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UPCU의 안정성 검토 및 초정밀 위치결정

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Stability Analysis and Ultra-Precision Positioning for UPCU

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Abstract

The world, coming into the 21st century, is preparing a new revolution called a knowledge-based society after the industrial society. The interest of the world is concentrated on information technology, nano-technology and biotechnology. In particular, the nano-technology of which study was originally started from an alternative for overcoming semiconductor micro-technology. It can be applied to most industry subject such as electronics, information and communication, machinery, chemistry, bioengineering, energy, etc. They are emerging into the technology that can change civilization of human beings. Specially, ultra precision machining is quickly applied to nano-technology in the field of machinery. Lately, with rapid development of electronics industry and optic industry, there are needs for super precision finishing of various core parts required in such related apparatuses. This paper handles stability of a super precision micro cutting machine that is a core unit of such a super precision finisher, and analyzes the results depending on the hinge type and material change, using FEM analysis. By reviewing the stability, it is possible to achieve the effect of basic data collection for unit control and to reduce trials and errors in unit design and manufacturing

Key Words : Cutting force, Finite Element Method, Ultra Precision Cutting Unit(UPCU), Micro Cutting Machine, PZT(Pb(Zr,Ti)O3, Nano Positionin

1. Introduction

Recently, the world is preparing for new revolution, called, 'IT(Information Technology), NT(Nano-Technology), and BT(Bio-Technology)." NT can be applied to various fields such as semiconductor-micro technology. Ultra precision processing is required for NT in the field of mechanical engineering. Because of radical advancement of electronic and photonics industry, necessity of ultra precision processing is on the increase for the manufacture of various kernel parts. In this paper, stability of ultra precision

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cutting unit(UPCU) is investigated and this unit is the kernel unit in ultra precision processing machine. According to alteration of cutting force and material of micro stage, stability investigation is performed. Elasticity and strength are analyzed on micro stage by FEM analysis. The micro stage in ultra precision processing machine has to keep hinge shape under cutting condition with 3-component force (cutting component, axial component, and radial component) and to reduce modification against cutting force.

Then we investigated its elasticity and strength under these conditions. The material of the micro stage is generally used for duralumin with small thermal deformation. Since the elasticity and the strength quiet become important, the stability of the micro stage is investigated. Used materials are composed of aluminum of low strength and cooper with medium strength and spring steel with high strength. Also, we wish to compare Hysteresis curve by FEM and experiment, and verify validity of stability analysis. Lastly, we wish to do nano position control of UPCU.[1]

2. Finite element modeling

For finite element analysis modeling, MARC and MENTAT, which are commercial finite element analysis programs and widely applied to industrial fields, were used for preprocess and post process for finite element analysis.[2,3,4,5]

In material selection of each unit in modeling, the micro stage was made of aluminum and cooper and spring steel, the bite tip was made of diamond as shown in Table 1. The micro stage and the bite tip were considered as one rigid body. For modeling of a piezoelectric sensor, the laminated form was considered as one rigid body. Hinge type is generally used to design the elastic hinge. Thus it was intended to evaluate safety of UPCU for cutting force by analyzing stress distribution and displacement characteristics present in the elastic hinge. Fig.1 shows 3-dimentional modeling of the UPCU. Since this system is intended to use in a super precision finisher, there must be stability for three component cutting force generated in finishing.

Therefore, FEM analysis was carried out by applying three-component force to the bite tip and the value, which was measured directly on the bite tip of a precision lathe, was applied. Since this system is used in super precision finishing, the amount of cutting is a very small value. But it was assumed that cutting was carried out to maximum 2mm with consideration of safety. Fig.2 shows the value measured when the Feed (f) amount was 0.3mm/rev, the speed (V) was 150 m/min, and SM45C was finished.

