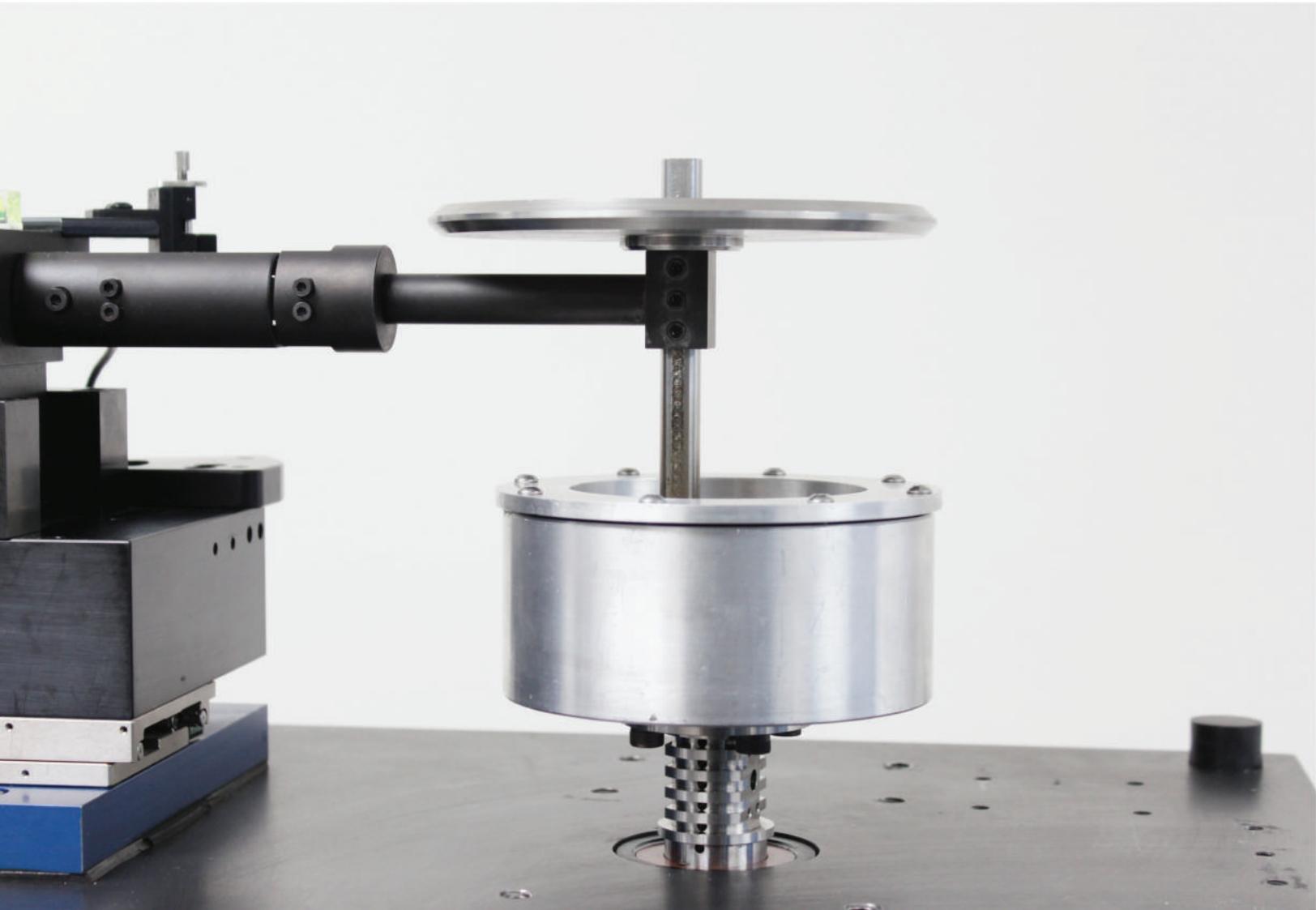


CONTINUOUS STRIBECK CURVE MEASUREMENT

— USING —

PIN-ON-DISK TRIBOMETER



Prepared by
Jocelyn Esparza and Pierre Leroux

Introduction

When lubrication is applied to reduce the wear/friction of moving surfaces, the lubrication contact at the interface can shift from several regimes such as Boundary, Mixed and Hydrodynamic Lubrication. The thickness of the fluid film plays a major role in this process, mainly determined by the fluid viscosity, load applied at the interface, and relative speed between the two surfaces. How the lubrication regimes react to friction is shown in what is called a Stribeck [1-4] curve.

