Gear Up for Performance:

An Introduction to Synthetic Lubricants for Fractional Horsepower Applications

Jeffery Lay

Editor's Note: *The following article details the advantages of synthetic lubricants in certain applications. However, the user should be aware of certain design issues arising from the exact chemistry of the synthetic. For example, some synthetics may have low solvency for additives. Others may not be compatible with mineral oils or nonmetallic components such as seals and paints. Some synthetics may absorb water and may not have the same corrosion resistance as mineral oils. Finally, the user should consider biodegradability or toxicity before switching to any new lubricant. Many of these concerns are present in petroleum-based lubricants as well, so consult a lubrication specialist before specifying a lubricant.*

Introduction

DeWalt Industrial Tools, Towson, MD, was close to putting its new Northstar line of power hand drills into production when quality testing raised a red flag. Gear pinions were failing the rigorous 300-hour bench test. The problem wasn't the gear design, it was the grease.

Designed for the professional tradesman, Northstar drills are faster and more compact than DeWalt's previous models, and petroleum grease could no longer take the heat. When the power toolmaker switched to synthetic grease, a blend of light polyalphaolefin and ester oils, the Northstar gearboxes still ran flawlessly after 700 hours of testing. Because of the base oils' low viscosity and exceptional lubricity, the synthetic grease also reduced internal drag, optimizing motor speed and overall tool performance.

The DeWalt story is not unique. While petroleum-based lubricants are still the norm in the world of gearing, more and more OEMs are discovering—often out of necessity—that synthetic lubricants solve gearing problems and improve product performance, extending operating life.

A Synthetic Lubricant Primer

Petroleum or mineral oils will always have a place in the world of gearing. After all, they are much lower in cost than most synthetic lubricants on the market and work well in many gear applications. In spite of their higher cost, however, synthetic lubricants can be a viable choice—and in some cases the only viable alternative—for gear designers.

What are synthetic lubricants? The basic building blocks of any lubricating oil come from nature. Animal, vegetable, and mineral oils are harvested, refined, and sent to market. Synthetic oils undergo another step: They are manipulated at the molecular level to change and improve lubrication characteristics. For example, a synthetic hydrocarbon oil starts with ethylene, a petroleum product. The ethylene is resynthesized to purify the oil and to narrow its range of molecular weights. The result is a synthetic hydrocarbon oil that is much less volatile than petroleum or, in more practical terms, an oil that has a longer operating life and a broader operating temperature range. In short, each family of synthetic oils relies on Mother Nature for its raw materials, but their unique properties are the product of scientific invention and rigidly controlled chemical processes.

Compared to petroleum, synthetic oils can offer several intrinsic advantages. The best known advantage is broad temperature capability

Fig. 1—A Class N gear motor (rated at 200° C) by Autotrol Corporation uses a perfluoropolyether grease to meet its customers' 6,000 wear-cycle and 450° F temperature requirements.

Fig. 2—A sub-fractional horsepower electric gear motor by Autotrol Corporation powers the TEG® Coagulation Analyzer by Haemoscope Corp. Plastic gearing is lubricated with a light, thixotropic, synthetic hydrocarbon grease.

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(See Table 1: "Lubricant Temperature Ranges"). In fact, the ambient temperature of an application is the most common reason design engineers first turn to synthetic lubricants. It was the primary reason Autotrol Corporation of Crystal Lake, IL, specified one of the most expensive synthetic lubricants for their new Model 150, Class N gearmotor.

The Class N motors automatically lock oven doors when the temperature hits 450° F (232° C) during self-cleaning cycles. The motor then releases the door latch when the temperature drops below 450° F during the cool-down phase. Autotrol used a high-temperature, engineered plastic for the gearing; however, the gears did not meet the customer's 6,000-cycle wear requirement. External lubrication was needed and perfluoropolyether (PFPE) grease, which can easily withstand continuous temperatures of 250° C as well as even higher spikes, was the logical choice. While the cost may have seemed prohibitive—PFPEs can cost up to $100/lb.—a little goes a long way. For Autotrol, four cents worth of PFPE grease in each gearmotor is all it took to exceed customer specifications—and build a reputation for quality in high-temperature appliance applications.

