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DIAMOND TURNING OF TEXTURED SURFACES USING FAST TOOL SERVO SYSTEM

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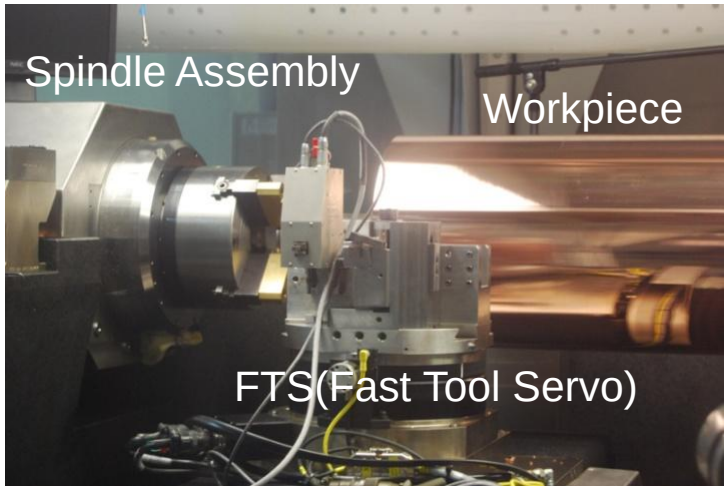
Outlines

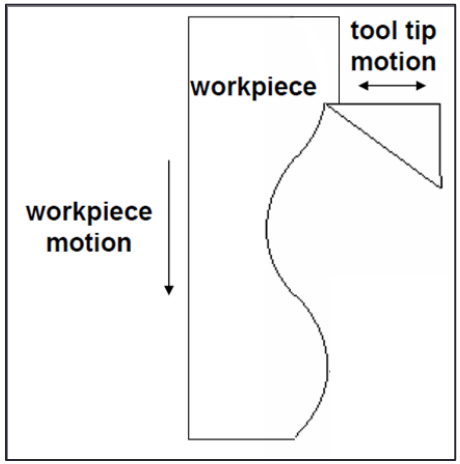
- Background of diamond turning using FTS
- Aims of this work
- Design and evaluation of FTS
- Machining test using FTS
- Conclusions

Background of diamond turning with FTS

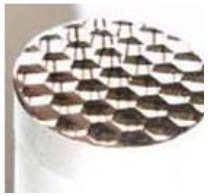
✓ **Fast Tool Servo (FTS)**

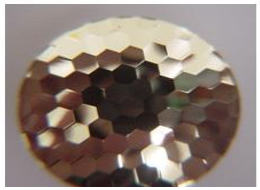
- An auxiliary servo module of the tool holder with an actuator that oscillates the tool at a particular bandwidth.
- FTS System is used in a variety of the diamond turning applications.



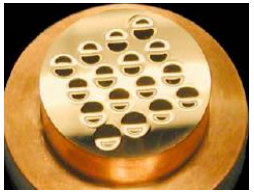


Optical surfaces

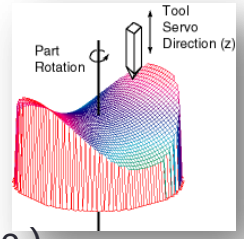




Micro lens array(ITRC)



Lens(Precitech Inc.)

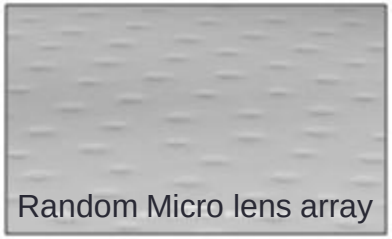


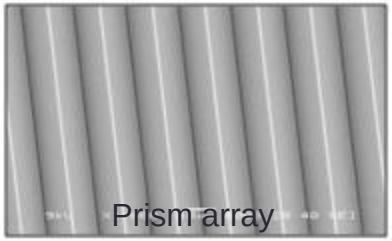
nonrotationally symmetric surfaces

Background : Motivation

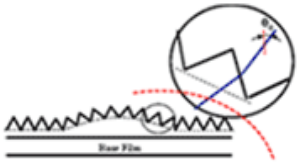
✓ Technological trends of micro machining using FTS

- Rising luminance of display as concentrating light through diffuser sheet vertically with light condensing function of prism and micro lens.(LMS Co., LTD)





Complicate textured patterns



Hybrid micro structure

- light condensing of micro lens => luminance up

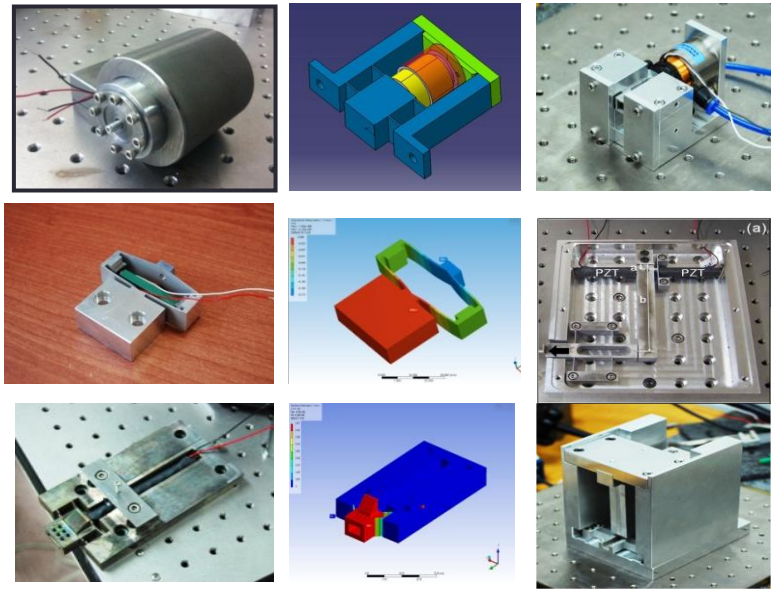
✓ Technologies ;

- How to manufacture master roll using FTS, **efficiently**.
  - High bandwidth FTS actuated with the effective stroke
- How to get high machining **accuracy**(form accuracy, surface roughness)
  - FTS errors ; hysteresis, frequency response, etc.
  - Cutting conditions ; tool design, cutting path(CAD/CAM)

Aims

Purposes of this work

- Developing FTS System for improving machining accuracy in diamond turning
  - Reducing dynamic errors of FTS(hysteresis, frequency response etc.)
- Finding machining conditions to perform high bandwidth FTS cutting



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- Background of diamond turning using FTS
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- **Design and evaluation of FTS**
- Machining test using FTS
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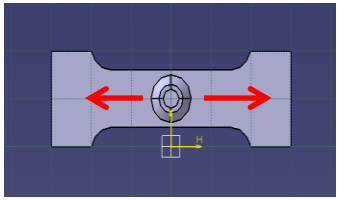
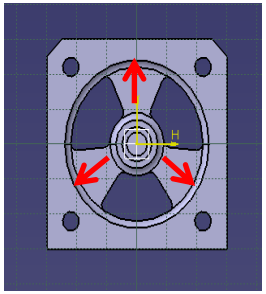
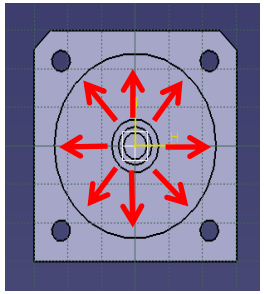
Developing fast tool servo(FTS) system for diamond turning

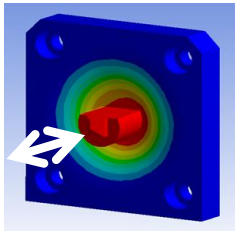
- ✓ Designing the various leaf springs of FTS actuated by PZT.
- ✓ Investigating the hysteresis and the stroke of FTS for designed models.

