Physics Lecture 13 - Lubrication Breakthrough

Summary/Conclusions

By combining a high quality graphite dry solid lubricant with a high quality liquid oil a synergistic effect has been obtained that gives a coefficient of friction for the combination that is substantially lower than the friction coefficients of either taken separately. The solid graphite is known as Super-Z graphite and the proprietary oil is called Super-Z oil. The combination, applied using standard techniques, can produce a coefficient of wheel/axle friction, μ, that is only 0.04 as measured at the wheel angular (rotational) velocity of a fast car on the horizontal run.

Experimental Method.

Figure 1 shows a 2.00" diameter cylinder(called fitting FDS) into which a standard BSA wheel may be inserted. The wheel bore and axle are first lubricated and then the axle end is held in a swivel-head pin vise. A 4.00" diameter chuck on a lathe with a wide rubber band encircling the chuck is used as a driver to spin the FDS/wheel assembly on the axle initially at rate of 50 rps or 3,000 rpm. The rate at which friction causes the spin to slow is determined by using a stop watch to time the appearance of resonances between 60 cycle flourescent lighting and the 4 bands on FDS.

Figure 1 - *Aluminum fitting FDS used to determine friction coefficients at different rotational velocities.*

The main difficulty with this approach is that at a high rpm of 50 rps the drag from air friction is 5 or 6 times more than drag from a well lubricated wheel/axle. Nevertheless, it is possible to correct for this air drag and obtain the coefficient of friction at the wheel bore/axle surfaces. At low rpm's, μ can be obtained by measuring the total time it takes for the FDS/wheel assembly to go from a fixed medium or low initial spin to a complete rest. The weight of fitting FDS is 53 g to simulate a net car rear-end weight of 106 g which is a good average rear end weight for most cars. And, of course, μ is largely independent of contact area or applied weight. The advantage of this spin method is that lubricant effectiveness can be evaluated at different car velocities.

The wheel bore is a low taper 0.0989"/0.0982" (See Lecture 12) running on a Hodges nickel-plated axle of 0.0860" ± 0.0002" diameter.

Table 1 - *Oil properties* at 25.2° C.

OIL	DENSITY	VISCOSITY
	(g/cc)	Centipoise -cP
NYE	0.792	23.3
MINERAL-USP	0.797	28.1
KRYTOX	1.86	24.2
SUPER-Z	0.844	16.8

Experimental Results

There are 8 lubricants to be evaluated—4 oils and 4 graphites alone and in combination with molybdenum disulfide (MoS_2) or with an oil. **Table 1** shows the oils used. The density of all the oils except Krytox was measured by simply weighing 10 cc of the liquid. For example, 10 cc of Mineral Oil weighed 7.97 grams. The viscosity was measured by measuring the amount of liquid that can flow through a known capillary tubing size in a certain time under the force of gravity. The viscosity in centistokes can be obtained if needed by multiplying the centipoise value by the density.

