

May 9<sup>th</sup>, 2018

**On-Machine Dimensional Measurement Technology  
for Prognostics and Health Monitoring for Precision  
Manufacturing Systems and Processes**

NIST, Gaithersburg, MD

Presentation

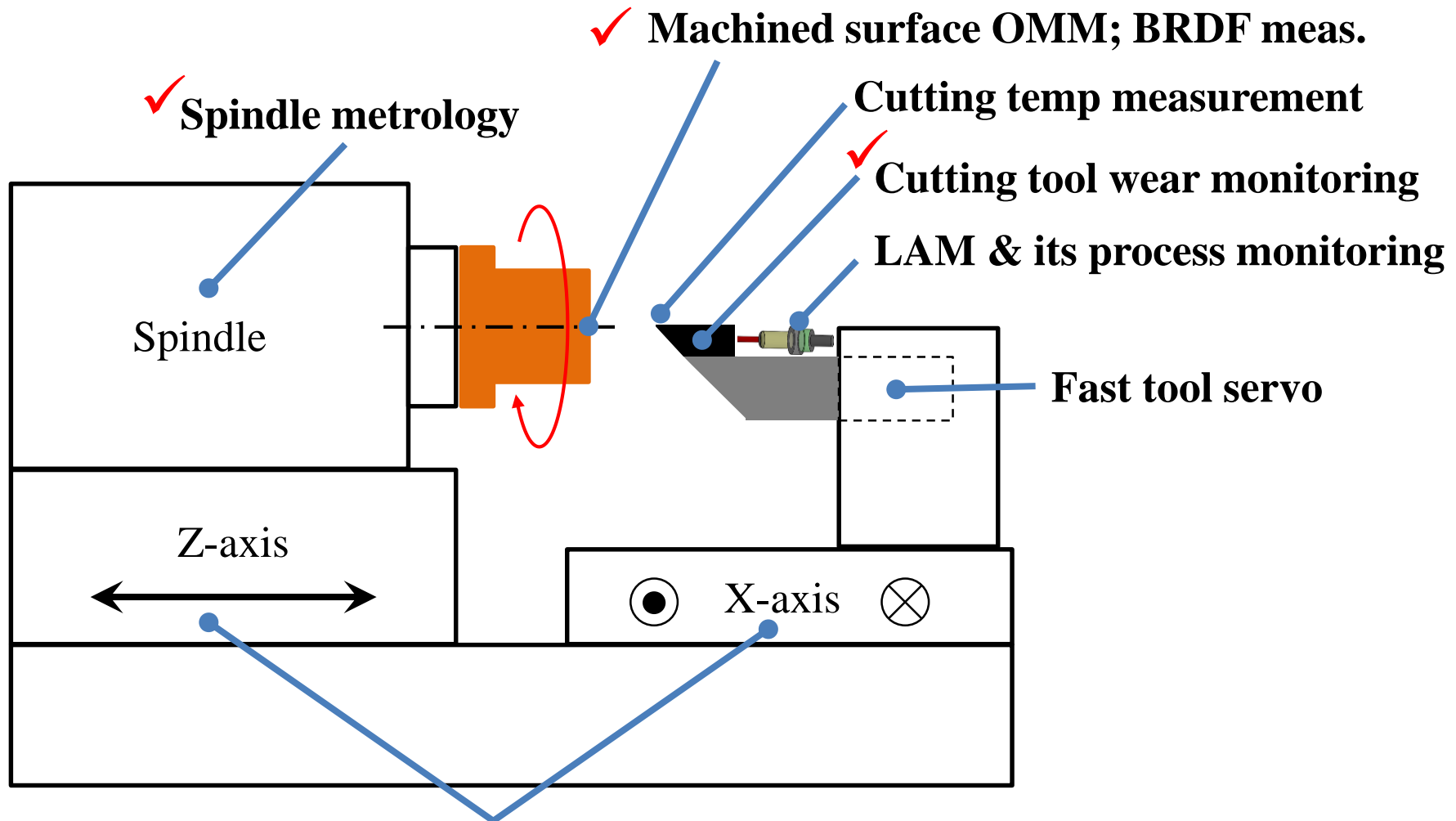
by

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Tennessee Technological University, Cookeville, TN

# OMM: Manufacturing Process Monitoring



**Grating interferometry, motion error, positioning control**

OMM: On-Machine Measurement

LAM: Laser-Assisted Machining

BRDF: Bidirectional Reflectance Distribution Function



## **Part A. Introduction: On-Machine Measurement (OMM)**

## **Part B. Current Research**

- a. Machined Surface Measurement #1
- b. Machined Surface Measurement #2
- b. Cutting Tool Wear Monitoring
- c. Spindle Metrology
- d. Conclusion



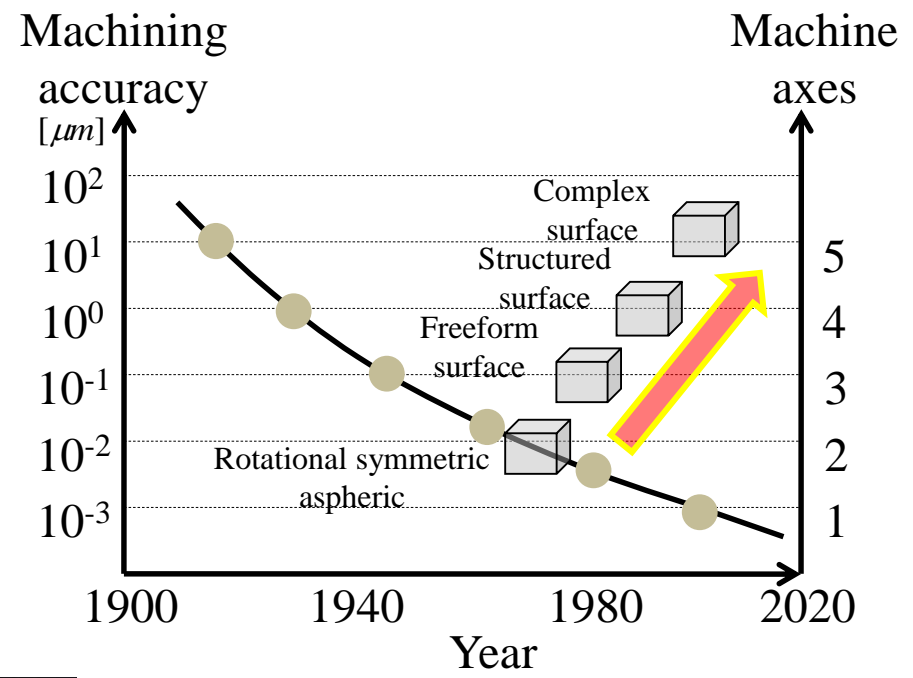
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# Part A. Introduction: OMM

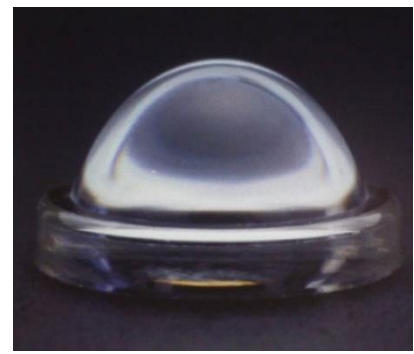
# Ultraprecision Technology: Machining



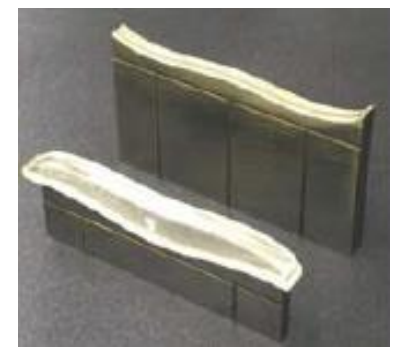
Referred to [www.jtekt.co.jp](http://www.jtekt.co.jp)



Automotive display



Aspheric lens



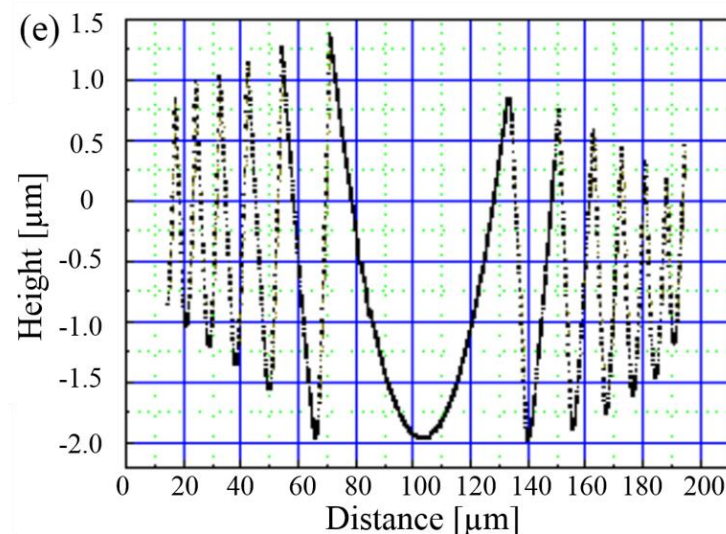
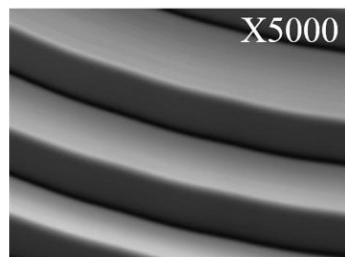
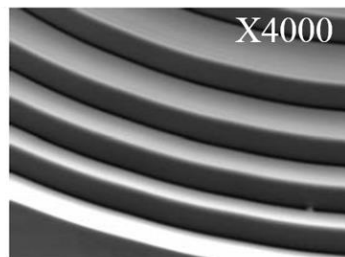
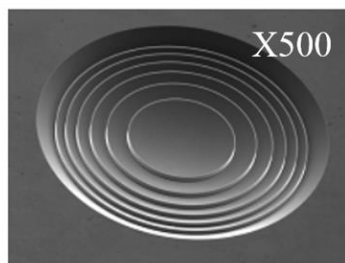
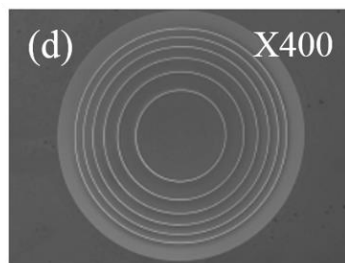
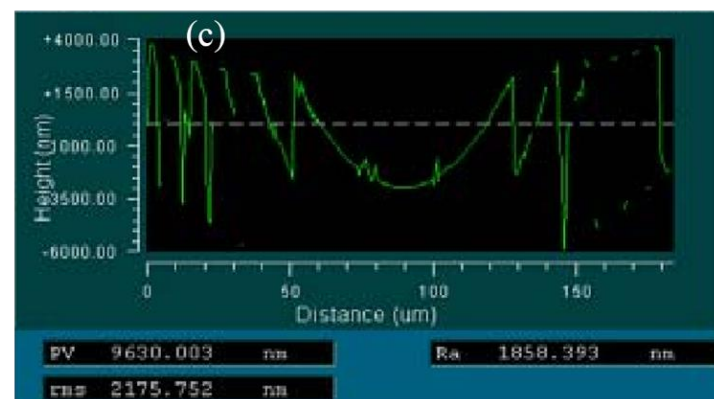
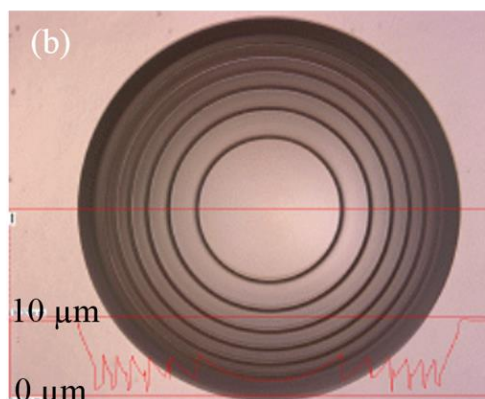
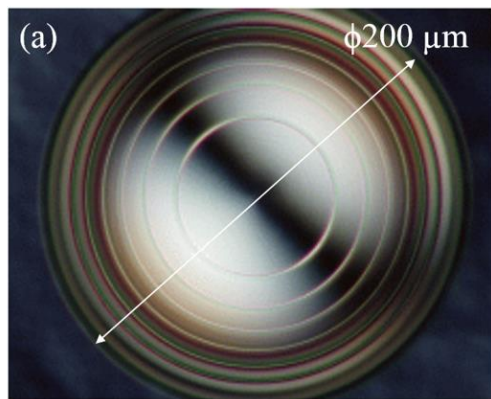
F- $\theta$  lens



Fresnel lens

# Cosine Error in Freeform Optics Metrology

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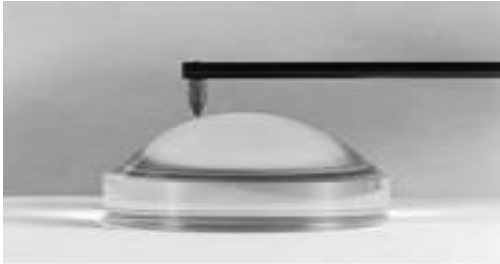
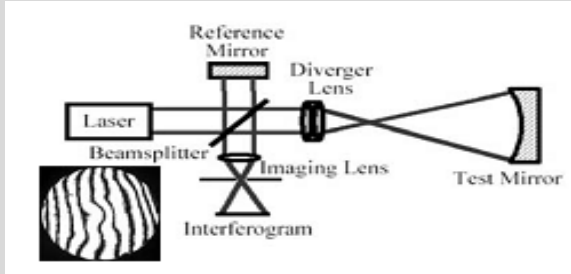


Measurement results obtained by instruments: (a) nomarski microscope (Olympus), (b) laser scanning microscope (LSM, Keyence), (c) white light interferometry microscope (WLIM, Zygo), (d) scanning electron microscope (SEM, Hitachi) and (e) form talysurf (Taylor Hobson).

