Hysteresis Compensating of PZT Actuator in Micro Tensile Tester Using Inverse Compensation Method

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Abstract: Researches about micro technology travel lively in these days. Such many researches are concentrated in the field of materials and a process field. But properties of micro materials should be known to give results of research developed into still more. In these various material properties, mechanical property such as tensile strength, elastic modulus, etc is the basic property. To measure mechanical properties in micro or nano scale, actuating must be very precise. PZT is a famous actuator which becomes a lot of use to measure very precise mechanical properties in micro research field. But PZT has a nonlinearity which is called as hysteresis. Not precision result is caused because of this hysteresis property in PZT actuator. Therefore feedback control method is used in many researches to prevent this hysteresis of PZT actuator. Feedback control method produce a good result in processing view, but cause a loss in a resolution view. In this paper, hysteresis is compensated by open loop control method. Hysteresis property is modeled in Mathematical function and compensated control input is constructed using inverse function of original data. Reliability of this control method can be confirmed by testing nickel thin film that is used in MEMS material broadly.

Keywords: Micro Tensile Tester, PZT Actuator, MEMS, Nickel Thin Film, Hysteresis, Compensation, Inverse Method

1. INTRODUCTION

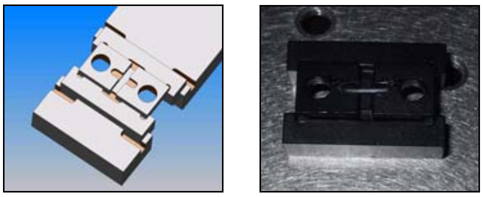
It is forecasted that market demands on ultra-micro sized optically functional components rapidly increase in next generation display device or optical communication industries. Since these high priced core components require high precision and accuracy, evaluation of reliability such as the life cycle endurance test, impact test, residual stress test is necessary for these components. However, in practice, real reliability tests are not easy to perform due to consideration of various factors. Rather than real test it would be much easier to evaluate reliability of the components by analytical approach. Although analytical method [1] is utilized by software tool, it is obviously necessary to acquire fundamental properties of materials through real test methods. Test methods for fundamental properties include tensile test, bending test, hardness test and resonance test. Among these tests, the tensile test is the most efficient method because it directly measures elastic modulus, fracture strength and Poisson's ratio without any conversion using special equations. However, micro tensile test requires a precise alignment of specimen and reliance of testing machine itself because of the miniaturized specimen. Many researchers have studied micro tensile tests in order to overcome these restrictions, especially, in gripping methods and tensile forcing methods. Greek and Johansson [2] made the testing machine inside the SEM chamber using load sensor with strain gauge and PZT actuation. Tsuchiya et al. [3] studied gripping method using electrostatic force instead of adhesion. Ogawa et al. [4] made a tensile tester using a DC servo motor and the measured Young's modulus and the fracture strength of the micro-fabricated thin film of titanium with 0.5mm thickness using a microscope and two CCD cameras. Chasiotis and Knauss [5] marked two lines of gold on poly silicon specimen and calculated the strain using AFM. Sharpe et al. [6-8] proposed ISDG (interferometric strain displacement gauge) method. They used poly silicon and nickel film as a sample material and deposited gold line marker on it. Yi and Kim [9, 10] developed tensile tester using ISDG method and verified the tester developed using the single crystalline silicon (SCS). These results are summarized in Table.1. In this paper, PZT actuating type micro tensile testing machine has been developed in order to apply to various types of materials including metallic materials, polymer materials and single crystalline silicon. This tester is designed to easily test a miniaturized specimen. The 200㎛ thickness nickel thin film is used to test the reliability of this PZT actuated micro tensile testing machine. The PZT actuated tensile testing machine had a special automatic specimen installing equipment in order to prevent undesirable deformation and misalignment of specimens during handling of specimen for testing. The control method using the inverse function of the nonlinearity curve of the PZT actuator is applied to this system to compensate the nonlinearity of PZT actuator.