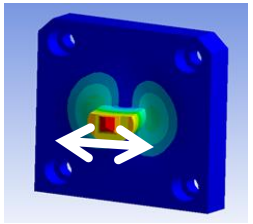




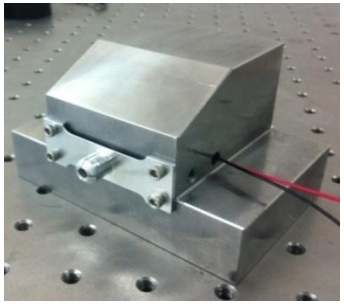


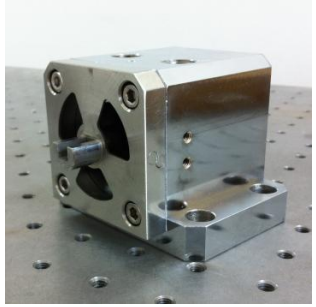
<Type A:two bridges> <Type B:three bridges> < Type C:disk >

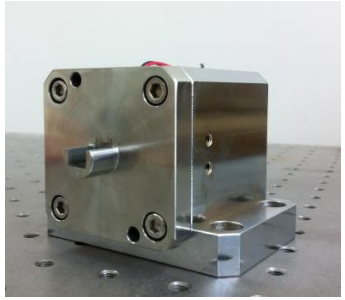




<Mode1> <Mode2>





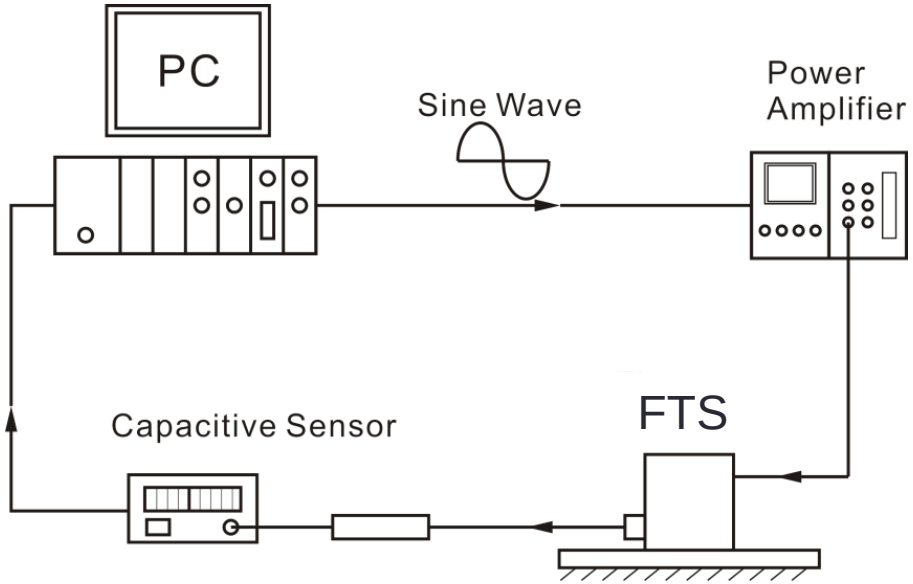


	Natural Frequencies		
Type	A	B	C
Mode1	895Hz	1873Hz	2489Hz
Mode2	1150Hz	2615Hz	3592Hz
Mode3	2074Hz	2703Hz	3669Hz
Mode4	12179Hz	14483Hz	20033Hz

- ✓ Natural frequency : type C > type B > type A

Experimental Setup for testing performances of FTS

- ✓ The waveforms which was generated in a PC with Lab VIEW S/W were amplified by power Amp. to supply to the PZT actuator.
- ✓ The corresponding displacement of FTS stroke was measured by a capacitive sensor.



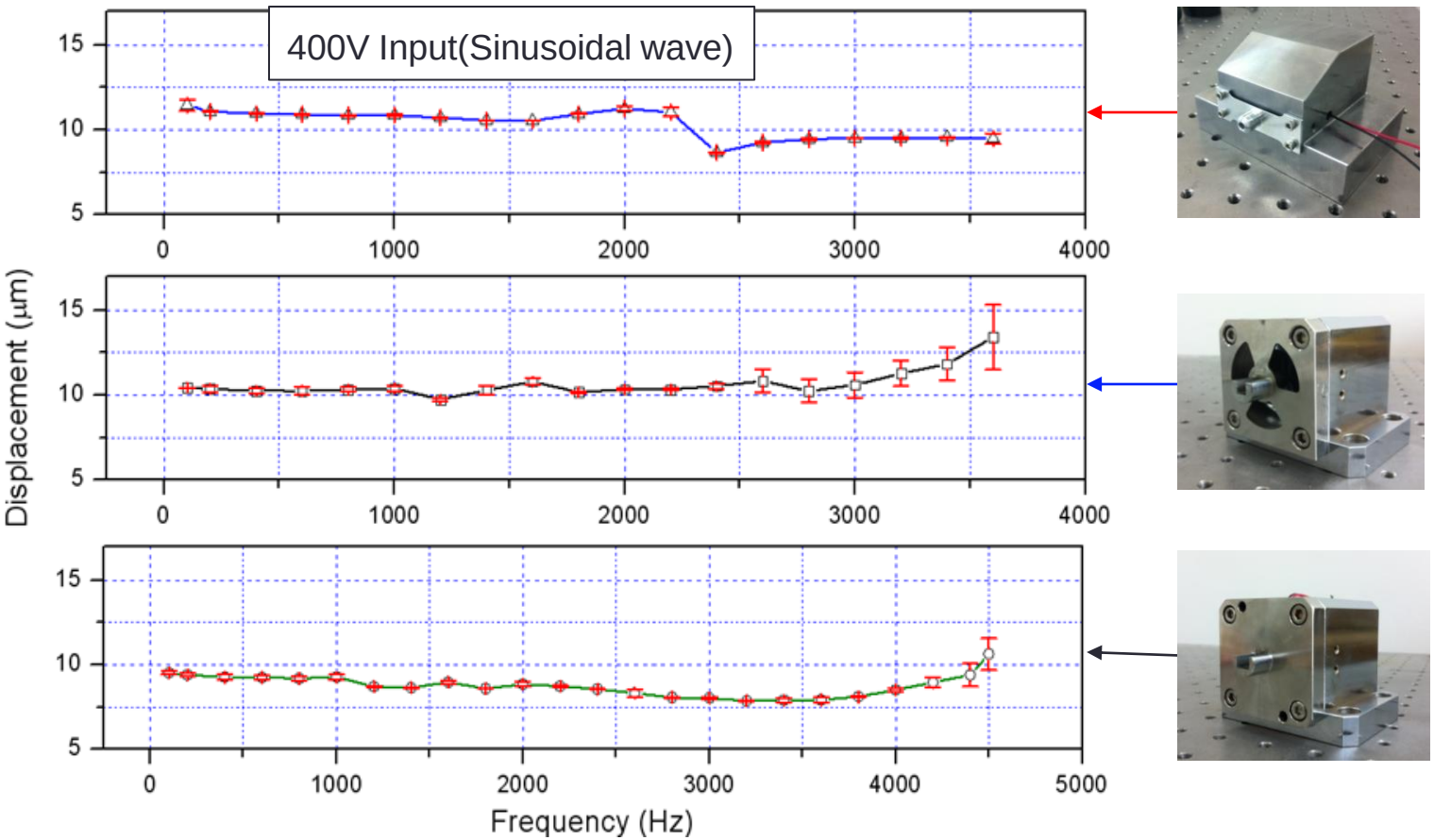
Test setup for measuring FTS performances