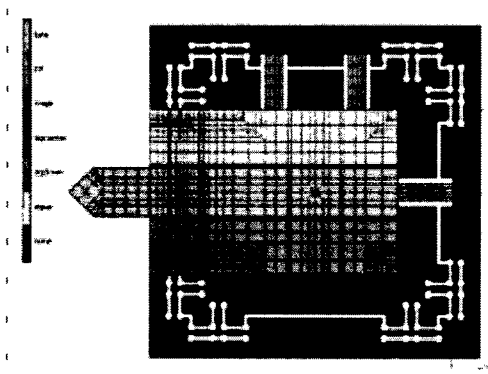


Fig.1 FEM Modeling of ultra precision cutting unit.

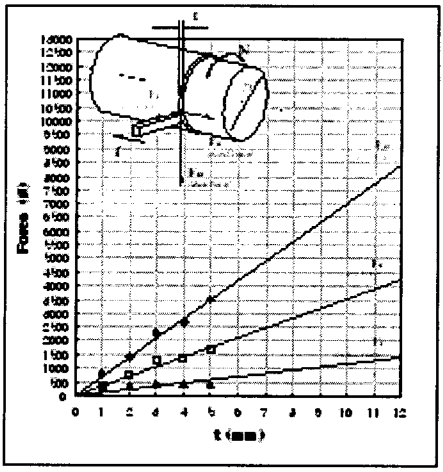


Fig.2 Cutting force of micro cutting machine

Table 1 Material properties of ultra precision cutting unit

Unit(Material)		E(kg/mm²)	ν	ρ (mm³/kg)
Stage	Aluminum	7,000	0.32	2.70e-6
	Copper	9,800	0.30	8.6e-6
	Spring Steel	19,000	0.26	7.8 e-6
PZT(AE0505D16)		4,400	0.34	2.50e-6
Bite Tip(Diamond)		114,550	0.20	3.50e-6

3. Results and analysis of FEM interpretation

The hinge type is carefully designed for the elasticity and the stability. In this paper, the elasticity and strength of a micro stage was analyzed using the FEM. The micro stage for super precision finishers must keep the hinge shape during cutting by which three-component force is applied to, and also minimize deformation by cutting force. The elasticity and strength depending on such a cutting force load was examined in this paper.

Generally the material of the micro stage is duralumin with less thermal deformation. However, in this paper it is aluminum of less strength, spring steel of more strength, and copper of intermediate strength to examine stability by checking elasticity and strength of the micro stage depending on material change, using the FEM. The following three items were used to interpret stability.

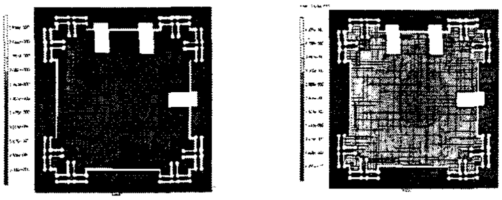
(1) Examination of stability depending on the PZT load.

(2) Examination of stability depending on the cutting force load.

(3) Examination of stress distribution and displacement response capability depending on material change.

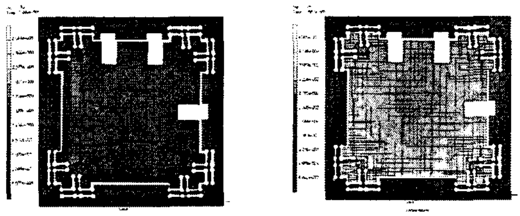
The boundary conditions of a model to examine stability were two states. The one was applied to the three components force, when cutting 2mm, at the bite tip of the aluminum micro stage model including the PZT in Fig.3. The other was unloaded to PZT. Stress distribution and displacement on the hinge is shown in Fig.3. Table 2 shows maximum shearing stress and displacement value. Analysis result, displacement is 9.6㎛, maximum shearing stress is 4.468 (kg/㎟). the safety coefficient was about2.35. Therefore, it was confirmed that in terms of generated cracks at the hinge, it was stable. In order to check the above result, three-component force was applied to the bite tip and load of 85kg was given to the PZT, as shown in Fig. 4. Also, when the PZT is loaded, the shearing stress tended to be reduced about 0.3% at the micro stage hinge. Such reduction of the shearing stress is considered to be. It is caused by loaded resistance of the PZT for the axial force of the bite tip (reduction of hinge deformation).

