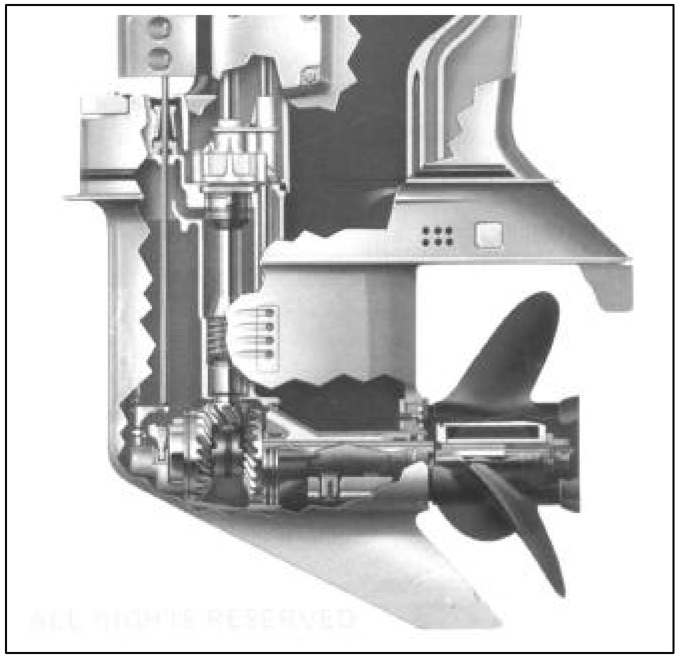
Outboard Transmission Diagnosis



Shifting Problems

Gear shifting is something everyone does, but not everyone does it correctly. Outboard motors nearly all use a simple dog clutch type mechanism for connecting the propeller to the engine. This is a very old technology that's different to nearly all other types of transport today.

Figure 1 shows how the dog clutch hides neatly inside the gears. Herein lie the reasons why the old dog clutch system is still with us - it takes up very little room, can transmit a vast amount of torque in relation to its size and is relatively cheap and simple to make. That makes it just about ideal for marine applications where the gearcase must be kept as small as possible to reduce underwater drag.

The clutch dog is splined to the prop shaft and allowed to move fore and aft sufficiently to engage the teeth machined on the side faces of forward and reverse gears. Both gears spin freely on the propshaft and are rotating while ever the engine is running. The dog clutch is moved to engage the desired gear by a cross pin and shift rod inside the hollow prop shaft. Because the gears are always rotating when shifting occurs, the dog clutch is subject to some wear and tear forces. Maximum dog clutch life comes from following some simple rules -

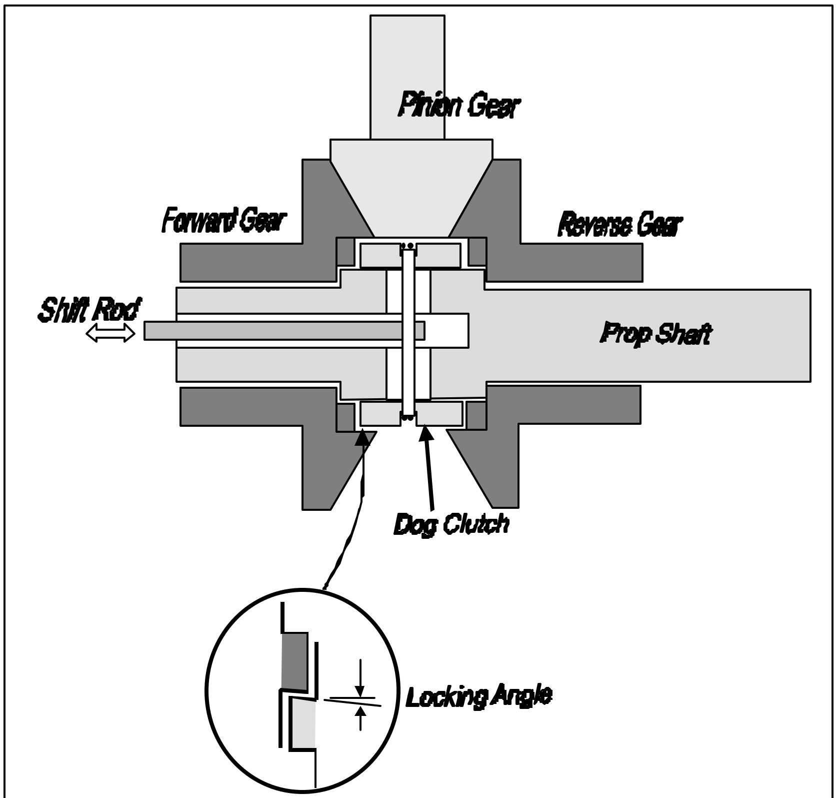


Figure 1 - Typical Outboard Dog Clutch Shift System

1. Always shift at the lowest possible speed, engine at idle and boat stationary. A low engine idle speed is very important here.

