Triboelectrification Observed in the Spiral Orbit Tribometer

Introduction. Triboelectrification is the term given to the static charging of electrically nonconductive or insulating materials by rolling or sliding or rubbing against another material (counterface) which itself may be either electrically insulating or conducting. If this counterface is isolated from ground, it may also acquire a charge. In this note the ability of the Spiral Orbit Tribometer (SOT) to observe such charging or triboelectrification is demonstrated by running a silicon nitride or Si_3N_4 ball against steel plates. Both the charging of the ball and that of the electrically isolated plate that constitutes one of the SOT's steel "races" is observed.

Instrumentation. SOT III at NASA-GRC is used in its usual configuration in that the fixed upper plate is electrically isolated from ground and is electrically connected to a vacuum BNC electrical feedthrough. The only addition is the insertion of a .06" diameter copper wire to the vicinity of the silicon nitride ball. The wire is suspended from a vacuum BNC electrical feedthrough on the top 8" conflate flange and ends about the center of the lower rotating plate. The wire is about 1 cm from the ball at the ball's closest approach. This wire will be termed the "probe" and is illustrated in Fig. 1 where it should be understood that the wire is actually behind the guide plate and force transducer and not in front.

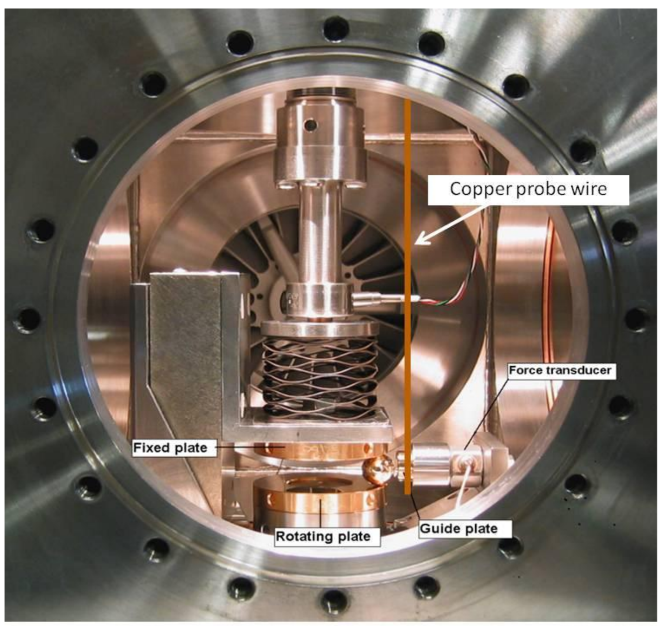

Fig.1. SOT III chamber with the probe wire, which is actually behind the guide plate.

The probe's BNC goes to a Kistler Model 504 charge amplifier whose analog output goes to a Tektronix Model 3014B oscilloscope with a floppy drive to save a trace. The charge amplifier gives a positive voltage output for a negative charge input. This is consistent with the use of the Kistler piezoelectric force transducer which gives a negative charge output upon compression, such as with the guide plate's force transducer. In the case of the probe, the electric field from a negatively charged ball will repel electrons and induce a negative charge injection into the charge amplifier, resulting in a positive voltage out. The charge amplifier was calibrated and used so that 5000 pC input gave a 10 V output, for 500 pC/volt. The probe's analog output was then expressed in pC .

The potential developed on the electrically isolated fixed plate was sensed by a Trek Model 347 Electrostatic Voltmeter. The fixed plate was connected to a 4" brass plate faced by the Trek's probe as shown in Fig. 2. More information on measuring electrostatic charging potential can be found on the Trek's website www.tekinc.com, especially the 347Sales.pdf and 3001_Vibrating_ Probe.pdf downloads. Boris Vayner assisted with this measurement.

