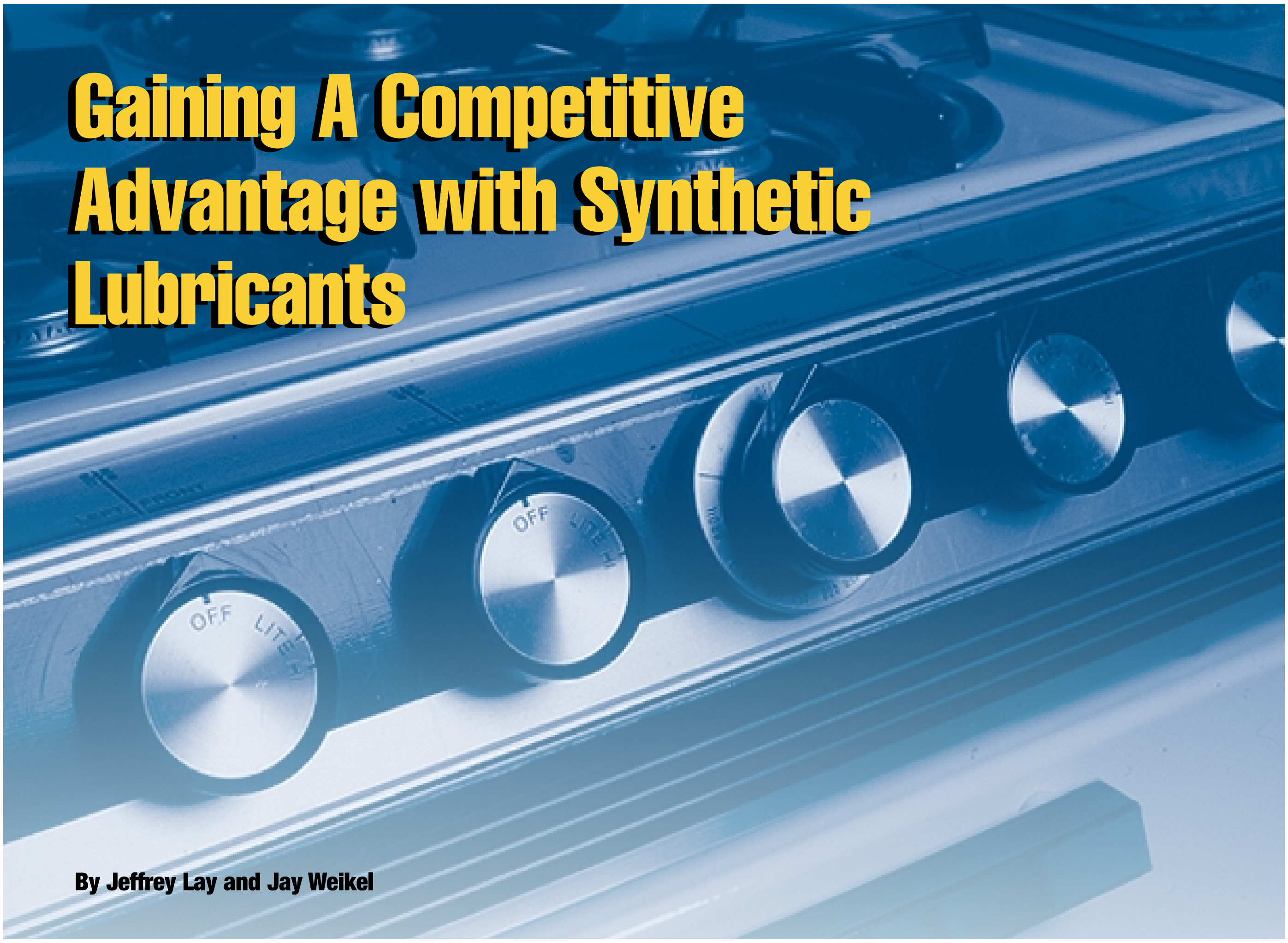
Gaining A Competitive Advantage with Synthetic Lubricants



By Jeffrey Lay and Jay Weikel

Kingston, a Scott Fetzer Company in Smithville, Tenn., designs and manufacturers a variety of motors, switches, sensors, and timers for OEMs. But its new low-profile motorized range lock, which locks the oven door closed at the start of the self-cleaning cycle and unlocks the door only when the cleaning cycle is over, is in a class by itself.

Kingston's new range lock is compact, which helps OEMs give consumers what they want: more oven space. It's economical because it uses thermo-plastic cams, instead of traditional all-steel construction. And it keeps working for the life of the range in probably the most hostile environment of any appliance — continuous temperature at or above 232°C. Its secret of long life? Perfluoropolyether/polytetrafluoroethylene (PFPE/PTFE) grease (*See Figure 1*).

