JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Design and Development of an Experimental Setup for Characterization of Piezoelectric Actuators for Scanning Tunneling Microscope

S. S. Sawant[a], P. K. Gaikwad[b]

[a]Department of Physics, Shri Chhatrapati Shivaji College, Omerga (MS) 413606, India.

[b]Department of Physics, B. S. S. Art's Science and Commerce College, Makni (MS) 413604, India.

Abstract:

For development of Scanning tunneling microscope (STM), we have designed and developed an elaborate experimental setup for determination of static and dynamic characteristics of piezoelectric actuators. Using this setup, we have obtained static as well as dynamic characteristics of Piezoelectric tubes ($BaTiO_3$, $Pb(Zr,Ti)O_3$) and results on Piezoelectric response as well as the effective factors such as the hystersis creep and fatigue on performance of actuators. These results are important in the contest of development of piezoelectric based Scanning tunneling microscope (STM).

PACS No.: 68,35Bs, 68.35Ct

Introduction:

The trends towards minimization in science and technology require more and more precise on submicron scale. High precision positioning is also required in modern analytical instruments with very high resolution [1-3]. Scanning tunneling microscope (STM) is very fine precession positioning device having subatomic resolution. Piezoelectric devices allow for extremely fine positioning because of piezoelectric effect.

STM and Atomic force microscopy (AFM) [4] are latest one having subatomic resolution [5,6].

In STM, a sharp tungsten tip is brought so close to the surface (5 to 10 A^0) that the electron wave function of the tip and sample overlap by applying small bias voltage (2 mV to 2 V) between tip and sample which gives tunnel current nanoampere range [7-9].

The tip is mounted on three orthogonal piezoelectric transducer. As the tip is scanned along the surface there is change in tunneling current as the separation between tip and sample. The tunneling current is kept constant by feedback loop that applies correction voltage to Z transducer, which is normal to surface.

To convert this correction into absolute displacement, it is necessary to know the piezo-sensitivity for small and fast changing voltages. STM is not merely a static instrument, the sensitivity of tube sets the available scan size but the response of the feedback loop and the speed of scanning are ultimately determined by tubes dynamic response. It was therefore, felt that a systematic study of static and dynamic response is required to develop and experimental setup for scanning tunneling microscope.

Laser based displacement measurements:

Michelson interferometer can be used for the measurements of small displacement ranging from few hundred A^0 to few thousand of A^0. This can be done by replacing micrometer assembly by the device on which measurements are to be made. The mirror is mounted on the device and the shift in fringes are observed, which can be calibrated into distance. For slow motions normal laboratory level setup consists of sodium or mercury lamp can be used to observe the fringes either through a telescope or directly by necked eyes. For dynamic measurements, however, these sources are inadequate so the techniques of visual observation, a combination of laser and laser detector has to be used. The essential parts are schematically represented in figure (1).

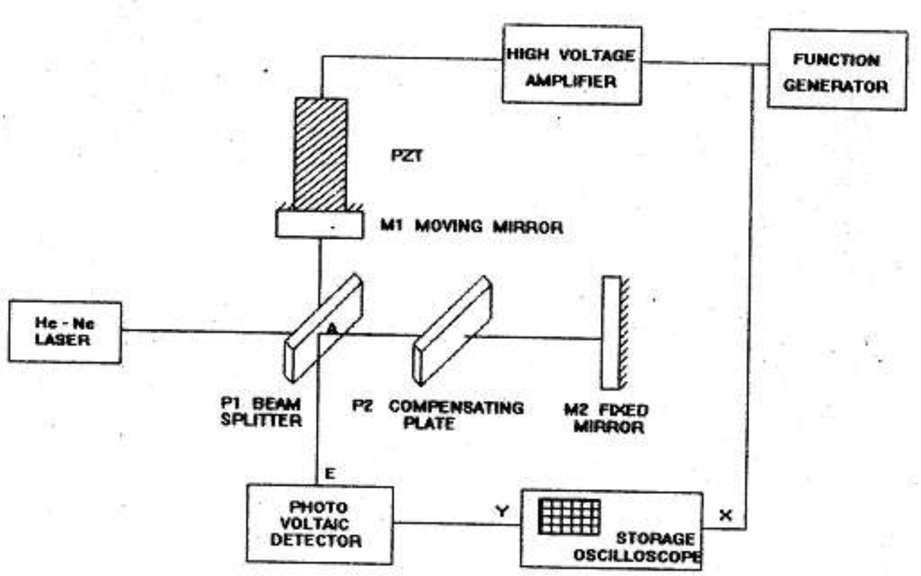


Fig. 1. Block diagram of experimental setup.

