

# **NANOVEA** **TRIBOMETER**

# **NANOVEA<sup>®</sup>**

A Better Measure.

Offering More than **25 Years** of Material Science Experience



## **RESEARCH AND CONSULTATION**

Extensive range of research content such as brochures, application notes, publications, and videos.



## **EXPERT ASSISTANCE**

Dedicated Tribology experts happy to guide you through any question or project request.



## **CUTTING EDGE INNOVATION**

At Nanovea we are always developing cutting edge technologies and standards. We innovate our instruments so that you can innovate your own products.



## **PRE AND POST INSTALLATION SUPPORT**

Full walk-through and guide to make sure the instrument is installed perfectly. Dedicated support team to help you after your instrument has been installed.

## WHY USE A TRIBOMETER?

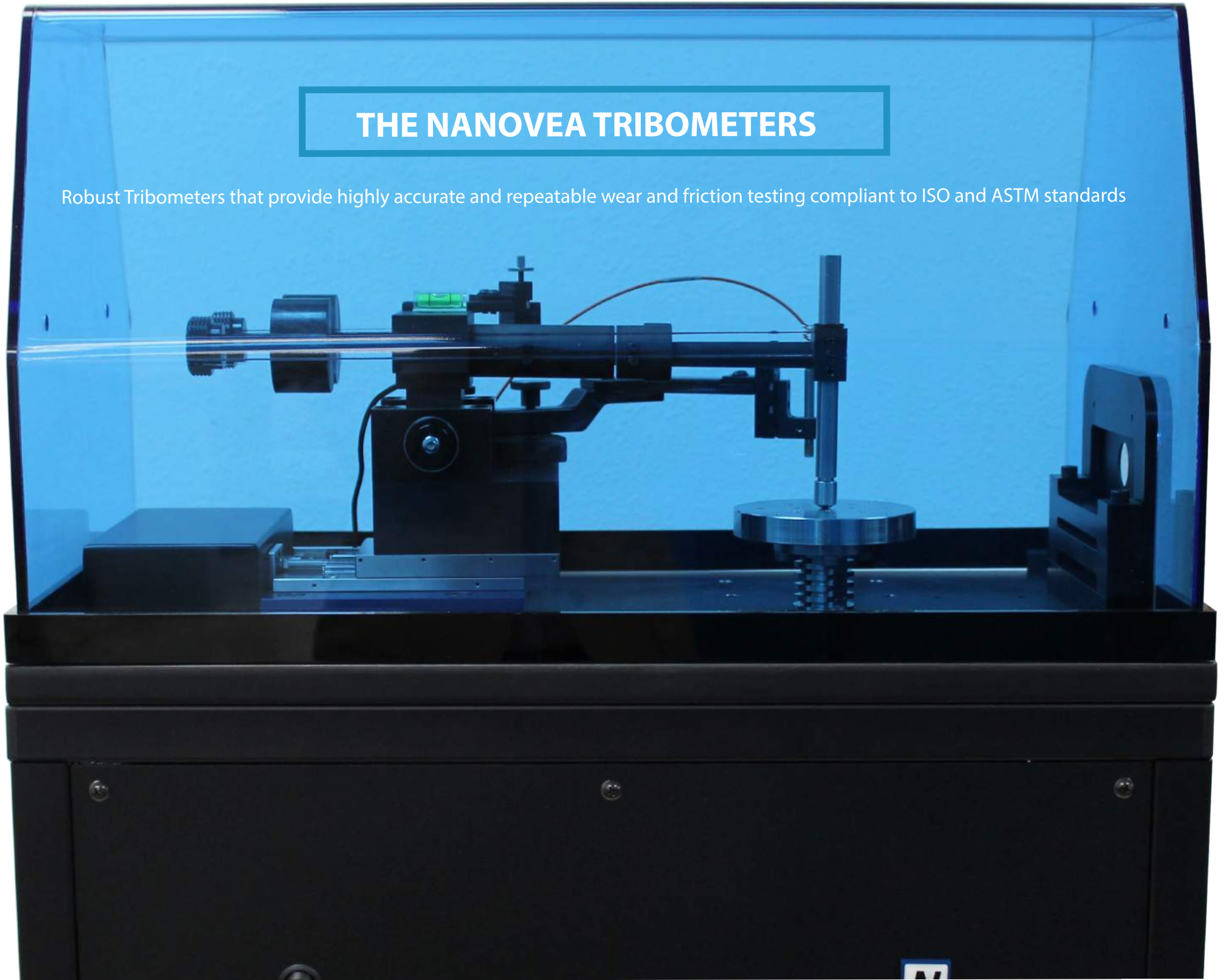
Tribometers help replicate real life applications in a wide range of industries including Automotive, Aerospace, Consumer Products, and Industrial Applications.

Environmental modules on the Tribometer allow for testing under specific conditions such as wear of tires during the winter or during mining operations involving liquids and corrosive elements.



## THE NANOVEA TRIBOMETERS

Robust Tribometers that provide highly accurate and repeatable wear and friction testing compliant to ISO and ASTM standards

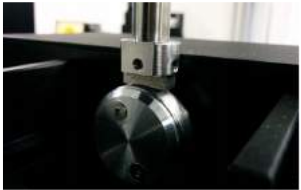


# NANOVEA T50

- Benchtop with Loads up to 60N
- Highest Stability with solid 20mm thick steel plate base
- High Quality Bearings for smooth rotation & longevity
- Best Accuracy Friction measurement with direct load cell



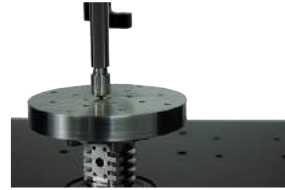
## TESTING MODULES



Block-On-Ring



Linear



Rotative



Ring-On-Ring

*\*Limited Capability*

## ENVIRONMENT MODULES



Corrosion



High Temperature



Low Temperature



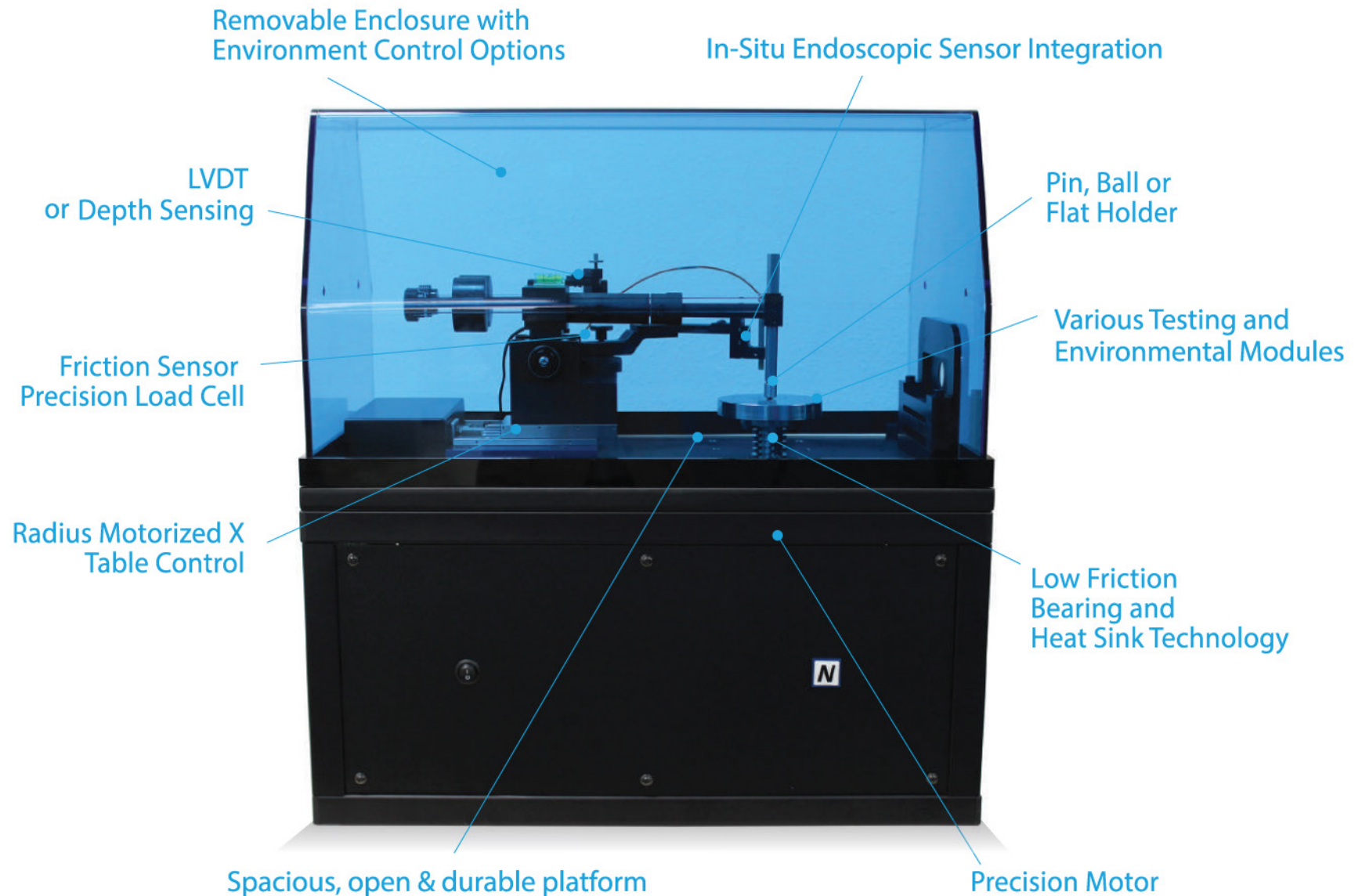
Liquid



Humidity and Inert Gases



# Unmatched Speed Control. Robust and Stable Design.



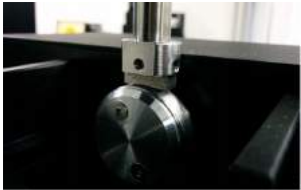
60 x 39 x 62cm

# NANOVEA T100

- Advanced Pneumatic Loading Technology
- Perfect Vertical Loading
- Direct Friction Measurement from independent load cell sensor
- Integrated Full Track Profiling and Visual Imaging



