The Rest of the Story
For the RotorWay Community
By Matthew Dock, P.E.

Pro-Drive and its affiliates have decided to respond to a number of claims set for by Jack Kane, of EPI, Inc in recent publication and on the EPI Engine website. Namely, Jack Kane has asserted a number of errors in recent writings and Pro-Drive feels the need to expose these errors and explain, as Paul Harvey would say, the rest of the story.

BELT STRETCH

First, Jack Kane starts talking about belt stretch. Well, let's put the numbers down. Pro-Drive has calculated, from numbers given by Gates, a belt stretch of 0.220 inches. Jack Kane comes up with a belt stretch of 0.067 inches. Here is the problem, Jack Kane wants you to believe this causes the belt or secondary to fail. So, let's look at the worst case, the belt only stretches 0.067 inches under load. At the same time both the driver and driven pulleys and the frame expand due to an increase in temperature. Let's assume the temperature starts at 70F and increases to 125F, giving a 55F change in temperature. The thermal coefficients of expansion are listed in Table 1.

Material	Coef of Thermal Expansion In/In / F	Temperature Change	Length	Change in Length
Polychain	-.000004	55 F	19.5 inches	.004 inches
Steel	.0000063	55 F	20.3 inches	.007 inches
Aluminum	.000012	55 F	27.5 inches	.018 inches

Table 1, Change in materials sizes due to temperature variation.

So, the belt will shrink approximately 0.004 inches, the frame of the helicopter will lengthen .007 inches between the secondary and the total length around the driver and driven pulley will increase by .018 inches. Therefore, on the tension side, the belt will seem to tighten by .029 inches, but stretch under load by 0.067 inches. So, while under load, such as in a hover, the slack side of the belt will still gain .038 inches of belt, getting looser, just as demonstrated at Homer's. If the system is immediately stopped at these elevated temperatures, then there will be an increase in the preload of the system. Jack Kane wants you to believe that an increase in preload due to temperature changes is a problem.

So, there is an increase in preload of the system once it is hot, how does that affect the belt? Let's look at it a different way. The belt has a tensile modulus similar to a spring. If we put a particular tension in it, we get an elongation in the belt. Initially, there is a pretension which is distributed on both sides, with no torque being transferred as shown on the left of Figure 1. As torque is applied to the driving pulley, tension is developed on the tight side. This causes the belt to stretch, according to Jack Kane it stretches 0.067 inches. That increase in length shows up as extra length on the slack side, making the slack side have less tension. This is exactly what was shown at Homer's. No snake oil, simple physics. If Jack Kane had taken the time to look at the demonstration he would have seen that the two pulleys were held apart to prevent a change in the center distance, so the only slack in the system was generated by the belt stretch.

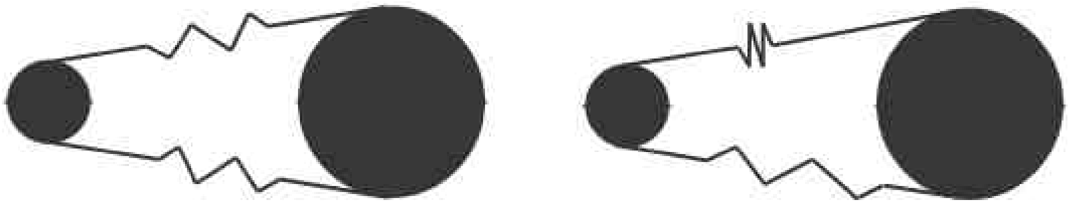

Figure 1. Results of adding torque to a belt drive, Left-no torque, with preload   Right-torque applied

Now, with our numbers from the pulleys changing in diameter due to temperature, the frame stretching, and the belt shrinking, we know that the total added strain is 0.029 inches, so even with a 55 F increase in temperature, the system is still generating slack in the belt.

