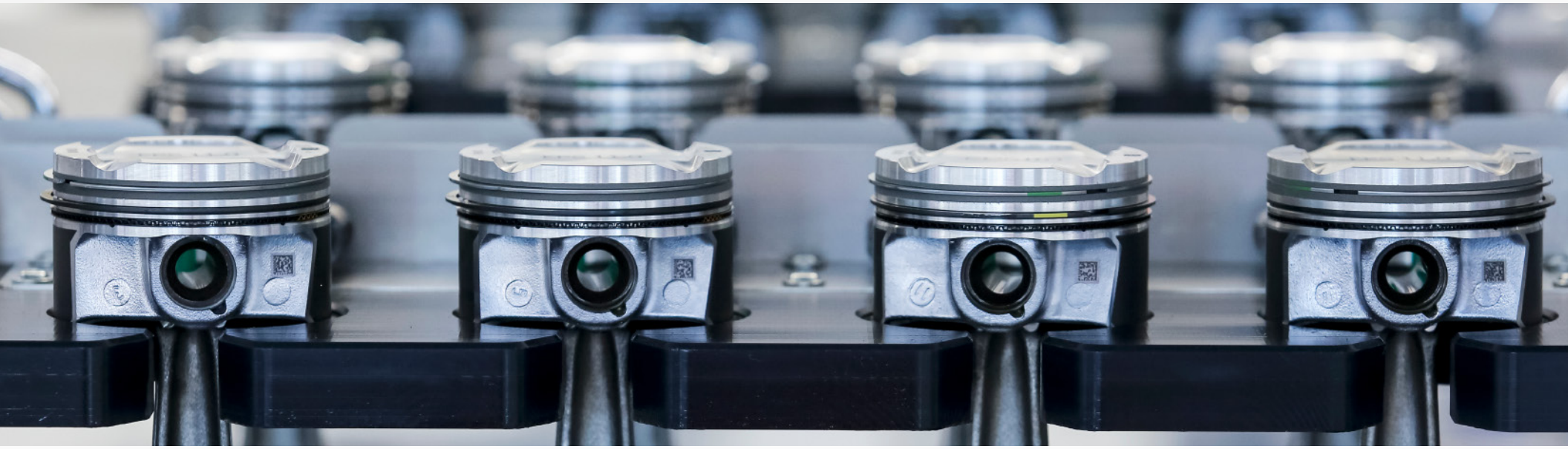
NANOVEA

PISTON WEAR TESTING

USING A TRIBOMETER



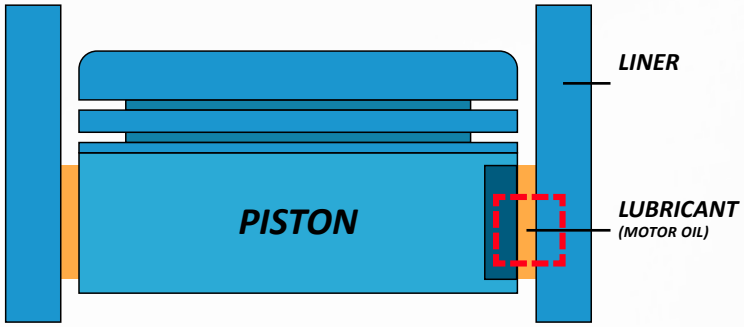
Prepared by

FRANK LIU

INTRODUCTION

Friction loss accounts for approximately 10% of total energy in fuel for a diesel engine[1]. 40-55% of the friction loss comes from the power cylinder system. The loss of energy from friction can be diminished with better understanding of the tribological interactions occurring in the power cylinder system.

A significant portion of the friction loss in the power cylinder system stems from the contact between the piston skirt and the cylinder liner. The interaction between the piston skirt, lubricant, and cylinder interfaces is quite complex due to the constant changes in force, temperature, and speed in a real life engine. Optimizing each factor is key to obtaining optimal engine performance. This study will focus on replicating the mechanisms causing friction forces and wear at the piston skirt-lubricant-cylinder liner (P-L-C) interfaces.



