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BLOCK-ON-RING SLIDING WEAR EVALUATION

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INTRO

Sliding wear is the progressive loss of material that results from two materials sliding against each other at the contact area under load. It occurs inevitably in a wide variety of industries where machines and engines are in operation, including automotive, aerospace, oil & gas and many others. Such sliding motion causes serious mechanical wear and material transfer at the surface, which may lead to reduced production efficiency, machine performance or even damage to the machine.

IMPORTANCE OF BLOCK-ON-RING WEAR EVALUATION

Sliding wear often involves complex wear mechanisms taking place at the contact surface, such as adhesion wear, two-body abrasion, three-body abrasion and fatigue wear. The wear behavior of materials is significantly influenced by the work environment, such as normal loading, speed, corrosion and lubrication. A versatile tribometer that can simulate the different realistic work conditions will be ideal for wear evaluation. Block-on-Ring (ASTM G77) test is a widely used technique that evaluates the sliding wear behaviors of materials in different simulated conditions, allows reliable ranking of material couples for specific tribological applications.

MEASUREMENT OBJECTIVE

In this study, we evaluated the sliding wear behaviors of an H-30 block on as S-10 ring in dry and lubricated environment using Block-on-Ring module to showcase the capacity of Nanovea Tribometer in simulating the sliding wear process of metal couples in a well-controlled and monitored manner.

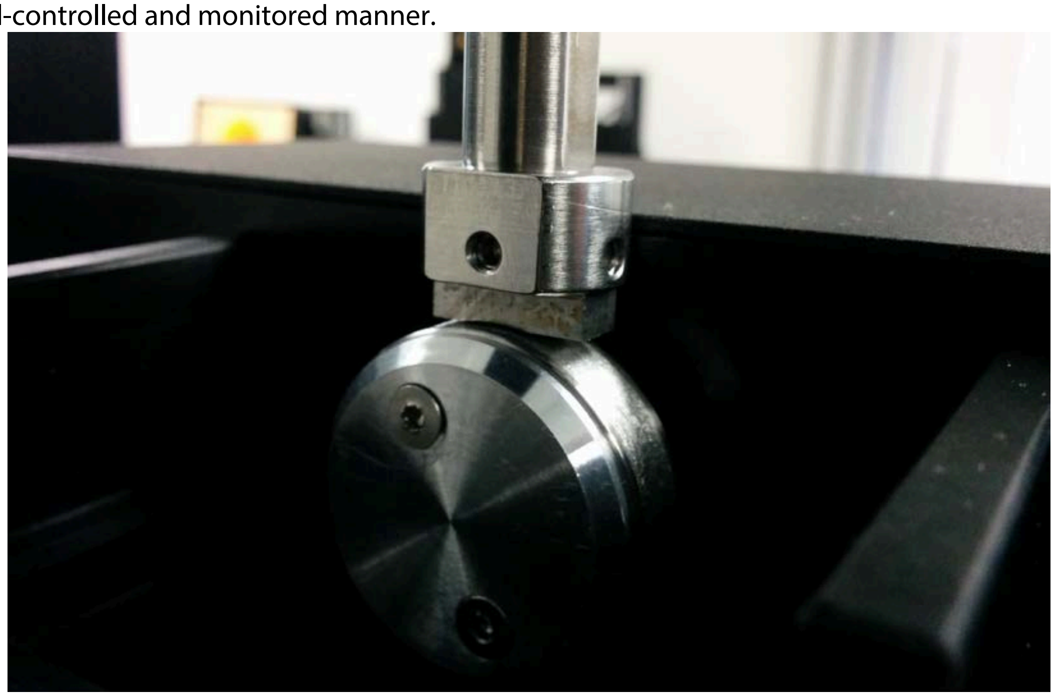


Fig. 1: Block-on-Ring wear test setup.

TEST PROCEDURE

The sliding wear behavior of an H-30 block on an S-10 ring was evaluated by Nanovea Macro Tribometer using Block-on-Ring module. The H-30 block is made of 01 tool steel of hardness 30
HRC, while S-10 ring is steel type 4620 of surface hardness 58 to 63 HRC and ring diameter of ~34.98 mm. The Block-on-Ring tests were performed in dry and lubricated environment respectively to investigate the effect of lubrication on the wear behavior. The lubricated test was performed in the USP heavy mineral oil. The wear track was examined using Nanovea 3D non-contact profilometer. The test parameters are summarized in Table 1. The wear rate, K, was evaluated using the formula $K=V/(F\times s)$, where V is the worn volume, F is the normal load, s is the sliding distance.