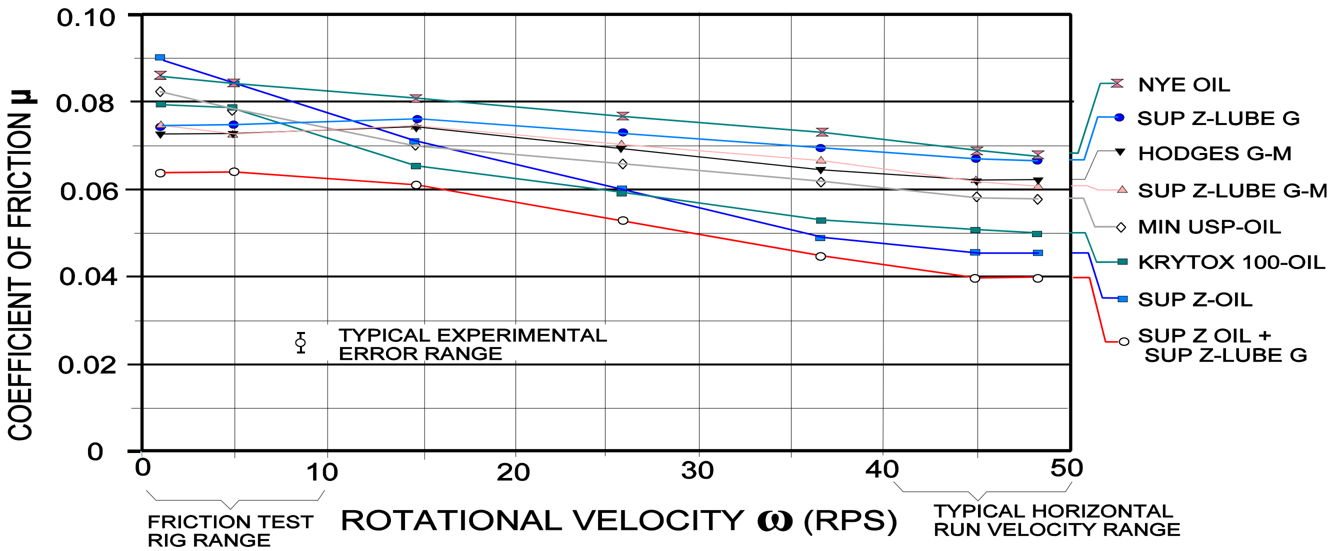

Figure 2 - *Friction coefficients for 8 graphites, oils, and combinations*

Figure 2 shows the results. The following points are noteworthy.

Graphites - Consider the graphites, Super Z-Lube G (a 99.9% pure virgin graphite), Hodges G-M lube (a mixture of Graphite & MoS_2), and a similar mixture based on Super Z-Lube graphite called Super Z-Lube G-M. These start out at a μ of about 0.07+ at low rps (revolutions per second) and end up at 0.06+ at high rps. Notice the beneficial effect of adding MoS_2 to Super Z-Lube making it about the same as Hodges G-M to within experimental error. The Hodges G-M lube has been a favorite lubricant for many years. One thing that has been noticed over the years is that the MoS_2 in some cases can cause hard lumps on the bore hole surface that are difficult to remove. This usually occurs if the wheel bore is repeatably coated with the G-M mixture between lube jobs. If the bore is polished before lubing, the lumps do not form and the lube performs well. Also, moisture from humidity or handling reacts with MoS_2 to cause corrosion on non or thinly plated axles.

Oils - Consider the oils. The lubrication mechanism is different from that of the graphites. Details of the theory of lubrication and the experiments described here can be found in Chapter 9 of the book *Physics of the Pinewood Derby*. These oils start out at a μ of 0.08+ at low rps and end up at 0.046 to 0.058 at high rps. Nye oil goes from 0.086 to 0.068, USP Mineral oil goes from 0.082 to 0.058, and Krytox goes from 0.079 to 0.050, about twice the low to high rps drop in μ with oils compared to graphites. A new oil blend that outperforms even Krytox has been named Super Z-Oil and as **Figure 2** shows goes from 0.09 to 0.046. This oil has a substantially lower viscosity than Nye, USP Mineral, and Krytox which helps high rps performance. Also, certain lithium additives help the boundary lubrication at high rps. Note that Krytox, a very expensive oil, is almost 2 ½ times more dense than normal oils. It is sort of the tungsten of oils. This high density is due to the heavy fluorine atoms in its formulation. Its intended applications are for extreme conditions such as very high temperatures or in low pressure space applications such as lubricants for the Mars rovers. Ordinary oils can boil in these extreme conditions. Notice that the μ at high rps is at least 3 times more important in affecting the final car time compared to its initial values on the ramp, especially if the track has a long horizontal run. Also, the end of ramp to finish line linear velocities on most tracks give a wheel rps of 40 to 50 on the horizontal run as noted in **Figure 2**.

The Breakthrough - The Super Z-Oil discovery was important enough, but the results when Super Z-Lube graphite is used as a preliminary treatment before applying the oil must be considered as a very fortuitous and synergistic finding. It was apparent that the oils had a higher μ at low ω (rps) and a lower μ at high ω. And the graphites had a lower μ at low ω. So the thought occurred that perhaps a graphite/oil mixture would lower μ at low ω but retain the oil-like lower μ at high ω. Normally, because graphite and oils have different mechanisms of friction reduction, it was not expected that their combination would have an effect other than perhaps an average behavior. But the results were almost unbelievable. A low ω value of μ = 0.053 and a high ω value of μ = 0.040. In the application, the Super Z-Lube graphite is applied to a polished axle and a polished bore as stated in the Speed Package instructions. But just before spinning the graphited wheels, a very tiny drop of Super Z-Oil is put on the axle using a blunt ended No. 22 hypodermic needle. The oil cannot be seen after it spreads. The wheel will then spin with ultra low friction as seen in **Figure 2.**

The Super Z-Oil/Graphite combination gave a total spin time from ω = 50 rps to ω = 0 of 2 minutes 7 seconds or 127 seconds. Only one other time has this been observed, and that was 12 years ago in an experiment with a powdered Teflon silicone oil lube mixture. In that case, the low friction of 0.047 was observed at low ω but was larger at 0.069 at high ω. As discussed earlier, for faster finishing times, the lowest μ should be in the ω = 40 to 50 rps range.