Two plane mirrors M1 and M2 highly silvered on their front surfaces to avoid multiple internal reflections. M2 is fixed M1 can be mounted on piezo tube [10,11], by applying voltage to piezo tube M1 can be moved along the precise straight. The parallel glass plate P1 and P2 of equal thickness cut from a single optically plane plate and are mounted vertically parallel to each other on a heavy frame are inclined at 45^0 to the interferometer arm [12,13]. The rare side of P1 is covered with a film of silver of such thickness that one half of the amplitude of incident wave is reflected while the rest is transmitted through it.

The wave reflected at M1 crosses the plate P1 twice while the optical path of the other wave is absence of P2 lies in air. The light reflected from M2 passes twice through P2 and optical path AM1A and AM2A is completed [14].

The two waves shall interfere constructively or destructively, the optical path difference between them is either even or odd multiple of $\lambda/2$.

$A = 2n(\lambda/2)$ for maxima

$A = (2n+1)(\lambda/2)$ for minima

Moving M1, i.e. by applying high voltage to pezotube, can alter the path difference between two coherent beams. Thus, any point in the field of view appears alternately bright and dark. Depending on the orientation of M2 with respect to M1 interference fringes of different shapes are formed, i.e. straight circular, elliptical, hyperbolic etc. As the beams have traveled over different distances, interference fringes will be formed on detector, for high-speed readout is required, i.e. PIN diode is used.

Development of experimental setup for piezo calibration:

The piezoelectric ceramic tube is fixed on holder of Michelson interferometer, the tube has silver coating and poling is along the radial direction. The parameter concerned here is piezo expansion coefficient d31 defined by

$$d31=\left(\frac{\Delta l}{l}\right)\left(\frac{t}{v}\right)$$

where l is increase in original length for increasing applied voltage and t is the thickness of the tube. The piezo expansion coefficient d31 is defined as by applying electric field along the poling direction yields elongation along radial direction resulting in contraction along the length of tube and vice versa [15,16].

A series of hyperbolic fringes is formed which are seen by detector as a set of concentric circles. By applying high voltage to piezo tube causes elongation in length the piezo, which in turn causes shift in the fringes, which can be measured. For high frequency response the number of fringes crossing the detector hole can be observed by connecting piezo voltage to x-axis and detector output to y-axis of storage oscilloscope. Since the difference between the two dark fringes is corresponding to λ/2. The elongation in the piezo is accurately measured as distance between two peaks on x-y display. The PIN diode does not need external power supply. Its output is extremely stable with respect to time and current is directly proportional to intensity of light and cell area [17].

Electronic control system:

i) High voltage amplifier: - The basic electronic control system for piezo drive requires a voltage ramp with variable frequency. The piezo was earlier tested and its response 16 A^0/volt, which means a voltage ramp of few hundreds is required to get at least shift of λ/2 [18].

The general function generator available in laboratory have +15 volt to –15volt ramp. Therefore, a special amplifier is built for this purpose. Figure (2) shows a diagram of amplifiers, which can be designed and fabricated. The high voltage transistor is used which are easily available in local market. The class B amplifier concept was used, in which the Q point is located at cut off; due to this the transistor conducts half cycle of input. The unity gain operational amplifier is in inverting configuration, which works as an adder to shift dc level of input signal by an amount required to bring the transistor in active region.