Sample description	H-30 block vs. S-10 ring
Normal Load	134 N
Revolutions	200 for dry wear; 500,000 for lubricated wear
Speed (rpm)	72 for dry wear; 197 for lubricated wear
Temperature	Room Temperature (RT)

Table 1: Test parameters of the Block-on-Ring wear measurements.

RESULTS AND DISCUSSION

Fig. 2 compares the Coefficient of Friction (COF) of the Block-on-Ring tests in Dry and Lubricated environment. The block has significant friction against the ring when the wear test is performed in a dry environment. The COF fluctuates in the first 50-revolution run-in period, and then it reaches a relatively constant value of ~0.8 during the rest of the 200-revolution wear test. In comparison, the Block-on-Ring test performed in the USP heavy mineral oil exhibits a constant low COF value of 0.09 throughout the 500,000-revolution wear test. The lubricant reduces the COF between surfaces of the block and ring by ~90 times.

Fig. 3 and Fig. 4 show the optical images and the cross-section 2D profiles of the wear scars on the blocks after the Dry and Lubricated wear tests, respectively. The wear track volumes and wear rates are listed in Table 2. The steel block after the dry wear test at a lower rotational speed of 72 rpm for 200 revolutions exhibits a big wear scar of volume 9.45 mm^3. In comparison, the wear test carried out at a high speed of 197 rpm for 500,000 revolutions in the mineral oil lubricant creates a substantially smaller wear track with a volume of only 0.03 mm^3.

As shown in the images taken under optical microscope in Fig. 3, severe wear takes place during the Block-on-Ring test in the dry atmosphere, compared to mild parallel wear scars on the block after the much longer lubricated wear test. The high heat and intense vibration generated during the dry wear test promotes oxidation of the metallic debris and results in severe three-body abrasion. In the lubricated test, however, the mineral oil ultimately reduces the friction and cools the contact face, as well as transports away abrasive debris created during wear, leading to significant reduction of wear rate by a factor of $\sim 8\times10^5$. Such a substantial difference in wear resistance measured in different environment shows the importance of proper simulating sliding wear in the realistic service condition.

Wear behavior can change drastically when small changes in testing conditions are introduced into the tribosystem. The versatility of the Nanovea Tribometer allows measuring wear under various conditions, including high temperature, lubrication, tribocorrosion and others. The accurate speed and position control by the advanced motor enables users to perform the wear test at speeds ranging from 0.001 to 2000 rpm, making it an ideal tool for research/testing labs to investigate the wear in different tribological conditions.

The surface condition of the blocks and rings were examined by Nanovea non-contact optical profilometer. Fig. 5 shows the surface morphology of the rings after the wear tests as an example. The cylinder form has been removed in order to better present the surface morphology and roughness created by the sliding wear process. Significant roughening of the surface took place due to the three-body abrasion process during the dry wear test of merely 200 revolutions. The block and ring after the dry wear test exhibit a roughness R_a of 14.1 and 18.1 µm, respectively, compared to 5.7 and 9.1 µm for that after the long-term 500,000-revolution lubricated wear test at a higher speed. This demonstrates the importance of proper lubrication of the piston ring-cylinder contact. Severe wear quickly damages the contact surface without lubrication and leads to irreversible deterioration of the service quality and even breakage of the engine.