This is also one of the reasons that preload plays a minor role in the failures. Let us take an extreme example of a system with 500 lbs of pretension. The system starts with 500 lbs of preload on each side of the belt drive, distributed over the two springs shown in Figure 1. Now, we want to transfer power from the driver to the driven pulley, so, we have to increase the tension on one side of the system. So, we know that we need to have around 1600 lbs of belt tension to get off the ground. As we begin raising collective the tension on the tight side increases, causing the belt to stretch. As the belt stretches there is more belt available on the slack side, reducing the tension on that side, causing the system to get loose, exactly as shown using the cog belt fixture at Homer's 2004.

Jack Kane also talks about belt preload. Well, he throws around a lot of numbers, calculations, and statements from Gates engineers, but let's look at the manual. There are two criteria for belt tension, A: Be sure it is tensioned properly to prevent tooth ratcheting, B: Avoid extremely high tension. There it is, set the tension so it doesn't ratchet and isn't excessively high. So, looking at the minimum tensions for the Pro-Drive belt, calculations yield a 13lb force with a deflection of 0.29 inches, or, drum role please, about 10 lbs at ¼ inch. Now, if you go into the horsepower calculations it suggests a higher belt tension, Pro-Drive took the minimums and those minimums allow the system to operate without ratcheting (criteria A) and without excessive tension (criteria B).

BELT

Now, the rest of the story about the belt. Jack Kane has been burning up a lot of magazine space talking about Pro-Drive and the Gates belt. Well here it is, everyone already knows it is a Gates belt, the problem is that if the belt had a big Gates logo on the side, I think Gates would be very concerned about the application. Everyone in the Rotorway community knows it is a Gates belt, but Jack Kane comes along, having never owned a RotorWay helicopter, and makes the manufacturer of the belt a big issue. Now, Gates is going to see this magazine article which clearly states that their equipment is being used in experimental aircraft, and the availability of the 8mm x 62mm wide belts may be brought into question. What about Al Behuncik's drive running a Gates belt? What about the fact that Rotorway's tailrotor belts have the logo removed, and some of their other belts are Napa belts, built by, you guessed it, Gates.

There has also been a lot of concern about the two failed cog belts. Pro-Drive has talked with Gates about one of the failed belts and provided a lot of information to Levi Campbell, a Power Transmission Applications Engineer for Gates, and his assessment is "This break could be due to poor handling. If the belt were crimped during handling it could have damaged the belt. I have attached a document that talks about handling of the belt." He also said that ratcheting caused by low tension could cause the belt to break and ended with "From the calculation I sent you previously the belt is rated for the amount of power that you put though it." He also included an excellent resource, which I had not seen before, "Belt Handling for Poly Chain", Vol 49, No. 5, January 2002. In that Gates Application Note, there is a description about how improper handling of the belt may damage the load carrying fibers. Specifically, the note describes the minimum diameter that the belt can be bent backward (5 inches), explains the danger of twisting the belt, and states no sharp edged tools should be used during installation.

Any of these can damage the outside fibers of the belt causing the belt to fail within one tooth, just like both belt's failures. It is like trying to tear a stubborn piece of Duct Tape, you have to tear the first fiber on the outer edge, then the rest will rip across easily. Any damage to the edge of these belts will quickly cause them to separate. So, Gates said it was either poor handling / damage or the belt was ratcheting. Well I know from the test fixture that was setup for Homer's 2004 that if the belt is extremely loose, so loose in fact that you can just take the belt off, that it will ratchet. So, I am probably one of a few people that have seen a belt ratchet and you should know that it is a violent process. The belt "pops" and causes a shutter that is unmistakable. I talked with the owners of the two failed belts and both said that they never experienced any ratcheting. They felt like the drives were tensioned correctly and that the systems were working fine, until the belt broke, leaving both to believe that they had experienced a secondary failure.
One of the failures was on a 162F with an ACIS typically flying at gross weight. The other failure is on a Scorpion with a 152 engine and a single barrel carburetor; two different horsepower capabilities, different engines, different ships. So, the Gates engineer says that the system was very under-tensioned with ratcheting occurring or the belts were somehow damaged. The owner / operators said they did not have ratcheting and that the system was tensioned within John Spurling's recommendations.

