Off To The Races With A Liquid-Solid CVT Transmission Fluid

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This past spring Utah State University in Logan was the host for the Mini-Baja competition, sponsored by the Society of Automotive Engineers (SAE). As its name suggests, the Mini-Baja is a relatively short but grueling race, where vehicles encounter mud, steep hills, 18-inch high logs, and similar obstacles. About 80% of the hundred or so vehicles entered don't reach the last stages of the race, but those that do, after putting their vehicles through advanced vehicular mayhem, survive only by demonstrating - in addition to superb mechanical toughness – the ability to maximize their engine power by squeezing maximum distance out of their remaining fuel.

Every vehicle in the Mini-Baja competition is powered by a 10-hp engine supplied free by Briggs & Stratton. The vehicle itself is designed and built by a team of engineering students who must also "sell" their design in a presentation made to a group of professional engineers. The race is designed to weed out the designs that have inherent flaws, however tiny, as well as those vehicles whose teams encounter plain bad luck.

One of the more interesting entries in the '02 race was the vehicle designed and built by Team #52, consisting of team leader Nathan Rose, James Midgley, Mark Hayes, Eric Aston, Brett Bell, Andrew Merryweather, Steve Snyder and Todd Saunders, all mechanical engineering students at Utah

State. Team #52 set its sights high. The modest 10-hp engine demands that the design team find ways to extract maximum performance from the engine. Performance, the members of Team #52 reasoned, depends in part on the efficiency of the transmission. Traditional toothed gear transmissions can be wonderfully efficient under specific loads, but they lose some of that efficiency when the gear ratio is changed (along with the engine's rpm) in response to varying loads. And varying loads, from an engineering perspective, are the essence of the Mini-Baja.

Better efficiency would come from some type of infinitely variable transmission (IVT) or continuously variable transmission (CVT). The terms are nearly interchangeable, and describe transmissions where energy is transferred by opposing smooth surfaces, rather than gears, and where the ratio can therefore be varied without the energy-losing steps required by manual transmissions.

The simplest form of CVT has been in commercial use on snowmobiles and ATVs for years. This design uses rubber belts and pulleys to transfer power, but suffers from some inefficiencies because the belts tend to slip when the pulleys shift ratios. Belt-and-pulley CVTs are limited to light-weight vehicles, because of the small size of the opposing surfaces and because of the limited stamina of the rubber belts. Team #52 could have selected this type of transmission (every other team entered in the race did so), but they were after something that would provide even higher efficiency for their 10-hp engine.

The more sophisticated types of CVT involve contact between two curved metal surfaces such as a roller and a cone. Moving one of the surfaces (such as the cone) changes the “gear” ratio. The pressure between the opposing surfaces is much greater than it can be in the belt-and-pulley type of CVT. And the possible gear ratios are limited only by the diameters of the elements.

The efficiency of the transmission can be further enhanced by the introduction of an elastohydrodynamic liquid/fluid (EHL, for short) to increase the traction coefficient and thereby greatly increase the power transmssion between the components. An EHL has a unique property. In all parts of the transmission except between the opposing surfaces that are transferring power, an EHL acts as a premium “slippery” lubricant. But when an EHL finds itself between the two opposing metal surfaces, the great pressures involved turn the EHL into a glassy solid for a microsecond or two. In other words, the fluid lubricant becomes a solid just at the moment when it is needed to transfer power. This odd phenomenon increases energy transfer by 50% to 100% and prevents the two metal surfaces from coming into contact with one another.

Part of this increase in efficiency is suggested by the “elasto-” portion of the fluid’s name. At the moment of contact, when pressure between the two curved metal surfaces is very high, each metal element is very slightly deformed - in other words, it becomes slightly elastic. This very slight deformation, which is on the order of 0.001 inch, increases the surface area of contact between the two surfaces, and thus increases the transfer of energy.