In this study we demonstrate for the first time the ability to measure a continuous Stribeck Curve. Using the Nanovea Tribometer advanced step-less speed control, from 15000 to 0.01 rpm, the software directly provides a complete Stribeck Curve within 10 minutes. The simple initial setup only requires users to select the Exponential Ramp Mode and enter initial and final speeds, rather than having to perform multiple tests or program a stepwise procedure at different speeds requiring data stitching for the conventional Stribeck curve measurements. This advancement provides precise data throughout lubricant regime evaluation at substantially reduced time and cost. The test shows a great potential to be used in different industrial engineering applications.

Importance of Using Tribometer for Stribeck Curve Testing

The Stribeck Curve plots the coefficient of friction (COF) as a function of viscosity, speed and load. Effective and efficient measurements for evaluating and developing cost-saving lubrication systems are critical for battling friction and wear in various industrial applications. The purpose of tribology research is ultimately the minimization and elimination of losses resulting from wear and friction and the enhancement of production efficiency, application performance, controlled replacement breakdowns, and most importantly the cost savings to allow industrial growth.



MEASUREMENT OBJECTIVES

The Stribeck curves were measured using two lubricant oils with different kinetic viscosities for comparison. The Nanovea Pin-On-Disk Tribometer equipped with the lubrication module was used. The rotational speed decreased at an exponential rate from 2000 to 0.01 rpm to showcase the continuous Stribeck Curve measurement and the precise sensitivity of the Tribometer capabilities.

