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Improving Appliances with Plastic Gears

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For the appliance engineer, plastic gears are a powerful means to cut cost, weight, noise and wear. They also open new opportunities for smaller, more efficient drives. What are the payoffs when using plastic gears in place of metal? The questions are timely as more engineers turn to plastic gears in higher-power, high-precision applications.

When Maytag engineers designed their new washer transmission around plastic gears, they effectively eliminated the noise of steel gears (figure 1). They also saved 13 pounds and did away with 42 parts compared with a previous metal gearbox. Gears injection molded from unfilled and fiberglass-reinforced acetal copolymer proved that they could maintain their strength and tight tolerance even in an oil-bath transmission. They also demonstrated the long-term durability essential in an appliance expected to have a long service life.

Figure 1. The pioneering dual drive washer transmission from Maytag uses spur gears molded in fiberglass-reinforced Celcon® acetal copolymer. It saves 13 pounds and eliminates 42 parts compared with a conventional metal gearbox, and dramatically reduces gear noise while enhancing long term performance.

To improve the reliability of the "World Washer" manufactured in several countries, Whirlpool Corporation introduced a splined clutch or "splutch," containing a spline and gears molded in acetal copolymer (figure 2). The low-wear epicyclic gear assembly lasts four times the projected washing machine life with a 20% reduction in the number of moving parts compared with earlier designs using metal gears.

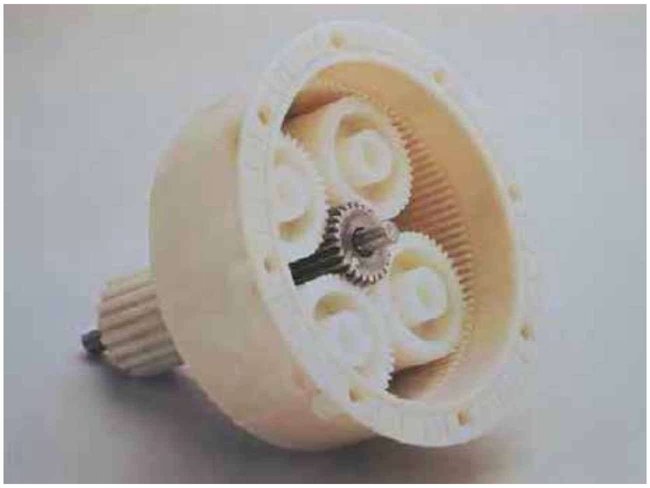

Figure 2. The Whirlpool "splutch" used molded plastic gears to reduce parts count and extend the life of the World Washer. The gears are molded in Celcon® acetal copolymer.

Hewlett-Packard working with UFE took plastic gears to new standards of manufacturing quality in DeskJet 660 color printer (figure 3). Acetal copolymer cluster gears were designed to comply with the high quality standards of AGMA (American Gear Manufacturers Association) Quality Class Q9. Accuracy was necessary for precise paper movement to prevent "banding" – obvious skipped lines or overprinting. For 48-pitch gears 1.25 inches diameter, AGMA Class Q9 denotes Total Cumulative Error (TCE) of just 0.0015 inch, and Tooth-To-Tooth (TTT) error of 0.00071 inch. The molding consistency of acetal copolymer enabled the high quality rating.

Plastics Pay Off

In food processors, mixers, slicers, and other appliances, engineers have turned to injection molded plastic gears to reduce parts count and cut cost. Injection molding is fast and economical compared with hobbing teeth in metal blanks. Generally, plastic gears can be used as molded and require no finishing. They are therefore far less costly in production quantities. The cost of plastic alternatives can be one-half to one-tenth that of stamped, machined, or powder metal gears, depending on the manufacturing technique. Injection molded cluster gears such as those in the Maytag transmission also consolidate parts without expensive machining.

Figure 3. Hewlett-Packard took plastic gears to AGMA class Q9 quality standards to give its color printer precise paper motion. The gears are molded in low wear Celcon® acetal copolymer.

