Connectors are big business. Connector shipments worldwide exceeded $25 billion in 2001.[1] Sales statistics, however, only begin to suggest a connector's critical role in the marketplace. Connectors impact the operating life, performance, and quality of countless electronic and electrical products, and every year many of those products — along with a manufacturer's brand image and warranty program — become victims of faulty connectors.

Connectors play an especially vital role in cars and light trucks. A luxury car can have more than 400 connectors with 3,000 individual terminals[2] — 3,000 potential electrical trouble spots. Auto studies report that approximately 30% of signal and accessory circuit failures and more than 50% of power circuit failures are attributed to connections.[3] This is not to say that connector design is inherently flawed. The automotive environment challenges even the highest quality connector.[4] In the engine compartment, connectors must survive rapid heating and cooling cycles as well as corrosive gasses, fuel, water, salt water, and road grit. Power mirrors, door locks, and other external systems face water and detergent baths in car washes. High levels of humidity threaten connector performance between door panels. Inside the passenger compartment temperatures can soar when exposed to sun and drop well below freezing in cold climates. Throughout the vehicle, connectors are subject to vibration from the engine, drive train, suspension system, and related components. All these conditions are catalysts for oxidation and fretting corrosion, which create resistive oxides, which in turn cause intermittent faults or electrical failure. As carmakers lengthen warranties and increase reliance on electrical and electronic systems, the challenge for connector manufacturers is to extend the operating life of connectors in ever more harsh environments.

Today, connector manufacturers face an additional challenge: the ergonomics of separable connector design. The force required to mate separable connectors is of particular concern. NIOSH warns that employees who perform repetitive wiring tasks on assembly lines may be at risk of developing carpal tunnel syndrome and other musculoskeletal disorders of the hand, wrist, and arm.[5] The risk of injury is exacerbated in the auto industry because workers often have to mate connections in hard-to-reach positions.

Historically, connections with mating forces in excess of 130 Newtons (30 pounds) have been used in vehicles, and repetitive mating of these has resulted in increased worker complaints.[6] USCAR specifications have slashed maximum allowable insertion force to 75 Newtons (16 pounds). Consequently, connector manufacturers must ensure that the force required to securely mate or re-mate separable connectors, a key requirement for good electrical performance, is not hazardous to autoworkers. Further, in the fiercely competitive automotive world, all these connector design requirements — long life, optimal electrical performance, protection against oxidation and fretting corrosion, and low insertion force — are coupled with the mandate to reduce costs.

Nye Lubricants collaborated for nearly two years with one of the world's leading connector manufacturers to develop a new synthetic grease for connector terminals that would help connector manufacturers meet these stringent design goals. This paper discusses this development process and its outcome: UniFlor™ 8917, a novel, urea-thickened, perfluoropolyether (PFPE) grease. Independently tested on both 2.8 mm and 6.35 mm terminal products, UniFlor 8917 easily met the insertion force and resistance requirements of SAE/USCAR-2, Revision 3, the Performance Standard for Automotive Electrical Connection Systems.

Role of Lubricants in Connector Performance

Connector quality depends on many factors, including materials, contact geometry, normal force, and design of springs, crimp mechanisms, and housings. Lubrication also plays an important role, especially for low-voltage connectors (0.1W to 0.5W). A properly selected lubricant lowers insertion force by decreasing the coefficient of friction between mating surfaces. It reduces mechanical wear by placing a film of oil between the mating surfaces. With additives, a lubricant minimizes corrosion. Lubricants also reduce fretting corrosion, a special type of mechanical wear caused by low amplitude vibration, typical with tin-plated contacts. The vibration may be caused by vehicular motion in general, motion of nearby components, such as fans or small motors, and thermal expansion and contraction of connector components. Fretting corrosion continually exposes fresh layers of metal to oxidation. An anti-fretting lubricant reduces mechanical wear, provides an oxygen barrier, and helps to move any oxide debris away from the contact area.

For gold-plated connectors a lubricant reduces noble metal wear during mating and separation. It also protects against substrate corrosion. Thin gold plating can be microscopically porous and a film of lubricant can seal the pores to prevent substrate oxidation, which can eventually exude through the pores, build up on the noble metal surface, and lead to high contact resistance. By sealing microscopic pores, lubrication also enables manufacturers to apply thinner plating and reduce costs.

Generally, a lubricant's ability to reduce wear and retard oxidative resistance extends connector life.