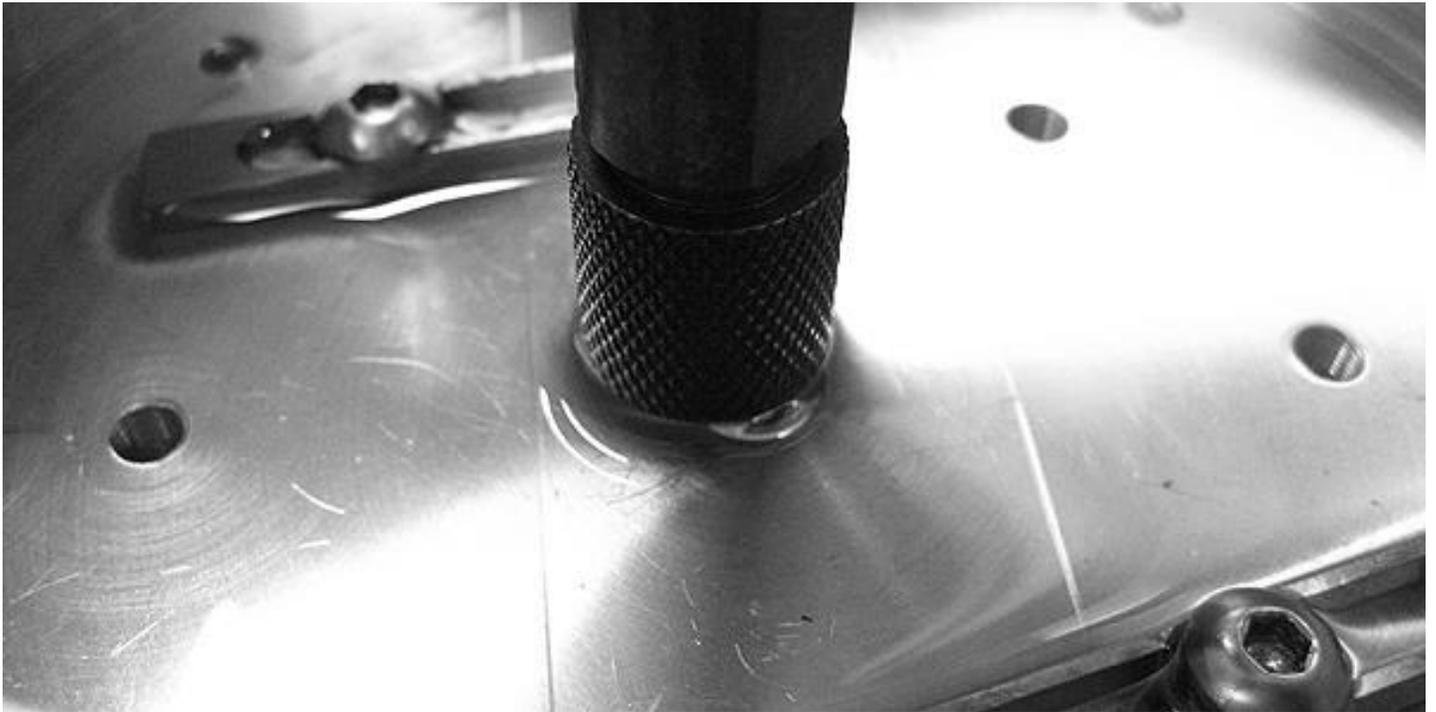


Figure 1: Liquid pin-on-disk test setup.

TEST PROCEDURE

A SS440 ball tip (6 mm dia., Grade 100) was applied on an optically clear cast acrylic sheet, to ensure a smooth surface contact and eliminate the impact of surface inhomogeneity. Two PAO-based lubricant oils (Mobil-1, see properties in Table 1) with different viscosities were studied for comparison. The oil was introduced drop by drop in front of the pin to ensure formation of the lubricant film at high speeds.

Oil	Specific Gravity	Kinematic viscosity (cSt) at 40°C
Lower viscosity oil (LVO)	0.852	54.8
Higher viscosity oil (LVO)	0.863	124.7

Table 1: Physical properties of tested lubricant oils.

The speed decreased at an exponential rate in a step-less fashion from 2000 to 0.01 rpm (see Fig. 2). These two values correspond to the tangential, linear velocities at a 10 mm radius of 2.1 m/s and 1.05×10^{-5} m/s, respectively. The COF was recorded in situ with a time interval of 0.1 s. The test parameters are summarized in Table 2.

Test Parameters	Value
Force applied	10N
Speed of Rotation	2000-0.01 RPM Continuous, at an exponential rate
Radius of wear track	10 mm
Duration of test	8 min
Total disk rotations	1312
Distance traveled	82.37 m

Table 2: Test parameters of the Stribeck Curve measurement.

RESULTS AND DISCUSSION

The impact of lubricant viscosity on transitions of lubrication regimes is displayed in Figure 2 (below). Thanks to the capacity of performing accurate measurement at extremely high and low speeds (2000 and 0.01 rpm, respectively) by the Nanovea Tribometer, three lubrication regimes of the Stribeck curves are present. The function of speed shift at an exponential rate allows direct generation of Stribeck curve with continuous data points homogeneously distributed on the curve.

Boundary

In the Boundary lubrication regime (a), the lubricated surface by the higher viscosity oil (HVO) shows a slightly lower COF of ~ 0.18 , compared to ~ 0.21 for the lower viscosity oil (LVO). Such a behavior in the Boundary lubrication regime can only be observed by performing an accurate COF measurement at a very low controlled speed below 0.1 rpm.

Mixed & Hydrodynamic

As the speed increases, a hydrodynamic pressure is built up in the lubricant. In the Mixed regime (b), the loading is carried by a combination of the hydrodynamic pressure and the contact pressure between the asperities of both surfaces. When the Tribometer reaches higher speeds, the hydrodynamic pressure further increases and the surface asperities are completely separated by a lubricant film. The load and hydrodynamic pressure is in equilibrium. The higher the load, the higher the speed threshold will be between Mixed and Hydrodynamic lubrication regimes.

