Case Study - Characterising the Effect of Applied Voltage on Component Wear

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We are keen to hear your thought questions and comments, please send to Eleanor.Barrett@pcs-instruments.com.

1.0 Introduction

The ever-increasing dependence on electric vehicles and electric driven systems has brought to the forefront a host of new tribological challenges. It is well known that using high powered electric motors to drive systems such as a gearbox in an EV can lead to stray / parasitic potentials across tribological contacts of the machine elements which has been shown to lead to premature failure. Currently, the influence of these applied electric potentials on lubricated contacts is poorly understood and there is no accepted test method or design criteria to negate their risks. This study aims to introduce the effects of applied voltages on steel components, with a particular focus on **friction**, **tribofilm formation** and **wear** and aid in the creation of lubricant test method guidelines for electrified systems.

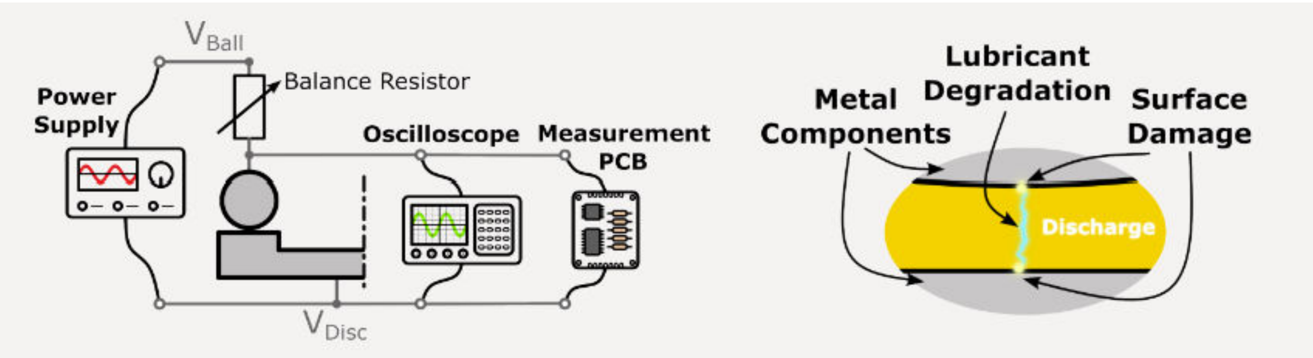


Figure 1 - schematic of the MTM-EC conditions across the ball and disc contact

2.0 Background

In PCS' development of the MTM-EC, large scale validation testing was completed. Interesting trends quickly emerged. When testing a fully formulated motorcycle gear box lubricant (containing ZDDP) and applying 5V, tribofilm thickness differed by 50% when comparing electrified to non-electrified conditions, see figure 2 and 3. Deciding it most prudent, the next investigation studied an E-transmission fluids at mixed regimes to most replicate gear/transmission component conditions.

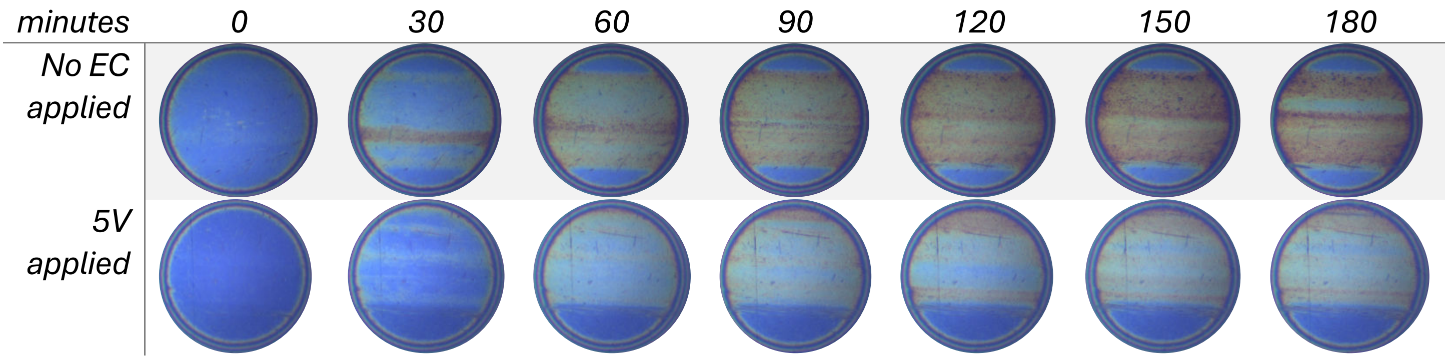


Figure 2 - tribofilm growth of fully formulated gearbox oil with 0V and 5V applied

