BALL BEARING WEAR RESISTANCE
USING MACRO TRIBOLOGY

Prepared by

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INTRO

A ball bearing uses balls to reduce rotational friction and support radial and axial loads. The rolling balls between the bearing races enable much lower coefficient of friction compared to two flat surfaces sliding against each other. Ball bearings are widely applied in nearly all industrial sectors that involve moving parts, from transportation industries such as aerospace and automobile to toy industries including skateboards and Yo-Yos. Ball bearings are often exposed to high stress level at the contact and extreme application environment combining wear, high temperature, etc. Therefore, wear resistance of the balls under high loads is critical for extending the lifetime of the ball bearing and cutting the cost and time on repairing and replacement.

IMPORTANCE OF BALL BEARING WEAR EVALUATION AT HIGH LOADS

Ball bearings can be made from many different materials, such as metals including stainless steel and chrome steel, and ceramic such as WC and Si_3N_4. In order to ensure that the manufactured ball bearings possess required wear resistance under the application conditions, reliable tribological evaluation under a high load is in need. It allows us to quantitatively compare the wear behaviors of different ball bearings in a controlled and monitored manner and to select the best candidate for the targeted application. Conventional pin-on-disc tribometers usually have a fixed wear track radius. The ball bearing always slides in the same wear track throughout the wear test. The sandpaper might wear out faster than the ceramic ball bearings with superior wear resistance, which undermines the reproducibility of the wear test on the ball bearings.

MEASUREMENT OBJECTIVE

Nanovea Macro Tribometer is designed with high torque capability for loads up to 500 N and automated motorized radial positioning. In this study, we showcased that the Nanovea Macro Tribometer is an ideal tool for comparing the wear resistance of different ball bearings under high loads.

Fig. 1: Setup of the bearing wear test.

TEST PROCEDURE

The coefficient of friction, COF, and the wear resistance of the ball bearings made of different materials were evaluated by Nanovea Macro Tribometer. A P100 Grit sandpaper was used as the counter material. The wear scars of the ball bearings were examined using Nanovea 3D non-contact profilometer after the tests. 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. Wear scars of the balls were evaluated by the Nanovea Optical Profilometer to ensure precise wear volume measurement.

The automated motorized radial positioning allows continuous change of wear track radius during the pin-on-disc spiral test, ensuring that the ball bearing always slides on a new surface of the sandpaper as illustrated in Fig. 2. It significantly improves the repeatability of the wear resistance test on the ball. The advanced 20bit encoder for internal speed control and 16bit encoder for external position control provide precise real-time speed and position information, allowing for a continuous adjustment of rotational speed to achieve constant sliding speed at the contact.

Please note that the P100 Grit sandpaper as a counter material was used as an example in this study. Any solid material can be applied to simulate the performance of different material coupling under actual application conditions, such as in liquid or lubricant.

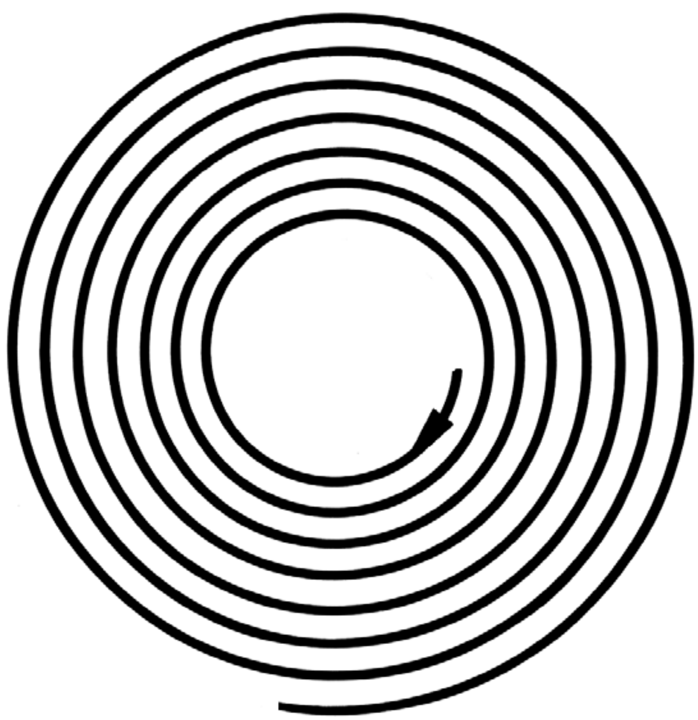


Fig. 2: Illustration of the spiral passes for the ball bearing on the sandpaper.

