DriveGuardian™

Stern Drive Reliability

Under ideal operating conditions, a stern drive is subjected to the engine's horsepower in a smooth and continuous manner. Assuming the engine's torque output is properly matched to the stern drive, one would expect that it would provide a long and predictable service life. Unfortunately, this is rarely the case for most performance boats. The intent of this paper is to analyze a leading cause of stern drive failure and offer a creative solution that will significantly increase reliability.

Boats are frequently operated in waters that cause the propeller to become aerated and then re-submerged due to wave action. By throttling, the operator attempts to control the engine from over-revving and to minimize strain on the stern drive by trying to match the revolutions of the propeller with the speed of the boat as it re-enters the water.

For the most boat operators, it is unreasonable to believe that propeller revolutions and boat speed can be matched perfectly every time by throttling alone. For example, a propeller can become aerated and then be re-submerged in less than a tenth of a second, making it virtually impossible to react fast enough every single time. And it only takes one mistake to cause damage that will eventually lead to stern drive failure.

Throttling & Rotational Inertia

The rotating mass of a typical big-block marine engine (crankshaft, flywheel, coupler, etc.) exceeds 160lbs and is rotating 32% to 50% faster than the propeller shaft, depending on the gear ratio of the drive. This rotating mass stores a large amount of kinetic energy and will resist any sudden change in RPM, exactly what a flywheel is designed to do. Stern drive damage is caused when the engine's rotation is rapidly slowed down by the drag of a propeller re-entering the water. The resulting deceleration rate is many times greater than is possible by just moving the throttles. During each of these events the stern drive will be over-stressed until the propeller's revolutions once again synchronize with the boat's forward speed.

It is these ***Synchronization Events*** that generate damaging torque spikes, and are the leading cause of stern drive failure. Your stern drive is caught right in the middle between the rotational inertia of the engine/flywheel and a propeller being slowed down by being dropped back into the water.

Why can't I just learn how to throttle better? You definitely should, and it would provide a safer ride, but the only *driving technique* that can eliminate stern drive failures is to never let the propeller leave the water. Unfortunately, this isn't an option for most of us.

Many factors influence the duration of a synchronization event and severity of the torque spikes such as:

- **Propeller design** – Basically, just about every characteristic that improves a propeller's ability to convert horsepower into thrust (more blades, larger diameter, higher pitch, less slip) is also likely to increase the severity of a torque spike. Propeller technology continues to advance and deliver increased efficiencies and speed. At one time a three blade Stainless Steel propeller was considered high performance. Today you won't find an offshore powerboat running less than four blades, with many running five, six, or even seven blades. Unfortunately, many boat owners are experiencing frequent stern drive failures, especially after upgrading their propeller. The basic cause is that the increased blade area and more efficient propeller designs result in higher loads, particularly in the midrange, being placed on the stern drive. In many of these applications, the torque rating of the engine is already close to the maximum rating of the stern drive, leaving very little overhead to accommodate for even a modest torque spike that occurs when a propeller momentarily leaves, and re-enters, the water.

- **Hull Weight** – A common misconception is that accelerating a boat onto plane is the cause of stern drive failures. But, unless you have modified your engine to greatly exceed the drive's torque rating, then getting on plane has very little impact on reliability. Sure, a heavy V hull will take longer to plane than a lightweight catamaran, and the V hull's engine will be working harder and the drive will be under a load for a longer period of time. But a smooth continuous application of torque, like getting on plane, is exactly what the drive was designed to handle.

- **Rough Water / Wake Jumping** – Obviously you aren't catching air when the water is dead calm but anytime water conditions are such that the propeller is leaving the water then you are likely to generate torque spikes. Interestingly, if the wave heights allow you to run near the top of your RPM range then the spikes will likely be lower than at midrange cruising speeds. This seems counter-intuitive but the torque spikes are being generated by large changes in RPM over very short periods of time. For example, if you have a 5,400RPM rev. limiter and you can run through the waves at 5,200RPM then in theory you are only going to see a 200RPM drop. It will vary because the rev limiter's capabilities aren't absolute, but for argument's sake let's call it 200RPM. If you run in the same waves at 3,400RPM and you aren't quick with the throttles then you could potentially see a 2,000RPM drop which will create a torque spike that could be as much as 9X larger over the same re-synchronization time.

