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Giving electrical connectors the slip

New grease for automotive connectors prevents resistance buildup.

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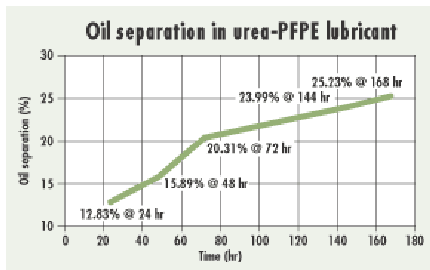
Electrical connectors rely on lubricants to keep corrosion from degrading the terminals and to reduce the amount of force needed to connect them.

The number of electrical systems in a typical passenger vehicle continues to grow, powering everything from headlights and DVD players to body impact sensors and global-positioning systems. And with each new system comes additional connectors. Luxury cars, for example, now have upwards of 400 connectors with 3,000 individual terminals, and that translates into 3,000 potential trouble spots.

Connectors also have to protect against water, changing temperatures, road grit, and vibrations, all of which speed oxidation and fretting corrosion on connectors. Corrosion generates resistive oxides on the connectors, which causes intermittent faults and electrical failure. So the challenge for connector manufacturers is to extend the operating life of their products as more are used on each car and car companies continue to extend their warranties.

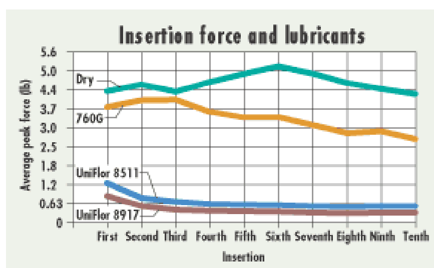
At the same time, stringent ergonomic standards have made their way to the assembly line. The force required to put together separable connectors is of particular concern. Historically, this force has exceeded 30 lb. The National Institute of Occupational Health recently warned that employees performing repetitive wiring tasks on assembly lines could develop carpal-tunnel syndrome or other hand, wrist, and arm disorders. This warning prompted the U.S. Council for Automotive Research (USCAR) to update its Performance Standard for Automotive Electrical Connection Systems (published in April 2001 as SAE/USCAR-2, Rev. 3). The revised standard slashes the allowable mating force to 16 lb. In addition, the force must stay the same and electrical resistance remain below 10 mΩ over 10 matings (10-mate standard).



After 24 hr at 200°C, oil loss for the PFPE-urea grease (UniFlor 8917), is only 12.8%, which should pose little if any threat to nearby components, given that only a small amount of grease is used on each terminal. Oil loss stabilizes quickly, leaving plenty of oil in the grease to protect the connector.

It's not hard to see that lubricants have an important role to play in connector performance, including corrosion prevention and reducing costs. This is especially true for low-voltage connectors (0.1 to 0.5 W), which now constitute about 75% of connectors in passenger cars.

Greasing the high-temperature terminals

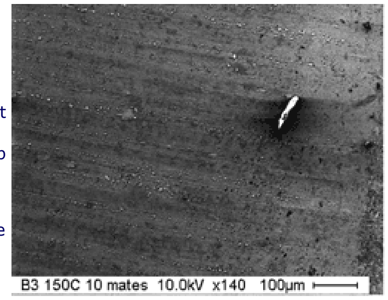


AN Instron 5566 measured the force needed to mate a 6.35-mm connector by inserting it 0.375 in. at 0.0333 in/sec. The test connection was made 10 times and values recorded for each. Tests showed that connectors lubricated with UniFlor 8917 had insertion forces only half as great as those lubricated with UniFlor 8511, a previous benchmark.

The right lubricant lowers the insertion force needed to assemble connectors, reduces mechanical wear by placing a film of oil between mating surfaces, and, if the lubricant contains the proper additives, it minimizes corrosion. Such lubricants can be based on a variety of chemistries, but synthetic hydrocarbons and ethers currently dominate the market. Perfluoropolyether (PFPE)-based greases, for example, are among the most frequently chosen synthetic lubes. They are usually selected for high-temperature applications (up to 250°C) and thermooxidative stability (i.e., it doesn't oxidize at higher temperatures).

In the 1980s, when issues like insertion force began to catch automakers' notice, engineers at our company developed greases that combined the stability of PFPEs with polytetrafluoroethylene (PTFE) and its exceptionally low coefficient of friction (UniFlor 8512 and 8511). PTFE, however, comes with a cost. Connectors that use it have low insertion forces, but after eight or nine matings and a 1,008-hr heat treatment at 150°C, contact resistance of the terminals sometimes exceeds USCAR recommendations. That's because the high normal force and heat, combined with the action of putting it together and taking it apart several times burnishes PTFE into the surface of the contact, insulating the contact asperities that actually carry current. This leads to intermittent and catastrophic connector failures. The industry needed a new grease to meet the new regulations.

Grease that meets the regs



A 6.35-mm terminal after 1,008 hr of testing shows that UniFlor 8917 protected its surface. If it hadn't, the terminal would be pitted or show signs of the tin plating separating from the copper base material.

In the new connector grease, urea replaces PTFE to avoid burnishing that increases contact resistance. (Urea is a soluble, slightly basic nitrogen compound, $CO(NH_2)_2$.). But urea isn't as "slippery" as PTFE, and using it meant the final product (UniFlor 8917) might not meet USCAR's 16-lb insertion-force limit.