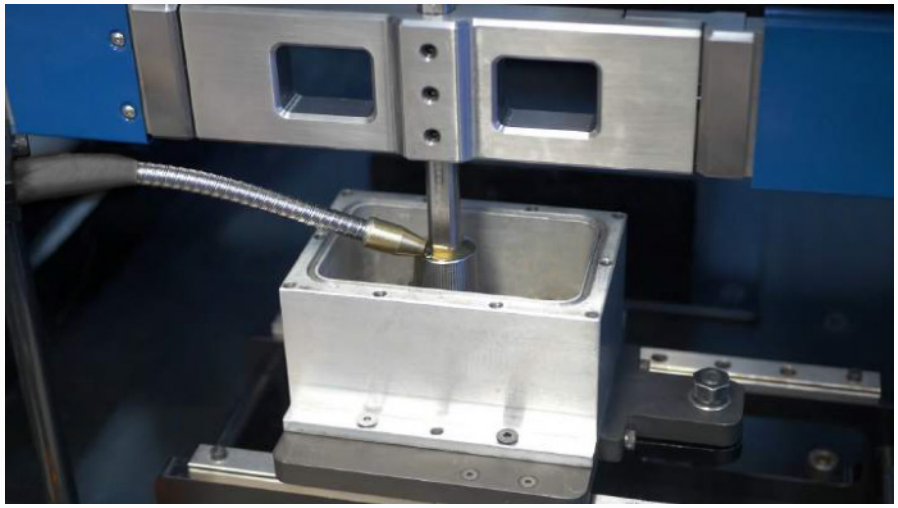
Schematic of power cylinders system and piston skirt-lubricant-cylinder liner interfaces.

[1] Bai, Dongfang. Modeling piston skirt lubrication in internal combustion engines. Diss. MIT, 2012.

IMPORTANCE OF TESTING PISTONS WITH TRIBOMETERS

Motor oil is a lubricant that is well-designed for its application. In addition to the base oil, additives such as detergents, dispersants, viscosity improver (VI), anti-wear/anti-friction agents, and corrosion inhibitors are added to improve its performance. These additives affect how the oil behaves under different operating conditions. The behavior of oil affects the P-L-C interfaces and determines if significant wear from metal-metal contact or if hydrodynamic lubrication (very little wear) is occurring.

It is difficult to understand the P-L-C interfaces without isolating the area from external variables. It is more practical to simulate the event with conditions that are representative of its real-life application. The ***NANOVEA*** Tribometer is ideal for this. Equipped with multiple force sensors, depth sensor, a drop-by-drop lubricant module, and linear reciprocating stage, the ***NANOVEA*** T2000 is able to closely mimic events occurring within an engine block and obtain valuable data to better understand the P-L-C interfaces.



Liquid Module on the NANOVEA T2000 Tribometer.

The drop-by-drop module is crucial for this study. Since pistons can move at a very fast rate (above 3000 rpm), it is difficult to create a thin film of lubricant by submerging the sample. To remedy this issue, the drop-by-drop module is able to consistently apply a constant amount of lubricant onto the piston skirt surface. Application of fresh lubricant also removes concern of dislodged wear contaminants influencing the lubricant's properties.