Team 52 elected to design their own toroidal (donut-shaped, roughly) IVT that would run with an EHL fluid. This was a daring decision: they would be the only one of some 100 teams not using an off-the-shelf belt-and-pullley CVT. Each team competing in the Mini-Baja is responsible not only for building their vehicle, but for finding the resources to build it, so Team 52 went looking for a corporate sponsor who would supply the components for the IVT. But as the rough economy of 2001 headed downhill, one of their sponsors was forced to withdraw. Time was running short, and the chances of finding another corporate sponsor to supply the transmission were remote. Team 52 members explained what happened next:

"We were left scrambling, and as a result, several members of our team enrolled in night classes at the local community college to learn CNC [computer numerically controlled] *machining. Since we don't have the funds to have our transmission built for us, we are attempting to do it ourselves. This is posing our most formidable challenge, but we are close to completion. All that remains is the machining of the case to house our transmission. . Thankfully, Findett Corporation, a company located in St. Charles, Missouri, that develops and manufactures Santotrac high performance fluids, graciously donated the essential traction fluid needed to make our transmission design a reality. That means that as soon as we can find a free CNC mill, we will have all of the components we need to begin testing."*

Santotrac traction fluids were developed jointly by the Monsanto Company and the Findett Corporation (www.findett.com) in the 1960s. The fluids were developed after evaluating thousands of synthetic chemical molecules in order to identify a base fluid structure with the highest possible coefficient of traction. Traction is "useful friction" that transmits power from one body to another in rolling motion. Over the past ten years, Findett has developed many new traction base fluids and state-of-the-art formulations to meet the requirements of today's automotive transmissions.

The transmission that Team 52 built was a full toroidal transmission whose critical elements are two cup-shaped disks having idler rollers between them. It was designed to use an EHL, and had a gear reduction ratio of 4:1. Obtaining the EHL might have been a problem, except that Santotrac Fluids (www.santotrac.com) heard of their remarkable effort to build their own IVT from scratch, and sent the team several different traction fluid formulations of the EHL. The engine would be most efficient if it could run constantly at its optimum rpm. The overall plan was to let the engine remain at a nearly constant rpm, and to vary the vehicle's speed by means of the continuously variable transmission. By keeping engine speed between 3400 and 3600 rpm, Team 52 could achieve speeds up to 35.7 mph.

The team was able to machine the parts for their IVT by borrowing machine time from local firms. Working day and night, they completed the transmission in time for the race, and had time to run multi-hour tests of the transmission traction fluid. Everything worked perfectly. In the race itself, though, bad luck struck in the form of a mechanical failure unrelated to their transmission design, and put Team 52 among the 80% of vehicles that did not complete the race.

Even after the race, Team 52 remained enthusiastic about their vehicle and its obviously superior transmission. They are in good company: there is probably not a major auto manufacturer anywhere that is not developing some type of advanced CVT or IVT, and it is clear that these transmissions will be in large-scale production within a few years. One non-U.S. manufacturer who prefers anonymity for the moment will very soon offer a half-toroidal CVT using a traction fluid as standard equipment in one of its model lines.

The driver of a vehicle having an advanced CVT or IVT will soon become accustomed to the transmission that goes from zero to top speed with none of the little thumps that traditionally accompany automatic transmissions. He will also find that the transmission runs far more quietly, and that overall vehicle noise (much of which is transmission whine) is substantially reduced. EHLs run far more quietly than other transmission fluids. In a number of countries, it has become common practice to use traction fluids in motorcycle transmissions and many industrial applications to reduce the decibel level.

Over the long run, the driver will also find that the transmission lasts much longer. The EHL transmission fluid will probably last the life of the vehicle. In fact, the traction fluid actually makes the transmission itself last longer.

Since the pressures involved are very high, the opposing metal surfaces that transfer power in the CVT are a place where microscopic cracks may eventually occur. If a purely liquid transmission fluid were used, it would be forced into these micro-cracks under high pressure, and the cracks would tend to propagate. But the EHL becomes a solid under contact. As a result, it has much less ability to accelerate the growth of micro-cracks, and the longevity of the transmission is greatly extended.

A conventional transmission fluid (technically, a hydrodynamic fluid rather than an elastohydrodynamic fluid) is limited to the smaller belt-and-pulley CVTs in part because of its behavior under stress. Between the two opposing surfaces of an advanced CVT, a conventional transmission fluid will shear - that is, the molecules of the fluid are torn apart. The same thing can happen to motor oils, where shearing can turn a long-molecule 30-weight oil into a shorter-molecule 10-weight oil. Even an EHL will shear if the forces involved are high enough, but such forces are unlikely in automotive transmissions.