PFPE/PTFE grease, a unique synthetic grease made by combining a fluorinated oil and a fluorinated thickener, is the only lubricant that can survive grueling oven temperatures for extended time periods. In addition, PFPE/PTFE grease is so inert that it poses no compatibility problems when applied to metals, plastics, or elastomers. When tested under load and in a heated environment with the PFPE/PTFE grease, Kingston's low-profile range lock still works like new after 6,000 cycles — which far surpasses both the typical life expectancy of the range as well as UL requirements.

"The PFPE/PTFE grease, though more expensive than traditional lubricants, helps ensure that our lock easily lasts the life of the range," said Kingston engineer Don Smith. "Technically, this lube lasts forever because if the oil ever does break down, the PTFE thickener is slippery enough to keep on lubricating."

Currently, very few appliance components use PFPE/PTFE grease. In fact, few appliance components use any type of synthetic lubricant. Most still rely on petroleum products for lubrication — for two reasons. Petroleum is what engineers are used to and, ounce for ounce, petroleum costs less. Nonetheless, appliance engineers are discovering the benefits of synthetic lubricants, usually when confronted with a temperature issue.

Petroleum lubricants would fry at temperatures above 100°C and turn to sludge at –18°C. In either case, they stop lubricating. Synthetic lubricants offer much broader temperature capabilities. Some PFPE lubricants, for example, can stay fluid and lubricious from –90°C to +250°C.

As components get smaller and faster, as plastics parts proliferate, as consumer quality expectations continue to rise, and as extended warranties become real competitive advantages, synthetic lubricants are likely to play an increasingly larger role in the appliance industry — just as they have in the automotive industry. Fifteen years ago, there were only five to ten components in an automobile that contained synthetic lubricants. Today, there are well over 100. As the appliance industry follows this same migration path, this tutorial is intended to help appliance engineers understand and capture the many performance advantages synthetic lubricants can offer.

A BRIEF HISTORY OF LUBRICANTS

Synthetic lubricants can be seen as a relatively recent point on a timeline that tracks the evolution of materials that are used to reduce friction and wear between two sliding surfaces. We can pick up the timeline in the mid-19th century when the discovery of petroleum represented a quantum leap from animal fat, vegetable oil, nut oil, and whale oil — which were at that time "state of the art" lubricants for axles, watches, clocks, and early appliances like sewing machines and typewriters. Crude oil fast became the chief source of modern lubricants. Over time, processes were developed to remove lighter fractions and unwanted materials from the crude, which improved the thermal and oxidative stability and the viscosity/temperature characteristics of lubricant base stocks. By blending base stocks and using chemical additives, petroleum lubricants were gradually adapted to meet the specific needs of new technology, including automobiles, airplanes, appliances, and a plethora of power machinery. As distillation, extraction, finishing, and blending processes advanced, petroleum lubricants enabled components and machinery to run faster and last longer.

Petroleum does have its limits, however. As early as the 1920s chemists had begun to search for a synthetic alternative to petroleum to improve the performance of automotive crankcases in cold weather. Petroleum becomes virtually intractable at freezing temperatures — and so did the crankshafts it lubricated. World War II made the research more critical. The need for a low-temperature lubricant in high-altitude

Figure 1 Kingston's new low-profile, motorized range lock relies on thermo-plastic parts lubricated with a PFPE/PTFE grease to survive oven cleaning-cycle temperatures in excess of 232°C. Its Class N motor also uses a PFPE/PTFE grease.

aircraft produced the first synthetic esters. The introduction of jet engines called for lubricants that did not degrade at high temperatures. With the burgeoning market for automobiles and the surge in military spending during the Cold War, the development of new synthetic lubricants became the focus of many government and industrial laboratories. Dow-Corning developed silicones, one of the first synthetics to be used in the automotive industry. Monsanto introduced polyphenyl ethers. Hooker unveiled chlorofluorocarbons. DuPont synthesized fluorinated ethers. Finally, in the early 1960s, Sun and then Mobil introduced the first successful synthetic hydrocarbon oils for use in automotive crankcases, more than 30 years after the search had begun.