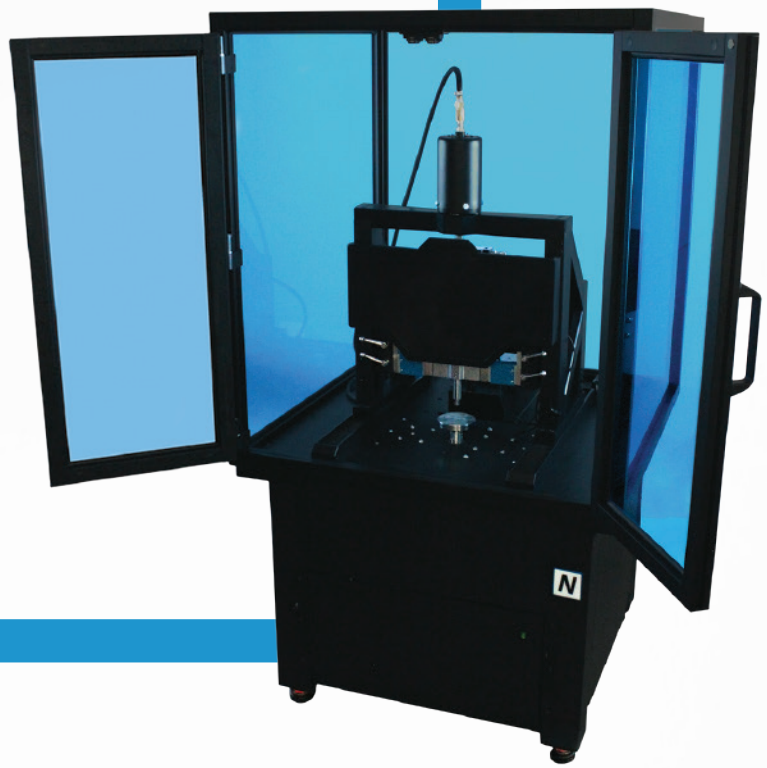
MEASUREMENT OBJECTIVE

The piston skirt-lubricant-cylinder liner interfaces will be studied in this report. The interfaces will be replicated by conducting a linear reciprocating wear test with drop-by-drop lubricant module.

The lubricant will be applied at room temperature and heated conditions to compare cold start and optimal operation conditions. The COF and wear rate will be observed to better understand how the interfaces behaves in real-life applications.

CLICK HERE TO LEARN MORE ABOUT THE INSTRUMENT

NANOVEA
T2000

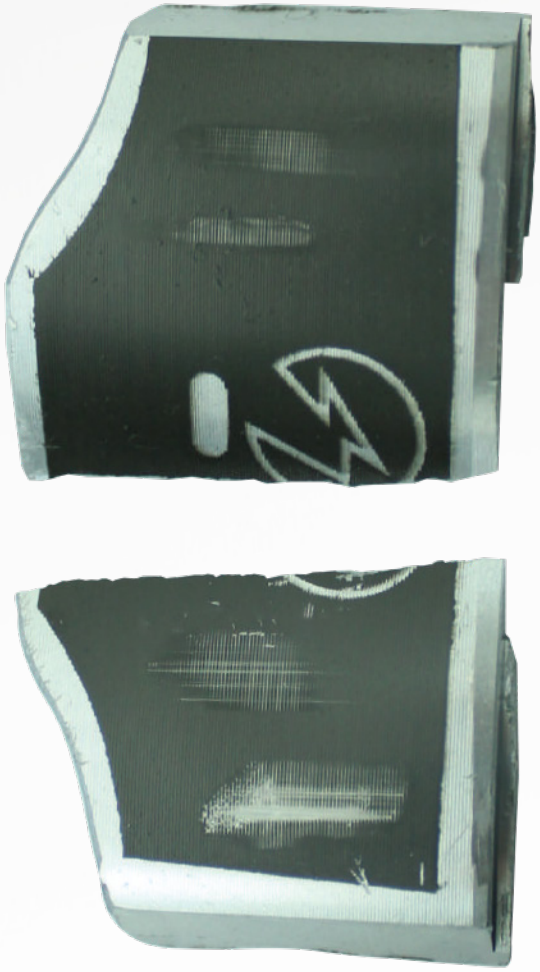


TEST PARAMETERS

for tribology testing on pistons

LOAD ..... 100 N
TEST DURATION ..... 30 min
SPEED ..... 2000 rpm
AMPLITUDE ..... 10 mm
TOTAL DISTANCE ..... 1200 m
SKIRT COATING ..... Moly-graphite
PIN MATERIAL ..... Aluminum Alloy 5052
PIN DIAMETER ..... 10 mm
LUBRICANT ..... Motor Oil (10W-30)
APPROX. FLOW RATE ..... 60 mL/min
TEMPERATURE ..... Room temp & 90°C

LINEAR RECIPROCATING TEST RESULTS



the samples after the test

In this experiment, A5052 was used as the counter material. While engine blocks are usually made of cast aluminum such as A356, A5052 have mechanical properties similar to A356 for this simulative testing [2].

