A METHOD OF PRECISE CALIBRATION FOR PIEZOELECTRICAL ACTUATORS

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Abstract: Piezoelectrical actuators are very useful for making translations over distance less than 10 μm. One of the most important applications of such piezo actuators is the scanning tunnelling microscopy and the related scanning probe microscopies because atomic scale distances have to be measured and controlled in scanning probe microscopies applications. Especially, tube shaped piezoelectrical actuators have been widely used for such purposes. In this study, a piezotube scanner is calibrated at three stages. First calibration was done by using interferometer. At the other two stages Scanning Tunnelling Microscope was used for measurement.

Keywords: STM, piezoelectric, Calibration, Interferometer.

INTRODUCTION

Piezoelectric actuators (PZTs) are used widely to produce small, precise mechanical motions (Deck, 1995). Piezo actuators are becoming increasingly popular for generating small displacement in mechanical constructions. By applying a voltage or current to a piezo it extends or retracts due to the piezoelectric properties of the ceramic material (Holman et al, 1995). Piezoelectrics are classified as ferroelectric materials. Their gain depends sensitively on the material bulk polarization. PZT responds to a voltage variation, which in turn changes the gain and hence the length (Deck, 1995).

The requirements of a good scanner are (Park and Barrett, 1993):

1. High resolution,
2. Orthogonality (Movement along the three axes should be independent),
3. Linearity (The amount of movement should linearly be proportional to the applied voltage)
4. Mechanical rigidity (A rigid scanner will have a high resonant frequency, which is desirable for vibration isolation and feedback performance)
5. Wide range

There are several types of piezos which can be used for different positions, such as required extension range, control voltage, temperature range, etc. (Holman et al, 1995).

Piezoplates and piezotubes are widely used. The principles of the piezoelectric behaviour also are the basis of operation of the tube scanner. In this geometry the inner and outer surface of a tube of piezoelectric material are coated with a thin metal electrode. The outside electrode is separated into four parts, which are electrically isolated from each other (Bonnell, 1993). The single tube piezo element has become a mechanical scanner for use in scanning probe microscope instruments. Some advantages of these piezo tube scanners are high mechanical resonance frequencies, ability to scan in three dimensions with a single element and ease of manufacture and use (Porter, 1994).

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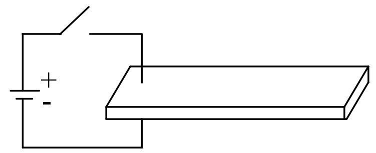
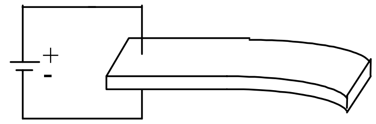


(a)



(b)

Figure 1.
Sheet shaped piezoelectric material. (a) There is no applied potential difference between electrodes (b) A certain potential difference between electrodes is applied.

Upper and lower side of the silver coated piezoelectric material are electrically isolated as shown in Figure 1.a. When a positive potential is applied to the upper side of the material with respect to the underneath, the upper side will be extended and the under surface will be compressed. As aresult as seen Figure 1.b, it will be bended downward.

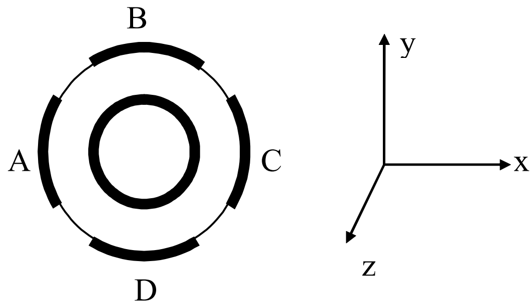


Figure 2.
Cross section view of piezotube.

MEASUREMENTS

Piezotube's silver coated outer electrode, which cross-section is shown in Figure 2, is split into two symmetrical parts along piezotube axis in order to get displacement in three dimensions. The inner part of the cylinder is connected to the ground.

A potential difference should be applied to the inner face of the cylinder in order to get a certain amount of displacement. Displacement of piezotube as follows; when a positive potential difference is applied to the part A of piezotube, this part will be extended and the other portions will be remain constant. As a result, free end of the piezotube will be bended in the +x direction. If a negative potential is applied at the same time to the C-section of piezotube with respect to the inner section, the amount of bending will be increased. In order to get a displacement in z-direction, a positive potential difference should be apllied to all. Accordingly, length of the piezotube will be extended in all parts. The total piezotube's displacement by applying potential difference to the electrodes of piezotube will be measured by an interferometer.

PREPERATION and CALIBRATION of PIEZOTUBE

In order to get four different electrodes from the outer part of the piezotube, the etching process was used. The etching process was made using 40 ml of %63.01 HNO_3 diluted with 60 ml of distilled water.

The device was set up for coarse calibration of piezotube as shown in the Figure 3.

