Precision Metrology Lab
ME Dept. NTU

Person in charge: Kuang-Chao Fan, PhD
Lifetime Distinguished Professor
Fellow of SME, CSME, CIAE

Lab Introduction

This laboratory was established in 1984 by Prof. Fan, specialized in teaching and research on dimensional measurements from macro to micro and nano scales.

Course offered: Precision Metrology, Precision Engineering Design, Machine Tools, Automatic Optical Inspection.

Equipments: 6 Laser interferometers for length measurement,
4 3D microscopes (one white light, one confocal, one holographic and one stereo) for micro/nano profile measurements,
3 contact profilers (one roughness, one profile and one roundness) for geometrical measurements,
3 non-contact image apparatus for optical dimension measurements.
A range of gauges and meters is available for general dimensional inspection.
A number of self-developed sensors are also available for industrial on-line measurements, such as displacement, angle, force, acceleration, level, flatness, etc.

This Lab has the capability to design customized measurement equipment for particular use that cannot be purchased from the market or the market price is too high.

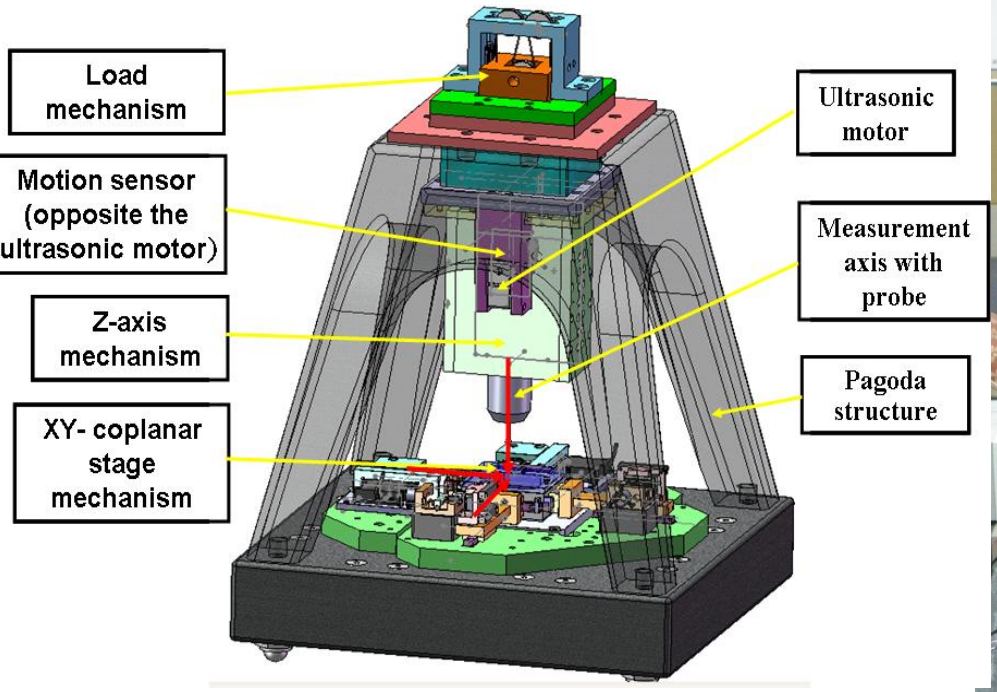
Current Researches

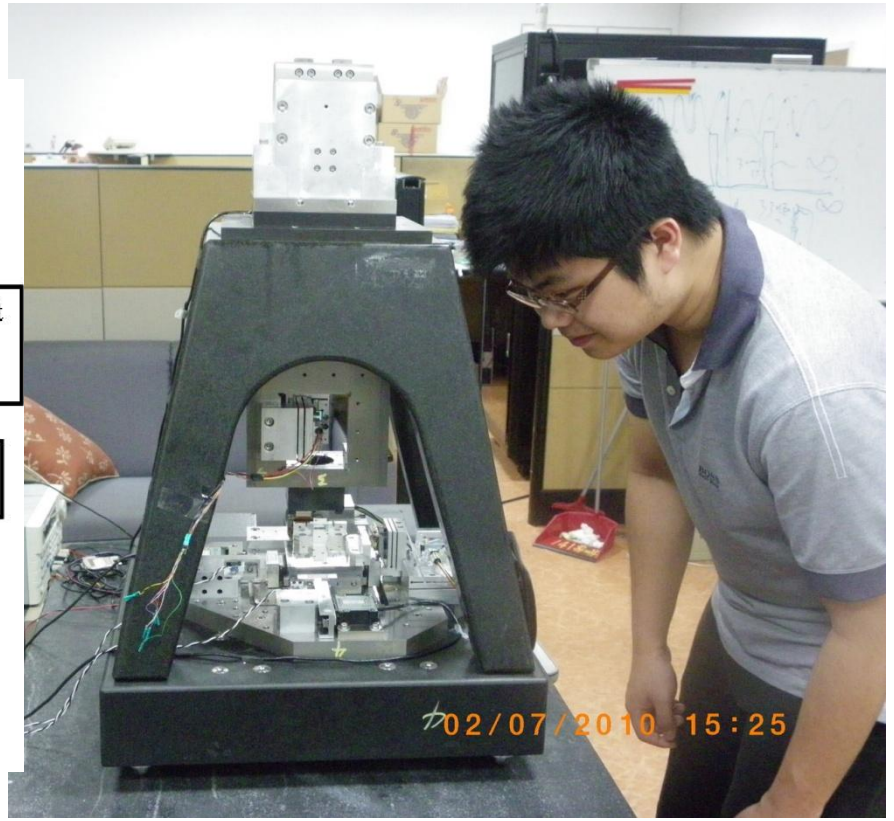
1. **Development of a Micro/nano-CMM**
2. **Development of miniature interferometers as built-in sensors for precision machines**
3. **Chromatic confocal microscope**
4. **Machine tool metrology**

1. Development of a Micro/nano-CMM

Micro-CMM at NTU Taiwan (2011)

Concept Design → **Reality**

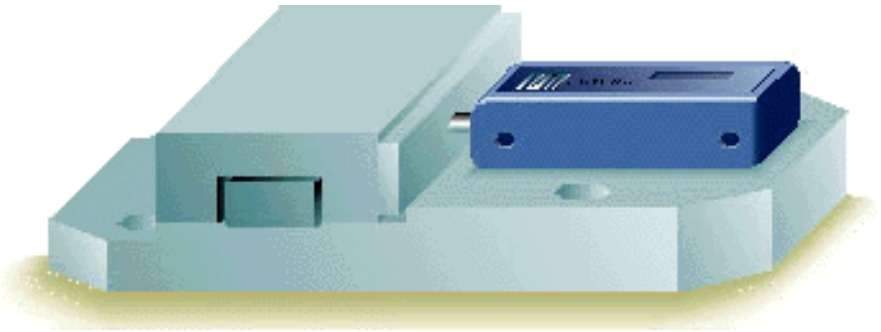


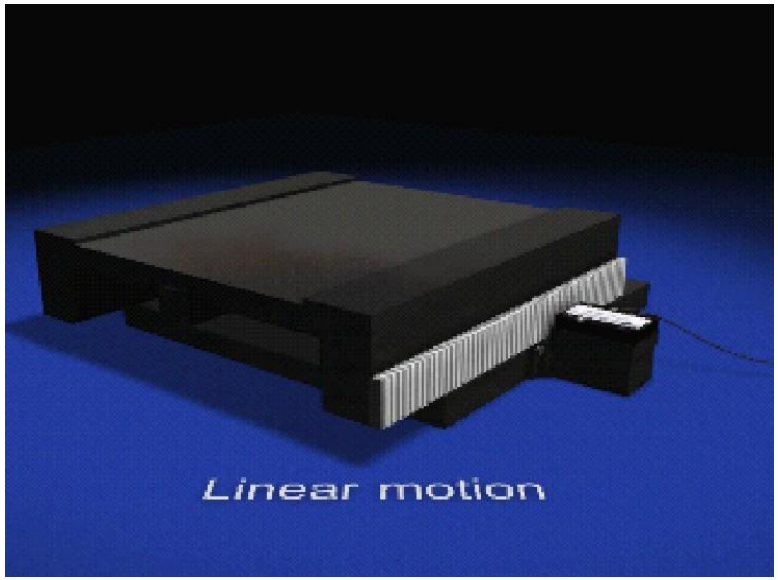


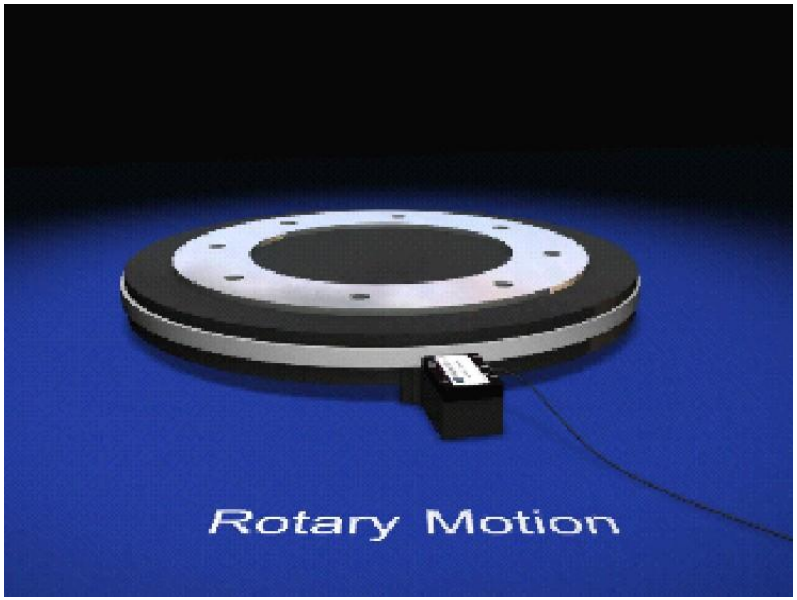
J of Nanomanufacturing (2011)