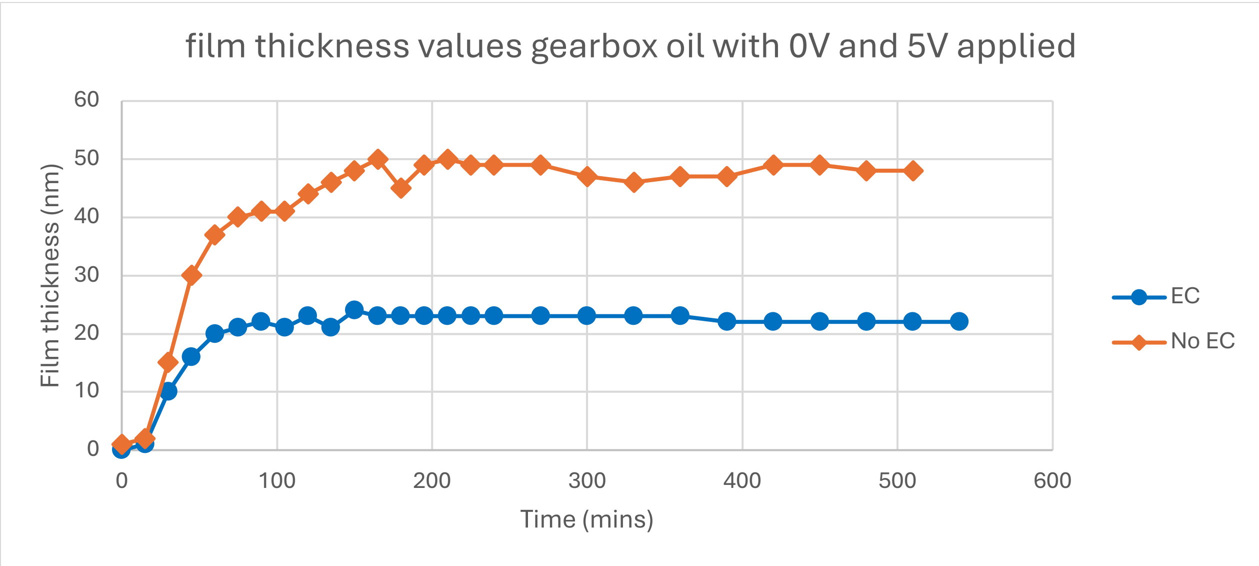


Figure 3 - calculated film thickness of tribofilm in figure 1

3.0 Materials and Methods

Lubricant – Vaico V60-0278 E-TF

Specimens: Polished AISI 52100 steel ball and disc

Lubrication Regime: Mixed

Temperature: 100°C

Speed: 250 mm/s

Load: 50 N

SRR: 50%

PSU set Voltage: 1 V

Balance Resistor: 1 kΩ (fixed)

Current Type: DC (1mA Theoretical limit)

Polarity: Disc and ball live

Stribeck and traction sweeps were conducted on the test lubricant to determine ideal speeds and SRR conditions, see figure 4&5. The mixed regime, roughly highlighted in figure 4, was chosen as it is a realistic regime for gear-like components and was likely to produce interesting electrically influenced results due to lack of an insulating EHL film and occurrence of metal on metal contacts which could results in more extreme wear phenomena. 50% SRR was chosen to match the mixed Stribeck coefficient of traction and be a realistic value of sliding.