High voltage amplifier

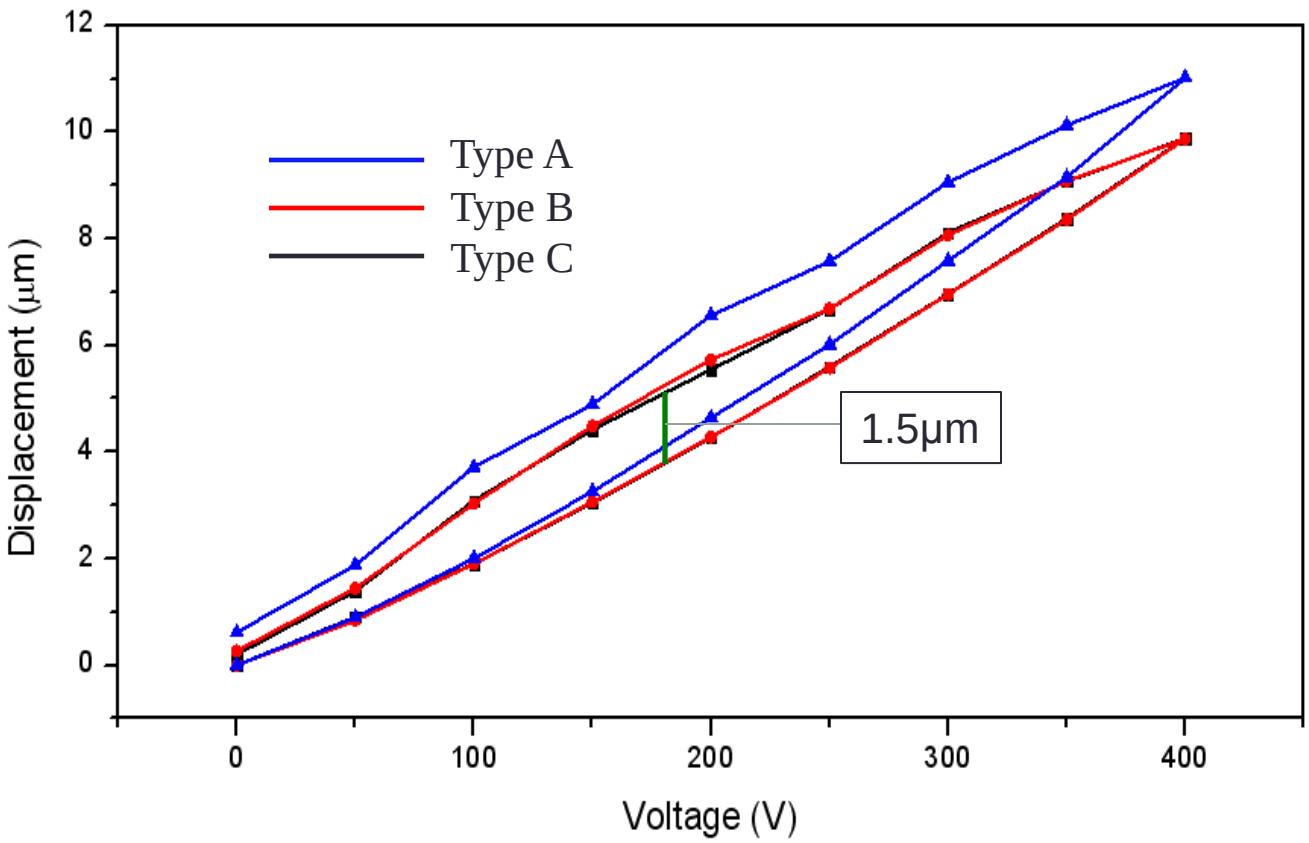
Amp - Models	E-472.20(PI)
Channels	2
Average output power	110 W
Voltage gain	100±1
Output voltage	3 to 1100 V

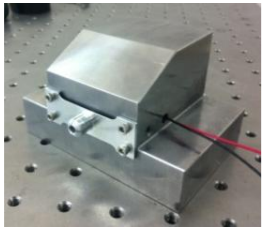
Peak to peak strokes according to actuating frequencies of FTS

✓ Compared three types of FTS

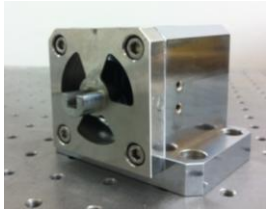


Comparing hysteresis for three types of FTS

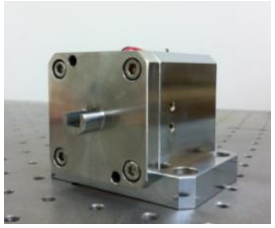




Type A



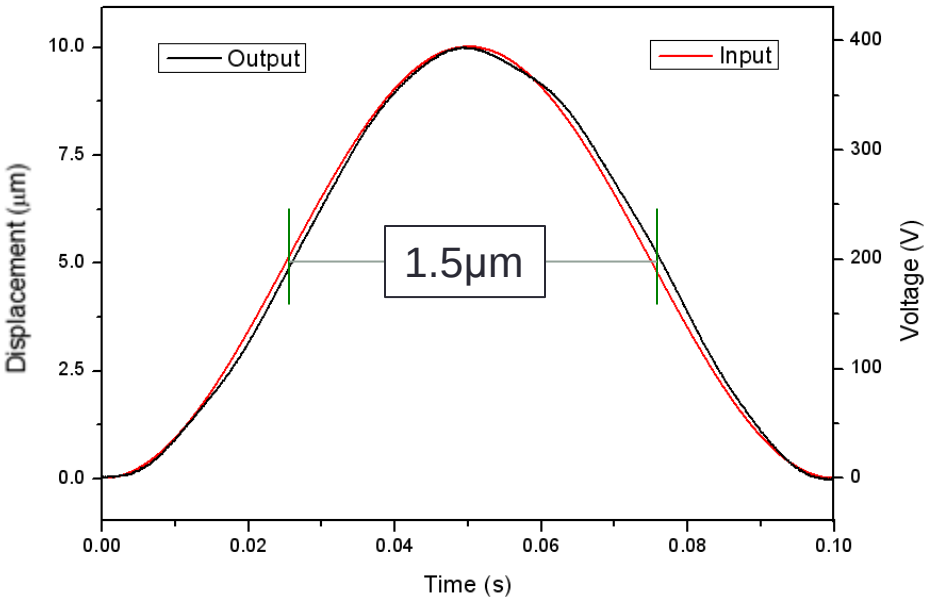
Type B



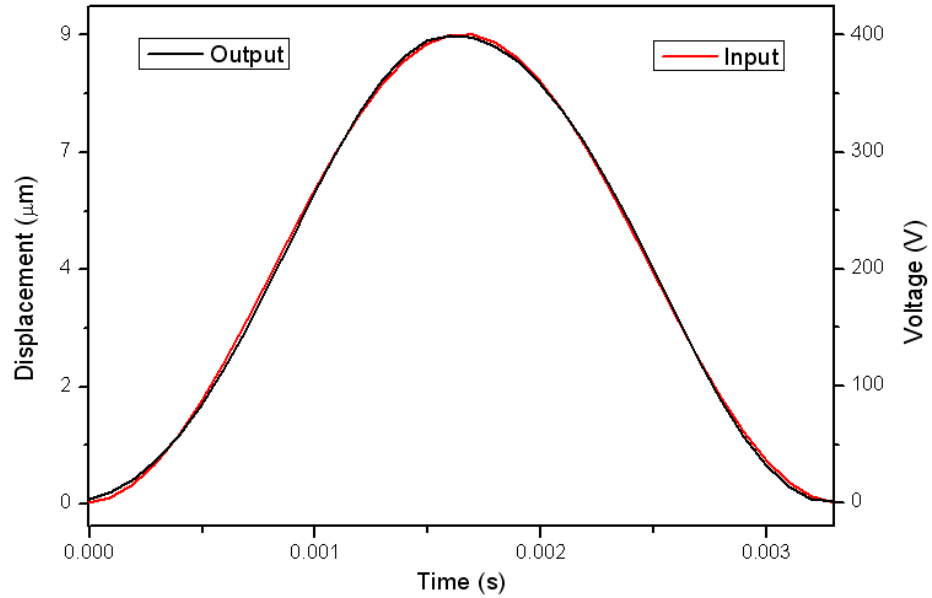
Type C

Comparison of profile errors between input and output signals of FTS(type C)

Actuating frequency : 10Hz
Input voltage : 400V(Sine wave)

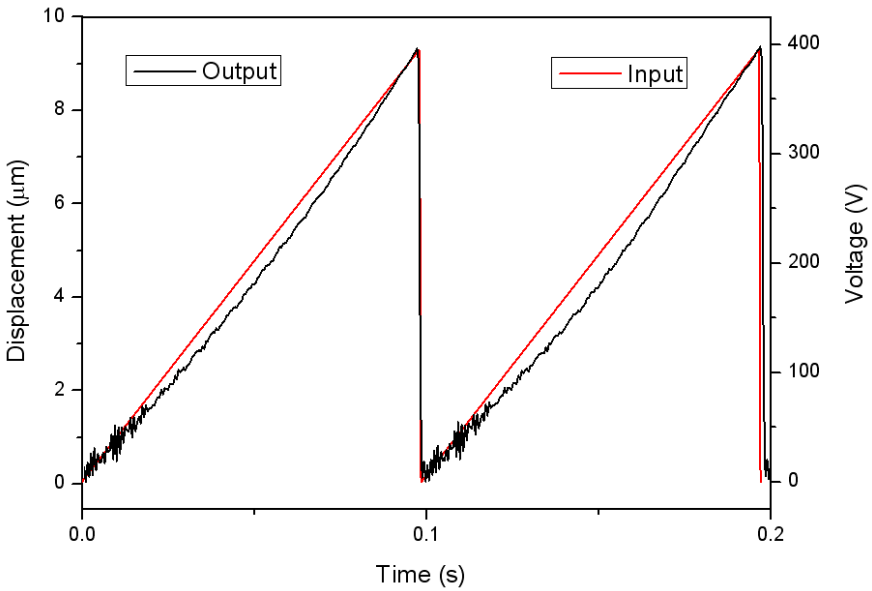


Actuating frequency : 300Hz
Input voltage : 400V(Sine wave)