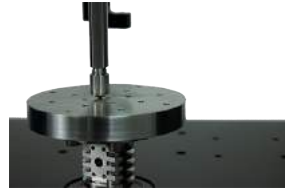
## TESTING MODULES



Block-On-Ring



Linear



Rotative



Ring-On-Ring



Scratch

## ENVIRONMENT MODULES



Corrosion



High Temperature



Low Temperature

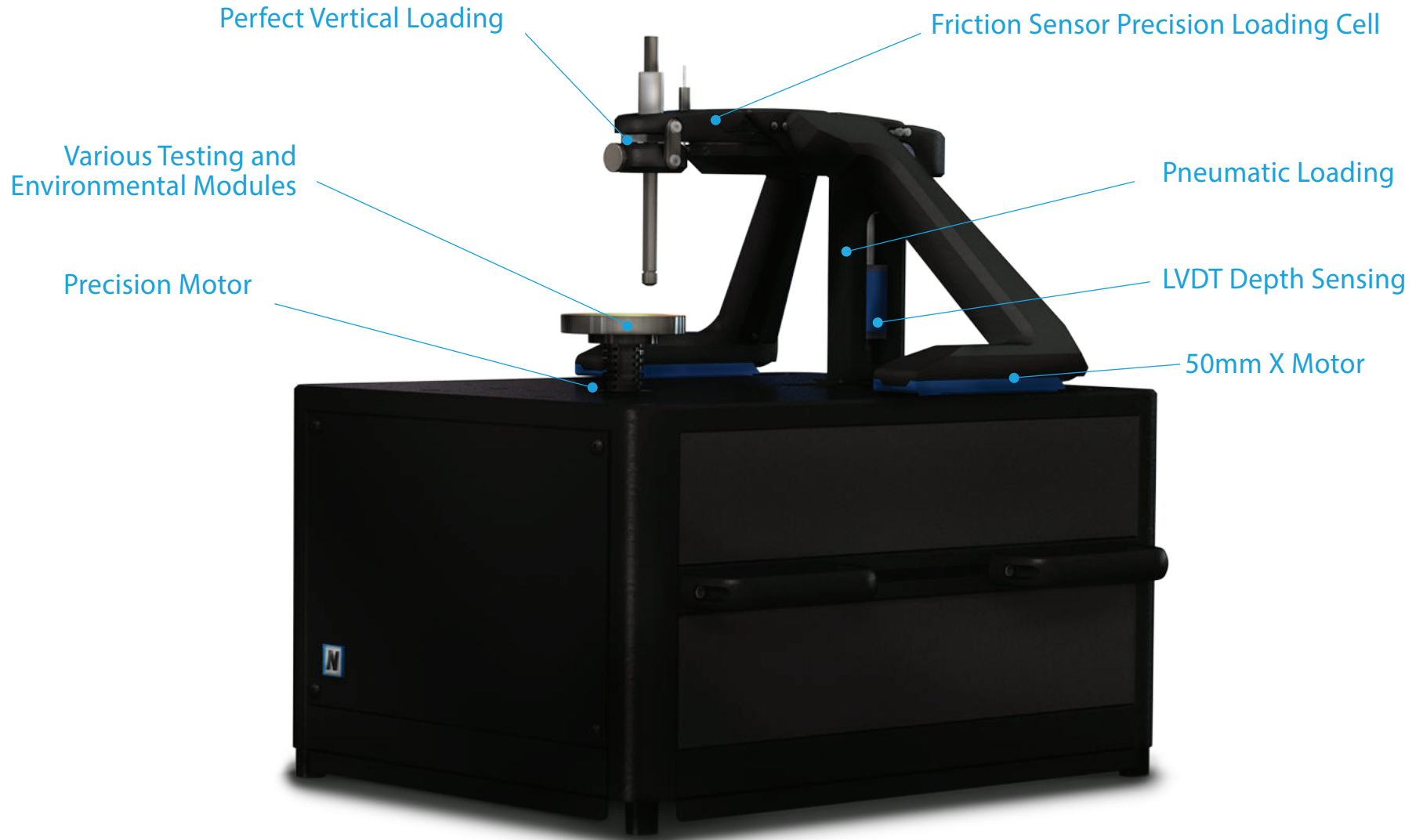


Liquid



Humidity and Inert Gasses

# Advanced Pneumatic Loading Technology.

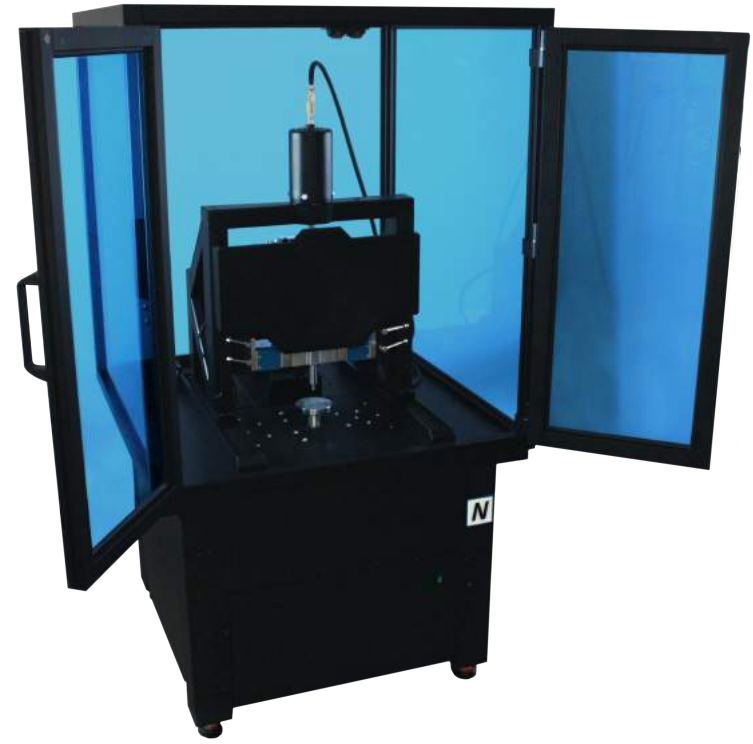


65 x 52 x 65cm

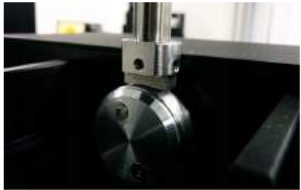


# NANOVEA T2000

- Advanced Pneumatic Loading Technology
- Additional loading for real life fatigue and oscillation simulations
- Direct Friction Measurement from independent load cell sensors
- Integrated Full Track 3D Profiling and Visual Imaging