Under the testing conditions, significant wear was observed on the piston skirt at room temperature compared to at 90°C. The deep scratches seen on the samples suggest that contact between the static material and the piston skirt occurs frequently throughout the test. The high viscosity at room temperature may be restricting the oil from completely filling gaps at the interfaces and creating metal-metal contact. At higher temperature, the oil thins and is able to flow between the pin and the piston. As a result, significantly less wear is observed at higher temperature. ***FIGURE 5*** shows one side of the wear scar wore significantly less than the other side. This is most likely due to the location of the oil output. The lubricant film thickness was thicker on one side than the other, causing uneven wearing.

[2] "5052 Aluminum vs 356.0 Aluminum." MakeItFrom.com, makeitfrom.com/compare/5052-O-Aluminum/A356.0-SG70B-A13560-Cast-Aluminum

The COF of linear reciprocating tribology tests can be split into a high and low pass. High pass refers to the sample moving in the forward, or positive, direction and low pass refers to the sample moving in the reverse, or negative, direction. The average COF for the RT oil was observed to be under 0.1 for both directions. The average COF between passes were 0.072 and 0.080. The average COF of the 90°C oil was found to be different between passes. Average COF values of 0.167 and 0.09 were observed. The difference in COF gives additional proof that the oil was only able to properly wet one side of the pin. High COF was obtained when a thick film was formed between the pin and the piston skirt due to hydrodynamic lubrication occurring. Lower COF is observed in the other direction when mixed lubrication is occurring. For more information on hydrodynamic lubrication and mixed lubrication, please visit our application note on ***Stribeck Curves***.

OIL TEMP	MAX COF (HIGH/LOW)	MIN COF (HIGH/LOW)	AVERAGE COF (HIGH/LOW)	WEAR RATE ($m^3/(Nm)x10^7$)
RT	0.229/0.106	0.053/0.045	0.072/0.080	36.77
90°C	0.345/0.161	0.008/0.021	0.167/0.094	10.77