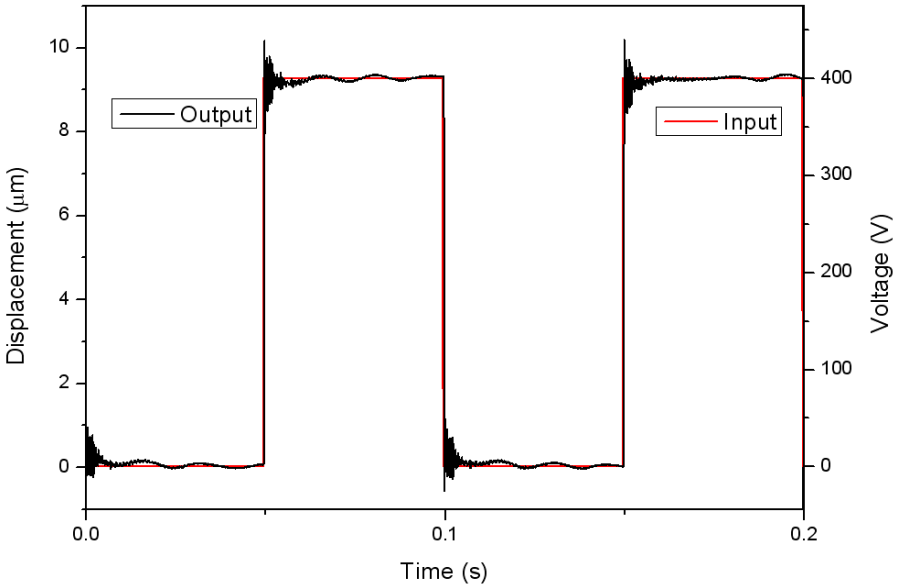


Comparison of profile errors in triangular and square wave input (type C)

Actuating frequency : 10Hz, Input voltage : 400V



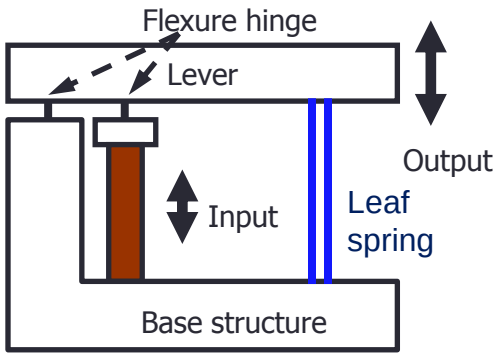
Triangular wave



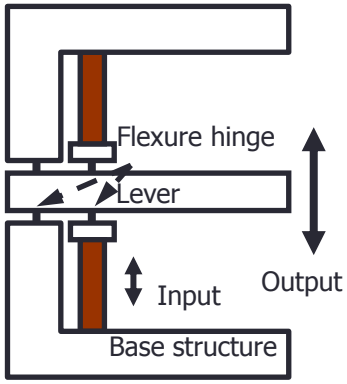
square wave

Design FTS actuated by dual PZT

- ✓ Comparing two types of FTS actuated by single and dual PZT
- ✓ Using lever mechanism to amplify the output stroke of FTS

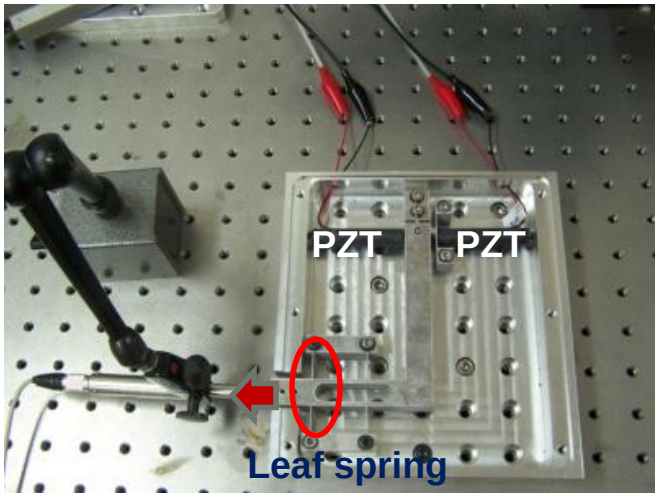


FTS actuated by single PZT : SFTS



FTS actuated by dual PZT : DFTS

<Schematic diagrams of two types PZT>



<Experimental Setup>

Specifications of piezoelectric actuator

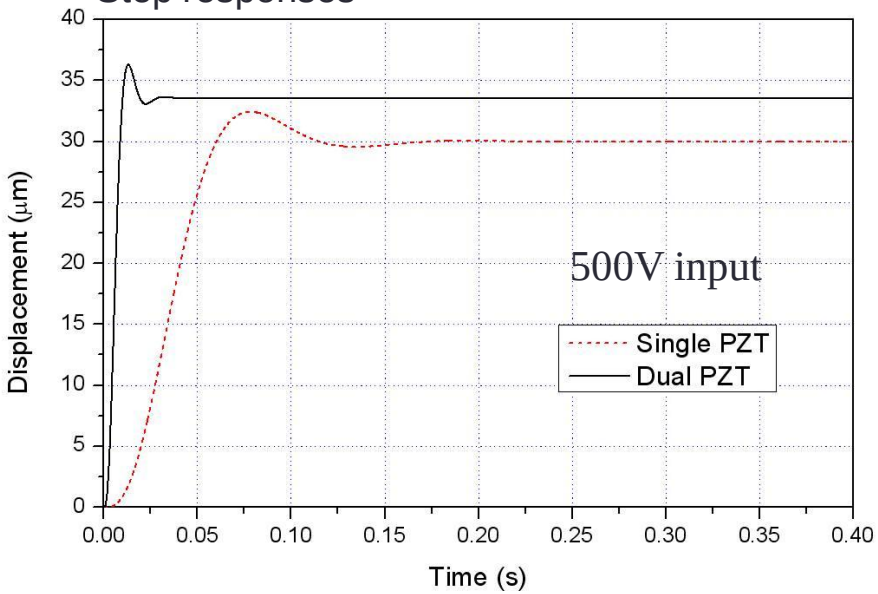
PZT P-010.40 (PI)	Displacement	Blocking farce	Stiffness	Capacitance
	60 μm	2200 N	38 N/μm	260 nF

Comparison of response characteristics between single and dual PZT actuators

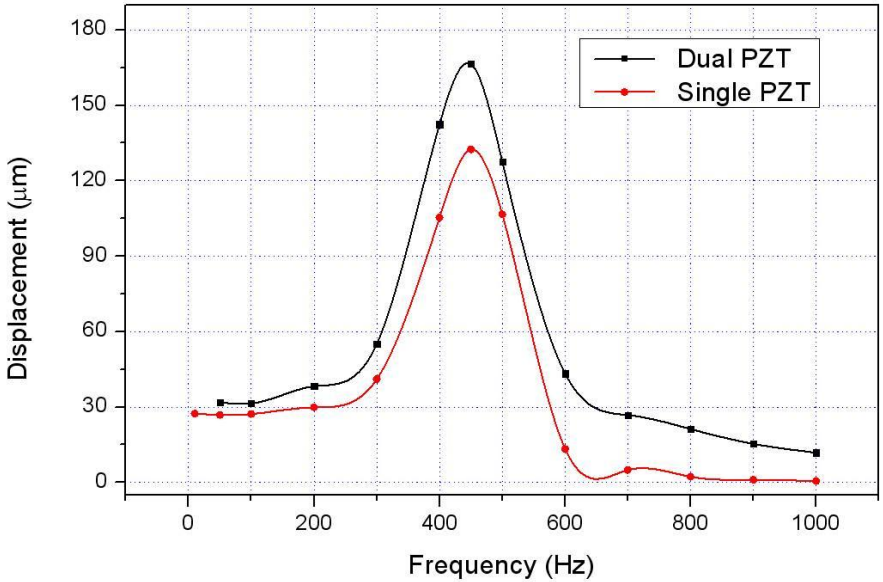
✓ Frequency response and step response

DFTS: FTS actuated by dual PZT; SFTS: FTS actuated by single PZT

Step responses



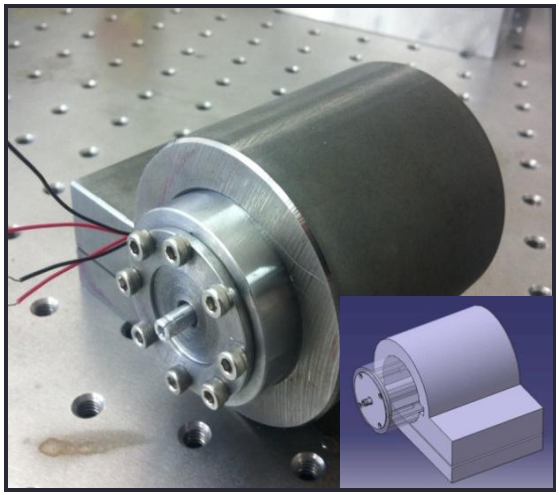
Frequency responses



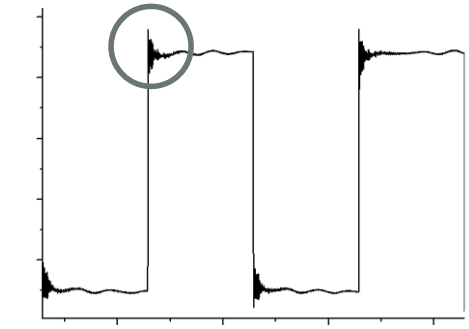
Response characteristics in new DFTS designed for roll machining