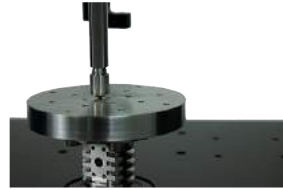
## TESTING MODULES



Block-On-Ring



Linear



Rotative



Ring-On-Ring



Four Ball



Scratch

## ENVIRONMENT MODULES



Corrosion



High Temperature



Low Temperature

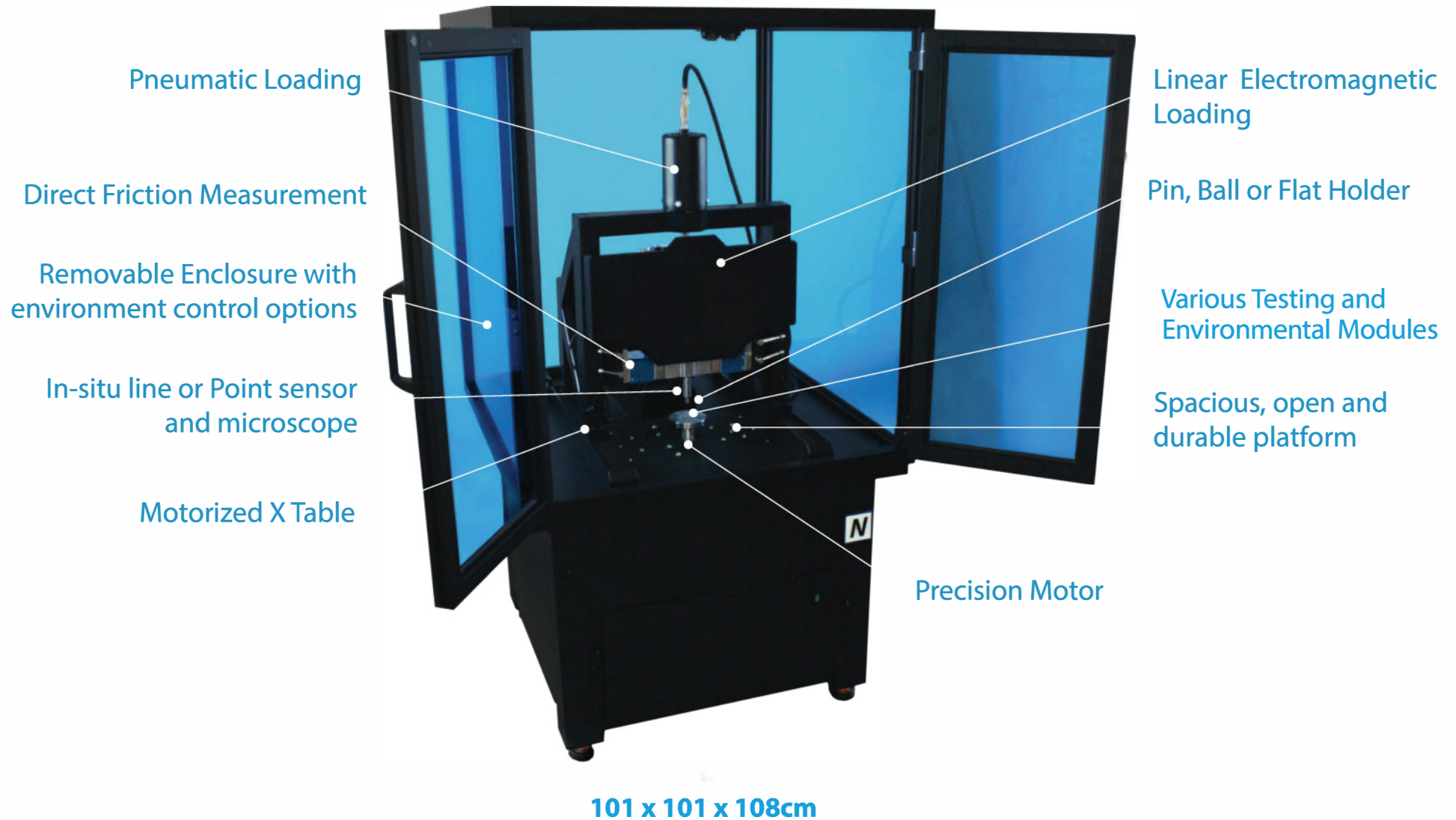


Liquid



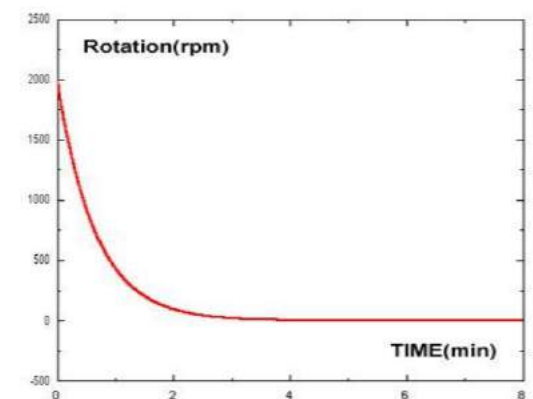
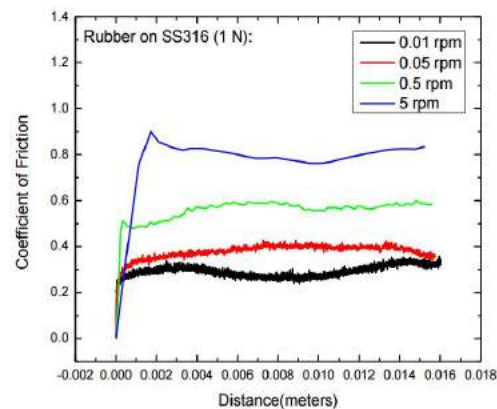
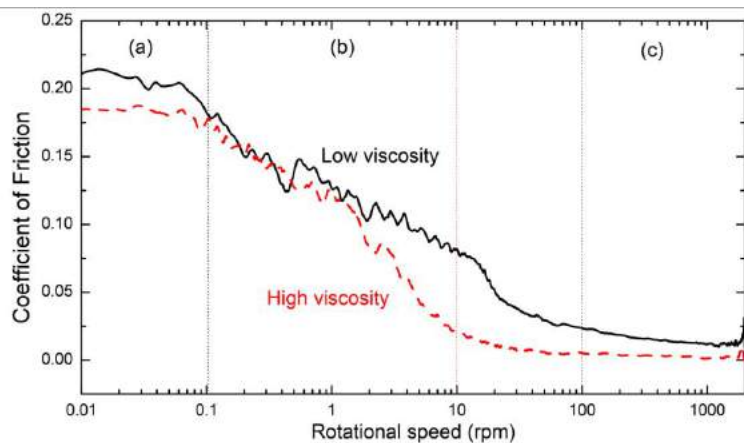
Humidity and Inert Gasses

# Highest Level of Accuracy. Widest Range of Applications.



# ADVANCED MOTOR TECHNOLOGY | T50, T100, T2000

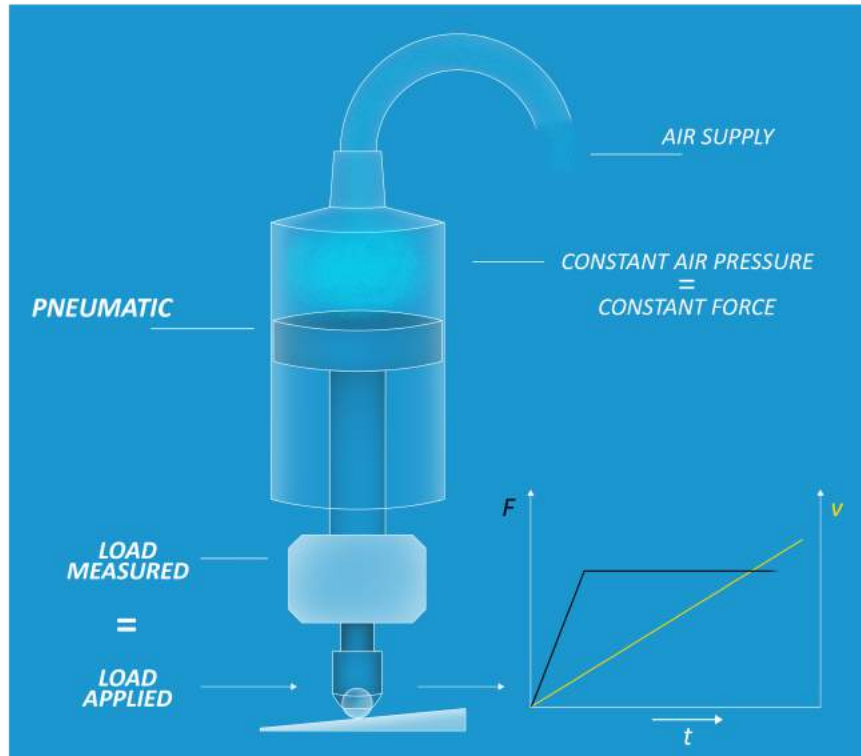
- Unmatched Speed Control w/ 20bit internal speed encoder
- Ultimate Positioning Precision w/ 16bit external position ( $>0.006^\circ$ )
- Widest Speed Range 0.01 to 15000rpm
- Study of quasi static coefficient of friction (0.01 to 0.1rpm)
- Powerful | Max Intermittent Torque up to 14.7Nm (T2000) and 4.4Nm (T50)
- Instantaneous Speed Change | 0 to 1000rpm in 0.15 seconds



# ADVANCED PNEUMATIC LOADING TECHNOLOGY | T100, T2000

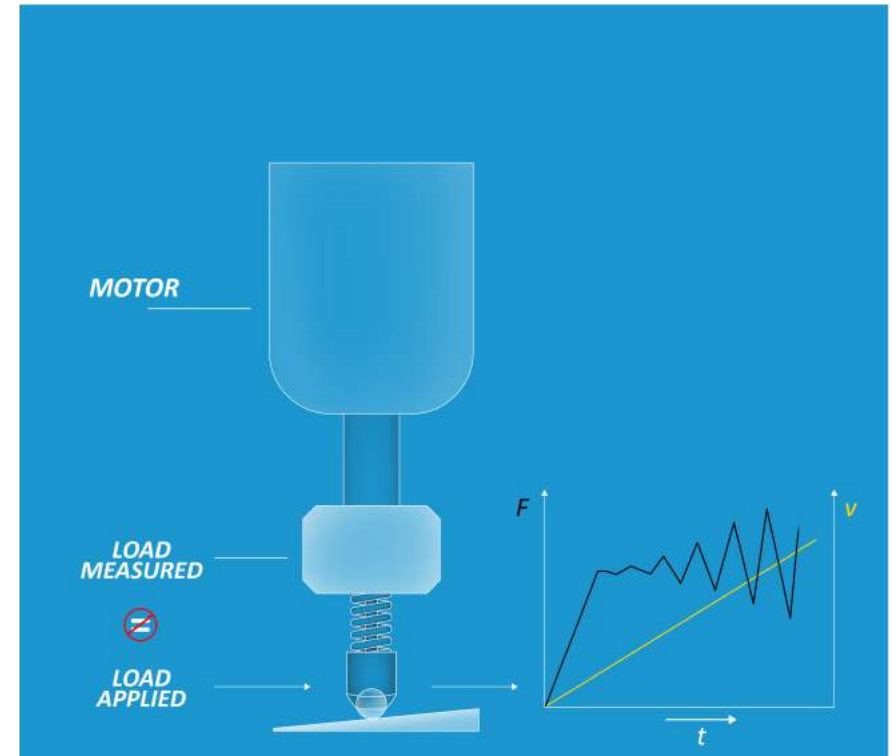
- Accurate Load Measurement (no spring in-between load cell and surface)
- Superiority of air medium as a natural fast damper
- Unmatched stability of load applied (fast speed & rough surfaces)
- Speeds of up to 15000 rpm

## ADVANCED PNEUMATIC



**N** **NANOVEA**

## PASSIVE SERVO MOTOR

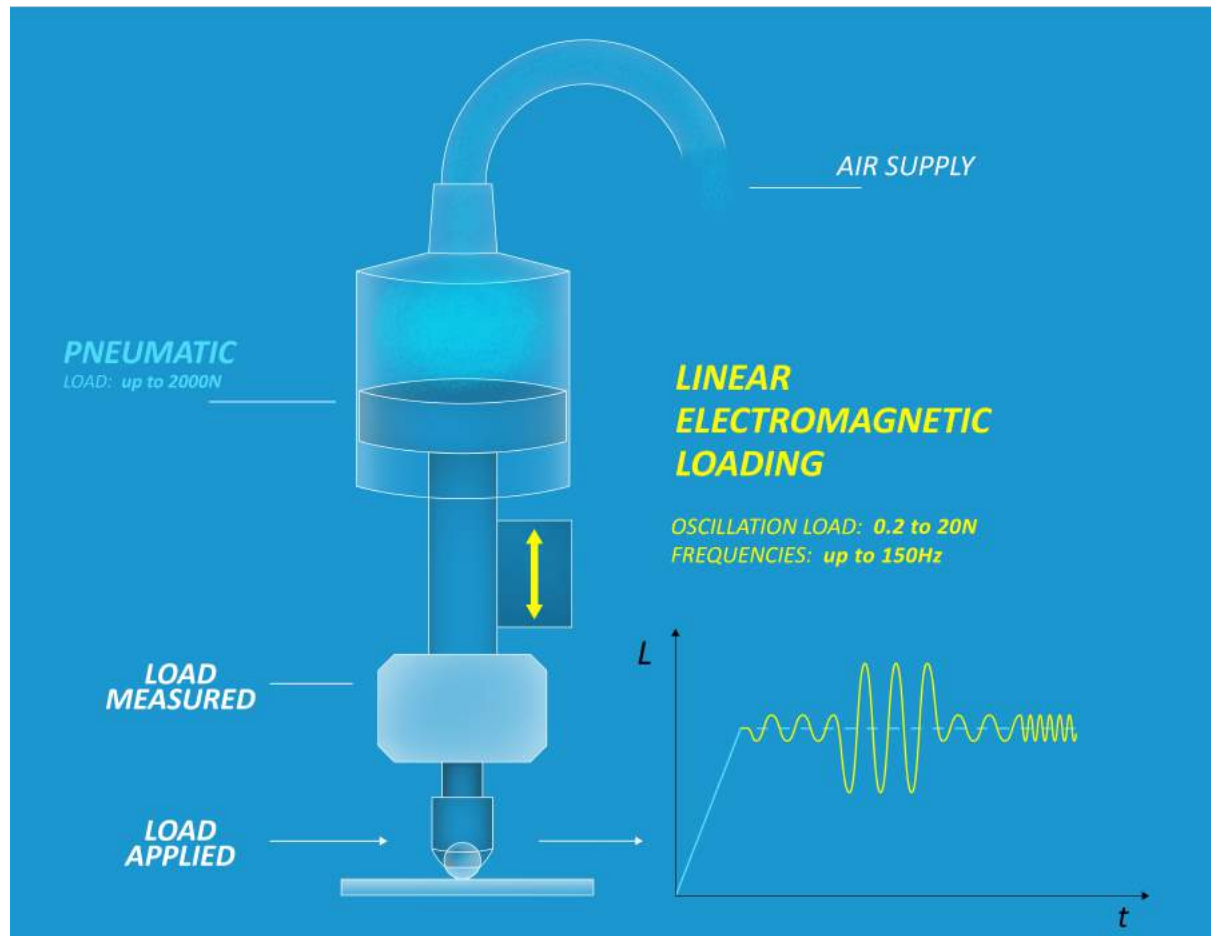


**OTHERS**

# CONTROLLED VERTICAL FATIGUE LOADING UP TO 150HZ | T2000

- Superimposed Pneumatic Oscillation Loading of 0.2 to 20N load
- Adjustable frequencies of load oscillation up to 150Hz
- Unique control for real life fatigue and vibration effects on wear

