WHY ARE MAGNI ROTORS SO SMOOTH

It is true that the Magni gyroplanes, even the 2-seat models, have much less stick and body vibration than you find on even most light single-place gyroplanes. Normally, for 2-blade rigid teetering rotor systems, the amount of rotor induced vibration goes up with the higher weight gyroplanes. This is why most 2-seat gyroplanes available today will most often have stick or body shake that many people feel is objectionable. The rotor shake problem will typically become exponentially more difficult as rotor diameters go up for the heavier gyroplanes.

Typically, the best you might find on light gyroplane is somewhat less than 1/8 inch stick shake. This means you observe a small dot on the top of the cyclic stick and it will trace a pattern that is no larger than about 1/8 inch across. This is typically what is achievable and repeatable on even 2-seat Magni gyroplanes.

Most people relate rotor induced vibrations to "balance" of the rotor blades. This may be true, but often rotor blade mass balance is not the only, or even the major culprit.

Magni rotor technology, which is more than just the rotor blades themselves, employ quality attention to fabrication as a main approach to rotor shake. But, engineered design configuration of the rotor, rotorhead and entire rotor and airframe are principal players in the uncanny smoothness of a Magni gyroplane.

First, the production quality control issues: On any rotor there are a number of "balance" issues, not just the normal one most people consider as the mass balance. An assembled rotor has several centers:

- Mass dynamic center
- Aerodynamic center
- Geometric center

The mass center - or the DYNAMIC mass center to be more precise - is the point on the rotor system that appears to remain still when the rotor is spinning at its normal RPM. This is the parameter most people associate with rotor vibration or shake. This would be like a small pinpoint at the center of the hub that remains a single point when the rotor is spinning. All other points on the hub or rotor will be spinning exactly concentric about this mass center point. The trick here is to make sure that this mass center point exactly coincides with the spindle spin axis of the rotorhead. If the mass center does not coincide exactly with the spindle spin axis, there will be a specific wobble induced in the rotor head from this misalignment. The wobble will be a once per revolution (1 per) of the rotor head - a wobble that translates to a certain amount of stick or body shake. The rotor, being of extraordinary inertia will always rotate exactly around the mass center, forcing either the rotorhead/stick to shake, or, if there is a lot of friction in the controls, forcing the mast to shake. The rotor mass center will always be stationary, and something else, the controls or the gyroplane, will be forced to shake if the mass center is not aligned with the spindle axis. If you could be looking down on the rotor / rotorhead while it is spinning in flight, you would see the rotorhead or top of the spindle making circular pattern while the true center of mass of the rotor would appear stationary.

The dynamic mass center is not the same as the static mass center, or where the rotor would balance if placed on top of a balancing nail. This static balance does not assure the weight distribution along each blade is the same. One blade might be lighter with more of its weight concentrated closer to the tip than the other. The dynamic mass center can only be determined on a rotor that is spinning. But, you can get close to balancing a rotor dynamically if you do two things statically:

1. Balance each individual blade to the exact same point of balance - span and chord wise
2. Assure that the two blades exactly match in total weight.

It also helps a lot if the fabrication method assures a near identical distribution of weight along and across the blade - fabrication quality consistency.

As you might guess, this is one of the things that Magni does - their fiberglass lay-up procedures on each rotor blade is precisely controlled in both fabric and resin dimensions and weights. After curing and painting, each blade is precision balanced, sometimes adding a small weight at the hub section if necessary, to balance the blade exactly at the prescribed span and chord point. Then, each blade is precision weighed to match it with its mating blade. In the end, only a very small dynamic balancing weight may be added at the blade tip to achieve a near-perfect dynamic mass center - if necessary, this is fine tuned under installed flight conditions.

The second critical rotor center is the aerodynamic center. This is the point at the center of the hub where all aerodynamic lift and drag forces are centered. It is critical that this aerodynamic center be precisely at the same point as the spindle spin axis - which must also coincide with the mass dynamic center. A mis-match of these two critical centers, dynamic mass and aerodynamic centers. is why some rotors will never "balance" and why some rotors may be as smooth as silk!!! If both of these centers are exactly coincident with the rotor head spindle axis, the rotor has a strong potential to be smooth.