SYNTHETICS VS. PETROLEUM

What is a synthetic oil? The basic building blocks of any lubricating oil come from nature. Animal, vegetable, and mineral oils, including petroleum, are harvested, refined, and sent to market. Synthetic oils undergo another step: They are manipulated at the molecular level to improve lubrication characteristics. For example, a synthetic hydrocarbon oil starts with ethylene, a petroleum product. The ethylene is re-synthesized to purify the oil and to narrow its range of molecular weights. The

Table 1

Comparison of Base Oils

BASE OILS	ADVANTAGES	LIMITATIONS
Petroleum Hydrocarbon	– Very Low Cost	– Limited temperature range – Product variability
Synthetic Hydrocarbons	– 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	– Not suitable above 125°C
Polyglycols/Polyethers	– 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	– Not compatible with some plastics and elastomers – Poor volatility above 100°C
Synthetic Esters	– 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	– Not compatible with some plastics and elastomers
Silicones	– 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	– Poor load-carrying – Tendency to migrate
Perfluoropolyethers (PFPE)	– 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	– High cost – Reduced effectiveness under heavy loads
Polyphenylethers (PPE)	– 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	– Not suitable for temperatures below 10°C – Not compatible with some plastics and elastomers – High cost
Multiply-Alkylated Cyclopentane	– Proprietary fluid that combines the low vapor pressure of a PFPE with the lubricity and film strength of a synthetic hydrocarbon	– Not suitable above 125°C – High cost

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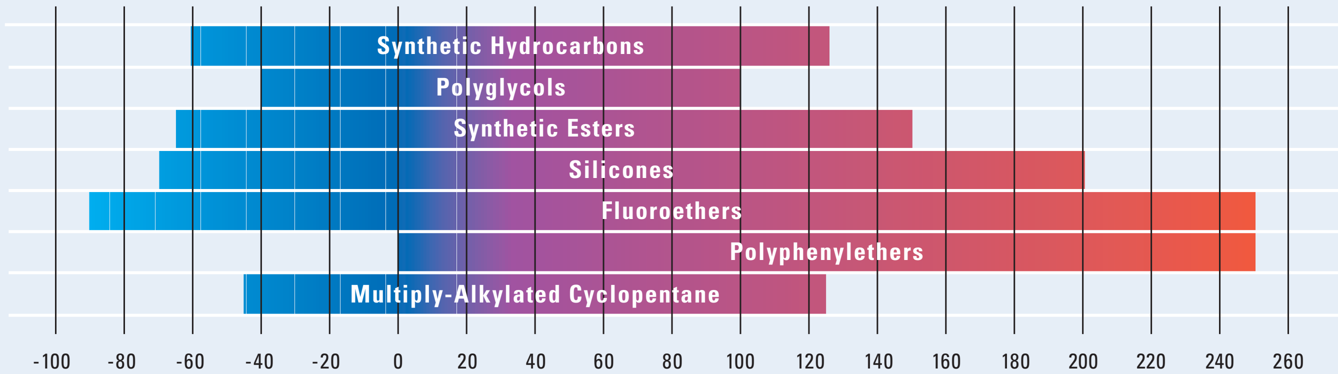
Table 2 Temperature Range of Lubricating Oils



Synthetic oils offer a broader operating temperature range than petroleum lubricants, whose temperature limits range from about –18°C to +100°C.

result is a synthetic hydrocarbon oil that is much less volatile than any petroleum base stock or, in more practical terms, an oil that has a longer operating life and a broader operating temperature range. In short, synthetic oils rely on nature for their raw materials but the unique properties of synthetic oils are the products of rigidly controlled chemical processes.

While different families of synthetic oils are better suited for specific types of applications, the molecular homogeneity of synthetic oils in general make them more consistent, more predictable, and more robust than petroleum products in several ways. Synthetic lubricants are engineered for improved "thermooxidative stability," which denotes the simultaneous effects of heat and oxygen on the chemical and physical properties of the oil. Compared to petroleum, synthetics survive hotter temperatures, last three to five times longer, and are not as likely to form carbon deposits, a.k.a. varnish and sludge, which create drag and hasten wear. In broad terms, the thermooxidative stability of synthetic oils contributes directly to improved performance and extended life of the lubricated device.

Synthetic oils, with the exception of polyphenyl ethers, also have lower cold-temperature service limits than petroleum. For example, synthetic hydrocarbon oils remain fluid at –60°C; linear perfluoropolyethers, one of two general classes of PFPE oils, withstand temperatures down to –90°C.

The molecular structure of many synthetic oils also gives them a higher film strength than petroleum. It is the film of oil that keeps two moving parts from rubbing against one another. Higher film strength enables synthetic oils to withstand heavier loads and faster speeds, which make them better able to prevent wear.

Figure 2 Plastic gears in Mallory Controls' Model 620, a timer for commercial laundry, laboratory cleaning equipment, dairy equipment, and domestic clothes washers and dishwashers, use a NLGI Grade 2 synthetic hydrocarbon grease with special lubricity and adherence additives. Mallory reported that the grease reduced gear tooth wear, dampened acoustic noise, and substantially increased timing cycles.

