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In 1970, when the super-performance SR-71 Blackbird spy plane was being developed at Lockheed’s Skunk Works, designers faced a significant obstacle: No lubricant could withstand the operating temperature of 315°C (600°F) in the plane’s engines, two Pratt and Whitney J-58 axial-flow turbojets with afterburners. Fortunately, Monsanto was able to develop a new type of lubricant, known as a polyphenyl ether or PPE, that could withstand the heat and protect the engines. The SR-71 went on to perform even beyond expectations. Although the maximum numbers are still secret, it cruised at an altitude of at least 85,000 feet at a speed of at least Mach 32, or 2100 mph. One SR-71 set an absolute speed record by averaging 1817 mph from London to New York in 1 hour 54 minutes 56.4 seconds — back in 1974. During their service on reconnaissance missions, SR-71s were fired upon by more than 1000 hostile missiles, none of which ever reached its elusive target.

The 30 to 40 Blackbirds were officially retired in 1996, in part because of age and in part because they are expensive to maintain and fly. However, several have been brought out of retirement for various research projects, because no other aircraft can match their performance. For example, wind tunnels cannot achieve speeds of Mach 3, so NASA has mounted experimental devices on the SR-71.

At its introduction more than 30 years ago, the Blackbird was clearly a breakthrough, and so were the PPEs that lubricated its engines. It turned out that PPEs had a number of useful features in addition to resistance to very high temperatures. In the 1970s, not many applications were available for these advanced lubricants apart from the SR-71. But in the last decade or so, since the rights to PPEs were transferred to Santovac Fluids Inc., new applications for PPEs have been turning up in all sorts of unexpected places. Today, PPEs are likely to be found in computers, automobiles, and cell phones.

Positional stability of PPE

Most lubricants form a continuous film that creates a protective layer between two surfaces. However, PPEs lie on a surface not as a continuous film, but as a field of microscopically small droplets. This unusual structure is a result of high surface tension. For example, the surface tension of one preferred PPE is 49.9 dynes/cm. Each tiny droplet vibrates constantly with something akin to Brownian movement, but the whole field of droplets remains where
Polyphenyl ethers (PPEs), which have the unusual properties of positional stability, thermal stability, and very low vapor pressure, are long-chain aromatic ethers consisting of phenyl groups linked by oxygen atoms. Chemically rather nonreactive, they are also unmatched in resistance to ionizing radiation. For some applications, sulfur or another element is substituted for oxygen. The many types of PPEs have from two to six phenyl groups, and sometimes more. A six-ring PPE is shown here.

Atmospheric contaminants and abrasion from micromotion work together to create reaction products that pile up as debris (top), eventually pushing the pin and contact apart. Application of a PPE (center) covers the high spots (asperities) on the pin surface and prevents corrosion. If an already corroded pin (center) is treated with a PPE, the droplets capture the reaction products and normal electrical performance is restored.

How PPE protects
When a pin is coated with a PPE, corrosion never begins, for two reasons.
• The lubricating action of the PPE keeps the pin from wearing against its contact, while still permitting electrical conduction. One careful test showed that a PPE-coated pin was undamaged by 1000 times the amount of contact motion that destroyed an uncoated pin.
• The droplets in the PPE field appear to absorb contaminating molecules. This assumption is made because, in spite of the presence of spaces between the droplets, these spaces never corrode. The droplets themselves are chemically almost inert.

A cell phone, like many other appliances, is subjected to all sorts of vibration, from riding in a car, to being dropped, to being on the same table as a stereo speaker. Inside the phone’s connectors, this translates into micromotion — a relative sliding motion, sometimes on the order of only a few microns — between a connector pin and its contact. Before long, small scratches appear on the pin. If the pin is plated with gold (which does not corrode), the gold is worn away. If the pin is a metal such as a tin-lead alloy, it is also abraded. In either case, the way is open for airborne contaminants to do their work. Even if vibration is absent, temperature changes can cause micromotion because different materials expand and contract at different rates.

Over 150 common organic airborne contaminants attack these materials. The most famous is probably sulfuric acid, but nitric acid and many others are found everywhere, usually as aerosols. The summer haze hanging over a U.S. city may consist of 50% sulfuric acid. Somewhat in the manner of dew settling on grass, these aerosols condense on surfaces along with water molecules, even if the relative humidity is low. This is how contaminants appear on the surface of connector pins in a cell phone. Even if the connector were sealed, contaminants and humidity could migrate through the plastic. This is why electronic components or systems in truly critical applications, such as a remote marine buoy placed by the Navy, are sometimes housed in truly hermetic containers that are filled with a nonreactive gas such as nitrogen.

No other known lubricants have this property of positional stability.

Positional stability explains why PPEs were a good choice for the SR-71 engines, but not why they are the choice for automobiles, cell phones, and computer systems. The challenges in these more mundane systems are vibration, wear and abrasion, atmospheric contamination, temperature cycling, and corrosion. Over time, it became clear that PPEs could protect against these effects as well. As a result, in both cell phones and computers, PPEs are applied to the electronic junctions, usually multiple pin-and-socket connectors. Their purpose on electronic connectors is to protect against abrasion (just as in a jet engine, but on a far smaller scale), and to prevent corrosion.

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If no PPE is present, oxides, sulfides, and other products of corrosion begin to pile up as debris around the area of abrasion on the pin. Eventually the debris reaches such a size that it moves the contact and the pin apart. Electrical contact becomes intermittent and then is lost. The user of a cell phone may notice diminished range or other quirky behavior as an early consequence of corrosion.

When an appliance with electronic connectors fails, it may often be revived by unplugging and re-inserting the connectors. This action knocks off some of the corrosion products and may re-establish electrical contact. However, the reverse may also take place: a computer may stop working just after being moved from one location to another, because the debris piles on the connectors have accidentally been jolted into arrangements large enough to interfere with electrical conduction.

One interesting experiment is to coat failed pins with a PPE. The PPE droplets seem to swallow the debris, and the connector begins working again. On balance, the breakdown of a system or appliance is more likely to be caused by the failure of an electronic connector than by the failure of a chip,
even though chips are presumably more fragile and are subjected to similar types of corrosion.

The lifetime of the PPE lubricant on the connector pins in a cell phone, automobile, or computer system is likely to be far greater than the lifetime of the appliance itself. PPEs have an extremely low vapor pressure, meaning that it takes the PPE roughly 40 to 50 years to evaporate. Its longevity is just as good in the vacuum of space, and PPEs are widely applied in earth-orbiting satellites, where they lubricate, among other things, the control elements that move solar cell panels.

For similar reasons, PPE is the preferred lubricant in high-vacuum diffusion pumps.

Composition of PPE

In its pure form, a PPE is a very viscous liquid. During application, it is often diluted in a solvent. Connector pins are often dipped in a PPE that has been greatly diluted, and evaporation of the solvent leaves a thin deposit of PPE on the pin’s surface. By controlling the percentage of PPE in the solvent, the thickness of the PPE can be controlled rather precisely.

PPEs are also suitable for disk drives, because the microscopic droplets do not interfere with electrical conduction. In disk drives, the PPEs have little to do with preventing corrosion. Instead, the lubricant first developed for a spy plane permits the drive read/write head to do exactly what it is supposed to do — make a soft near-landing on the disk drive without quite touching it.

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Very useful, Circle 161
Of general interest, Circle 162
Not useful, Circle 163