The third critical rotor center is the geometric center. This normally would be identified by stretching a string tip-to-tip on the rotor. To many people, this is the critical alignment required when you assemble the two rotor blades to the rotor hub. This is often called "stringing" the blades. This actually has no part to play, if the previous two centers are aligned. The trouble occurs when the hub bolts or "stringing" the blades forces this geometric center to be misaligned from the other centers and/or the spindle spin axis. The geometric center is a quality fabrication issue again. The mechanical geometric center must align with the other two centers if those centers are going to be coincident with the spindle spin axis.

Most rotorblades use vertical bolts to attach the rotor blades to the rotor hubbar. Slop in these bolt holes or misalignment of the machined holes will likely not perfectly hold the geometric center solidly - the bolts in this orientation can allow creep or re-adjust the geometric center. In some cases this can be good, the blades may creep in geometrical alignment a bit to center the dynamic mass center more precisely over the spindle axis (this is a similar mechanism to self-balancing truck tire mechanisms). The problem with allowing the geometric center to re-adjust itself through spinning is that the aerodynamic center is probably misaligning itself at the same time! The vertical bolting arrangement in assembly of most rotor blades allows for two possibilities of misalignment - first the initial "stringing" of the blades will likely creep from where the bolts are tightened, and there is no assurance that the geometric center is coincident with the aerodynamic and dynamic mass centers when the bolts are tightened.

Again, Magni controls the geometric parameters of each rotor blade to be repeatable on every rotorblade through fabrication quality control. But, even more precision is achieved by the horizontal bolting arrangement of the blades to the rotor hubbar. On the Magni blades, the rotor blades are sandwiched horizontally between two hubbar plates. Every re-assembly of the rotors to the hubbar assures perfect geometric, and therefore aerodynamic and mass alignment of the rotors to the hubbar. There is no possible way that either the "string" or the pitch of either blade can be anything other than what it is - very repeatable. The only possible misalignment or slipping of the blades with respect to the hubbar might be in the coning angle, a parameter that has very negligible effect on the overall smoothness of the rotor blade system.

Notice too, that the horizontal bolting arrangement of the blades to the hubbar also does not allow any deviation in individual rotor blade pitch. Most other rotor systems allow for "tracking" adjustments - changing the individual blade pitch angle relative to the hubbar. This is done to allow for adjustment of the aerodynamic center. The problem with making such an aerodynamic center adjustment is that the aerodynamic profile, spanwise on each blade may not match each other. This adjustment would be similar to making a static mass balance adjustment - the dynamic result is highly dependent on the distribution of the aerodynamic qualities (lift and drag, along the span of each rotor. Again, nothing can substitute for quality precision fabrication, fabrication that assures that all three centers are repeatable aligned precisely over the exact center of the rotor head spindle axis.

Precision alignment of the rotorhead parts, especially the parts between the spindle bearings and the teeter boltholes is very critical, otherwise the rotor will not be bolted precisely aligned with the spindle axis. The traditional teeter tower mounting of the rotor on most rotor heads requires precise symmetry between the two separate towers and their bolting to the spindle bearing block. Any misalignment of these two towers, relative to the spindle bearing axis presents some wobble in the rotorhead on even a perfect rotor. Magni rotor heads do not use the twin tower arrangement. Instead the Magni bearing block is a single machined aluminum block who's precision is assured by computer controlled lathe fabrication.

The Magni hubbar consists of two plates that straddle this teeter bearing block. That arrangement also allows the very precise rotor blade to hubbar horizontal attachments described above. The total arrangement assures precision alignment of the critical centers over the spindle bearing axis. But, another rotor shake advantage comes from this arrangement. Most 2-seat gyroplane "twin teeter towers" arrangement can allow for some bending or "sway" in the tall towers. This sway could cyclically misalign the rotor centers from the spindle axis as the rotor turns. This is why you see many tall teeter towers braced by plates between the towers - to stiffen them. The Magni "teeter block" is a near solid block of aluminum, a very stiff arrangement that eliminates this source of rotor shake.

