Things you should know about sizing and applying

Plastic gears

Some say don't call on plastic to do a metal's job, but the lines between the two materials' capabilities are blurring. Plastic gears can be used successfully without lubrication in 60 to 70% of open gear applications. They'll even work lubrication free in such demanding applications as a 21-in. diameter main drive for a packaging machine or a 300-rpm drive for a diaper-making machine.

Even further closing the gap between metal and plastic are hybrid gears, incorporating nylon 12 castings around knurled metal hubs. Nevertheless, when a gear design incorporates plastic, a number of variables come into play.

The knurled metal core around which nylon 12 is cast provides ample torque transmission and even heat dissipation from the gear teeth through to the shaft. The metal also reduces thermal expansion by about 50%, increasing operating stability. Once the nylon 12 material is cast around the core, the finished bar, second from left, is "sliced" into blanks. Then the blanks are hobbed to create teeth, while the hub center is machined out, usually with a keyway for secure attachment to the shaft.

Sizing protocol

The key to any gear's performance is proper sizing. A metal gear is generally rated by evaluating load data, but plastics have different properties than metals and are sensitive to changing operating conditions. A plastic gear, therefore, must be selected, actually, calculated, with load data, environmental conditions, and material properties in mind. Things to consider include:

- DRIVE GEOMETRY — center distance; available space (face width).
- LOAD DATA — torque; rpm; transmission ratio.
- ENVIRONMENT AND OPERATING CONDITIONS — operating temperature; shock loading; exposure to chemicals; exposure to water or humidity; clean room, etc.
- PLASTIC MATERIAL PROPERTIES — moisture absorption; swelling and backlash requirements; impact strength at low and wear resistance at high temperatures.

You'll likely know the gear ratio, the center distance, and possibly the motor's horsepower. If you're lucky, you'll have the freedom to determine the space needed for the gears. It's usually better to start working with a plastic gear supplier early in the design process, rather than reaching for a cookie cutter catalog solution at the last minute.

Selecting the right plastic

There are many engineered nylon gear materials on the market, choosing the right one depends on your specific application needs. Some materials, such as nylon 6, have limitations such as moisture absorption and swelling (sometimes more than 3%) resulting in dimensional change and loss of tensile strength. Other polyamide (nylon) gears are not as limited, for example, with cast nylon 12, you get high torque transmission, self lubrication, quiet operation, light weight, shock and vibration absorption, long wear, low maintenance, and no corrosion.

Assignment: metal gear replacement

With so many variables involved, each plastic gear application is likely to be different, as evidenced in the following example. The problem was quite common, oil leaks in a machine using lubricated metal gears. To complicate matters, the machine must operate for 12 months without failure, as wear components are to be changed only during the annual shut-down or after 2,000 hours of operation.

Plastic gear selection for the application begins with review of the existing gear set parameters:

Center distance: 5 in.
Output speed: 300 rpm
Input speed: 1,200 rpm
Start-up torque: 1,200 in.-lb
Continuous torque: 700 in.-lb

The original metal gears have the following specs:

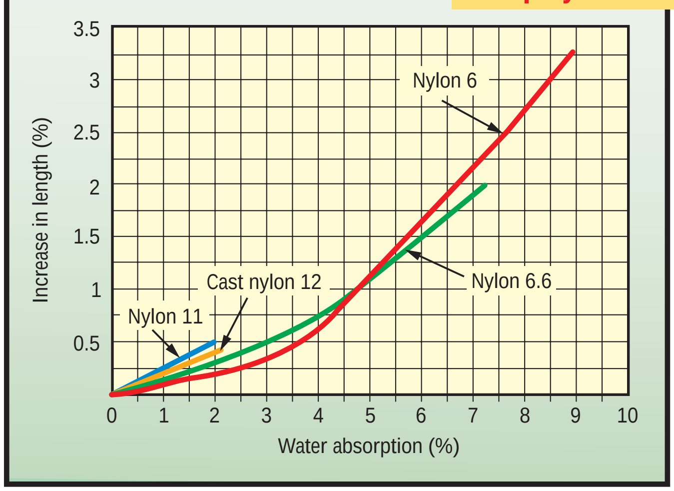
Pinion: spur; 20 teeth (T), 10 diametral pitch (DP); 20° pressure angle (PA); attachment to shaft via keyway; 1.25-in. face width; 2.25-in. length trough hub (LTH); mild steel material.

Gear: spur; 80 T; 10 DP; 20° PA; keyway; 1.25-in. face; 2.25-in. LTH; material cast iron.

Rated torque is 1,307 in.-lb.