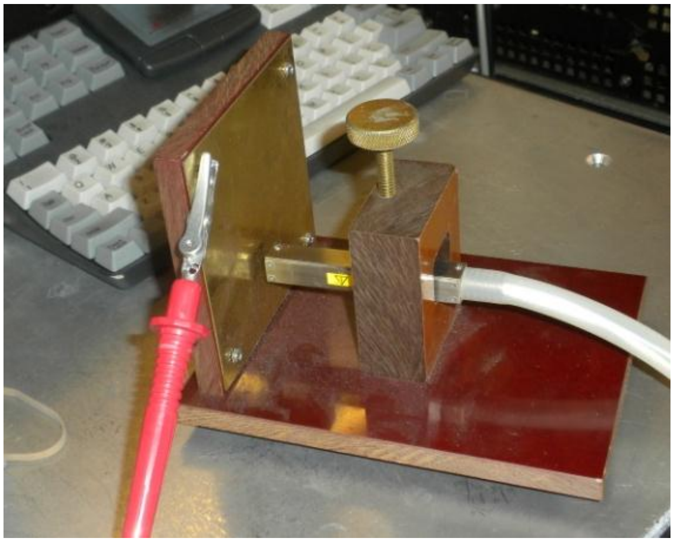

Fig. 2. The Trek probe arrangement

Materials. The ball was Cerobear .5" diameter silicon nitride, S/N VKU00000002, Cerbec 101C material. The plates and guide plate were 440C steel. The ball was lubricated with 34 μg of Castrol 815Z.

Procedure. The test was run in vacuum**.** The load on the ball was 30 lb., giving a Hertz pressure of 1.5 GPa. The plate rotational rate was 60 rpm, giving a ball rotational rate of an orbit/2 sec. The coefficient of friction and fixed plate potential were recorded once an orbit. The probe response could not be recorded so often because it was limited by the oscilloscope's floppy drive's lengthy time (about 80 sec.) to transfer and record data for one trace.

Results. Fig. 3 shows the probe response for orbit No. 450, plotted over the time to complete one orbit. There is a response as the ball passes near the probe. The response is a positive voltage (it was always positive in these tests), indicating that the ball has picked up a negative charge, as explained above. Stopping the ball at the distance of closest approach to the probe wire resulted in a steady value of the probe response over many seconds. In other words, the charge on the ball was not drained off, but remained constant over this time frame, even though the ball was in contact with the grounded lower plate. This was observed whether the fixed upper plate was grounded or floating. It thus appears that the charge is locally fixed – not mobile – on the dielectric ball. The charge survived an atmosphere of dry nitrogen, but was dissipated by humidity. No probe response was observed when running a metal ball.

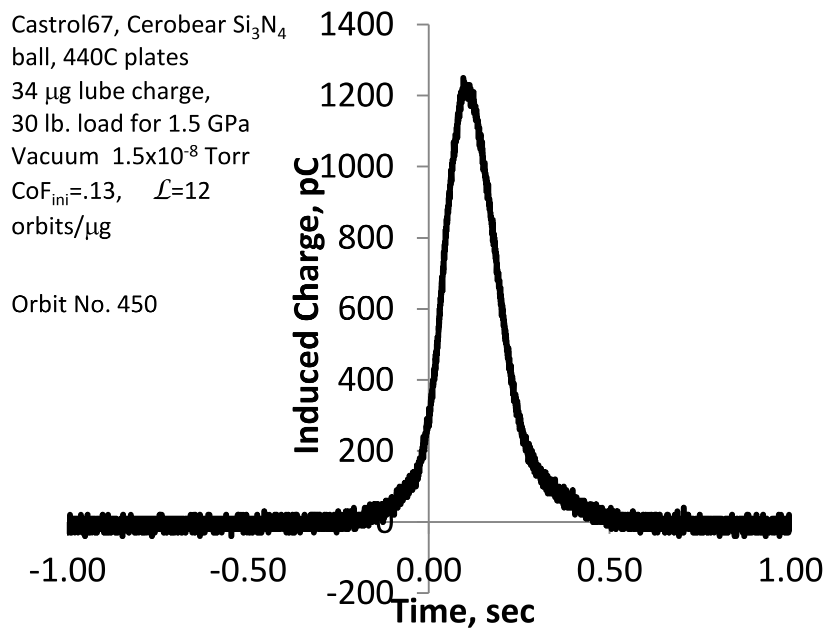

Fig. 3. Probe response during orbit 450.

The maximum value of the probe response is plotted in Fig. 4, together with the coefficient of friction. First note that the initial CoF is about .13, consistent with previous values found for this lubricant with a steel ball. The friction trace is somewhat noisier than that for previous tests with the steel ball. The normalized lifetime of 12 orbits/μg is rather less than the values found for tests with a steel ball. The earliest probe response indicated that the ball picked up charge within the first few orbits. After that, the charging exhibited no particular trend with the development into failure of the lubricant – high coefficient of friction. The charge did, however, always remain high enough to give probe responses in the near nC range. Also, the charge may not be uniformly distributed on the ball, perhaps leading to the observed scatter.