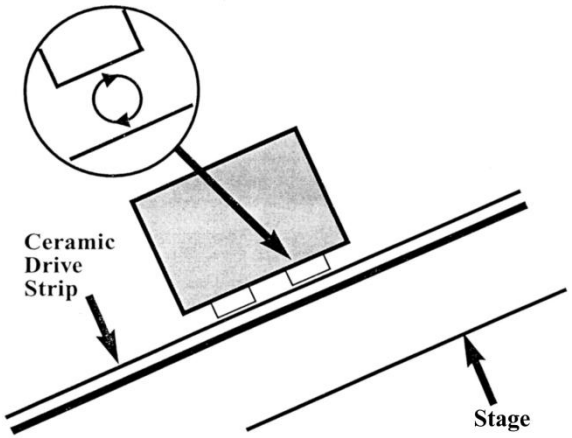
Core Technology: Nano-motion

Nanomotion Ultrasonic Motor



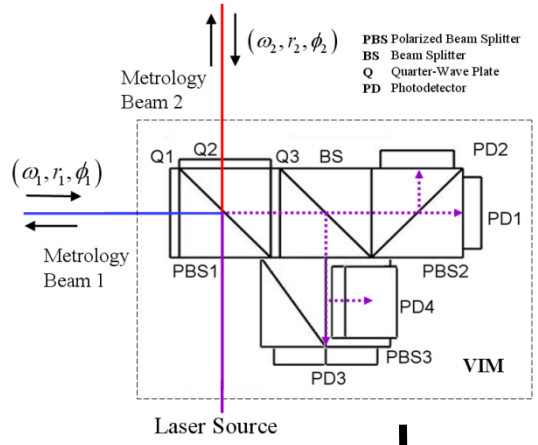




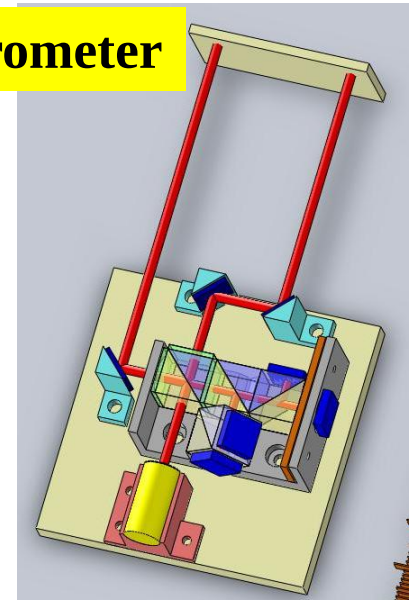


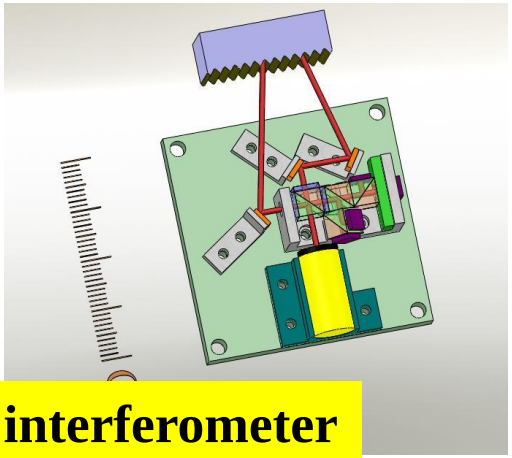
Reconfigurable Interferometric Module

Core module

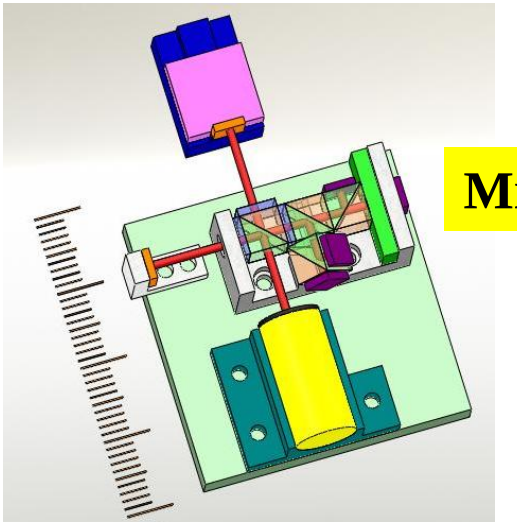


Angle interferometer





Grating interferometer

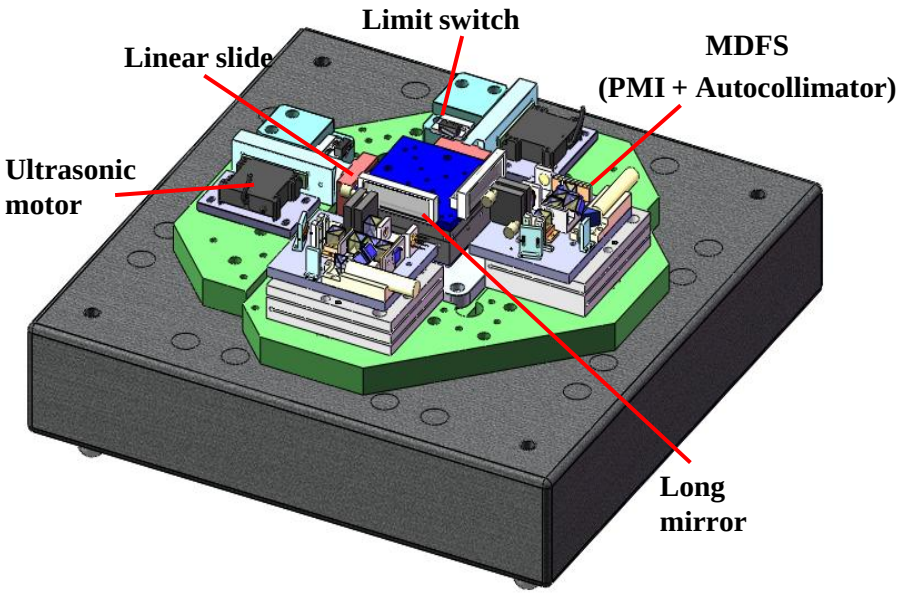


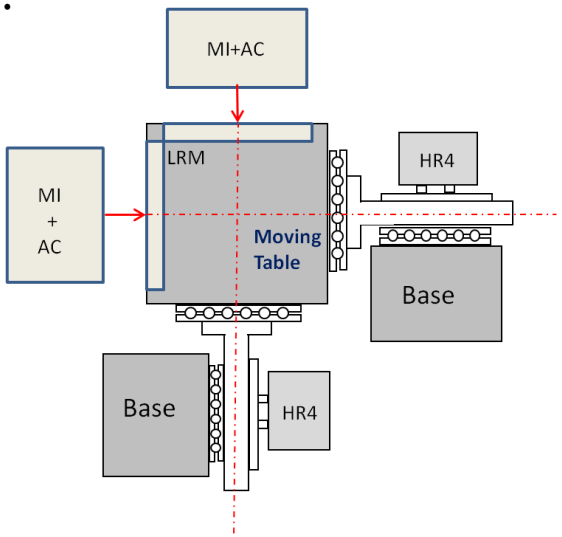
Michelson interferometer

2-D high precision coplanar stage (2012)

Introduction:

- Conventional XY stage is stacked up by two linear stages. The Abbé error of the lower stage is high. An innovation coplanar stage is thus proposed in this study.
- The stage motion is actuated by a ultrasonic motor, the opposite side is the motion sensor of MDFS.

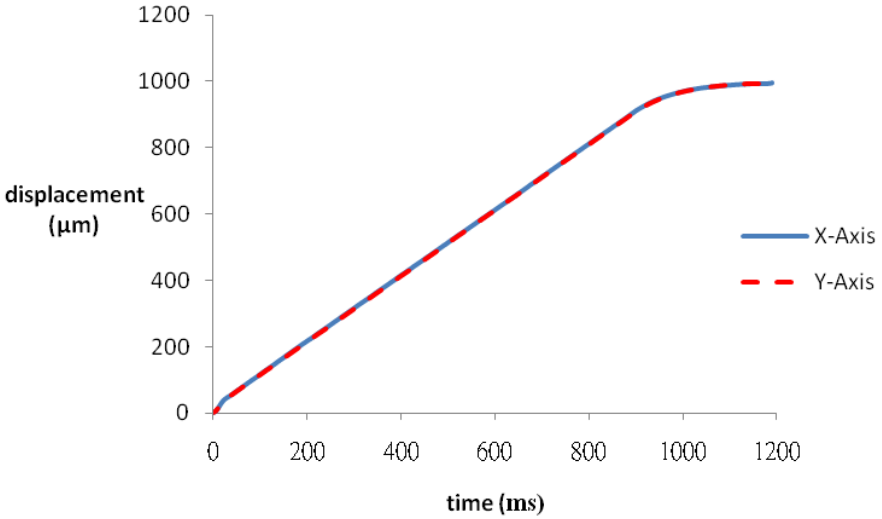


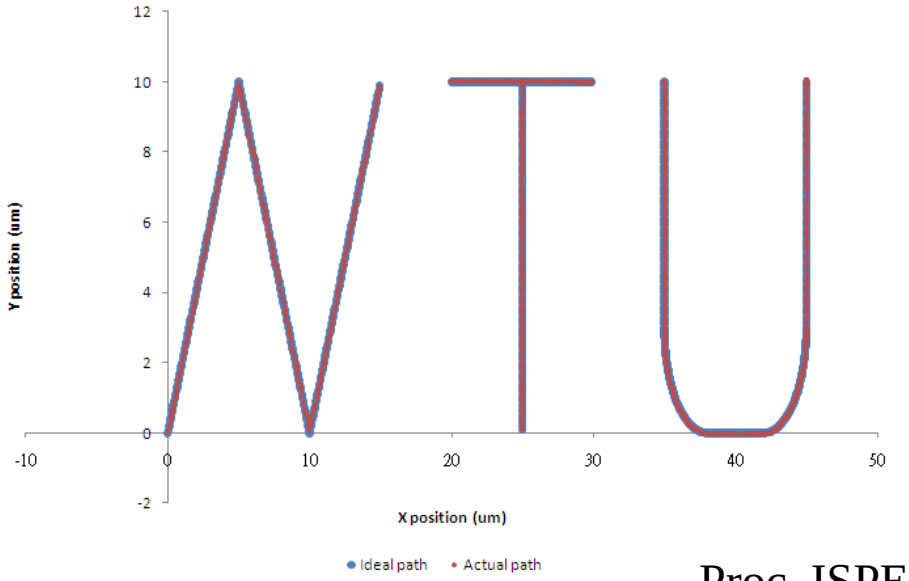


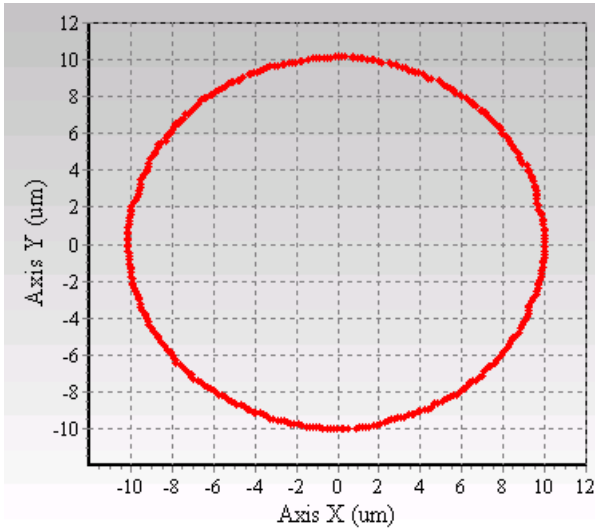
Motion control of a coplanar stage

Introduction:

- This research presents the motion control of a coplanar stage which is driven by ultrasonic motors. Applying the self-tuning neuro-PID controller to control the displacement and speed of the coplanar stage, any contouring path of any geometry could be achieved.