Evolution of Connector Lubricants at Nye

Nye has been actively involved in the design and manufacture of lubricants for separable connectors since 1964 when we introduced NyeTact® lubricant dispersions. NyeTacts are lubricants consisting of a synthetic oil or grease dispersed at various concentrations by weight in a solvent. Typically, polyphenyl ether oils were used for gold contacts and synthetic hydrocarbons oils for tin-lead. Later, dispersions using PFPE oils were added because PFPEs offer broader operating temperature ranges than polyphenyl ethers and synthetic hydrocarbons. Greases, which are made by mixing a solid thickening agent with an oil, were formulated with soaps, silicas, or clays. When applied to the terminal surface, the solvent evaporates leaving a thin, protective lubricating film with excellent stability against oxidation or aging. Some NyeTacts contain additives to improve surface coating and "stay-in-place" properties. Some also contain a UV-tracer for identification of the lubricant on the contact.

The increasing use of low voltage stationary separable contacts in data processing equipment, where high loads on the contact are required to assure low contact resistance, increased the need to keep insertion forces from becoming excessive. To mate a 300 contact circuit board, for example, requires nearly 100 pounds of force![7] Further, as normal force increased, the potential for wear on thin metal platings increased as well. Nye responded with new NyeTact products formulated with ultra-high viscosity synthetic hydrocarbon fluids stabilized with a special binder.

While dispersions are suitable for small volume applications, cost and solvent recovery often make dispersions impractical for large manufacturing operations. In the early 1980s, with the advent of more sophisticated production line dispensing systems, connector greases grew in demand. About the same time, broader temperature requirements and material compatibility issues sent automotive OEMs and connector manufacturers looking for new connector lubricants. Some automotive connector manufacturers had begun lubricating female terminals with a petroleum-based, lithium-soap grease with a zinc oxide fortification. Over time, the grease attacked connector housings, which started falling off wire harnesses — an obvious safety, quality, and warranty problem. Nye was asked to design a solution. We formulated NyoGel® 759G (Ford: ESB-M1C203-A; GM: 9985821), a soft, silica thickened, high viscosity synthetic hydrocarbon grease. NyoGel 759G offered plastic and elastomer compatibility, an operating temperature range of –40°C to 125°C, and solved the problem caused by the petroleum connector grease.

Connector manufacturers then requested a stiffer version of NyoGel 759G to improve production line injection capabilities. They also requested a connector grease with a higher temperature capability and lower oil separation. Nye responded with NyoGel 760G (Ford: WSB-M1C239-A; GM: 9986087; DaimlerChrysler: MS-9469). NyoGel 760G is a high viscosity, silica thickened, synthetic hydrocarbon grease. Its stiffer consistency enabled presses to run 30 to 50% faster and much cleaner. A new antioxidant boosted its temperature limit to 135°C, and the addition of a UV dye facilitated quality inspections.

NyoGel 760G was also fortified to minimize corrosion of exposed copper substrate. NyoGel 760G was originally used in tail lamp connectors but soon became the grease of choice for ECM, EGR, air bag, starter, ABS, and more than 50 other connectors. Connector manufactures use NyoGel 760G on terminal products as well as inside the housing, taking advantage of the grease's water and salt-water resistance to create an added environmental seal.

Research in the late 1980's and early 1990's suggested that fretting corrosion could be controlled by connector design instead of lubrication by adding an elastic element inside a separable connection to compensate for movement between mated pin and socket at the contact point.[8] No movement, no fretting corrosion. While increasing the normal force on contacts does control fretting corrosion, it also boosts insertion force, a problem that multiplies with the number of pins or blades. In the automotive industry, the problem was compounded by the proliferation of larger connectors in hard to reach places. Early resolutions included bolt-together connectors as well as other forms of mechanical assists like cams, levers, gears and slides. Mechanical assists enable a worker to mate connectors with less force but they come at an increased cost and require additional space. They also increase complexity, which can have an effect on service.[9]

Lubricants resurfaced as a cheaper, simpler way to help reduce insertion force. However, the proliferation of connections on or near the engine block often disqualified NyoGel 760G, whose upper temperature limit is 135°C and whose initial design was focused on material compatibility, wear and oxidation prevention — and not insertion force reduction. OEMs needed a high-temperature connector grease that could reduce mating force for high normal force connectors.

Nye responded with UniFlor 8512 and UniFlor 8511. Each of these greases combine PFPE oil, with an operating temperature range to 250°C, with polytetrafluoroethylene (PTFE), perhaps the world's most slippery polymer. Each of these greases delivers high-temperature connector capability and excellent insertion force reduction. For example, a dry 6.35 mm terminal has an average insertion force of 4.4 lbs. Lubricated with UniFlor 8511, the average insertion force drops to 1.3 lbs. There was one drawback. After eight or nine matings, contact resistance of terminals lubricated with UniFlor 8511 exceeded allowable USCAR recommendations. The combination of high normal force, heat, and the sliding action of multiple insertions and withdrawals seemed to burnish the PTFE into the surface of the contact, insulating the contact asperities (A-spots), where current actually flows. This elevated resistance after multiple matings set Nye on a path to develop a new grease that would not only reduce insertion force but also meet USCAR resistance standards.