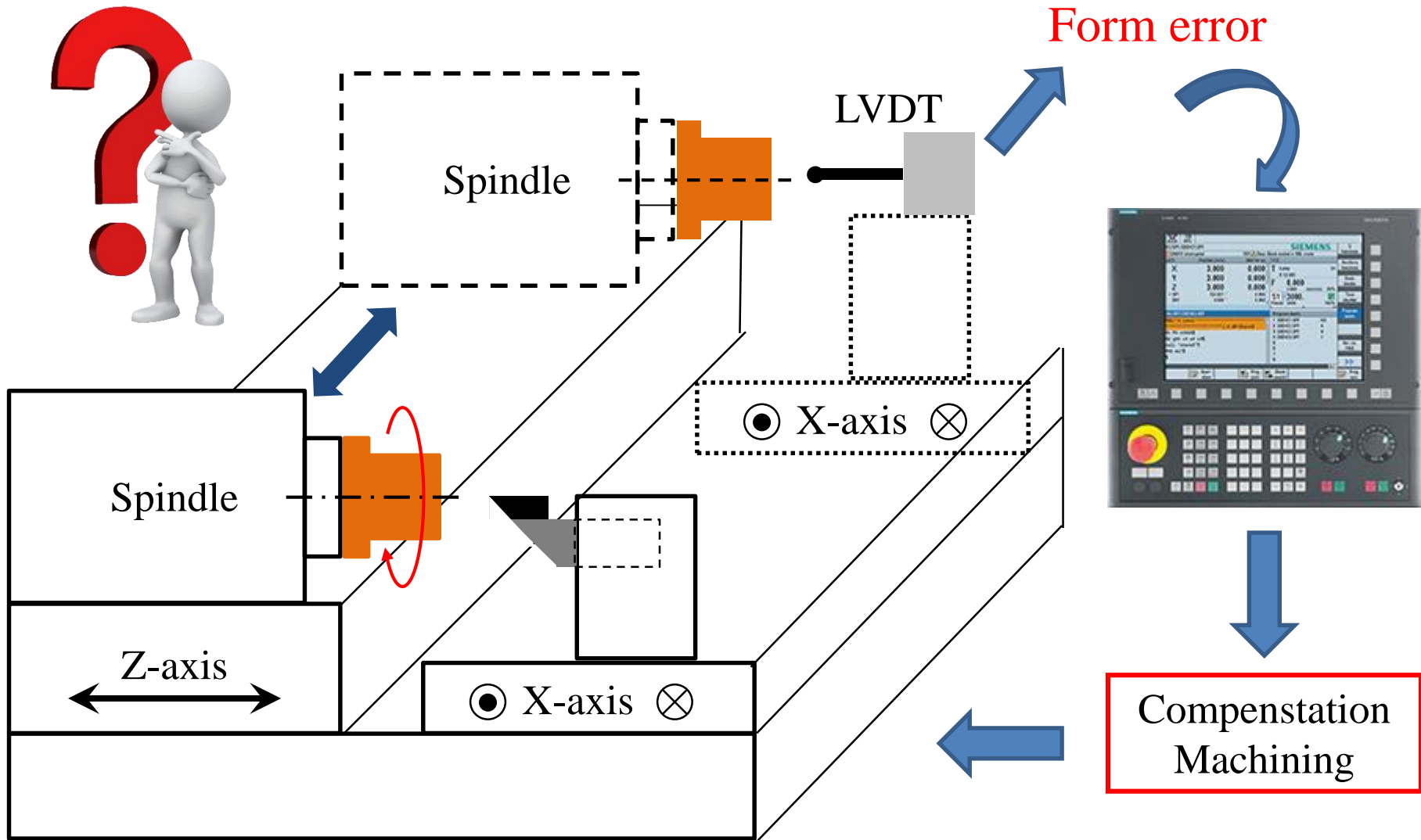


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# Current Measurement: Postprocessing

<b>Measure</b>		
	<b>Contact</b>	<b>Non-contact</b>
<b>Advantage</b>	<b>-High accuracy</b>	<b>-High speed, immune to measuring force</b>
<b>Disadvantage</b>	<b>-Easy to make the surface damage</b>	<b>-Difficulty to align the optical axis</b>
<b>Instrument</b>	<b>-LVDT, Stylus</b>	<b>-Interferometer, Confocal</b>

# Current Measurement: OMM





# What to Measure by OMM Tools?



- Form error
- Cutting tool wear
- Cutting temperature
- Positioning or motion
- Spindle runout
- Machine vibration
- Cutting tool axis stiffness
- ...



OMM expensive?

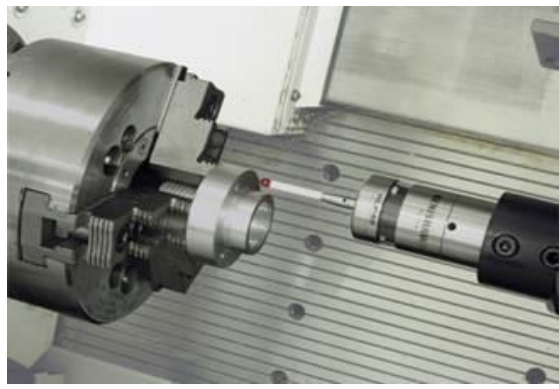


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# **Part B. Current Research**

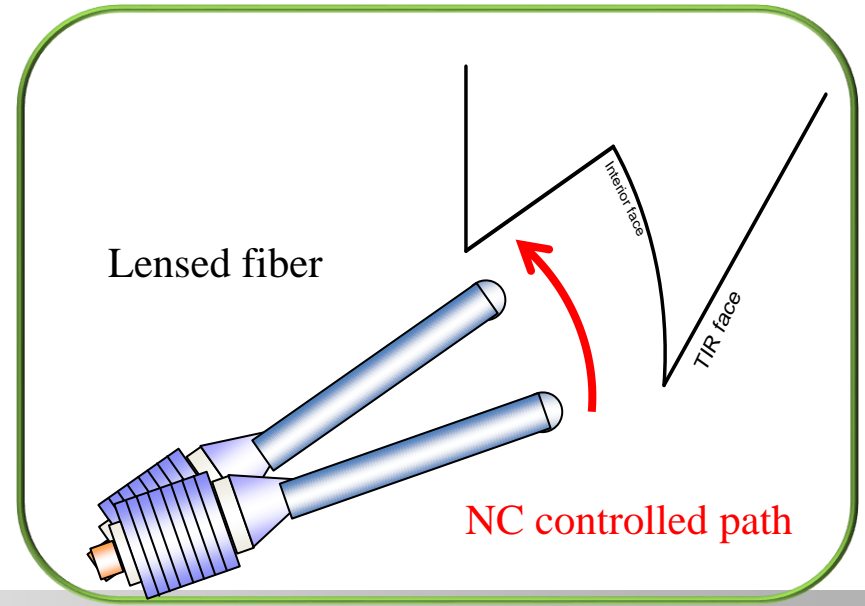
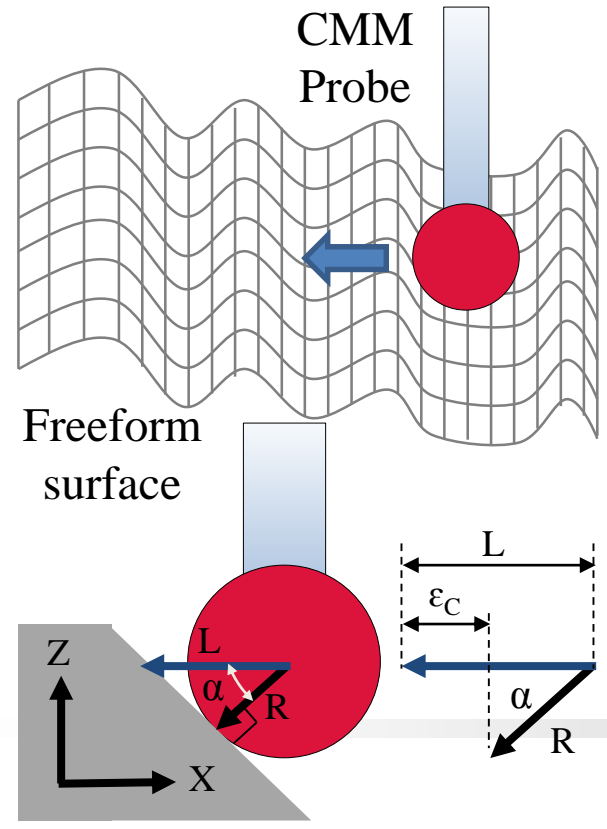
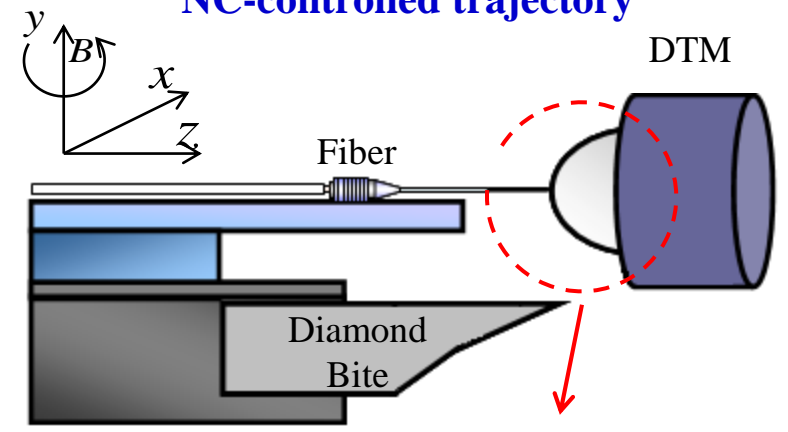
## **a. Machined Surface Measurement #1**