Proc. ISPEMI (2011)

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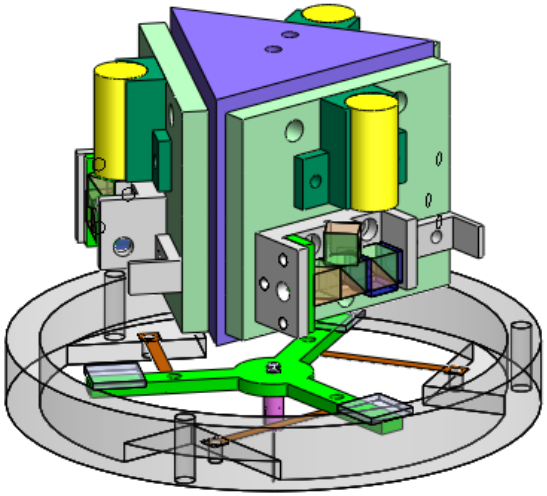
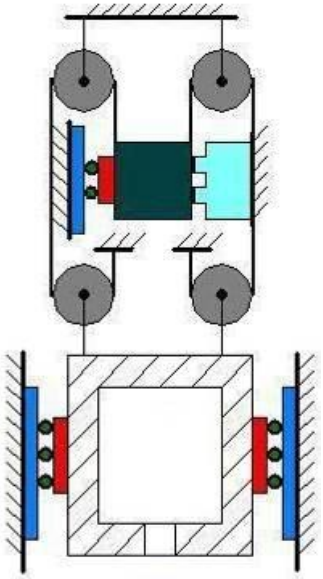
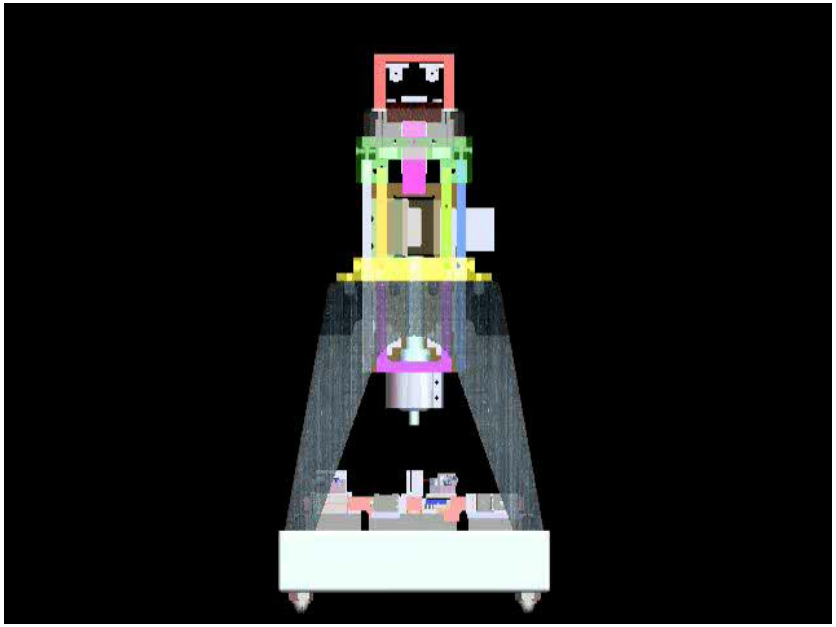
Z-axis Spindle and Probe Pesign

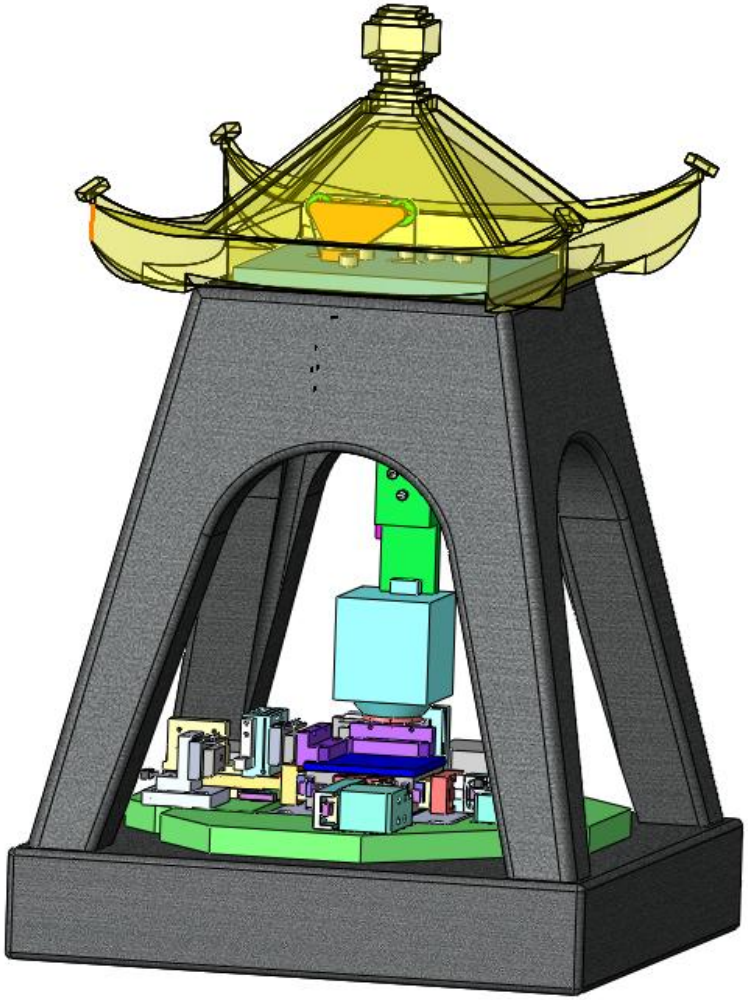




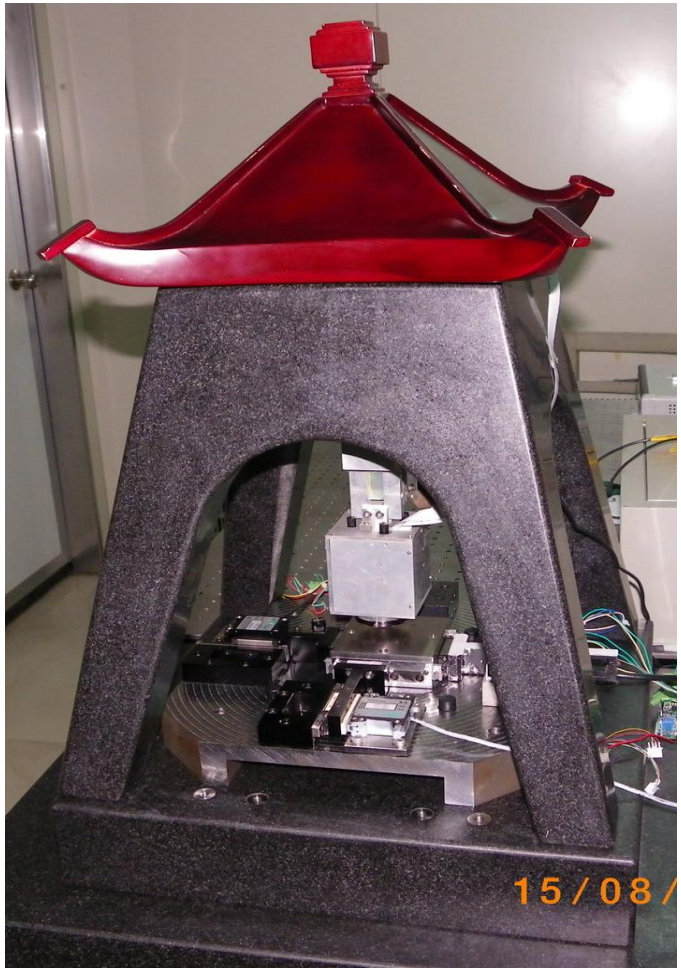


Nano-CMM at HFUT China (2011)

Pagoda Bridge



Reality



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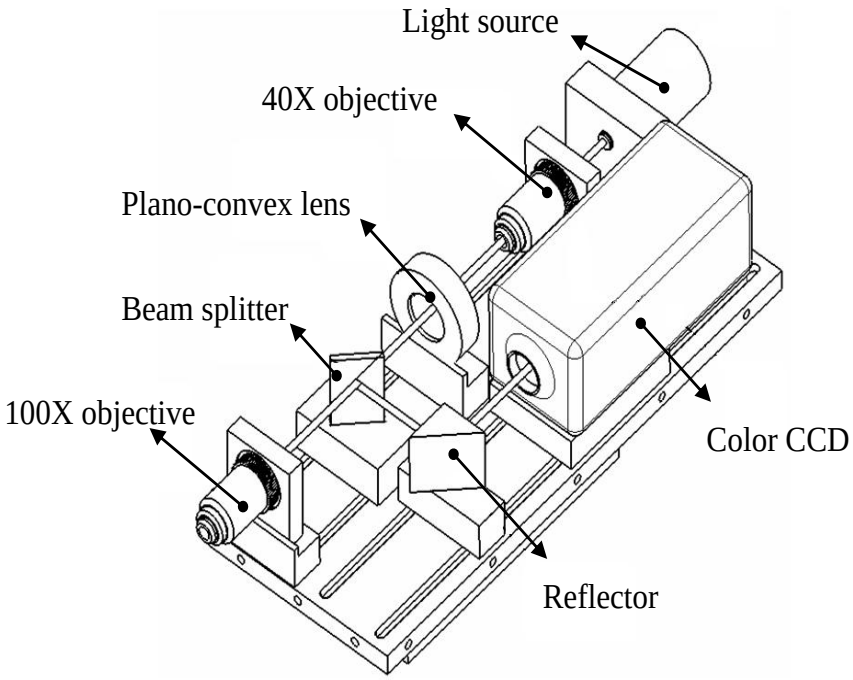
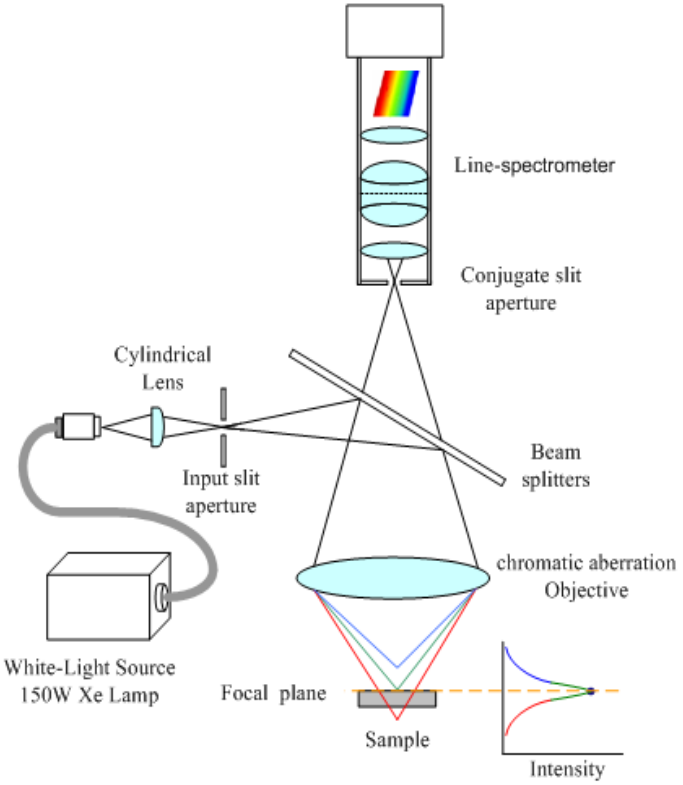
3. Chromatic confocal microscope