In addition to surviving hotter temperatures, most synthetic lubricants have lower pour points than petroleum; that is, they do much better in cold environments as well—a key reason why synthetic oils and greases have replaced petroleum in

Table 1: Lubricant Temperature Ranges

SYNTHETIC BASE OILS	CHARACTERISTICS
Synthetic Hydrocarbons Temp. range: -60 to 125°C	• Excellent thermal stability • Good friction reduction and lubricity • Wide range of viscosities • Low-temperature serviceability • Good plastic and elastomer compatibility • Long and growing list of applications in many industries
Polyglycols (a.k.a. Polyethers) Temp. range: -40 to 100°C	• Non-carbonizing, no residue • Good lubricity and film strength • Wide range of viscosities • Unusually good elastomer compatibility • Good load-carrying • Only synthetic oils which include water-soluble versions • Good high-temperature stability with proper antioxidant • Commonly used in arcing switches, and particularly effective in large worm and planetary gears
Synthetic Esters (Includes diesters, polyolesters) Temp. range: -65 to 150°C	• Excellent oxidative and thermal stability • Low volatility • Excellent anti-wear properties • Outstanding lubricity • Good low-temperature properties • Minimal viscosity change with temperature • Excellent load-carrying ability for bearing applications
Silicones (Includes dimethyl, phenyl, halogenated) Temp. range: -70 to 200°C	• Excellent oxidative and thermal stability • Low volatility • Wide range of viscosities • Minimal viscosity change with temperature • Excellent plastic and elastomer compatibility • Good wetting capability • Commonly used with plastic and elastomer components, including gears, control cables, and seals. Higher viscosities provide mechanical damping.
Fluoroethers Temp. range: -90 to 250°C	• Excellent oxidative and thermal stability • Low volatility and vapor pressure • Nonflammable and chemically inert • Excellent plastic and elastomer compatibility • Resistant to aggressive chemicals and solvents • Commonly used in extreme-temperature environments and applications which require chemical, fuel, or solvent resistance
Polyphenylethers Temp. range: 10 to 250°C	• Highest thermal and oxidative stability of all oils • Excellent radiation, chemical, and acid resistance • Excellent lubricity • Excellent high-temperature stability • Non-spreading even in thin film • Traditional lubricant for noble metal connector applications; also used for high-temperature, specialty bearings
Multiply-Alkylated Cyclopentane Temp. range: -45 to 125°C	• Proprietary fluid distributed by Nye, that combines the low vapor pressure of a PFPE with the lubricity and film strength of a synthetic hydrocarbon

Table 2: Overview of Synthetic Lubricant Families

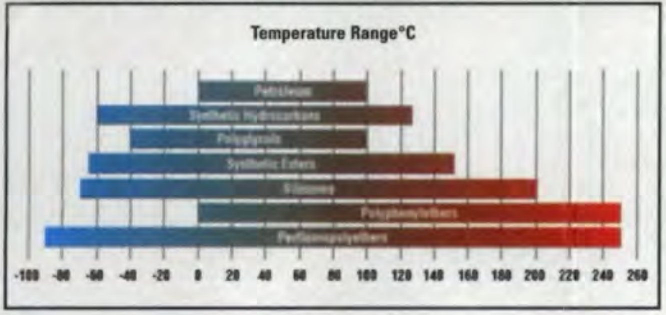

Fig. 3—In Bayside Control Group's precision gear set, even a film of lubricant can potentially be thick enough to cause a positioning error. A very light thixotropic grease not only passed rigorous life tests, it also lowered internal temperatures by five degrees.

Fig. 4—Special adherence and lubricity additives keep the synthetic grease on the gears and extend the operating life of Mallory's new Model 620 appliance timer.

Fig. 5—A new synthetic fluorocarbon gel on rack-and-pinion steering systems reduces wear, damps noise and eliminates the need for polishing racks after heat-treating.

most automotive components. Synthetic lubricants also last three to five times longer and do not form carbon deposits as readily as petroleum lubricants. They also have higher viscosity indices, the viscosity of the base oil showing greater consistency as temperatures change. Therefore, because there is less evaporative loss, you usually use less synthetic lubricant per part.

Each family of synthetic oils—there are six of them—also has its own unique, designed-in qualities (See Table 2: "Overview of Synthetic Lubricant Families"). A family consists of chemically similar oils in a variety of viscosities. Synthetic hydrocarbons, commonly known as polyalphaolefins (PAOs), are the most widely used synthetic lubricants for gears and gearboxes. They offer excellent cold-temperature performance (to –60° C) and are known for their oxidative stability. PAOs are compatible with many plastics, seals and paints used in gear applications. Compared with other synthetic fluids they are also relatively inexpensive. In addition, PAOs can be formulated for use as food-grade lubricants where toxicity issues such as contact with food products are of concern.