✓ Comparing two types of FTS actuated by single and dual PZT

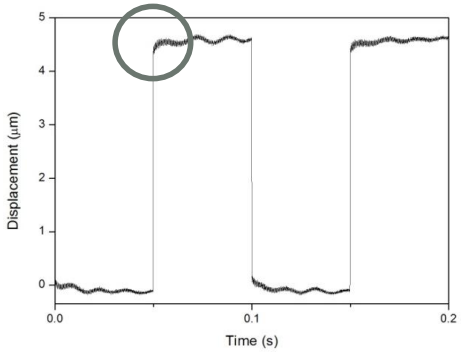
DFTS

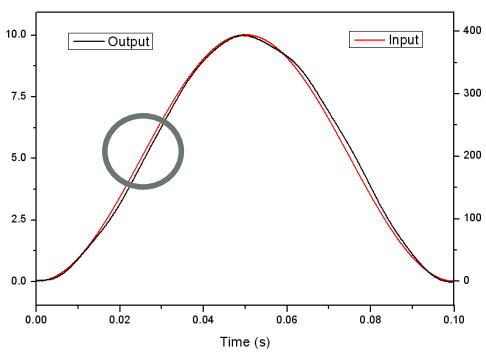


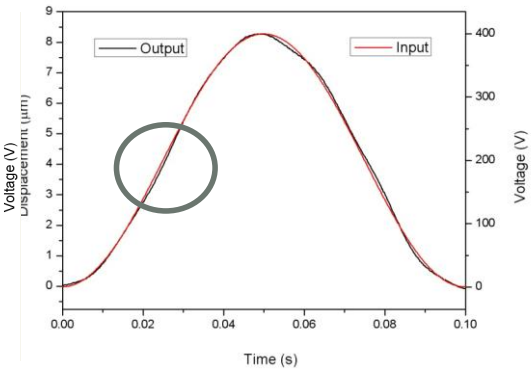
SFTS



DFTS







Output stroke of FTS (10 Hz)

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- **Machining test using FTS**
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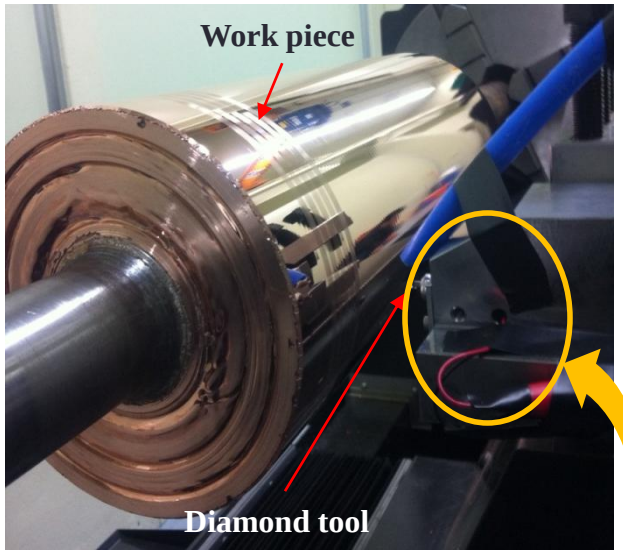
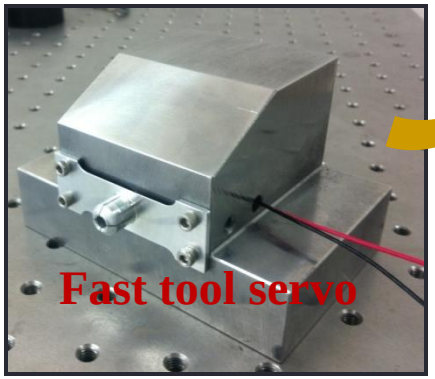
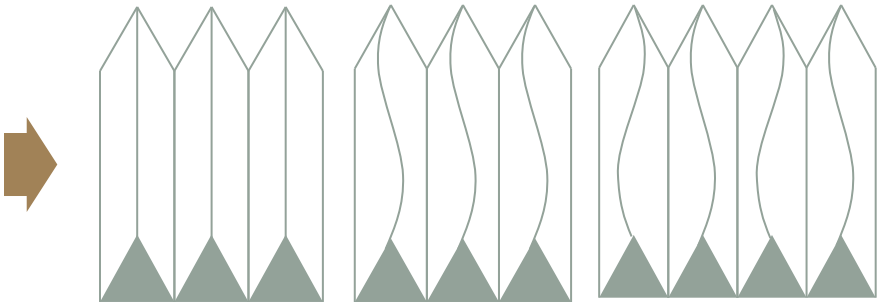
Machining test of mold roll using FTS





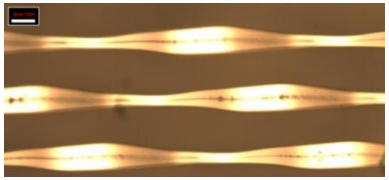
Experimental Setup



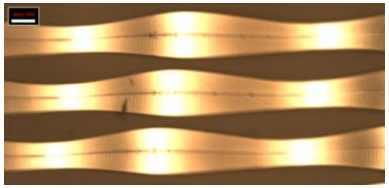
Cutting conditions

Feed rate 100 μm/rev	f = 1000 Hz n = 48 rpm	Wave length(L) 440 μm
	f = 1500 Hz n = 72 rpm	
	f = 2000 Hz n = 96 rpm	
Feed rate 20 μm/rev	f = 1000 Hz n = 48 rpm	
	f = 1500 Hz n = 72 rpm	
	f = 2000 Hz n = 96 rpm	

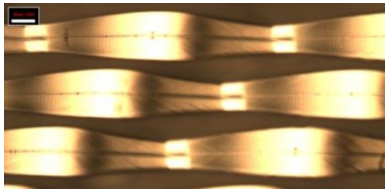
1000Hz, 48 rpm



1500Hz, 72 rpm



2000Hz, 96 rpm

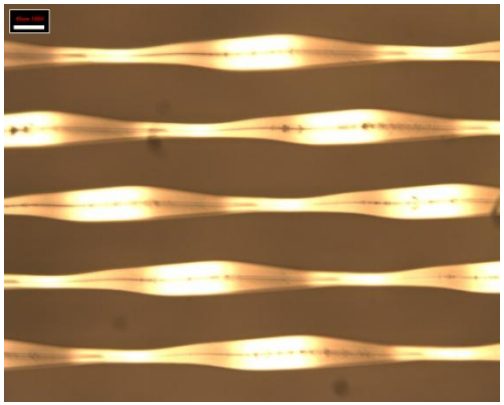


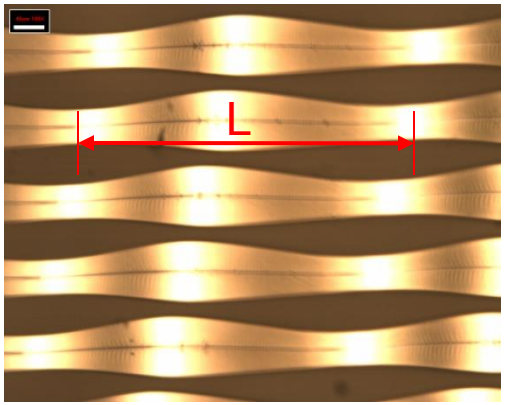
Results of micro patterning on mold roll surfaces(Type A)