Further, unlike petroleum, the viscosity of most synthetic oils does not undergo radical shifts with temperature. Viscosity is a critical property when matching an oil to specific operating conditions. If the viscosity is too low, the contact surfaces will not be separated and excessive wear will occur. If viscosity is too high, excessive power will be required for actuation or rotation of the device. While both synthetic and petroleum oils come in a wide range of viscosities, the viscosity of any fluid gets thinner as temperatures increase and thicker as temperatures decrease. How much the viscosity changes with temper-

Table 3 Common Thickeners for Synthetic Grease

GELLANT	ADVANTAGES	DISADVANTAGES
Paraffin Wax	– Lower cost	– Low melting point: low load/low friction only
Alkali Soap	– Lower cost – Water resistance – Pumpability	– Reacts with some oils and metals
Organoclay	– High loads – Melting temperature >+250°C	– Limited oil content/oil separation
Alkali Complex Soap	– Water resistant – Pumpability – Low oil separation – Melting temperature >+250°C	– Reacts with some oils and metals
Polyurea	– Water resistant – Pumpability – Low oil separation – Melting temperature >+250°C	– Stability at low shear – Storage Hardening
Silica	– Water resistant – Low oil separation – Very high melting temperature	– Mechanical instability with some base oils
PTFE	– Lubricity – Inertness – Melting temperature >300°C	– Moderate loads only
Metal Oxide	– Thermal conductivity – Inertness – Very high melting temperature	– Limited oil content, oil separation

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ature is indicated by the "Viscosity Index" (VI), which is a standard (ASTM D-2270) dimensionless rating: A higher number indicates a *lower* rate of change, which is the ideal from a lubrication standpoint. Synthetic oils generally have higher VIs than petroleum, that is, the viscosity of synthetic oils remains more consistent over temperature changes. Most petroleum oils have VIs well below 100; most synthetics have VIs well above 100. For example, the VI of synthetic hydrocarbon oils ranges from 125 to 250; the VI of silicone oils falls between 200 to 650. Higher VI means a more stable molecule, which translates to longer lubricant life — and less lubricant per part.

Petroleum will always have a place in the world of lubrication. It's functional, adaptable to a variety of applications, readily available, and lower in cost than most synthetic lubricants. But the inherent advantages of synthetic lubricants make them an important tool in the appliance engineer's arsenal.

FAMILIES OF SYNTHETIC OILS

All lubricating oils must have the ability to separate adjoining, moving surfaces to prevent or at least minimize wear. However, different families of oils, which consist of chemically similar oils in a variety of viscosities, have different advantages and limitations (*See Table 1, "Comparison of Base Oils"*). An understanding of these differences helps an engineer choose the best possible lubricant for the job at hand. There are currently six families of synthetic oils.

Synthetic hydrocarbons, also known as polyalphaolefins (PAOs), are the most widely used. Because they are generally compatible with mineral oils, paints, plastics, and elastomers, switching from a natural to a synthetic hydrocarbon is relatively easy. They offer excellent cold-temperature performance and oxidatively stability. Compared to other synthetic oils, they are also relatively inexpensive.

Synthetic esters, which are chemically similar to PAOs, have an inherent polarity that makes them even less volatile and more lubricious. They are often blended with PAOs or other synthetic oils in lubricant formulations. Due to their affinity for metal, especially steel and iron, esters provide maximum wear protection. They are ideal for loaded bearings, potentiometers, and cut-metal and powdered-metal gearing, if proper seals are used. Because esters can withstand temperatures as high as 180°C, they have become the choice for automotive supercharger gearing and other severe duty applications. A word of caution: esters have been known to attack certain plastics and elastomers.

Table 4 **Common Lubricant Additives**

ADDITIVE	CAPABILITIES
Antioxidant	Prolongs life of base oil
Antiwear (EP)	Chemically active protection of loaded metal surfaces
Antirust	Slows rusting of iron allows
Anticorrosion	Slows corrosion of non-noble metals
Filler	Thermal/electrical conductivity, special physical properties
Fortifier (EP)	Solids burnish into loaded surface under extreme pressures
Lubricity	Reduces coefficient of friction, starting torque, or stick/slip
Viscosity Index (VI)	Reduces rate of change of viscosity with temperature
Pour Point	Improves lower temperature limit
Dye	Visual/UV markers as inspection/assembly aids

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Figure 3 A modular surgical handpiece system by OsteoMed Corporation is used for the dissection and drilling of small bones. A filtered, fortified synthetic hydrocarbon oil by Nye Lubricants is recommended prior to autoclaving to flush and lubricate bearings in the system's 11 saw and drill attachments. High-speed dental handpieces also use synthetic hydrocarbon oils in the turbine bearings. Typically, the bearings are re-lubricated with oil and placed in an autoclave after each use.