Chromatic confocal 3-D Microscopy

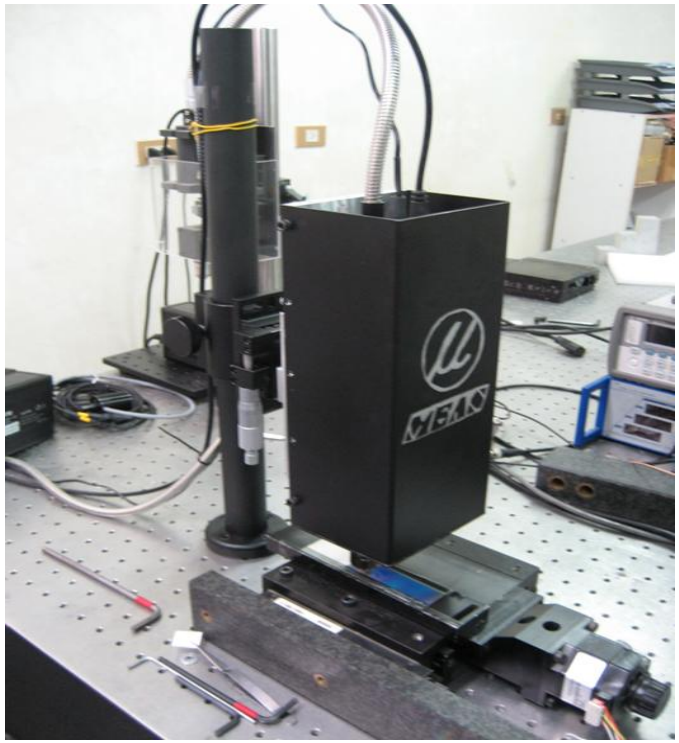


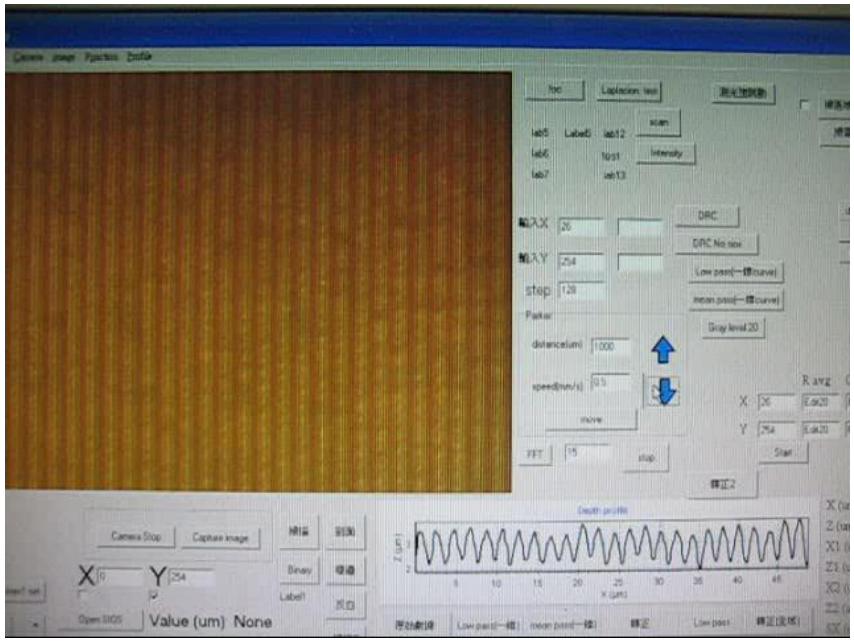


Enlarge measuring range

CCD for full field image

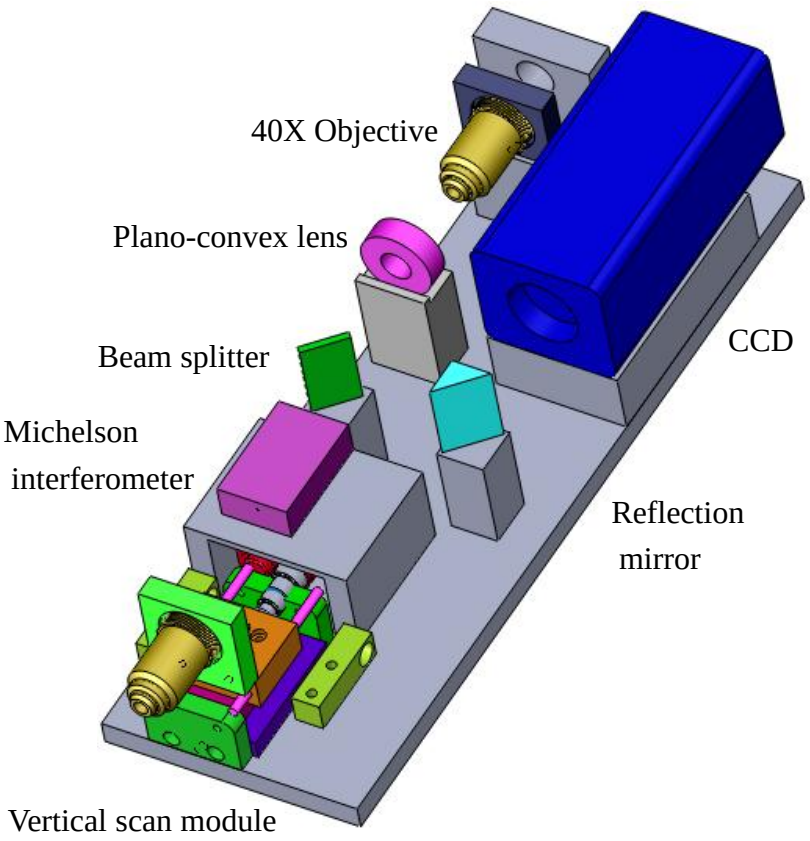
Measurement Under Vibration





Video show

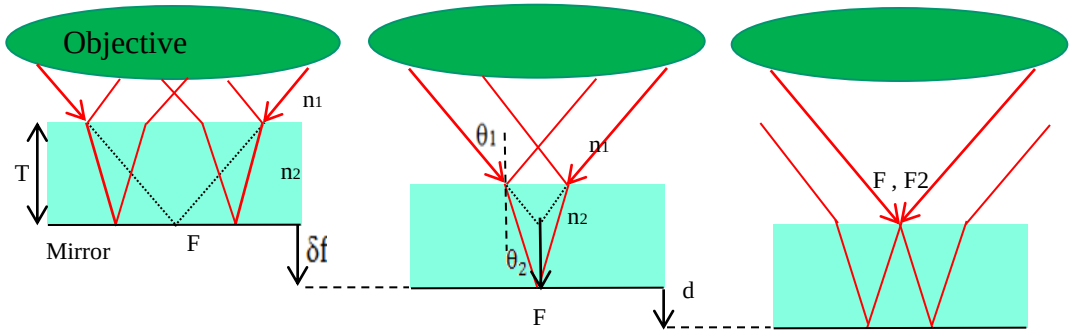
Confocal microscope system

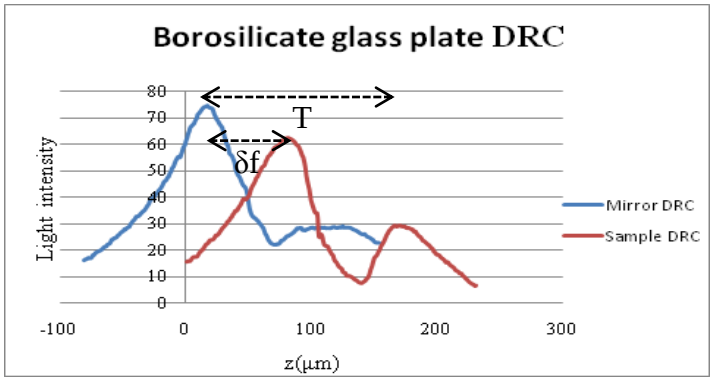


Introduction:

- Based on confocal theorem and Snell's law, a long measuring range confocal microscope system is being developed to measure the thickness and refractive index of transparent thin film.
- The vertical scan module is sensed by a miniature Michelson interferometer.

$$T = \frac{\delta f}{1 - \sqrt{\frac{n_1^2 - NA^2}{n_2^2 - NA^2}}} \qquad n_2^2 = \frac{1 - NA^2 + (\frac{T - \delta f}{T})^2 NA^2}{(\frac{T - \delta f}{T})^2}$$





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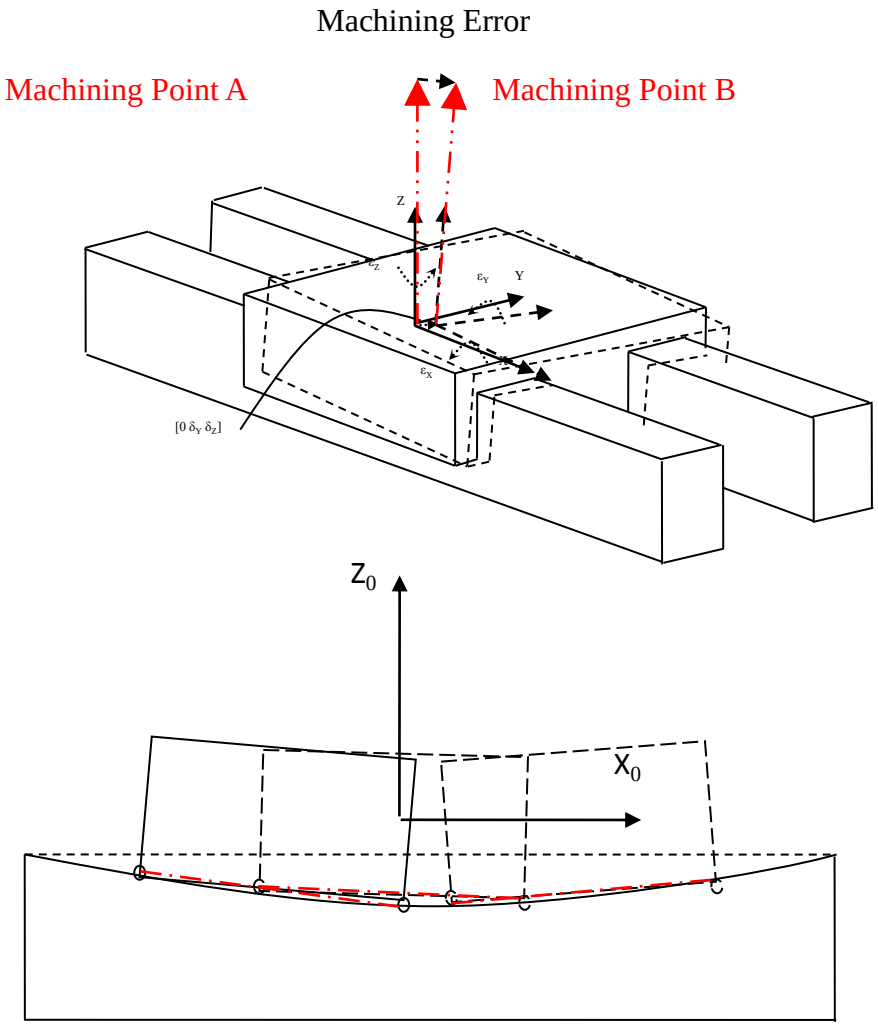
4. Machine tool metrology

Prediction of Machine Tool Slideway Wear

Introduction:

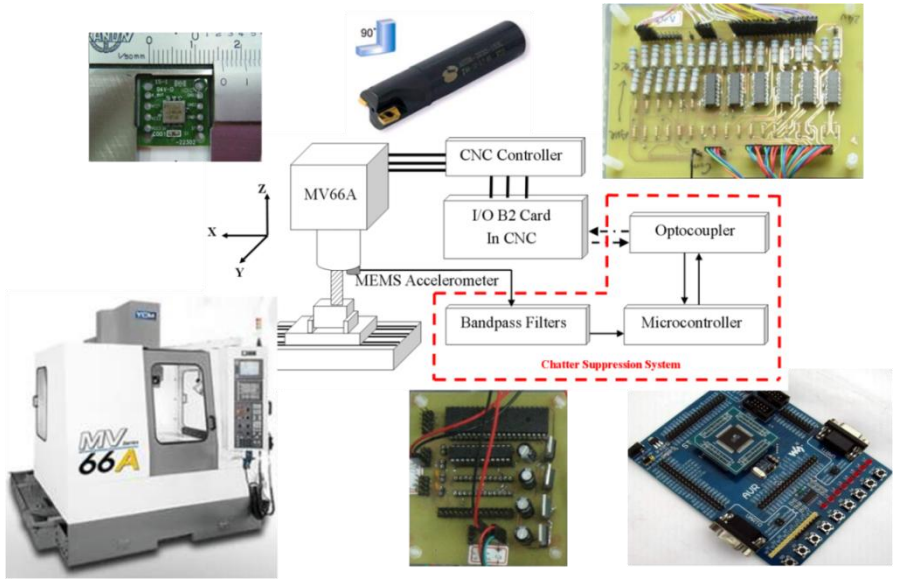
● After a long period of cutting operations, any machine tool will appear obvious wear on the slideways. Such a wear will degrade the accuracy of the machine tool due to the increase of angular errors yielding to serious Abbé errors. This research proposes a mathematical model so that at given cutting forces and parameters of the slideway it is able to calculate the geometric errors of the slider due to contact deformation caused by the wear of the slideway and then predict the machining errors after a long-term operation.