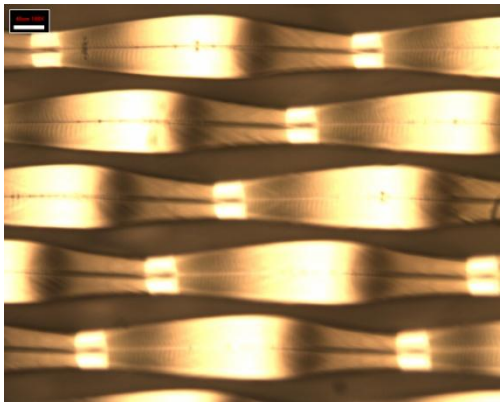
✓ Patterns machined by various cutting conditions

1000Hz, 48 rpm | 1500Hz, 72 rpm | 2000Hz, 96 rpm

Feed rate 100μm/rev

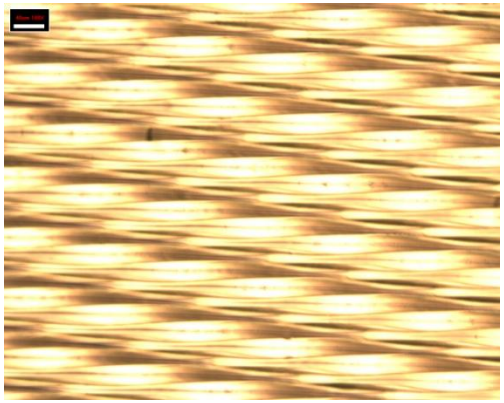


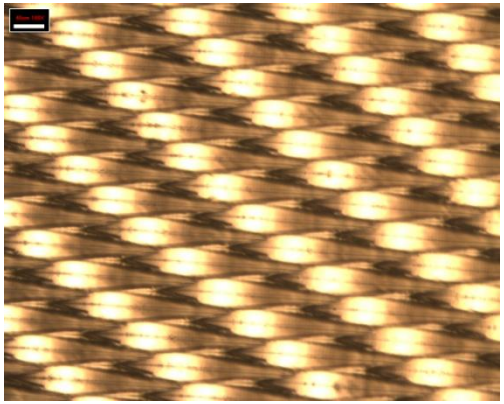


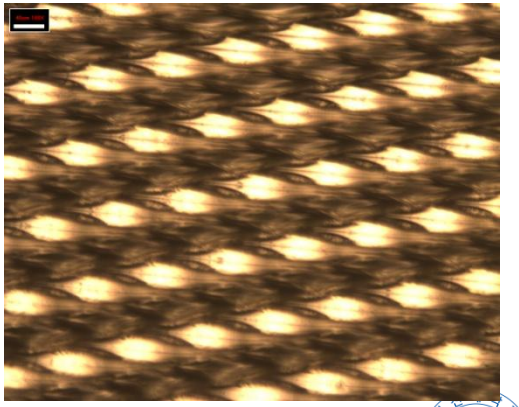


1000Hz, 48 rpm | 1500Hz, 72 rpm | 2000Hz, 96 rpm

Feed rate 20μm/rev

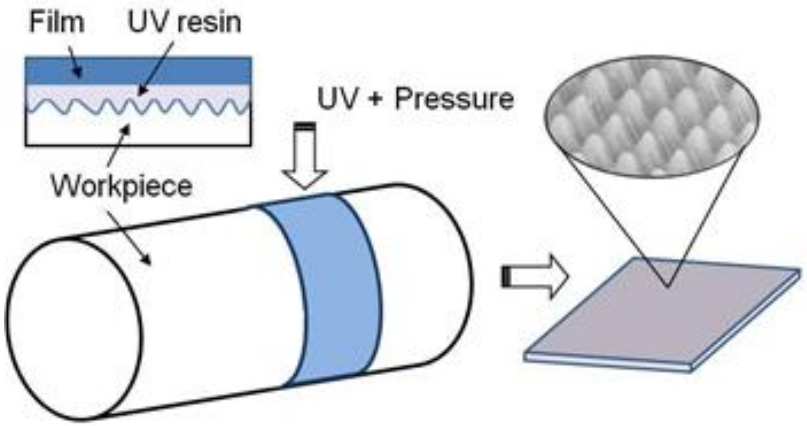




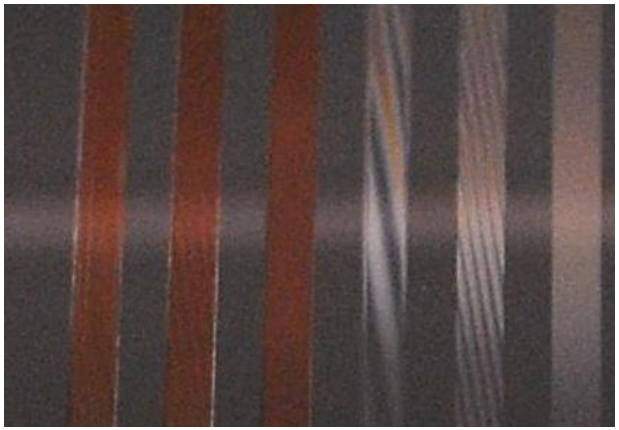


Evaluating of pattern profiles machined on mold roll surfaces

✓ UV-casting process



Patterned film by imprinting process

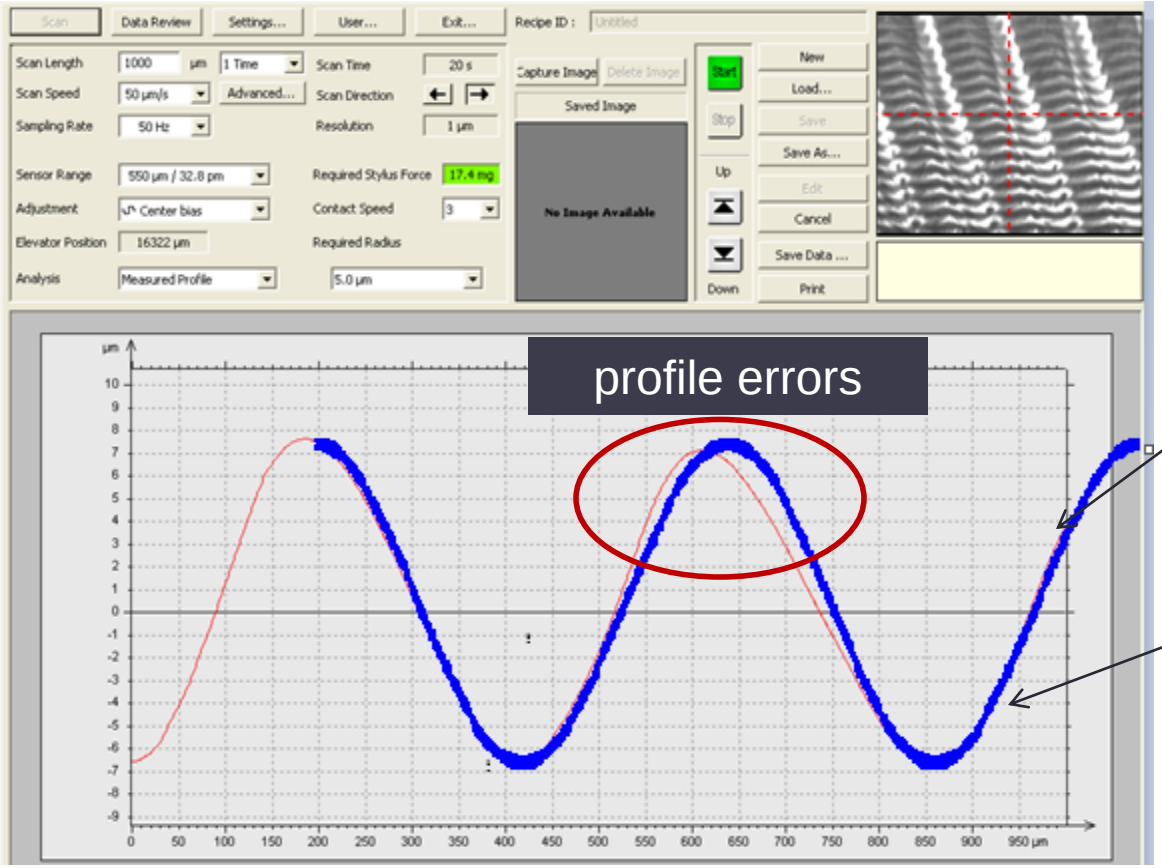


Conditions of UV-casting

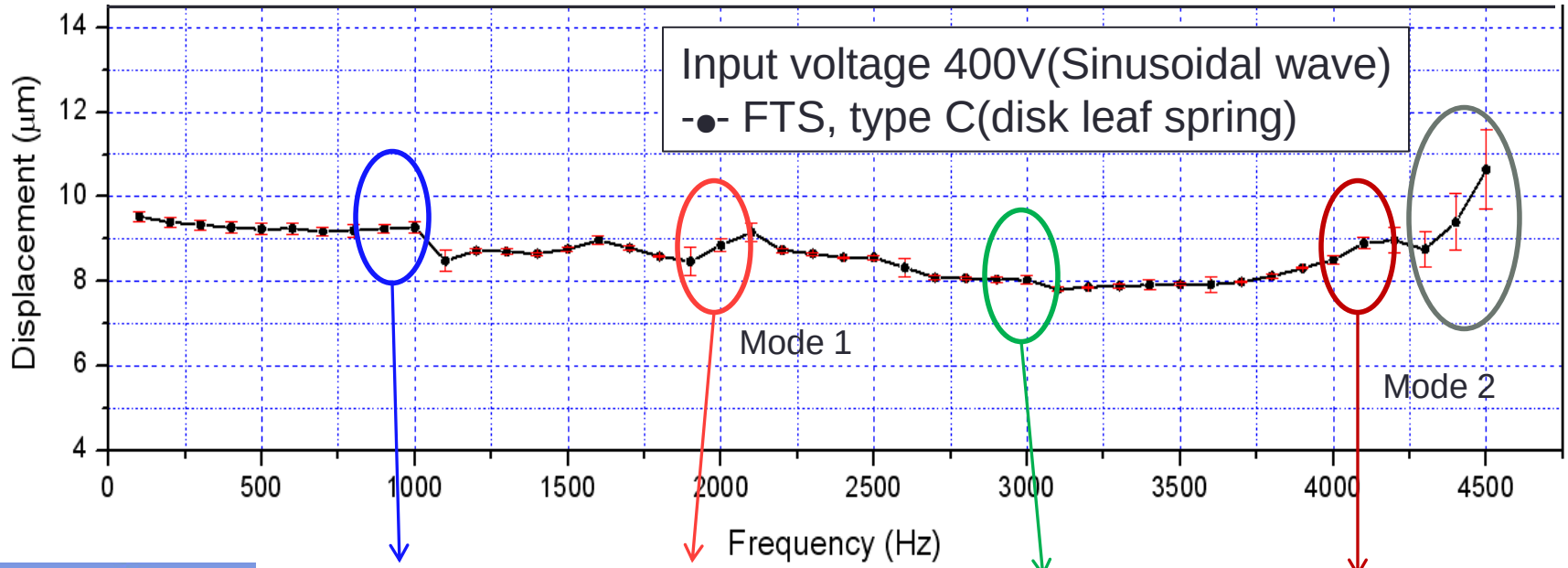
Resin	UV resin
Film	290 x 210 mm Thickness: 100 μm
Time (UV light applied)	5 min

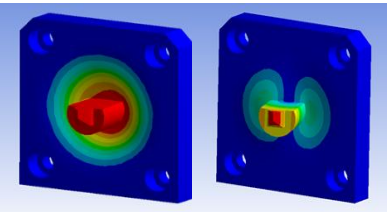
Pattern profiles transferred by UV film casting

- Input Voltage 500V, FTS 1500 Hz, spindle speed 72rpm, feed rate 100μm/ rev
