Take a PEEK at Polymer

With the right design, plastic molded gears can exceed their metal brethren. The following article is a detailed examination of the approach taken by Kleiss Gears.

By Rod Kleiss
Much has been written about PEEK polymer’s ability to withstand extreme temperature environments and other key properties including strength and chemical resistance, which make it the material of choice for a number of applications, replacing metal with molded polymer for gears. A recently published case study cited the example of a successful metal to plastic gear conversion in an automotive balance shaft module. The molded PEEK gears highlighted by the article were quieter, lighter, lower cost, and reduced power consumption of the metal gears they replaced. Figure 1 shows the little molded gear that could.

However, this project required much more than simply molding the original metal gear design in PEEK—for “polyether ether ketone”—polymer to realize the full benefit of this remarkable material. Ultimately, the plastic molded gear required significant modification from the original metal gear shape to ensure its success. So, in the parlance of the late newscaster Paul Harvey, here's the rest of the story.

When Kleiss Gears was initially contacted about this project, another molder had built tooling to try and reproduce a molded gear to the specifications of the ground metal gear, but the performance of this molded gear was not acceptable. The customer initially contacted Kleiss Gears to inspect the molded gear and comment on the quality level. Figure 2 shows a molded gear in the original ground gear design.

The shape of the final plastic gear obviously differs significantly from the metal gear it replaced. Our inspection of the molded gear in the original design showed that it was not too bad, but demonstrated the usual molded gear problems: the base cylinder was not quite right; the lead was off; and the taper across the face was excessive. We could have improved all of these characteristics, but they weren’t far off enough to explain the gear failure. Kleiss Gears suggested redesigning these gears to achieve the best function as molded plastic parts. This requires a paradigm shift in the design approach.

First, we should look at how the majority of gears are designed now. The standard approach to gear design in today’s world is to design standard pitch- or module-based gears with standard pressure angles of 20° or 25°. The design of the gear also involves the use of a standard rack or hob cutter, or the design of a new cutter or hob shape. This approach allows very little modification opportunity for the gear designer. This is because selecting a tooth thickness while designing for production with a standard topping hob predefines outside, root, and involute form diameters. Using a custom hob allows the gear engineer more freedom in these choices, but it still predefines the actual cut shape of the gear trochoid. Not only that, but the standard approach tends to stay with standard pitches or modules and pressure angles even when taking the license to design custom gears. Finally, in this standard design approach, the actual shape of the hob gears is still important. One would not want to make the hob tip too thin or it would wear prematurely or break too easily. Tip and corner radii should be considered carefully for the tool construction. These are all necessary considerations for gears that will actually be manufactured using hobs, which is not the case with molded gears.

The paradigm shift is that the plastic gear designer and toolmaker needn’t care about hobs. We seldom, if ever, use them. We need to make one nearly perfect cavity from which we will produce thousands—if not millions—of molded gears. Most plastic gears are produced in what are called three-plate molds. The gear is molded in one part of the
three-plate sandwich. The runner, through which the molten material is sent to the gear, is formed in the other part of the three-plate sandwich. This allows the plastic resin to be injected into the face of the gear with the effect of more even filling and allows distance between the point of injection and the gear teeth. An example of such a cavity and the gear it forms are shown in fig. 3.

Wire EDM achieves the finest accuracy for cutting these molded gear cavities, which presents the first challenge to the original design. Wire EDM cannot correctly shape the high helix angle.
of the original gears. The most practical methods to produce a high helix angle such as this are to hob, or to grind an electrode and burn the shape into the steel. These methods can be done and have been done, but they introduce another step in the process and limit the designer’s versatility. Kleiss Gears prefers to greatly reduce the helix angle, so that a tilted wire EDM axis can cut a very close approximation to the theoretical shape. The reduced helix angle gives us the advantage of reducing tooth slap, while maintaining our ability to directly cut a two-dimensional pattern of our choice into the steel cavity and adjust the wire path to correct for molded shrinkage.

The next thing we do is adjust the cross-sectioned shape of our gear tooth. We want to make the depth of the tooth as large as possible to increase contact ratio. We also adjust the pressure angle of the tooth to balance performance goals with tolerance realities. Quite simply, bigger pressure angles make stronger teeth, but reduce tooth height and contact ratio. The trade-off for stronger teeth is less contact ratio and more sensitivity to tolerance issues. Tolerance is a big issue for molded gears because the gears will shrink or expand with temperature, and perhaps humidity. They will also vary somewhat during production, much more so than the expected tolerance range of closely tolerated cut gears.

Finally, we shape the root or trochoid of the gear so that it will have clearance with its mating gear. We think that shaping the root or trochoid of the gear is a very important step in making better-molded gears. Hobs remove enough material from the root so that the gear can be mated with any number of teeth without trochoid interference. Our molded plastic gears do not have to be versatile in that fashion since we know exactly what gear will mate with it, so we design the gear shapes accordingly. Figure 4 shows a comparison of a 30-tooth gear cut with a hob, and that same gear with its trochoid shaped to assure clearance with an eight-tooth mating gear.

Shaping the trochoid for the mating gear allows a much stronger gear tooth with more rounded corners for higher strength.

Fig. 4: Shaped trochoid, at left, and a hobbed trochoid, right.
It should be noted that the shaped trochoid of the gear in fig. 4 is not a simple fillet radius. It is the traced outline of the mating eight-tooth gear in close mesh. A picture of that mesh is shown in fig. 5. You will see that the eight-tooth gear used to form the trochoid in this example is highly undercut with a very sharp tip. The tip of that gear has a fillet radius of .00425. For this example, we didn’t do a truly functional mesh because we want to show that the gear doing the shaping is just a mathematical construct. We describe a tip radius on the gear because we know a wire EDM will cut the cavity, and the mating gear will have a tip radius equivalent to the wire radius plus a small amount of overburn.

Using this method, we do not have to consider pitches or modules at all. Pressure angle is chosen to balance the need for strength against the tolerance requirements. The designer sets the base pitch of the gear set or designs the gears simply by knowing their actual center distances and selecting a base pitch to match that center distance. In
general, we allow the depth of the gear to be approximately 95 percent of possible entire depth if the gear had a sharp point for the outside diameter.

After we optimized the gear design for the molded plastic application in this fashion, we built the tool. Gear tools are in general much easier to design than other molded products with thin walls, changeable sections, and large surface areas. Plastic molded gears are small disks with bores in them. It is very fortunate for us that the shape is simple because we have to make features accurate to less than .001 inches, and sometimes much less. We do that by paying very close attention to tool accuracy, molded gear shrinkage, stiffness, cooling, and smooth operation.

The final piece of the puzzle is molding. We use CNC controlled injection molding presses with statistical process control monitoring built in. Repeatability is the name of the molding game. Hit the marks for injection timing, pressure control, temperature stability, and material consistency. The final shape of the mesh for this gear project is shown in fig. 6. Kleiss Gears molded both gears with the new design and gears with the previous design. The new molded gear design surpassed the old design by a significant margin and succeeded in the application.

The point to be made with this article is that plastic molded gears can indeed exceed their metal brethren with the right design. However, it is not as simple as simply changing materials. In plastics, everything is important!

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**External Gears**

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<th>Gear Diameter</th>
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