Synthetic esters are ideal for cut-metal and powdered-metal gearing, if proper seals are used. Due to their affinity for metal, especially steel and iron, esters provide maximum wear protection. Because esters can withstand temperatures as high as 180° C, they have become the clear choice for automotive supercharger gearing and other severe duty applications. A word of caution: esters, whether used alone or in combination with PAOs, have been known to attack certain nonmetallic components, i.e. plastics, elastomers, and paints.

Like esters, polyglycols have an affinity for specific metals, such as brass or phosphate bronze. Therefore, they are frequently used in worm gear applications to reduce friction and improve efficiency. In contrast to some of their mineral oil cousins and other synthetic fluid families, some polyglycols are biodegradable and non-toxic.

Silicones and PFPEs are compatible with nearly all gearing plastics. Both are suitable for broad temperature applications and have shown exceptional, low-temperature torque characteristics. PFPEs are also resistant to chemically aggressive environments and will not dissolve in the presence of fuel vapors or brake fluid. In addition, some PFPEs have very low vapor pressure, which is essential for vacuum chamber and aerospace applications where outgassing can be problematic. Both silicones and PFPEs have a low solvency for certain types of additives and as a result can have less corrosion resistance than other synthetic fluids or mineral oils.

Polyphenylethers (PPEs) are not widely used in gear applications. However, it is important to point out that these synthetic oils have high radiation resistance. In medical or dental applications, where radiation sterilization is mandatory, a PPE would be an ideal choice for gearing. (Note: Because of their radiation resistance they can not be exported to some countries for security reasons.)

In general, synthetic lubricants are simply new design materials that offer gear engineers an alternative to mineral oils or greases. They should be considered when mineral or petroleum lubricants can not meet operating conditions, such as extreme temperatures or the need for lifetime lubrication. Before replacing petroleum with a synthetic in an existing gearbox, always consult the gearbox manufacturer and do a cost-benefit anaylsis. When designing a new gearbox, weigh all options and consult with a synthetic lubrication specialist before specifying a lubricant.

So You're Designing a Gearset or Gearbox

Why would gears require lubrication? Simply stated, to make gears run smoother and last longer. Mechanically, a lubricant forms a protective film between the mating gear teeth and retards wear.

Selecting the best lubricant for an application is not always easy. The American Gear Manufacturers Association (AGMA) has developed an Industrial Gear Lubrication standard (ANSI/AGMA 9005-D94) to help engineers select an oil viscosity based on pitch line velocity of enclosed and open industrial gears. This standard references spur, helical, herringbone, straight bevel, spiral bevel, and cylindrical worm drives. However, there is no handy guide for the selection of greases or appropriate synthetic oils for gearing applications, which means the design engineer should have a basic knowledge of tribology and/or partner with lubrication engineers, especially for gearboxes that are "lubricated for life."

While the proper oil viscosity is important, choosing the right oil is the real key to getting the best lubricant for a specific application. All oils are subject to freezing and evaporation. In either state, they cannot lubricate, and the component fails. So matching the temperature range of an oil to the temperature extremes of the device is essential. Choosing the right oil is essential even when specifying a grease. Greases are made by mixing a powdered material or thickener—like lithium—with a base oil, but the oil is still the critical component. Greases can be thought of as a "sponge of oil." Moving parts, such as gear teeth, squeeze oil out of the matrix to prevent friction and wear. While many people are comfortable with a term like "lithium grease," it really tells little about the lubricant's properties. Lithium is only the "sponge." Lubricant behavior depends on the type of oil in the formulation.

What's better, grease or oil? When lubrication service intervals are part of the picture, oils generally get the nod. For example, oils are the norm in most large industrial gearing. Oil baths act as a cooling system and reduce operating temperature. They are also very effective in keeping wear debris suspended or out of the gear teeth mesh. The cooling and cleaning advantages of oil, however, have to be weighed against oil's tendency to leak. Seals add cost to the gearbox. Further, worn-out seals can pose safety and environmental hazards in an industrial setting as well as image and warranty issues in the consumer market.