  Wavelength 440 μm, Depth of cut 14 μm

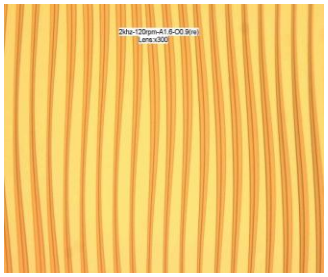


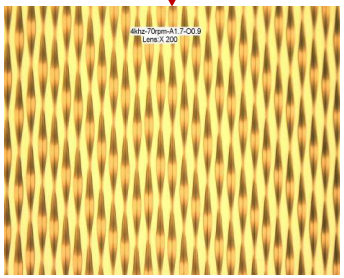
Evaluating machined patterns at each actuating frequency





Mode1 Mode2

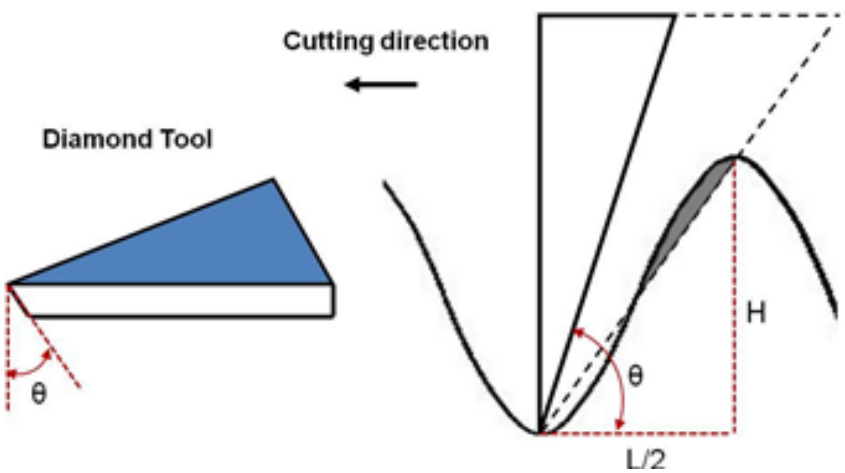




✓Irregular patterns at near 2kHz and 4kHz due to uncontrollable vibration.

Deformed profiles caused by conditions of FTS cutting

✓ Selection of tool clearance angle



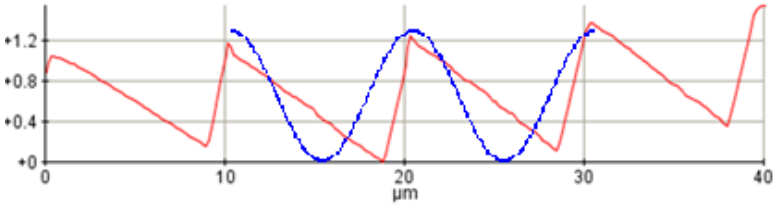
- $\theta > \theta c$, $\theta c = \arctan(2H/L)$

Θ : the clearance angle of tool
Θc: the tangential angle of input wave
H: the amplitude of profile ; depth of cut
L: the wavelength of profile

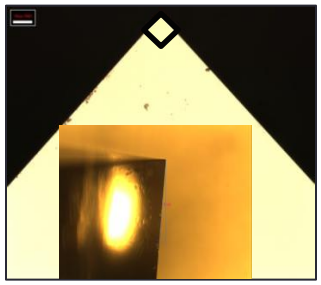
❖ Ex.) Height, H = 5μm, Wavelength, L=100μm.
Clearance angle of tool, θ ≥ 6 degrees.

Statistics

Line	Min(μm)	Max(μm)	Mid(μm)	Mean(μm)	Ra(μm)	Rz(μm)
Red	0.003	1.553	0.778	0.700	0.292	0.059