# Problem: Cosine Error in Measurement



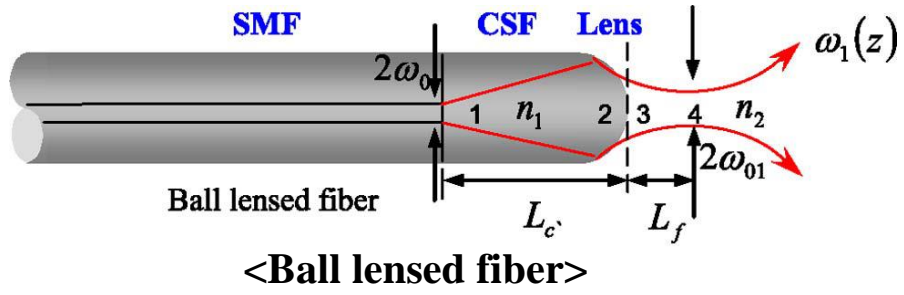
**Machining** ↔ **Measurement**

NC-controlled trajectory

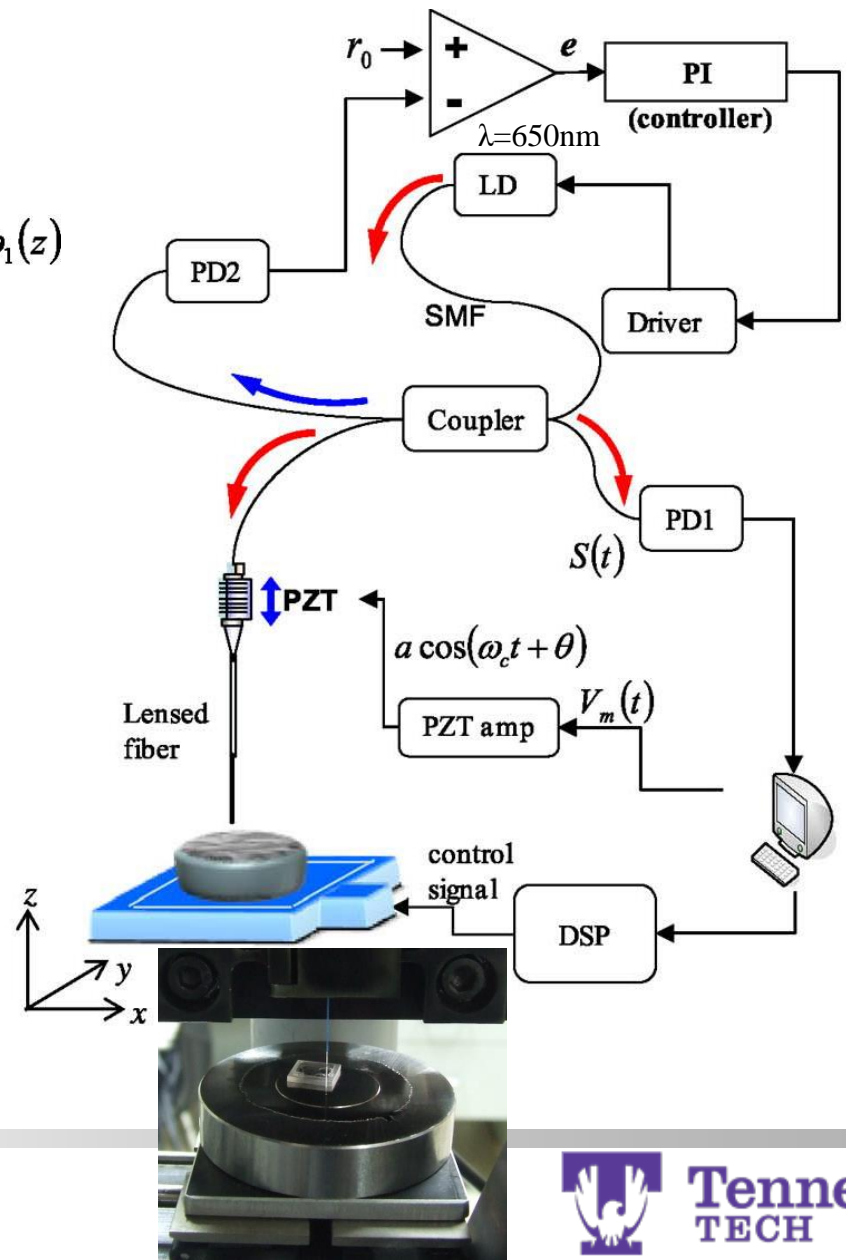
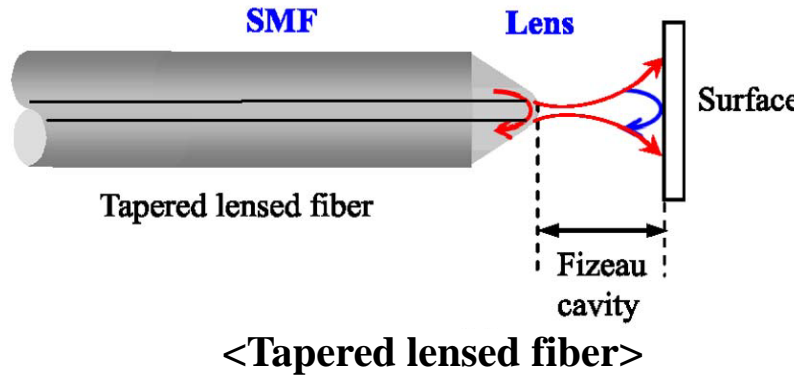


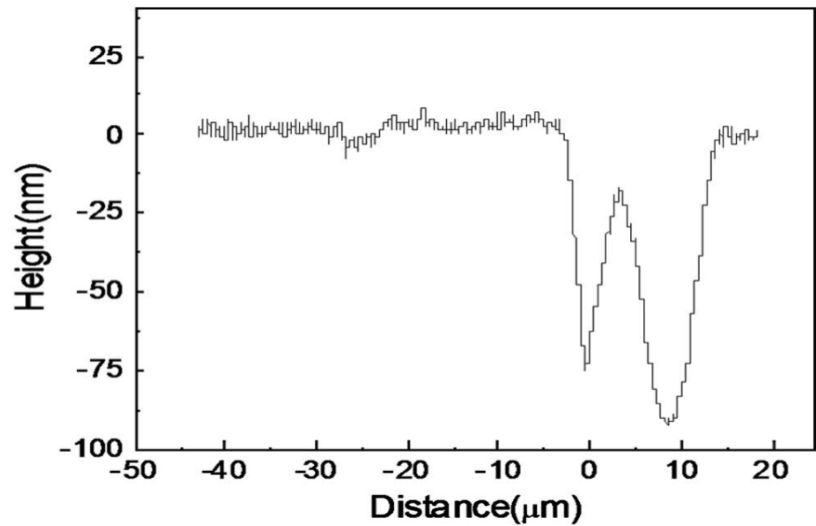
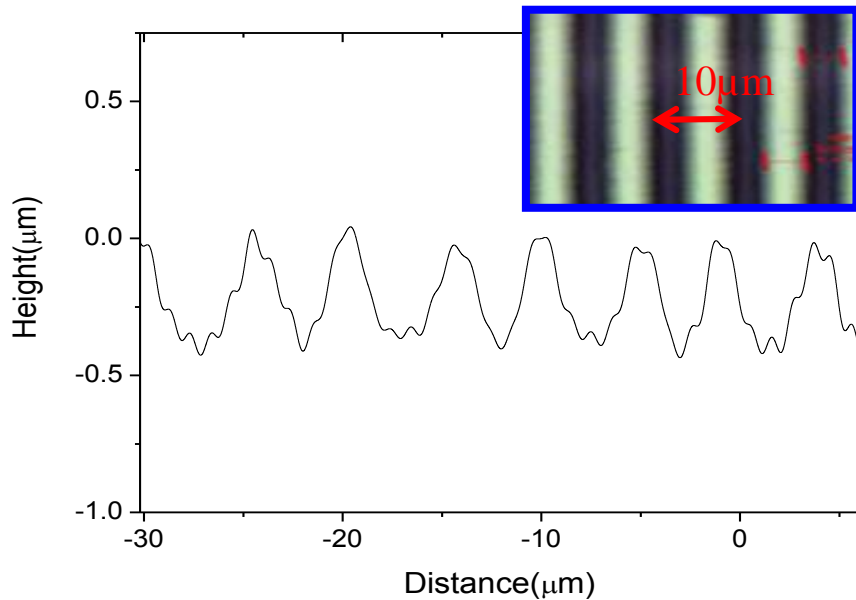
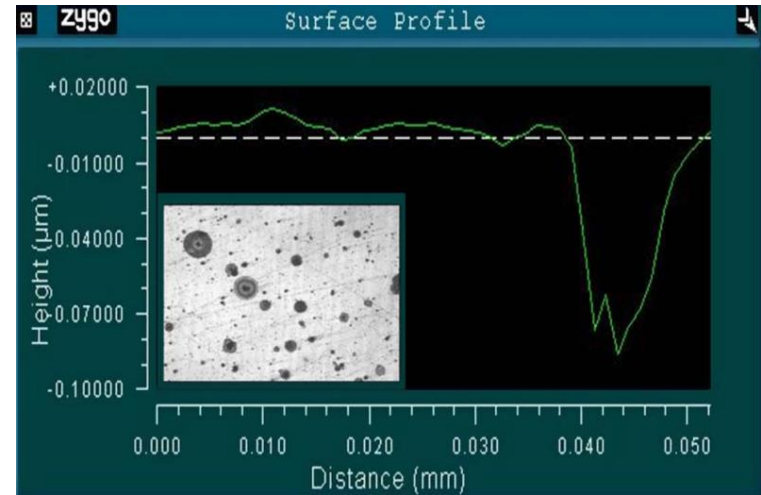
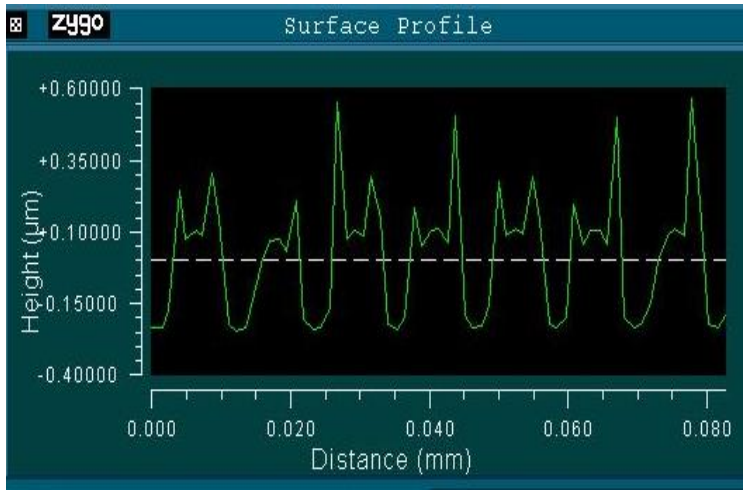
# Experiment

## Autofocusing



## Fizeau interferometry





Fizeau interferometry

Autofocusing Method

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# **Part B. Current Research**

## **b. Machined Surface Measurement #2**



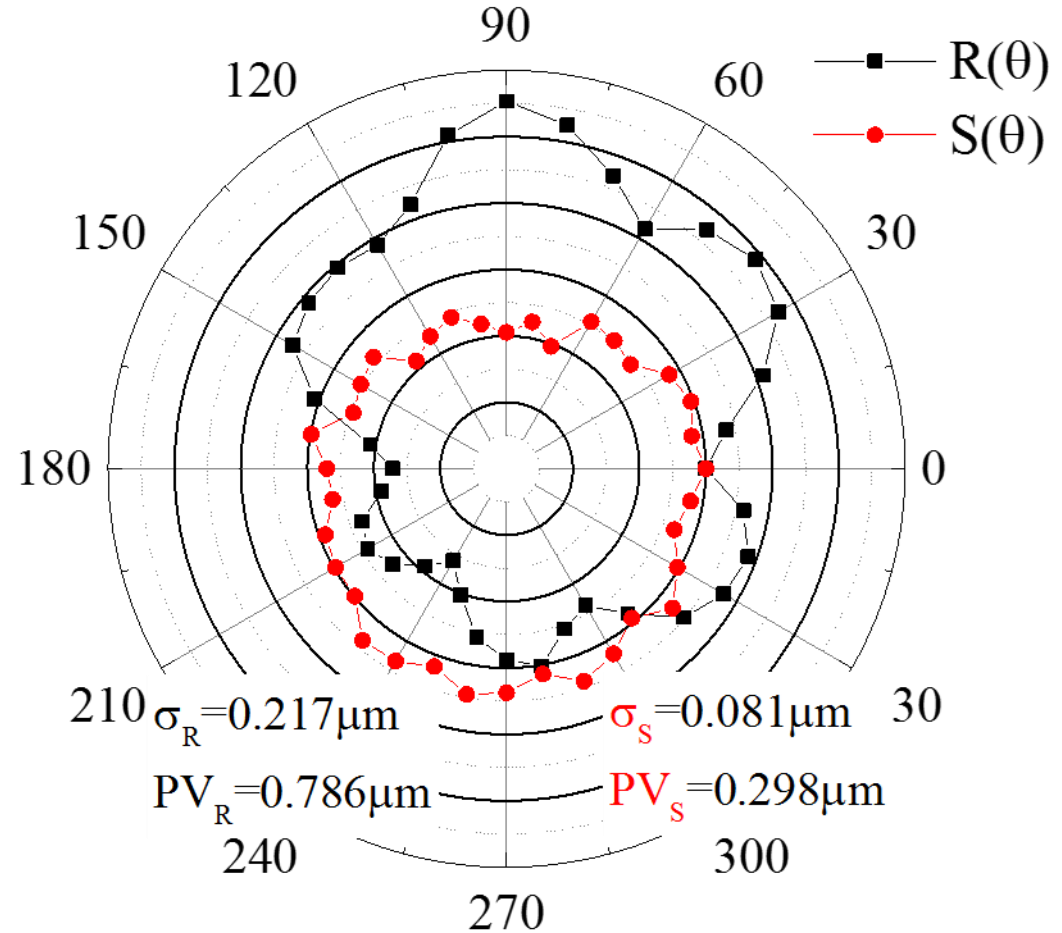
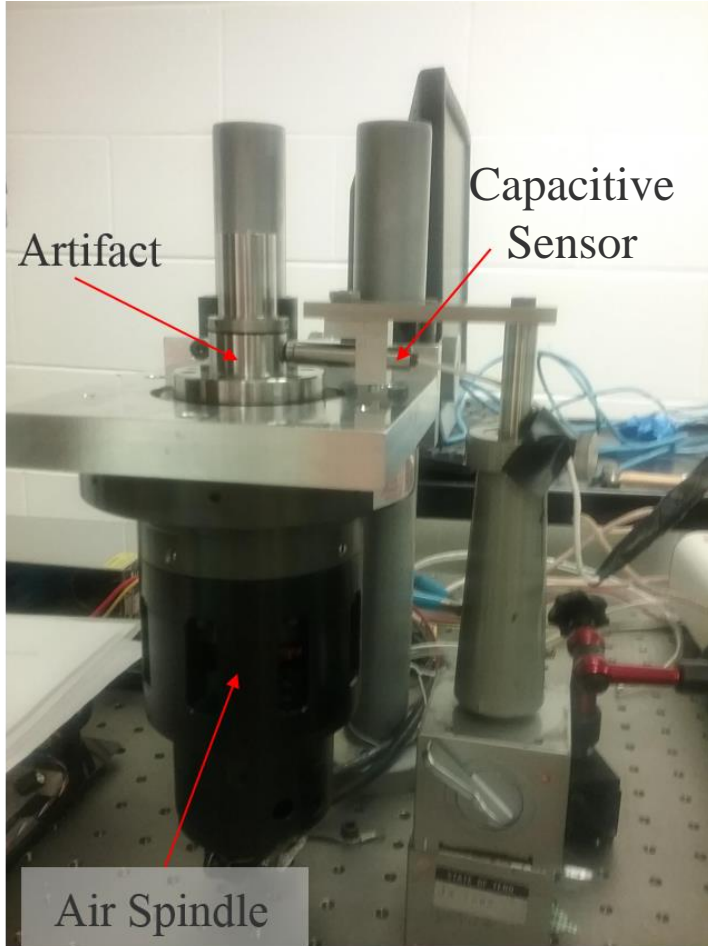
# Cosine Error Elimination by Using Spindle

