especially in FSR-V boats, which employ a submerged drive. The design is straightforward – a plain bearing supports the propeller shaft at the propeller end, which is normally 5 mmin diameter order to keep the drag on the shaft casing to a minimum; a ball-raced bearing supports the shaft at the engine end and a bush bears against the upper bearing to isolate the engine bearings from the thrust of the propeller. A Kalistratov coupling is used to isolate the shaft from the vibrations associated with the engine, although ball-and-socket couplings are used by some people as vibration isolation.

In some models, a very-high tensile steel solid shaft of minimum diameter is flexed to join the engine with the stub axle holding the propeller. Models with the flexing solid shafts hold several world speed records (see, for example: *http://rcraceboat.com/storewiredrive.html*). However, manufacturing these shafts is still something of a black art.

3. Hybrid shaft systems

Rigid propeller shafts with intermediate joints have been used for many years, especially in high-performance hydroplanes (see for example, Roger James A3 tethered hydroplane) where it is important to minimise the drag generated from the propeller shaft and achieve a horizontal thrust line for the propeller as well. More recently, boats with shafts using one ball-and-socket joints (see photograph below) or two ball-and-socket joints have been built for fun-boating or FSR-O racing.

The differences between the solid shaft and the flexi-shaft are:

- that the rotational deflections of the solid shaft are less than a flexi-shaft. For a tuned 26 cc petrol engine at maximum torque and for a 500 mm long flexi-shaft, the shaft twists approximately 30 degrees, whereas a solid steel shaft will twist approximately 8 degrees;
- the sources of frictional losses are different for a flexi-shaft the grease in the stuffing tube, internal heat generated by wires moving against one another, for a jointed solid shaft frictional losses at the bearings and the joints are probably the major contributors.
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Photo of a solid 5 mm diameter shaft installation using a single ball-and-socket joint at the stinger end and a Kalistratov coupling at the engine end. ©GNP

Adjusting the trim angle of the propeller and its height in the hull is very difficult with ball-and-socket terminated shafts. This is because the ball joint must sit precisely in the socket during operation and the angle of the drive shaft has to be capable of being changed very slightly.

Another drive shaft arrangement that reduces the problems associated with adjusting the trim angle is shown in the photograph below. This utilises a short section of flexi-shaft to provide a mechanism for adjusting the trim of the thrust line. A square-drive collect should really be used with this arrangement so that the propeller thrust is not acting on the ball-races supporting the shaft.

Photo of the Tiger King “thrust terminator” – this uses a 6 mm diameter shaft and a short flexi-shaft fits into the collet on the right-hand side of the picture. This is an early version of the system, later models are slightly different and have a carbon-fibre tube casing arrangement between the two ball-race units. ©GNP

A minor drawback with the hybrid shafts is the reduced clearance with the fuel tank and the radio box though this should not present a major problem, for example many fuel tanks allow for a shaft to pass underneath and only have to be lifted by a few millimetres.

Summary

A flexi-shaft offers a well-proven and reliable transmission for even the highest-powered engines. However, other drive-shaft arrangements are worthy of consideration and those may have some advantages.

Acknowledgements

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