2. Always shift into gear quickly. Slowly shifting allows the dog teeth to "rattle" across the driven gear teeth. You want the teeth to contact only once for each shift, for minimum wear.

3. Don't shift when the engine is switched off (unless someone is turning the propshaft). This is because if the dog clutch and gear teeth meet end on, you can bend the shift linkages and then end up in gear jumping trouble because the bent

linkages will mean the dog clutch won't be engaged sufficiently.

4. Regularly check the shift system adjustments to ensure the dog clutch is moving to full engagement. Worn cables or linkages that reduce dog clutch travel can result in gear jumping under load which very rapidly destroys the side faces of the dog clutch teeth, not to mention the "hammer blow" type forces applied to the rest of the transmission. (Gear jumping is usually described as feeling somewhere between a severe engine misfire and an invisible giant beating on the back of the boat with a very large hammer)

Most large motor dog clutches have some "locking angle" machined into the dog teeth (refer to Figure 1). This angle helps to hold the dog engaged, when the engine torque forces are trying to separate them. Wear and tear reduces the locking angle and the area of the dog teeth in contact with the gear. When the teeth are worn sufficiently that the dog can no longer resist the torque forces on it, it will slide away from the gear and gear jumping will occur. Gear jumping can have a very destructive affect on the whole drive system, so must be addressed immediately. If you catch it very early and it's only caused by bad adjustments/worn links, then you can fix it easily. Once it has been occurring for a while then gear and dog replacement is required to cure the problem. Gears and dog clutches are surface hardened, so resist the urge to grab the hand grinder and reface the dog teeth. If you do it will only be a rather temporary fix, as the softer surfaces exposed will just wear much quicker than the originals.

The locking angle on dog clutch teeth also increases the force required to shift out of gear, especially on fast boats that use big pitch propellers. Most large outboards therefore have a "Shift Interrupter" device that momentarily interrupts ignition as you shift to take the load off the gears for a fraction of second. It's usually a spring loaded switch in the shift linkages on the engine that will ground an ignition circuit if the load on the shift cable or links exceeds and preset minimum. If your customer says "I rammed the wharf because I couldn't get the *!#@*&!* thing out of gear!" then the chances are you've got a shift interrupter problem.

Gear Problems

Gears are pretty durable components, if we make sure they mesh together correctly and have a good lubricant. Broken gears result from high loads, either from the sudden shock loads of the propeller striking a hard underwater object (or from jumping out of gear), or if the normal loads are concentrated on a small area of the gear teeth leading to a fatigue failure. The end result (broken gear teeth) looks quite similar from any cause, but the telltale signs of the root cause are usually there for the astute technician.

To carry the load the contact area between meshing gear teeth is critical. It not only needs to be spread out across the tooth to use a large area, but it also be centred on the tooth when at maximum load. If the contact pattern is concentrated to one end or one corner of the gear teeth, the load is concentrated in a small area and a fatigue failure is all too likely early in the engine's life.

Figure 2 shows how the tiny lines left from grinding the gear tooth faces can indicate the centre of the high pressure or contact area. After a few hours of operation the lines at the highest pressure area are worn away leaving a very shiny surface, shown in figure 2 by the blank area. If your gears look like this they are in good contact as most of the tooth area is