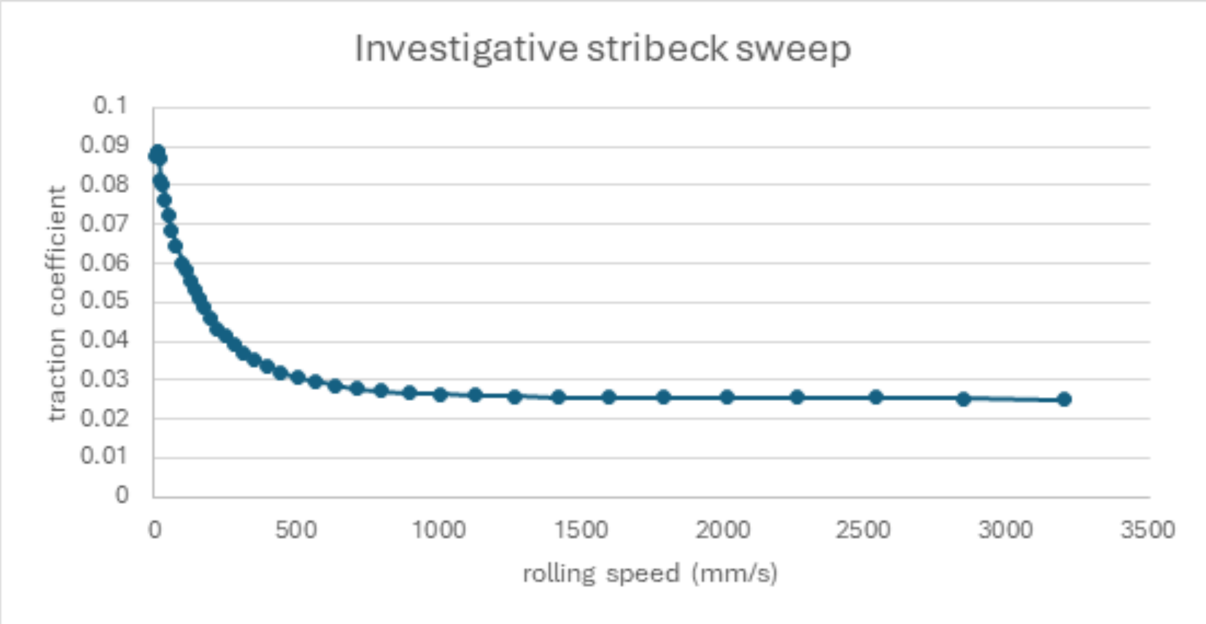


Figure 4 - Stribeck sweep with mixed regime highlight

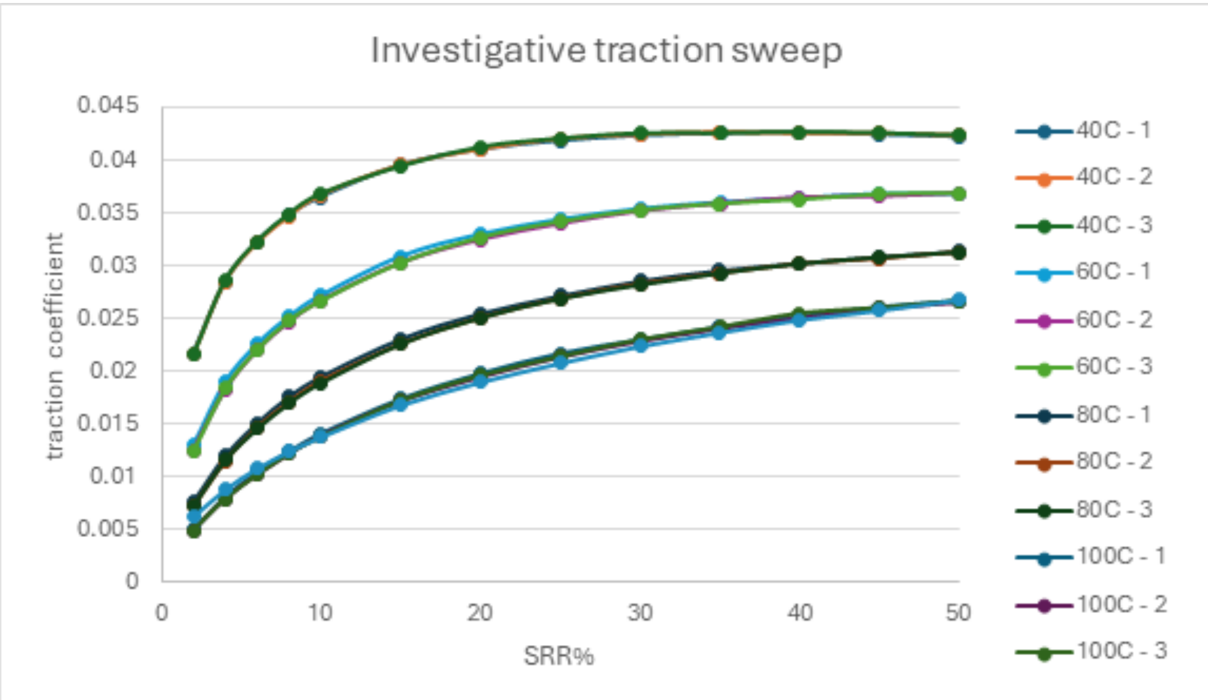


Figure 5 - traction curves used to determine mixed regime SRR

When considering electrical conditions a voltage ramp from 0V to 25V gave the following results (figure 6). The greatest change in measured outputted voltage happened between 0-1V for the specified lubricant hence 1V been used as the test parameter. After 300 (2.5V) seconds of the voltage ramping, the outputted voltage of the lubricant stabilised.