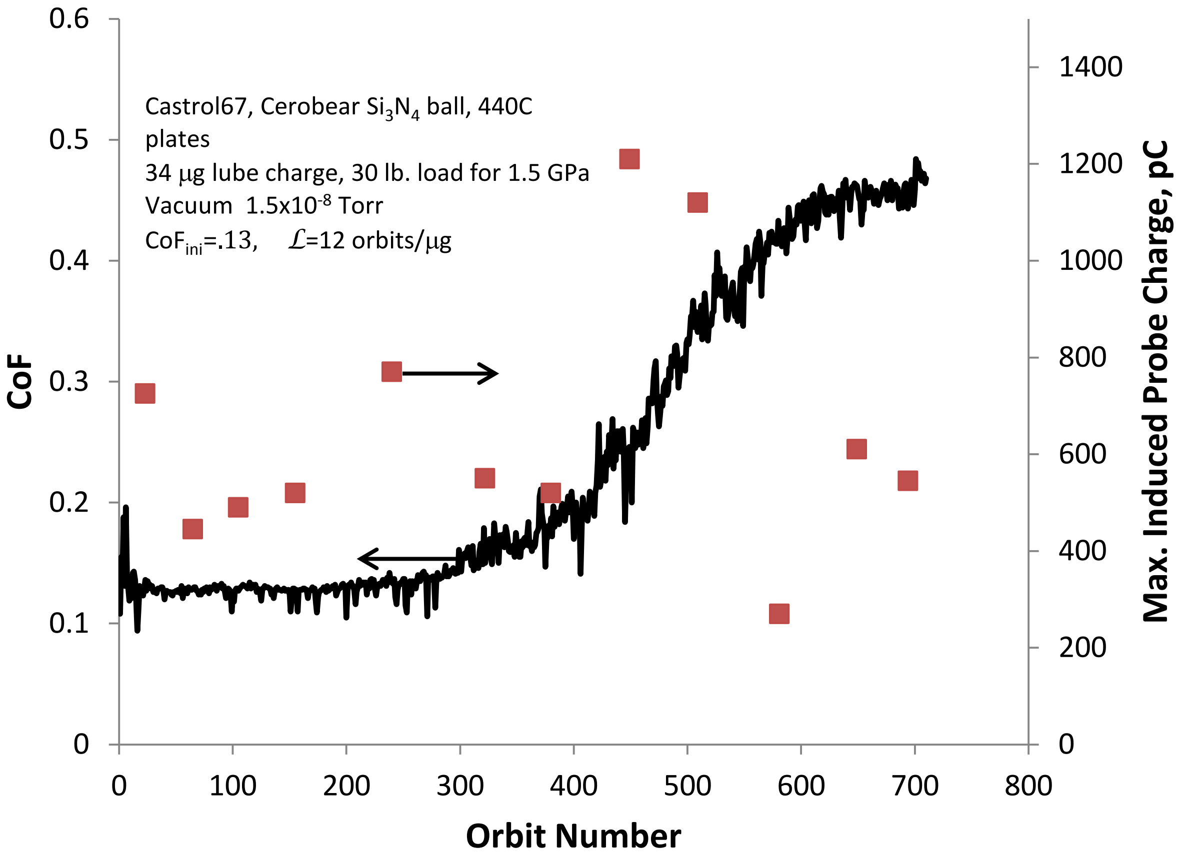

Fig. 4. Coefficient of friction (black) and maximum value of the probe response (red).

The potential of the fixed plate is shown in Fig. 5 together with the coefficient of friction. The potential dips slightly negative at the initiation of rolling, then became positive up to almost 100 V, dips again (staying positive) and then achieves a value greater than +200V before trending downward in the failure region. These positive values of potential are consistent with the observation of a negatively charged dielectric ball – electrons are transferred from the plate to the ball, leaving the electrically isolated plate positively charged. Of course, electrons can also be transferred to the ball from the grounded rotating bottom plate.

There is a limit to the potential that can be achieved by the isolated fixed plate and a limit to the charge acquired by the ball. This is because electrons can be attracted back to the positively charged plate from the negatively charged ball. Thus, assuming that material, environmental or loading conditions do not change, the potential and charging should eventually reach an equilibrium or steady state. Such an equilibrium has not been reached in the tests done to date.