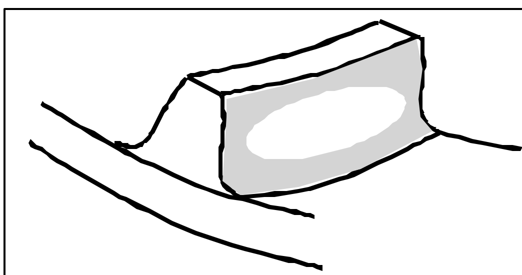


Figure 2

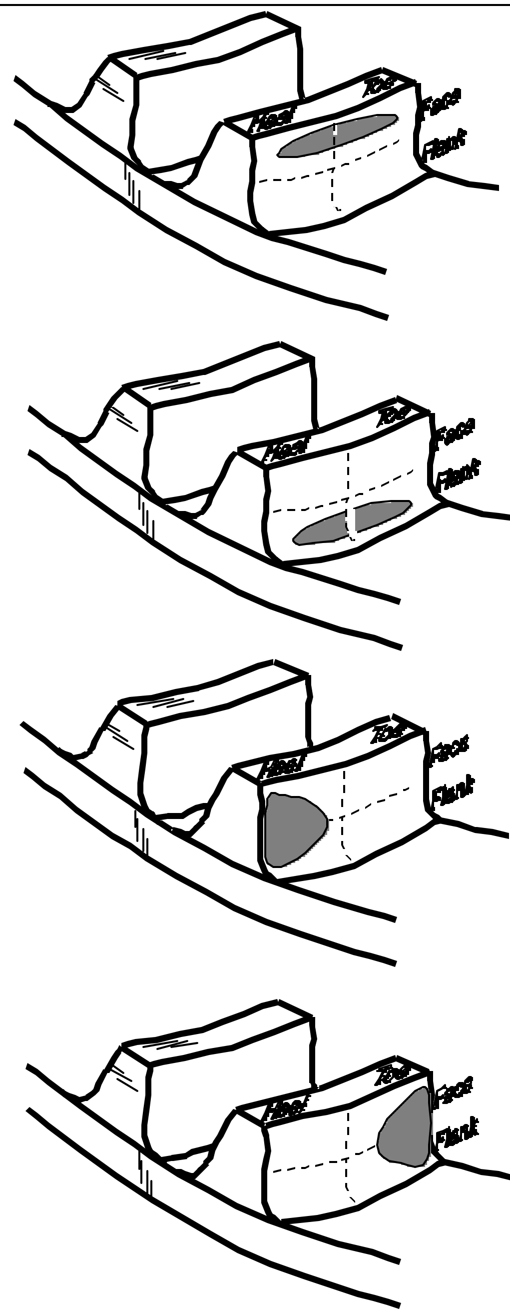
being used and it's also centred near the middle of the tooth face. However if the highest pressure area on your gear teeth is not centred like this, then just where it is can show you what's wrong. Most outboards use simple spiral bevel gears, so the tooth contact patterns conform to certain rules, as shown in Figure 3. These basic rules apply to the teeth on the DRIVEN gear (they will be exactly opposite on the drive gear), which is usually the bigger gear and therefore easier to inspect anyway.

If the unbroken teeth on your damaged set of gears shows the shiny (high pressure) area to be concentrated either toward face or flank, or toe or heel, like those shown in figure 3, then you now need to go looking for why the gears are out of position.

Is it because the shimming is wrong, or is it because the casing or bearings that locate the gears are damaged? Just where the contact pattern is concentrated, compared with how the shimming measures up, should be able to tell you.

What about using a marking compound on the gears and checking the contact pattern during assembly? Yes, this can be done and often is required on some models. The contact pattern you are looking for with new gears will look similar to figure 2, except, that the contact area will be smaller and on the Toe side on the middle of the tooth.

This is because the load we can apply during testing by hand is much lower than that applied by the engine with the throttle open (300+ Nm on large motors).



Gear tooth contact pattern is concentrated on ***Face*** area of tooth. Pinion gear is too far away from driven gear.

Gear tooth contact pattern is concentrated on ***Flank*** area of tooth. Pinion gear is too close to driven gear.

Gear tooth contact pattern is concentrated on ***Heel*** end of tooth. Driven gear is too far away from pinion.

Gear tooth contact pattern is concentrated on ***Toe*** end of tooth. Driven gear is too close to pinion.

Figure 3 - Gear Tooth Contact patterns

Getting a good reading takes a little technique because it's easy to destroy the marking or make a false one, just getting the gears in or out of the casing. The simplest method is to install the forward and pinion gears completely dry and clean, and assemble the gearcase except for the reverse gear and propshaft bearing housing. Use a long handled brush to apply the barest minimum amount of marking compound to the teeth on the lower half of forward (the driven) gear. Now without moving the gears, install reverse gear and the bearing housing. Clamp the propshaft using vice grip pliers and soft metal jaws to provide some resistance. Now use a socket and bar to rotate the driveshaft in the normal direction (usually it's clockwise, looking from the engine down) until the prop shaft has done one or two complete rotations and is back where you started (marked teeth at the bottom). The gears should only be rotated while there is load applied (to force them apart onto their thrust bearings), in order to get an accurate marking.