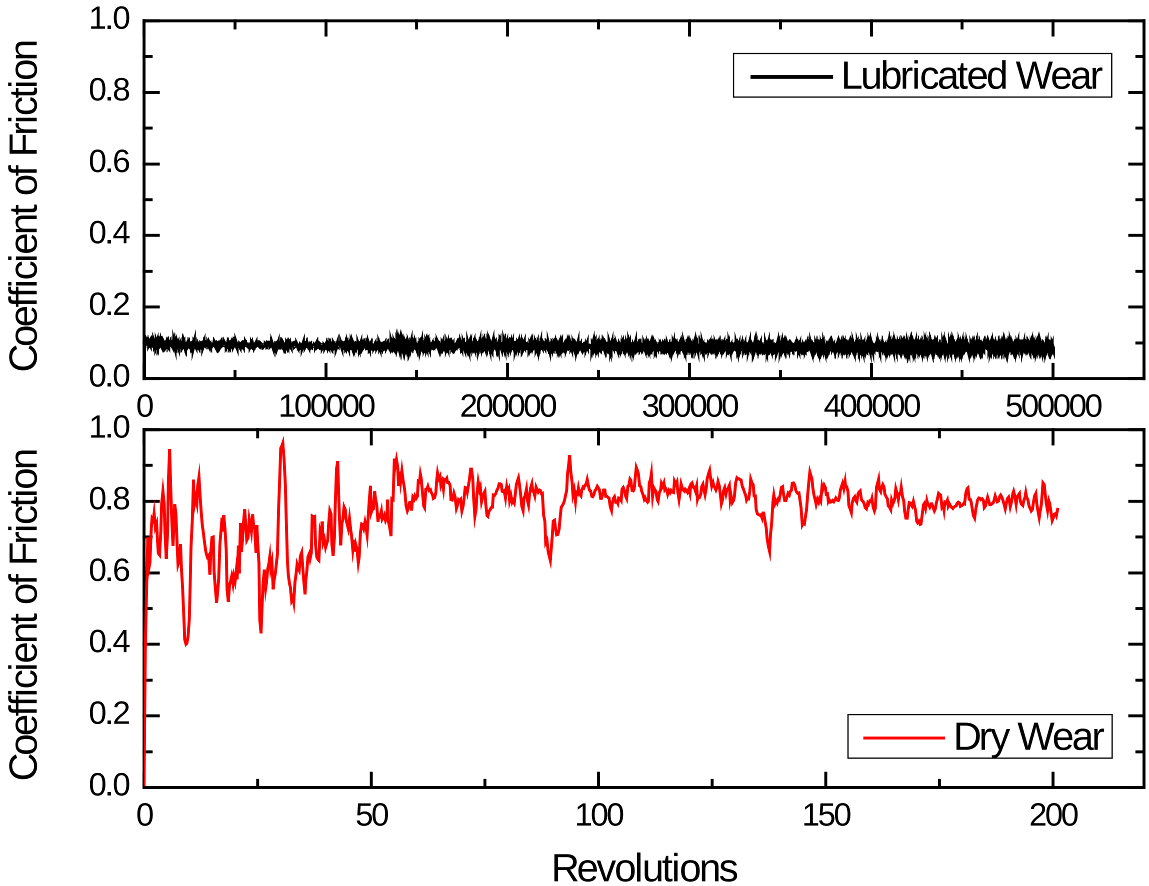


Fig. 2: Coefficient of Friction of the Block-on-Ring tests in Dry and Lubricated environment.

(a) After Dry Wear Test: (b) After Lubricated Wear Test:

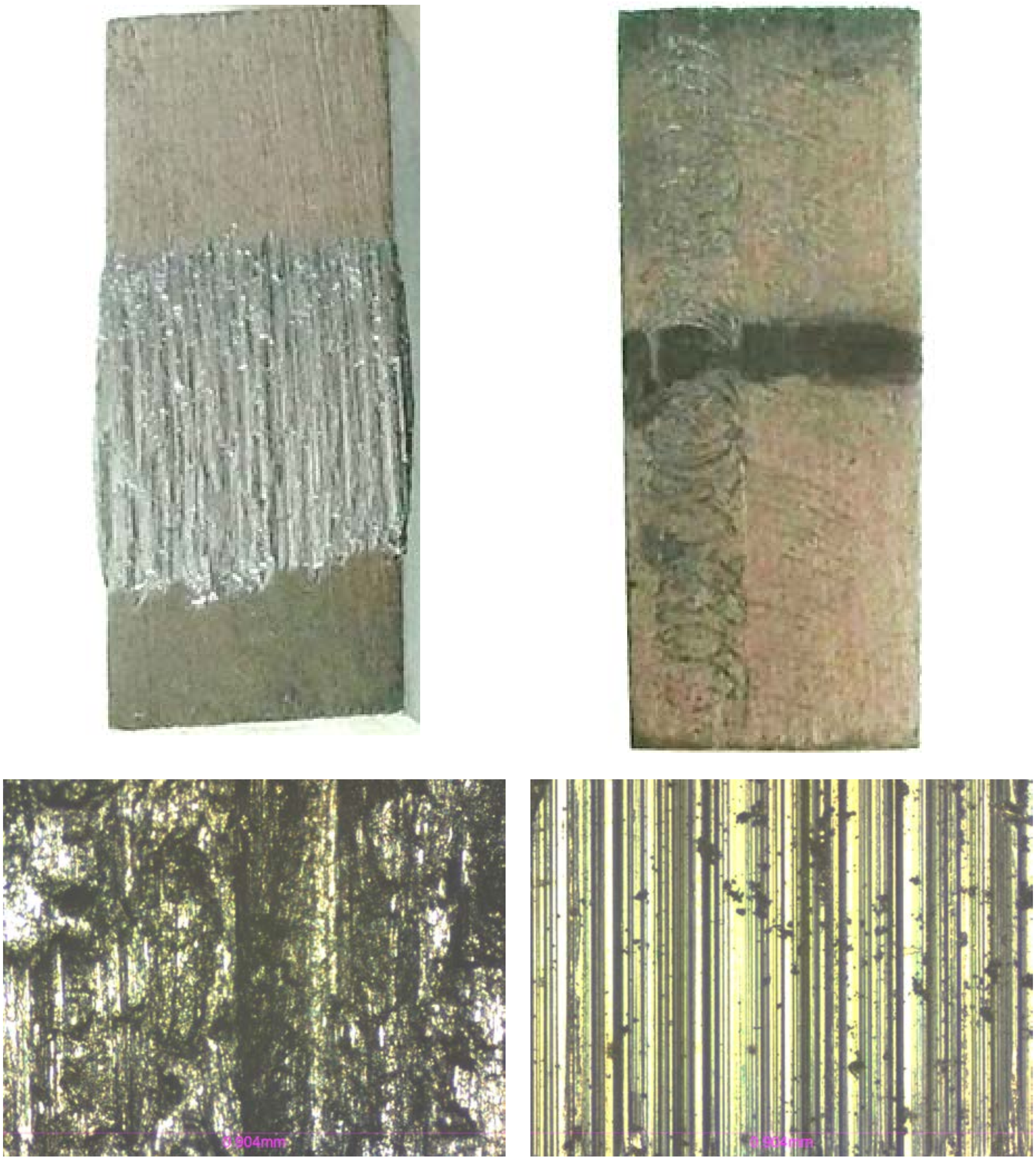


Fig. 3: Wear scars of the blocks after (a) dry and (b) lubricated wear tests.

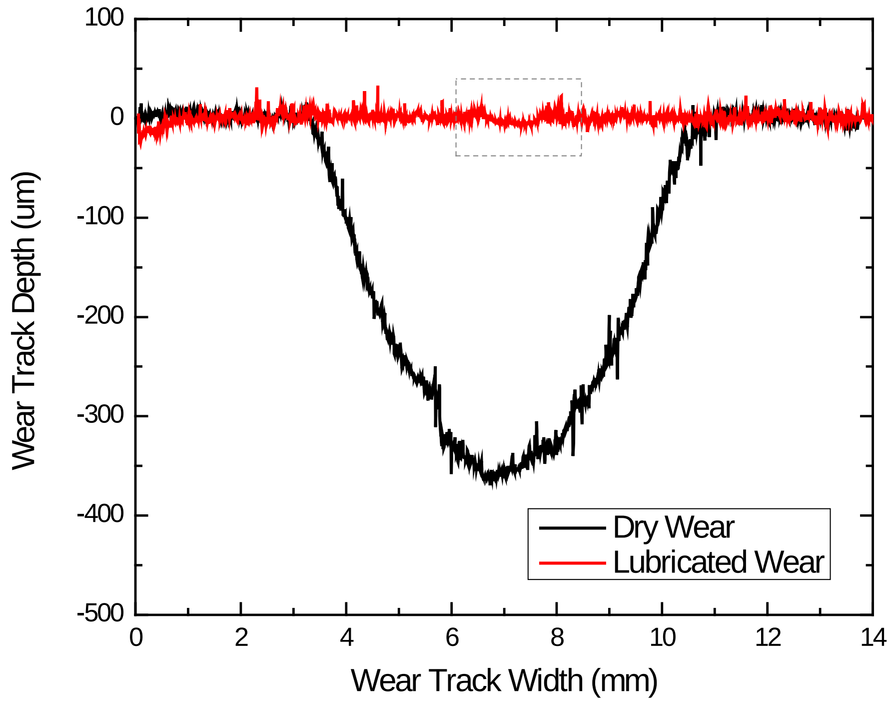
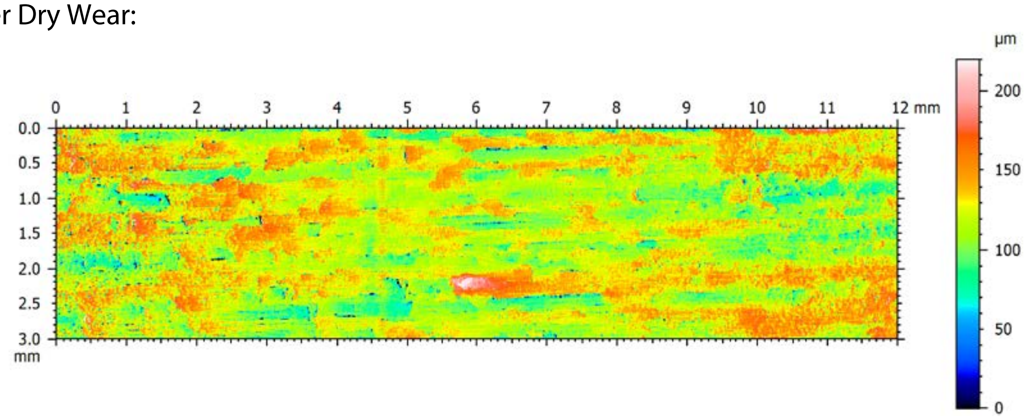