- **Shallow Water / Debris in the Water** - Another source of stern drive failure is from impact with floating debris such as logs, tree branches, navigational aids (it happens), fishing nets, or trash. Typically, these events result in propeller damage, catastrophic stern drive failure, coupler damage and towing fees. Depending on circumstances, repair costs from a single incident can exceed $10,000 and may not be covered by insurance.

Failure Analysis

The best case scenario resulting from repeated torque spikes is that the tremendous stress on the gears will eventually lead to damage on the face of the teeth as shown in (Figure 1). This damage will inevitably increase in size and propagate until the gear fails. Evidence of this shock loading is slivers of metal appearing on the drain plug magnet as the mating surfaces of the teeth break off. Once this process begins, the only remedy will be a drive rebuild.

Figure 1: Tooth Damage on a Mercury Racing SSMVI Pinion Gear

The worst case scenario is that the torque spike is severe enough to break a tooth off one of the gears and become jammed between the gears, which will most likely cause the housing to break open and result in catastrophic failure.

Many boaters have experimented with different gear lubes and additives in an effort to extend the life of their drives. Some have reported a reduction in gear failures by using aftermarket gear lubes or additives. However, no lubricant or additive exists that can eliminate metal-to-metal contact under the severe loading of a torque spike, or offer 100% protection against these types of failures.

Several aftermarket companies have developed components to improve stern drive reliability, or provide a complete bolt-on alternative to the OEM units. Aside from the significant cost, many of the aftermarket options actually consume more horsepower and/or increase drag to a point where performance is significantly reduced. Some require relocating the engines or the installation of standoff boxes on the transom, both of which can have adverse effects on boat handling and safety.

Many of these solutions increase the continuous torque ratings, but none of them address the inertia-induced torque spikes that are the root cause of most stern drive failures. Still, most boaters would prefer to be boating instead of repairing so they are willing to try any solution that can lead to increased reliability.

With the exception of some very high-end (and expensive) surface drives, there isn't a stern drive on the market that can survive the repeated stress of torque spikes from current propeller designs, high X-dimensions and the horsepower options available today.

DriveGuardian™

DriveGuardian is a patented device designed to absorb and dissipate the shock-induced loading of the gear sets and shafts in a marine drive system and eliminate the damage from overloading. DriveGuardian's design controls the maximum torque seen by the drive with zero impact or adverse effects under normal operation.

Importantly, as designed, DriveGuardian's operation is 100% mechanical, operates automatically, is completely transparent to the boat operator, and requires no additional maintenance.

DriveGuardian replaces the existing coupler or drive-plate that connects the engine to the stern drive's input shaft or driveline in staggered installations. Installation is straightforward and can be performed by any reputable dealer or experienced boat owner. DriveGuardian is suitable for single and multi-engine installations and is compatible with most stern drives on the market. Figure 2 is a DriveGuardian for Bravo style drives such as Mercury Racing Bravo One XR™, IMCO SC, IMCO SCX & B-Max.

Figure 2: DriveGuardian Bravo

DriveGuardian is a torque-limiting coupler designed to absorb the excess torque that exceeds a preset value. Since DriveGuardian's torque rating is designed higher than the engine's output, there will be zero impact (no slip) under normal operating conditions. Going from idle to full throttle to climb onto plane will never cause DriveGuardian to activate and will never impact performance.

The torque required to force DriveGuardian to activate is nearly identical to the torque that the coupler will transmit while slipping. In other words, DriveGuardian will always transmit the engine's torque to the drive even while protecting it from overloading. This unique aspect of the coupler's design allows it to continue to apply regulated torque to the drive, and makes it impossible for the operator to detect DriveGuardian's operation.