TABLE 1: ***Results from lubricated wear test on pistons.***

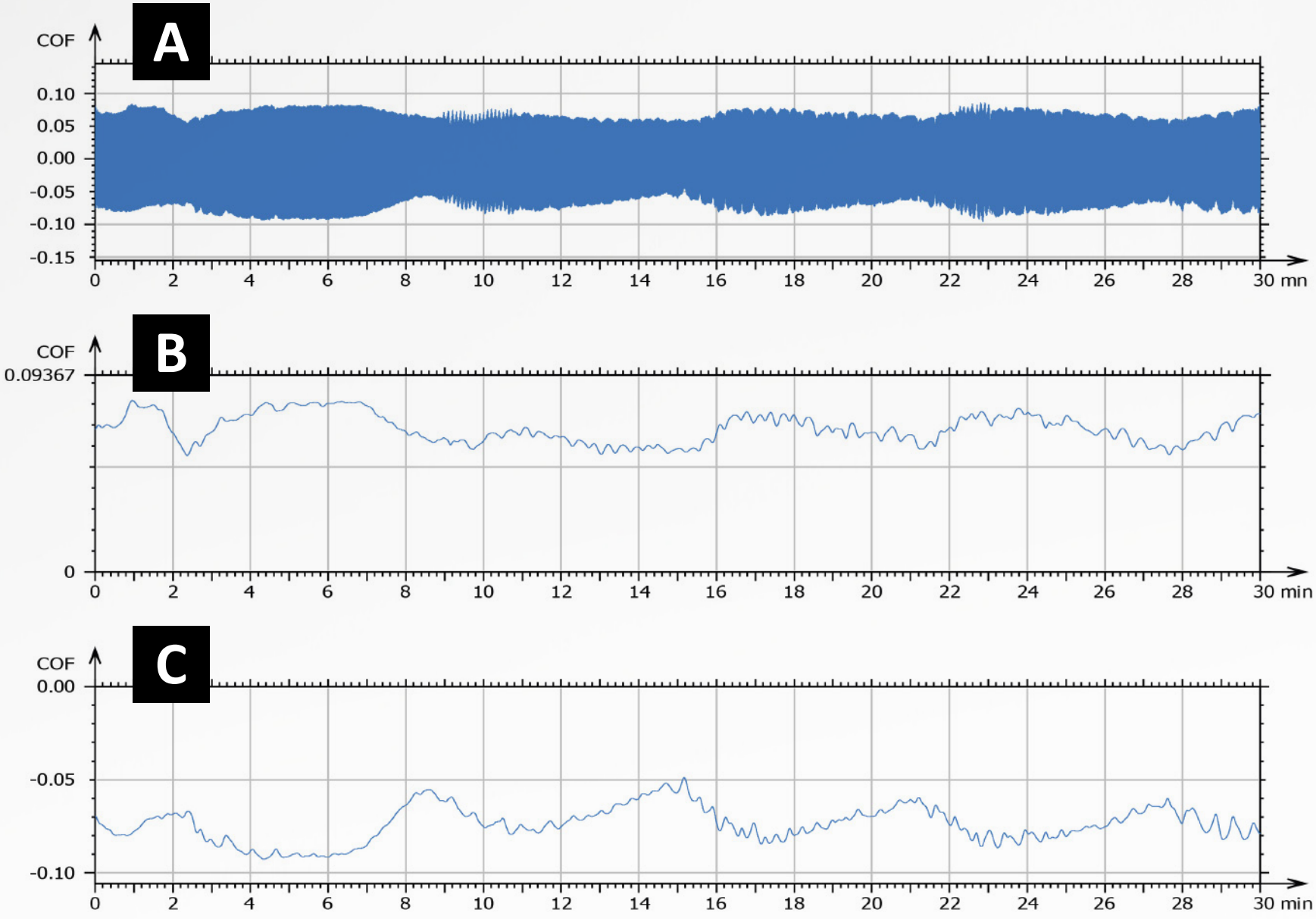


FIGURE 1: ***COF graphs for room temperature oil wear test*** **A** ***raw profile*** **B** ***high pass*** **C** ***low pass.***