Development of UniFlor 8917

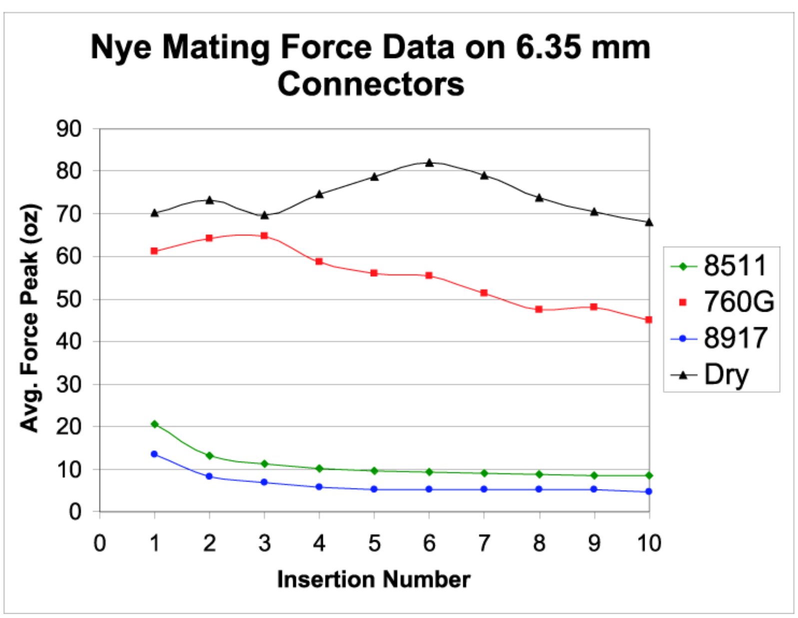
PFPE meets demanding temperature requirements and possesses excellent thermooxidative stability, so it remained the base oil of choice for the new connector grease. Since PTFE was the suspected culprit for increased resistance, we replaced it with a urea, though we knew of no other urea-thickened PFPE grease. Some caution was needed because PFPE's inert chemistry and high specific gravity make it more challenging than other oils to thicken; these characteristics also tend to promote some oil separation at high temperatures. Further, because PTFE is more lubricious than urea, it was counterintuitive to assume that a urea would further reduce insertion force.

The insertion force required to mate a 6.35 mm connector was measured on an Instron 5566, inserting the connectors 0.375 inches at a rate of 0.0595 in/sec for 10 insertions. We tested connectors lubricated with NyoGel 760G, UniFlor 8511, and UniFlor 8917. An unlubricated connector was included and tested as the control (*See Figure 1*).

An unlubricated connector had an average insertion force of 4.4 lbs., virtually unchanged from the first to the tenth mating. NyoGel 760G had an insertion force of 3.8 lbs on the first mating and 2.8 lbs. on the tenth mating. UniFlor 8511 had an insertion force of 1.3 lbs on the first mating and 0.5 lbs on the tenth mating. UniFlor 8917 had an insertion force of 0.8 lbs. on the first mating and 0.3 lbs. on the tenth mating — nearly 50% lower than the PTFE-thickened UniFlor 8511 and well within the USCAR insertion force requirements of 75 Newtons (16 pounds).

Figure 1

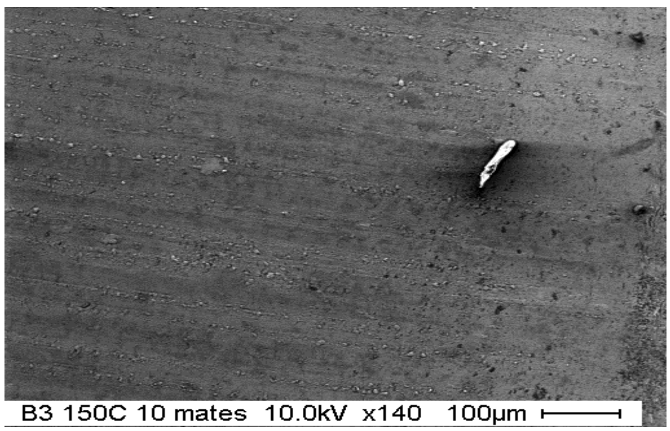
Insertion Force Data on Various Nye Connector Greases.