Now remove the bearing housing and reverse gear and look at the contact patterns. They should reveal where the high pressure contact area is concentrated and with a little deduction, whether or not you've found the root cause of the problem.

What about short gear life, when the contact pattern looks OK? One circumstance that can happen with outboard motors will cause this type of problem, overloading or underpowering a boat. When a large boat gets a motor too small for the job (needs to run at high throttle settings all the time), and has to use a small pitch prop to get the RPM up into the recommended range, then the gear tooth loading is very high. This can lead to spalling of the gear teeth, even when the contact pattern is centred.

Spalling is when the metal at the surface of the gear teeth is compressed too far as each tooth is loaded and then relaxed, leading to tiny surface cracks developing as the surface area fatigues. Eventually some of the cracks join up and small pieces of metal come out of the tooth surface. Contact area is then reduced loading the remaining area even more, and the metal pieces are now circulating with the oil causing other problems. The fix? Well other than repowering the rig correctly, one thing that does help is to use thicker oils. Thicker oils enlarge the contact pattern area, ever so slightly, but even a slight decrease in surface load provides a big increase in life. Some heavy commercially used rigs have doubled their gear life just by using thicker oils.

Propeller Cavitation and Ventilation

With the gearcase being immediately in front of the propeller, you'd expect that some gearcase problems could lead to propeller problems, and they do.

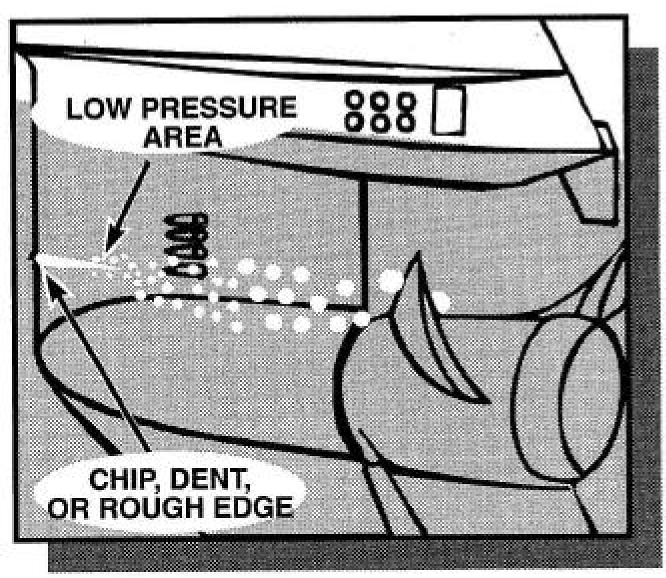


Figure 4 - How damaged leading edges on the gearcase can cause propeller cavitation.

The two common propeller problems are cavitation (vapour bubbles formed by extremely low pressure areas) and ventilation (air or exhaust gasses getting into the propeller blade area).

Cavitation can be caused by a disturbance to water flow on the gearcase or even in front of it, on the hull. If the water flow is disturbed sufficiently that it can no longer follow the gearcase shape, it separates leaving a low pressure vapour bubble. When these bubbles meet the high pressure area on a prop blade they collapse with considerable force, enough to erode the surface of softer metals like aluminium and bronze. The resultant marks on the metal are usually called "cavitation burns" because they look a bit like what happens when a cigarette is left on painted or wooden surface, a long thin mark remains, tapered at each end.

Figure 4 shows how these happen and Figure 5 shows what the resulting "Burns" look like.

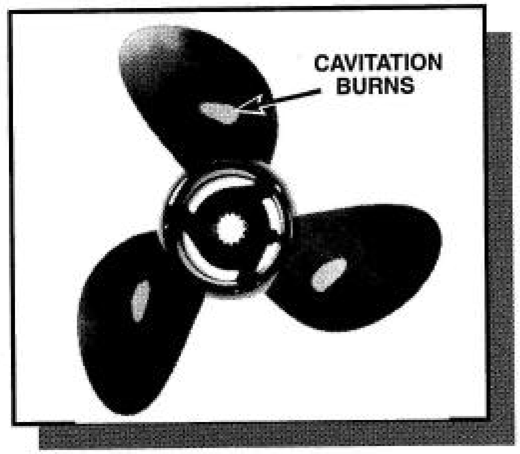


Figure 5 - Cavitation "Burns" on a painted propeller.