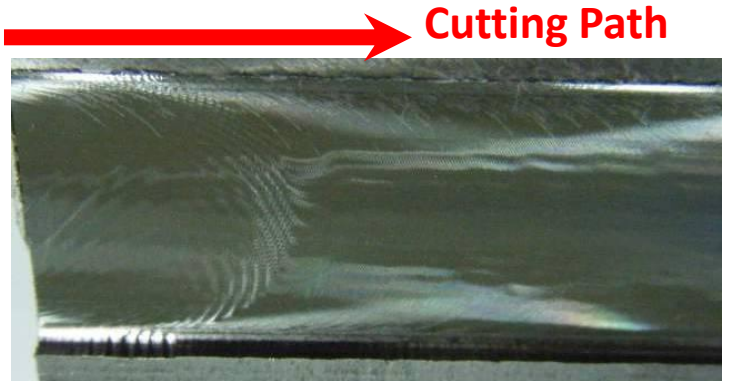


Machine tool chatter suppression system

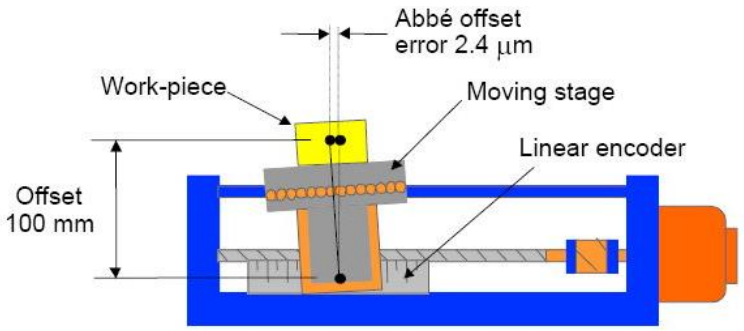
Introduction:

- This research presents a method to control the spindle speed for chatter suppression during cutting. A MEMS accelerometer is used to acquire the vibration signal during cutting. A band-pass filter is used to obtain the bandwidth of self-excited vibration signals, and the microcontroller is employed as the control unit of the chatter suppression system.
- The standard deviation of acceleration is calculated and compared to the chatter threshold value. Whenever the calculated standard deviation is larger than the chatter threshold value, the control unit will actively adjust the spindle speed by fuzzy incremental PI control scheme.