Test parameters	Value
Ball material	Cr steel, SS440, Al_2O_3 and WC
Ball diameter	10 mm
Counter material	P100 Grit sandpaper
Normal force	50 N
Rotational speed	100 mm/s
Duration of test	2 min
Wear track radius	10 to 25 mm, change continuously
Lubricant	None
Atmosphere	Air
Temperature	24°C (room)
Humidity	40%

Table 1: Test parameters of the wear measurements.

RESULTS AND DISCUSSION

Wear rate is a vital factor for determining the service lifetime of the ball bearing, while a low friction is desirable to improve the bearing performance and efficiency. Fig. 3 compares the evolution of COF for different ball bearings against the sandpaper during the tests. The Cr Steel ball shows an increased COF of ~0.4 during the wear test, compared to ~0.32 and ~0.28 for SS440 and Al_2O_3 ball bearings. On the other hand, the WC ball exhibits a constant COF of ~0.2 throughout the wear test. The jitters of the COF during the tests are caused by vibrations created by the sliding movement of the ball bearings against the rough sandpapers.

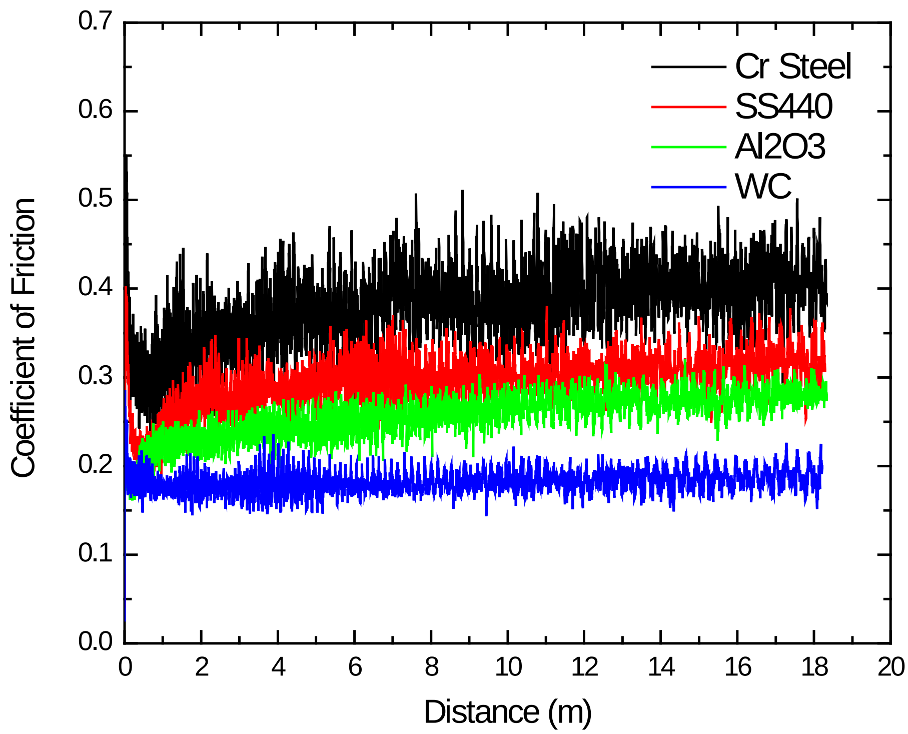


Fig. 3: Evolution of COF during the wear tests.

Fig. 4 and Fig. 5 compare the wear scars of the ball bearings after the tests measured by optical microscope and Nanovea non-contact optical profilometer, respectively, and Table 2 summarized the results of the wear track analysis. The Nanovea 3D profilometer precisely determines the wear volume of the ball bearings, making it possible to calculate and compare the wear rates of different ball bearings. It can be observed that the Cr Steel and SS440 balls exhibit much larger flattened wear scars compared to the ceramic balls, i.e. Al_2O_3 and WC after the wear tests. The Cr Steel and SS440 balls have comparable wear rates of 3.7×10^{-3} and 3.2×10^{-3} m^3/N m, respectively. In comparison, the Al_2O_3 ball shows an enhanced wear resistance with a wear rate of 7.2×10^{-4} m^3/N m. The WC ball barely exhibits some minor scratches on the shallow surface after the wear test, resulting in a significantly reduced wear rate of 3.3×10^{-6} mm^3/N m.