The above design issues are only a part of the overall technology to minimize rotor-induced vibration. There is a lot more to follow:

The teeter pivot axial play is another major source of rotor-induced vibration. Most teeter pivots rely on shims or spacers to minimize chord-wise movement of the rotor on this teeter pivot or bolt. Most systems manage to keep this play below 10 mills - an old Bensen guideline. But, any amount of axial movement in this teeter joint results in rotor shake - and a hard-hitting rotor shake pulse as the rotor slams aft to the end of its axial play every time the rotors align laterally - the total rotor drag slams the teeter pivot back against its stop. This is a hard-hit, disturbingly felt in the controls, because as the rotor slides back on the teeter axial play, it hits a hard stop at the rear limit. Magni gyroplane's teeter block / hubbar configuration with teeter thrust roller bearings assures zero axial play on this teeter joint.

Another source of rotor-induced vibration comes from possible friction in the actual teeter bearings or bushings themselves. Many rotor head designs use bushings for this teeter pivot joint. Bushings tend to corrode, scar, loose their lubrication and get dirty - causing some friction in the teeter joint. Friction in the teeter joint is a source of vibration because what doesn't pivot on the teeter joint does "teeter" on the pitch and roll joints. On other gyroplanes, the first thing I do to attack a rotor shake problem is to clean up and freshly lubricate these teeter pivot bushings. The teeter joint on the Magni (and on a few other rotorhead designs) uses roller pin radial bearings to keep friction low in this joint - avoiding this possible source of rotor-induced vibration.

Magni rotor systems have a very shallow coning angle. This allows a very short teeter height - height of the teeter bolt above the plane of the hubbar. The teeter height should be such that it matches the vertical CG of the CONED rotor. When the rotor cones under flight loads, the CG of each blade is higher than the hubbar - this should be precisely the teeter height offset built into the rotor head teeter towers or block. If the CG of the coned rotor does not match the vertical position of the teeter axis - the bolt about which the rotor teeters, cyclic out-of-balance will occur because the spanwise CG will not be aligned with the spindle axis when cyclic control is applied. If the CG of the coned rotor is precisely aligned vertically with the teeter axis, the spanwise CG (and other critical centers) will remain centered over the spindle axis. Misalignment of the coned rotor CG with the Teeter axis (bolt) will result in rotor shake - most noticeable when moving the cyclic control or when flying through turbulence. The amount of misalignment is proportional to the amount of rotor induced vibration.

Exacerbating this and any other rotor -induced vibration, the taller the teeter height, the more leverage arm that vibration has to impart shake into the control stick. It is better, to minimize the effect of residual shake in a rotor system, to keep the teeter height to a minimum.

Magni rotor designs employ low coning angles and therefore low teeter heights, in the order of 3 inches as compared to six or eight in most other 2-place rotor systems. This further minimizes any rotor-induced shake into the control system because of the shorter leverage arm. But also, the shallower coning angle and shorter teeter height mean that a smaller span-wise displacement of the CG will occur when coning angle changes. Coning angle can change, from dynamic loads imparted on the rotor and from actual loading, air density, rotor RPM, etc. that can change the coning angle and mis-match it from the teeter height built into the rotor head. This slight mis-match cannot be avoided, but by minimizing the average coning angle and teeter height, the changes in coning angle result in smaller span-wise dis-locations of the CG when they do happen.

How does Magni keep the rotor coning angle this shallow, and therefore allow shorter teeter heights? I'd like to say it is a trade secret, but almost anyone can tell you it is done by using shorter diameter rotors. The rotor-induced vibration issues get exponentially worse with rotor blade diameters over about 25 ft. The Magni rotor on the 2-seat gyroplanes are 28 ft diameter - this compares with normally 30 or 32 ft diameter rotors on most other 2-seat gyroplanes. So, just the shorter rotor diameter makes the vibration issue a lot less challenging - in consideration of the other factors described above.