Back in the 1930s, and later in the 1970s, General Motors patented a toroidal traction drive - effectively a CVT - and came close to offering a toroidal automatic transmission in the 1937 Buick and again in the 1980 Pontiac. Instead, the hydromechanical three-speed transmission was selected, and - aside from manual transmissions - has been widely used ever since. Now, though, toroidal CVTs and IVTs are being installed in production vehicles. They can even - as Team 52 has shown – be successfully designed and built on borrowed CNC mills by a group of engineering students with a tight budget and only a few weeks left until race day.

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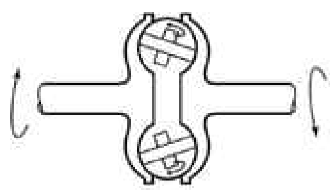

Traction Fluid Characteristics

	S-50	S-2000	S-2500	S-2500T
Kinematic Viscosity				
Centistokes:				
@ 40° C	33.6	19.1	21.2	21.3
@ 100° C	5.1	3.5	4.0	3.8
Dynamic Viscosity				
Centipoise:				
@ -30° C	39,500	12,500	10,600	31,500
@ -40° C	300,000	85,000	65,000	275,000
Shear Stability				
% Kin. Visc. Loss				
@ 100° C	17.8%	0%	0%	0%
Traction Coefficient	0.10	0.08	0.08	0.10

The design traction coefficient for most transmissions is a minimum of 0.065, based on toroidal geometry.

Figure 1 Traction Fluid Characteristics

Figure 2 Team 52's vehicle sails through the endurance portion of the Mini-Baja. For maximum efficiency, engine rpms were kept constant, while speed was varied by the IVT/CVT and its liquid/solid transmission fluid.

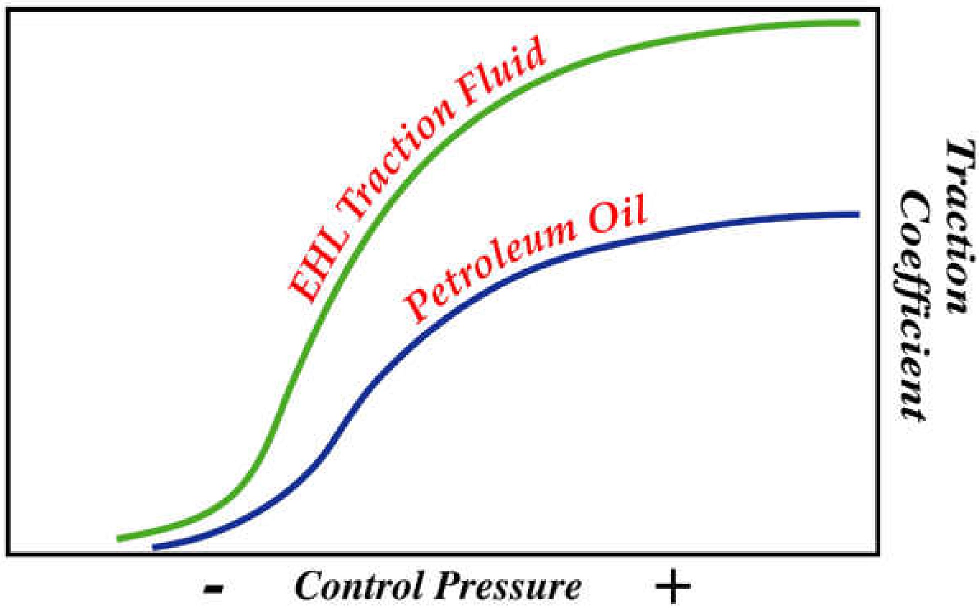

Figure 3 The traction coefficients of standard transmission fluids (bottom curve) and EHL fluids both increase with pressure. But only traction fluids – by turning from a fluid lubricant into a glassy solid at the moment of contact – can be used in the toroidal-type continuously variable transmissions that most vehicles require.

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