Figure 6 shows how engine exhaust bubbles get into the propeller blade area. Air from the water surface or exhaust gasses both have the same affect. Engine rpm goes up and boat speed stays the same or drops because the areas of each prop blade now in contact with gas bubbles are providing no thrust.

As the area of the blades pushing gas instead of water increases, the load comes off the engine (hence the rpm rise) and the thrust being produced drops, along with boat speed.

Air from the water surface is always available and close to the prop, what prevents it being a problem most of the time is that horizontal plate just above the prop (the anti-ventilation plate) forming a barrier. Along with the modern designs of props being used today that featuring lots of rake angle and trailing edge cup, so they can handle a lot more air without performance loss.

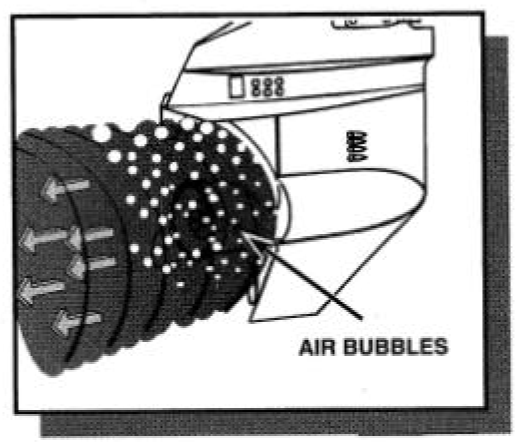


Figure 6 - Propeller ventilation

One place where a gearcase problem can cause propeller ventilation is when the hydrostatic seals rings become damaged or worn (refer Figure 7). These are parallel grooves machined inside the trailing end of the gearcase housing where the propeller spigots inside the housing. They form a seal to stop exhaust gasses being able to exit in front of the propeller through the small gap that must exit where the propeller is attached.

Not only can a leak here cause ventilation from exhaust gasses, but on high speed boats water can be forced into the exhaust from the leading edge of the propeller sufficient to raise back pressure and cause a power loss. Only a real close eye for detail can find that sort of tricky problem.

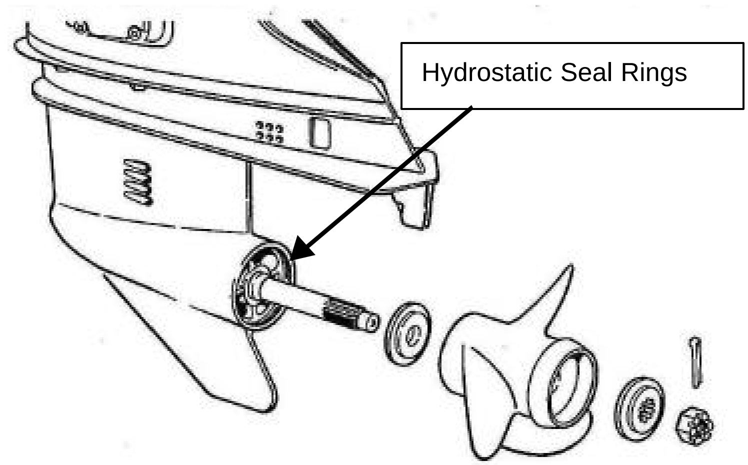


Figure 7

Case Study -1

The dealer technician said "These 10 HP dog clutches sure are weak, I'm replacing them every second day".
"Why do they need replacing?" said the manufacturer's rep.
"They break easy. I've got some in two prices and others in dozens of pieces. It's strange though, only this engine out of the hire fleet of 6 seems to be affected. The others can go for months".

An examination of the gearcase showed some damage from the broken dog clutch pieces, but no obvious cause as to why they kept breaking, so a river test was arranged after the damaged had been repaired.
The engine started from cold OK and warmed up at a fast idle. Then when the throttle was reduced to idle the motor stalled. Perhaps it was just still cold, so it was restated easily and allowed to warm up for a few more minutes. But the same thing happened when throttled back to idle, it stalled.

The technician then asked the other staff members who normally use these boats and show prospective hirers how to operate them, if the stalling problem was new.
"Oh, that one often does that", said one of the sales staff, "we just give it a handful in neutral then get it into gear quickly, and then it's OK".