2. DEVELOPMENT OF PZT ACTUATING TYPE MICRO TENSILE TESTING MACHINE USING COMPENSATING NONLINEARITY METHOD

The PZT actuated tensile tester is constructed with a horizontal type as shown in Fig.1(a). The PZT actuator has generally very high stroke resolution in relatively small displacement range although the full stoke is almost 1mm. Since the applied voltage to PZT produces the actuation, more precise control can be possible when the relation between voltage and displacement of PZT is linear.

Vertical load removing system is designed using a LM guide and ball screw to prevent specimen's deflecting by its weight under horizontal testing. Tensile testing of a micro sized specimen is difficult to handle the specimen because of its size. It is necessary that the experimenter's dependence should be eliminated at the installation stage in order to ensure and increase the repeatability.

(a)



(b)

Fig.1 (a) Micro tensile tester with the PZT actuator and (b) Automatic specimen-setting device.

In this paper, an automatic specimen-setting device is developed using the micro stepping motor with resolution of 0.1mm in vertical direction with respect to the stroke. Fig.1(b) shows this special equipment. PZT actuators generally have its unique nonlinearity by inversion appearance of spontaneous polarization that is appearance by the electric and mechanical combination of the ferroelectricity. The PZT actuator for the micro tensile tester also has this features as shown in Fig.2. To improve the reliability of micro tensile tests, a method for compensating nonlinearity is proposed.

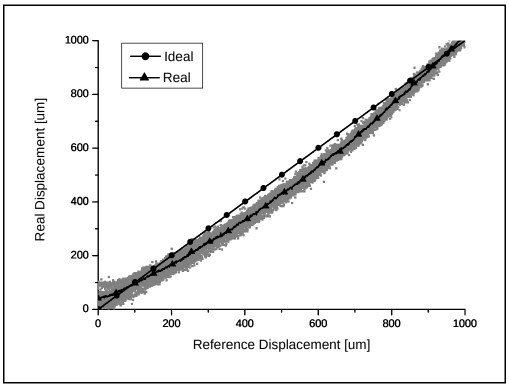


Fig.2 Nonlinearity of the PZT actuator in system

In this paper as a control method, the method which compensate the nonlinearity by using the inverse function of the nonlinearity curve of the PZT actuator was adopted.

First, in order to test the nonlinearity of the PZT actuator, a potentiometer was used as shown in Fig.3. In the same conditions 10 tests was repeated, and the averaged nonlinearity curve was extracted from the acquired 10 test results by using the moving average method, and the 2nd order polynomial curve fitting process was carried out about the averaged offset nonlinearity curve.

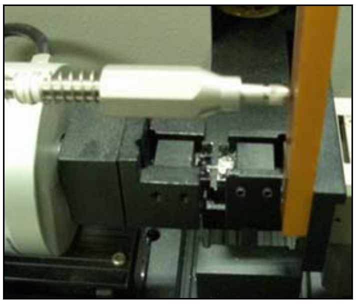


Figure 3. Micro tensile tester configuration

Eq.(1) is the nonlinearity curve function of the PZT actuator for the micro tensile tester.

$$y_{real}=0.40126u_{ref}^2+0.58559u_{ref}+3.79871e\text{-}6 \quad (1)$$

where,

$u_{ref}=$ reference displacement, $y_{real}=$ real displacement

The inverse function as a control input compensating the nonlinearity can be derived as follows.

