Traction fluids in infinitely variable transmissions

By R. David Whitby

In the search for better energy efficiency, most manufacturers of vehicle transmissions are developing either continuously variable transmissions (CVTs) or infinitely variable transmissions (IVTs). Both types require fluids with high metal-to-metal friction coefficients, which are also called traction coefficients.

U.K.-based Torotrak has developed an IVT that provides all ratios, from full reverse through zero-speed to high overdrive, without the need for a starting device such as a clutch or torque converter. The running engine is connected to the road wheels even while the vehicle is stationary. Torotrak claims the absence of a clutch or torque converter gives significant savings in cost, weight and, thus, fuel economy.

The Torotrak IVT has a variator, consisting of two outer input toroidal discs, that are engine-driven via a torsional damper and two output toroidal discs between which are six rollers. The angle at which the rollers are inclined governs the ratio between the speed of rotation of the input and output discs.

Within the geometric limits of each cavity, the rollers can have any angle of inclination, providing a continuous range of drive ratios. Forces are transmitted between the discs and rollers by the traction fluid. Transmission ratio changes are achieved, under computer control, by raising or lowering the hydraulic pressure, and this torque control distinguishes the Torotrak IVT from all conventional transmissions, including belt CVTs.

Traction fluids have historically been naphthenic oils. During the 1960s, Monsanto started research on pressure-stiffening lubricants, resulting in the development of synthetic hydrocarbons based mostly on derivatized cyclohexanes and decalins that possess relatively high coefficients of traction, C. Other companies have now developed similar synthetic cycloaliphatic hydrocarbon traction fluids.

Because of the pressures involved, traction fluids function in the elastohydrodynamic region, and it is the combination of physical and chemical properties of the lubricant in this regime that controls the performance of traction drives. Several theories attempt to explain the properties of traction fluids. The leading one suggests that under high contact stress (pressure) and high shear rates of rolling contact, the viscosity of the lubricant film in the contact area increases to a glassy solid state.

This “pad” of solid film transmits the tangential force with a shear resistance far beyond the capability of a liquid film in addition to preventing metal-to-metal contact, minimizing wear and, when compressed in surface cracks, inhibiting the propagation of fatigue cracks. The more “solid” the fluid becomes under pressure, the higher will be its C, and the more powerful it will transmit between rolling elements for a given normal contact load.

The lubricant returns to its normal liquid properties immediately after the pressure is relaxed. The output of a given traction drive design is limited primarily by the traction fluid’s C, which has been shown to be independent of viscosity, viscosity index, pressure viscosity, specific gravity or other common physical properties. Typically, variations in normal load, rolling speed and temperature all have some effect on a lubricant’s C, depending on the design of the drive and the rolling motion in the contact area.

It has been shown that molecular geometry has an important effect on the coefficient of traction. The ability of molecules to arrange themselves into an apparent glassy state under high shear increases the coefficient of traction. Commercial traction lubricants, based on cycloaliphatic hydrocarbons, have been used successfully in industrial, automotive and aircraft CVTs. At present, Shell is working closely with Torotrak on the development and application of traction fluids for the company’s IVT, although they have not disclosed the type of fluid being used in field trial units.

Although more work remains to be done to determine the operating lifetimes of IVTs and the traction fluids used in them, the future for these transmissions could be very promising. The fluids must function as good lubricants, but with exceptionally high frictional properties in the pressure contacts of the IVT.

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