The HVO shifts the transition from the Mixed to the Hydrodynamic lubrication regime (c) from a rotational speed of ~ 100 rpm for the LVO to ~ 10 rpm. Such information is critical for selecting the proper lubricants for specific engineering applications.

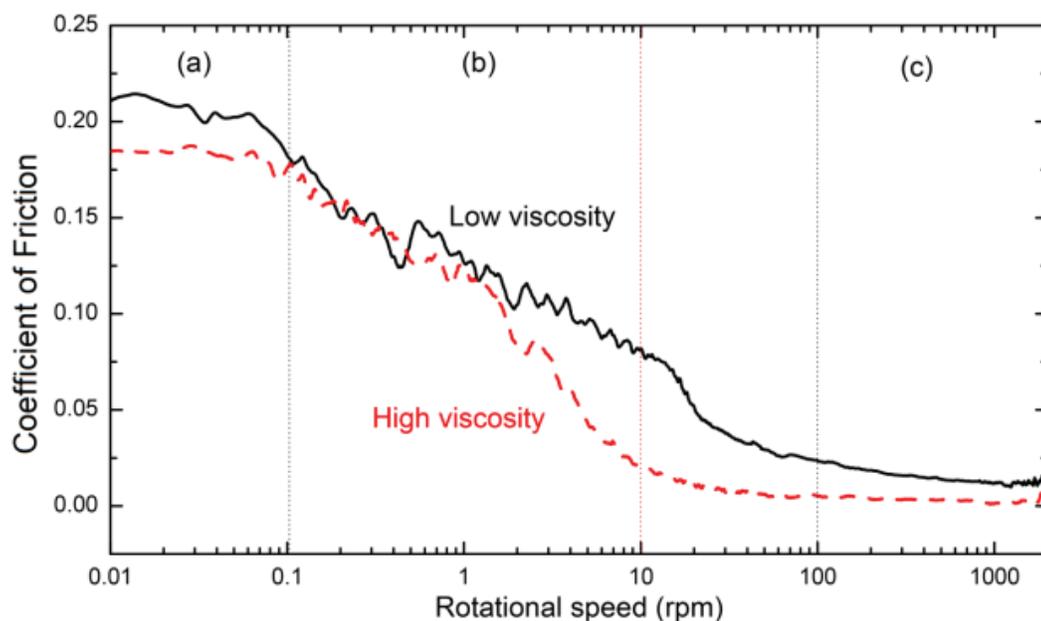
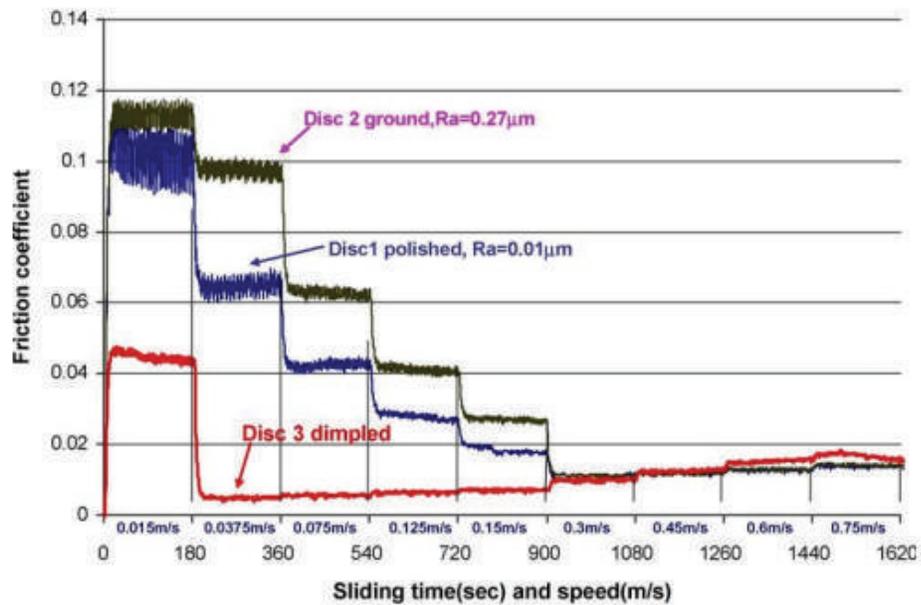


Figure 2: COF vs. Rotational speed at different lubrication regimes:
(a) Boundary lubrication, (b) Mixed lubrication, and (c) Hydrodynamic lubrication.