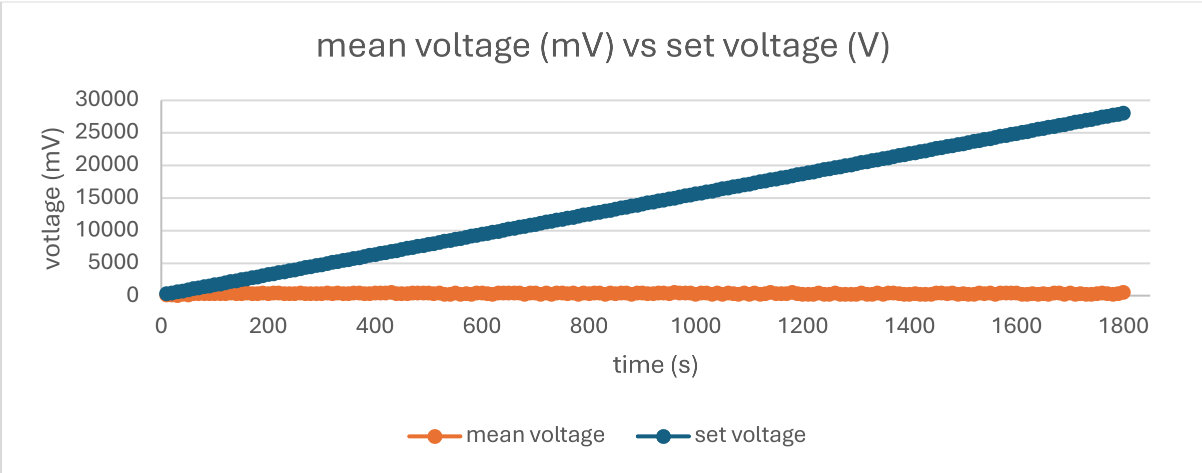


Figure 6 - 25V voltage ramp

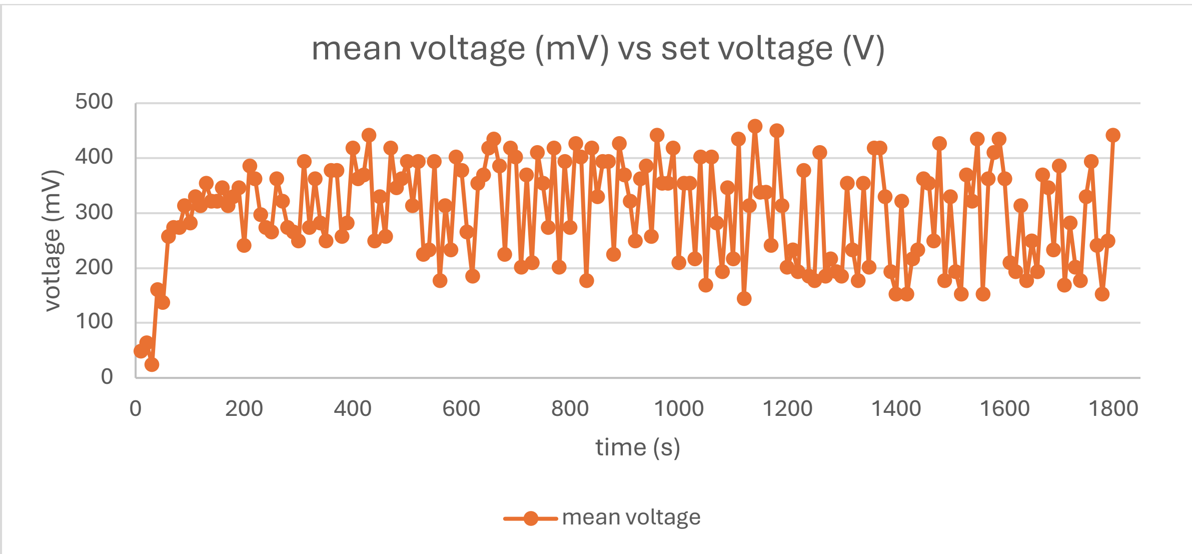
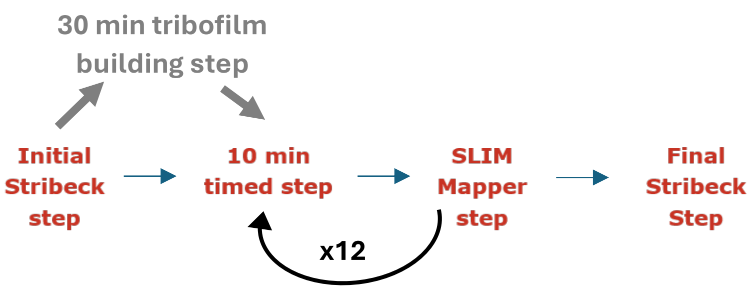


Figure 7 - mean voltage outputted on 30 min scale

Test Method - The profile was built with the following procedure and variables, 3 repeats were completed

Test Procedure



Test Variables

1. No EC
2. 1V Disc live
3. 1V Ball live
4. 1V Disc Live 30 min tribofilm build step
5. 1V Ball Live 30 min tribofilm build step