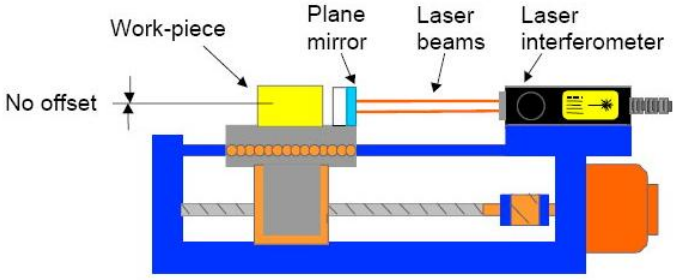




Abbé error compensator

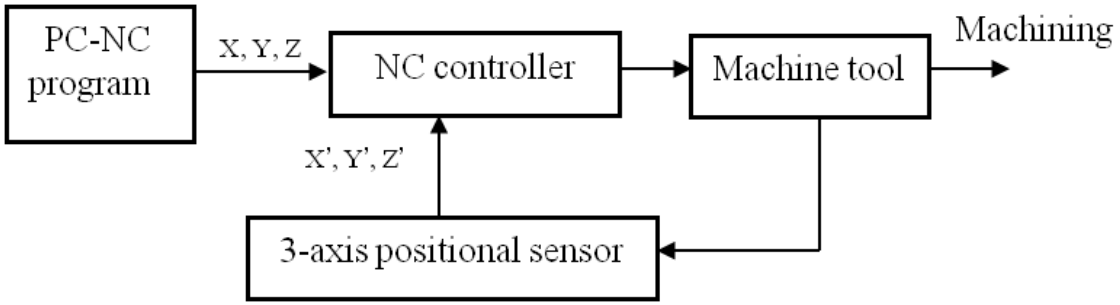


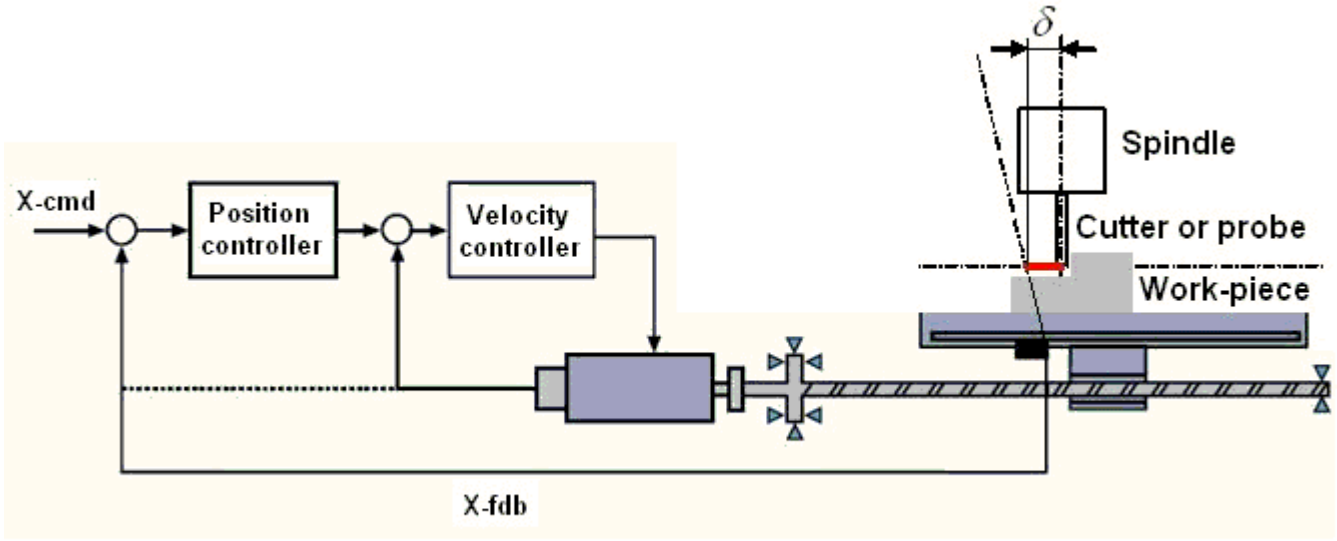
Linear encoder feedback



Laser interferometer position feedback

Current NC Control Loop

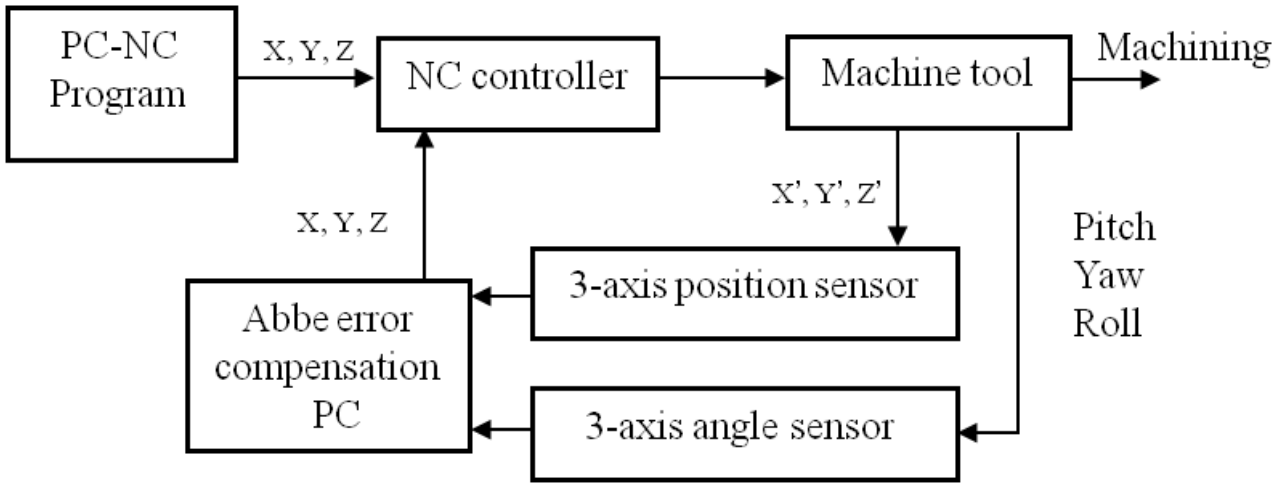




Problem: feedback position is not the commanded position

Abbé error is inevitable

Proposed Feedback-compensated Control Loop

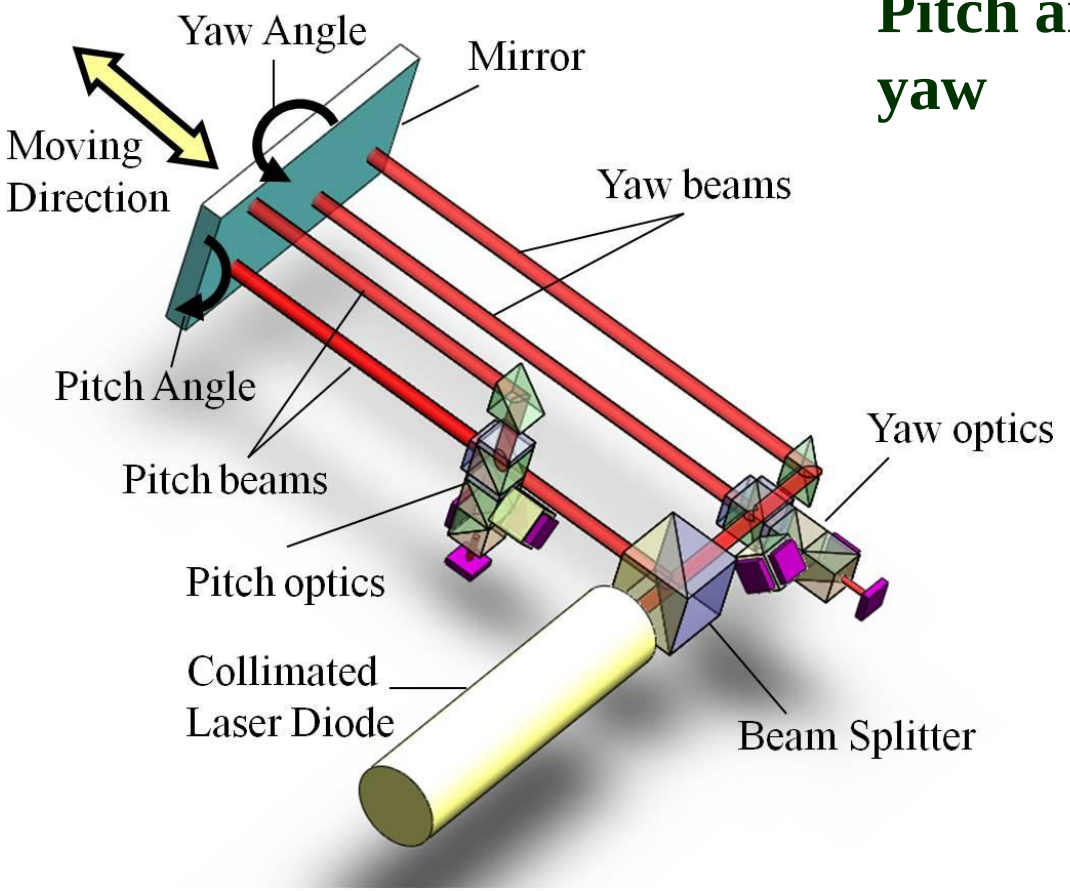


Problem:

How to design a miniature and low cost 3-axis angle sensor?

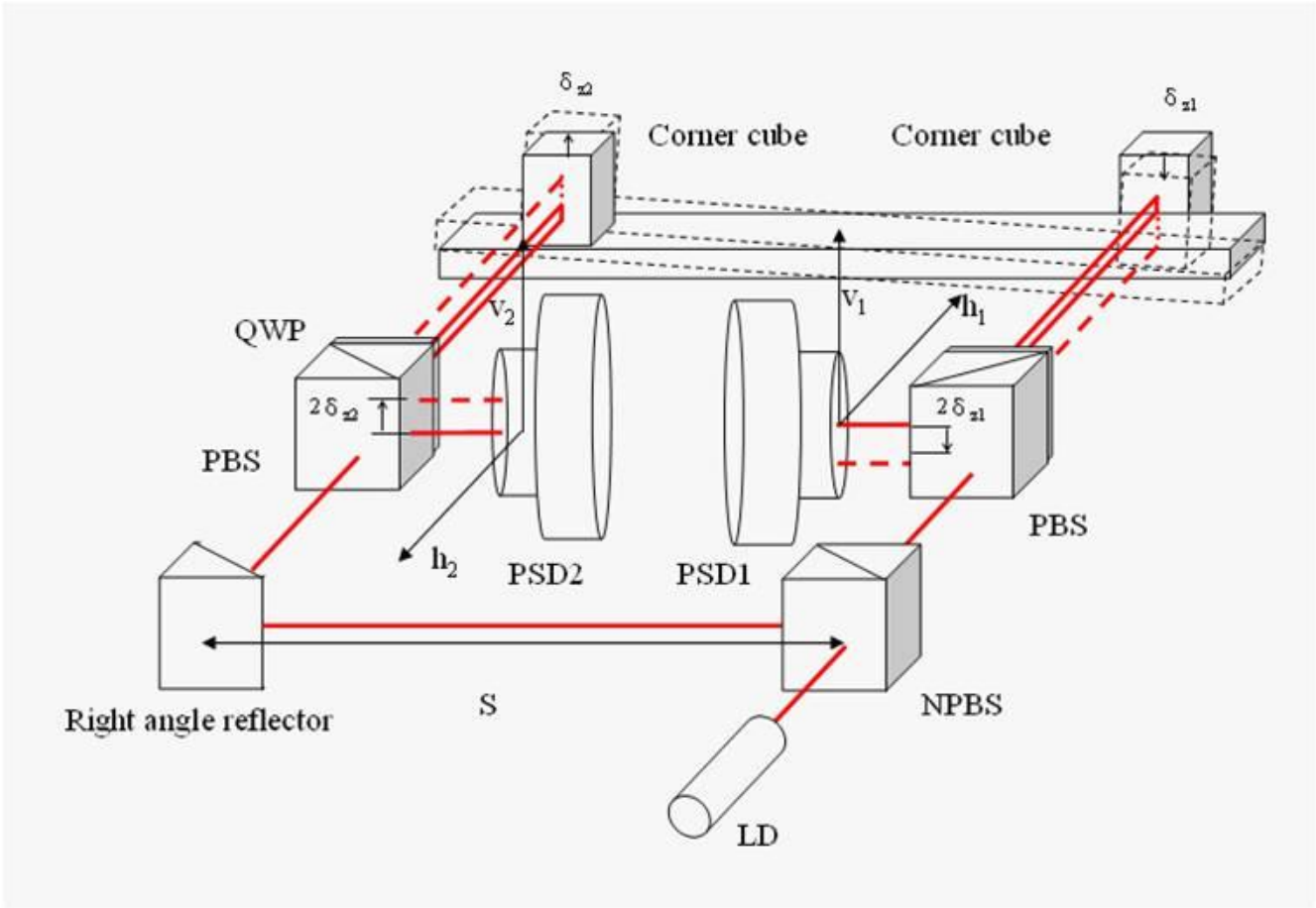
How to integrated the Abbé error compensator into current NC controller?