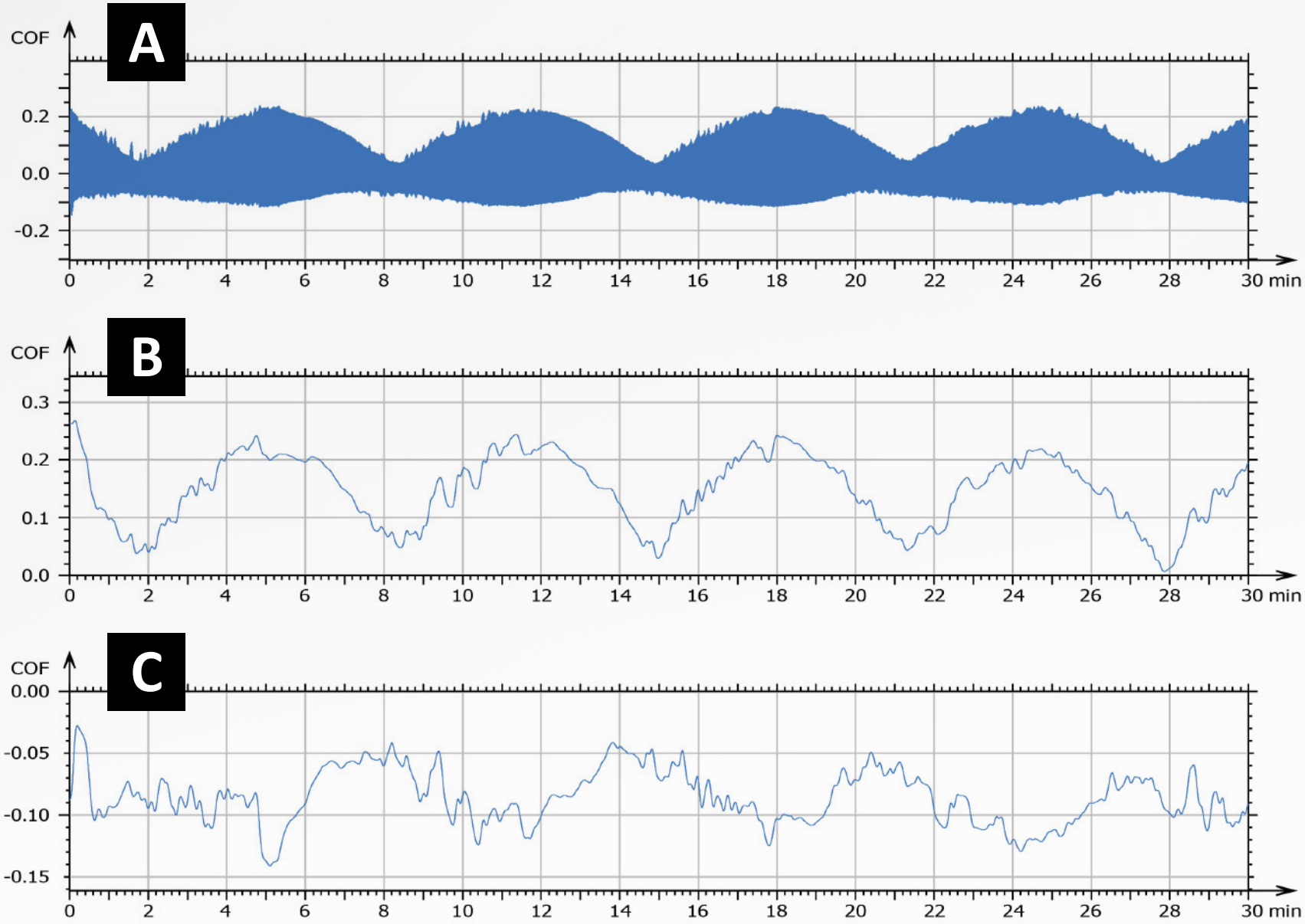


FIGURE 2: ***COF graphs for 90°C wear oil test*** **A** ***raw profile*** **B** ***high pass*** **C** ***low pass.***

