Gear Tip Chamfer and Gear Noise; Surface Measurement of Spiral Bevel Gear Teeth

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Could the tip chamfer that manufacturing people usually use on the tips of gear teeth be the cause of vibration in the gear set? The set in question is spur, of 2.25 DP, with 20° pressure angle. The pinion has 14 teeth and the mating gear, 63 teeth. The pinion turns at 535 rpm maximum. Could a chamfer a little over 1/64" cause a vibration problem?

Bill Janninck replies: A 1/64" chamfer on the tips of gears that are as coarse as 2.25 DP would certainly not be considered a cause for gear vibrations. The chamfer is more likely to have a positive effect, such as the removal of sharp edges or burrs, than a negative one. There are other more likely causes for gear vibration or noise.

The usual first step followed in investigating any gear problem is to do some computations or computer modeling to assure that basic geometric requirements are met. The engineer checks for interferences, that suitable root clearances and backlash are present, and that the gear set has a contact ratio of 1.0 or more. The latter assures that there are proper conditions for a smooth transfer of contact from one gear tooth pair to the next. If the contact ratio were less than 1.0, the smooth passage of motion from pair to pair would be broken and could cause some impacting and vibration.

Since the details of the tooth depth system were not given, we investigated three cases.

- Fully standard gears using the 2.25" whole depth basic rack with 1.0" addendum.
- 25% long addendum pinion and 25% short addendum gear using the same basic rack as above.
- Fully standard stub depth gears with 1.8" whole depth and 0.8" addendum system.

Two sets of computations were made for each of these cases, one with no tip chamfer, and one with not a 1/64" tip chamfer, but rather a 1/16" tip chamfer, on both pinion and gear. The contact ratios resulting are shown in Table I.

In no case is the contact ratio below 1.0, even on the shallower depth stub teeth. Geometrically the design is good and, as mentioned before, the tip chamfer is not a likely cause for vibrations.

Another source of vibration is the gear and gear box support, where bend-

Table I — Contact Ratio Comparison

	No Chamfer	1/16" Chamfer
Standard Full Depth	1.54	1.42
25% Long & Short Addendum	1.56	1.36
Standard Stub Depth	1.34	1.13

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ing and torsional elasticity in shafting, the gear box, or bearings may be stimulated by gear tooth action.

A more likely cause for vibrations is in the functioning of the gear teeth themselves. The smooth engagement and transfer of contact and load to successive tooth pairs requires a certain degree of accuracy in tooth profile, tooth spacing, pitch line runout, and tooth parallelism. There is no easy way to predict the exact tolerances to use, but AGMA 390.03 gives some suggested values. With the pinion running at 535 rpm, the gear set pitch line velocity is 870 sfpm. AGMA Q8 or Q9 is suggested. Specific elemental tolerances can be taken from ANSI-AGMA 2000-A88. For the pinion,

Profile	.0015 - .002
Runout	.005 - .006
Spacing	.001 - .0013
Parallelism	.0008 - .0010

If the problem is serious enough, then actual inspections must be made to see just where the gear quality levels lie. Usually, the first thing checked is the profile, as it is more subject to manufacturing variations. A high profile near the tip is also cause for concern. The profile should preferably have a relieved tip and a high area near the pitch line. Next to be checked is spacing, where the errors can cause impacting, and then parallelism. Runout is the easiest to measure and is usually readily correctable.

At times it is worthwhile to examine the contact pattern occurring from running the gears together. Tip contact or any edge contact could indicate a quality problem.

Is equipment available for measuring surface finish on spiral bevel gear teeth (Q12)? The unit we have works best on flat straight surfaces and measurement taken on spiral bevel gears is questionable. Also, I am looking for reports or documents on surface finish requirements. (Our 30Ra has been "upped" to 32Ra by the manufacturer, so visual comparator type inspection can be used. I feel 25-30 Ra should be maintained.)

Bob Smith replies: First, there is nothing that relates surface finish requirements to a given AGMA quality level, such as Q12. The only relationship is that the finish must be good enough to prevent interference with the measurement of dimensional requirements of spacing, profile, etc. However, finish is related more to surface durability and scoring. You will find a discussion of this factor in AGMA 2001, *Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth, Appendix A.* The bevel gear rating standard, AGMA 2003, and the *Bevel Gear Design Manual*, AGMA 2005, vaguely discuss surface condition factor, C_t. Another reference is Dudley's *Gear Handbook*, Second Edition, 1991, page 15.21.

Measurement of surface finish on spiral bevel gear teeth can be difficult,

but not impossible. It is somewhat limited by diametral pitch. As with all surfaces, it should be measured at right angles to the lay of the finish pattern. This means roughly tip to root rather than toe to heel. This limits the amount of stylus travel. Generally, the length of stylus travel should be five times the cutoff wavelength. The most typical cutoff wavelength is .030". The only AGMA document on surface finish, AGMA 118.01 (now undergoing revision), defines roughness wavelength as 1/20th of tooth length. This probably puts wavelength in the proper perspective to tooth size. Most instruments have a limited selection of cutoff wavelengths, such as .003", .010", .030", and .100".

Another problem when trying to assess surface texture in gear teeth is the large curvature of the tooth form. Form is not of interest for surface texture, so it must be removed by some electronic or mechanical means. This can be done with a "skid" type instrument. This, however, sets a limit on how fine a diametral pitch can be checked. Another technique is to use a smooth curved datum surface to guide the stylus. This might be an optical circular or elliptical curved element that is adjusted to approximate the curve of the gear tooth. The more modern measuring instruments have a stylus with a very long travel (.040") normal to the surface. This can move across surfaces with large form error, but still digitize the surface roughness data. With PC-based analysis of data, it is then possible to quantify the roughness data with the desired cutoff wavelength. This type of equipment is well-suited to measurement of gear tooth surfaces.

Another way to get around the problem of getting into small gear tooth slots is to use a replica material. This is a filled two-part epoxy material designed specifically for surface finish measurement. It can faithfully replicate a surface down to six micro-inches Ra. The replica is removed from the slot for measurement. The resulting measurement is a negative of the actual surface, but roughness data will be the same.

Finally, you show concern that a tolerance limit was changed from 30 to 32Ra. The measurement of surface finish is not very exacting. Do two people measure at exactly the same spot? A difference of two micro-inches out of thirty is not very alarming and shouldn't make any difference in the functionality of the gear. As an example of this, the parameter for measurement was changed many years ago from RMS to Ra. Most people used the same numerical tolerances without conversion. Some people still use the parameter terms interchangeably, but with the same numerical values. Many pieces of current literature still use RMS, even though it is not equivalent to a surface with the same value for Ra. ■