## DUAL LOADING SYSTEM







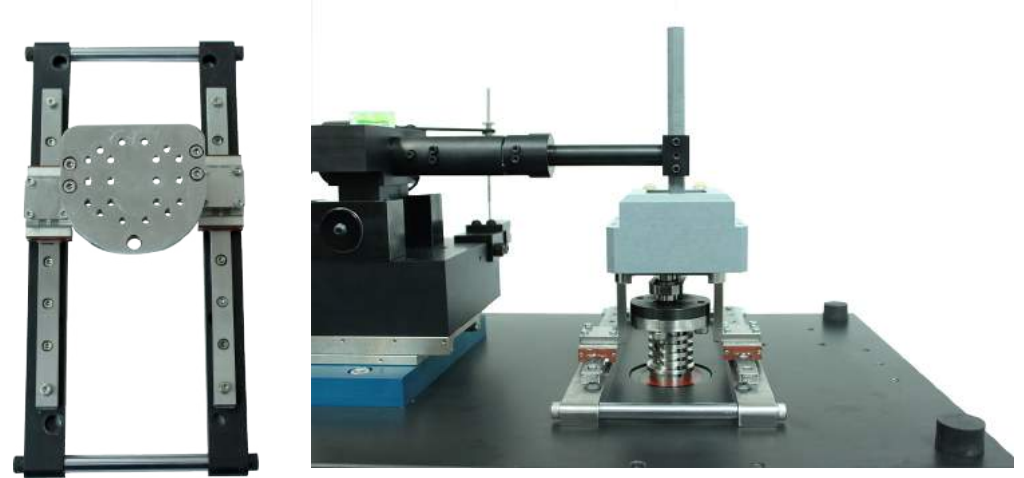
## TRIBOMETER TESTING MODULES

In order to replicate real life applications, Nanovea offers a versatile range of testing modules that can test a multitude of applications.

# LINEAR MODULE | T50, T100, T2000

Linear Wear Friction Test reproduces the linear reciprocating motion found in many real-world tribology mechanisms.

A flat, pin or ball tip is loaded onto a test sample with a precise weight. The test samples can be of varied shape (such as cylindrical) as long as there is a flat zone of a certain length in the direction of movement. The length of the track can be adjusted prior to starting the measurement. As the test starts, the tip creates a linear wear track (zigzag pattern also possible). Because of the integrated 16bit external position encoder, friction can be displayed for any specific point for each pass. This is essential to accurately study the trend of friction across the full length of the test.



## Standards:

- ASTM G133 • ASTM G171 • ASTM F732

## Properties Analyzed:

- Friction Coefficient • Wear Rates • Failure Points • Electrical Resistance
- Lubrication & Corrosion Studies • Friction vs Speed • Scratch Hardness
- Friction versus Load

## Sensors

- Depth • Acoustic Emission • Electrical Resistance

## Rotating Lower Sample

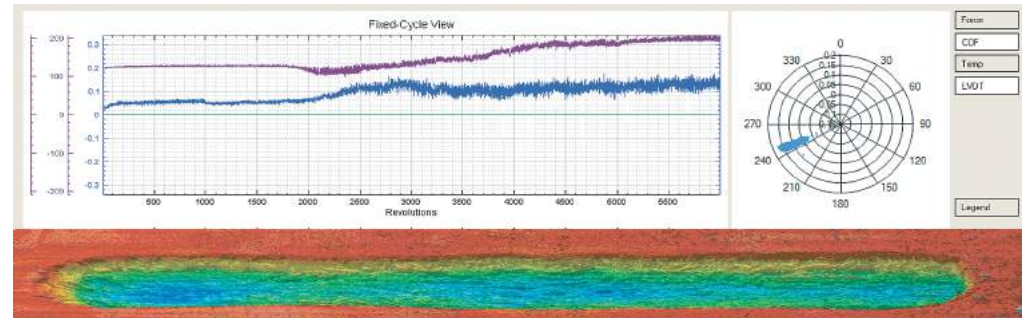
- Samples with flat surface for the test • Cylindrical Samples
- Any types of materials.

## Fixed Upper Sample:

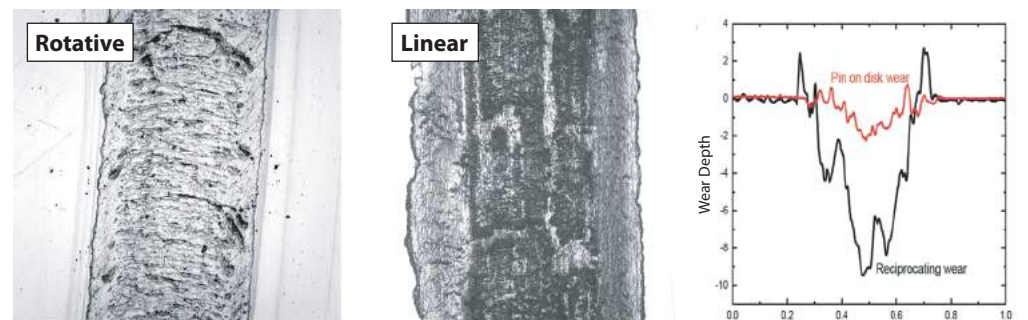
- 3, 6, 10, and 25mm ball • Custom ball sizes • Custom Pins
- Flat Plate • Custom geometries • Diamond, WC, Rubber and many other materials

## Environmental Conditions:

- 1100°C Heating Oven • Liquid Cup and Liquid Heating up to 150 °C
- Lubrication Drop by Drop • Humidity Control • Cooling Chamber -40 °C
- Corrosion Testing Cup • Various Gases • Vacuum (Custom)



Friction & depth vs cycle/ time using precise fix cycle view with 3D profiler integration



Same system linear testing provides a critical comparative wear evaluation

# ROTATIVE MODULE | T50, T100, T2000

Rotative Wear Friction Test reproduces the rotational motion found in many real-world tribology mechanisms.

A flat, pin or ball tip is loaded onto a test sample with a precise weight and at a specific position from the center of rotation. As the sample starts rotating, the tip creates a rotational wear track. An arc test (back and forth) can also be performed at a specific degree range.

## Standards:

- ASTM G99 • DIN 50324 • ASTM D3702 • ASTM D2266
- ASTM D4172 • ASTM G132

## Properties Analyzed:

- Friction Coefficient • Wear Rates • Failure Points • Electrical Resistance
- Lubrication Studies • Friction vs Speed • Stribeck Curve • Scratch Hardness
- Static Coefficient of friction • Static Coefficient of friction
- Friction versus load (T2000) • Spiral Test at constant linear speed
- Semi Linear (back and forth) Wear and Friction at specific angles
- Friction and wear distribution across the lap

## Sensors

- Depth • Acoustic Emission • Electrical Resistance

## Rotating Lower Sample

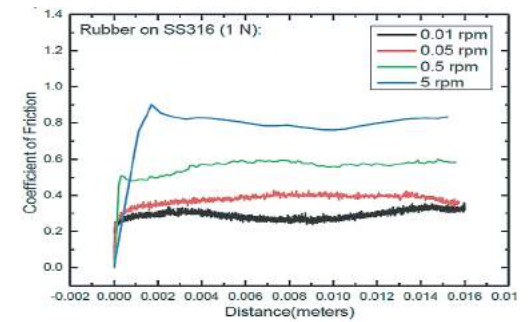
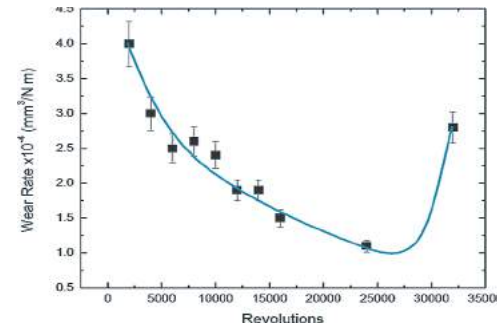
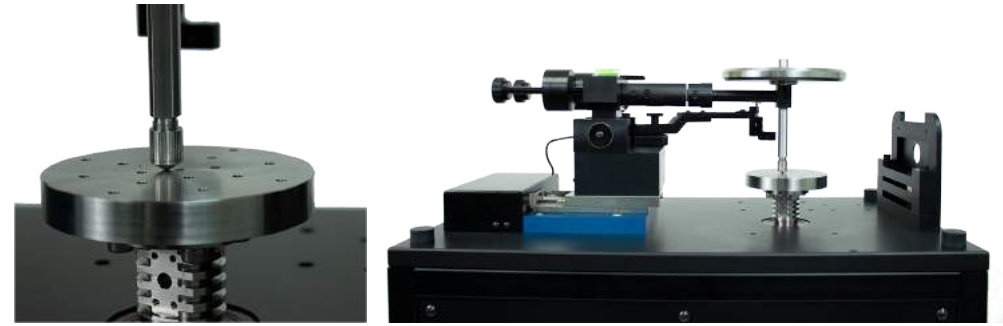
- Samples with flat surface for the test

## Fixed Upper Sample:

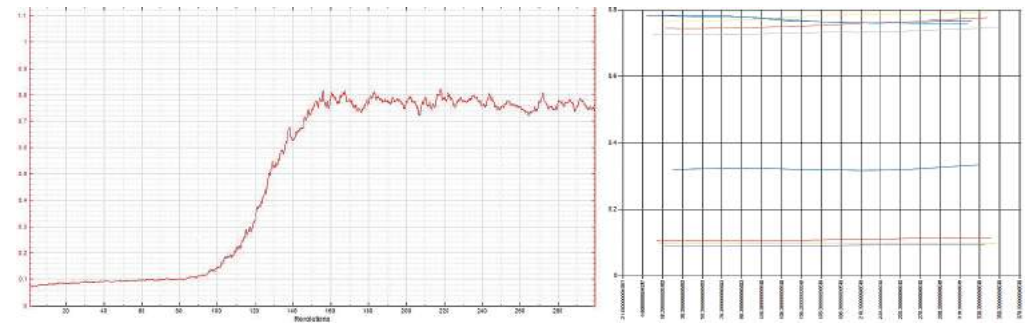
- 3, 6, 10 and 25mm ball • Custom ball sizes • Custom Pins
- Flat Plate • Custom geometries • Diamond, WC, Rubber and many other materials

## Environmental Conditions:

- Fully Removable 1100°C Oven • Cooling down to - 150°C
- Liquid Cup & Liquid Heating to 150°C • Lubrication Drop by Drop
- Humidity Control • Various Gases • Vacuum (Custom)



Continuous rotative coefficient of friction and depth by LVDT or depth profile by in-situ 2D optical profiler



A 16bit encoder provides Friction vs. Time at fixed position & Friction vs. Position (0° to 360°) at various cycles



# BLOCK-ON-RING MODULE | T50, T100, T2000

Block-on-Ring Test is a widely used technique that evaluates the sliding wear behaviors of materials in many different simulated conditions.