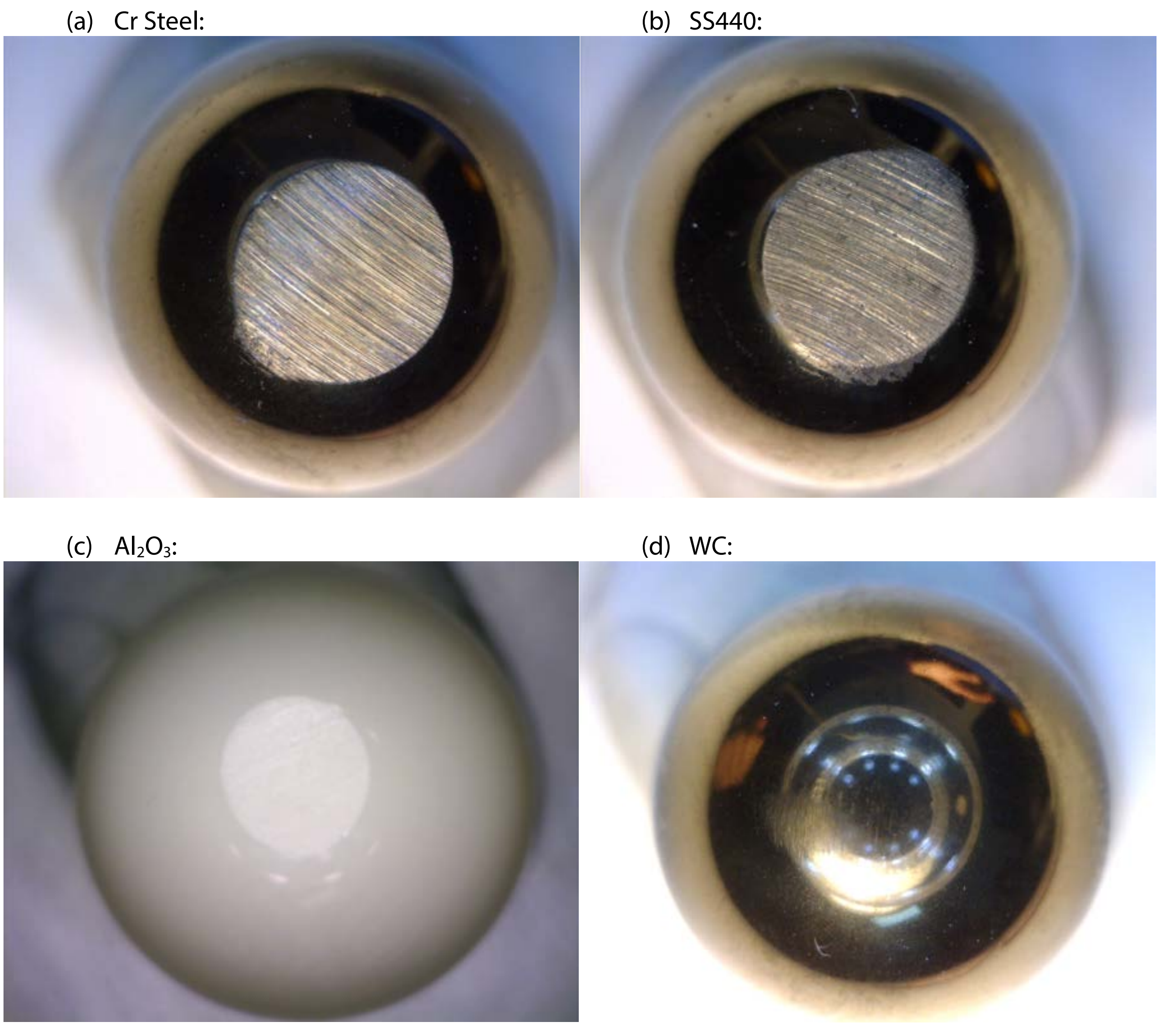


Fig. 4: Wear scars of the ball bearings after the tests.

