When noise reduction is incorporated into design, the outcome will be increased quality and precision. The following is a practical approach to producing low-noise molded gears.
Gear noise reduction is best addressed in the design phase. Establishing optimized tooth counts, ratios, pitch, pressure angle, helix angle, tooth proportions, and modifications early in the design cycle can provide a robust and cost-effective solution to noise reduction.

**THE NATURE OF NOISE**

Noise created by a gear-driven enclosed drive is produced by a rather complex dynamic system. The gears in the drive are accountable for a measure of the excitation resulting in noise. There are other elements, however, that also bear some noise generation and propagation responsibility.

The motor itself inputs a torque ripple that is a function of its electrical and magnetic cogging attributes. Another likely source of noise comes from the armature shaft clearances in the motor bearings. Excessive clearances will allow the armature shaft to bounce back and forth in the clearances. The size of the clearances will vary with the unit and any bearing wear. The frequency of these bounces will be random but tend to be one to five times the shaft rotating frequency in small motors.

The housing design and material yield resonant frequencies that often promote noise propagation. The mounting of the gear shafts and their arrangement and stiffness in the housing also play a role in noise transmission.

This article centers on the noise-reduction potential of the gears from a design perspective. Taking a proactive approach to noise reduction at the beginning of the design cycle utilizing currently available design software is a cost-effective way to minimize noise before going into production.

**LOW-NOISE GEAR THREATS**

A prime goal for minimum noise generation is conjugate motion when operating under the design load. In this state the gear mesh produces uniform motion transmission. Transmission errors will be at a minimum. The involute tooth profile is well suited to yield uniform motion, even when the center distance varies. The enemy of a low-noise output is any gear parameter or condition that increases transmission error, which in turn results in non-uniform motion. The fact that the properties of plastic vary with temperature and moisture affect a number of gear parameters that must be considered as we work toward our noise-reduction goal. The impact of these and other features that affect plastic gear noise are shown in fig. 1.

**Deflection:** All gear teeth deflect under load. With the lower modulus of elasticity of plastic materials, tooth deflection is one issue that must be addressed. Tooth deflection alone causes non-uniform motion by distorting the involute form. The deflection is not the same for both members since the engagement begins with the tip of the gear at the pinion start of active profile near the root area and ends with the tip of the pinion, leaving engagement with the gear at the end of the end of active profile for the pinion. (See fig. 2).

For spur gears the sudden mesh contact of a leading unloaded tooth on the driven gear produces an impact load that also contributes to the noise excitation. Helical gears are not prone
to this level of impact since the contact lines are on an angle relative to their axis and gradually move from one side of the face to the other. The optimum helix angle for noise reduction is one that yields a face contact ratio near an integer value. However, if that is not possible—due to axial thrust, for instance—a lesser helix angle will excite less noise than an unmodified spur gear.

Then there is another deflection issue regarding load sharing. If the profile contact ratio of a gear pair is 1.5, the load will be carried by one pair of teeth for half the time and two pairs for the other half. The amount of deflection will vary when the load sharing and mesh stiffness changes. The resultant changes in motion transmission will influence the noise generation.

Profile Errors: Tooth profile errors add to the motion transmission errors that further add to the excitation causing noise. There may be uniform errors on all the teeth that result from thermal expansion or contraction. Profile errors may also be a result of the non-uniform rim, web, or rib configurations. Gate locations and the resulting weld lines may also result in profile errors if not accounted for in the grooming of the mold.

Pitch Errors: Tooth pitch errors like profile errors may be uniform errors on all the teeth that result from thermal expansion or contraction. They may also be a result of the non-uniform rim, web, or rib configurations. Gate locations and the resulting weld lines may also result in pitch errors if not accounted for in the tool.

Lead Errors: Lead errors are less prone to generate mesh related excitations. In spur gears lead errors are not as great a noise factor in the meshing of the gears. However, heavy contact on the end of the tooth will present a noise issue. If the lead error changes direction multiple times per revolution, a disturbing rattle or shuttling noise could result.

**Fig. 1: Chart showing relative noise reduction impact.**

<table>
<thead>
<tr>
<th>Relative Noise Reduction Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact Ratio</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Raycar Gear & Machine Co.
4884 Stenstrom Road • Rockford, IL 61109
Phone: 815-874-3948 • Fax: 815-874-3817

www.raycargear.com
**Interference:** Any form of interference would be a major noise contributor. This interference is usually a result of the tip on one gear touching the root area of the other. Excessive runout or out of round, and lack of accounting for the tolerance stack-up, can be an issue.

**Loss of Profile Contact:** If all the variables that make up the extreme conditions relating to center distance are not properly accounted for, the profile contact ratio may drop below 1.00. When that occurs the driver will jump to the next tooth after the previous tooth exits its mesh. The resulting impact will be heard.

**Sliding Velocity:** Gears are quieter when they roll at the operating pitch line. Unfortunately, they are there for only an instant. There can be a wide range of radial velocity especially when the pinion has a small number of teeth.

**Surface Finish:** The undulations in two mating surfaces sliding over each other add to the noise generation.

**Frictional Forces:** These are of a lesser consequence than the factors that affect motion transmission. What is notable is that they change direction at the operating pitch diameter.