A Block-On-Ring test allows reliable ranking of material couples for specific tribological applications. A block is pressed down on a rotating ring.

## Standards:

- ASTM G77

## Properties Analyzed:

- Friction Coefficient • Wear Rates • Failure Points • Lubrication Studies
- Friction vs Speed • Friction vs Load (T2000)

## Sensors

- Depth • Acoustic Emission

## Rotating Lower Sample

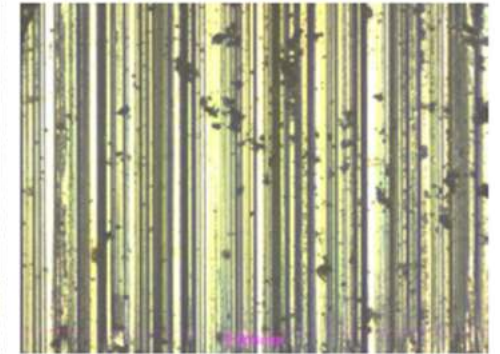
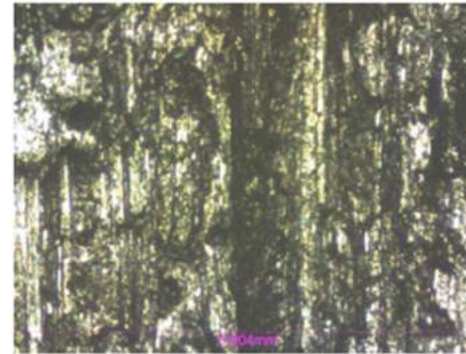
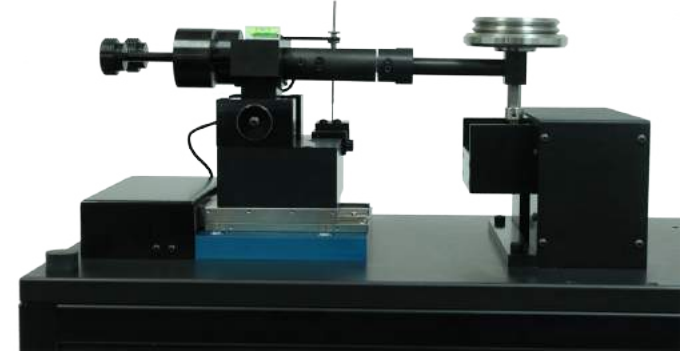
- Ring (34.98mm outer diameter) - material can vary
- Rotating speed capability up to 5,000 rpm

## Fixed Upper Sample:

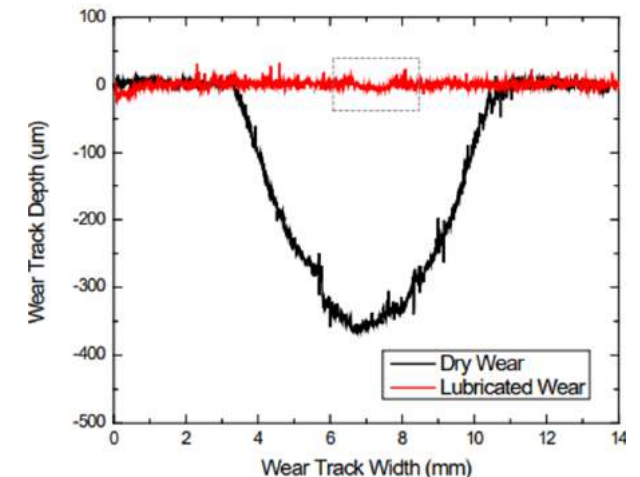
- Steel Block (15.75x10.16x6.35mm)  
(Diamond, WC, Rubber and many other materials) • 3, 6, 10 and 25mm ball
- Custom ball sizes • Custom Pins • Flat Plate • Custom geometries

## Environmental Conditions:

- Liquid Cup and Liquid Heating up to 150 °C • Lubrication Drop by Drop
- Humidity Control • Cooling Chamber -40 °C • Various Gases • Vacuum (Custom)
- Cryogenic Adapter (custom)



Wear scars of the blocks after (a) dry and (b) lubricated wear tests



# RING-ON-RING MODULE | T50\*, T100, T2000

Ring-on-Ring Test is also called a Thrust Washer Test.

This is when a ring or washer is pressed against another ring or flat surface for full contact friction and wear testing.

## Standards:

- ASTM D3702

## Properties Analyzed:

- Friction Coefficient • Wear Rates • Failure Points
- Lubrication Studies (custom) • Friction vs Speed

## Sensors

- Depth • Acoustic Emission

## Rotating Lower Sample

- Ring of any materials type of (Outer Diameter (OD): 28.5mm, Inner Diameter (ID): 25.4mm.) Other materials possible but same diameter • Other geometry (custom)

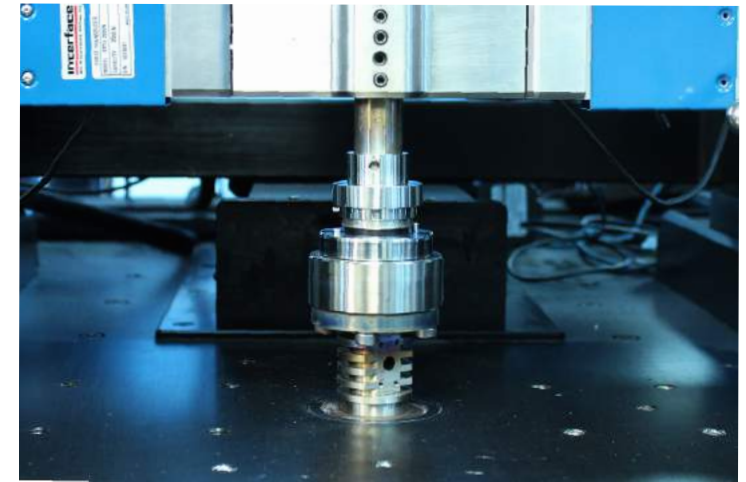
## Fixed Upper Sample:

- Ring of any materials type of (OD: 31.6mm, ID: 15.8mm)
- Other geometry (custom)

## Environmental Conditions:

- 1000°C Heating Oven • Liquid Cup and Liquid Heating up to 150 °C
- Lubrication • Humidity Control • Cooling Chamber -40 °C
- Various Gases • Vacuum (Custom)

*\*Limited Capability*





## FOUR BALL MODULE | T2000

Four Ball Testing is designed to test lubricant properties under various conditions.

The setup is three balls in contact that are fixed but rotates in relation to the center point. A fourth ball centered on that center point comes down to make contact and put controlled pressure. A lubricant to be studied fills the full area and friction is studied.

### Standards:

- ASTM D2266 • ASTM D4172 • ASTM D5183

### Properties Analyzed:

- Friction Coefficient • Lubrication Studies • Friction vs Speed
- Friction vs Load • Friction vs temperature of liquid, Incipient seizure load, Average wear-in scar

### Rotating Lower Sample

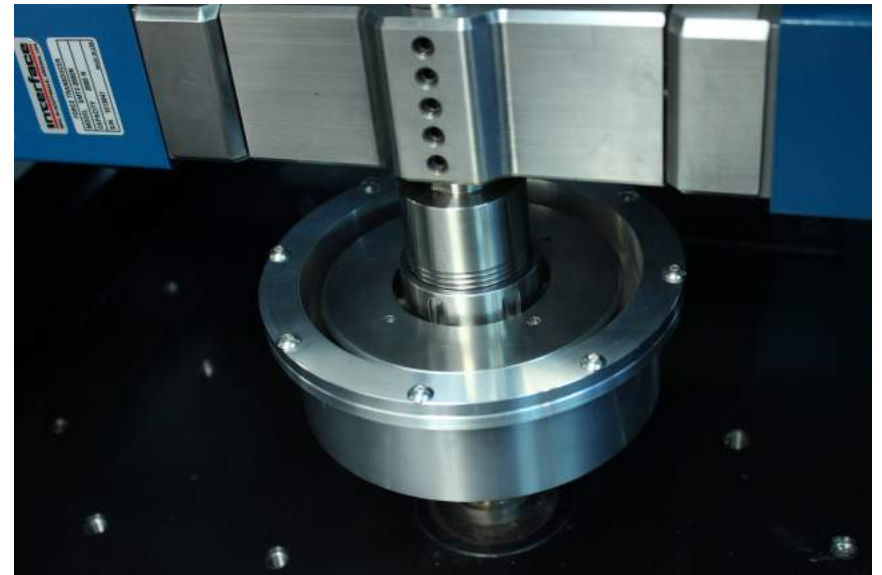
- (3) 1/2inch (12.7mm) Steel balls. Other ball materials can be used)

### Fixed Upper Sample:

- (1) 1/2inch (12.7mm) Steel balls. Other ball materials can be used.

### Environmental Conditions:

- Liquid Heating up to 150 °C



# SCRATCH TESTING | T100, T2000

During Scratch Testing, a conical spherical tip, diamond or WC, is drawn across the coated surface with an increasing load, resulting in various types of failure at specific critical loads. Micro Scratch Adhesion Testing identifies critical loads optically using a built-in video microscope. These critical loads are used to quantify the adhesive and cohesive properties of different film/substrate combinations. In addition, failure points can be determined using frictional force and depth measurements. Depth measurements provide the plastic and elastic portion of the deformation. Constant load scratch testing can be used, in mapping, to check the surface uniformity.

## Standards:

- ASTM D7187 • ASTM C1624 • ASTM D7027 • ASTM G171 • ISO 20502
- ISO 1518 • DIN EN 1071 • DVM-0058-PA

## Properties Analyzed:

- Cohesive & Adhesive failure • Adhesion Strength
- Marring (Resistance) and Crack/Fracture initiation
- Plastic & Elastic Deformation depth and others
- Full Scratch Image for post inspection using tracking zoomed view
- Tracking Zoomed View for easy post inspection with data depth, friction and AE analysis

## Sensors

- Depth • Acoustic Emission

## Rotating Lower Sample

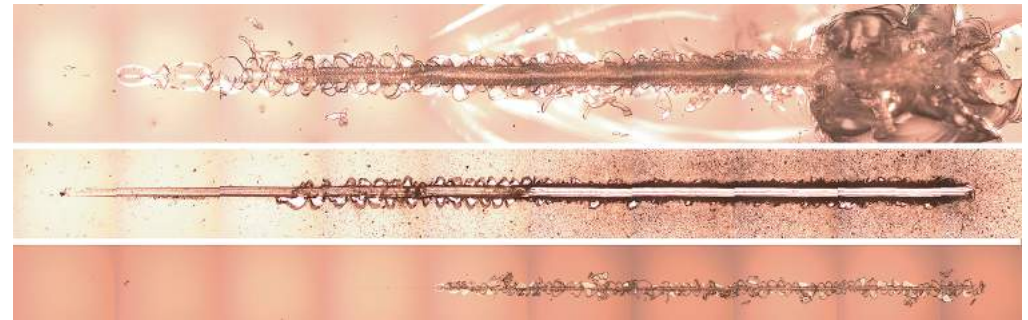
- Samples with flat surface for the test, Cylindrical Samples.
- Any types of materials.

