EHLs: The Secret Behind CVTs

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Over the next several years continuously variable transmissions (CVTs) will become a common item in passenger cars, in light trucks, and even in heavy trucks. The concept of the CVT has been around for nearly a century, since it was realized early in automotive development that stepping through a series of gears is less efficient than a continuous changing of the power ratio. Until recently, though, there wasn't enough incentive to manufacture CVTs for automobiles. Transmission efficiency and quality, improved gas mileage, weight reduction and driving smoothness (at least within the drivetrain) were not high priorities of the driving public or the automotive industry.

CVTs in one form or another have been used in machine tools and other applications for 75 years or more. Late in the 1930s, General Motors obtained a patent on an automated ratio-controlled system for a toroidal traction drive, the first of a series of traction drive patents by GM research. Extensive road tests by GM research led to a proposal by Buick to adopt the dual toric automatic transmission in 1937, but it lost out to the hydromechanical three-speed transmission.

An American inventor, Charles Kraus, built and tested several types of traction drives in the early 1950s primarily for automobiles. The technology and prototypes he developed have been licensed to a number of companies around the world. Transmission Technologies Corporation (TTC) in Toledo, Ohio, is one of these companies and is on the verge of commercializing a modified Kraus traction transmission.

Meanwhile, inventors in Europe and Japan were developing and perfecting a wide variety of metal-to-metal lubricated traction drives, or CVTs, for adjustable-speed industrial, automotive, and aerospace applications. In the 1970s, one automated knitting machine used a CVT. The transmission that provides all of the electrical power for the Harrier jet is a CVT roughly the size of a cantaloupe.

The basic principle of a CVT is that power is transferred by friction contact between two essentially smooth surfaces, rather than by toothed gears. Some light-weight automobiles are already using CVTs of a type in which power is transferred by a belt in contact with one or more pulleys. But CVTs that use belts (or sometimes chains) are limited to fairly light vehicles, usually those weighing under 2,000 pounds. The Ford Festiva uses a CVT, as does the Subaru Justy. In the light passenger vehicles they are now being used in, CVTs provide high efficiency and thus boost fuel mileage while reducing emissions.

More robust CVTs suitable for heavier autos and for trucks use balls, cones, or toroidal (doughnut-shaped) elements rather than belts or chains. Both types of CVTs are also used in snowmobiles, go-carts and ATVs.

In one of the many varieties of CVTs rollers meet the input shaft at an angle. When the rollers are tilted more toward the input shaft, the speed decreases;

when they are tilted away from the input shaft, speed increases. Traction occurs at the contact between the roller and the shaft. In other CVT designs, the traction occurs between a cone and a ring, or between a ball and a disk, or between a toroidal element and a roller. Nearly all CVTs are also classified as traction drives (think of traction as “useful friction”) because they transfer power by smooth-surface contact rather than by gears, chains, belts, or pulleys.

In all of these designs, there are two forces at work. One is a normal force in which one element (such as a roller) is pushing down onto a second element (such as a toroidal element). The second is the tangential force, the lateral motion by which one element transfers power to the second element. The tangential force divided by the normal force gives the traction coefficient of a given design. The traction coefficient measures the efficiency of power transfer between the two elements.

There must obviously be some lubricant between the two elements, which would otherwise burn out and fail rather quickly. But the lubricant must not only lubricate, it must also serve as a medium for transferring power, since the two metal elements are not in intimate contact. Three classes of lubricants are available for use in CVTs: boundary lubricants, hydrodynamic lubricants and elastohydrodynamic lubricants/fluids, or EHLs.

In boundary lubricants, the lubricating film is sheared or ruptured under high pressure. Hydrodynamic fluids (ordinary transmission fluid is a mixture of both hydrodynamic and boundary lubricants) tend to maintain a film of oil on the surfaces of the two metal elements. Under low forces, this film remains in place. When the forces become too great, hydrodynamic fluids tend to shear. The opposing elements undergo gross slippage, and surface damage to the metal elements is likely to occur.