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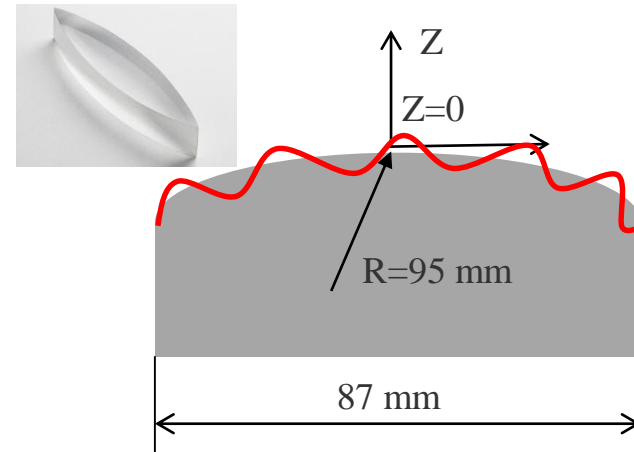
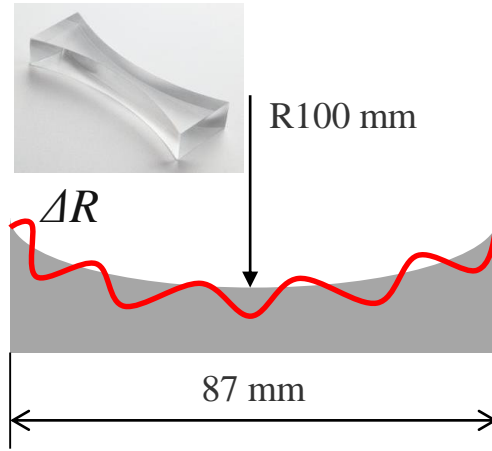
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**TECH**

# Rotational and Spindle Error Separation





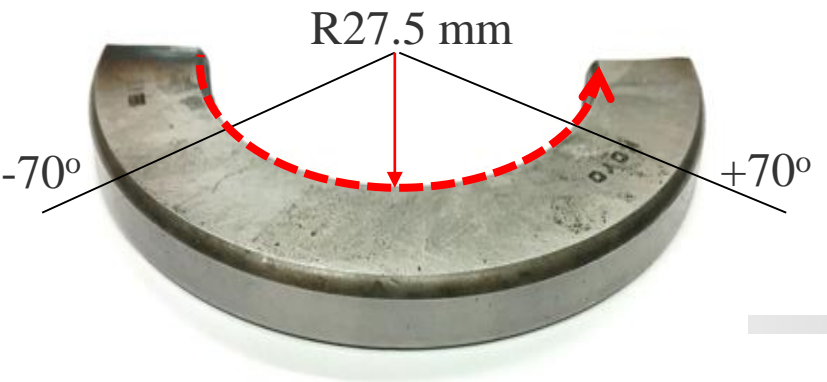
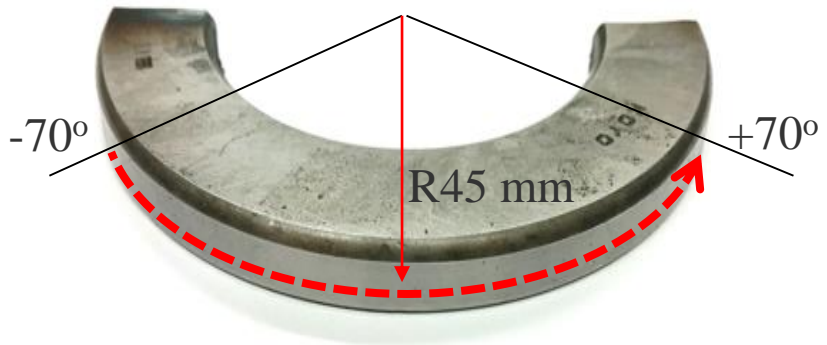
# Concave/Convex Mirror Measurement



# Bearing Inner/Outer Surface Profiles



Koyo 51211 Thrust Bearing



# OMM System Integration for Freeform Surface Metrology



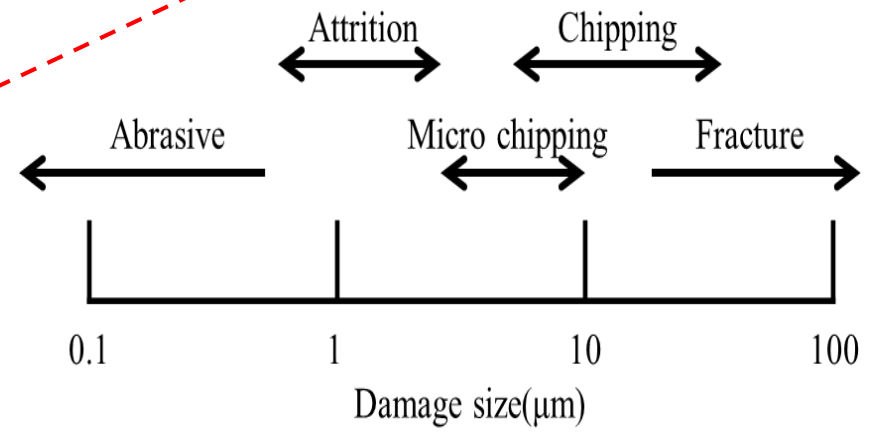
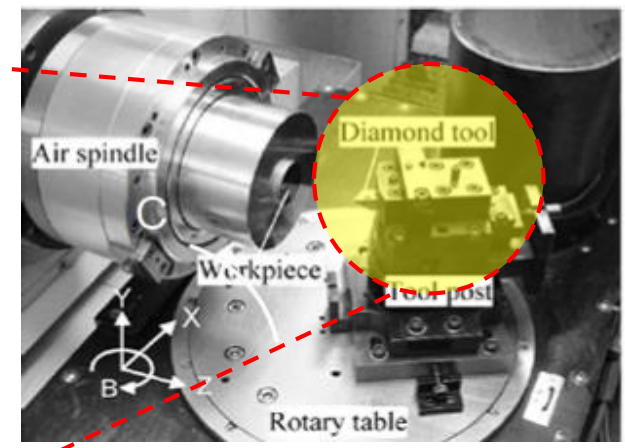
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# **Part B. Current Research**

## **c. Cutting Tool Wear Monitoring**

# Motivation

Roundness within 50 nm



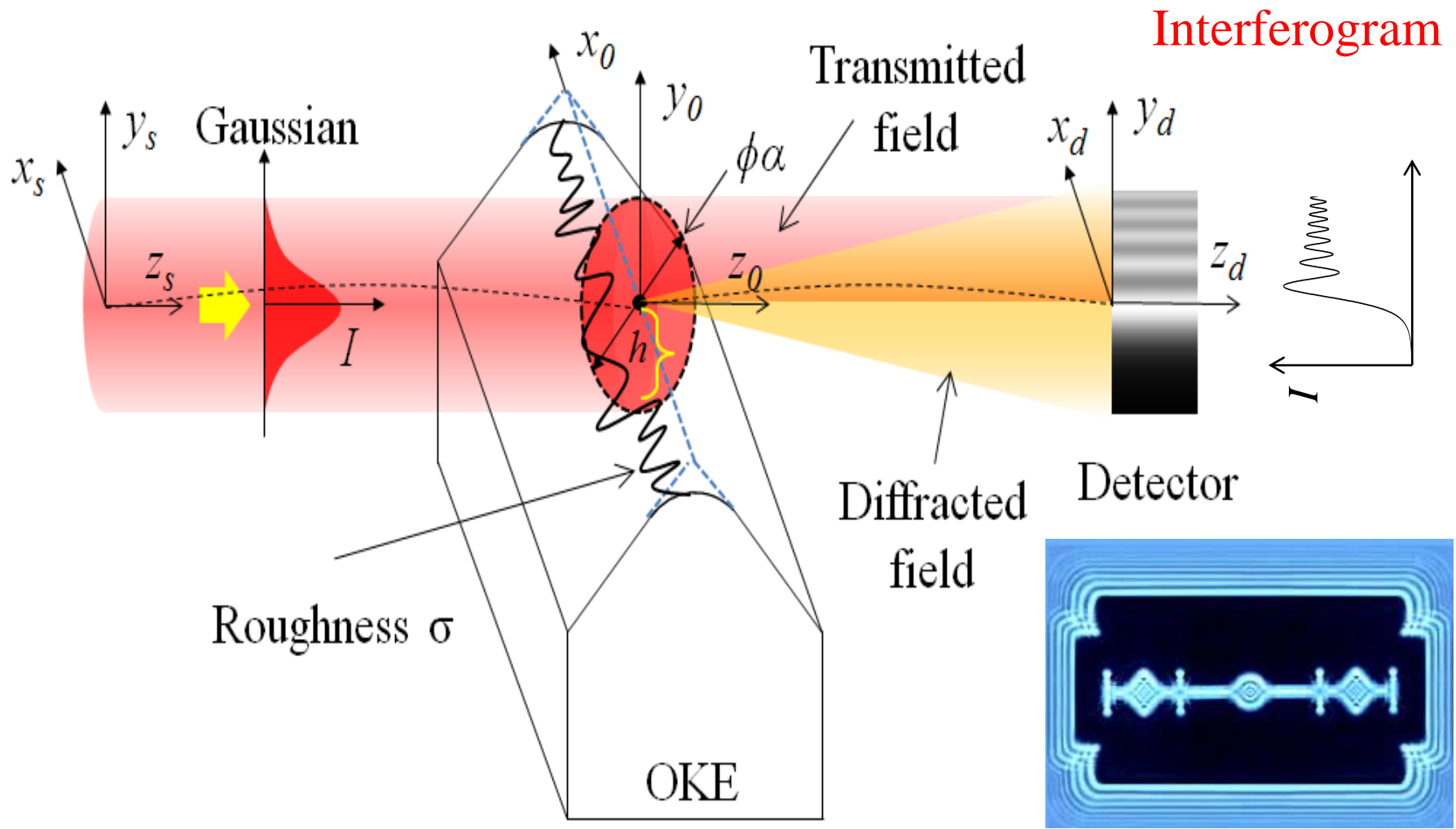
Damage classification of cutting tools [\*]



## How do we measure **damage size**?

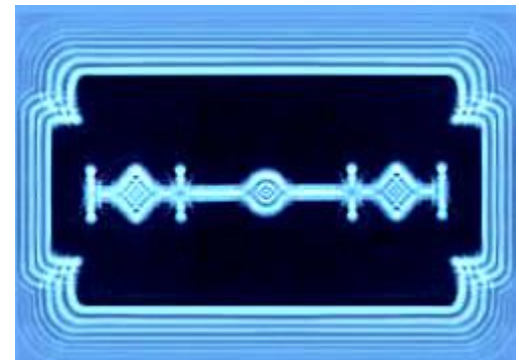
[\*] Frederick Winslow Taylor, On the Art of Cutting Metals, American Society of Mechanical Engineers, 1907.