## Fixed Upper Sample:

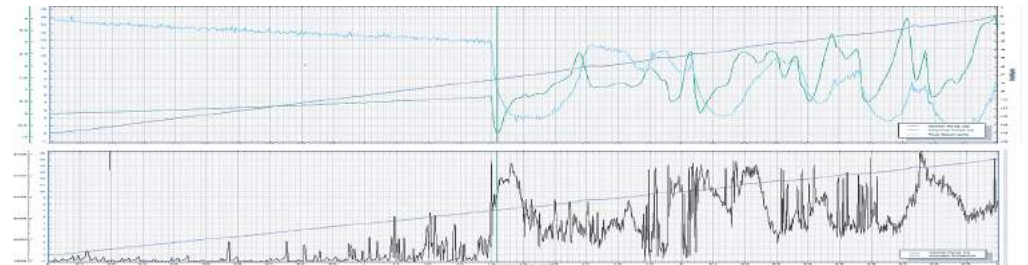
- Various sizes Sphero-conical or Rockwell Diamond or WC tips.
- Custom materials and geometries

## Environmental Conditions:

- Liquid Cup and Liquid Heating up to 150 °C • Lubrication Drop by Drop
- Humidity Control • Cooling Chamber -40 °C • Corrosion Testing Cup
- Various Gases • Vacuum (Custom)



Full scratch imaging for failure identification & analysis



Highly accurate friction, true depth & acoustic emissions measurement



## TRIBOMETER ENVIRONMENT MODULES

In order to replicate environmental applications, Nanovea offers Environmental Modules that can test various environmental effects.

# HOT TEMPERATURE

Temperature plays a critical role on the extent of wear damage to materials. The Tribometer conducts wear experiments at high temperatures up to 1100°C for the rotative and linear tests.

The contact of the wear process is totally enclosed in a removable large oven which ensures uniform and stable temperature surrounding the sample and the counter material. The thermal couple is either set up to be very close to the point of contact or directly touching the back on the ball inside the ball holder to achieve the best accuracy of the temperature reading. The unique heat sink design on the main shaft of the rotative motor makes air supply sufficient for cooling. The load cell is self-calibrated for high temperatures to ensure accurate data.

## Modules

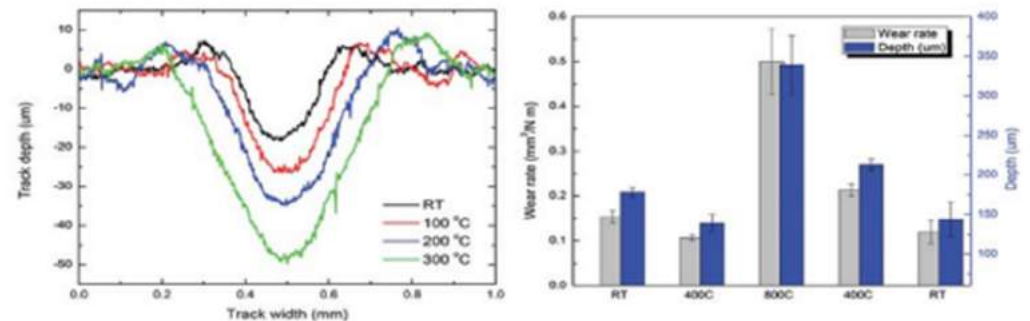
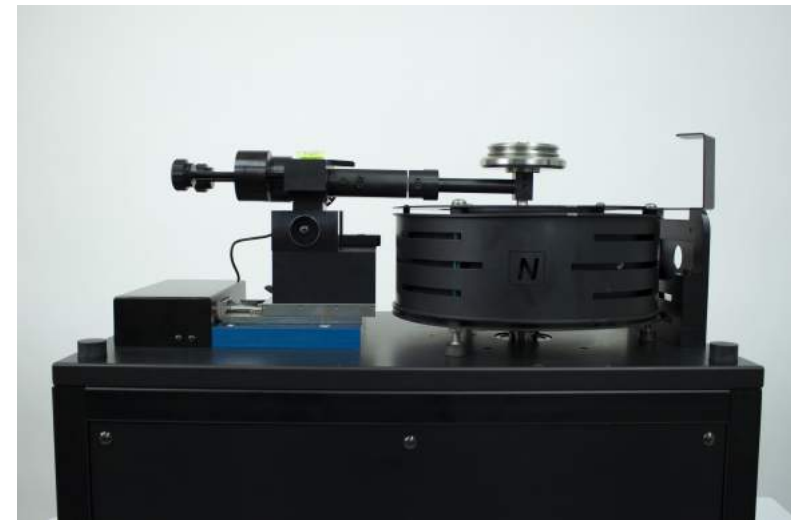
- Rotative
- Linear
- Scratch
- Ring-On-Ring

## Properties Analyzed:

- Temperature Wear & Friction Data

## Environment

- Inert Gas feed in the oven



Scratch Hardness evaluation at different temperatures and Wear Rate comparison at different temperatures



# COLD TEMPERATURE

To conduct wear experiments at cold temperatures down to -40C, the contact area of the wear process is totally enclosed in a removable enclosure in which cold dry air is introduced by positive pressure.

This ensures uniform and stable temperature surrounding the sample and the counter material during the wear test. The Cooling Unit and chamber are ideal for a wide range of applications such as tire rubber or other parts either subjected to colder temperatures. A cryogenic adapter can be setup on the system for temperature as low as -150C for the linear and rotative modules.

## Modules

- Rotative
- Linear
- Scratch

## Properties Analyzed:

- Temperature Wear & Friction Data

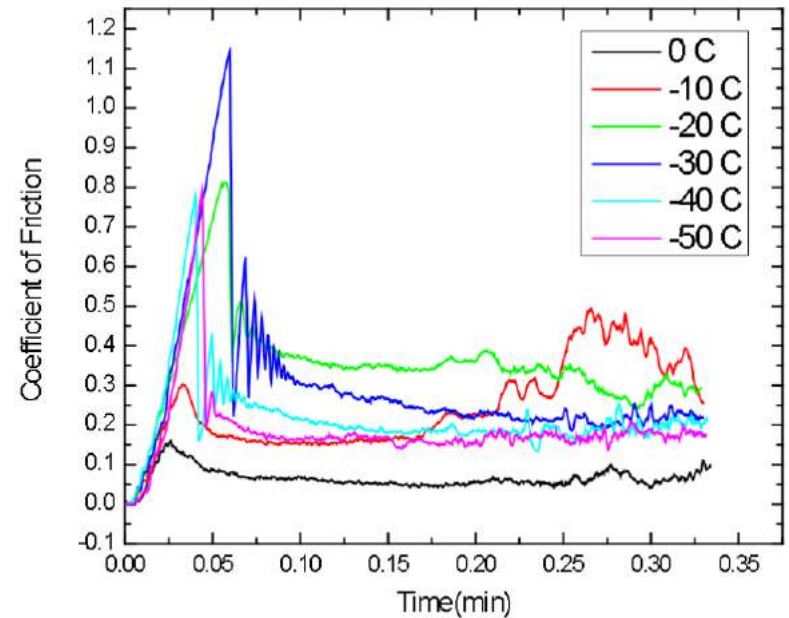
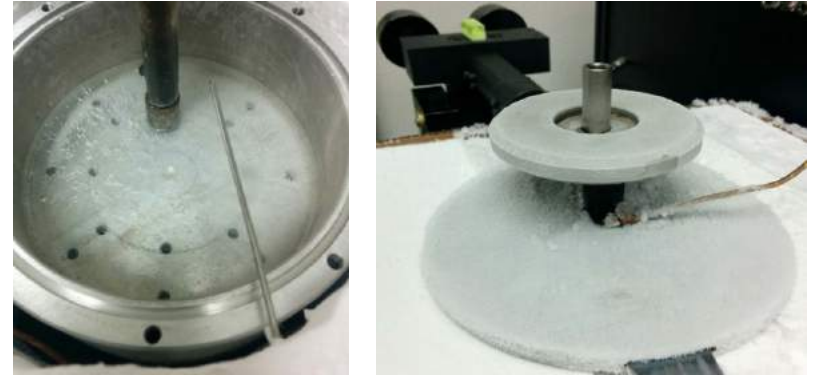


Fig. 3: Evolution of COF of the rubber ball on ice at different temperatures



# CORROSION

Tribocorrosion is a surface degradation process resulting from simultaneous tribological and electrochemical actions in a corrosive environment.

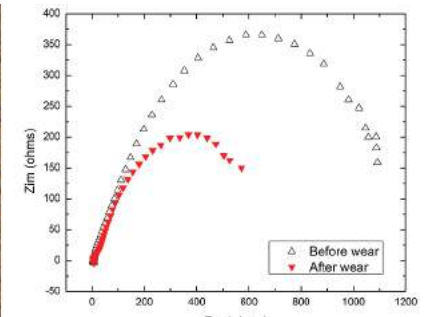
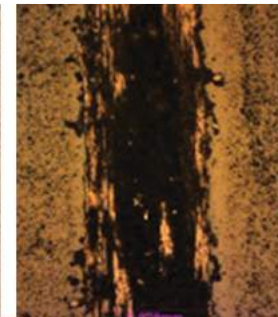
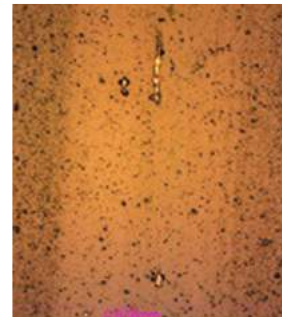
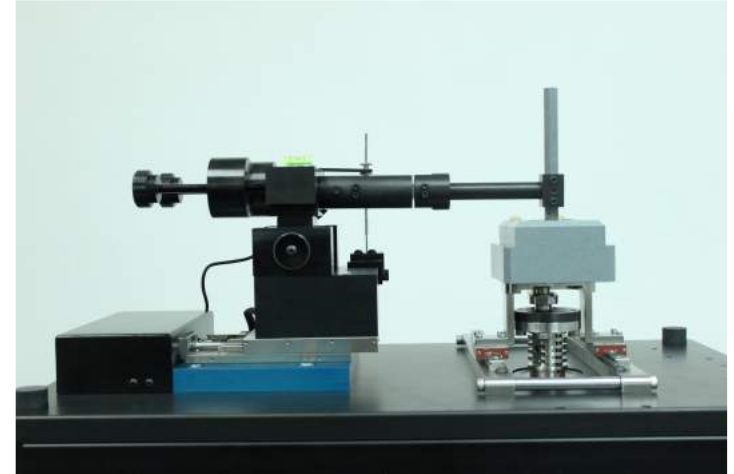
Wear and corrosion experiments are conducted simultaneously using a sliding ball-on-plate configuration, where the contact is totally immersed in the test electrolyte. The tribocorrosion module is a three-terminal electrochemical cell installed on the sample stage, with the sample, a platinum wire and an Ag/AgCl, NaCl (sated) electrode acting as working, counter and reference electrodes, respectively. The open circuit potential (OCP) is measured in situ to monitor the evolution of the tribocorrosion process. The reduction of OCP works as an indicator for the failure of the protective films. The change of coefficient of friction (COF) also provides insight in different stages of the wear development. The wear tests can be carried out under anodic or cathodic polarization conditions to either accelerate or inhibit the corrosion process, in order to investigate the effect of corrosion reactions on the tribocorrosion rate.