With DriveGuardian, your stern drive will never be overloaded. As noted earlier, as propeller technology advances and X-dimensions are raised in search of less hydrodynamic drag and more speed, the stress on the stern drive increases dramatically. While many boaters experience significant gains in efficiency when switching to five, six and now seven blade propellers; unfortunately, this gain in efficiency can instantly overload a stern drive when a spinning propeller re-enters the water. DriveGuardian allows owners to leverage the latest propeller technology without sacrificing reliability.

DriveGuardian also protects the drivetrain when running aground during impact events by absorbing and dissipating the destructive energy. With DriveGuardian, the repair costs can be greatly reduced as compared to the stock coupler which has a tendency to self-destruct under these circumstances.

Please note that nothing will prevent the failure of a stern drive that is being operated well beyond its rated horsepower capacity. No matter how "easy" you are on the throttles, if you are exceeding the continuous torque rating of the stern drive there will be issues. However, by removing the torque spikes with DriveGuardian you can reduce the added strain that occurs when the propeller re-enters the water after hitting a wave.

On Water Test results

The following data was collected in a 42' Fountain Lightning with HP700SCi engines, SSMVI drives with 6-blade Hering propellers and without a DriveGuardian installed. A video of the run can be found at http://youtu.be/7s2NbrbGc6E

The boat was fitted with a number of sensors and a Data Logger to collect and store the information. Once back on shore the data was downloaded to a laptop for analysis. The parameters collected during the test run included:

- **Throttle Position** – This information was used to measure the reaction time of the operator and determine the exact amount of throttle applied during each Synchronization Event.
- **Vertical Acceleration** - An accelerometer was used to determine exactly when the boat began to leave the water after hitting a wave and the force experienced re-entering the water.
- **RPM** – The crankshaft speed was captured to determine the peak RPMs when the propeller was out of the water and how far they dropped when it was re-submerged.
- **Boat Speed** – A GPS sensor was used to determine the exact speed the boat was traveling during the run.
- **Torque & HP** - A Strain Gauge was fitted to the port engine's driveshaft that accurately measures the output of the engine and the torque spikes generated by the propeller. This technology is extremely accurate and similar to what is being used in Formula 1, NASCAR, & NHRA. Once downloaded to a laptop the engine's horsepower can be calculated using SAE J1349 JUN90 to correct for atmospheric conditions. Essentially this device functions as an onboard dynamometer with a data logger to collect the information for analysis.

Test Data – (no DriveGuardian)

This test was conducted in 1'-3' waves (per the NOAA near shore forecast) on Lake Michigan, with Northwest winds at 10-15 knots. The purpose was to confirm the existence of torque spikes and to measure the peaks and durations of the Synchronization Events.

Figure 3: Three Second Snapshot Shaft Dyno Data

At a test boat speed of approximately 65MPH, two torque peaks (yellow plot line) are visible in the Shaft Dyno output in Figure 3. Both of the spikes in Figure 3 are 60% more than the engine's peak output and beyond the stern drives maximum input rating of 1,160 ft-lbs. it is interesting that the throttle position (blue plot line) at the peak of the torque-spike had very little effect on the severity of the spike. This makes sense if you recognize that the torque-spikes are a direct result of having a large mass (engine, flywheel, coupler, drive shaft, U-joints, gear sets, etc.) rotating at high RPM (red plot line) and then being suddenly slowed down by the propeller.