The micro stage materials were aluminum, copper and spring steel. The material of a micro stage generally used is duralumin, but aluminum was applied whose physical properties are similar to duralumin in terms of strength. Therefore, aluminum for soft material, spring steel for strong material and copper for intermediate property were used for FEM interpretation to check their characteristics. The border condition was that the micro stage edge was fixed, the PZT was excluded in order to check stability of only the micro stage, and three component cutting force was applied to the bite tip. As a result of examination of stability depending on micro stage material, stress concentration occurred at the hinge, but the safety coefficient was 2.86~5.57. Cracks did not occur at the hinge in all of the three materials, which means they are safe. As the micro stage material was stronger, the maximum shearing stress across the micro stage increased by 2.6~7.1% as compared with aluminum. Therefore, in terms of strength, the stability of the micro stage for three component cutting force was more secure in stronger material, but there was no crack in aluminum, which is soft material. Fig.5 shows FEM interpretation results of each material for stress distribution. Table 3 shows the result. The following describes displacement response at bite tips by applying load of 85kg to the PZT. This is intended to check how the response characteristics change depending on material change. As the result of examination of the displacement response at the bite tip depending on the weighted PZT, the stronger the material of the micro stage was, the less displacement response was obtained. Table 4 shows FEM interpretation result depending on the material change of the micro stage. Fig.6 shows displacement characteristics at the micro stage and the bite tip depending on material change. In terms of displacement response, it is required to select softer material than stronger material for a micro stage.



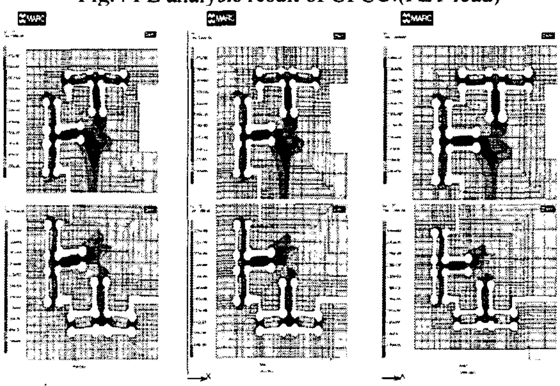
(a) Von-mises stress distribution (b) Deformation

Fig.3 FE analysis result of UPCU.(No PZT load)



(a) Von-mises stress distribution (b) Deformation

Fig.4 FE analysis result of UPCU.(PZT load)

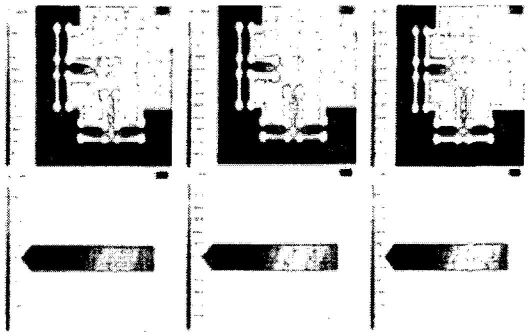


(a) Aluminum (b) Copper (c) Spring steel

Fig.5 Max. shear stress distribution UPC

Table 2 FEM analysis results

PZT/Stage		Applied contact problems	
Cutting Force Bite loading		Radial(25), Axial(100), Main(-140)	
PZT load		0	85Kg
τ_{max} on Stage (kg/㎟)		2.212	2.844
Crack (Safety Factor)		No (3.57)	No (3.69)
Right-center PZT disp.(㎛)	X	+1.749790	-4.70866
	Y	+6.274620	+6.04134
	Z	-3.085020	-3.06680
Left-top PZT disp.(㎛)	X	-6.434690	-6.09568
	Y	+9.587570	+3.034800
	Z	+0.366429	+0.406138
Right-top PZT disp.(㎛)	X	0.000000	0.000000
	Y	0.000000	-8.878390
	Z	0.000000	0.000000