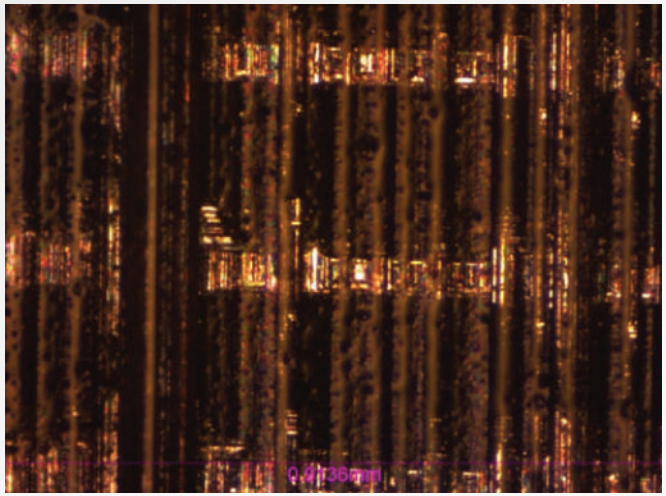
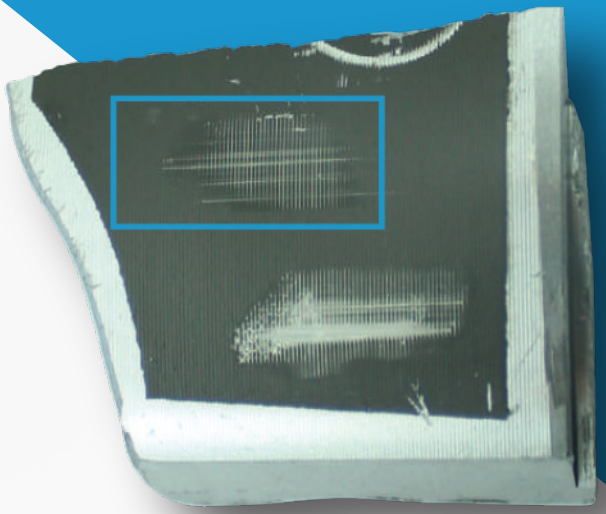
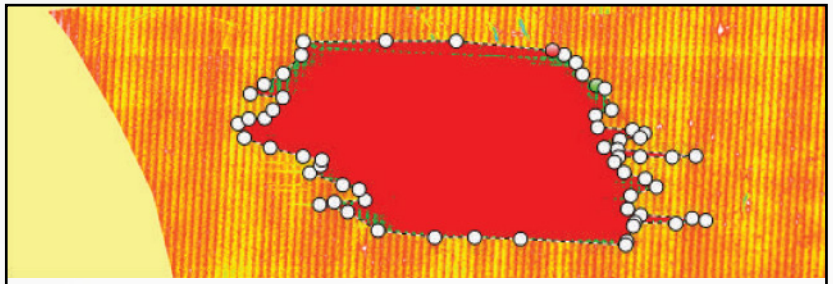