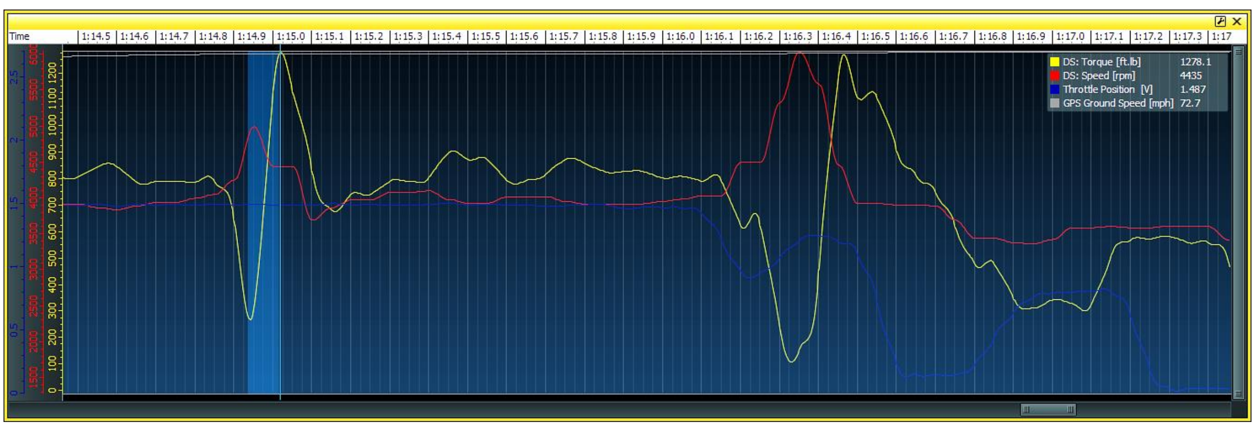

Figure 4: Shaft Dyno Plot: 1,278 ft-lb Torque Spike

In the highlighted area of Figure 4, a drop of 193 RPM, (red plot line) resulted in the torque jumping from 263 ft-lbs (propeller nearly out of the water) to a spike of 1,278 ft-lbs (yellow plot line) in 0.08 seconds. In this example the event duration is so short that the operator was unable to compensate and the throttle position remained essentially constant at 55% open (blue plot line).

PARAMETER	VALUE	UNITS
Engine Revolutions START / STEADY	4,628	RPM
Engine Revolutions END	4,435	RPM
Engine / Propeller Revolution SYNC Time	0.079	(t) Seconds
Inertia-Induced Torque (T) at Crankshaft	***1,278***	***ft-lb***
Number of Crankshaft Revolutions	***5.97***	***Rev***
Incremental Torque (T) at Propeller Shaft	***1,918***	***ft-lb***
Number of Propeller Shaft Revolutions	***3.93***	***Rev***

Table 1: Torque Calculations: 193RPM Drop in 0.079 Seconds

Table 1 is the results of a mathematical model of the 1,278 ft-lb torque spike that is highlighted in Figure 4. Based on the1.52:1 gear ratio for the drive, you can see that the propeller shaft sustained an even greater torque spike of 1,918 ft-lbs.

Figure 5: Shaft Dyno Plot: 1,262 ft-lb Torque Spike

In the highlighted area in Figure 5, a drop of 863 RPM (red plot line) resulted in the torque (yellow plot line) jumping from 103 ft-lbs (propeller out of the water) to a spike of 1,262 ft-lbs in 0.129 seconds. Operator reaction time was relatively good with the throttle position (blue plot line) dropping just before the propeller left the water and then increasing to 44% in less than a 1/10th of a second before torque spike.

As a great example of rotational inertia, please notice that immediately following the highlighted torque spike in Figure 5, the throttle position was held at 10% for more than 2/10ths of a second. At this point the propeller is in the water and the torque spike is gradually dissipating, but the RPMs barely change for a full the full 2/10ths of a second, even with the throttle practically closed.

PARAMETER	VALUE	UNITS
Engine Revolutions START / STEADY	5,270	RPM
Engine Revolutions END	4,407	RPM
Engine / Propeller Revolution SYNC Time	0.129	(t) Seconds
Inertia-Induced Torque (T) at Crankshaft	***1,262***	***ft-lb***
Number of Crankshaft Revolutions	***10.40***	***Rev***
Incremental Torque (T) at Propeller Shaft	***1,894***	***ft-lb***
Number of Propeller Shaft Revolutions	***6.84***	***Rev***

Table 2: Torque Calculations: 863RPM Drop in 0.129 Seconds

Table 2 is a mathematical representation of the highlighted portion of the plot in Figure 5. With just under seven propeller revolutions, the boat travelled approximately fifteen feet during the synchronization event.