Fig. 4: Wear scar profiles on the block after the dry and lubricated wear tests.

(a) After Dry Wear:



(b) After Lubricated Wear:

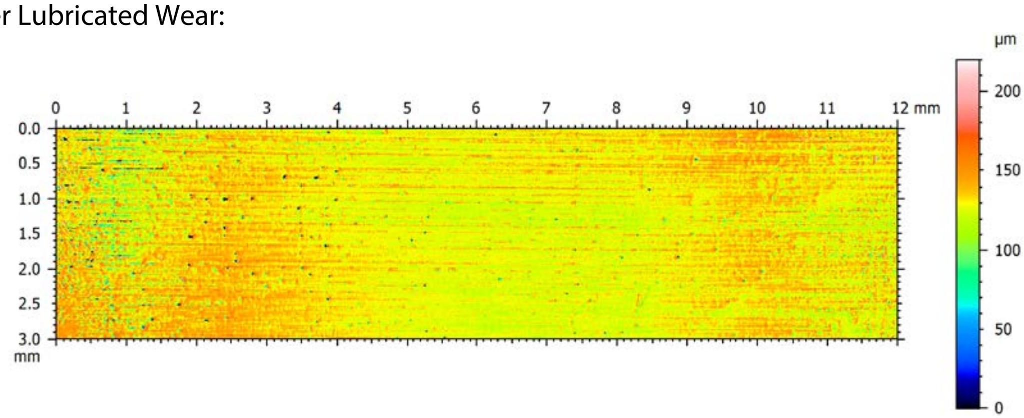


Fig. 5: Surface morphology of the rings after the wear tests (form removed).

	Wear Track Width mm	Wear Volume mm^3	Wear Rate mm^3/N m
Dry Test	6.8 ± 0.2	9.45	3.2×10^{-3}
Lubricated Test	1.0 ± 0.1	0.03	4.1×10^{-9}

Table 2: Result summary of wear tracks measured using different test parameters.

CONCLUSION

In this study, we showcased the capacity of Nanovea Tribometer in evaluating the sliding wear behavior of a steel metal couple using Block-on-Ring module following the ASTM G77 Standard. The lubricant, the mineral oil in this study, plays a critical role in the wear properties of the material couple. The mineral oil substantially reduces the wear rate of the H-30 block by a factor of ~8×10^5 and the COF by ~90 times. The versatility of the Nanovea Tribometer makes it an ideal tool for measuring wear behavior under various conditions, including lubrication, high temperature, tribocorrosion and others.

Nanovea Tribometer offers precise and repeatable wear and friction testing using ISO and ASTM compliant rotative and linear modes, with optional high temperature wear, lubrication and tribo-corrosion modules available in one pre-integrated system. Nanovea's unmatched range is an ideal solution for determining the full range of tribological properties of thin or thick, soft or hard coatings, films and substrates.