4.0 – Discussion of Results

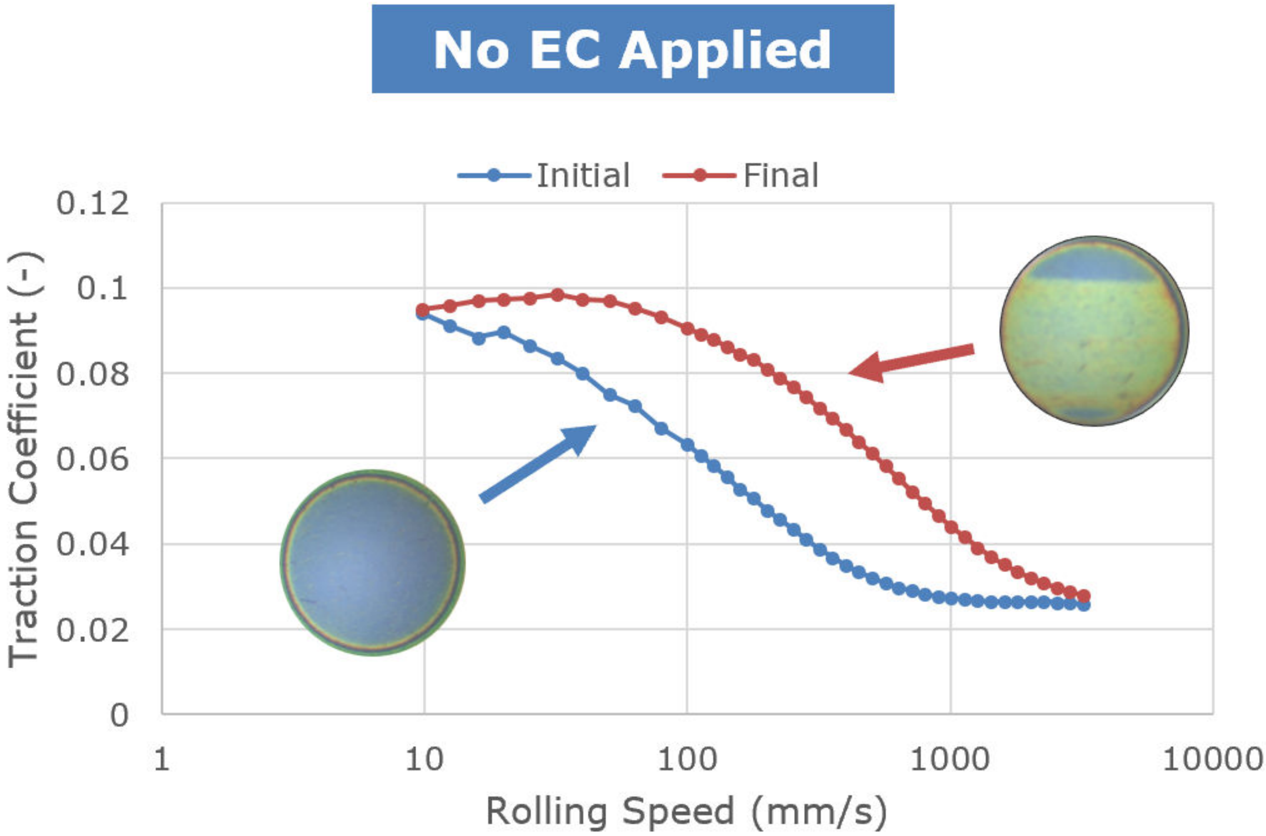


Figure 8 – initial and final Stribeck comparison when no electrical conditions were applied

4.1 Stribeck curves

Stribeck curves are taken before and after any electrical conditions were applied. As expected the traction coefficient increased in the final Stribeck due to wear on the disc and ball generated by the test.

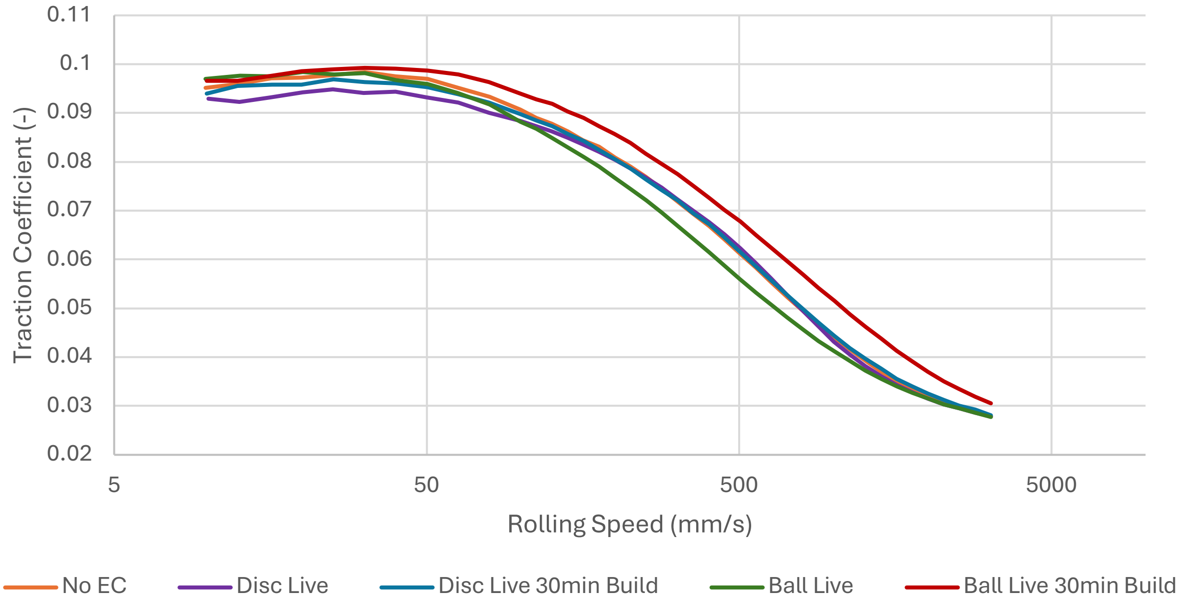


Figure 9 – Comparison of all final Stribeck

What was of interest was if the electrical conditions had a large effect on the surface wear and consequently the final Stribeck but there were no substantial effects, as seen in figure 9 the largest difference is between the 'ball live' and 'ball live 30 min build' rather than when no electrical conditions.