The technician asked for demonstration and the sales guy showed how he started the engine with the throttle open, allowed the rpm to get up to about 3000 or 4000 in neutral, then quickly brought the throttle back to idle, shoved it in gear and opened the throttle again. This all occurred in a second or two, before the rpm had dropped so it did not have time to stall. The noise of the clutch engaging at something like 2000 rpm could be heard for a hundred meters.

The technician then explained, "Hear that loud clunk noise? That's the dog clutch getting a severe beating. It's just like if you were to hit it with a very large hammer. That's why this engine keeps breaking dog clutches".

The sales guys had not realised that their technique was the problem, after all it was only a little 10 HP motor and after they got it into gear everything seemed to be OK.

When the carburetor problem that was causing it to stall was rectified, there were no more dog clutch breakages on this motor.

Case Study - 2

The group gathered around the workbench were all wearing frowns. The 115 HP outboard gearcase spread out before them had just failed another set of gears, for the third time in less than a year.

About a year ago this 10 year old motor struck a local reef with considerable force, damaging the prop, bending the propshaft and breaking the pinion gear. There were also a few large scratches on the gearcase housing, but they only looked like a cosmetic problem.

Now two sets of new gears had broken in less than one season, when the originals had lasted 9 years. It had to be something wrong with the new gears, so the remains were sent away for testing. The results came back showing correct hardness and part numbers, so the materials had checked out OK.

That left them with installation and lubrication. The oil used was the outboard manufacturers normal type for that size motor, and it was only contaminated by metal gear chips, so that leaves gear installation. A hard look at the unbroken teeth left on forward gear did tend to show the main contact area was not in the centre of the teeth, so the broken gears were cleaned and set up in the shimming tool to see if they had been shimmed correctly before.

This model, like many outboards does not require shims for all of the gears, just the pinion depth. This simplifies gearcase assembly. Both broken set's were found to be very close to the ideal shimmed dimension. The previous repair jobs had not shimmed the gears wrong, but still, the off centre contact pattern indicated something was wrong.

It was about this time that the thinking caps went on. A close look at the undamaged forward gear teeth showed the main contact pattern was roughly centred between face and flank, but was concentrated towards the heel end of the teeth. The pinion gear shimming on this type of gearcase only affects the face and flank contact area, for toe and heel problems the driven gear (forward gear) position needed to be out. How could this be when it wasn't adjustable with shims?

Remember those apparently cosmetic heavy scratches visible on the gearcase housing from the underwater collision? It turns out they were really more than just cosmetic. The casing shape had changed allowing forward gear to move away from the pinion, consequently all the tooth loading moving up to one end of the teeth, which greatly shortened their life.

A new (unbent) housing and a fresh set of gears fixed the problem. That motor has since run several more seasons without any more gearcase trouble.

Case Study - 3

The V6 200 HP powered ski boat was about 10 years old and apparently in very good condition. It started well, ran nice, pulled gears as good as ever, there was only one problem - it had mysteriously lost 500 rpm and several knots of top speed.

A test prop run showed the engine still had all of its 200 horses, for it pulled the same test prop rpm as it had before this problem and then same as other 200's of this model. The prop was still the same old one with very little damage, just some paint rubbed off from a sandy beach. Still a quick test with new prop was performed, just to be sure. No change, still the same speed.

From the way the motor felt to the driver it had "gone soft" at the top end. Acceleration in the upper half of the speed range was slow and the engine just felt "tired". Something was sapping top end power on the boat, but not when the engine was tested by itself. This should indicate a problem with the set-up, prop, motor height, subtle changes in hull shape, and so on but no evidence could be found to support any of these. Everything seemed to check out.

On a hunch the technician tried a gearcase from a different engine, and magically the speed was back. So the gearcase was the culprit, could it be gear meshing or oil drag? Dismantling the gearcase showed no signs of any problem. Until someone took a close look at the hydrostatic seal rings. There was considerable wear evident here. At some time in the recent past someone had installed the propeller without the large thrust washer causing the prop to move forward and damage the rear of the gearcase. The damage is not visible from the outside when the prop is fitted. Could this be the culprit?

To prove the theory, the worn area was quickly built up using an epoxy filler so that a test could be conducted where the only change to whole rig was this repaired seal area. That should really prove if the worn seal rings were the culprit, and it did.

On this 50+ knot fast ski boat the water pressure at the leading edge of the prop is high enough to force water into the exhaust and raise the back pressure enough to cause a power drop.