Since the two metal elements in CVTs are curved rather than flat, the area of contact between the two elements is very small, so the ability of the lubricant to transfer power is important. Unfortunately, hydrodynamic fluids have a relatively low traction coefficient. They are used in the CVT in the Subaru Justy, but because of force limitations are unsuitable for more robust CVTs. In theory, a CVT using a hydrodynamic fluid as a lubricant could be built, but in order to limit force per unit area the transmission would become so large that it would be uneconomical to manufacture and too large to install in a vehicle.

EHLs have higher traction coefficients and behave very differently. Under the high normal and tangential forces needed for transmissions in heavier vehicles, the film of EHL on a metal surface is actually much thinner than the film of a hydrodynamic fluid would be. But where the two metal elements are in rolling contact, the EHL briefly ceases to be a fluid and turns into a glassy solid. The thickness of the solid is minute - about 10 micro-inches - and the solid state lasts for only a few microseconds. As rotation carries the EHL out of the contact area, it immediately becomes a fluid again and regains its normal properties.

But during the brief period as a solid, the EHL actually stops being a lubricant and becomes part of the machinery. By doing so, it achieves a much higher traction coefficient than is possible for any hydrodynamic fluid.

EHLs have the highest traction coefficients of any known lubricant. In tests where both EHLs and hydrodynamic fluids are applied to the same surfaces under the same conditions, the traction coefficients of hydrodynamic fluids are usually between 0.05 and 0.06, while the traction coefficients of EHL are typically 0.1. EHLs are between 50% and 100% more efficient at transferring power than hydrodynamic fluids.

Since the reasons behind CVT development are greater fuel efficiency, improved driving comfort or feel and reduced emissions, this difference is very significant. Traction coefficient, by the way, is not the same as mechanical efficiency. In two transmissions having identical designs, the mechanical efficiency of the transmission using an EHL will be 50% to 100% greater than the mechanical efficiency of the transmission using a hydrodynamic fluid.

Both EHLs and hydrodynamic fluids can shear if the force applied is too great. What happens is that one element undergoes gross slip with respect to the other element; this condition is called boundary lubrication. Damage to the metal surfaces is likely. During shear, the molecules of the lubricant may actually be torn apart. For example, a 30-weight oil subjected to excessive shear can be degraded to a 10-weight oil because the long-chain molecules have been chopped up into shorter-chain molecules. An important characteristic of EHLs is that they can tolerate the relatively high forces present in transmissions for heavier vehicles for long periods without shearing.

EHLs differ from hydrodynamic fluids in another way as well. During rotation, the curved metal elements are slightly deformed by the forces exerted on them; this is what the “elasto-” part of the name refers to. The deformation is slight - on the order of 0.001 inch - but it has an important result: the area of contact between the two metal elements becomes significantly greater, since the two elements are very slightly flattened. Greater area in turn means that there is a significant variation the force per unit area.

The ability of EHLs to become solid under force also plays an indirect role in extending the life of the metal elements in a CVT. One of the common failure modes is the formation of minute surface cracks. A fluid lubricant very efficiently transmits both force and vibrations down into the cracks, and causes the cracks to grow. But an EHL, which becomes a solid at the moment of contact, is much less efficient at transmitting force and vibrations. Surface cracks can develop on the metal surfaces of a CVT using an EHD lubricant, but the cracks will grow far more slowly.

EHLs have one other attribute not shared with other lubricants: they run very quietly. They are so quiet that they have been used for years by the U.S. Navy to lower the sound output of underwater equipment. In crowded Japan, EHLs have become popular for use in motorcycle transmissions for the same reason: to lower the noise level.

Current applications for EHLs are spread over a number of industries and applications; consequently, they are classified as specialty lubricants and are fairly expensive. But their high traction coefficient makes them the lubricant of choice for autos and trucks using CVTs. Santotrac (www.santotrac.com), the chief supplier of EHLs, predicts that the price will fall significantly as this market grows. EHLs will also undergo some molecular tweaking and formulation modification (to improve their performance at extremely low temperatures, for example), but they will be the secret ingredient - the lubricant that turns into a solid and becomes part of the machinery - that turns the long-awaited CVT into an everyday fuel-saving convenience and a new driving smoothness.