Why don't all gyroplanes use shorter rotors - now here is the BIG secret! Also, not so much of a secret, just ask any rotor blade manufacturer. Shorter rotors spin faster - they also spin faster to carry the heavier weights of 2-seat gyroplanes. The concern with most rotor blades is that when they get so fast, the tips have air velocities that are a significant fraction of sonic speed - compressibility starts becoming a factor on the center of lift on the tip portions of the blades. The closer the tip of the rotor blade gets to sonic speed, the center of lift on the blade tip starts moving aft on the blade. Ideally, the center of lift on the blade should align chordwise with the feathering axis of the blade - this is to balance stick forces. If the center of lift on the blade starts moving aft, most blades will twist somewhat, torsionally from tip to root. If/when this happens at the tip of the blade, the rotor naturally speeds up to handle the same gyroplane weight load but with less blade angle of attack. The blade spins even faster, with the tips seeing even more compressibility effects, and the whole cycle continues again. In the extreme this can result in "blade runaway", where the blades get destructively faster and faster, the blades twist flatter and flatter and the cycle repeats to destruction. Actually, what the pilot first notices is strong forward forces on the stick, as the center of lift on the blades moves further and further aft on the blade tips. To avoid this possible situation, because most rotor blades can twist torsionally from tip to hub, most gyroplane manufacturers keep the rotor diameters exceptionally long to keep blade tip speeds low enough to avoid compressibility speeds where blade twisting might become significant.

Magni shorter rotors are allowed to spin faster because the construction of each fiberglass blade is designed to resist torsional twisting. If the blades cannot twist from tip to root, there is little danger of blade runaway and higher rotor RPMs can be allowed. Higher rotor RPM means shallower coning height and shorter teeter heights with all the paybacks noted above. The Magni rotors are also very heavy and very stiff, reducing the coning angle further. It is interesting to note that a fully loaded Magni under high g loading (steep bank turns or sharp pull-ups) can achieve rotor RPMs of nearly 500 RPM - with no perception of excess forward stick pressures above what would be expected by the higher g load - the rotor shows no indication that the center of lift on the blades is moving excessively aft on the rotor blades.

A blade parameter called "tracking" can play an important part in rotor-induced vibrations. For rotor blades that are exactly aerodynamically balanced (aerodynamic center coincident with dynamic mass center) the blade tips should track along the same path in the air. If the blades are not precisely aerodynamically balanced, the visible tracking of the blade tips may not be ideal - some offset may actually present minimum vibration. The vibration from poor tracking or aerodynamic misbalance usually results more in vertical "cabin hop" than stick shake. Most rotors allow tracking adjustments to compensate for aerodynamic out-of-balance. Magni rotors have no tracking adjustment, relying on the proven quality precision of the blade fabrication. When the aerodynamic shape of each blade is precisely controlled as it is, any tracking error really means a slight dynamic mass balance error - center of mass is slightly offset from the spindle axis and the coned rotor is angled a bit to the heavy side. With the aerodynamic and geometric centers assured. Any slight out-of-track can be adjusted by slight balance weights at the tips of the blades. In fact, this is how the final dynamic balance is achieved, adjusting weights at the tips to attain perfect track.

Now, I'm almost running out of things that play a part in the extreme smoothness of the Magni rotor system - but there is a little more. No rotor system is perfect, and 2-blade teetering rotor system have at least one vibration issue that cannot be avoided completely. Rigid 2-blade rotor systems will incur a 2-per shake, fore and aft, due to the differences in rearward drag on the advancing blade relative to the retreating blade. More involved rotor systems such as on helicopters employ a lead-lag hinge on each blade to eliminate this cause of vibration. To keep our gyroplane rotors simple this mechanical complication is not normally employed on gyroplane teetering rotor systems.

To minimize this drag-related 2-per vibration, Magni rotors employ very clean and low drag airfoil and surface perfection - no rivets, no seams, precise airfoil contours throughout the whole span, etc. Just keeping the drag low minimizes the drag resultant shake.