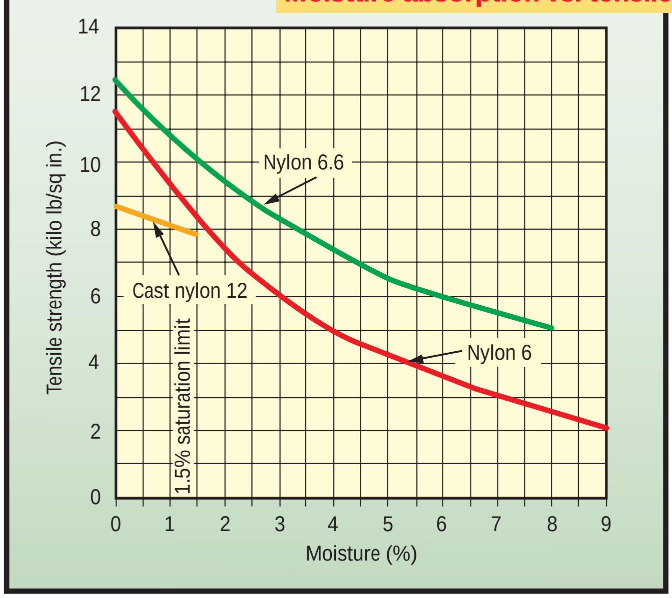
If these gears were to run without lubrication, they would last anywhere from

How polyamids handle moisture



Cast nylon 12 (PA 12G) gears grow less than 0.2% even when permanently immersed in fluid.

Moisture absorption vs. tensile strength



Cast nylon 12 (PA 12G) material absorbs very little moisture compared to other nylon gear materials, and therefore maintains nearly all of its original tensile strength. Moisture not only causes swelling and related backlash problems, but also causes tensile strength properties to fall precipitously.

Plastic gear alternatives	Unit	1		2		3	
Mating pinion (steel)	T	20		20		23	
Gear (cast nylon 12)	T	80		80		92	
Face width	in.	1.25		2.5		2.5	
Diametral pitch		10		10		12	
Pressure angle	°	20		20		20	
Torque	in.-lb	Continuous	Start-up	Continuous	Start-up	Continuous	Start-up
		700	1,200	700	1,200	700	1,200
Tooth root stress safety factor		2.2	1.1	3.5	2.6	3	1.9
Tooth flank stress (wear) safety factor		0.6	0.4	1.1	0.7	1.32	0.9
Minimum safe life, init. lube	hr	150	10	2,500	175	2,500	250

Materials comparison

Benefit	Cast nylon 12 (Power-Core)	Delrin	Nylon 6 family	Phenolic fiber	Metal
Noise reduction	6 dB	>3 dB	>3 dB	>3 dB	0
Shock absorbtion	Yes	Yes[a]	Yes[b]	Some	No
Vibration damping	Yes	Yes[a]	Yes[b]	Some	No
Corrosion resistance	Yes[1]	Yes	Yes	Yes	Yes[2]
Non-hygroscopic, no swelling	Yes	Yes	No	No	Yes
Light weight	Yes	Yes	Yes	Yes	No
Wear resistance	Yes	Yes[c]	Yes[d]	Some[e]	No
Lubrication free	Yes	Yes	Yes	Recommend lube	No
Free of internal stresses	Yes	No[f]	No[f]	No[f]	Yes
Homogeneous crystalline structure	Yes	No	No	No	Yes
Metal hub part of gear blank	Yes	No[g]	Some[g]	No[g]	N/A
Large gear size blanks with metal core	Yes	No[h]	No[i]	No	N/A
Keyway in metal, stress risers absorbed	Yes	No[j]	No[j]	No[j]	Yes
Physical properties stable in varying conditions	Yes[4]	No	No	No	Yes
High AGMA class achievable	Yes[3]	No[k]	No[l]	No	Yes
Dimensionally stable	Yes	No[m]	No[n]	No	Yes
Gear durability calculation available	Yes	Call mfg.	Call mfg.	—	Yes
Gear engineering and design assistance	Yes	Call mfg.	Call mfg.	—	Call mfg.

a. Internal stresses will diminish capability to absorb shock and vibration.
b. Capability to absorb shock and vibration will vary with changing moisture content and internal stresses, e.g. brittle when dry.
c. Lower resistance to wear compared to cast nylon 12.
d. Changing moisture content affects internal stresses and physical properties, including tensile strength and wear resistance, are diminished.
e. High coefficient of friction and swelling when lubricated will cause wear.
f. Residual internal stresses result from manufacturing processes, e.g. extruding, and chemical reaction during such processes, e.g. polymerization. Variation of tension will also occur with moisture or temperature changes and will result in dimensional changes on the pitch line.
g. Manufacturing processes and chemical composition ordinarily make casting around metal hub not feasible. In some nylon 6 derivations, a metal core is offered.
h. Injection molding and extruding limits OD of blanks. Larger gears are made from plates and require additional flange.
i. Large blanks, available as castings, require separate metal flange.
j. In all-plastic gears, torque forces cause stress risers from the key-way to the gear teeth, diminishing the load capability of the gear. Keyway becomes the weak part of the gear, enlarges with temperature increase.
k. Internal stresses and varying operating conditions will change required pitch line tolerances to lower AGMA class.
l. Same as above (k), and swelling due to moisture will magnify tolerance changes.
m. Changing internal stresses will cause change in gear dimensions.
n. Increased moisture content will cause swelling, i.e. dimensional change of 3% or more in nylon 6.