Polyglycols, like esters, have an affinity for specific metals, such as brass or phosphate bronze. They offer good lubricity and film strength. A "clean-burning" lubricant, they are commonly used in arcing switches where they leave little or no residue, which would act as an insulator. Because they offer good load-carrying ability, polyglycols are also particularly effective in large worm and planetary gears to reduce friction and improve efficiency. They are the only synthetic oils which include water-soluble versions. Like esters, however, they present compatibility problems with some plastics and elastomers, particularly polycarbonates, ABS resins, natural rubber, Buna S, and butyl.

Silicones and PFPEs are compatible with nearly all 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 are unaffected by sulfuric acid, hydrochloric acid, alkalis, halogens, and petroleum solvents. They do not react with oxygen — even at 300°C under 500 psi of pure oxygen. In addition, some PFPEs have very low vapor pressure, which is essential for vacuum chamber and aerospace applications where outgassing can be problematic.

Polyphenylethers (PPEs) are the traditional lubricant for noble metal connectors. With the highest thermal and oxidative stability of all oils, they are also used for high-temperature, specialty bearings. PPEs are radiation-resistant, which makes them candidates for medical or dental apparatus, where radiation sterilization is mandatory (Note: because of their radiation resistance they can not be exported to some countries for security reasons). PPEs are not suitable for temperatures below 10°C, nor are they compatible with some plastics and elastomers.

Multiplyalkylated cyclopentane, a type of synthetic hydrocarbon, is one of the newest synthetic lubricants. Its uniqueness lies in the fact that its low vapor pressure (3.5x10-11 torr) rivals the vapor pressure of PFPEs, but its sturdier hydrocarbon backbone makes it able to handle heavier loads better than a PFPE. Nye is one of the few companies that formulates custom lubricants with this oil.

WORKING WITH GREASE

Choosing the right oil is the 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 the oil to the temperature extremes of the component is essential (*See Table 2, "Temperature Range of Lubricating Oils"*). Importantly, though perhaps not quite as obvious, selecting the right oil is essential even when specifying a grease. Greases are made by mixing a powdered material — for example, a wax, soap, or clay, which are referred to as thickeners or gellants — with a base oil, but the

Table 5 **Grease Stiffness**

NLGI GRADE	PENETRATION (worked 60x)	ANALOG (unworked)
000	445-475	Ketchup
00	400-430	Applesauce
0	355-385	Brown mustard
1	310-340	Tomato paste
2	265-295	Peanut Butter
3	220-250	Vegetable Shortening
4	175-205	Frozen yogurt
5	130-160	Smooth paté
6	85-115	Cheddar cheese spread

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oil is still the critical lubricating component. By way of analogy, greases can be thought of as a sponge of oil. Moving parts, such as gear teeth, slides, cams, or ball bearings, squeeze oil out of the thickener-oil matrix to prevent friction and wear. Many people use a phrase like "lithium grease" (lithium is a type of soap-thickener), but the phrase really tells little about the lubricant's properties. Lithium is only the "sponge" and lubricant behavior — whether you use an oil or a grease — depends primarily on the type of oil in the formulation.

A wide variety of thickeners (*See Table 3, "Common Thickeners for Synthetic Grease"*) and performance enhancing additives (*See Table 4, "Common Lubricant Additives"*) provide grease manufacturers with the ability to formulate greases

Table 6 **Material Compatible with Synthetic Oils & Greases*** **(At Room Temperature)**

	SYNTHETIC HYDROCARBONS	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
Buna 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/elastomer quality, or any combination of these conditions, compatibility can be compromised. Any synthetic lubricant used with a plastic or elastomeric component should be tested to ensure compatibility in a specific application.