(a) Aluminum (b) Copper (c) Spring steel

Fig.6 Displacement response of UPC

Table 3 Stress distributions

PZT load	85Kg		
Bite load (Kg)	Radial(25), Axial(100), Main(-140)		
Material	Al	Co	Spring. Steel
τ_{max} on Stage (kg/㎟)	3.676	3.771	3.936
Yielding stress (kg/㎟)	21	42	40
Criterion Factor "Y"(kg/㎟)	7.352 (100%)	7.54 (102%)	7.872 (107%)
Safety Factor	2.86	5.57	5.08
Crack	No	No	No

Table 4 Displacement

PZT load		85Kg		
Bite load (Kg)		Radial(0), Axial(0), Main(0)		
	Material	Al	Co	Spring Steel
Disp. of Bite tip	X(㎛)	-21.23770	-15.52980	-8.315740
	Y(㎛)	-41.95670	-30.62520	-16.339000
	Z(㎛)	+0.163368	+0.078523	-0.0031655

4. Validity verification of stability analysis through an experiment

We used the laser interferometer (Renishow RLE10) as the displacement sensor to micro position the micro-stage and the DSP Board (dSPACE ds1103) as the micro-stage control system. A photograph of the designed micro-stage is shown in Fig. 7, and the schematic diagram of micro-stage displacement data acquisition system is shown in Fig 8. Displacements of the PZT applied with voltages between 0V ~ 100V were measured by the laser interferometer and the measured data were analyzed by FEM. The actual and FEM data of the micro-stage center displacement were compared and the results are shown in Fig. 9. Table 5 and Fig. 9 show the piezoelectric actuator displacements, which were input to the FEM micro-stage model, the resulting displacement at the bite tip of micro-stage, and FEM displacement results. They also show the deviation of the bite tip of micro-stage displacement between the actual data and FEM analysis data.

The results in Fig. 9 and Table 5show that the FEM displacement data are similar to the actual displacement data obtained by operating the micro-stage; the error ratio was 3.53%. It is error ration, between experimental and numerical analysis calculated from the average of standard deviation. With these results, we were able to design the most reliable, optimal model of the micro-stage. Fig.10 show the result of resolution experiment.[6,7,8]