So, we have gone through a large number of issues were Jack and I disagree. Jack says the Pro-Drive system is flawed, yet he uses it in his own equipment. He says he is going to build a transmission, then builds a secondary shaft. He is concerned about our comments that he copied our design. But isn't it strange that his secondary, with fillets, didn't come out until Pro-Drive had posted its filleted design on its website? Jack Kane says the Pro-Drive "agrees" with him about fretting and fatigue causing the shaft failures. Where was Jack Kane in 2000 when I spent a great deal of time researching and writing an article for Rotorheads March 2000 issue, describing fretting and fatigue as the cause of secondary shaft failures? Pro-Drive and I have been working on this problem for five years and Jack can say that we are agreeing with him?

TOUGHNESS

A lot of this marketing hype is very frustrating for an engineer. For instance, on Jack's website he has an entire page about how Pro-Drive misled everyone on toughness values of steel. Well, if you look at Pro-Drive's website it clearly shows the IZOD toughness of 9310 as 91 ft-lbs and the IZOD toughness of 4340 / 300M as 15 ft-lbs, a six fold difference. Jack Kane tries to confuse the situation by saying we got Charpy, when if you look at the Pro-Drive website there is no mention of charpy. This is truly an amazing piece of creative writing.

STRESS DOES NOT MATTER

Jack Kane has written a lot about my stance that stress doesn't matter. Jack is again using his creative writing skills to transfer importance away from real issues. Stress does not matter in this case because the failures are not due to high stress. The failures always start at the fretted edge as shown in Figure 2. The reason that the stress isn't the issue is that the shaft is much larger then it needs to be to support the loads imposed. Look at Figure 2 and notice the amount of material remaining when the part finally breaks (plastic zone). The shaft begins to break due to a small crack in the fretted edge. That crack then propagates across the surface, reducing the size of the shaft as the crack grows. So, with every cycle the crack grows a little farther, reducing the area available to hold the shaft together. As the shaft's area decreases the stress grows, finally causing the shaft to

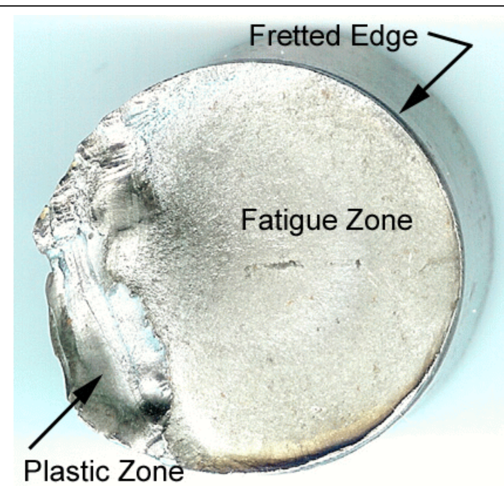

Figure 2. Fatigue failure of secondary shaft.

break all at once across the plastic zone. So, just look at the relative area of the plastic zone and the total area of the shaft, it shows that the part is approximately five times bigger then is necessary to support the load of the cog belt or chain. So, stress is important, but in the case of why does the shaft fail, it simply doesn't matter.

HISTORY

Here is the real problem, engineers take a large amount of information, from different sources, apply their experience and understanding of the problem, and come to conclusions. In most cases, what you are hearing from Jack and I are our conclusions. I said in March 2000, five years ago, that the problem was fretting, which lead to fatigue failure. Now, maybe everyone has followed the math, calculations, horsepower discussions, etc, however the conclusions are the same, broken shafts have fretting corrosion. See Figure 3.