Where, 1 Laser (λ=632 nm),

2 Michelson Interferometer,

3 Screen and phototransistor,

4 Amplifier

5 PC Lab Card (AD/DA converter) (PCL 818) and PC

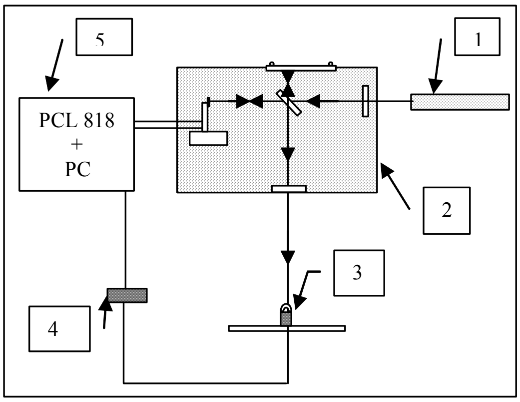


Figure 3.
A device that is count fringe, which is used for calibration of piezotube.

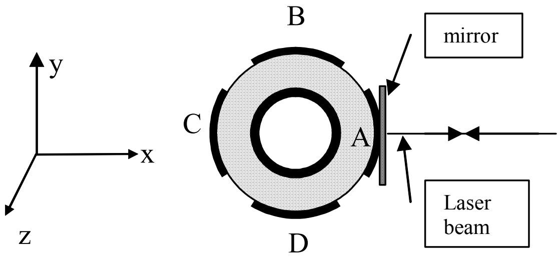


Figure 4.
Light mirror and cross-section view of piezotube.

A mirror is placed at the free end of piezotubes shown in Figure 4. This mirror was used instead of movable mirror in Michelson interferometer. 30 Volt potential difference was applied to the part A of piezotube. When the potential difference was increased, the free end (mirror) was bended. Therefore, mirror moved away from the laser source. When mirror was moving away, action of fringes at screen was red by phototransistor. Then incoming signal was gained by an amplifier and send to a PC. A diagram of amplifier circuit is shown at Figure 5.

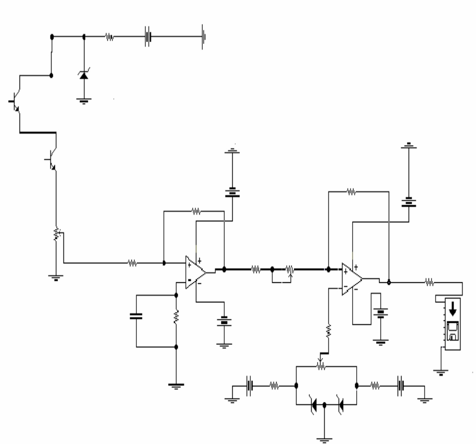


Figure 5.
Amplifier circuit which gains signal coming from phototransistor.

Same procedure is applied to the other parts of piezotube. An applied potential differences and amount of sliding of fringes are taken to a PC by using an AD/DA converter card. Graphs for each part are given at the Figure 6, 7, 8 and 9. In these graphs, the applied potential differences are represented in the horizontal axes and normalized numerical value of light intensity which is incoming to phototransistor are represented in the vertical axes.

As seen in Figure 6, 7, 8 and 9, when 30 Volt potential differences are applied to the part A, B, C and D, four, three, four and three slides of fringe has seen respectively.

He-Ne laser with 632 nm of wavelength is used in the Michelson interferometer. Therefore differences between two fringes is equal to 316 nm (half of wavelength)

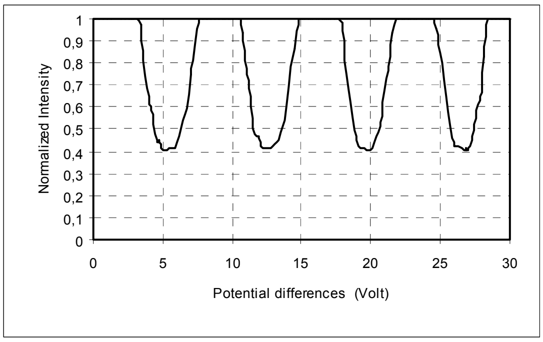


Figure 6.
For part A, the variation of normalised numerical value of light intensity with applied potential difference.

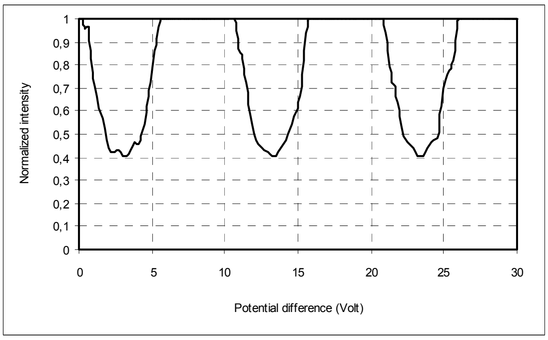


Figure 7.
For part B, the variation of normalised numerical value of light intensity with applied potential difference.