4.2 Electrical data

The MTM-EC can collect huge amounts of electrical data, in this section we look through trends on multiple time scales.

The data below (figure 10) shows the outputted voltage and current data across the entirety of the test (~2hrs). For reference 1V (1000mV) was imputed.

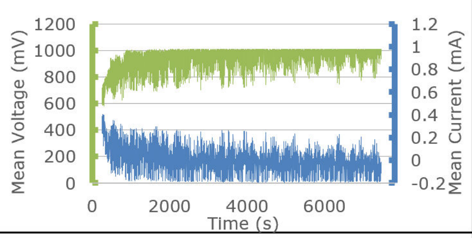
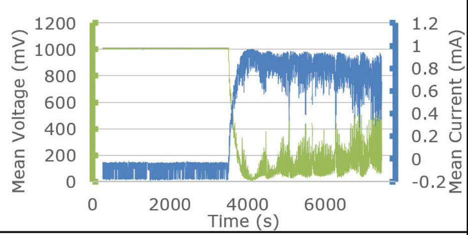
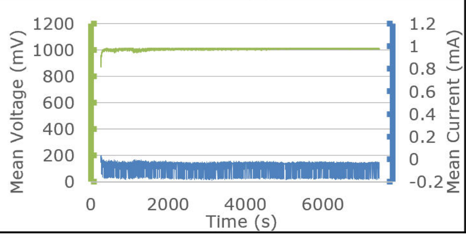
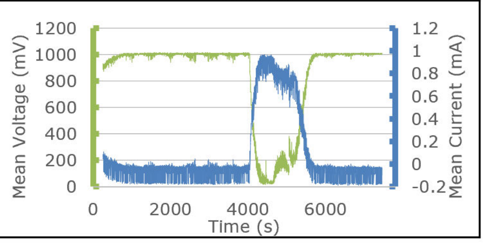
	Mean Voltage and Current vs Time		
1V Disc Live		1V Disc Live 30 min Tribofilm Build	
1V Ball Live		1V Ball Live 30 min Tribofilm Build	

Figure 10 – Measures outputted voltages from energy of test

Looking at tests '1V Disc live' and '1V Ball live' the trend is consistent but the directionality of the voltage has an effect on the magnitude and frequency of the voltage discharges. This may be explained through the difference in contact geometry, when the disc is live the voltage travels from a large flat disc to a smaller spherical contact point, this loss of accuracy going from a wide area to a narrow area may be the reason for a faster charge build up and how quickly the film can reach its most 'conductor-like' state.

Consistently to the previous trend, the 1V Ball live 30 min tribofilm build' system shows less frequent and smaller magnitude discharges throughout the test when compared to the same disc live test. At the 4000s time stamp the EC conditions are activated, the previous 30 minutes has no electrical inputs applied, at this point we see an interesting trend, the '1V ball live 30 min tribofilm build' test initially becomes fully insulating and then swaps back to conductive, whilst '1V disc live 30 min tribofilm build' test becomes insulating and stays that way. Both films seem to generate at a similar rate.

The overarching take away is that the presence of an established tribofilm has some effect on lubricant films ability to hold charge and that the polarity of the voltage has an affect of the films ability to stay conductive. From these initial results it is not possible to understand how the chemistry of a transmission fluid is affect by voltage but one possible theory, from literature, is that the orientation of the polymer chains which have a polar group at one end changes when a voltage is applied to the lubricant. This dipole moment aligns the polymers into ordered rows so that charge can flow through a more direct pathway and hence the lubricant acts as a conductor. These points where the lubricant film swaps between being insulting and conducting suggest some disordering and re-organisation of chains throughout the test.

See paper for further reading:

LaFreniere JMJ, Roberge EJ, Halpern JM. Reorientation of Polymers in an Applied Electric Field for Electrochemical Sensors. J Electrochem Soc. 2020;167(3):037556. DOI: 10.1149/1945-7111/ab6cfe. Epub 2020 Jan 31. PMID: 32265575; PMCID: PMC7138228.