When a gearbox is lubed-for-life, or if the orientation of the gearbox makes it prone to leakage, greases should be considered. Soft greases, those designed specifically for gears, not bearings, sometimes offer the best of both worlds. They will slump or flow back into the gear-teeth mesh like an oil while remaining gel-like to reduce leakage. Soft greases can be formulated to reduce internal operating temperatures. They also allow the addition of molybdenum disulfide (MoS_2) or polytetrafluoroethylene (PTFE), which do not suspend well in oil alone. These additives can dramatically reduce wear and friction under boundary lubrication conditions, where there are frequent changes in direction or sudden start/stops under load. Finally, a soft grease may reduce gearbox cost by eliminating oil seals and the manufacturing cost associated with seal designs.

Importantly, greases can be formulated light enough to accommodate even small gearmotors. For example, Autotrol designed a sub-fractional gearmotor for a medical device used to monitor the clotting ability of a patient's blood during surgery. Minimally, Autotrol needed a lubricant to protect against tooth wear and facilitate power transfer with minimal heat and noise. It also needed a plastic-compatible lubricant, since the gearmotor used plastic, brass, and steel components. A synthetic hydrocarbon grease with additives to minimize friction and start-up torque delivered the long, quiet life Autotrol's customer wanted.

Gear greases can be engineered soft enough to actually flow under shear and return to gel consistency when static. With their stay-in-place quality, these very light, thixotropic synthetic greases are a viable alternative to conventional gear oils, which are often automatically specified for low-torque applications.

Case in point: Bayside Motion Group, Port Washington, NY, designed a unique family of all-helical planetary gearheads with 30% more torque than other planetaries, backlash as low as 3 arc minutes, under 70 dB quiet operation, and over 92% efficiency.

Having pushed the laws of physics to the limit with its Helicrown gear tooth geometry and Plasma Nitriding, a computer-controlled hardening process, Bayside focused on the lubricant for further quality improvements. These gearboxes can see input speeds up to 10,000 RPM, so they require a robust lubricant to protect the tooth surface from wear and loss of profile accuracy. Compounding the task, in a precision gearset designed for servo motors, even a film of lubricant can potentially be thick enough to cause a positioning error. Lubrication engineers were able to formulate a very light, thixotropic synthetic grease whose flowability and durability assured continuous lubrication of the gears and bearings for the life of the gearhead. After a grueling, full-load, 300 hour/3,000 RPM life test, the gear teeth retained their original profile. In addition, the gearhead's operating temperature was 5 degrees cooler than with previously sampled greases.

Greases can be utilized in both high- and low-speed enclosed gear designs provided the housing or gearbox has been given proper consideration during the design process. The engineer must design the housing to reduce open spaces, where grease can become trapped and lead to lubricant starvation. In existing gearbox designs, engineers have incorporated plastic baffles to reduce the