Learn More about the Nanovea Tribometer, Nanovea Profilometer and Lab Service

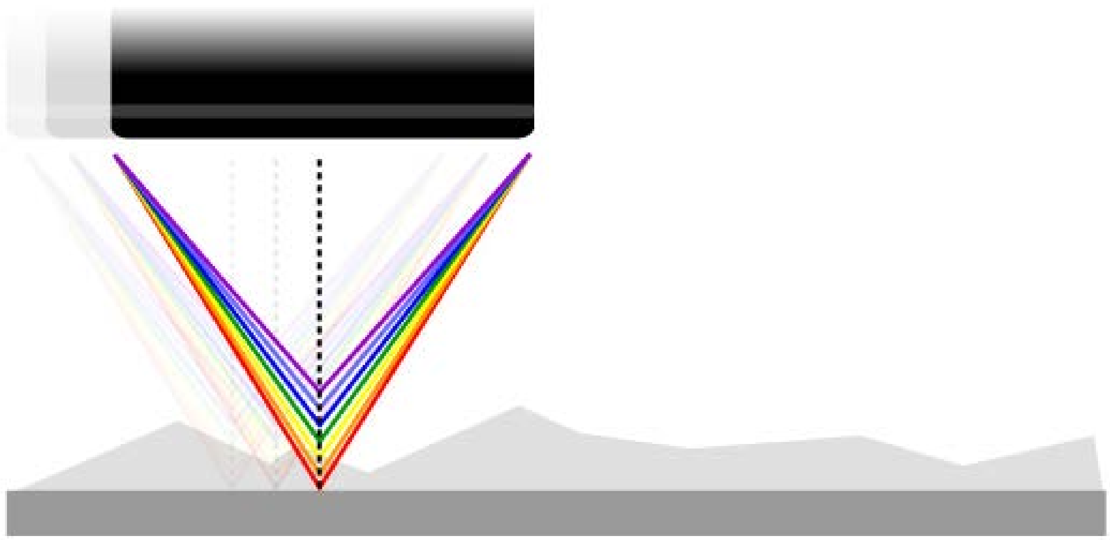
APPENDIX: MEASUREMENT PRINCIPLE

BLOCK-ON-RING WEAR PRINCIPLE

A test block is loaded against a test ring with a known force. As the ring rotates at a given speed, the resulting frictional force between the block and the ring is continuously measured during the test with a load cell. Wear rate values for both the block and ring are calculated from the volume of material lost during a specific friction run. The block scar width is measured to calculate the block scar volume, and ring scar volume is calculated from ring weight loss. This simple method facilitates the determination and study of friction and wear behavior of almost every solid state material combination, with varying time, contact pressure, velocity, temperature, humidity, lubrication, etc.

3D NON-CONTACT PROFILOMETER PRINCIPLE

The axial chromatism technique uses a white light source, where light passes through an objective lens with a high degree of chromatic aberration. The refractive index of the objective lens will vary in relation to the wavelength of the light. In effect, each separate wavelength of the incident white light will re-focus at a different distance from the lens (different height). When the measured sample is within the range of possible heights, a single monochromatic point will be focalized to form the image. Due to the confocal configuration of the system, only the focused wavelength will pass through the spatial filter with high efficiency, thus causing all other wavelengths to be out of focus. The spectral analysis is done using a diffraction grating. This technique deviates each wavelength at a different position, intercepting a line of CCD, which in turn indicates the position of the maximum intensity and allows direct correspondence to the Z height position.



Unlike the errors caused by probe contact or the manipulative Interferometry technique, White light Axial Chromatism technology measures height directly from the detection of the wavelength that hits the surface of the sample in focus. It is a direct measurement with no mathematical software manipulation. This provides unmatched accuracy on the surface measured because a data point is either measured accurately without software interpretation or not at all. The software completes the unmeasured point but the user is fully aware of it and can have confidence that there are no hidden artifacts created by software guessing. Nanovea optical pens have zero influence from sample reflectivity or absorption. Variations require no sample preparation and have advanced ability to measure high surface angles. Capable of large Z measurement ranges. Measure any material: transparent/opaque, specular/diffusive or polished/rough.