## Modules

- Rotating (custom) Max of 40N load
- Linear (Max of 40N)

## Properties Analyzed:

- Corrosion Resistance
- Tribocorrosion Behavior
- Wear at Open Circuit Potential
- Potentiodynamic Polarization
- Wear at Anodic/Cathodic Potential
- Electrochemical Impedance Spectroscopy Analysis



Wear tracks after dry/corrosive wear and Electrochemical Impedance Spectroscopy (EIS) analysis

# HUMIDITY AND INERT GASSES

The humidity control module with enclosure allows for humidity level down to below 5% and up to the dew point.

The enclosure can also be used to feed inert gases. Controlling humidity is important for some applications. In many applications, a change in humidity can affect the coefficient of friction and therefore change the wear property of the material.

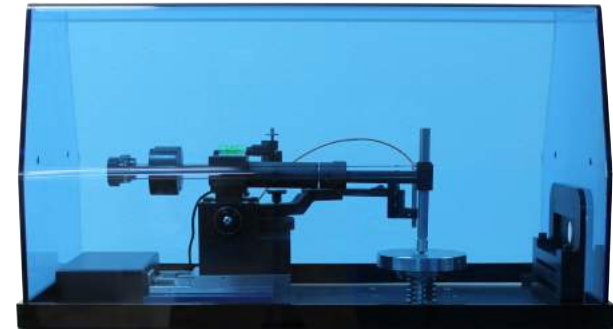
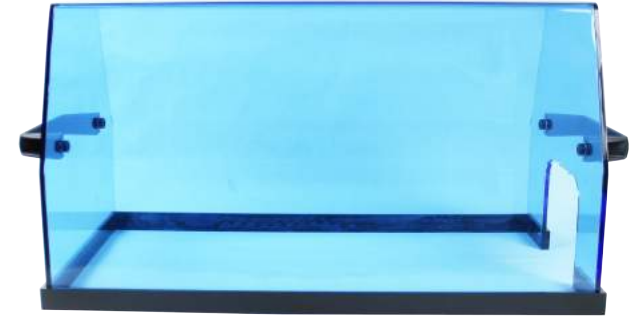
Vacuum version available on request.

## Modules

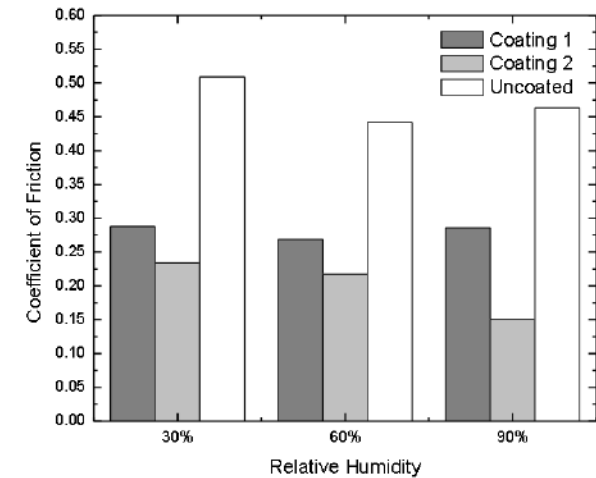
- Rotative
- Linear
- Scratch
- Block-on-Ring & Ring-on-Ring Wear (custom)

## Properties Analyzed:

- Friction & Wear vs % humidity



Formation of small water droplets on the coated glass surface

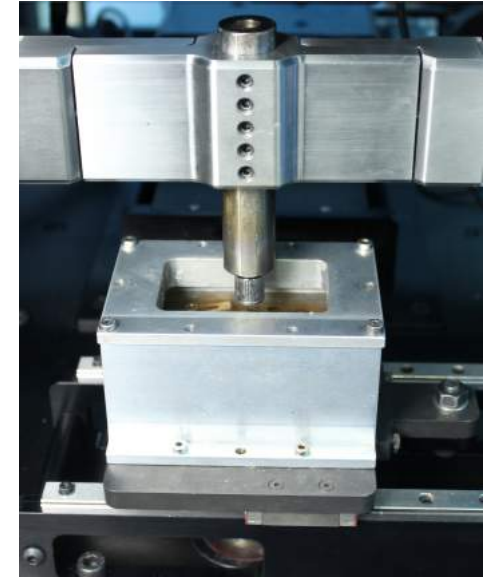


Average COF during the pin-on-disk tests in different relative humidity

# LIQUID

Liquid modules are used to carry out wear and friction experiments in liquids or lubricants. Different liquid solutions can simulate the wear process for realistic applications for various industrial applications.

For example, the biomaterials for biological replacements such as joints, stents, and dental roots, require excellent long-term resistance and adequate strength in a liquid environment. The parts in the motor engines should be protected by proper lubrication to reduce wear and friction and to extend lifespan. Combining with the precise control of speed and continuous change of speed, a continual Stribeck Curve for the test lubricant can be measured. A liquid heating coil is available to heat the liquid in the cups up to 150°C. An accessory to the cup is the drop by drop lubrication option which allows lubrication test even at 15000rpm.

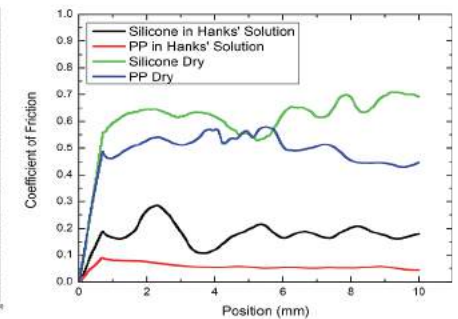
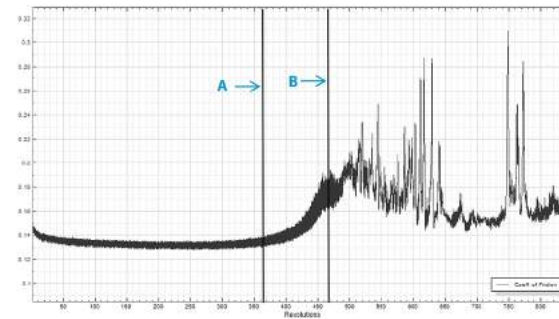


## Modules

- Rotative
- Linear
- Scratch
- Block-on-Ring & Ring-on-Ring Wear (custom)
- Four Ball (custom)

## Properties Analyzed:

- Wear Rates
- Friction versus speed
- Stribeck Curve



Evolution of COF at different stages of wear and COF of different polymers in liquid conditions

# VISUAL AND MEASURING TOOLS

## 2D & 3D OPTICAL PROFILER

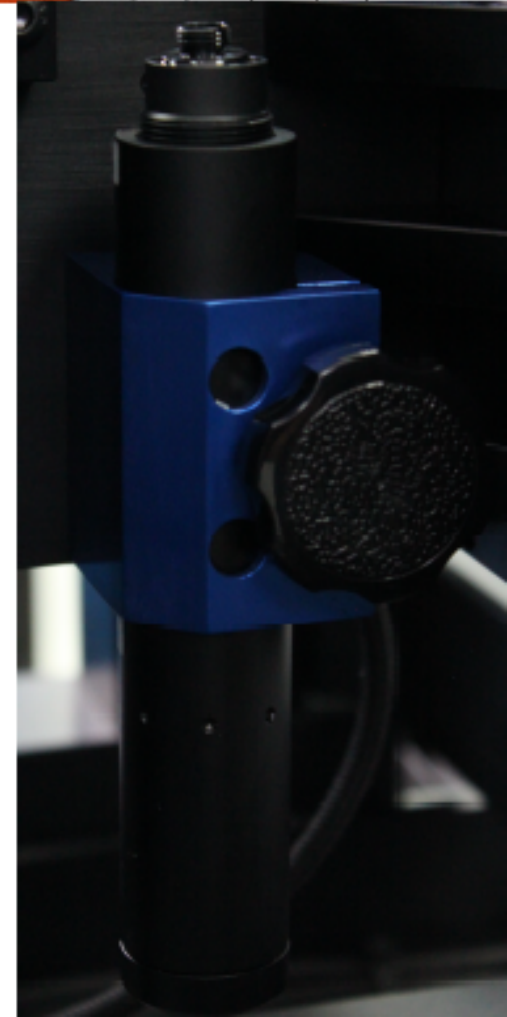
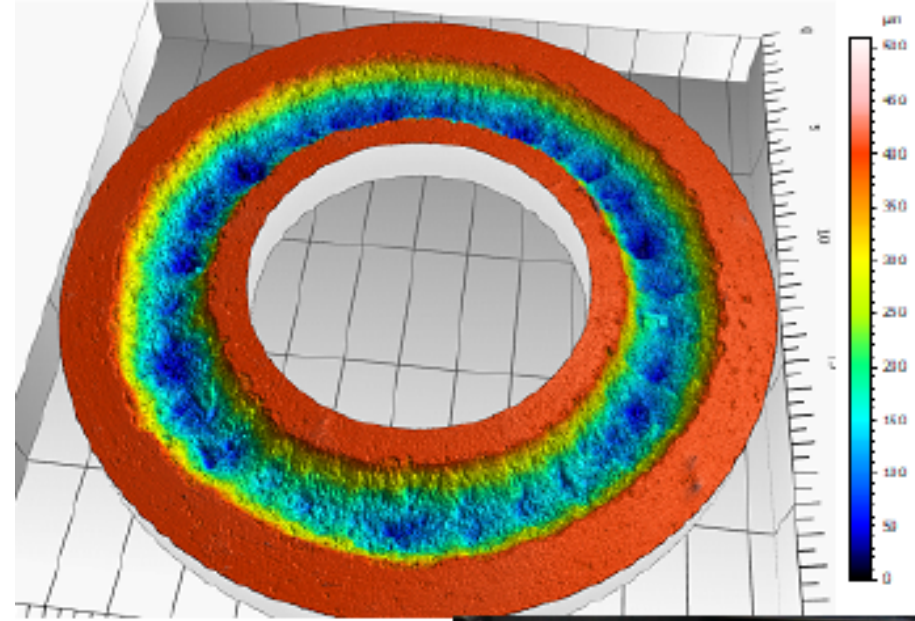
### T2000

Either the standard or the high speed optical sensors can be installed on the T2000 to measure the full wear track in 3D and obtain a very accurate wear rate calculation. The high speed sensor can measure the full wear track in a few seconds.