Specifications of diamond tool

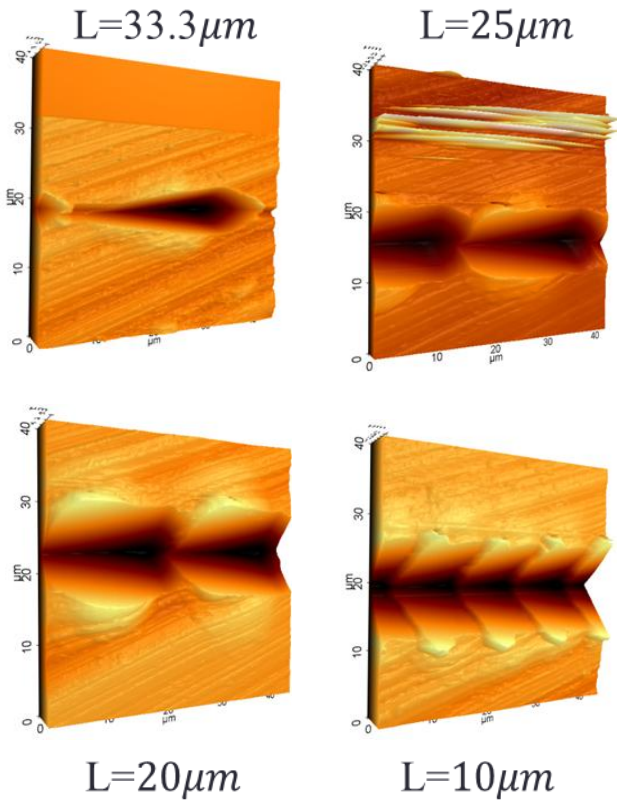


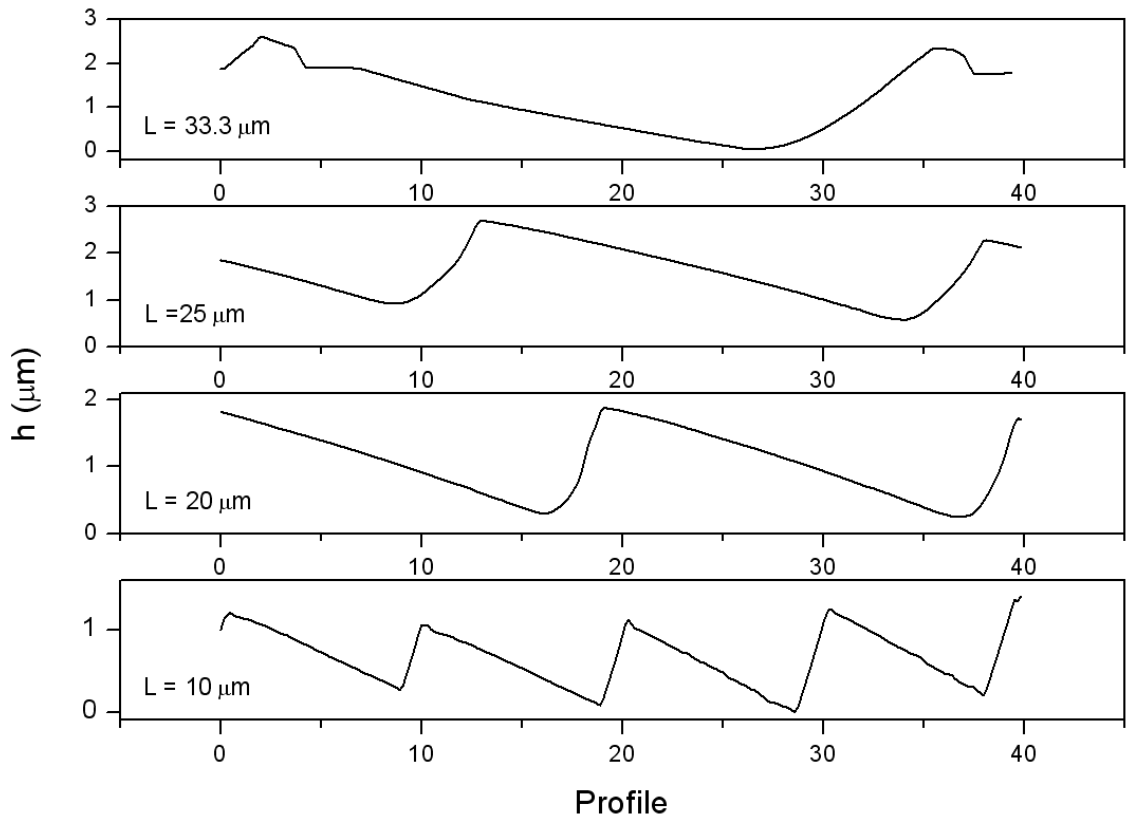
Microscope imagine

Tool material	Diamond
Clearance angle	5 degrees
Nose angle	90 degrees

Machining test to investigate deformed profiles

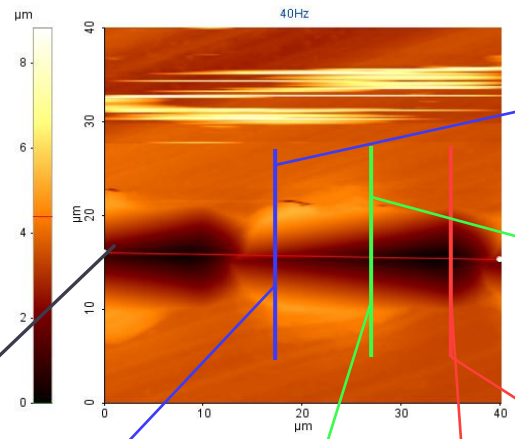
- ✓ Deformed profiles according to the variation of wavelengths

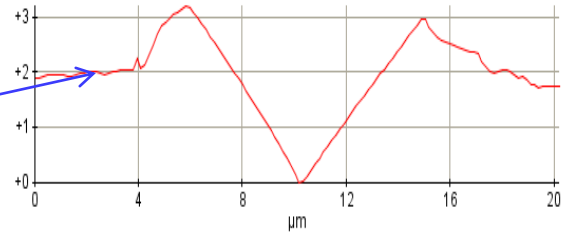


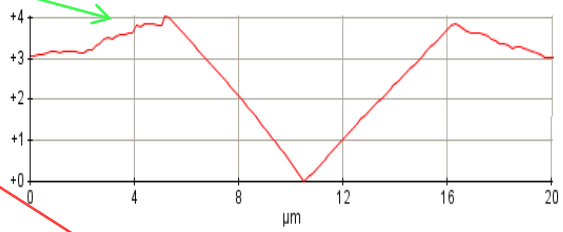


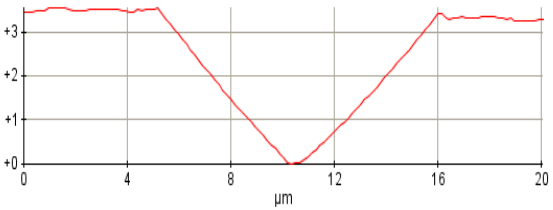
Bur formation due to plastic deformation of machined structure

<Cutting conditions>
FTS: 100Hz
Wave length, L=25μm
Clearance angle of tool,θ=5 degrees
Depth of cut, H= 5um

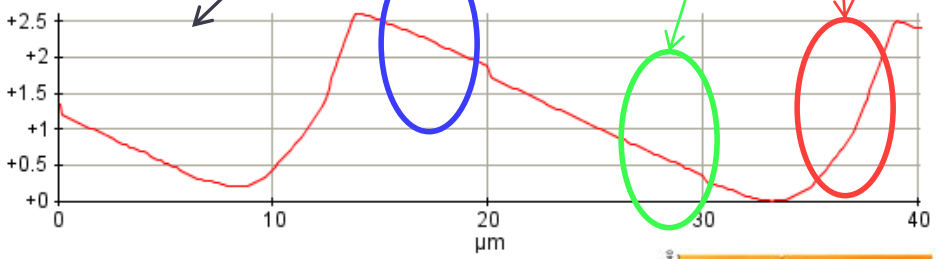




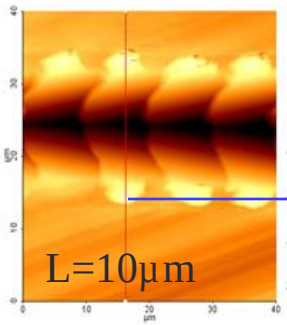




Longitudinal profile

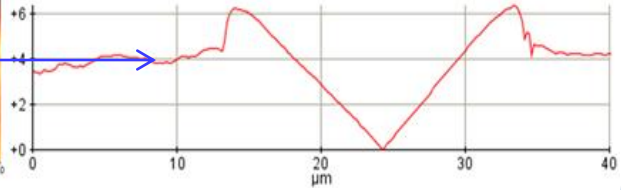


✓ Machining region : without bur
Plastic deform region : bur formation



Statistics

Line	Min(μm)	Max(μm)	Mid(μm)	Mean(μm)	Ra(μm)	Rz(μm)
Red	0.311	6.713	3.512	4.125	1.057	-0.594



Conclusions

- A prototype of FTS system with PZT actuator was developed for diamond turning applications.
  - Experiments to describe the hysteresis behaviors of FTS were performed.
  - The hysteresis nonlinearity of FTS must be compensated by feed back control in low bandwidth of FTS.
  - DFTS with dual PZT actuators showed better tracking performances and longer travel range than SFTS with single PZT actuator.
- Microstructures on mold roll surfaces were manufactured in diamond turning using FTS system.
  - It is necessary to select suitable tool shape according to given cutting conditions(especially, clearance angle of tool) in order to fabricate desired profiles.

Thank you for your attention !!!