Plastic gears are inherently lighter than metal. The specific gravity of steel is 7.85 while the specific gravities of glass-filled nylon 6/6 and low-wear acetal copolymer are both around 1.4. However, simple differences in material density are not direct indicators of potential weight savings. To transmit the same power, plastic gears must usually be larger than metal gears. However, plastics lend themselves to innovative gear designs thus providing smaller, lighter drivetrains.

The pioneering Maytag washer transmission is a split-path design rarely considered by designers because such arrangements once demanded greater numbers of expensive metal gears. With plastic gears, these compact transmissions can be made at lower cost than multi-stage spur drives.

Plastic gears are less prone to corrosion, and they have inherently low coefficients of friction to minimize wear. Lower friction also means less horsepower wasted in heat. Maytag estimates the cooler-running plastic transmission reduced heat rise 10 to 15% compared with previous metal drivetrains. Greater efficiency can be important in light of future US Department of Energy standards for appliances.

Plastic gears also lend themselves to applications where grease or oil is unacceptable, such as food processors or computer printers. Without the need to seal a gear box housing, unlubricated gearboxes are generally far less expensive than those designed to contain grease or oil. While unlubricated gears simplify transmissions, plastic gears can nonetheless operate with and benefit from lubricants when necessary. Whirlpool Corp. incorporated a plastic helical spin gear in the Design 2000 washer and the fiberglass reinforced acetal copolymer gears maintained tensile and impact strength in SAE60 oil.

Plastic gears provide the opportunity to cut drive noise by reducing dynamic loading. Gear misalignment and small tooth errors create tiny impacts resulting in running noise. However, lower modulus plastic gear teeth deform and absorb impact to compensate for the inaccuracies, making plastic gears quieter than metal – in some cases even quieter than more costly metal gears that are rated one or two classes higher in quality by AGMA.

Design Opportunities

The most powerful advantages of plastic gears may be the design opportunities they afford. Gear geometries overlooked by designers accustomed to metal are easy to mold in plastic, and they can reduce drive size, weight and cost. For example, a common arrangement of two external spur gears with a large ratio demands a wider center distance. The same ratio can be achieved in smaller space by replacing an external gear with an internal gear. Internal gears are tough to machine in metal but easy to mold in plastic.

While plastics make it easier to consolidate drive parts, they also allow designers to rethink the old axiom: The Fewer Parts, The Better. Split power paths in parallel or nonparallel axis drives can indeed have more parts, but they afford advantages in space, weight, efficiency and cost. The balanced Maytag dual-drive transmission eliminated a heavy counterweight built into the predecessor drive.

For all the advantages of plastic gears, the more critical the drive, the more complicated the up-front design effort required to make plastic gears work. Plastic gears are today in drives from ¼ to ¾ hp. Future applications will take them between 1 and 10 hp in the near-term and possibly up to 30 hp in the long term. The broader applications of plastic gears however complicates the design and specification process.

Things to Consider

The decision to lubricate or not lubricate, and the choice of a lubricant, are key factors for the appliance designer to consider. For plastic gears running in an oil bath or grease, the lubricant reduces frictional heat and allows higher load capacity. Unlubricated gears are aerodynamically cooled and therefore run hotter with lower load capacity. Unlubricated gearsets are often molded in different materials for reduced coefficient of friction (COF). For example, acetal copolymer is often mated with nylon 6/6 or polybutylene terephthalate (PBT). These combinations have much lower COFs than any of these materials working against themselves.

Unlubricated plastic drives can also have lubricants such as PTFE, silicone or graphite compounded into the polymer used for gears. While these additives reduce the coefficient of friction (COF), the COF might still be higher than that of greased gears.

Engineering resins can resist oils and greases. However, lubricants must be carefully chosen because some can cause dramatic changes in gear properties and dimensions. For example, extreme pressure oils are unnecessary with low contact pressures found in plastic gearing, and some can attack plastics chemically. Likewise, the resin formulation is critical. PTFE and other low-friction additives compounded in plastic gear resins may have little value or negative value if the gears are oiled or greased.