Dual-axis Angle Interferometer



Pitch and yaw

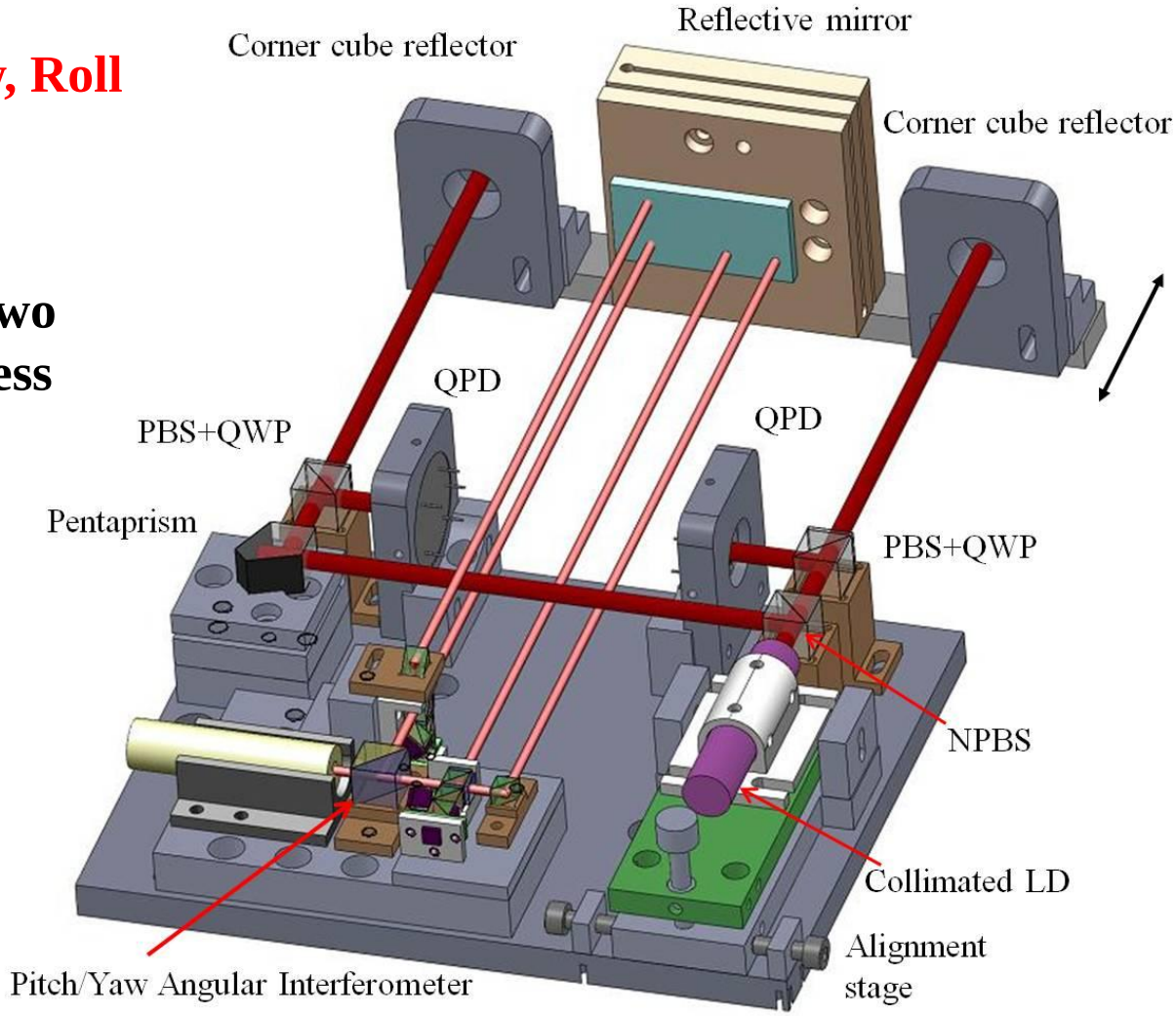
Design of a roll angle sensor



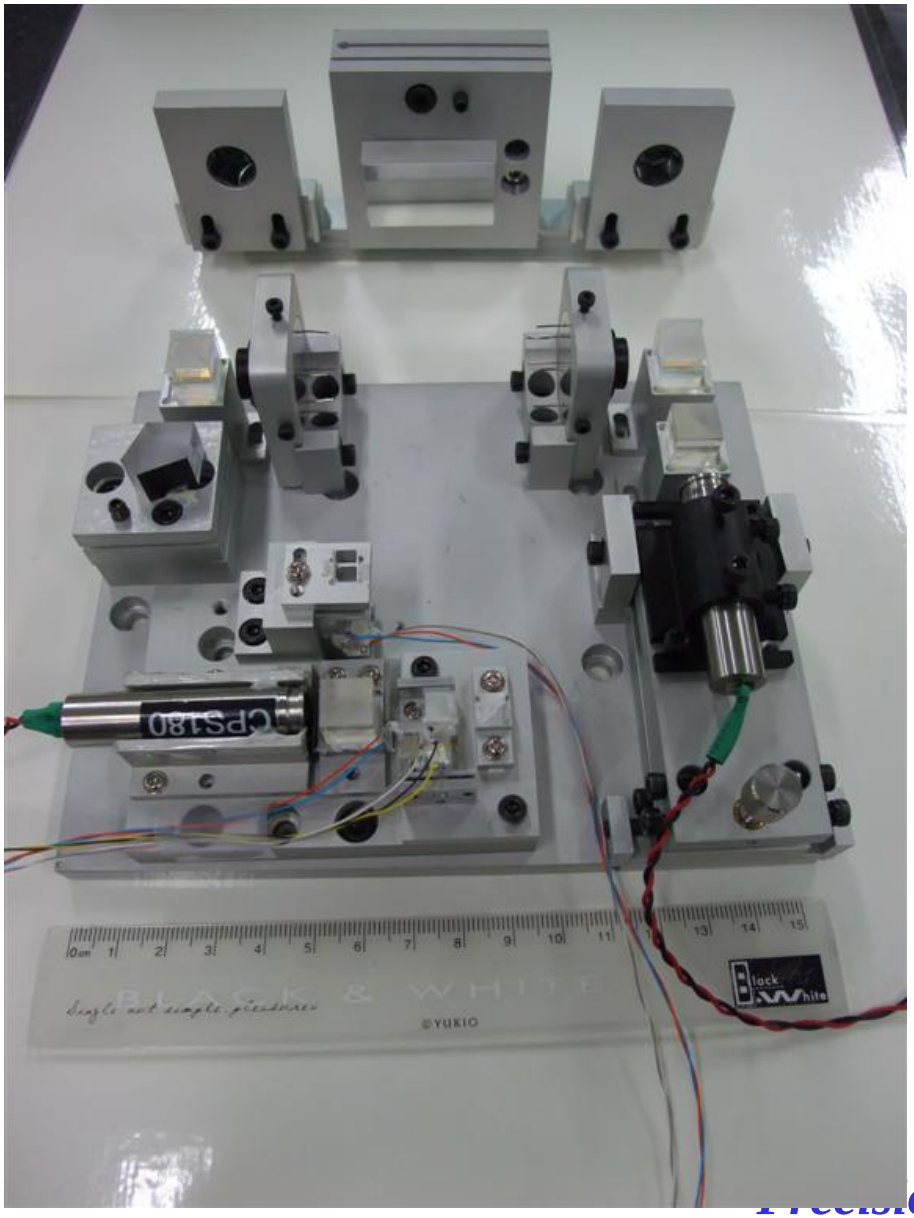
3-axis Angle Sensor System

Pitch, Yaw, Roll

Also for two straightness errors

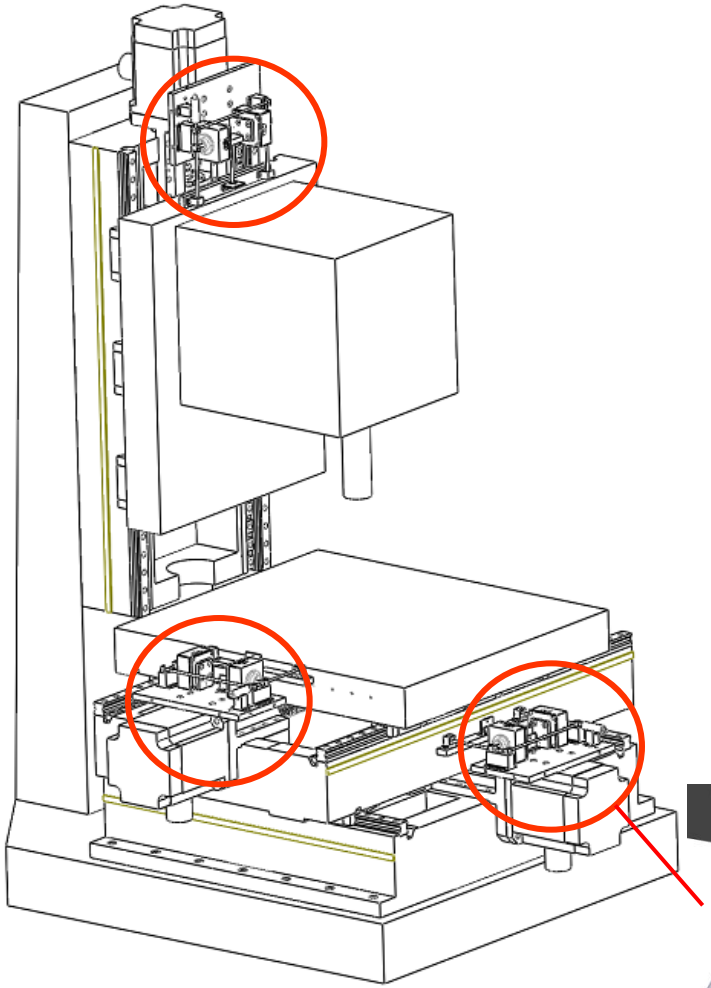


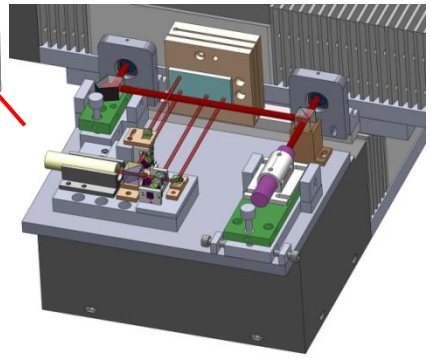
3-axis Angle Sensor System (Photo)