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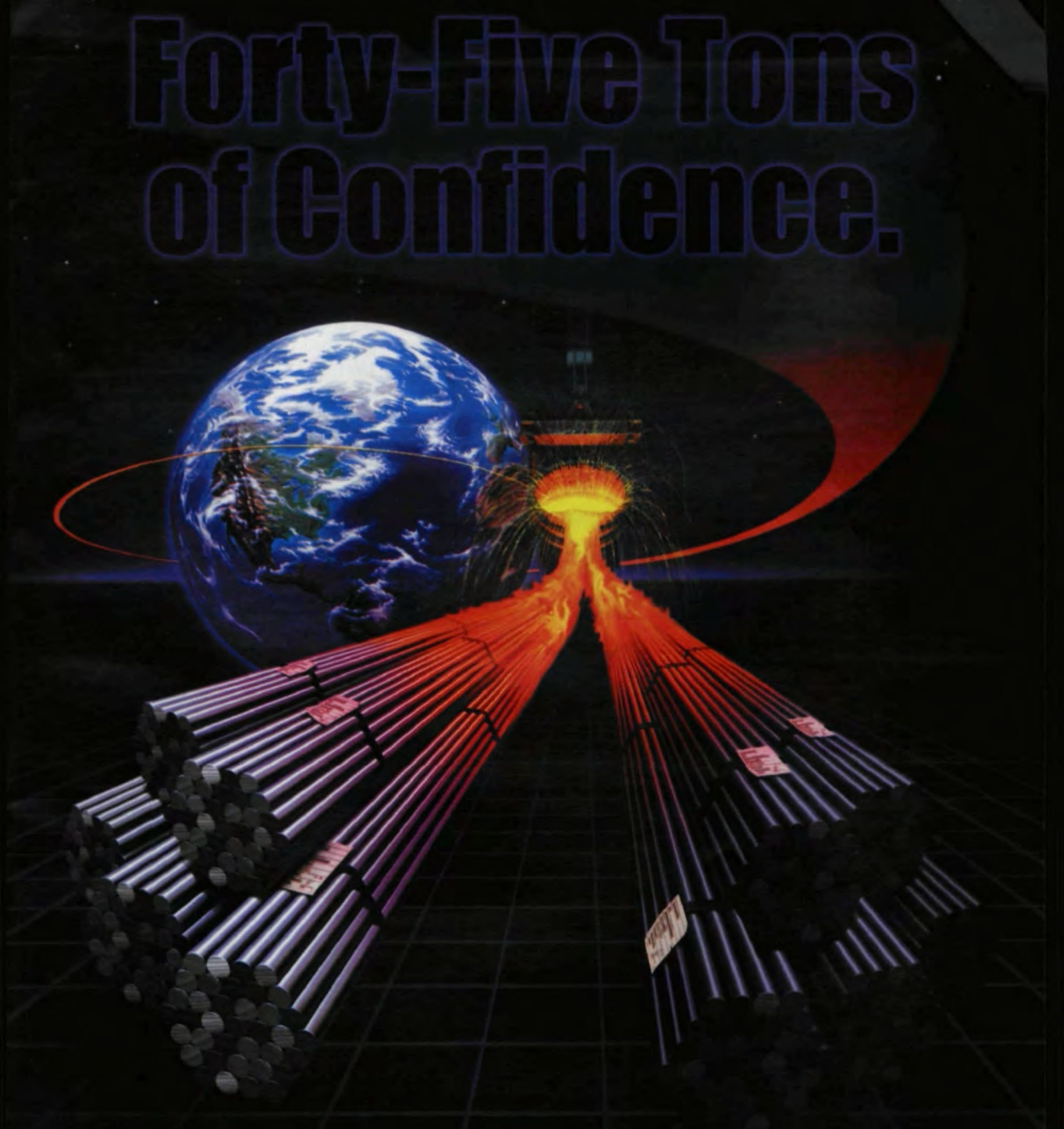
Forty-Five Tons
of Confidence.

amount of grease required to fill the box and to keep the grease where it is needed.

Plastic Gearing

Plastic gears are often "designed" to operate without lubrication—and they do. In the struggle to achieve maximum operating performance and life, however, many engineers are finding external lubrication dramatically improves plastic gear designs. In fact, it can be stated without exception that lubricated gears—even lightly loaded, low-speed, plastic gearing—will last longer and run quieter than the same gearset without lubrication. So the basic question is, How long and how quietly do the gears have to operate?

When selecting a grease for plastic gears, the base oil must be compatible with the design materials (See Table 3, "Materials Compatible with Synthetic Oils and Greases"). An engineer also needs to consider how well the lubricant will adhere to the gears. "Tackifiers," additives that improve a grease's ability to adhere to gear teeth, are usually recommended to reduce sling-off.

Mallory Controls of Indianapolis, IN, has a history of success with synthetic lubricants and plastic gearing. Recently, it set out to develop

Table 3 –Materials Compatible with Synthetic Oils & Greases (At Room Temperature)

	Synthetic Hydrocrbons	Esters & Polyglycols	Silicones (All Types)	Fluorinated Ethers
PLASTICS				
Acetals	A	A	A	A
Polyamides	A	A	A	A
Phenolics	A	A	A	A
Terephthalates	A	A	A	A
Polycarbonates	A	C	A	A
ABS resins	A	C	A	A
Polyphenylene oxide	A	C	A	A
Polysulfones	A	C	A	A
Polyethylenes	B	B	A	A
RUBBERS				
Natural Rubbers	C	C	A	A
Byna S	C	C	A	A
Butyl	C	C	A	A
Ethylene Propylene	C	B	A	A
Nitrile (Buna N)	A	B	A	A
Neoprene	A	C	A	A
Silicone	B	B	C	A
Fluoroelastomers	A	C	A	A

Legend: A=Usually OK; B=Be Careful; C=Causes Problems

Caution: *These compatibility ratings are intended to be guidelines for design engineers when selecting lubricants. Under high mechanical stress, high temperature, poor plastic/elastomerquality, or any combination of these conditions, compatibility can be compromised. Anysynthetic lubricant used with a plastic or elastomeric component should be tested to ensure compatibility in a specific application.*

the Model 620, a new longer-life timer for domestic clothes washers, dryers, and dish-washers.