On a millisecond scale we also see voltage discharges, some instantaneous and others lasting up to 1.5 ms, understanding the electrochemistry across these scales will be an interesting area of research

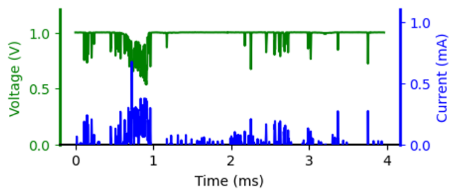
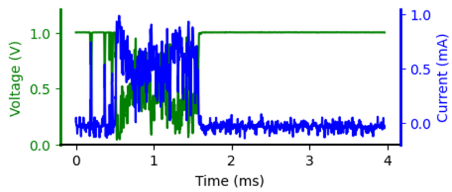
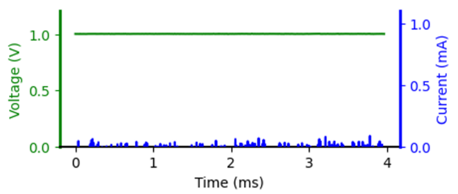
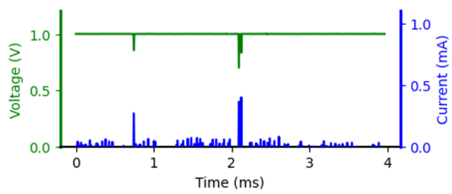
	Discharge Voltage and Current vs Time		
1V Disc Live		1V Disc Live 30 min Tribofilm Build	
1V Ball Live		1V Ball Live 30 min Tribofilm Build	

Figure 11 - Millisecond scale voltage discharges

4.3 Tribofilm Data

Overall there are not huge differences in the tribolfilm thicknesses across the tests, all films were very small and the maximum variance at one point was only 20um, not large enough differences to draw conclusions from. The most interesting results are from the '1V ball live 30 min' tribofilm buliding sequence; once voltage is applied we see the tribofilm thickness decrease. This matches the cumulative outputted electrical data we collected.

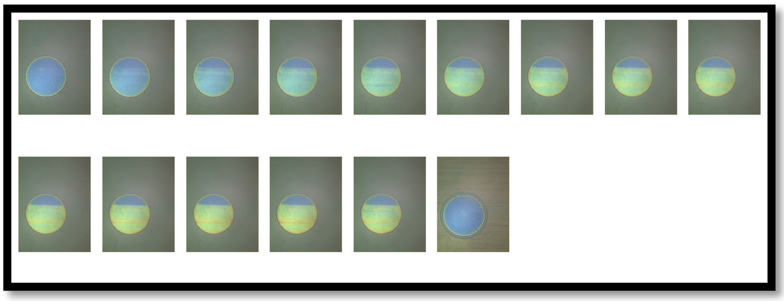


Figure 12 - No EC tribofilm growth progression – maximum thickness 14um

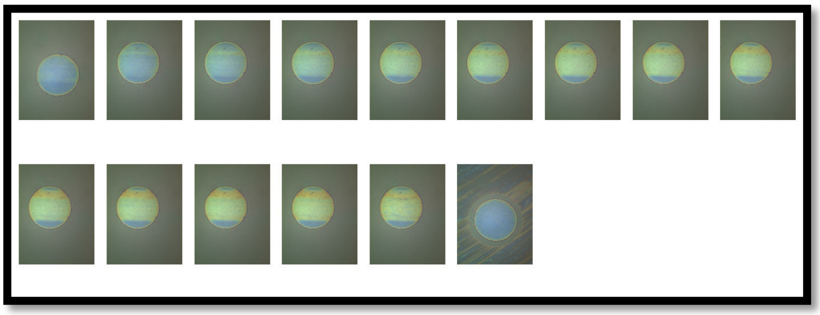


Figure 13 - 1V Disc live, potential applied immediately, maximum film thickness – 14um

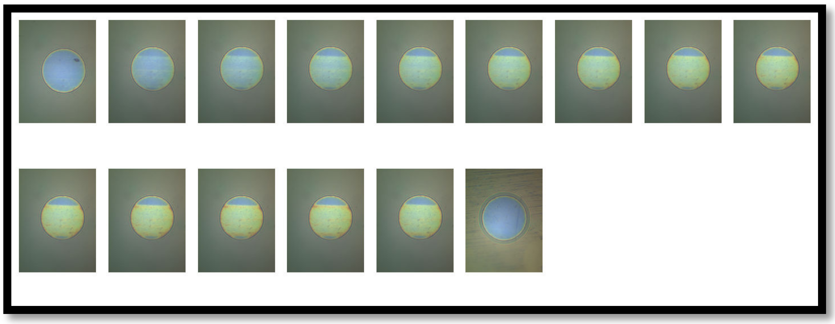


Figure 14 - 1V Ball Live, potential applied immediately, maximum film thickness – 20um

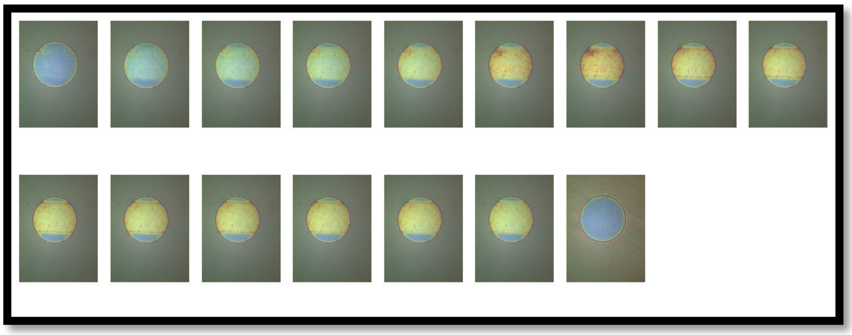


Figure 15 - 1V ball live 30 min to build a tribofilm, maximum film thickness – 35um