The Chromatic Confocal technology also used in our profilometer line. This technology is ideal for tribology applications since it works on any type of materials and it is the best optical technology to measure rough high angular surfaces. To also obtain full X-Y Profilometry capability, an upgrade is available to add a Y stage to the existing X stage. The profiler, which has extended capability, can also be used for roughness and many other surface topography studies.

### T50 / T100

The endoscopic sensor can be installed on the T50 or T100 to measure the wear track.





# VISUAL AND MEASURING TOOLS

## VIDEO ZOOM IMAGING

Only available on the T2000, this video zoom imaging allows the full automatic stitch image of the full wear track to be taken.

## DIGITAL IMAGING

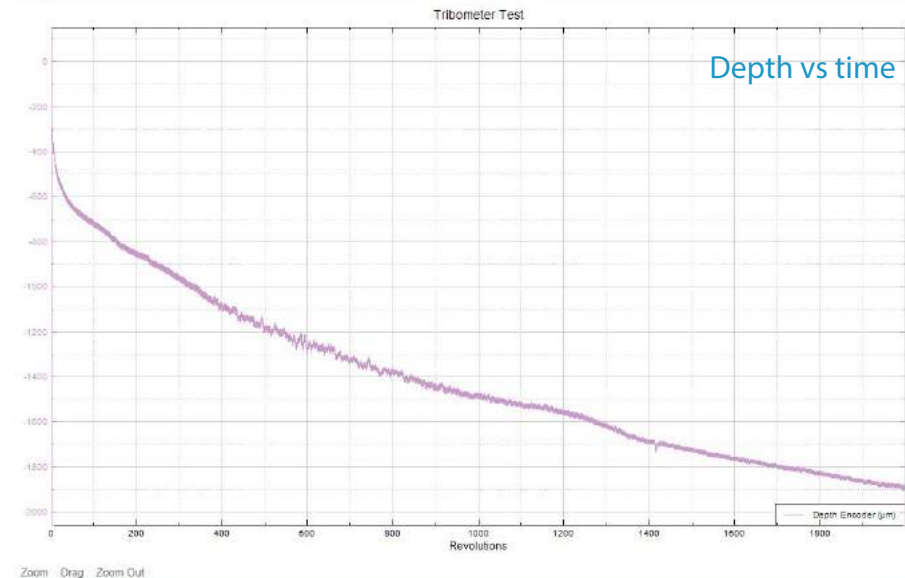
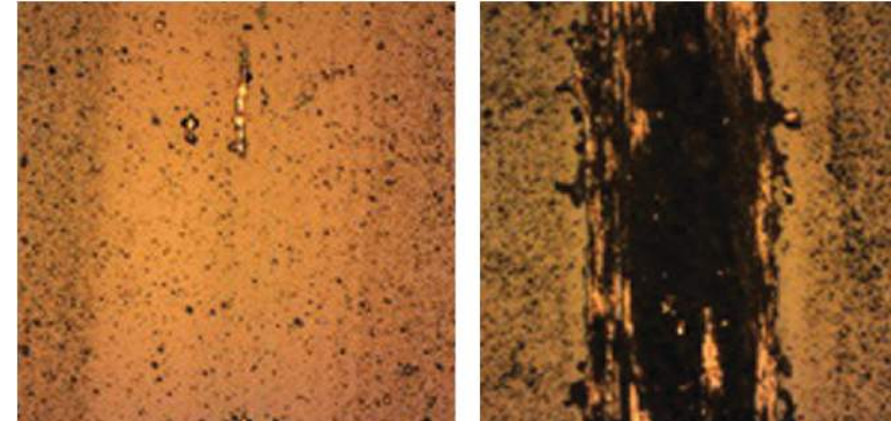
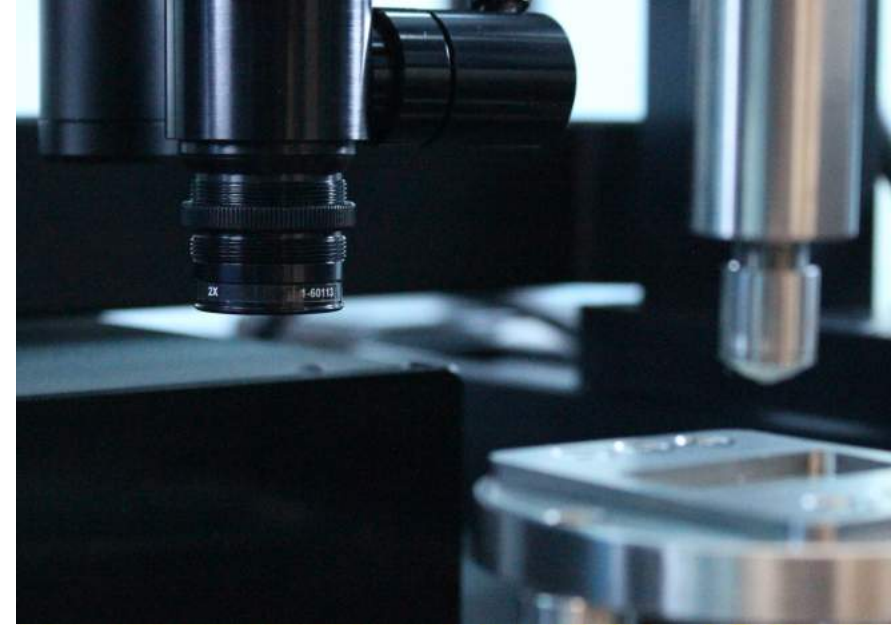
On the T50 or T100, a flexible mobile zoom imaging capture can be used by hand to conveniently allow zoom-in microscope capability.

## DEPTH ENCODER

Only available on the T2000, an extremely fast and high precision encoder (10nm) tracks the height change on the surface during the test even at speed up to 15000rpm. This data can be used to calculate wear rates. It also gives information on rate of wear change during tribology mechanisms.

## LVDT Depth Sensor

On the T50 or T100, an LVDT is available to measure depth change during the test.



BASE	T50	T100	T2000
Max Testing Loads	60N	100N	2000N
Load Resolution	10mN	0.006mN	0.12mN
Load Noise Floor	N/A	0.25mN	20mN
Loading Type	Weights	Advanced Pneumatic	Advanced Pneumatic
Fatigue Loading	N/A	N/A	0.2 to 20N
Frequency of Oscillation	N/A	N/A	up to 150Hz
Frictional Force Maximum   Resolution	(+/-)20N   2.4μN	(+/-)100N   6μN	(+/-)1000N   6μN
Motor Max Torque up to 1500rpm   Max Speed	1.27Nm   0.6Nm	1.27Nm   0.6Nm	4.9Nm   2.5Nm
Intermittent Max Torque up to 1500rpm	4.4Nm	4.4Nm	14.7 Nm
20Bit Speed and 16bit Position Encoders	Included	Included	Included
X Motorized Travel	50mm	50mm	250mm
Depth Sensor Range   Resolution	2mm   0.1nm	2mm   0.1nm	100mm   10nm
Instrument Dimension	61 x 35 x 69cm (Benchtop)	65 x 52 x 65cm (Benchtop)	101 x 101 x 188cm (Stand-Alone)
Weight	67kg	70kg	202kg

### ROTATIVE

Max Rotational Speed	5000   15000rpm	5000rpm	5000   15000rpm
Min Rotational Speed	0.01   0.05rpm	0.01rpm	0.01   0.05rpm
Speed Acceleration (0 to 1000rpm)	0.45   0.15 sec	0.45 sec	0.45   0.15 sec
Disk Size (Mounting Area)	100mm Dia.	100mm Dia.	100mm Dia.
Optional Modes	Block on Ring, Ring on Ring	Block on Ring, Ring on Ring, Scratch	Block on Ring, 4balls, Ring on Ring, Scratch

### LINEAR

Max. Stroke Range	25mm	25mm	25mm
Maximum Frequency (Up to 5mm stroke)	60Hz	60Hz	60Hz
Mounting Area	62 x 76mm	62 x 76mm	62 x 76mm

### SCRATCH

Max Scratch Length	N/A	40mm	50mm
Scratch Speed	N/A	0.002-10mm/s	0.002-10mm/s
Loading Rate	N/A	0.01-20N/min	1-200N/min

### TEMPERATURE

#### High Temp Oven

Mounting Area	78cm <sup>2</sup>	78cm <sup>2</sup>	78cm <sup>2</sup>
Rotative and Linear Ball/Sample Temperature	1100°C (2012°F)	1100°C (2012°F)	1100°C (2012°F)

#### Cold Temp Enclosure

Cold Air Temperature Enclosure	-10°C(14°F) to room temperature	-10°C(14°F) to room temperature	-10°C(14°F) to room temperature
Cold/Hot Air Temperature Enclosure	-40°C (-40°F) to 225°C (437°F)	-40°C (-40°F) to 225°C (437°F)	-40°C (-40°F) to 225°C (437°F)
Cryogenic Module (Liquid Nitrogen)	-150°C (-238°F)	-150°C (-238°F)	-150°C (-238°F)

### LIQUID

Linear Liquid Cup (Mounting Area)	80 x 45 x 25mm	80 x 45 x 25mm	80 x 45 x 25mm
Rotative Liquid Cup (Mounting Area dia.)	78 x 25   100 x 30mm	78 x 25   100 x 30mm	78 x 25   100 x 30mm
Drop by Drop (With or w/o outflow)	Available	Available	Available
Liquid Heating	room to 150°C (300°F)	room to 150°C (300°F)	room to 150°C (300°F)
Humidity Control	10 - 95% RH	10 - 95% RH	10 - 95% RH

### IN-SITU 3D PROFILER

Sensor	Standard	Standard	Standard or High Speed
Maximum Height   Resolution	300μm   17nm	300μm   17nm	3.9mm   1.2nm

\*Specifications continuously improving, please contact Nanovea for latest.

# **N** Today's Standard For Tomorrow's Materials.

Nanovea began designing and manufacturing instruments after years of experience in providing solutions for profilometry, mechanical and tribology applications. Firmly aligned with its vision, Nanovea aims to simplify advanced measurement technology to stimulate materials engineering for the common good. Ease of use, advanced automation and the dedication to superior accuracy are the driving forces behind Nanovea's full range of Profilometers, Mechanical Testers and Tribometers. Unlike other manufacturers, Nanovea also provides Laboratory & consulting services. Thus, clients are given access to years of experience in finding solutions to improve quality control and materials development. Nanovea offers many critically important tests including surface roughness, nanoindentation, scratch and wear testing among many others. Nanovea's instruments can be found internationally in distinguished educational and industrial organizations ranging from automotive to cosmetic, biotechnology to medical devices to microelectronics and space applications. Thousands of clients rely on Nanovea for accurate solutions, technically superior instruments, experienced assistance and comprehensive laboratory services.



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