Compared to the conventional step-by-step Stribeck curve measurements shown in Figure 3 (below) as examples, Nanovea Tribometer provides a novel solution to measure a continuous Stribeck curve in a much shorter time (8 min in this study). Such a continuous curve allows the users to accurately determine the speed at which the transitions of different lubrication regimes take place. Moreover, the capability of simple and fast measurement of the Stribeck curves of different lubricants makes Nanovea Tribometer an ideal tool for related industrial applications.

(a)



(b)

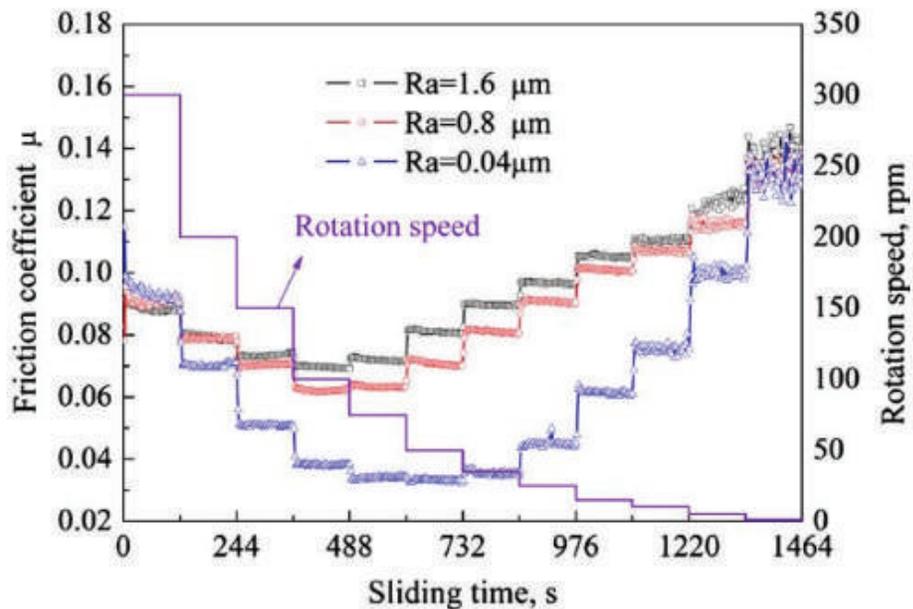
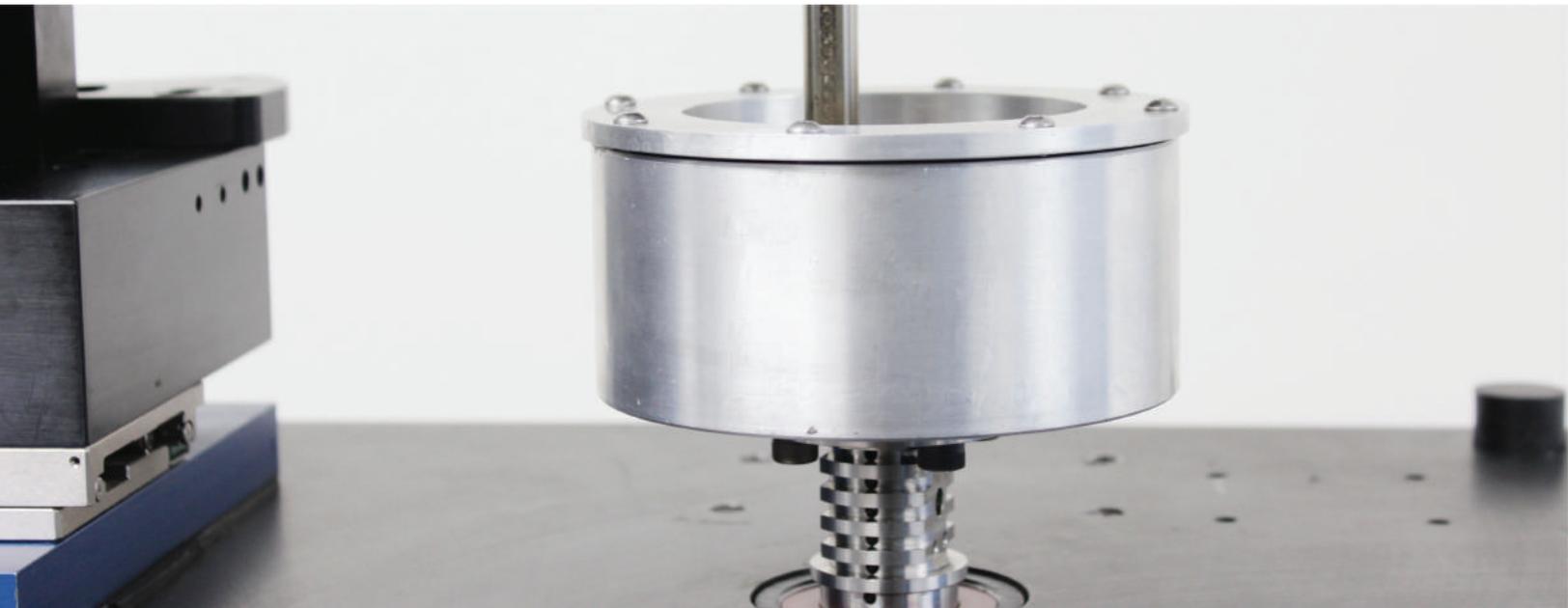