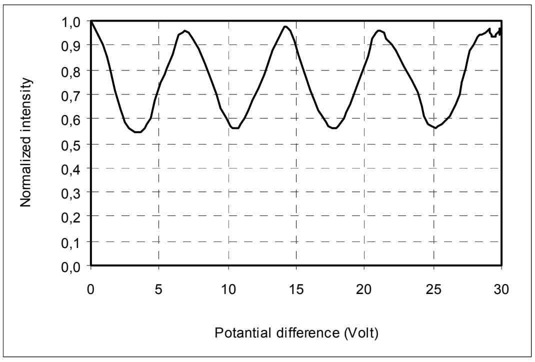


Figure 8.
For part C, the variation of normalised numerical value of light intensity with applied potential difference.

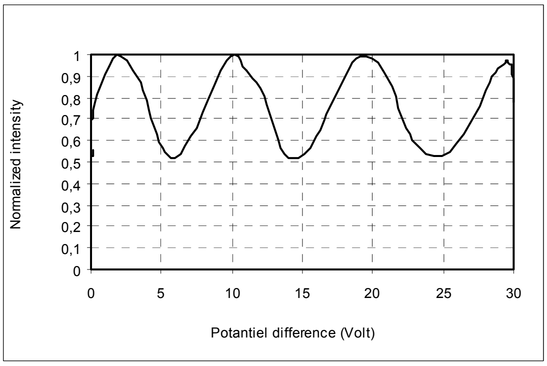


Figure 9.
For part D, the variation of normalised numerical value of light intensity with applied potential difference.

Average values of amount of differences between minima's of fringes are calculated from graphs. Then response of the piezotube to the applied voltage is found. Displacements per unit applied voltage are given below;

43.13 nm/V for part A,
30.29 nm/V for part B,
42.28 nm/V for part C,
33.57 nm/V for part D.

Then, the applied potential differences between electrodes of piezotube are changed from 0 to –30 Volts and response of the piezotube to the applied voltage is calculated;

43.22 nm/V for part A,
30.35 nm/V for part B,
42.10 nm/V for part C,
33.92 nm/V for part D.

According to these values, total displacements are given below:

85.23 nm/V for A and C electrodes,

61.91 nm/V for B and D electrodes.

For measurement of amount of elongation for z-direction, a light mirror is placed in front of the piezotube. Then, 0 to +30 volts potential difference is applied to all of electrodes. The amount of elongation is observed as 198.26 nm. So, The amount of elongation per unit applied voltage for z-direction is calculated as 6.6087 nm/V.

In order to study nanometer-scale devices, the initial and the important step is to fabricate regular nanometer-scale test structure.[Gu 1995] For the calibration of nanometer scale piezotube is used in Scanning Tuneling Microscope (STM) and image of the graphite structure in nanometer-scale is observed. Before the observation of graphite structure, test structure in micrometer scale is used for micrometer calibration. The STM image of the grating is given in the Figure 10. The Figure 10 is arranged according to the data obtained and shown the Figure 11.