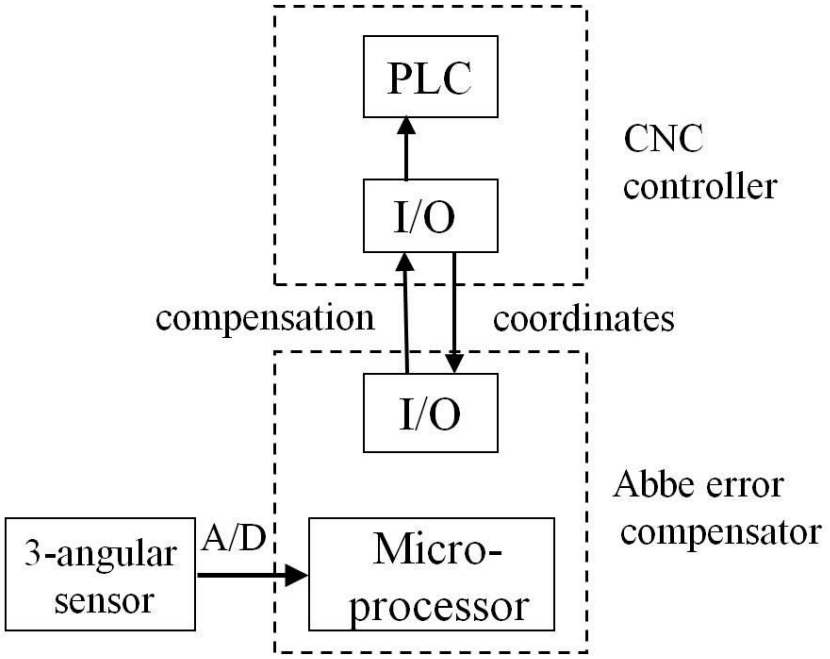
- **Size：**
- **16cm *13cm**

Embedded in the Machine Tool

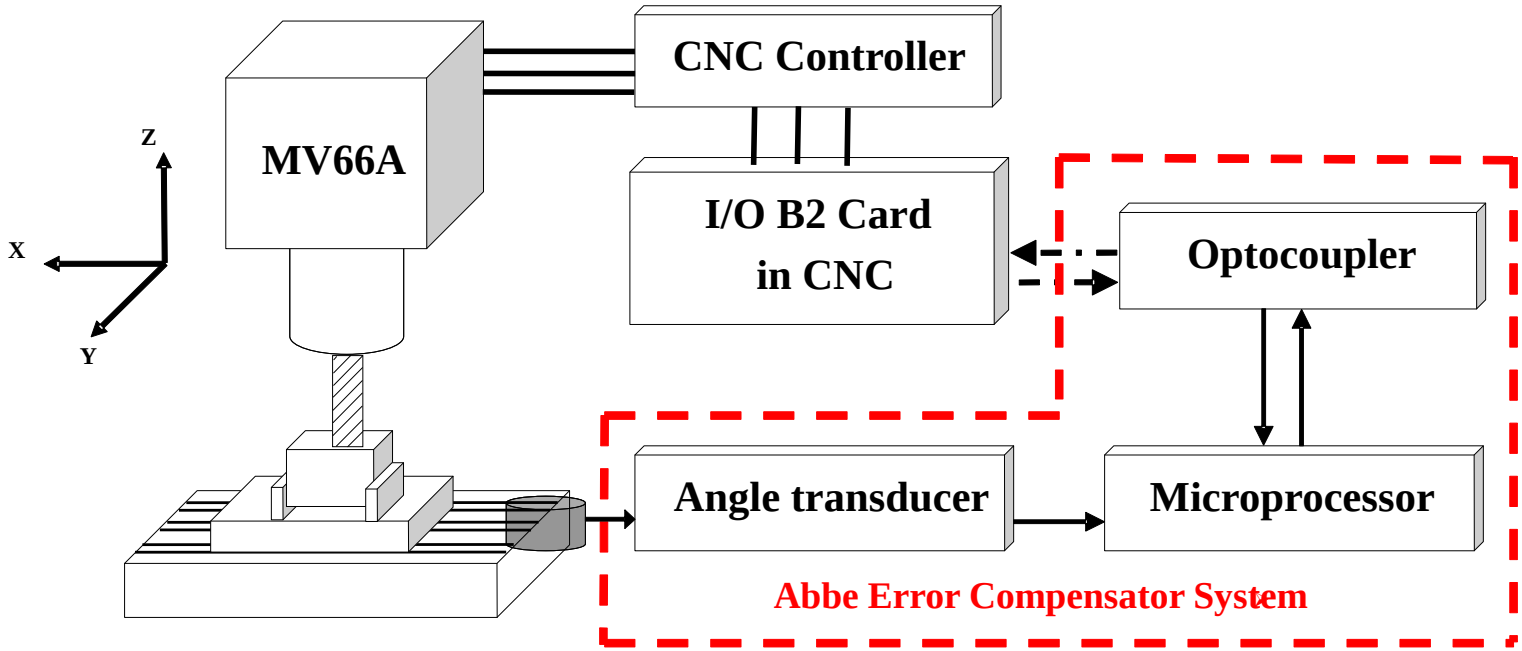




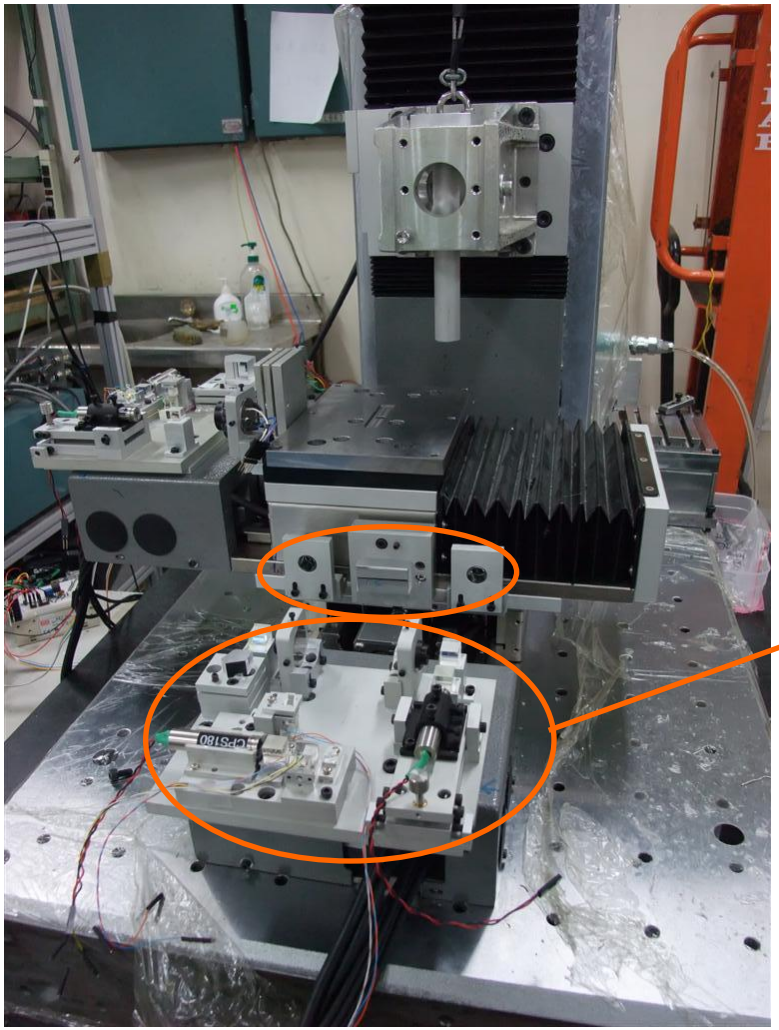
Integration with CNC controller

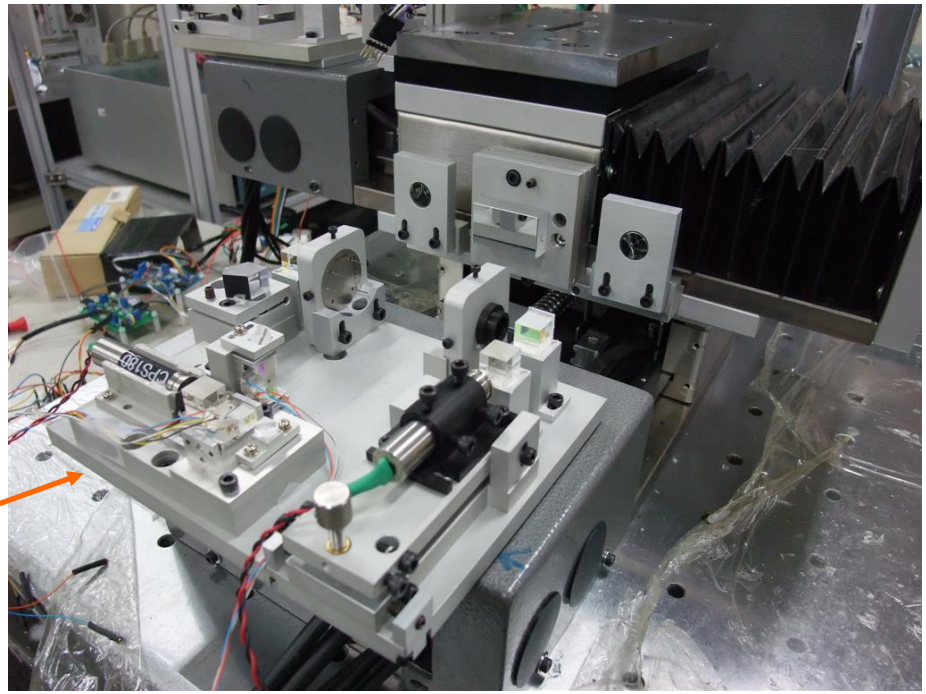


Integration with a FANUC Controller



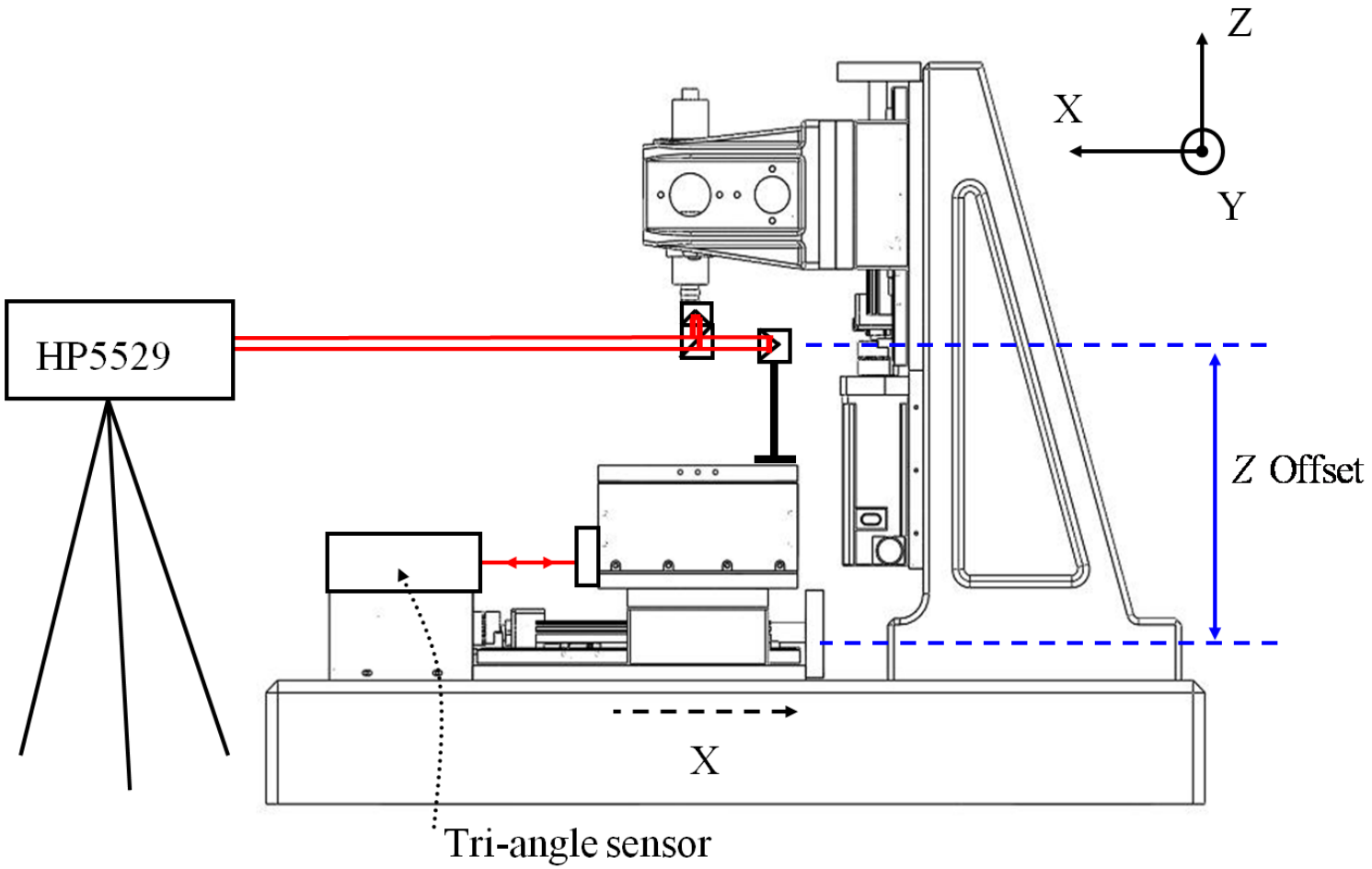
Photos of Angle Sensors in the Machine Tool





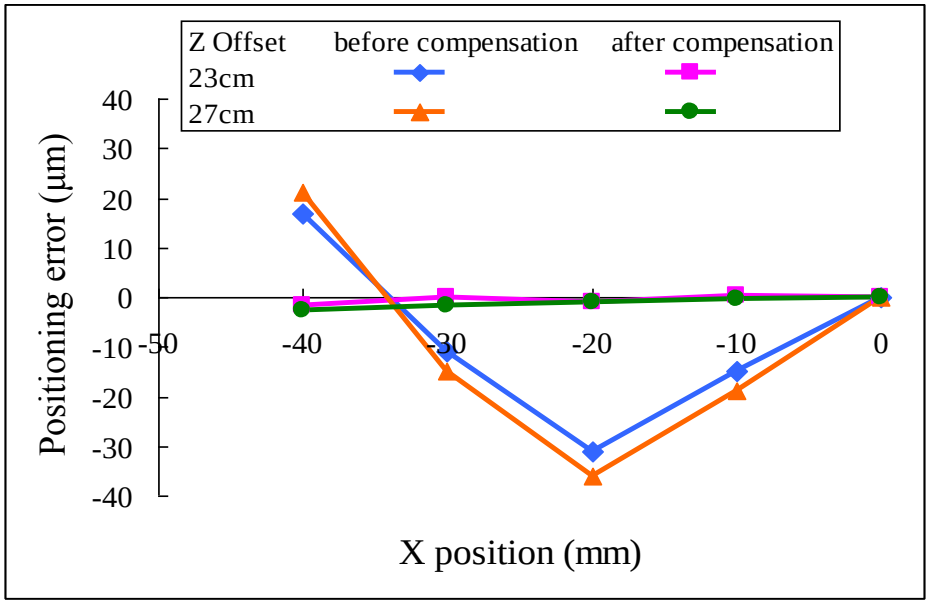
Positioning error in X-axis with Z-offset

Z-offsets: 23cm & 27cm

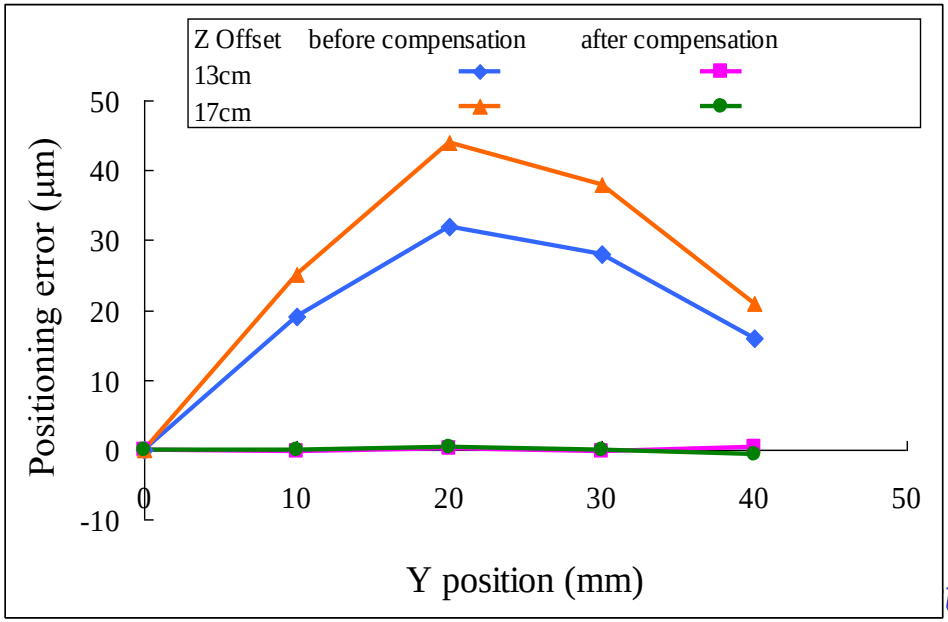


Experimental Results

X Axis



Y Axis



Thank you for your attention