# Principle: Edge Diffraction



Interferogram

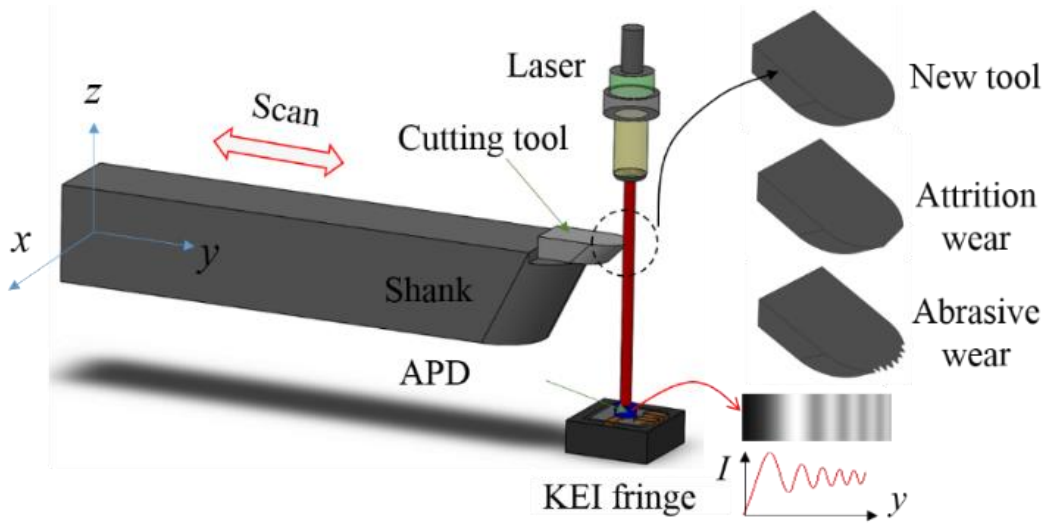
Detector



Roughness  $\sigma$

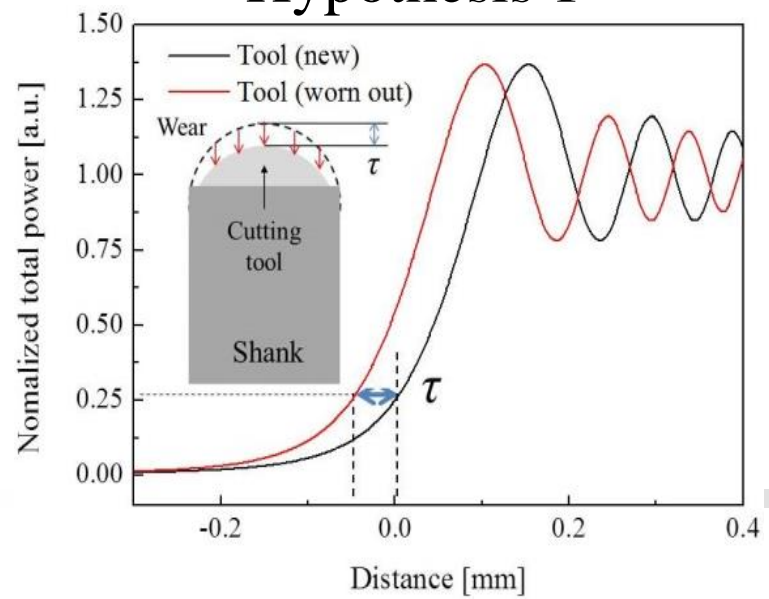
OKE

# Method: Cross-Correlation

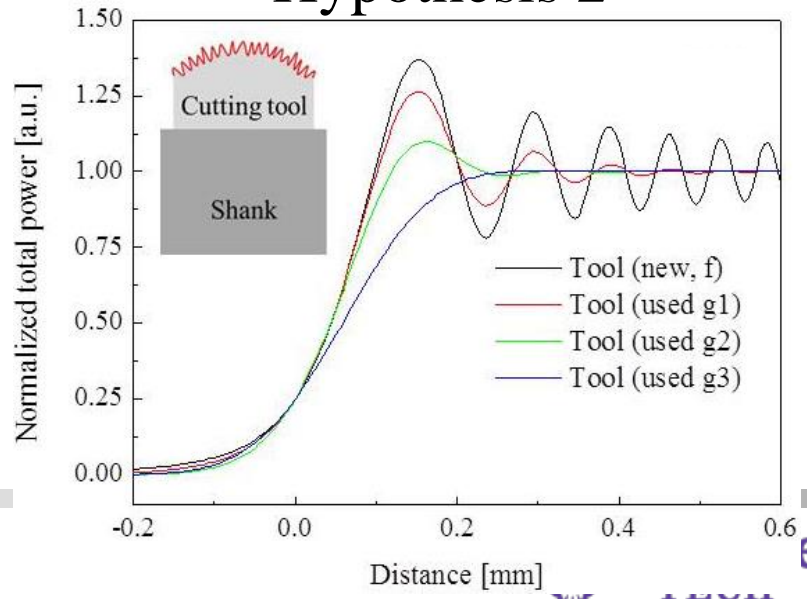


$$f(y) \otimes g(y) = \int f(\tau)g(y - \tau)d\tau$$

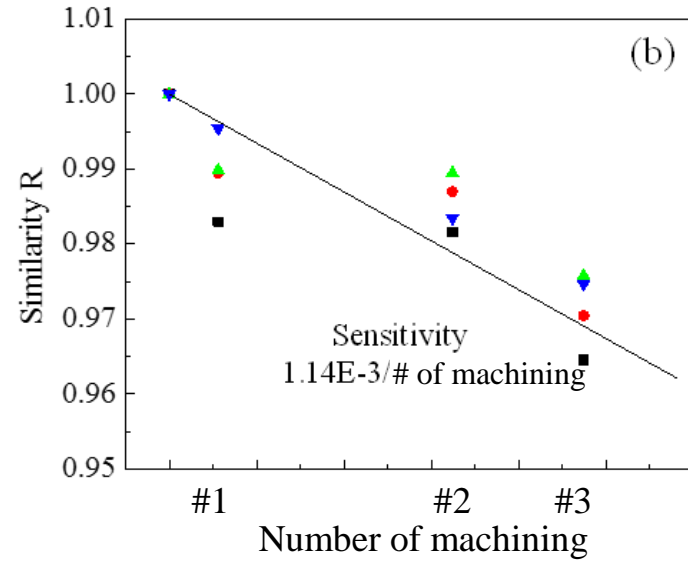
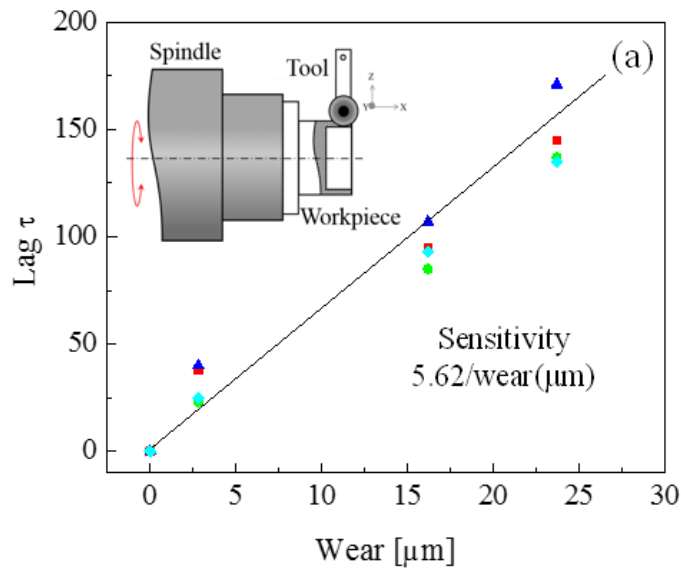
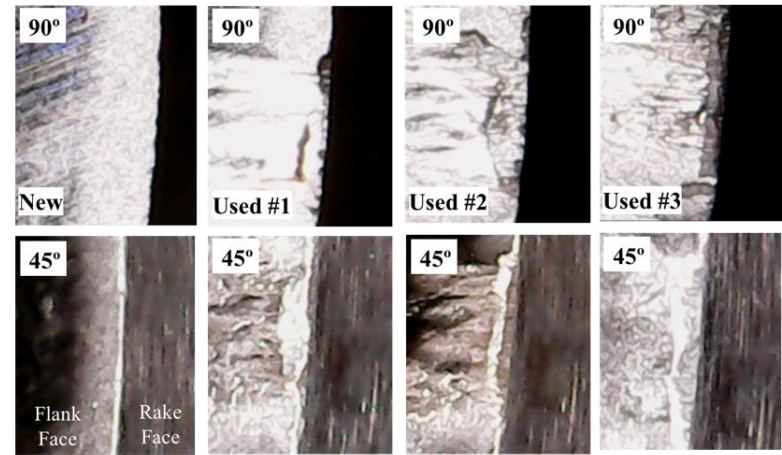
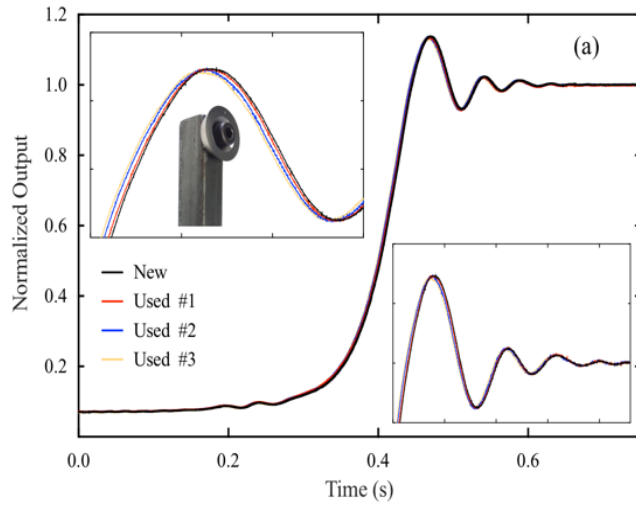
## Hypothesis 1



## Hypothesis 2

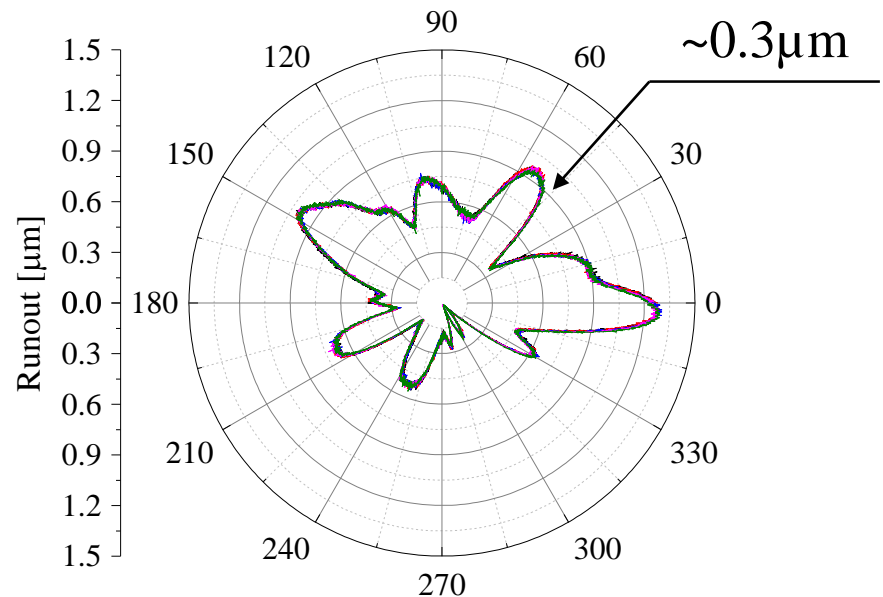
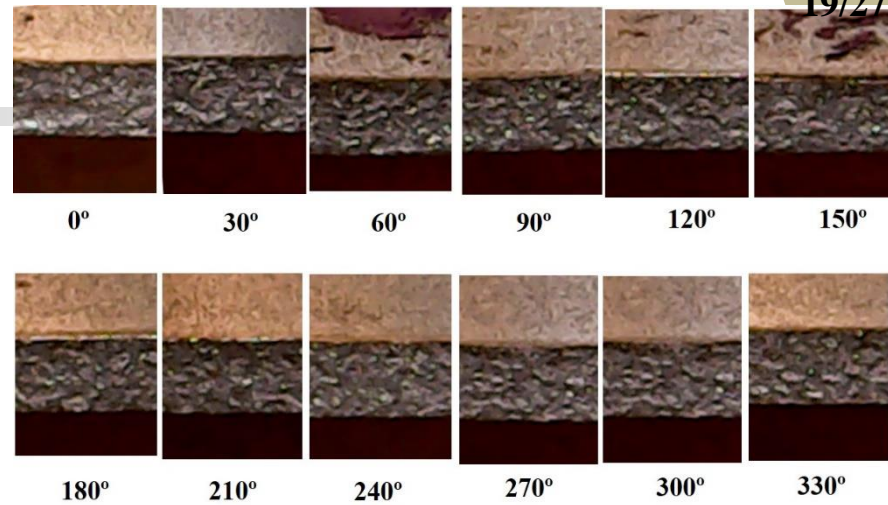
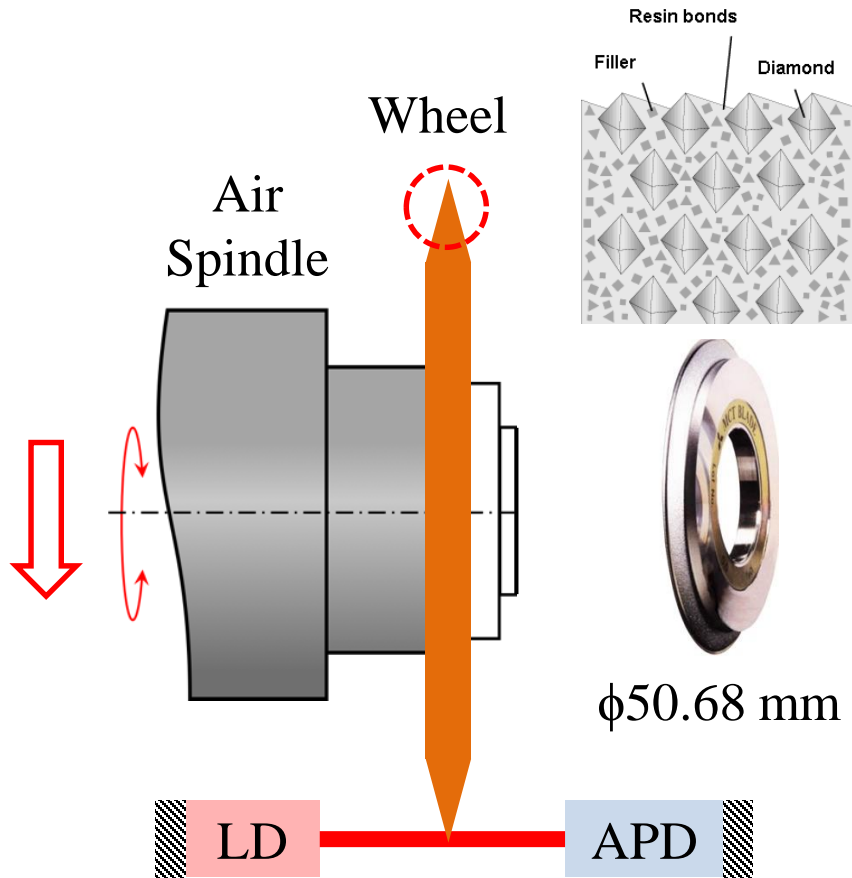


# Cutting Tool Wear Calibration





# Dicing Wheel Wear



Can we separate wheel wear from spindle runout?