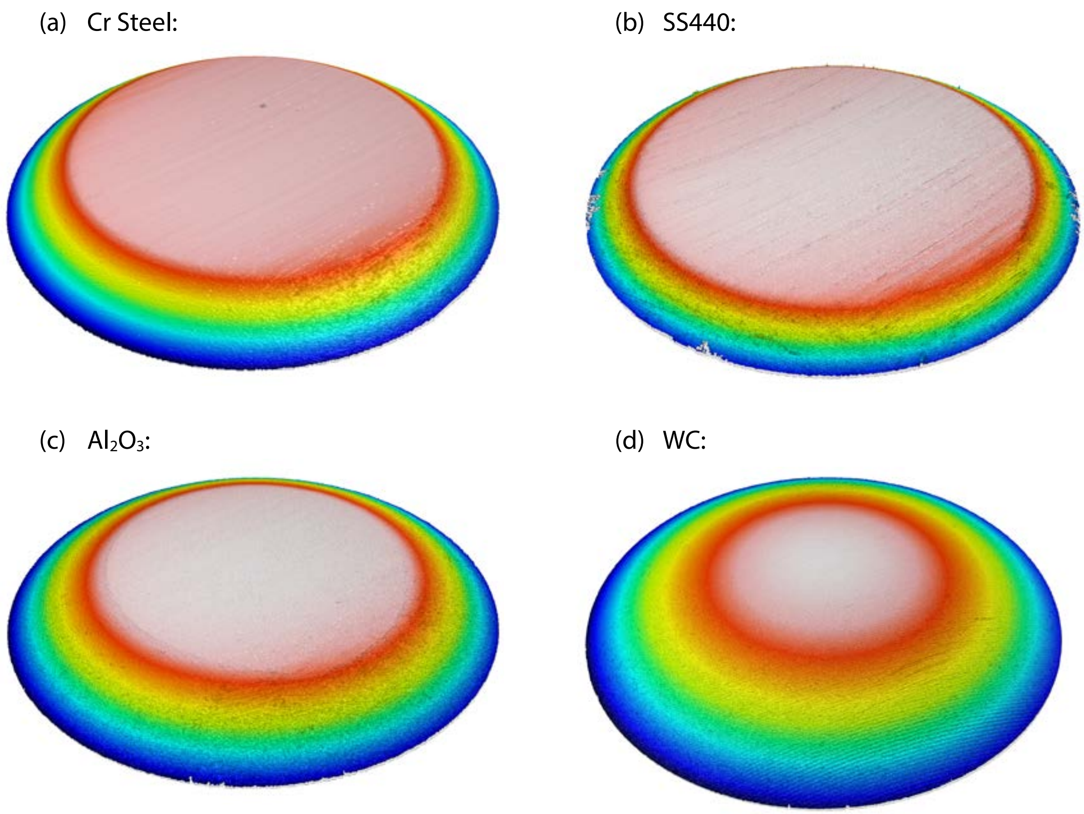


Fig. 5: 3D morphology of the wear scars on the ball bearings.

	Wear Volume mm^3	Wear rate $mm^3/N\ m$
Cr steel	3.390	3.7×10^{-3}
SS440	2.950	3.2×10^{-3}
Al_2O_3	0.657	7.2×10^{-4}
WC	0.003	3.3×10^{-6}

Table 2: Wear scar analysis of the ball bearings.

Fig. 6 shows the wear tracks on the sand papers against different ball bearings under the optical microscope. It is evident that the sandpaper shows severely worn wear track against the WC ball, which possesses the best wear resistance. The WC ball removes the sand particles as it slides on the sandpaper. In comparison, the Cr Steel and SS440 ball leave a large amount of metal debris on the wear track of the sand paper.

The above observation further demonstrates the importance of the capacity to continuously change the wear track radius by an automated motorized radial positioning motor during the pin-on-disc wear test of the ball bearings. It ensures that the ball bearing always slides on a new surface of the sandpaper, which significantly improves the repeatability of the wear resistance test on the ball.