Using its popular M–400 timer as a starting point, Mallory engineers upgraded the plastic gearing design. In initial prototype testing they used the M–400 grease, a plastic-compatible synthetic hydrocarbon with a wide serviceable temperature range that should have been suitable for the M–620. It did not meet cycle test requirements, falling short in the area of wear protection.

Because the M–400 grease was designed for small, slower-speed, plastic and metal gearing, the larger gears of the M–620 with their high pitch line velocity tended to sling off the M–400 grease. Without the cushion of grease between the gear teeth, friction exacerbated wear, which led to premature failure. Lubricant engineers recommended a similar formulation with special lubricity and adherence additives. Since a relatively light grease was needed to meet the unit's low-temperature, start-up torque requirements, a low-viscosity synthetic hydrocarbon base oil and lithium-soap thickener rounded out the chemistry. In cycle testing, this new lubricant dramatically reduced gear tooth wear, dampened acoustic noise, and substantially increased timing cycles.

Seitz Corp., Torrington, CT, manufactures precision-engineered, thermoplastic gears, gearboxes and components and is a recent convert to synthetic grease for plastic gears. Its latest actuated gearbox deploys and retracts canvas awnings on recreational vehicles. The gearbox incorporates both plastic and metal components that withstand output torques ranging from 140 to 220 inch-pounds under operating speeds from 30 to 14,200 RPM. The dry gears were noisy, which would have had a negative impact on the perceived quality of the product.

Seitz's lubrication supplier recommended a soft, clay-gelled, PAO grease with a tackifier for adhesion and PTFE to facilitate low-temperature start-up. When the gearset was loaded with the grease, it purred like a kitten. Subsequently, Seitz discovered a bonus to pass on to its customer. In wear tests, the greased gearset outlasted the dry gears by 300%.

One additional design note about lubricants for plastic gears: In cases where plastic gears have internal lubricants such as PTFE or silicone, the internal lubricant may interfere with the "wetting action" of some external lubricants, reducing the external lubricant's ability to provide an adequate film of oil between the gear teeth. Therefore, when selecting an external lubricant for plastic gearing, engineers should either choose gears without an internal lubricant or make certain that the internal lubricant works synergistically with the base oil in the external lubricant. Typically, if an external lubricant is used, no internal lubricant is required.

Heavy Metal

Some gear designs rely on mixed-film or boundary lubrication to prevent gear wear and failures. Visteon Automotive Systems' rack and pinion steering components, which are used in Lincoln, Thunderbird, and Mazda automobiles, were no exception.

Rack and pinion gears constantly change direction, and the potential for high shock-loading puts a great deal of stress on both the gears and the lubricant. Additionally, the Visteon system has a spring-loaded, yoke-to-rack mechanism, which keeps the rack mated to the pinion. Under mechanical shock-load testing, simulating pot holes and railroad tracks, the rack separated from the pinion, increasing wear and causing an annoying clunking sound—surely a warranty claim in the making. Visteon engineers needed a lubricant to reduce gear wear and the level of noise transmitted through the steering column, and their petroleum grease wasn't doing the job. They turned to lubrication experts for assistance on the project.

Synthetic lubricant formulators combined a newly developed, high-viscosity, synthetic base oil with a lubricious thickening agent and extreme pressure (EP) and antiwear additives. The grease was applied to the gear teeth as well as the spring-loaded, yoke-and-rack interface. It passed all gear and yoke wear tests while imparting a smooth, quiet, quality feel to the entire steering system.

Two other important benefits were realized. When Visteon switched from petroleum to synthetic grease, manufacturing costs decreased because less lubricant was needed per part. A bigger surprise, a manufacturing step was eliminated. Visteon typically hand-polished the back of the rack in some steering systems to reduce friction and wear between the spring-loaded yoke and rack. A lubrication engineer suggested that the new grease may eliminate the need to polish racks, without jeopardizing performance. In test runs, the unpolished racks lubricated with the synthetic grease actually outperformed the polished units lubricated with the petroleum grease.

Conclusion

Petroleum or mineral oils may always have a place in the world of gearing. However, synthetic lubricants are closing the gap. They are solving problems, reducing lubricant consumption, and making a real difference in the performance and life of demanding gearing applications. ⚙

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