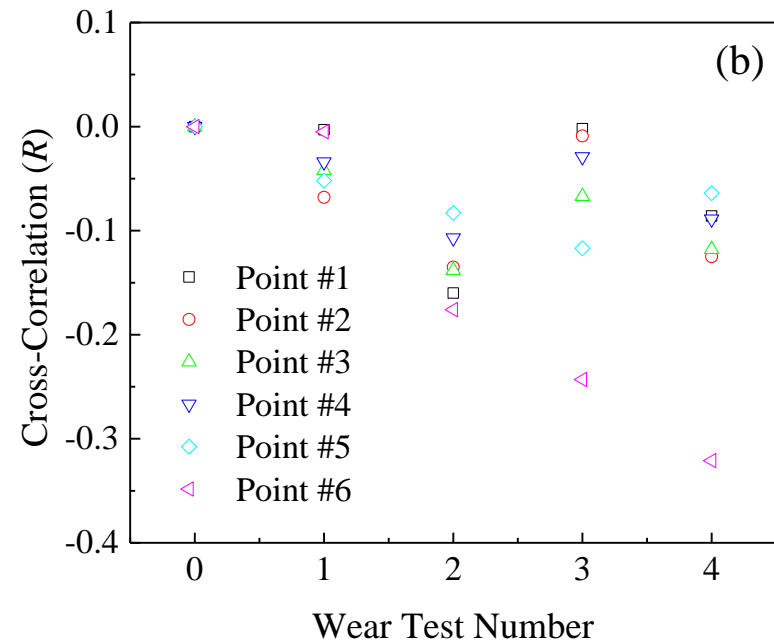
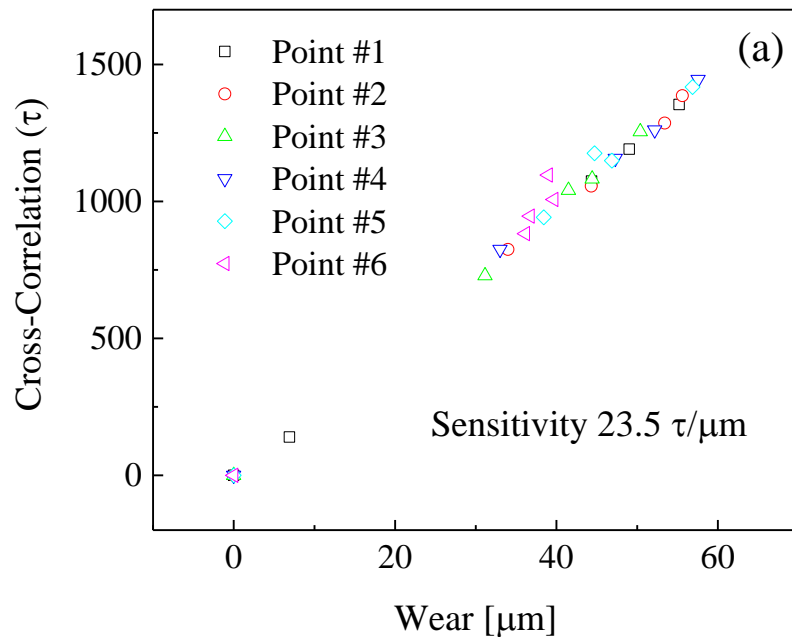
Spindle motion + Roundness + Roughness

# Fringes: Cross-correlation

$$[lag, r] = CORR(f, g)$$

**Hypothesis 1:** Attrition wear relates with lag.

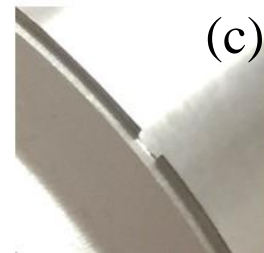
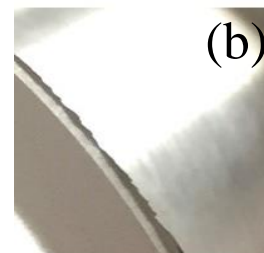
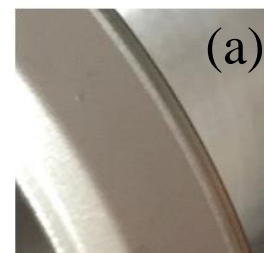
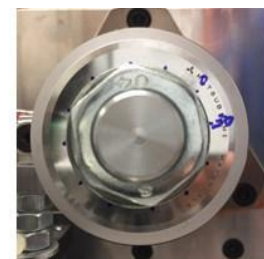
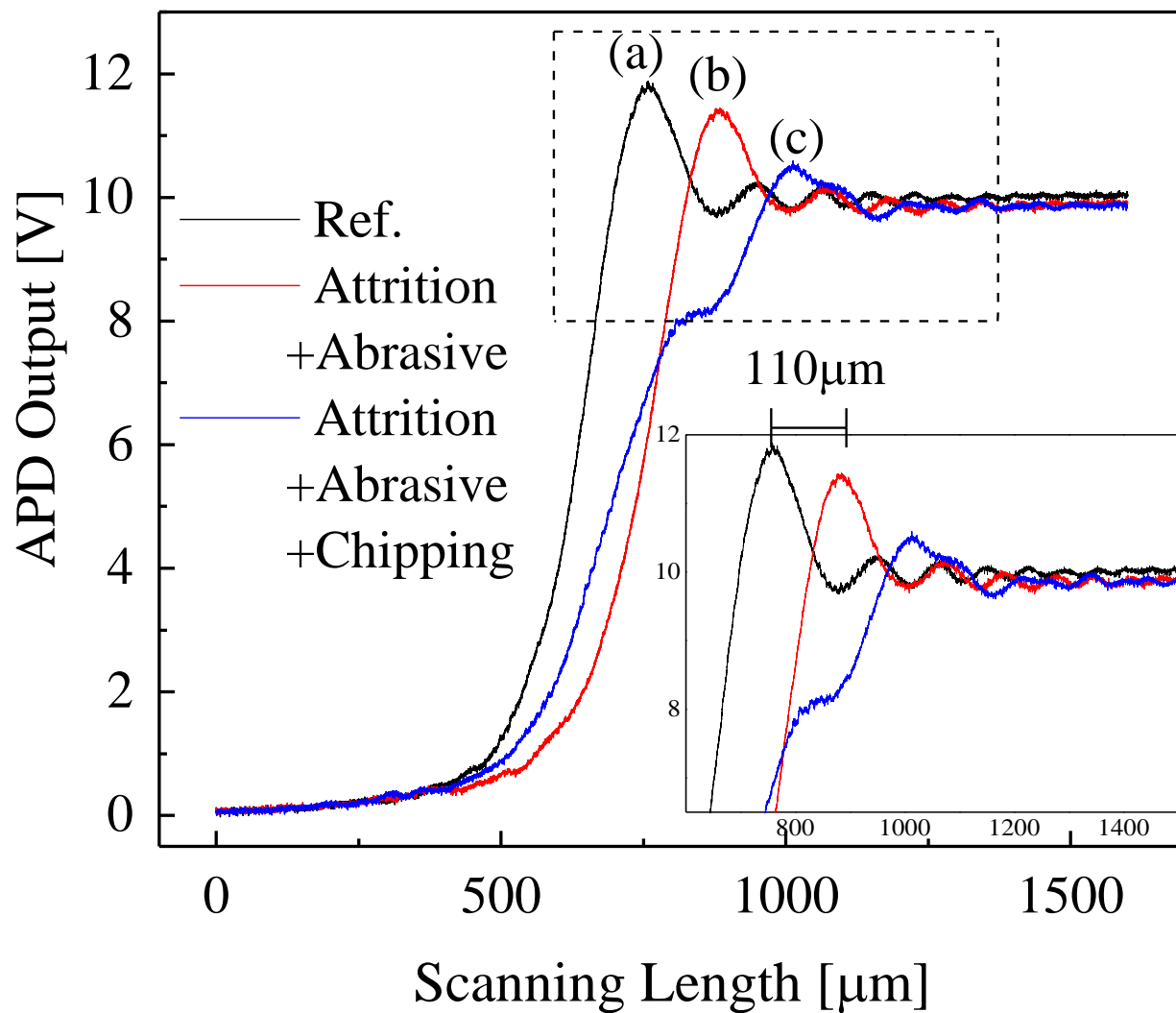
**Hypothesis 2:** Abrasive wear relates with r.



**When do we need truing or dressing?**



# Wear Characteristics v.s. Edge Conditions



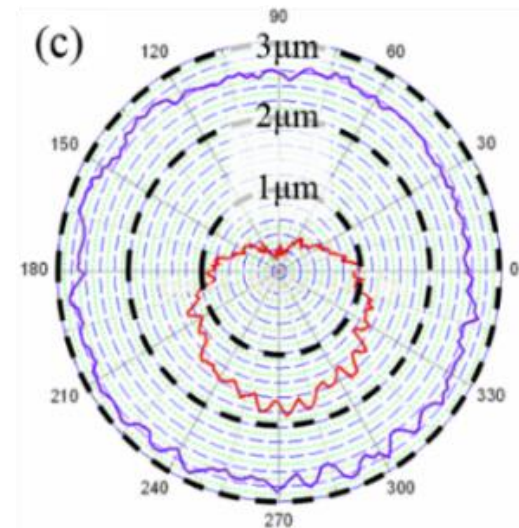
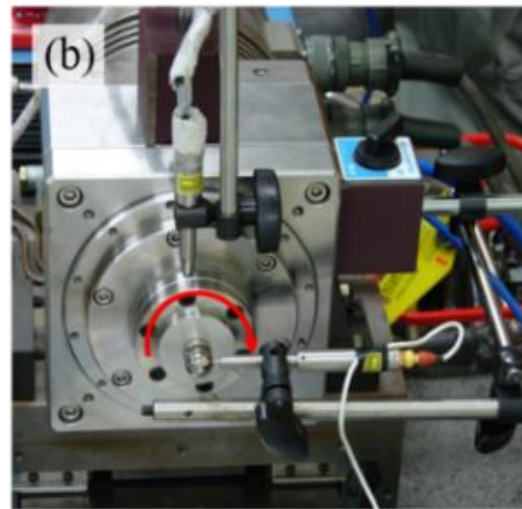
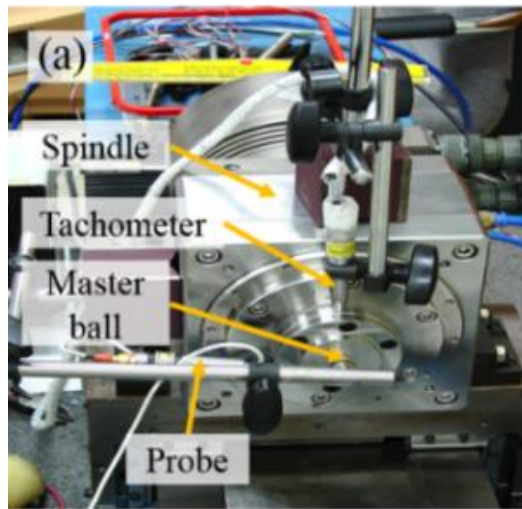
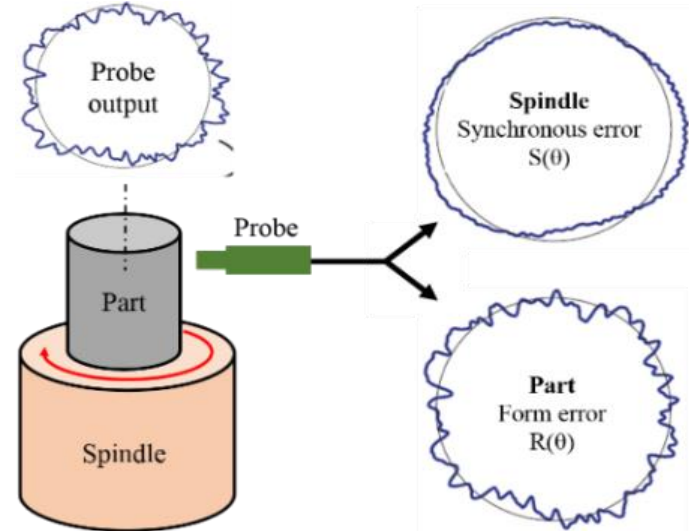
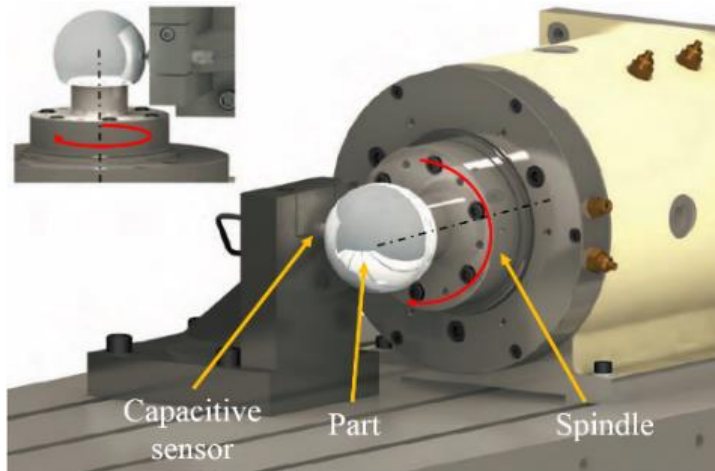
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# **Part B. Current Research**