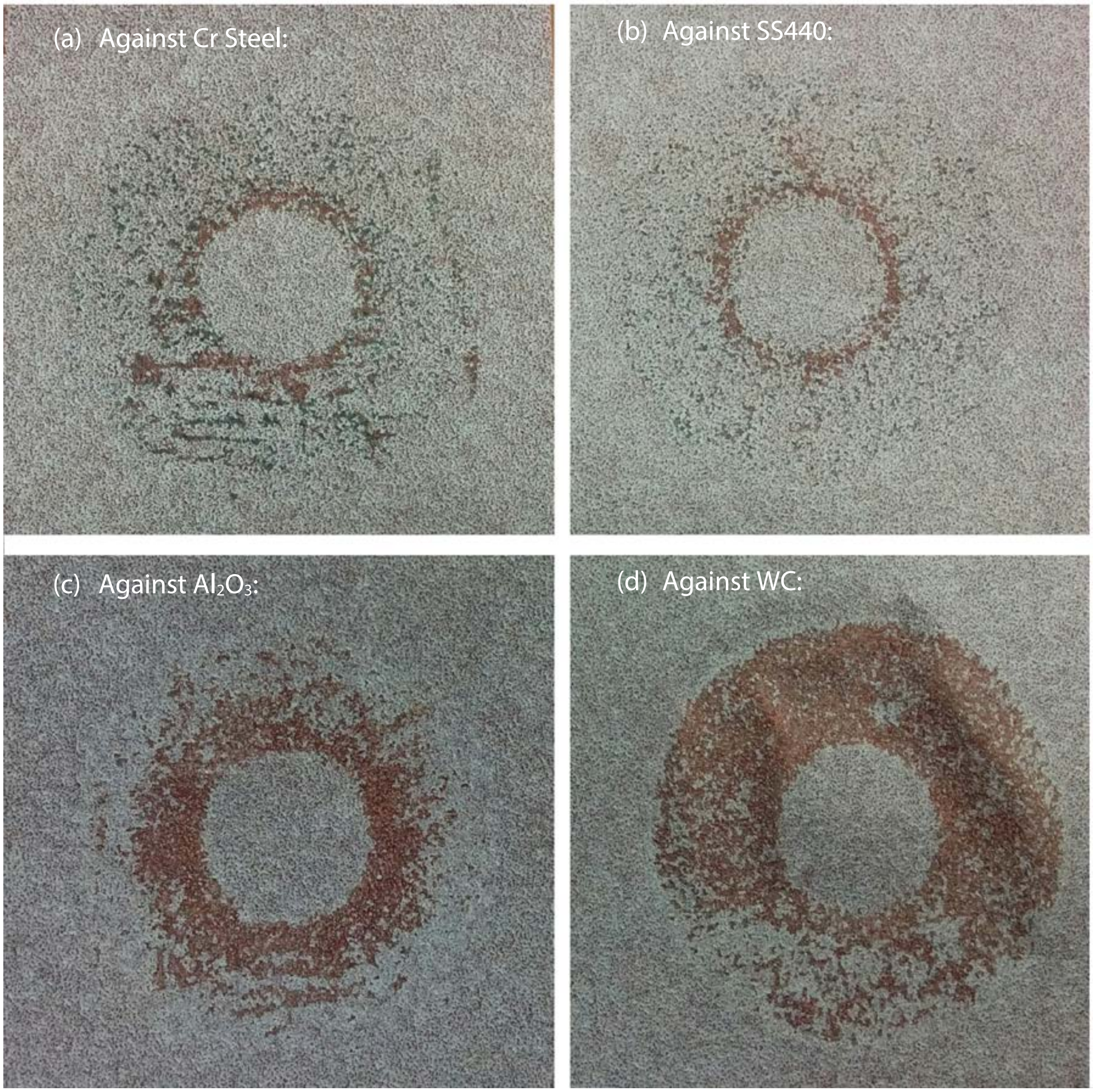


Fig. 6: Wear tracks on the sand papers against different ball bearings.

CONCLUSION

The wear resistance of the ball bearings under a high pressure plays a vital role in their service performance. The ceramic ball bearings possess significantly enhanced wear resistance under high stress conditions and reduce the time and cost due to bearing repairing or replacement. In this study, the WC ball bearing exhibits a substantially higher wear resistance compared to the steel bearings, making it an ideal candidate for bearing applications where severe wear takes place.

The Nanovea Macro Tribometer is designed with high torque capability for loads up to 500 N and precise controlled motor of rotational speeds from 0.01 to 2000 rpm. It offers repeatable wear and friction testing using ISO and ASTM compliant rotative and linear modes, with optional high temperature wear and lubrication modules available in one pre-integrated system. This unmatched range allows users to simulate different severe work environment of the ball bearings including high stress, wear and high temperature, etc. It also provides an ideal tool to quantitatively assess the tribological behaviors of superior wear resistant materials under high loads.