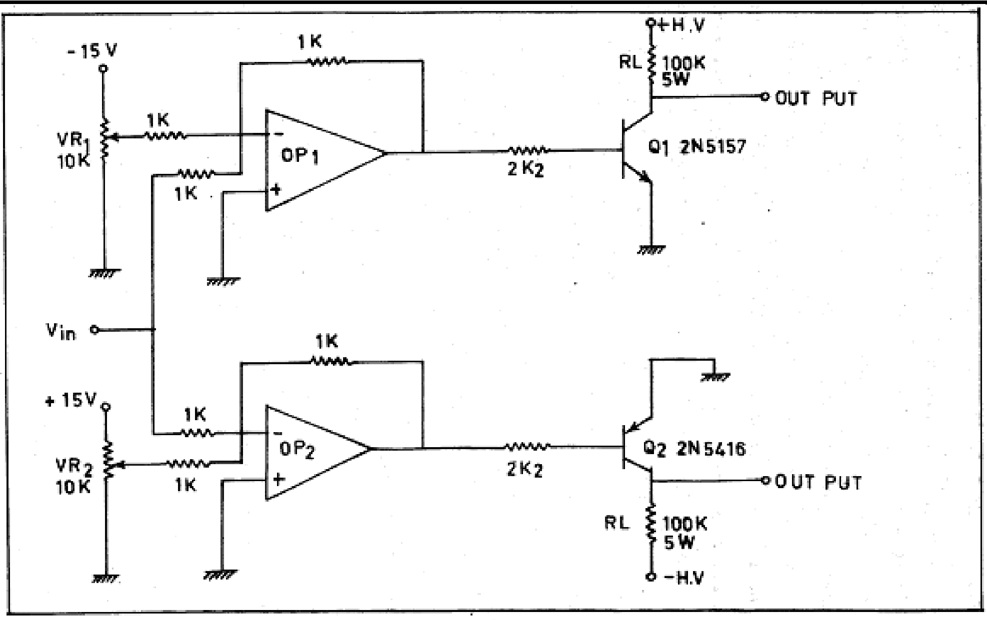


Fig. 2. High voltage amplifier.

ii) High voltage regulated power supply: - The high voltage amplifier works on dual concept + 300 volt to – 300 volts, which is regulated using the dual regulator IC. By using adjustable three terminal regulator type LM 317 and LM 337 as positive voltage regulator and negative voltage regulator (figure (3)).

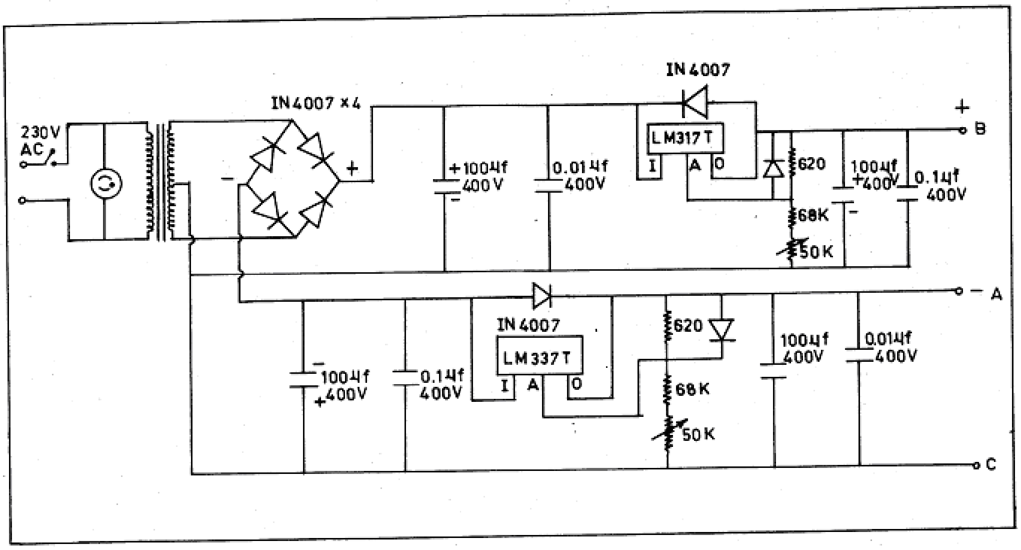
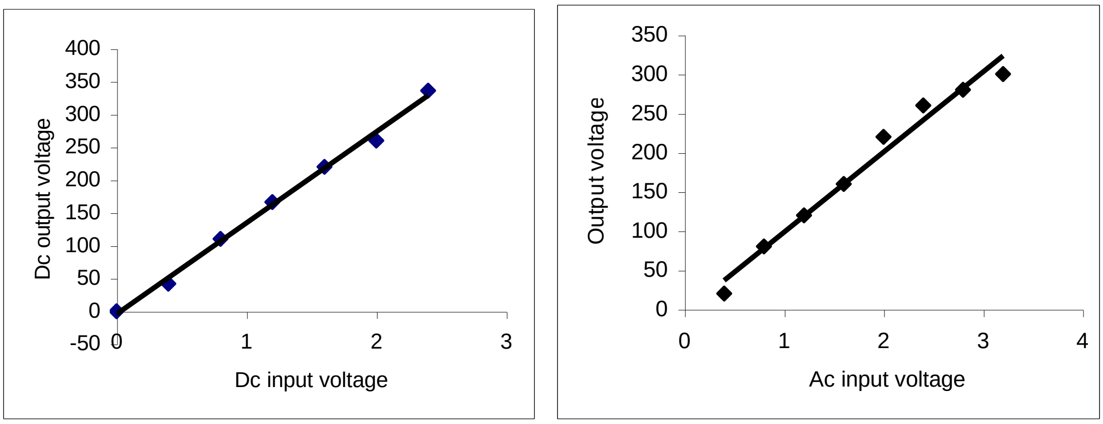