Lubricant Lifetime

One of the key measurements to determine μ at high ω is the time from spin start to first FDS resonance with 60 cycle fluorescent lights. **Figure 3** below shows 5 repeated spins for 5 different lubes also shown in **Figure 2**. As can be seen from the figure, the graphites and the Super Z-Oil+Graphite show a very slight increase in friction from run 1 through run 5 because the first resonance time decreases. The pure oils show little or no loss of lubrication with repeated runs. The loss of lubrication in a real race, which lasts only 3 to 4 seconds at most, should be much less than that shown in the figure, where total spin times each are about 100 seconds on the average.

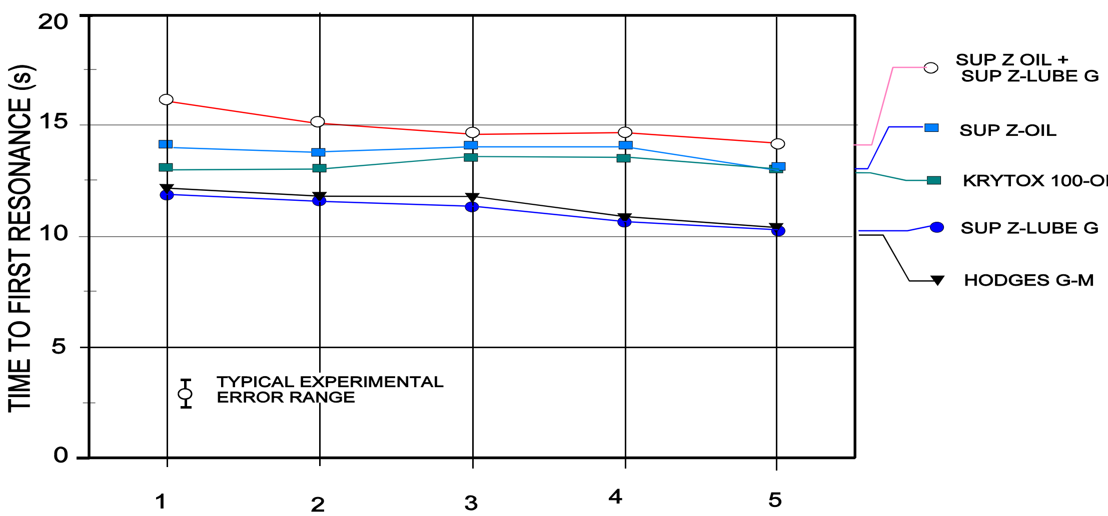

Figure 3 - *Showing time to first resonance for 5 repeated spins of key lubricants*

Future Work

It is planned to use the Virtual Race program to predict more quantitatively the actual finish time benefits of the different lubricants reported above. And recall another myth from the earlier days of PWD racing, namely, that oils can damage the polystyrene wheels. Actually, only aromatic liquid compounds (containing "ene" in the name) like benzene, toluene, xylene, napthalene, etc. show damage to polystyrene. But nevertheless, the oil stigma persists, causing some local race officials to outlaw oils. Actually, non-aromatic oils are much easier to use and less messy than graphites and molybdenum dry lubricants. Plus there is no way a thin film of oil can be seen on inspection. So if a car enhancement can't be inspected, there is no sense having a rule prohibiting it.

The friction test rig (FTR) experiments reported in earlier lectures kept the linear velocity at about 18% of the end-of-ramp and horizontal run velocities (ω = 0 to ω = 10 in **Fig. 2**). This was done to keep air drag, which is negligible at low velocities, from adding to and complicating the time changes caused by wheel/axle friction. And, because solid graphite type lubes high speed performance is not that much different from their low speed performance, the FTR data could be used to predict the solid lube performance at high ω. But with the oils, their high ω coefficient of friction is not so predictable from low ω . So more oil research will be done on a full scale track with an airfoil car to reduce the air drag effects. Of course, low moment of inertia wheels (such as RS wheels) should be used to reduce the wheel inertia effects on race times. And, if wheel/axle friction reduction testing is the objective, the bore and axle diameters should be at least as large as standard (about 0.088 to 0.098") so the lube effectiveness shows up well. The Super Z-Oil will be available in the Online store by October 1, 2006.