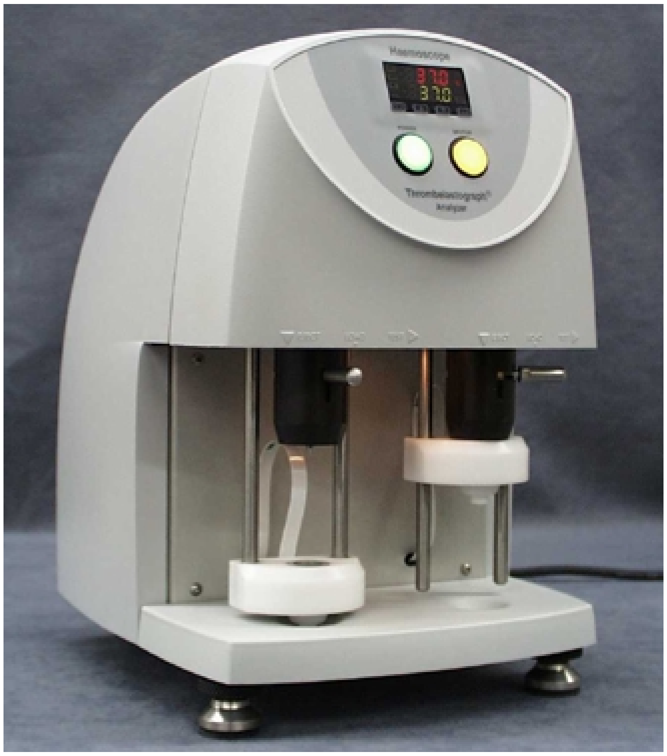
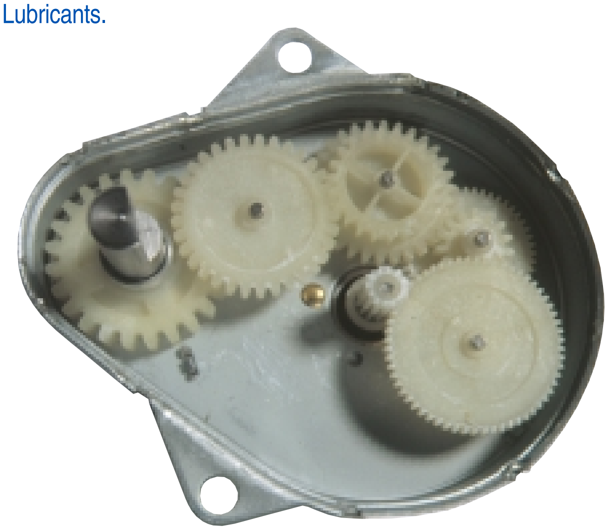


Figure 4 Thrombelastograph® (TEG®) Coagulation Analyzer, manufactured by Haemoscope Corporation of Skokie, Ill., tracks the shear elasticity of a clot and its ability to arrest bleeding — in real-time, during a medical procedure. It relies of two greases by Nye Lubricants, one in the gear motor (see below) and one where mating parts slide on the frame.

Figure 5 A sub-fractional horsepower electric gear motor by Autotrol Corporation powers the TEG® Coagulation Analyzer. Gearing is lubricated with a light, thixotropic, synthetic hydrocarbon grease by Nye Lubricants.



with specific physical and chemical characteristics. Some thickeners work only with some base oils chemistries while others, such as silica and PTFE can be considered universal. The additives used in a lubricant provide even greater design flexibility. Additives are mixed in small concentrations with the oil and thickener — usually less than 5 percent by weight — to enhance critical performance properties of a grease, such as low temperature torque, metal corrosion protection, or fluid oxidation resistance (*See Figure 2*).

What's better: grease or oil? Engineers have struggled with this question for many years. In some applications, oil may be the only viable alternative. Sometimes an oil is used to purge as well as lubricate (*See Figure 3*). Sintered or powdered-metal bearings are designed to be impregnated with oil. Small delicate mechanisms with extremely low starting torque, like those found in watches, micrometers, or other precision instruments, may also require oil if they lack the motive force to overcome even the lightest grease. With those few exceptions in mind, engineers should never quickly dismiss grease because it does offer cost and performance advantages over oil. Grease generally stays where it's put, so engineers can eliminate the cost of oil seals and seal design, which are essential to prevent leakage in an oil-lubricated component. Greases also prevent wear better than oils. Further, specially formulated greases can do more than provide lubrication. They can act as a seal against contaminants and moisture, quiet noisy plastic parts, control free motion such as coasting and backlash, promote electrical conductivity, and even impart a "quality feel" cost-effectively. Greases are also more forgiving, allowing engineers to be somewhat less exacting about perfectly mated parts.

Importantly, greases can be formulated light enough to accommodate components with low start-up torque. In gearing, for example, they 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 (*See Figures 4 and 5*).

The consistency or "stiffness" of a grease is determined by measuring the depth in tenths of millimeters that a metal cone penetrates a sample of grease under test conditions (ASTM D-217). The National Lubricating Grease Institute (NLGI) has a grading system for grease consistency (*See Table 5, "Grease Stiffness"*), where Grade 000 is similar to the consistency of ketchup and Grade 6 is comparable to cheddar cheese spread. NLGI Grade 2 is the most common grade. Grade 000 to Grade 2 can be pumped and therefore are suitable for large volume usage in automatic grease dispensing systems. The more fluid-