$$au_{ref}^2+bu_{ref}+c-y_{real}=0 \quad (2)$$

$$u_{ref}=\frac{-b\pm\sqrt{b^2-4a(c-y_{real})}}{2a} \quad (3)$$

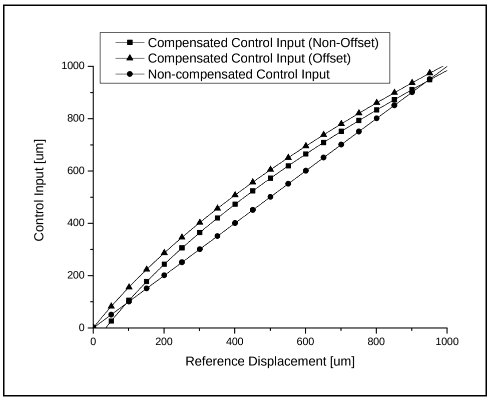
where,

a=0.40126, b=0.58559, c=3.79871e-6

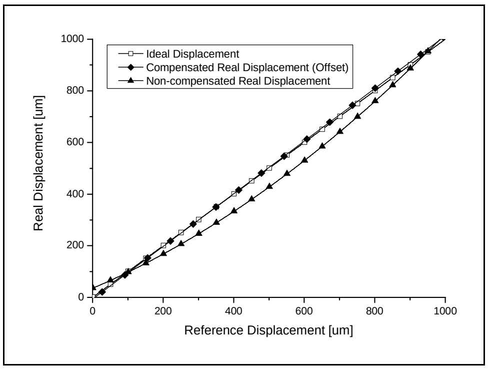
Because the minus sign is not valid, just the plus sign is used. Therefore the control input equation using the inverse function of the nonlinearity curve function is

$$u_{ref}=\frac{-b+\sqrt{b^2-4a(c-y_{real})}}{2a} \quad (4)$$

Fig.4 shows the comparison between the offset/non- offset compensated control input using Eq.(4) and the non-compensated one and shows that the compensated real displacement output is nearly equivalent to the ideal one. To prove whether the real displacement output by the PZT actuator is linear or not about the test speed variation, several tests have been carried out. Table.2 shows the relationship between test speeds and the linearity of real displacement output. 10 tests have been carried out in each speed, and the averaging process using moving average method and the linear curve fitting are performed and the coefficients and the percent error of the coefficients of the curve fitted function was filled in the Table.2. Finally, The linearity of the real displacement output is independent of the test speed. Therefore the method of compensation using the inverse function of the nonlinearity curve of the PZT actuator is proper to apply to the micro tensile tester.



(a)



(b)

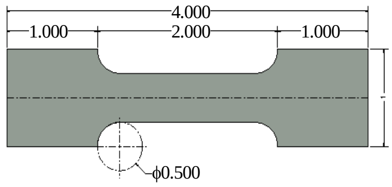
Fig.4 (a) control inputs and (b) real displacement outputs

Table.2. Relationship between test speeds and the linearity of real displacement output

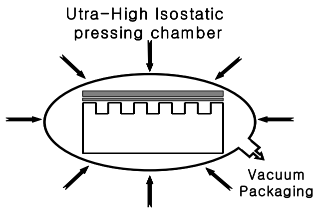
Test Speed [mm/min]	Slope	Error [%]	Y Axis Intercept	Error [%]
0.01	**1.01917**	**1.9**	**-0.00627**	**-0.6**
0.10	**1.02163**	**2.2**	**-0.00626**	**-0.6**
1.00	**1.01225**	**1.2**	**0.00936**	**0.9**

3. MICRO TENSILE TESTING FOR NICKEL THIN FILM

Micro tensile testing has been carried out with a nickel film which is widely used for an optically functional material in recent years. The film for the test is fabricated by electro-deposition with 200mm thickness. The dimension of the specimen is shown in Fig.5. The specimen is made by burr-less mechanical pressing process under the vacuum package and ultra-high isostatic pressure of 3000bars. The side edge of the specimen shows clean surface without any burrs. This method is useful for a mass production of specimen. To test precisely, we design a gripper that have a specimen holding adapter in a glue type as shown in Fig.6. This gripper can get a fine alignment of specimen setting as adjusting the specimen holding adapter. And this specimen holding adapter make easy to set and separate the specimen. Micro tensile testing has been carried out with 0.01mm/min tesile testing velocity.

