Ultra High Speed Driveshaft Balancing, Is It Necessary?

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There is a bit of a war of words as well as philosophies when it comes to high speed driveshaft balancing. Five hundred, 1000, 2000, 10,000 RPM and probably beyond has become a selling point for some in the business. Is it necessary to balance a driveshaft at actual operating RPM? Read on.

COMMON BALANCER TYPES - Once upon a time, before computerized machines made their debut, mechanical type balancers where prevalent in the balancing marketplace. Most of these machines relied on a simple but effective swinging beam that was measured and moved off center by imbalance forces. These are commonly referred to now as "soft bearing" balancers. Later, when electronics were employed, work supports tended to be much more rigid many times appearing to be absolutely fixed in position. Although these "hard bearing" machines do allow for some support movement, the amount is so slight that only electronics can measure it accurately.
So the debate rages - hard bearing vs. soft bearing, high speed vs. low speed and most of the time, some RPM in between. Let's examine the argument a bit closer. Some would have you believe that if a driveshaft operates in the application at 9000 RPM, it must be balanced at that same speed. While it is my opinion that high speed balancing as it pertains to driveshafts is more desirable, I don't see where it is necessary to balance the shaft at the operating RPM and I'll explain why.

BALANCE SPECS - Most things mechanical have some rating, parameter or tolerance at which the part or parts must operate or be manufactured to. Driveshafts are no different. A driveshaft is said to be so many "Ounce-Inches" within or out of balance. Without getting off on another thread, one ounce inch is one ounce of weight located one inch from the part's centerline. Two inches out, two inch ounces and so on. Currently, the specification for balancing a driveshaft in called out in "Ounce Inches." For example, Dana Corporation(r) says that a 1310 series driveshaft should be balanced to .375 ounce inches or below at 3000 RPM. A 1350 series shaft at .500 (1/2 oz-in) and every series from 1480 and larger reverts back to the venerable SAE standard of one ounce-inch per 10LB end. So, now we've established the industry standard for driveshaft balancing - Ounce -Inches. (other standards do exist such as the ISO 1940 / G-16 nomogram

that is RPM sensitive but is still expressed in oz-in's)

BALANCE SPECS - THE ARGUMENT - So, you're building a driveshaft for your local hot rod shop and he has a 'Rat Motor' that spins at warp speed. And when the transmission is in high gear the ratio is 1 : 1 thereby resulting in the driveshaft spinning at the same RPM as the motor. The customer insists that the shaft be balanced at 9000 RPM because that's how fast it's turning at the finish line. You have a machine that only spins a shaft at 3000 RPM. Can you do a good job?
Let's look back at the specification for a driveshaft. It's expressed in ounce inches. A driveshaft that is 2 ounce inches out of balance at 1000 RPM is still 2 ounce inches out of balance at 10,000 RPM. (assuming for the sake of this argument that nothing about the shaft has changed though I'll address that later) Here's an example of this:

Say you have a balancing fixture, jig, setup, etc. that is a four-bolt, piloted flange type fixture. It is impeccably balanced to well below the series specs with the four 3/8 bolts installed. Remove one of the four bolts. The fixture is now out-of-balance by the weight of the missing bolt. Let's say it is now 2 ounce-inches out of balance. The amount by which the fixture is out of spec doesn't change with RPM. It remains 2 ounce inches out of balance through a RPM range! So why does the shaft/part shake more as you increase the RPM? Centrifugal force. The "force" changes with the increase of RPM. In fact, it changes at the square of the RPM so a doubling in RPM produces a 4-fold increase in force.

But no one has established a parameter, or go-no go spec for force, or how a particular amount of force relates to a vibration in the drivetrain. It certainly exists but no number I'm aware of has been applied. Even someone with an ultra-high-speed balancer is still bound to hold a driveshaft to ounce-inch specifications since that is the established parameter.