1. Available with stainless steel core.
2. When made of stainless steel.
3. AGMA Class 10 or higher.
4. Excellent longterm dimensional stability. After initial stress relieve, stresses will not return with varying moisture or temperature.

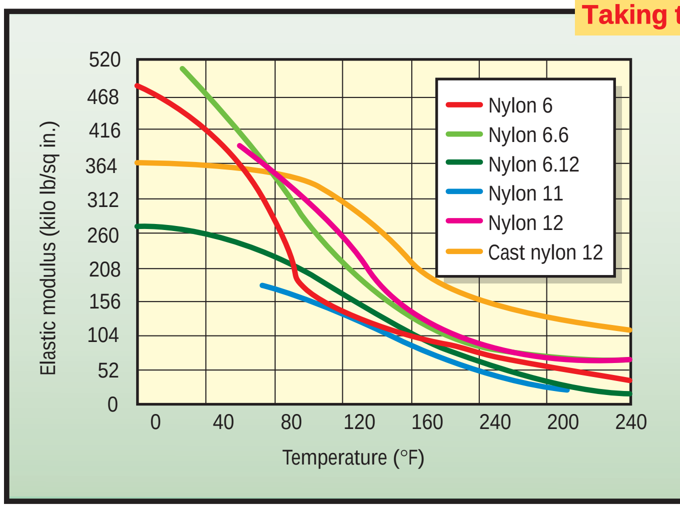
three days to three weeks. An alternative is to use plastic gears.

Three gear sets with different specifications, each pairing a steel pinion with a cast nylon 12 gear, are suggested. The potential of each is calculated using a modified Lewis formula for tooth root stress, including an algorithm that factors in stresses and wear behavior when gears are run without lubrication.

The application calls for a flank pressure safety (wear) factor between 1 and 1.3; this is an especially important issue with unlubricated gears. It's determined an initial grease application is acceptable. With this information, engineers reverse the calculation, starting with the target of 2,000 hours of gear life. By working with flexible parameters, such as face width, number of teeth, metal core size, three alternatives are speced.

Alternative 1 (see chart on p. 28) is a cast nylon 12 gear with the same face width as the cast iron gear it replaces. The life expectancy does not meet the 2,000-hr target. The gear has sufficient tooth root safety to carry the load, but because of the low flank pressure safety it

Taking the heat



At low temperatures stresses cause nylon 6 to become brittle, while cast nylon 12 is stress-free and retains its "toughness" throughout the temperature range.

will wear out in a relatively short time.

Gear alternatives 2 and 3, on the other hand, meet the operating life requirements. Both alternatives show a comfortable tooth root safety, but alternative 3 wins out for its higher flank pressure safety, while gear dimensions remain the same. So, by choosing tooth modification, we can make the gear 17% narrower, or 2.1 in. wide, and still achieve the flank pressure safety of the unmodified, wider gear. The tooth root stress safety would still be adequate in this case, and the face width reduction would let the plastic gear fit into the 2.25-in. available on the shaft. A further face width reduction of up to 20% is possible with a plus-plus modification

Alternative 3 will give 2,500 hours of gear life, and has a modified tooth for additional wear safety. The pinion is made of steel, and the gear is made of cast nylon 12 with a 5-in. metal core. About 10% of expected life is offered for machine start-up.

Because the gears are hobbed, the theoretical calculation can be verified economically in physical tests.

How plastic gears got a bad rap

At one time, metal was the only gear material choice. But metal means maintenance. You have to keep the gears lubricated and hold the oil or grease away from everything else by putting it in a housing or a gearbox with seals. When oil is changed, seals sometimes leak after the box is reassembled, ruining products or components. Metal gears can be noisy too. And, because of inertia at higher speeds, large, heavy metal gears can create vibrations strong enough to literally tear the machine apart.

In theory, plastic gears looked promising with no lubrication, no housing, longer gear life, and less required maintenance. But when first offered, some designers attempted to buy plastic gears the way they did metal gears — out of a catalog. Many of these injection-molded plastic gears worked fine in non-demanding applications, such as small household appliances. However, when designers tried substituting plastic for metal gears in tougher applications, like large processing equipment, they often failed.

Perhaps no one thought to consider that plastics are affected by temperature, humidity, torque, and speed, and that some plastics might therefore be better for some applications than others. This turned many designers off to plastic as the gears they put into their machines melted, cracked, or absorbed moisture compromising shape and tensile strength. ●

Material provided by Georg Bartosch, president, Tody Mihov, engineering manager, and Ruth Emblin, marketing manager of Intech Corp., Closter, N.J.

Next step

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