## **d. Spindle Metrology**



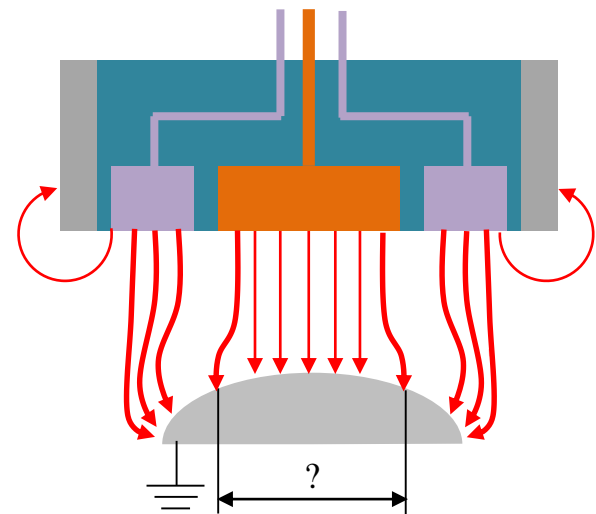
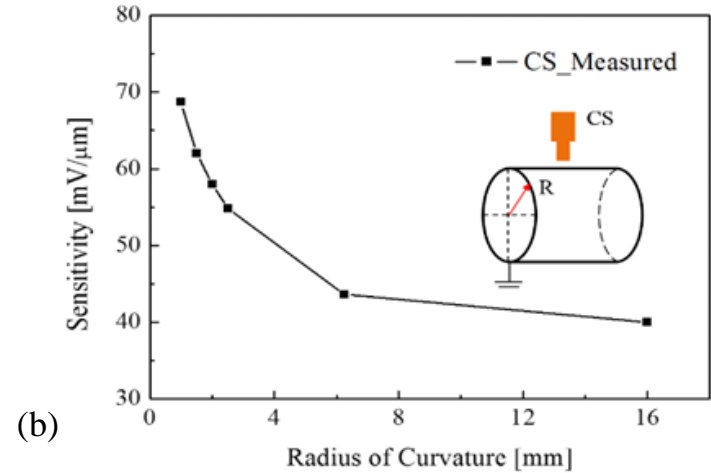
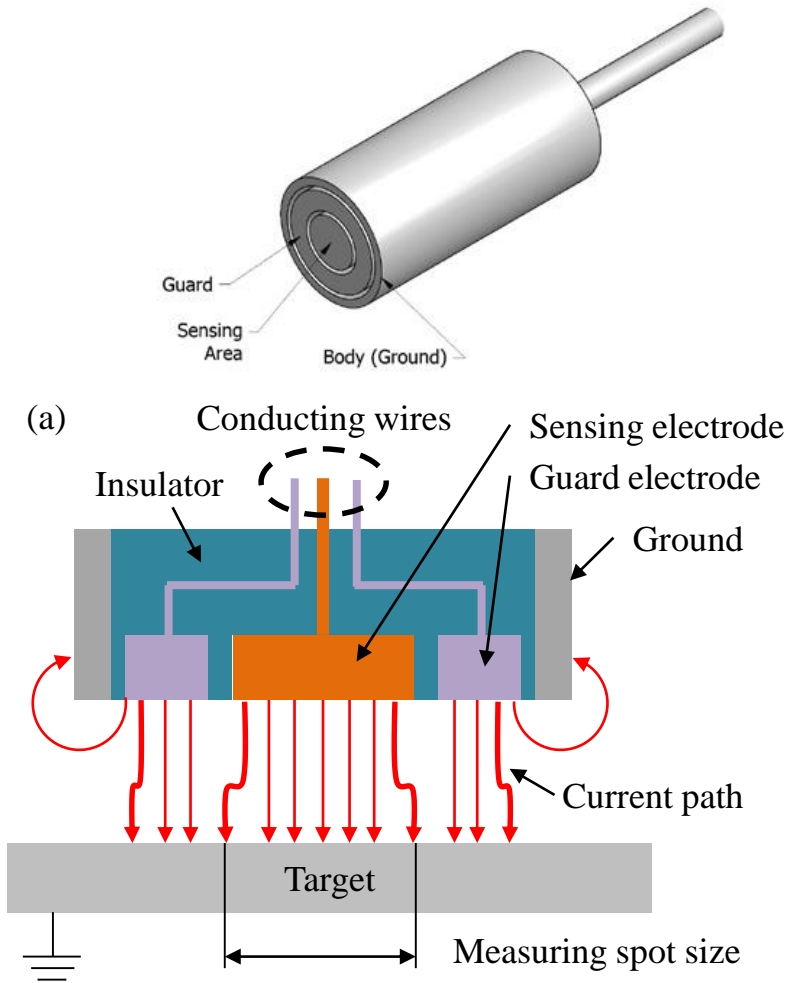
# Spindle Metrology



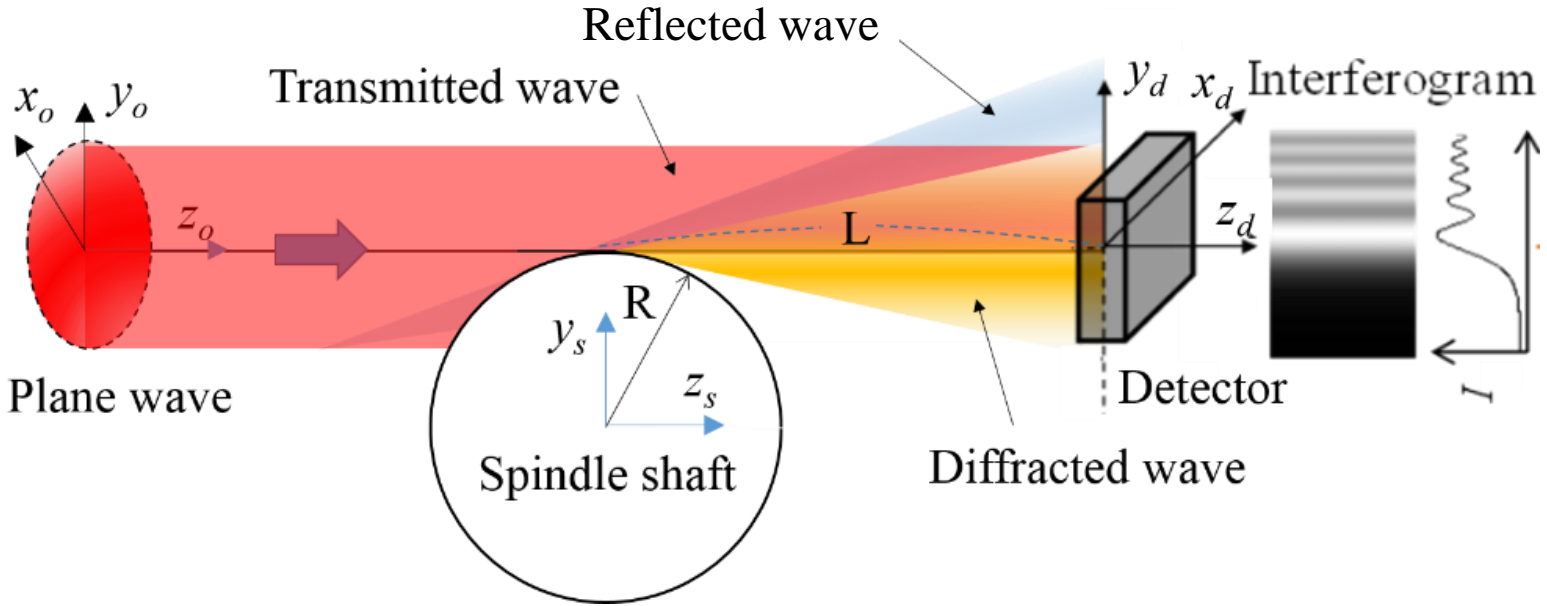
Reversal method: (a) measurement at  $\theta=0^\circ$ , (b) measurement at  $\theta=180^\circ$ , and (c) errors,  $R(\theta)$  in red and  $S_x(\theta)$  in purple.

# Research Objective

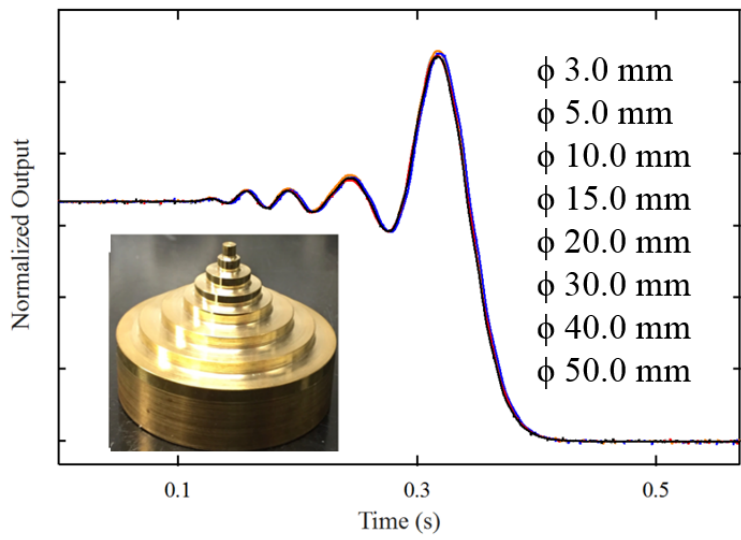
## Capacitive sensor for curved surface measurement?