Figure 3: (a) Variation of friction coefficient with sliding speed for various discs during tests with low viscosity oil [5]; (b) Variation of friction coefficient with sliding speeds for three specimens [6].



Conclusion

In this study, we demonstrate for the first time the ability of measuring a continuous full Stribeck curve using Nanovea Pin-on-Disk Tribometer in one test instead of a collection of multiple tests. This substantially reduces the total test time required for conventional Stribeck curve measurements by eliminating any preparation required between multiple tests. The exponential speed shift function directly targets the industrial applications that require such measurements. Linear speed change as a function of time is also provided as an option. The sensitivity of sensor allows for detecting small change in friction. The full range of speed from 0.01 rpm (and lower) to 15000 rpm allows accurate measurements of the full range of lubrication behavior.

The Nanovea Tribometer can be equipped with a temperature module to study the tribological properties up to 150 °C. The liquid cup can be used to test by full submersion or by using a lubrication module that provides a drop-by-drop or spray application. An optional electrical contact module can be installed to monitor the thickness change of the fluid film during the test. With precision and these features, the Nanovea Pin-on-Disk Tribometer is the ideal tool for tribological studies.

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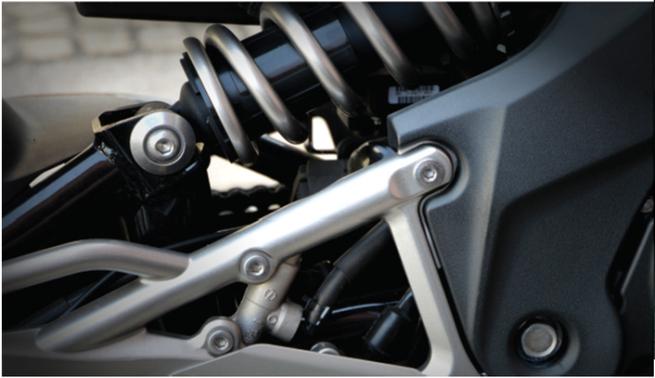
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Prepared by
Xavier Herrera-Keehn & Jocelyn Esparza

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