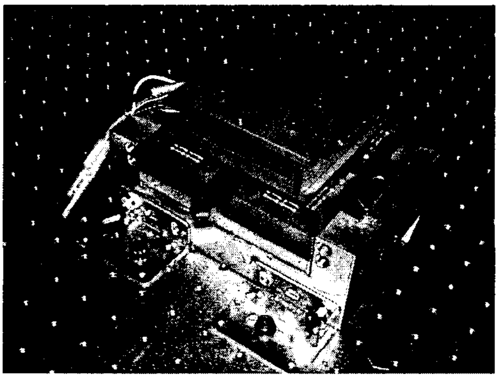


Fig.7 Photograph of micro-stage

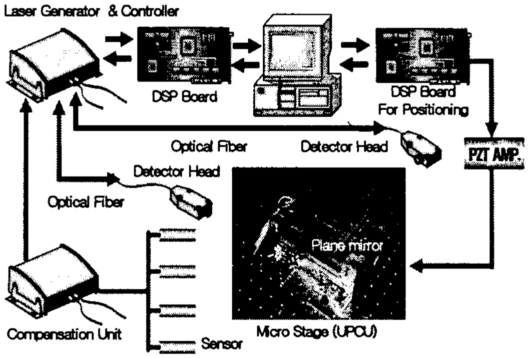


Fig.8 Schematic diagram of UPCU data acquisition system

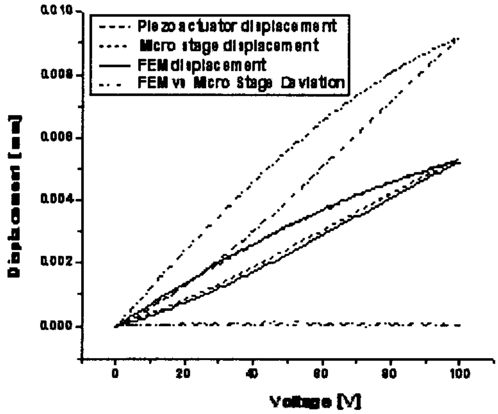


Fig.9 Hysteresis curve of UPCU

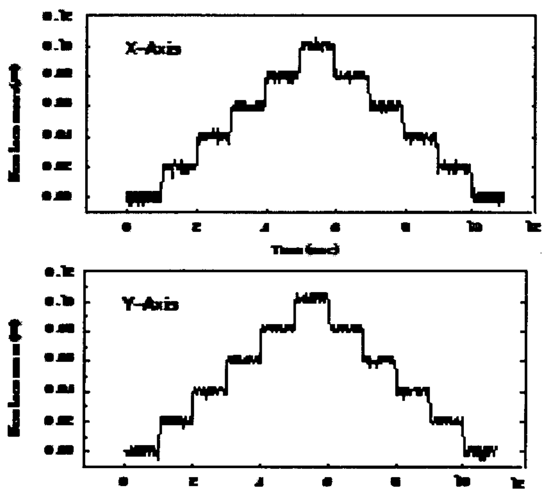


Fig.10 The result of resolution experiment

Table 5 Data of piezo actuator, FEM and micro-stage, deviation of FEM vs micro-stage

Input Voltage	PZT Displacement(㎛)	Stage Displacement(㎛)	FEM Displacement(㎛)	FEM vs Stage Deviation(㎛)	Remark
0 V	0.000	0.000	0.000	0.00000	
10 V	0.563	0.389	0.320	0.04880	
20 V	1.290	0.843	0.731	0.07930	
30 V	2.110	1.340	1.200	0.09900	
40 V	3.020	1.880	1.720	0.11300	
50 V	4.000	2.450	2.280	0.12000	Increased
60 V	5.050	3.040	2.870	0.12000	
70 V	6.120	3.640	3.470	0.12000	
80 V	7.180	4.220	4.080	0.09900	
90 V	8.230	4.790	4.680	0.07780	
100 V	9.180	5.300	5.210	0.06360	
90 V	8.700	4.980	4.940	0.02830	
80 V	8.070	4.580	4.590	0.00707	
70 V	7.340	4.150	4.170	0.01410	
60 V	6.510	3.670	3.700	0.02120	
50 V	5.590	3.140	3.170	0.02120	Decreased
40 V	4.590	2.580	2.610	0.02120	
30 V	3.510	1.970	1.990	0.01410	
20 V	2.380	1.330	1.350	0.01410	
10 V	1.200	0.662	0.681	0.01340	
0 V	0.000	0.000	0.000	0.00000	

5. Conclusion

The purpose of this paper is to determine which hinge type and material to use when we design a micro stage for super precision finishers. FEM interpretation was applied in order to reduce number of trials and errors in manufacturing UPCU, and it was intended to check the tendency. Also we wish to verify validity of stability analysis through experiment. The result is described below.

1. The micro stage was stable in terms of cutting force load
2. When applying three materials of aluminum, copper and spring steel, no crack occurred and it was secure for all the materials.
3. When load was applied to the PZT and cutting force was not applied, better displacement response was obtained in softer material.
4. The deviation between FEM data and actual data obtained by driving the micro stage was 3.53%, which was less than the allowable engineering deviation with use of FEM; this low deviation value verifies the validity of the FEM used in our study.
5. Result that stability analysis and an experiment execute Nano position control to basic, We could construct system that have 10nm resolution performance.

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