Table 7

Matching Synthetic Lubricants with Applications

COMPONENT	LUBRICANT ALTERNATIVES
Rolling Element Bearings	– Synthetic hydrocarbons (SHC) offer thin film and excellent lubricity – Fluorinated ethers offer excellent temperature and chemical stability – Cyclic hydrocarbons offer low evaporation rates – Polyesters offer good anti-wear and load-carrying for high-speed bearings – Complex esters and SHC greases are non melting and resistant to water washout
Precision Bearings	– For any lubricant, ultrafiltration extends bearing life
Powdered Metal Bearings	– Fluorinated ether oils provide outstanding temperature and chemical stability – Polyol ester oils offer greater lubricity and good high-temperature capabilities – SHC oils are plastic-compatible and resist oxidation
Slides, Cams, Detents, and Gear Trains	– SHC offer a range of viscosities, good load-bearing, oxidation resistance, and temps to 125°C – Polyol esters push temperature limits to 150°C
Control Cables	– Silicones offer excellent wetting, durability, and a range of viscosities
Electrical Switch and Sliding Electric Contacts	– SCH greases are water-resistant, plastic-compatible, and non-melting – Polyether greases are better for arcing conditions. – Polyol ester greases offer high lubricity, salt-water resistance, and wide-temperature fluidity
Electrical Connectors	– SHC provide thin protective film on tin-lead connectors, while making a weather resistant seal – Fluorinated ethers offer long life without lubricant decomposition products – Polyphenyl ethers are traditional for gold on gold
Potentiometers	– Halogenated silicones survive from –70°C to +200°C and offer good noise reduction – Polyol ester s provide high-temp stability, good – Noise reduction and low, thin-film volatility – Fluorinated ethers resist chemicals and solvents (except fluorinated solvents) from –65°C to +225°C
Chemical, Fuel, Solvent and High Temperature Environments	– Fluorinated ethers are nonflammable, plastic-compatible, chemically inert, and extremely stable. They offer low evaporation rates and come in a wide range of viscosities

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like grades, NLGI 1 and lower, can also "slump" physically. These may be more effective in applications like gear boxes where slumping aids the continuous refreshing of the lubricant into the contact zone. Grades 3 and above are less common but can be required in applications such as high speed bearings where slumping can cause excessive device noise, excessive torque, or lead to splattering of the grease out of the device.

Damping greases deserve special mention (*See Figure 6*). They are one of the most cost-efficient ways to control free motion, achieve a "quality" feel, reduce noise, and enable fine tuning by hand in mechanical and electromechanical devices. It is a damping grease applied to the focusing threads of binoculars, microscopes, zoom lenses, and other optical instruments that controls coasting and ensures smooth, virtually silent operation. On electronic controls such as potentiometers, damping greases make possible very precise settings that could not otherwise be made by hand. They also control motion and reduce noise in gear trains, gear motors, appliance controls, electric switch mechanisms, outdoor recreation equipment, laser controls, television tuners, surveying instruments, stepper motors, and in many hand-actuated automotive applications — where "quality feel" usually indicates the presence of a damping grease. Because of their consistency, damping greases also help prevent the introduction of moisture, dust, and other pollutants to a device. And because they prevent much of the actual mating of moving parts, they reduce wear and extend product life.

Both objective and subjective criteria are used to match a damping grease to a specific application. Objectively, damping

Figure 6 A smooth "velvet feel" for appliance control knobs is one of the benefits of applying a synthetic hydrocarbon "damping grease" to the stem. Damping greases are used to cost-effectively control motion and noise in mechanical and electromechanical devices. A different application: bearings that are actuated during the spin cycle of washing machines purr more quietly because of damping grease.

greases must retain their damping qualities throughout the temperature range of the application. Synthetic hydrocarbon greases are often suitable for -40°C to +120°C. For temperatures lower than -40°C, silicone-based damping greases are available, some of which can damp at room temperature and still be operable at -60°C. Because of potential contamination problems, silicone-based greases are not recommended for many optical and electrical applications.

Subjectively, damping greases are selected for the "feel" the engineer wants to achieve. Generally, the more delicate the device, the lighter the grease. To achieve the right feel, testing various amounts of the candidate greases at the lowest expected operating temperature is recommended.

LUBRICANT SELECTION AND THE DESIGN CYCLE

While the performance of a lubricant depends on many variables, early evaluation of key lubricant selection criteria can help avoid design pitfalls and shorten product development time.

Operating Temperature. The most important design variable is the operating temperature range of the device. At the high-temperature limit the lubricant must be chemically stable and have sufficient film strength to adequately prevent wear. At the lowest expected temperature it must remain sufficiently fluid.

Material Compatibility. Some lubricants can "attack" certain plastics and elastomers. The base oil can infiltrate the solid material or cause the solid's components to leach into the lubricant (*See Table 6, "Materials Compatible with Synthetic Oils & Greases"*). Good design practice tests the compatibility of specific plastics and elastomers by evaluating physical properties such as tensile strength, dimensional stability, and gravimetric stability after immersion in the lubricant. Higher temperatures and lower base oil viscosities usually exacerbate chemical incompatibility. Certain metals which come in contact with the lubricant may exhibit accelerated corrosion or lead to undesirable polymerization or "varnishing" and failure of the lubricant base oil. These problems can be avoided by identifying early in the design process the metal alloys used in the device and analyzing and testing their compatibility with candidate lubricants and additives.