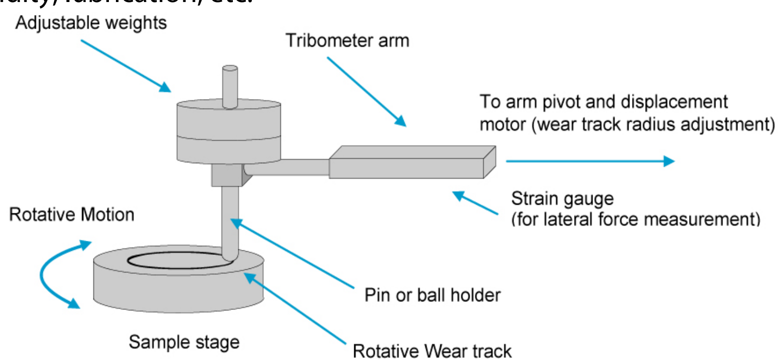
Nanovea 3D non-contact profilometer enables precise wear volume measurement and offers a tool to analyze the detailed morphology of the wear tracks, providing more insight in fundamental understanding of wear mechanism.

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

APPENDIX: MEASUREMENT PRINCIPLE

PIN-ON-DISC WEAR PRINCIPLE

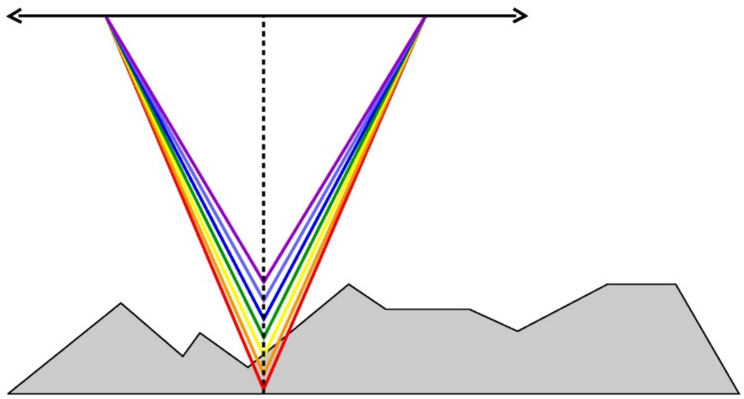
A flat or a sphere shaped indenter is loaded on the test sample with a precisely known force. The indenter (a pin or a ball) is mounted on a stiff lever, designed as a frictionless force transducer. As the plate slides in a rotational motion, the resulting frictional forces between the pin and the plate are measured using a strain gage sensor on the arm. Wear rate values for both the pin and sample may also be calculated from the volume of material lost during a specific friction run. 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 Chromatic Confocal technique uses a white light source (LED) that passes through a series of lenses, called an optical pen, which has a high degree of chromatic aberration. The refractive index of the lenses will vary the focal distance of each wavelength of the white light. In effect, each separate wavelength of the white light will focus at a different distance from the optical pen, creating the measurement range. When a surface of interest is within the measurement range a single wavelength of the white light will be in focus while all others will be out of focus. The white light is then reflected back through the optical pen, then through a pin hole filter that allows only the focused wavelength to pass through to a CCD spectrometer. The CCD will indicate the wavelength in focus, which corresponds to a specific distance for a single point.

- Physical Wavelength Measured + No Algorithms Needed for Results = Higher Accuracy.
- Level of accuracy independent of form, roughness level, illumination and measurement speed.
- No special leveling procedure required.
- Most claim very high resolutions. Nanovea provides high accuracy.



CHROMATIC CONFOCAL MEASUREMENT

Chromatic Confocal by design ensures the highest accuracy of all optical techniques. Specifically when measuring surfaces that are geometrically complex (randomly rough surfaces). Other techniques are subject to many error sources that are simultaneously present and it is not possible to remove or compensate for them or even to estimate their combined influences. The Profilometers offer high accuracy across the widest range of materials and surfaces conditions including tissues, biomaterials, polymers, plastics, metals, composites and ceramics. Examples of particularly demanding applications where Chromatic Confocal performs better than any techniques includes: corrosion pits, textured surfaces such as paper towel and sand paper, scratches and wear tracks, angular tooling parts and many more.