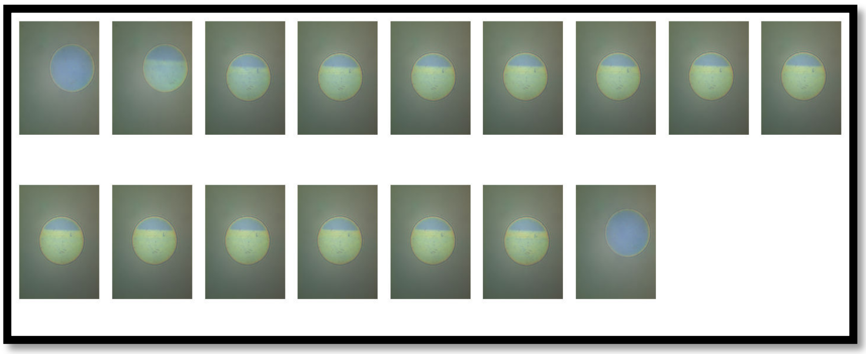


Figure 16 - 1V disc live 30 min film to build a tribofilm, maximum film thickness – 20um

Note – the final image in the SLIM image sequence is actually the zero step, and the first image the first in the series.

4.4 Wear scars

All wear scars take with 25x lens on Olympus DSX1000 camera

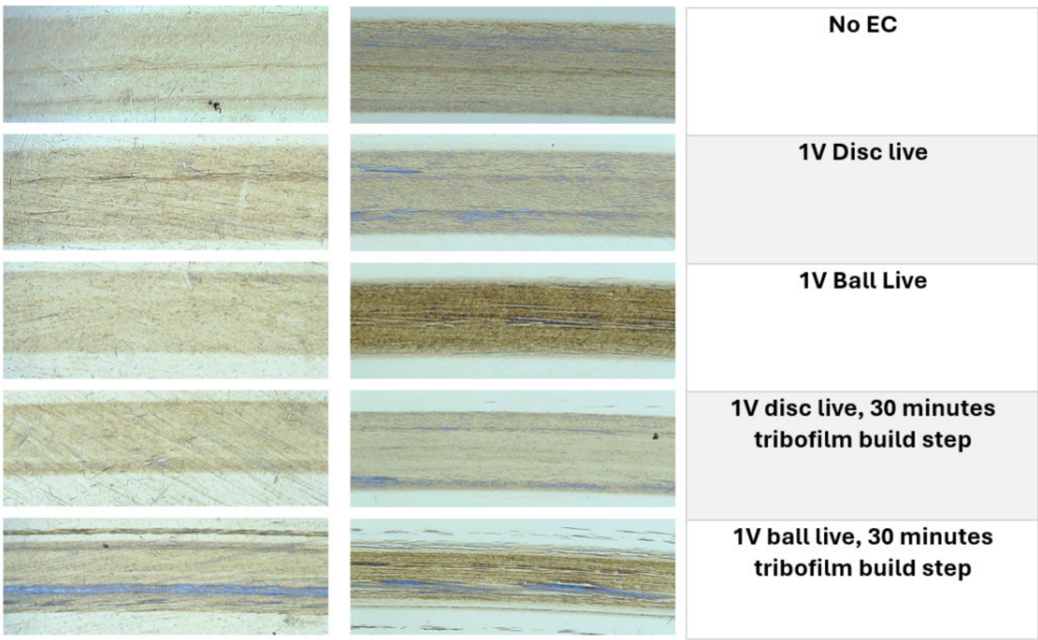


Figure 17 – Ball wear scar, disc wear scar and conditions respectively

Caution must be taken making conclusions from purely visual aids but there are differences from 'No EC' to the '1V ball live, 30 minutes tribofilm build step wear'. The addition of a secondary track outside the usual wear track indicates a different wear mechanism at play. We postulate that this could be arching damage, as it appears on tests when a tribofilm also this could cause electrical arcing and be the reason for a second set of wear tracks. We are looking to further exaggerate these conditions to prove this theory.

5.0 Conclusions

The E-transmission fluid tested in this experiment showed no significant differences in the coefficient of friction or to tribofilm thickness between electrified and non-electrified conditions.

Tribofilm building sequences could cause the film to act as an insulator, this may lead to discharge events which may cause surface damage. These generally occur outside the insulating contact path, shown most obviously in figure 17.

6.0 Future work

This study showed some interesting initial results but there is much more work to do:

Investigate effect of time spent in tribofilm building step to improve wear performance and try an isolate the hypothesised arcing damage

Investigate other lubrication regimes (boundary and full-film conditions) with the aim of creating design guidelines to better predict expected damage in electrified systems.

Study the tribological effects of AC electrical potentials.

Repeat test methods using a wide selection of commercially available lubricants especially those containing ZDDP.

Investigate effect of time spent in tribofilm building step to improve wear performance and try an isolate the hypothesised arcing damage.