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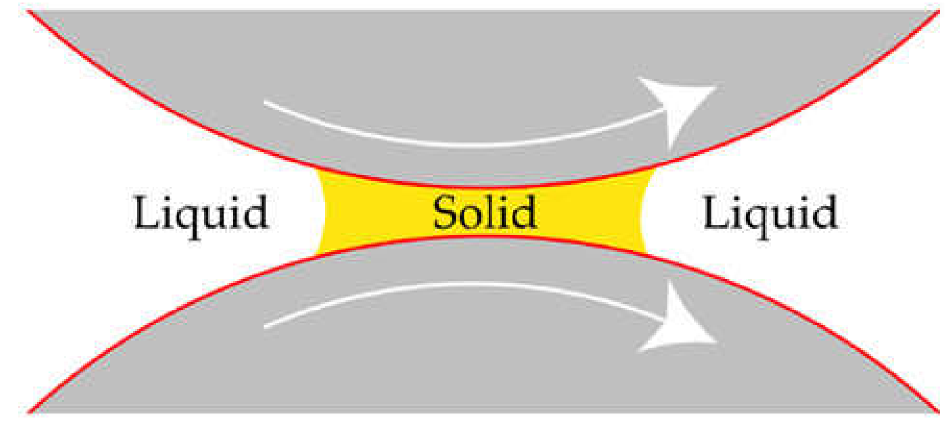

Figure 1 EHD lubricants turn into a glassy solid for a few microseconds under the high forces present in a CVT. This momentary solid state prevents metal-to-metal contact and greatly increases traction.

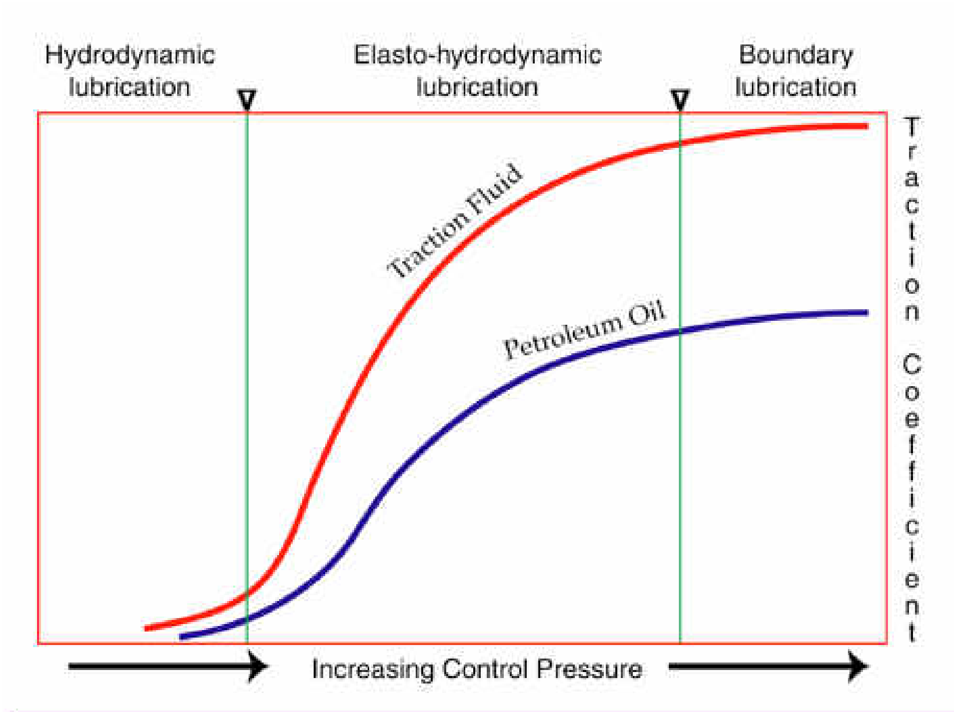

Figure 2 A comparison of behavior of petroleum-based lubricants and synthetic EHLs under increasing pressure. EHLs have a higher traction coefficient across the range of pressures.

Figure 3 Cut-away view of a continuously variable transmission (CVT) under development at Transmission Technologies Corporation.

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