Test Data – With DriveGuardian

DriveGuardian was installed in the same boat as in the previous test (42' Fountain) and run on Lake Michigan in a NOAA recorded wave height of 1' with a southeast wind of 5-10 knots.

Figure 6: Shaft Dyno Plot: DriveGuardian Limiting Torque Spike to 1,130 ft-lb.

In the highlighted area of Figure 6, a drop of 621 RPM (red plot line) resulted in the torque jumping from 155 ft-lbs (propeller nearly out of the water) to a DriveGuardian regulated spike of 1,130 ft-lbs (yellow plot line) in 0.095 seconds. Boat speed was 85MPH and the throttle remained approximately 85% open (blue plot line). So, with an RPM drop of more than 3X the highlighted area of Figure 4and over roughly the same period of time, the torque spike was still 12% lower. This plot clearly indicates how effective DriveGuardian is at regulating torque spikes.

PARAMETER	VALUE	UNITS
Engine Revolutions START / STEADY	5,408	RPM
Engine Revolutions END	4,787	RPM
Engine / Propeller Revolution SYNC Time	0.098	(t) Seconds
Inertia-Induced Torque (T) at Crankshaft	***3,316***	***ft-lb***
Number of Crankshaft Revolutions	***8.33***	***Rev***
Incremental Torque (T) at Propeller Shaft	***4,974***	***ft-lb***
Number of Propeller Shaft Revolutions	***5.48***	***Rev***

Table 3: Torque Calculations if DriveGuardian had not been installed

Using the same mathematical model as the previous test and based on the data from the DriveGuardian test, Table 3 shows that it would require an ***Inertia-Induced Torque of 3,316 ft-lbs*** to decelerate the rotating mass of the engine from 5,408 RPM to 4,787RPM in .095 seconds. While some of this energy would have been dissipated by the propeller, clearly the data proves that DriveGuardian regulated the torque spike to a preset value of 1,130 ft-lbs and protected the stern drive from a damaging torque spike.

Proven Results

Marine Design Corporation partnered with Saris Racing Engines to conduct a long-term test of the effectiveness of the DriveGuardian System. Team Saris races in OPA's Class 4 and runs a 32' Cobra weighing in at approximately 8,500lbs with twin 650HP engines and stock Bravo XR drives. The OPA racing circuit includes some open ocean races that are historically some of the roughest offshore race venues in the United States, which was the perfect testing ground for DriveGuardian.

Figure 7: Team Saris Racing Engines, OPS Class 4

Prior to installing DriveGuardians, Team Saris was replacing their Bravo XR upper gears every 3-4 races due to excessive pitting on the face of the teeth. Evidence of the pitting was showing up as metal particles on the lower drain plug magnet. Once the pitting starts it will propagate rapidly leading to complete gear failure and must be replaced immediately.

Figure 8: Team Saris Racing Engines, Bravo XR Upper Gear – 3 Races with Stock Coupler

Since installing DriveGuardians, the team runs an entire season on their drives and the only maintenance that has been required is to change the Mercury Racing Hi Performance gear lube. Below is a stock Bravo XR gear that Team Saris ran for 12 races across two seasons. This gear shows normal wear with no evidence of pitting and has since been re-installed in the drive. We will report on it's condition after the next inspection point.

Figure 9: Team Saris Racing Engines, Bravo XR Upper Gear – 12 Races with DriveGuardian

Summary

Stern drive repairs account for the majority of unscheduled maintenance costs for recreational boaters. DriveGuardian's design protects the stern drive from damaging torque spikes and significantly increases stern drive reliability and reduces repair costs. DriveGuardian does not alter the performance, and most importantly the handling characteristics, so safety is not compromised.

DriveGuardian's operation is completely transparent to the operator and does not require any regular maintenance. Every boater that has damaged a stern drive or is concerned about reliability should consider installing a DriveGuardian.