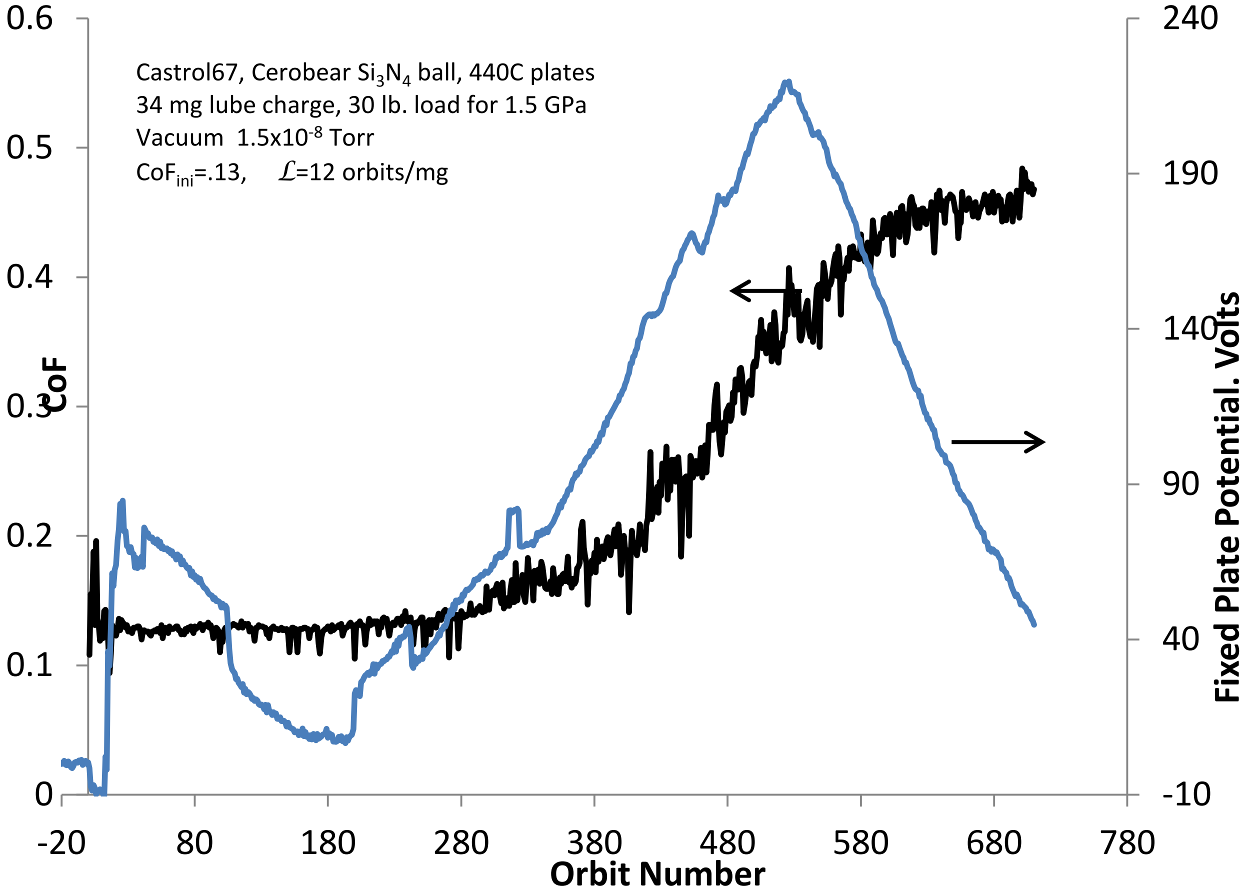

Fig. 5. Coefficient of friction (black) and fixed plate potential (blue).

Conclusion. Evidence has been presented here for the ability of the SOT to observe triboelectrification or frictional charging when running a silicon nitride dielectric ball against steel plates. There are many avenues of research that can be pursued-

- Quantification of the charge on the ball
- Fine grained time dependence of charging and discharging
- Dependence of the charge on the load, ball diameter, rotation rate, …
- Dependence of charging on the particular dielectric such as chemistry(e.g. Al2O3, PTFE,…), sintering aid, and metal such as 440C or other steels
- Dependence on environment
- Application to hybrid bearings