But, there will always be some minimal amount of rotor-induced shake. Magni uses one more trick to prevent the pilot and controls from seeing this remaining vibration as stick shake. Some amount of friction is applied in the roll and pitch pivots in the rotor head. This friction significantly prevents any rotor shake from transmitting through the controls to the stick, it prevents the rotor head from moving on its roll and pitch pivots with the vibration. By restricting movement of the rotor head itself, any rotor vibration is transmitted into the mast and airframe instead of through the control system. For the high airframe moment of inertia and very stiff mast and frame, the resultant body shake is hardly noticeable. What this is really doing somewhat, is to not allow the rotorhead spindle to completely move as the rotor centers remains stationary. Because of the high inertia of the airframe, some of the rotor out-of-balance or shake is forced into the rotor disk and not all of it into the airframe body. At any rate, when this slight friction in the roll and pitch pivots is applied, increased body or airframe shake is not noticeable, but the "stick shake" transmitted through the controls is very noticeably reduced.

Ok, the more perceptive among you might argue that it is not a good thing to have friction in the controls! Without starting into the whole issue of pitch stability in gyroplanes, I'll agree that control friction is a thing to be avoided on unstable type gyroplane. If a gyroplane's airframe is unstable, that means it moves or pitches in the wrong direction in response to a vertical gust or g load transient. Because historically, most gyroplanes were negatively or neutrally stable in this regard, it has been very important to avoid friction in the controls or even a tight grip on the controls in those gyroplanes. Such friction or tight grip transmits the airframe wrong-pitch movements into the rotor, exacerbating the unstable situation into possible PIO or PPO. The Magni airframe, however, is very aerodynamically stable. So, its airframe moves in the correct pitch direction relative to a gust or g load transient. This means that it is actually a GOOD thing to couple this airframe pitch movement into the rotor - it further enhances stability. So, we apply some friction into the roll and pitch pivots of a Magni gyroplane to accomplish two things - reduced stick shake and further enhanced pitch stability. Of course the amount of friction applied in these pivots is kept below the level which might induce pilot over-control to overcome the friction. Magni gyroplanes also employ a high degree of control force feedback - for pilot over-control prevention - so the friction applied in the rotor head pivots is not really noticeable in the control forces.

Another factor in the Magni gyroplanes that minimize stick shake is simply that there is no play in the control linkage to the rotor head. All joints are precision bearings. In many gyroplanes, some joints are simple bushing joints, which accumulate some play. When you let go of a cyclic stick with a lot of play in the controls, the stick naturally shakes a minimum amount in this "play". This would not be actual, forceful stick shake, but it appears to have a lot of shake when you let go of the stick. Magni eliminates control play for a different reason - any play in the controls is a potential source for over-control by the pilot. If there is "play" or slop in the controls, the pilot must physically move the stick through this "play" - with no effect on the rotor - and then suddenly adjust his stick movement when the slop suddenly is "bottomed" out and suddenly further stick movement is actually affecting the rotor. Stick "play" should be minimized to minimize this potential for pilot over-control.

Now I'm finished, but I suspect there are other things that Magni has employed in these rotors that I am not even aware of. A prominent original designer of fiberglass helicopter rotor blades developed the fiberglass rotor blade technology that goes into the Magni rotor blades. He and Vittorio Magni conspired decades ago to employ this technology for autogyros. Vittorio Magni advanced the technology for his autogyros - solving other rotor shake problems along the way. With this much expertise and experience and time and money spent on these rotor systems, I'm quite sure I don't know the entire story. After all, we do need to keep some competitive edge!

One last thing - no you can't buy a Magni rotor for your gyroplane. First, it wouldn't match your rotor head design, and secondly, the rotor dynamics, inertia, and other features would not be proper for most other gyroplanes. As explained above, there is much more that goes into a smooth rotor than just the rotor and rotor head. And, Magni nor I could either compensate for or assume responsibility that all those other factors are properly addressed on your gyroplane. It is certainly not recommended that you attempt to apply any of the design principles above unless you thoroughly conduct the required testing in close consultation with that rotor manufacturer. Many development and test hours went into this Magni design. While some issues seem straight forward, many important considerations are not immediately apparent, such as the issues involved with maximum rotor RPM, airframe stability and rigidity, etc. Kids, do not attempt this at home!

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