Load and wear. For most applications, the prevention of wear caused by friction is the primary reason for the use of a lubricant. Thus the load at the interface is an obvious concern. In general, higher viscosity base oils support heavier loads. If the load in the contact zone is too great or the speed is too slow, asperities on the rubbing surfaces can collide, causing excessive wear. In this situation, which is referred to as boundary lubrication, extreme pressure (EP) additives may be necessary. Synthetic ester greases are particularly suited for preventing heavily loaded metal-on-metal wear. Under relatively light loading, the outstanding viscosity properties of a silicone grease may be useful.

Type of device. Different types of devices can have a wide variety of lubrication requirements (*See Table 7, "Matching Synthetic Lubricants With Applications"*). An electric switch that carries low current within a non-inductive circuit will require a different lubricant that one that has the potential to arc during the make-break of an inductive circuit load. A bearing that supports a rotating shaft will have a lubricant system different than a set of plastic gears. The ultimate application of the component must be considered and the likely mode of failure determined. Many specialized lubricants have been developed for specific parts, including ball bearings, journal bearings, stationary electrical connectors, electrical switch contacts, plastic gear trains, lead screws, and cams. Choosing a lubricant designed for the device at hand is the key.

Operating environment. The end-use environment for the device should be considered. Is it corrosive? Is dust an issue? Will the lubricant be exposed to water, steam, solvents, or solvent fumes? Will the part see temperature cycling? Is micro-vibration a possibility? Just as other parts of the component are designed to withstand operating conditions, the lubricant must also be designed with these constraints in mind.

Delivery and handling. How the lubricant is applied to the device during manufacture is often critical to its success. The correct amount must be applied in the right location. In some applications, too much lubricant can be more detrimental than too little. Cleanliness of the lubricant is also an issue. Containers should be kept closed and exposure to contaminants minimized. Often the use of automated dispensing systems can preserve lubricant cleanliness and ensure that repeatable quantities are applied to the part. For automatic dispensing applications, grease should be deaerated to avoid spitting or misfires during high-speed dispensing, which leads to insufficient or no lubricant on some parts. Some precision applications may require that a lubricant be cleaned through microscopic ultra-filtration. In high-speed dispensing, the addition of a UV dye to the grease enables automated inspection for lubricant presence using machine vision. Finally, care must be taken to design delivery systems that do not apply excessive shear or static pressure, which can alter the characteristics of the grease.

Cost. As with all materials in a successful design, the cost of a lubricant must be justified by its performance. Some of today's design and performance requirements exceed the capability of petroleum and force the engineer to select a higher-cost synthetic lubricant. However, because synthetic technology often extends the life, reliability, and capability of a device, the additional cost can usually be justified. More importantly, while most synthetic greases are typically priced between US$5.00 and US$50.00 per pound (in 35-pound containers), note that *Table 8, "Calculating the Unit Cost for Small Amounts of Synthetic Grease*," demonstrates that the cost per device of even an expensive synthetic grease is often negligible when compared with the cost of other items in the bill-of-material. ■

About The Authors

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Table 8 **Calculating the Unit Cost for Small Amounts of Grease**

Amount of Grease Per Device (Dia. in mm.)	Volume (ml.)	lbs./100,000 Units LD	HD	Grease Cost Per Device (in Cents) LD@$10/lb	HD@$100/l
1	0.0003	0.06	0.12	0.0006¢	0.012¢
2	0.0021	0.46	0.93	0.005¢	0.09¢
3	0.007	1.6	3.1	0.016¢	0.31¢
5	0.033	7.2	14.4	0.07¢	1.4¢
10	0.26	57.8	115.5	0.58¢	11.6¢

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The table helps estimate the per-device cost of specialty greases. The dots, whose diameters are noted in millimeters, represent various "dollops" of grease. The volume of each dollop is given in milliliters in the second column. The next two columns indicate the weight of grease in pounds needed to lubricate 100,000 devices, if each device uses the amount of grease shown in the first column. "LD" stands for low or standard-density grease, that is, a grease with a density close to 1g/ml, such as most synthetic hydrocarbon, silicone, or ester-based greases. "HD" stands for high-density grease, that is, a grease with a density closer to 2g/ml, such as fluorinated ether-based greases. (Some fluorocarbon-gelled greases are intermediate in density; some hydrocarbon greases have densities lower than 1g/ml) Note that the volume is equivalent to the weight of the dollop in grams for an LD grease; an HD grease would weigh twice as many grams. The last two columns list the grease cost per device in cents, not dollars.