---

**LOW NOISE GEARS BY DESIGN**

Now that we have discussed the threats to low-noise gears we turn to the opportunities that are available. In any optimization it is important to keep in mind that a balance must be struck between low noise and other design parameters that must be met. For example, a gear set could be designed to have a profile contact ratio of 5.0. It most likely would not be practical since the fine pitch teeth would not be strong or robust enough to maintain an acceptable contact ratio with a reasonable center distance tolerance. The designer still has to consider multiple design parameters that set practical limits on the outcome.

**PROFILE CONTACT RATIO**

Increasing the profile contact ratio, which is the average number of teeth in contact, will improve the chances of reduced noise in a gear set. This can also be accomplished by using a lower pressure...
angle, a larger number of teeth, and a greater working depth. As fig. 3 points out, the smaller the number of teeth, the less tooth height is available before the two sides of the tooth converge at a point. The blue line labeled “Std. Tooth Thickness” is the number of addendums above the standard pitch diameter where the teeth come to a point. The orange line labeled “Long Addendum TT” is the number of addendums above the one addendum enlarged pitch diameter where the teeth come to a point.

A lower pressure angle allows for a greater tooth depth by increasing the pointed tooth diameter. The increased tooth depth allows the larger outside diameter that increases the active length of the line of action. This yields a higher contact ratio.

**SPECIFIC SLIDING RATIO**

The theoretical involute tooth profile curve begins at the base diameter. At that point the radius of curvature is zero. From there it continues to get bigger. To reduce the potential for noise it is best to keep the tooth contact as far from the base circle as possible. The specific sliding ratio is the ratio of sliding to rolling velocity. It is highest at the start of active profile then goes to zero at the operating pitch diameter and increases at a slower rate as contact moves to the end of active profile. The high specific sliding ratio results in a lower mesh efficiency and increases the noise potential. It is preferred to keep that ratio less than 3.0. Increasing the profile shift and long addendum, reduces the sliding ratio.

**TOOTH PROFILE TIP RELIEF**

The whine of a gear mesh is closely related to the profile accuracy. The shape of the profile will also affect the noise...
content. A variation in pressure angle or mean involute slope will produce a saw-tooth transmission error. The saw-tooth shape is not desirable. Adding tip relief to the gears, especially on the driven gear, will minimize the impact of the profile errors and the deflection that is load dependent. The deflection of the driving pinion when exiting the mesh does not contribute as much transmission error as the gear entering mesh. The amount of tip relief should not exceed the sum of the deflection and the mean profile error. It is important to design the amount of tip relief to account for the torque at the most common running position. The shape of the tip relief should be a gradual blend with the involute profile. The start of the tip relief should never be below the highest point of single tooth contact. The transmission error can be minimized for a specific torque. A torque increase or decrease will result in a larger transmission error.

Since the addition of tip relief reduces the no-load contact ratio, care must be taken to make sure that ratio does not fall below 1.0 in the maximum effective center distance condition and the minimum material condition. The upper gear mesh shown in fig. 4 shows the initial point of contact at the start of active profile of the driven gear. The lower gear mesh shows how the gear profile has been relieved at the tip of the gear.

LEAD CROWNING
If the error in the lead forces the mesh contact off to one end of the face, noise will increase. The condition would be aggravated in the case of a spur gear that has both minus and plus lead error in an alternating pattern. Added noise is initiated from the gear shuttling from one side to the other. Putting a crown on the gear tooth will reduce the effect. Crowning relieves the ends of the teeth creating a barrel shape when looking down on the tooth. There is little loss of effectiveness since the load pattern will spread out under a heavier load cycle.

HUNTING TOOTH
A hunting tooth ratio has tooth numbers that do not share common divisors. A 13-by 24-tooth ratio is a hunting tooth. A 12-by 24-tooth ratio is not since the 12-tooth
The pinion will always mate with the same teeth. For plastic gears where running-in is more of a common phenomenon, a hunting tooth ratio is not as desirable. Minor tooth errors are more likely to find "home" rather than continue to search for home in a hunting ratio. The long repeat period of a hunting ratio can produce annoying sounds.

CONCLUSION
Plastic gears are often specified for their dampening qualities. In addition they offer a wide window of opportunity to further noise reduction when their design potential is realized. Figure 5 summarizes some of the key issues.

<table>
<thead>
<tr>
<th>Gear Quality Characteristics and Their Influence on Gear Noise</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Quality Characteristic</strong></td>
</tr>
<tr>
<td>Involute tooth shape</td>
</tr>
<tr>
<td>Lead Error</td>
</tr>
<tr>
<td>Runout</td>
</tr>
<tr>
<td>Out-of round</td>
</tr>
<tr>
<td>Tooth spacing variation</td>
</tr>
<tr>
<td>OD or (ID on internal gears)</td>
</tr>
<tr>
<td>Root diameter</td>
</tr>
<tr>
<td>Circular tooth thickness</td>
</tr>
</tbody>
</table>

*Unless there is interference with the tip of the mating gear
**Unless there is rapid reversals or dithering

Fig. 5: Gear quality characteristics as they influence gear noise.

ABOUT THE AUTHOR:
Richard R. Kuhr is senior application engineer for ABA-PGT, Inc. For more information call (877) 840-2172, e-mail info@abapgt.com, or go to [www.abapgt.com].