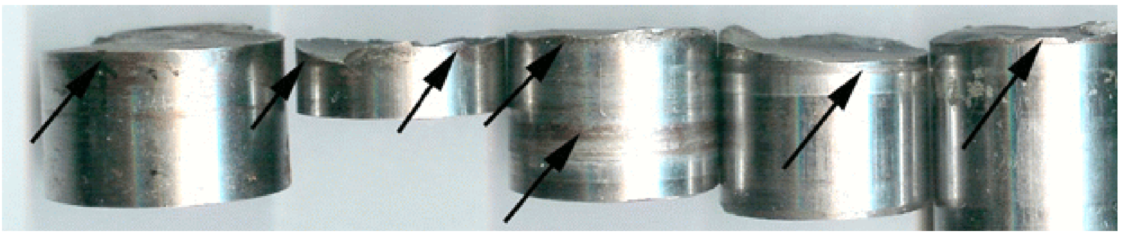

Figure 3. Broken shafts

Pro-Drive has taken apart dozens of secondary shafts since the introduction of the Pro-Drive 40mm shaft, and the amount of fretting varies between shafts, dependant mainly on the bearing fit between the shaft and the bearing's inner race. This includes recent disassembled 35mm secondary shafts run with a chain drive, showing fretting corrosion. Pro-Drive has reviewed numerous broken secondary shafts, most of them are the 30mm shafts, but a couple of 35mm secondary shafts too.

Every broken secondary shaft that Pro-Drive and I have reviewed has shown fretting corrosion as the initiator of fatigue cracks that lead to failure. If the part has failed, the failure starts in the fretting. It is that simple, every time a shaft breaks, the failure starts in fretting. Therefore, if you eliminate the fretting, how is the shaft going to break? What is important is that the fretting failure mode is identified and eliminated.

The real question comes down to designing the shaft so that fretting is eliminated. If the shaft does not exhibit fretting, it should last forever.   Jack Kane has jumped on a number of statements that I made at Homer's. Mainly, does Jack's design have the required toughness required? He talks about different numbers, but if you look on the Pro-Drive website it clearly shows toughness values. If you read his website, and read very carefully between the lines, you can see that the 9310 material has SIX times the IZOD toughness. Jack says his material is tough enough, fine, we will all learn over time. I also asked if the material that Jack had selected (300M a modified 4340) was hardenable to the point it could be used in the sprag clutch. Again, if Jack is comfortable with changing from a surface carburized 9310 with surface hardness near Rc 60 to a modified 4340 that is full heat treated through the core, then fine. John Spurling and I actually discussed changing to 4340 but decided the risk of an entire new material, with all of the new issues involved, was a bad idea. It may turn out to be a good design, but we won't know until a large number of ships get hundreds of hours with a lot of autorotations.

FIXED CENTER DRIVE

There is still a lot of discussion about idlers in cog belt drives. Let's take a look at what Gates has to say about idlers, fixed center drives, and proper drive design. Under "Use of Idlers" Gates says "Use of idlers should be restricted to those cases in which they are functionally necessary. Idlers are often used as a means of applying tension when the center distance is not adjustable." So, if the center distance is not adjustable, it is known as a fixed center drive. Gates then specifies the center distance allowances for a standard belt drive. The tensioning allowance for a Gates belt drive and the 1792 mm belt used by Pro-Drive is 0.040 inches. Therefore, if the system has approximately 0.040 inch of tension adjustment the system is not a fixed center drive. **Because shimming the secondary shaft can tension the drive, this system is the preferred configuration for the Gates belt drive.**

SUMMARY

So, what is the take home message? What do you need to get out of this article? There are hundreds of Pro-Drive cog belt drives out there that have hundreds of hours. The only known failure mode of the secondary shaft is the fretting induced fatigue. Adding fillets, removing the bearing-shaft fretting, and moving the stress concentration away from the bearing eliminate that failure mode. Pro-Drive has developed a secondary system that incorporates the necessary changes and has headed in a direction that minimizes potential negative effects of material modifications, surface hardness issues, and reductions in toughness. Pro-Drive is very pleased with its secondary installations on aircraft in service. By the time you read this, Pro-Drive will have shipped out their entire first production run and will be evaluating the timeliness of starting its next production run. The highest time ship has over 115 hours and dozens are accumulating hours. If you are interested in securing your position in the next production run, please contact John Spurling soon. 918-243-7635 or flyapro@aol.com