An independent laboratory then tested several terminals lubricated with UniFlor 8917 to the USCAR resistance standard. The test was run for 1,008 hours at 150°C with resistance readings recorded before and after the test for both 1 and 10 mates. After 10 mates, the average resistance across the terminals lubricated with UniFlor 8917 was 0.489 milliohms, easily within the 10 milliohms of resistance allowed by the USCAR standard. The replacement of the PTFE with the urea thickener drastically improved the resistance across the connector's surface, hence extending the life of the connector. The surface of the tested connectors was also analyzed at Nye with a scanning electron microscope (SEM) to see if there was any significant damage or evidence of oxidation on the surface of the connectors. No evidence of oxidation was found on the surface of the connector (*See Figure 2*).

Figure 2

SEM Image Of 6.35 mm Connector After 1,008 Hours Of Electrical Testing



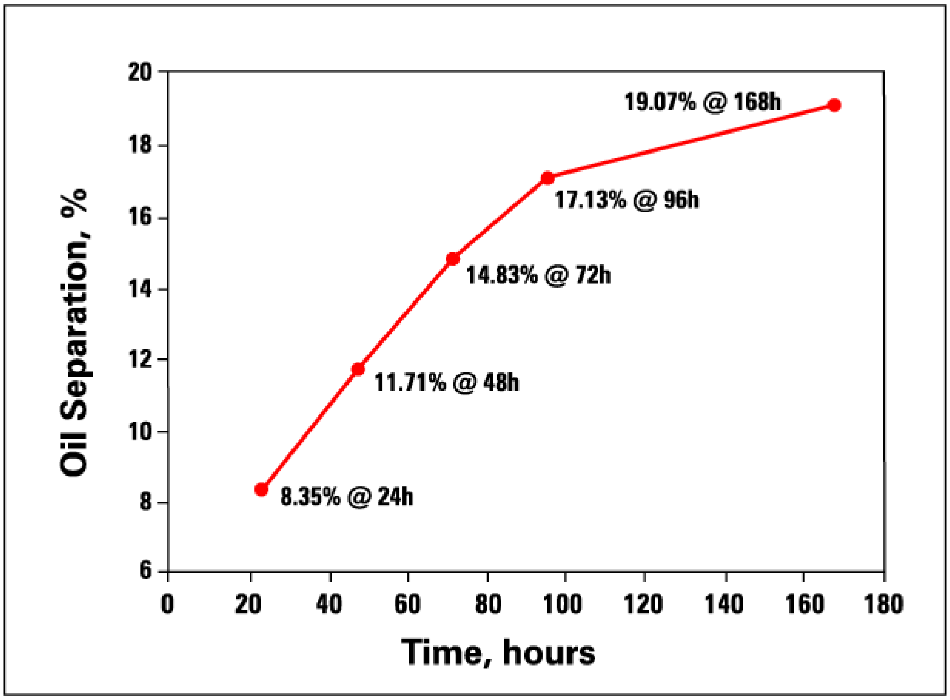
UniFlor 8917 effectively protected the surface of the connectors without compromising the electrical resistance requirements and reduced the insertion force to meet USCAR standards.

As anticipated, during the dropping point test (ASTM D-2265), the grease did exude a drop of oil at 140°C. However, like other PFPE greases, this lower dropping point is caused by the difference in specific gravity between PFPE and the thickener and not indicative of thickener melting. Importantly, the amount of oil separation is too small to jeopardize connector reliability or the reliability of nearby components such as relays or switches. There is approximately 15 mg of grease on each 2.8 mm terminal. Oil separation tests (FTM 791B, 321.2) on UniFlor 8917 show that after 24 hours at 150°C, oil loss was only 8.35%, or about 1.25 mg of oil from 15 mg of grease — posing little if any threat to nearby components. Further, oil loss stabilizes quickly over time (*See Figure 3*), which ensures a remaining reservoir of oil to protect the contact. The lubricity of the urea further ensures continued low insertion force over time.

Figure 3

Oil Separation For UniFlor 8917

168 hours @ 150°C



Cost, Information and Samples

Though PFPE's inertness and broad temperature range make it one of the most expensive synthetic oils, the cost per terminal of UniFlor 8917 should not be hard to justify. For 2.8 mm terminals, using 15 mg of grease per terminal, one pound of UniFlor 8917 will lubricate 30,266 terminals at $0.0033 per terminal. For larger 6.35 mm terminals, using 45.9 mg of grease per terminal, one pound of UniFlor 8917 will lubricate 9,891 terminals at $0.01 per terminal.

Several major connector manufacturers are currently testing UniFlor 8917, and we anticipate that this grease will become the standard for automotive applications where insertion force reduction is a primary concern. For an evaluation sample of UniFlor 8917 or more information about lubricants for separable connectors, contact Nye Lubricants, Inc., at 1.508.996.6721, techhelp@nyelubricants.com, or visit our web site at www.nyelubricants.com.

Endnotes

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