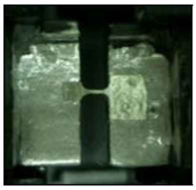


(a)

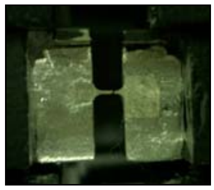


(b)

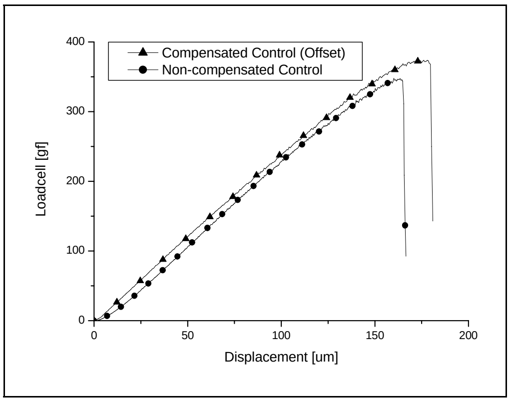
Fig.5 (a) Dimension of nickel specimen and (b) specimen fabrication process



(a) Gripped Picture



(b) Fracture Picture



(c) Test graph of nickel film specimen

Fig.6 Gripping/Fracture Picture of nickel specimen and Test graph of nickel film specimen

Load-displacement curves for nickel film are shown in Fig.6 and maximum loads and its displacements from the two tests (compensated and non-compensated) are shown in Table.3. In the non-compensated case, as supposed, the initial part of the load-displacement curve also includes nonlinearity. It is presumed that the reason is the affection of the PZT nonlinearity. As a result of the nonlinearity of the load-displacement curve, elastic region is not clear. Therefore it is certain that the non-compensated case is not reliable. On the other hand, it is shown that the linearity of real displacement output is well reflected in the compensated case. As shown in Table.3, differences between the compensated and the non-compensated are occured by the nonlinearity. Finally, it is certain that the compensated control input test is well performed.

Table.3. Comparison of displacements at maximum load and maximum loads

	Compensated(Offset)	Non-compensated
Displacements at Maximum Load	**178.0 um**	**163.5 um**
Maximum Loads	**373.7 gf**	**347.3 gf**

5. CONCLUSION

Micro tensile testing machines have been developed for various types of materials including metallic materials, polymer materials and SCS. The PZT type micro tensile testers are developed considering a load and an elongation limit of materials. Special automatic specimen installing equipment is adopted in order to prevent undesirable deformation. Tests of nickel film were carried out in this PZT actuated micro tensile tester that was developed in this paper. PZT actuator that is used in this micro tester that has a nonlinearity so linear input can't have a linear output performance. In this paper, as a control method which compensates the nonlinearity by using the inverse function of the nonlinearity curve of the PZT actuator was adopted. The linearity of real displacement output is well reflected in the compensated material tensile testing. The PZT actuating micro tensile tester that use offset compensating nonlinear control is well constructed systematically. More various optical and MEMS materials will be applied to this system and the PZT actuated micro tensile tester will be modified in the further study.

REFERENCES

[1] Y.A. Jeon, K.S. No, J.S. Kim and Y.S. Yoon: Metals and Materials Int., Vol. 9 (2003), p. 383

[2] S. Greek and S. Johansson: Proc. SPIE, Vol. 3224 (1997), p. 344

[3] T. Tsuchiya, O. Tobato, J. Sakata and Y. Taga: J. Microelectromech. Syst., Vol. 7 (1998), p. 106

[4] H. Ogawa, K. Susuki, S. Kaneko, Y. Nakano, Y. Ishikawa and T. Kitahara: Proc. IEEE Micro Electro Mechanical Systems Workshop (1997), p. 430

[5] I. Chasiotis and W. Knauss: Proc. SPIE, Vol. 3512 (1998), p. 66

[6] W.N. Sharpe Jr.: NASA Technical Memorandum 101638 (1989)

[7] W.N. Sharpe Jr., B. Yuan and R.L. Edwards: J. Microelectromech. Syst., Vol. 6 (1997), p.193

[8] W.N. Sharpe Jr., D.A. LaVan and R.L. Edwards: Proc. Int. Conf. Solid-State Sensors and Actuators (1997), p.607

[9] T. Yi and C.J. Kim: Proc. Int. Conf. Solid-State Sensors and Actuators (1999), p.518

[10] T. Yi: Microscale Material Testing of Single Crystalline Silicon (Univ. of California, LA, 2000)