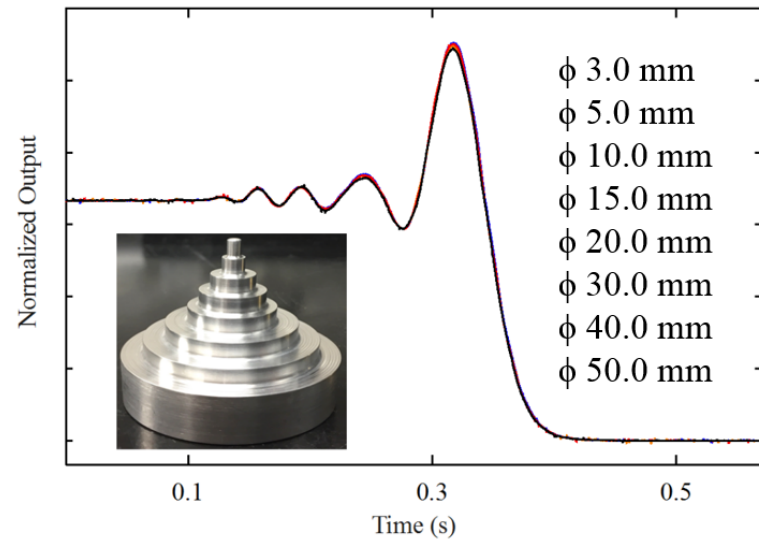
# Principle: Curved Edge Diffraction



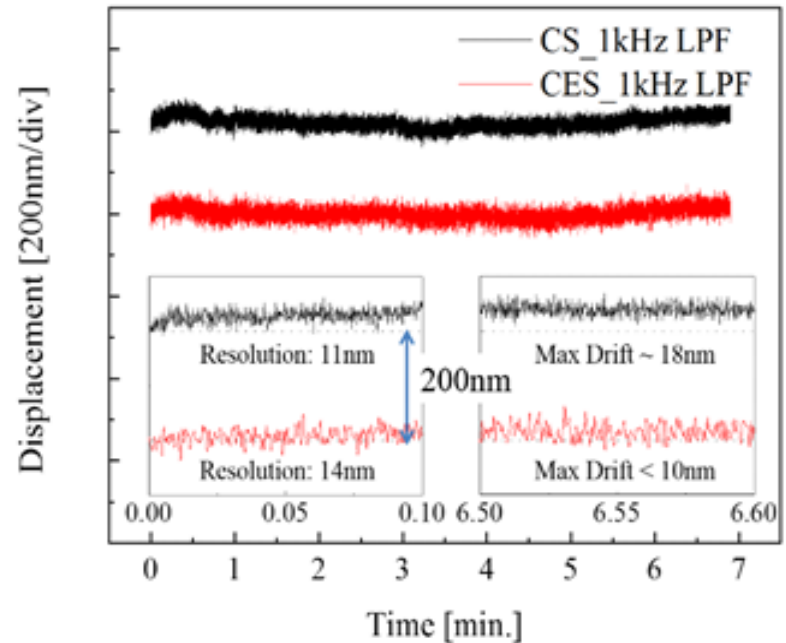
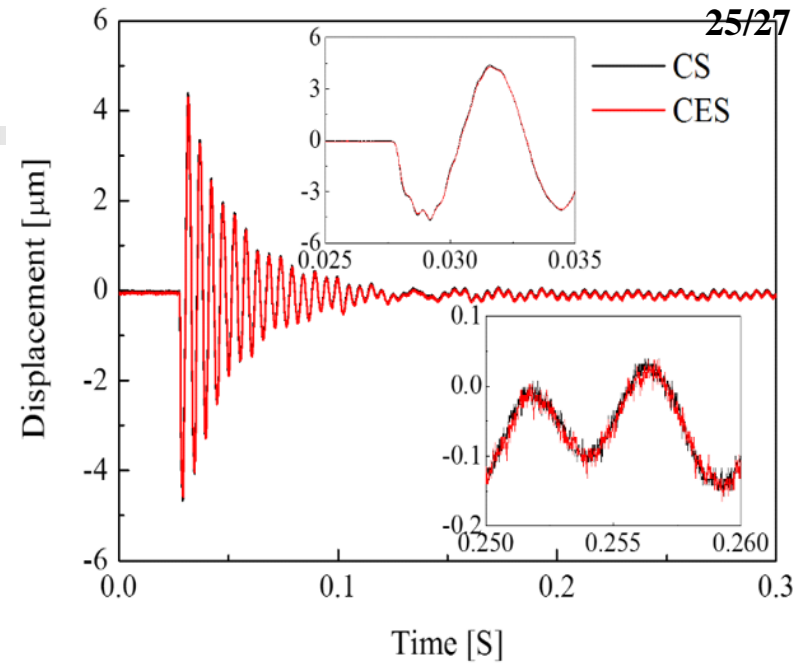
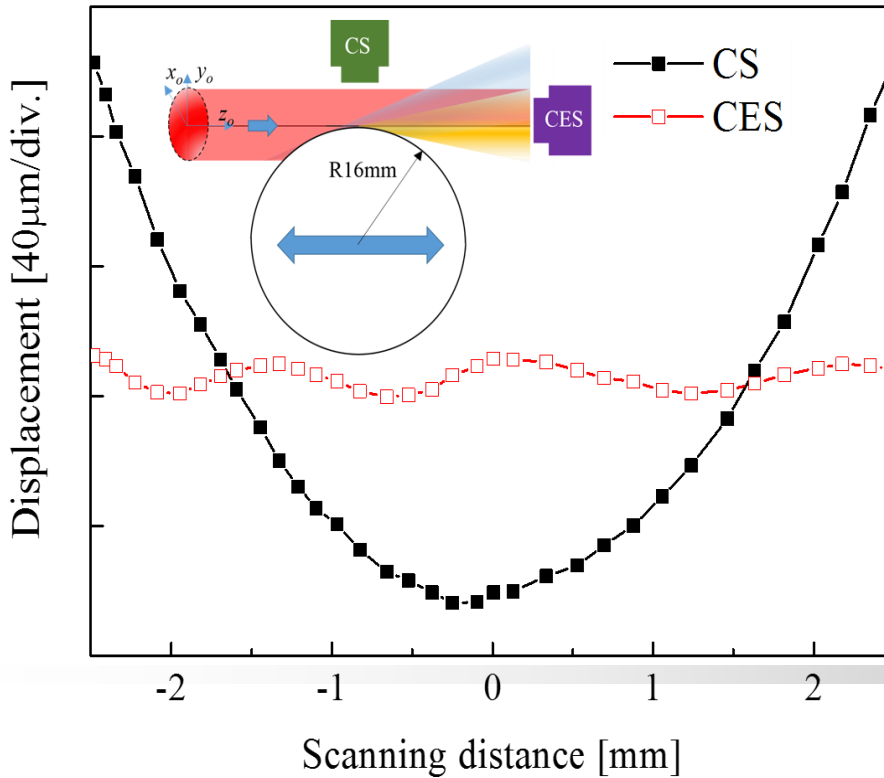
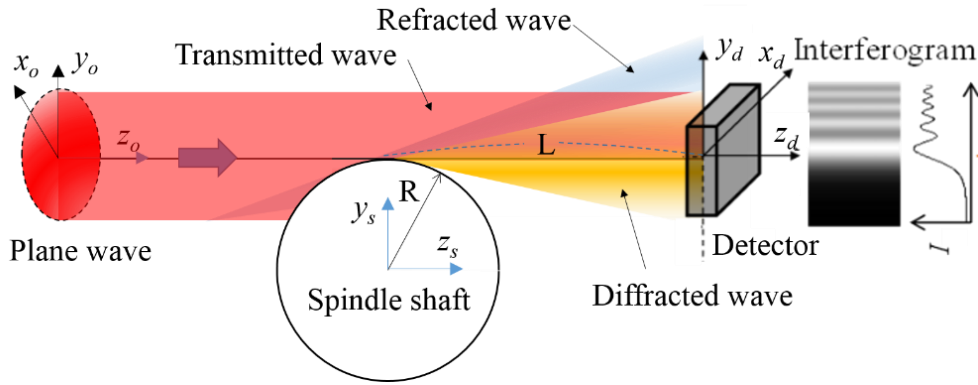
## Ultraprecision-machined



## Generally-machined

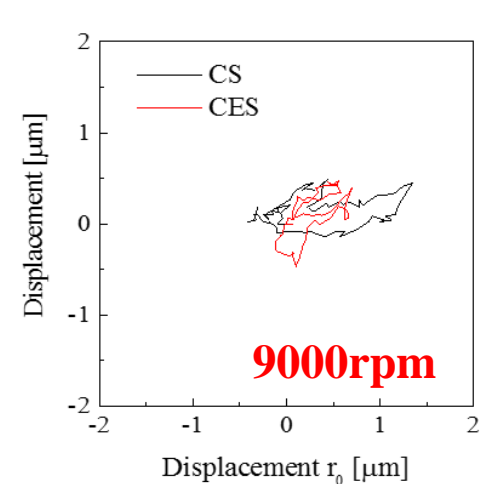
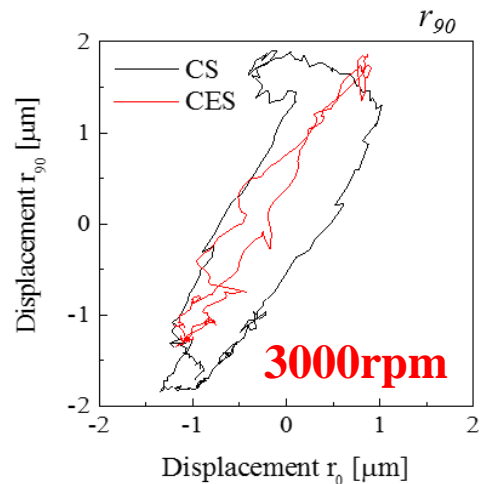
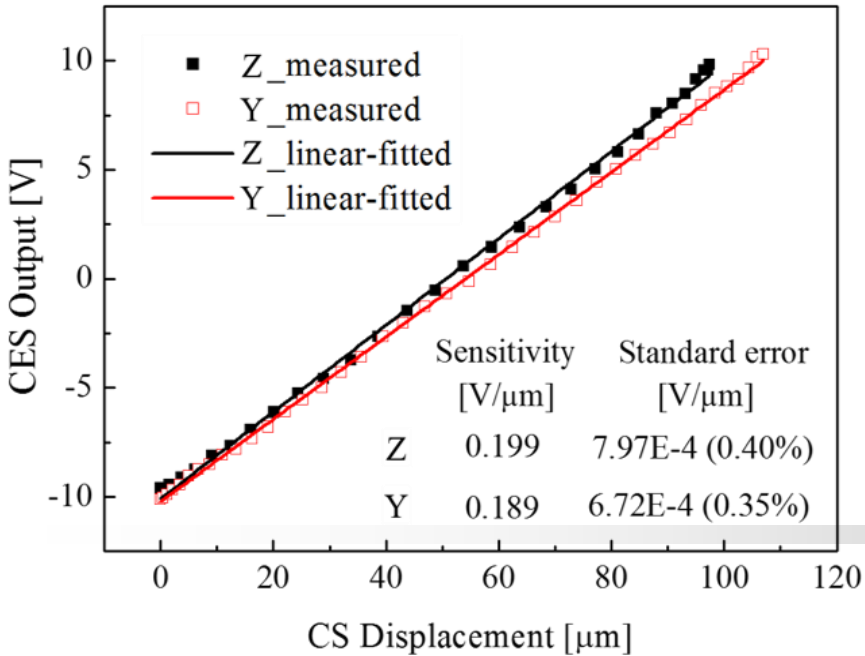
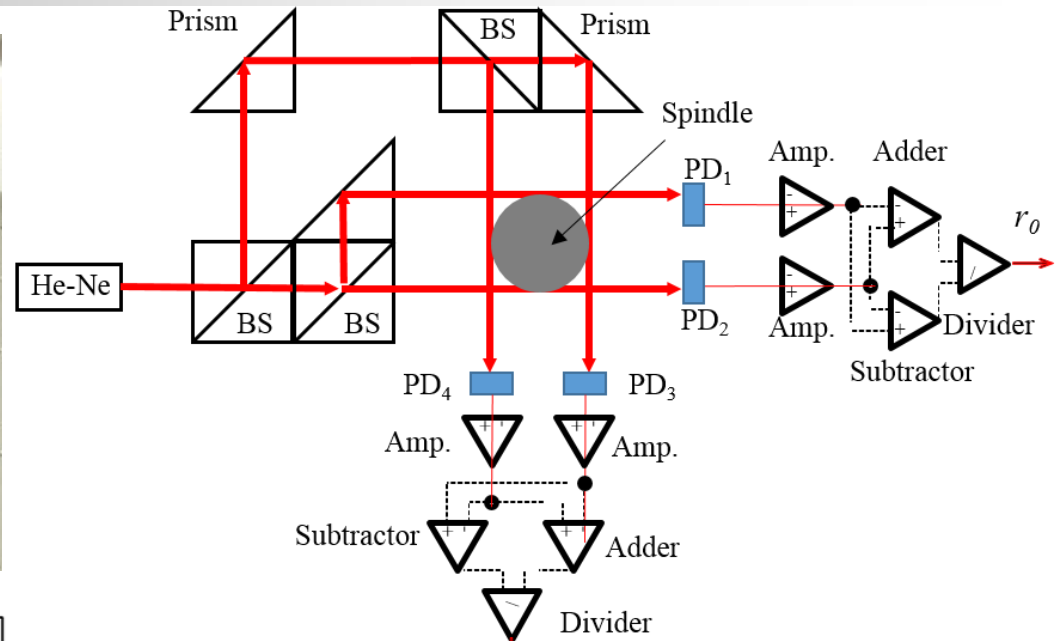
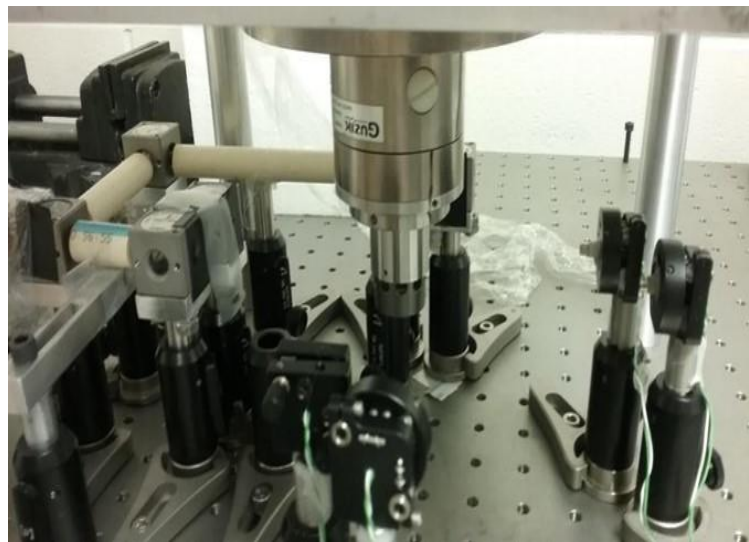


# Sensor Characteristics





# Experiment: Spindle Dynamic Char.



# Dynamic System Identification