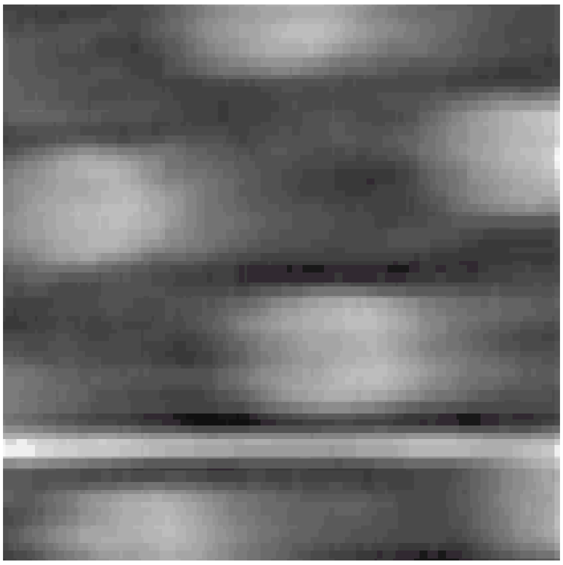


Figure 10.
Uncalibrated image of 2µm×2µm grating

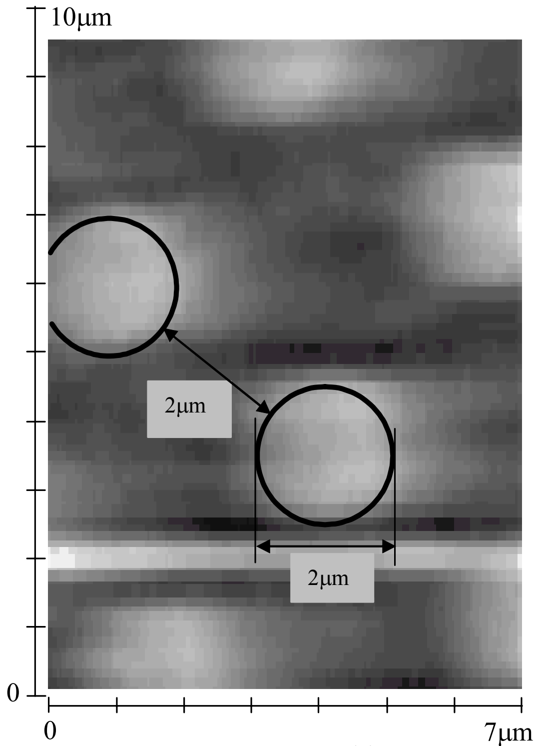


Figure 11.
2µm×2µm dimension's grating.

From the Figure 11, new calibration results that are given below are obtained;

84.36 nm/V for electrodes A and C,

62.26 nm/V for electrodes B and D.

And the final calibration is carried out by the graphite structure. A Simplicity reproducibility and reasonable theoretical understanding are compared a kind of test data obtained from surface for many STM investigations (Selloni et al,1987). The STM image of graphite structure is given in the Figure 12. According to this figure;

75.10 nm/V for electrodes A and C,

55.40 nm/V for electrodes B and D.

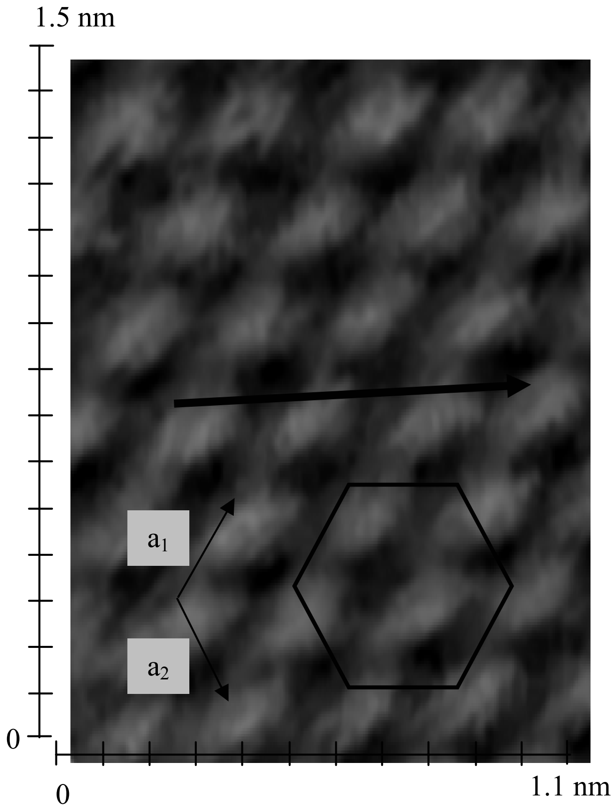


Figure 12.
STM image of graphite.

DISCUSSION

The STM is suitable for the determination of the voltage-displacement characteristics of the piezo scanners.

We have determined a voltage-displacement characteristic and calculated actual displacements for different tube-shaped piezo actuators.The actual displacement depends significantly on the controlling regime. It has been shown, that the maximum displacement depends monotonously on the maximum of the applied voltage.

In comparison to other calibration methods, the STM calibration is one of the precies method. The measurement of the voltage-displacement characteristics of tube piezo scanners for STM application show that the adjustment of the displacement depends on the scanning range. The proportionally constant between the displacement and the applied voltage has to be recalibrated to the actual total scanning voltage elongation.

REFERENCES

1. MÜLLER, F. et al., 1995. A Method for Contact-Free Calibration of Piezoelectrical Actuators, Rev. Sci. Instrum. 66 (9).
2. DECK, L., 1995. Accurate, Repetitive Motion from Biased Piezoelectric Actuators, Rev. Sci. Instrum. 66 (5).
3. HOLMAN, A. E. et al., 1995. Analysis of Piezo Actuators in Translation Constructions, Rev. Sci. Instrum. 66 (5).
4. PARK, S. and BARRETT, R. C., 1993. Design Considerations for an STM System. Methods of Experimental Physics, Vol 27.
5. BONNELL, D, A. 1993. Scanning Tunneling Microscopy and Spectroscopy. Chapter 2.
6. PORTER, T. L., 1994. A Dual-Scan Piezo Element for Scanning Probe Microscopes. Rev. Sci. Instrum.65 (7).
7. SELLONI, A. et al., 1988. Scanning Tunneling Spectroscopy of Graphite and Interlates, Physica Scripta. Vol. 38, 297-300.