The only possible advantage to higher speed balancing over low speed balancing when it comes to driveshafts is, being able to catch - and compensate, for changes that can occur at RPM. Some crankshaft balancers on the market have been converted to driveshaft balancers and spin at only 500-1000 RPM. The question comes down to, if you know you're going to be balancing a driveshaft at a lower RPM than at which it will operate, then you must balance it extremely close to, or below spec. Then, when the driveshaft is operated at a higher RPM than it was balanced, it will remain "in spec" and vibration free. The key here is vibration free because unless the tube deflects significantly or yoke ears spread, the "spec" will remain however, any residual imbalance will cause an increase in

force. How much? That depends on the integrity of the parts and actual RPM of the shaft. A driveshaft can only be balanced as close as operating clearances will allow! And if clearances constantly change due to RPM or poor tolerances, it cannot be balanced very closely - at any speed.

So, without a force specification, the technician can only hold an ounce-inch spec and have the customer tell him whether or not the shaft still vibrates at higher RPM. And at RPM's like 10,000, most manufacturers of off-the-shelf driveline components cannot insure the stability of the part. Tubing can deflect and yokes ears can spread from centrifugal forces. Many high performance shops are using exotic materials like aluminum, titanium, chromoly and carbon fiber for these extreme applications.

The argument here is that they tend to work better (by maintaining their integrity) at ultra high RPM. But if that's the case, a standard spec or below 3000 RPM balance will suffice up to the 10,000 RPM range in nearly all cases. Again, if you balance the shaft AT or BELOW the appropriate IN-OZ spec for the series.

IMPORTANT: ALWAYS USE CRITICAL SPEED GUIDELINES WHEN BUILDING EXTREME RPM DRIVESHAFTS

IN CONCLUSION (by the numbers) - Since a parameter of "how much is too much" force equals vibration has not been established and is subject to every vehicle's idiosyncrasies, I can only offer up some real world data.
A workmate and I once performed a crude but effective experiment on an older model SUV. We balanced the driveshaft to within specification (.36 oz-in) on a Ford Bronco II. The shaft was 1210 series with 2" diameter tube. At .36 ounce-inches (below the .375 called out by Dana) the shaft produced 2.6 LBS of force at 2000 RPM - and it produced a smooth ride. Had we been able to actually spin the shaft at 10,000 RPM, it would've produced approximately 63.9 LBS of force at the .36 oz-in spec. Would this have caused a vibration we could feel? Let's see.
At what out-of-balance point did it start to produce a noticeable vibration? We purposely started to add one ounce weights to the shaft until we could "feel" the vibration in the vehicle. One ounce, two ounces, three ounces and so on...it took 6 ounces of weight strapped to the two inch tube before we could feel and hear a rumble in the floorboard. That's 6 ounce-inches of imbalance (16 times greater than the spec) with approximately 43LBS of force as a result. (@ 2000 RPM)
Had we run the shaft up to 10,000 RPM at 6 ounce inches out-of-balance, it would have produced over 1000 LBS of force - and probably would have taken out part or all of the entire drivetrain!

It appears that the originally balanced shaft, spinning at 10,000 RPM, would have produced a vibration we could feel but had we balanced the original Bronco II shaft to an even closer and realistic .12 ounce inches* (at 0.9 LBS of force at 2000 RPM) and then increased the RPM to 10,000, it would have produced only 21.3 LBS of force - and we would not have felt a driveline vibration based on the real-world experiment above.

In conclusion, and in my opinion, it isn't so much about balancing at the actual operating RPM as it is about getting the shaft at or below balance specs at a reasonable - and safe - RPM, especially when you know you're balancing at a lower-than-actual RPM.

Can it be said that as long as you balance a shaft somewhere under 16 times closer than spec that a vibration won't noticed? Probably not but balanced is balanced at ANY speed however, it can never be perfect and some residual imbalance (and force!) will always remain - even if balanced at 10,000 RPM. It becomes more about an accurate machine, accurate tooling and operator knowledge than at what RPM it was balanced.

*** This translates to .0005 (1/2 thousandth) dial indicator deflection on a Shaftmaster balancer.**