Plastics are naturally more prone to dimensional creep than metal, and creep in plastic gears depends on duty cycle and temperature. Consequently, molded gears are best used in applications without static or stall loads. If static loads cannot be avoided, plastic gears should be designed to operate properly after teeth have deflected due to creep.

The operating speed of plastic gears obviously impacts their operating temperature. However, rapid loading rates can also affect material properties. For some materials, the faster a tooth is loaded, the higher the effective modulus and strength. Higher temperature reduces the modulus and strength of plastics and accelerates creep. These effects must be considered in the design process, and studies to quantify them are just beginning.

Seek Help

Gear load analysis is complicated, regardless of gear material, and gear design remains an area of special expertise. Gears also usually demand more precision than commonly molded parts, so their tooling can be expensive. A good detailed plastic gear design, up front, however, saves money in reducing trial-and-error design iterations. For appliance engineers, building a drive with plastic gears should start with a team including an experienced gear designer, molder, tool builder and resin supplier.

The team needs the most complete application information available to create the most detailed gear specification possible. Ambient temperature, lubrication and duty cycle all impact gear life and drive performance. A housing material that does not match the thermal performance and moisture absorption of the plastic gears can stall tight-meshed gears. Computer Aided Design tools, which are available from software suppliers such as Universal Technical Systems in Rockford, IL, can help designers allow for worst-case tolerances.

Standard metal tooth profiles are only a starting point for plastic gears. They need to be optimized for a material with a lower modulus, greater temperature sensitivity, and different coefficients of friction and wear than metal. Plastic gears can have working depths up to 35% greater than metal gears. This allows for variation in effective center distance due to thermal, chemical, and moisture expansion. The designer of plastic gears should also strive for a full root radius. An ample radius reduces stresses at the root and also enhances resin flow into the teeth during injection molding which reduces molded-in stresses. It also removes heat more uniformly from the plastic during the injection molding solidification phase for more stable part geometry.

The designer of plastic gears also should pay attention to shaft attachment. Bore tolerances naturally impact true center distances, and inadequate tolerances at the shaft sometimes result in loss of proper gear action. A simple press-fit demands extra molding precision for a secure mount without over-stressing the plastic. A press-fit knurled or splined shaft can transfer more torque but also puts more stress on the bear hub. Insert-molded hubs grip better, but during molding, as the plastic shrinks onto the shaft, they can induce residual stresses. Ultrasonic insertion of a knurled shaft produces the lowest residual stresses. In some cases, a single - or double-D keyed shaft prevents slippage and minimizes distortion with assembly. However, if torque is high, these can become loose. For high torque applications, splined assemblies are preferred.

Choosing a Resin

Horsepower limits for plastic gears vary with the resin, depending upon the modulus, strength, and creep characteristics which all change with temperature. Nevertheless, plastic gear limits can be defined, in terms of contact stress, velocity and temperature for dry running gears. For lubricated gears, fatigue strength and temperature are the critical issues.

Inexpensive commodity resins generally lack the fatigue life, temperature resistance, lubricant resistance, and dimensional stability required for high performance plastic gears. However, many of today's engineering resins provide the necessary performance for appliance gear trains. They also have the consistent melt viscosity, additive concentrations, and other qualities essential to consistent, accurate molding.

Crystalline resins generally have better fatigue resistance than amorphous plastics, and most plastic gears use crystalline resins such as acetal and nylon. Nylon, both with and without glass reinforcement, serves in many gear and housing applications.

Resin Database

Gear resin selection requires the appliance designer to focus on resin performance at the high end of the operating temperature range planned for the drive. However, higher temperatures lower both the modulus and strength of gear resins. They increase creep rate and introduce thermal expansion into precision parts. Fortunately, the temperature response of engineering resins is well understood, allowing designers to predict the effect on their gears.

The advantages of plastic gears are becoming more obvious as major manufacturers look to cut cost and increase reliability. Along with a range of compatible engineering resins, there is also ample expertise available about the design and manufacture of plastic gears. With the right material and some help, designers can realize the powerful potential of plastic gears in a wider range of appliances.

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- Vandar® thermoplastic polyester alloy (PBT)
- Vectra® and Zenite® liquid crystal polymer (LCP)

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