Another potential problem stemmed from PFPE being the base oil of choice due to its high-temperature performance and resistance to oxidation. It seems PFPE's inert chemistry and high specific gravity make it difficult to thicken the grease. And when urea is part of the mix, the grease separates at high temperatures due to density differences between PFPE and urea.

To test whether insertion forces remained within USCAR limits, engineers measured what it took to mate a 6.35-mm terminal, inserting the terminal 0.375 in. at a rate of 0.0333 ips for 10 insertions. Terminals were lubricated with a high-viscosity, silica-thickened, synthetic hydrocarbon grease (NyoGel 760G), a PFPE-PTFE grease (UniFlor 8511), and a PFPE-urea grease (UniFlor 8917). An unlubricated connector served as the control. The mating force for the unlubricated terminal averaged 4.4 lb, a value that changed little from the first to the tenth mating. The terminal lubricated with silica-thickened hydrocarbon grease required a mean insertion force of 3.8 lb on the first mating and 2.8 lb on the tenth mating. PFPE-PTFE grease yielded an insertion force of 1.3 lb on the first and 0.5 lb on the tenth mating. But the PFPE-urea grease beat them all, with an insertion force of 0.8 lb on the first and a mere 0.3 lb on the tenth mating, nearly a 50% reduction over PTFE-PFPE grease, and well within USCAR requirements.

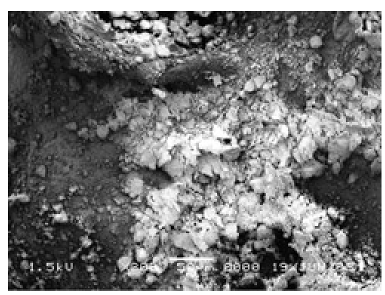
An independent laboratory then tested several terminals lubricated with PFPE-urea grease to USCAR resistance standards. The test ran for 1,008 hr at 150°C with resistance readings recorded before and after for both one and 10 matings. After 10 matings, the resistance across the terminals averaged 0.489 mΩ, well within USCAR's 10-mΩ limit.

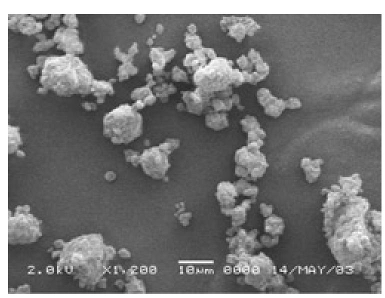
Technicians examined the surface of the tested connectors with a scanning electron microscope but found no evidence of oxidation or damage to the tin-lead plating. Thus, PFPE-urea grease effectively protected the connectors without compromising their electrical resistance, and reduced the insertion force to well below USCAR standards. In addition, FT-IR analysis of grease removed from the terminals after the 1,008-hr test showed no lubricant degradation.

During a dropping-point test (ASTM D-2265, which determines the temperature at which the thickener melts and no longer holds the base oil), the grease exuded a drop of oil at 140°C. However, as with other PFPE greases, this oil dropout was caused by the difference in specific gravity between PFPE and the thickener, and does not mean the thickener melted. Oil separation in a sample held at 100°C for 24 hr was less than 10% (determined by test standard FTM 791B, 321.2), which isn't enough to jeopardize the reliability of the connector or nearby components, such as relays and switches. Furthermore, oil loss stabilized within about 100 hr of use, ensuring there's still enough oil within the grease to protect the contact.

Though PFPE's inertness and broad temperature tolerance make it one of the most expensive synthetic oils, the cost-per-terminal for PFPE-urea grease (UniFlor 8917) is easy to justify. One pound of UniFlor 8917 lubricates 30,266 terminals at \$0.0033/terminal if you apply 15 mg of grease per 2.8-mm terminal. If the terminals are 6.35-mm wide, the same pound lubricates 9,891 terminals at \$0.01/terminal. And because PFPE-PTFE grease typically costs more than PFPE-urea formulations, the new grease not only meets USCAR insertion force and resistance standards, but also reduces cost.

Urea: more than just a resistance fighter





Polytetrafluoroethylene (PTFE) has earned its reputation as one of the slipperiest substances around. Under normal conditions, spherical particles act like little ball bearings within a lubricant, ensuring surfaces slide past one another without sticking. PTFE particles also have a tendency to build up within asperities and on surfaces. In many instances, this buildup puts a lubricious coating on surfaces, reducing friction between moving parts.

In electrical connectors, though, buildup of insulating PTFE in asperities impedes the flow of electricity. Thus, while PTFE in PFPE-based grease reduces the mating and remating forces for automotive electrical connectors, it also jeopardizes the lubricant's ability to meet resistance requirements after the eighth mate.

The urea that replaces PTFE in the new connector lubes has a flat, sheetlike shape. This flatness helps reduce insertion force, more so, in fact, than PTFE. Urea also provides a stable thickener. Its hydrogen bonds maintain a strong film thickness despite heavy loads and high temperatures. Most important, sheetlike urea particles do not collect within the asperities where electricity flows between terminals. Thus, not only is insertion force lowered, but separable connectors lubricated with the urea-containing grease meet resistance specifications as well.

Scanning-electron micrography reveals the tendency of PTFE particles to collect on the terminal, leading to buildup of the electrically insulating material (top). The urea used in UniFlor 8917, conversely, has a sheetlike structure that makes it spread out, maintaining the flow of electricity in reusable connectors.

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