FIGURE 3: *Optical image of wear scar from RT motor oil wear test.*





SURFACE ..... 76.57 mm²
VOLUME ..... 441298429 µm³
MAX DEPTH/HEIGHT ..... 25.87 µm
MEAN DEPTH/HEIGHT ..... 5.763 µm

FIGURE 4: *Volume of a hole analysis of wear scar from RT motor oil wear test.*

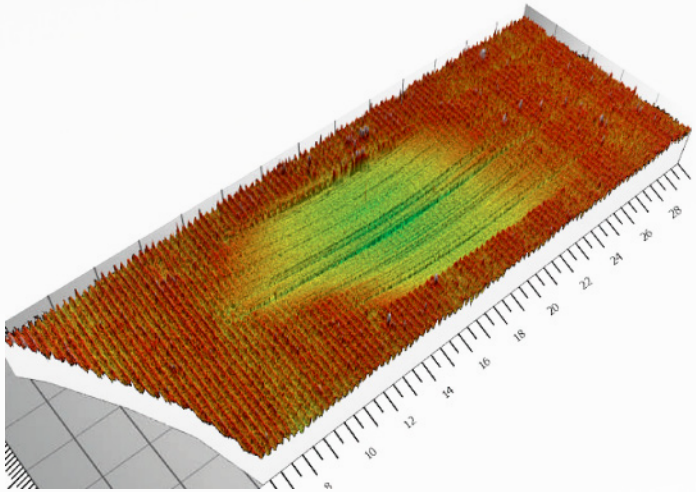


FIGURE 5: *Profilometry scan of wear scar from RT motor oil wear test.*

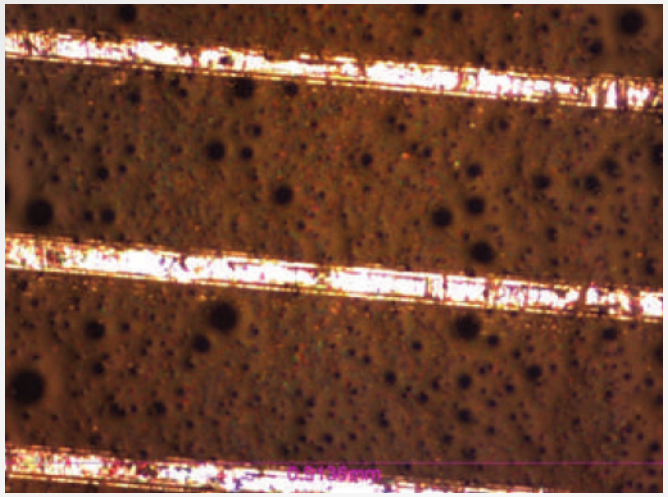


FIGURE 6: *Optical image of wear scar from 90°C motor oil wear test.*

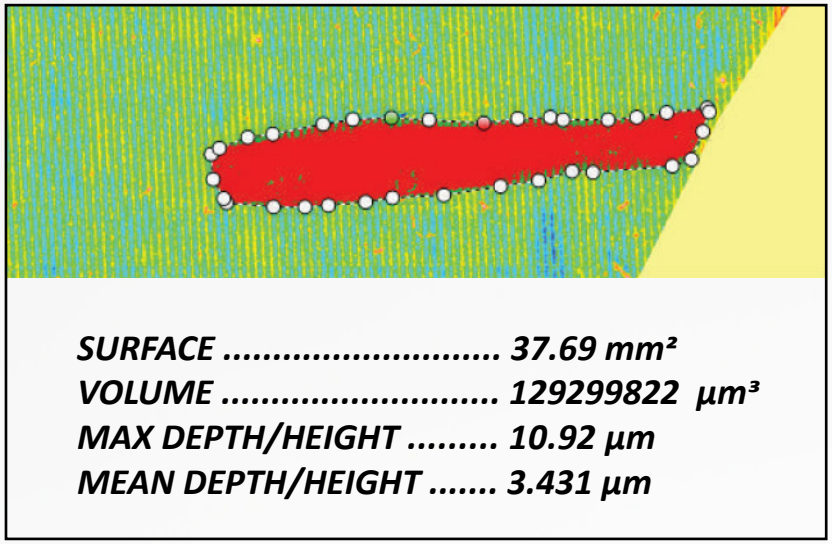


FIGURE 7: *Volume of a hole analysis of wear scar from 90°C motor oil wear test.*

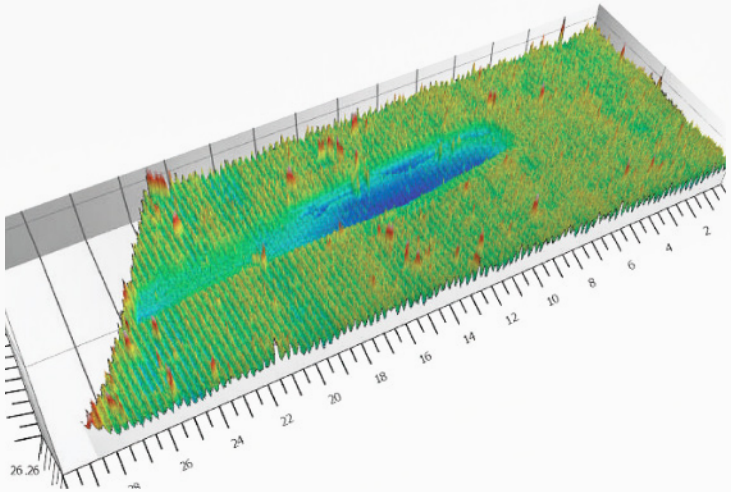


FIGURE 8: *Profilometry scan of wear scar from 90°C motor oil wear test.*

CONCLUSION

Lubricated linear reciprocating wear testing was conducted on a piston to simulate events occurring in a real-life operational engine. The piston skirt-lubricant-cylinder liner interfaces is crucial to the operations of an engine. The lubricant thickness at the interface is responsible for energy loss due to friction or wear between the piston skirt and cylinder liner. To optimize the engine, the film thickness must be as thin as possible without allowing the piston skirt and cylinder liner to touch. The challenge, however, is how changes in temperature, speed, and force will affect the P-L-C interfaces.

With its wide range of loading (up to 2000 N) and speed (up to 15000 rpm), the ***NANOVEA*** T2000 tribometer is able to simulate different conditions possible in an engine. Possible future studies on this topic include how the P-L-C interfaces will behave under different constant load, oscillated load, lubricant temperature, speed, and lubricant application method. These parameters can be easily adjusted with the ***NANOVEA*** T2000 tribometer to give a complete understanding on the mechanisms of the piston skirt-lubricant-cylinder liner interfaces.

NANOVEA.COM