Fig. 3. High voltage regulated power supply.

Experimental results and discussion:

The high voltage amplifier described earlier was tested for dc and ac performance by using function generator and storage oscilloscope. Figure (4a) show the dc response, a fairly linear response was obtained for 0 to 300 volts. Similar response was obtained for ac voltage shown in figure (4b). However, the gain was found to be 120 in contrast to 170 for dc measurement. Figure (5) shows the bode plot of the amplifier with the 3db point at 3.2 kHz. It can be seen that the operational amplifier characteristic satisfies the requirement for carrying on the experiment.



(a) (b)

Fig. 4. (a) dc and (b) ac response of high voltage amplifier respectively.

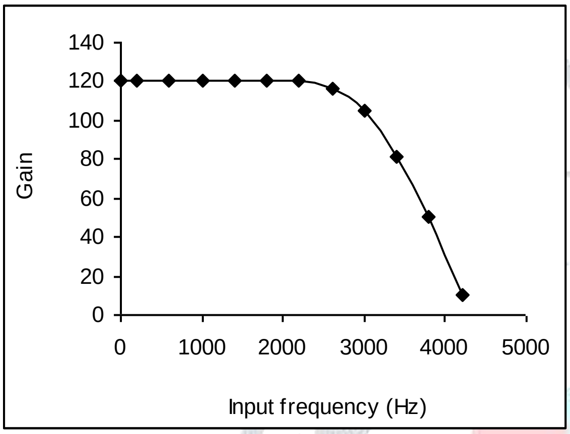


Fig. 5. Frequency response of high voltage amplifier.

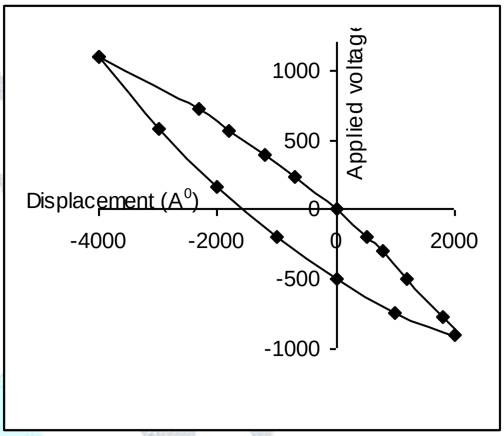
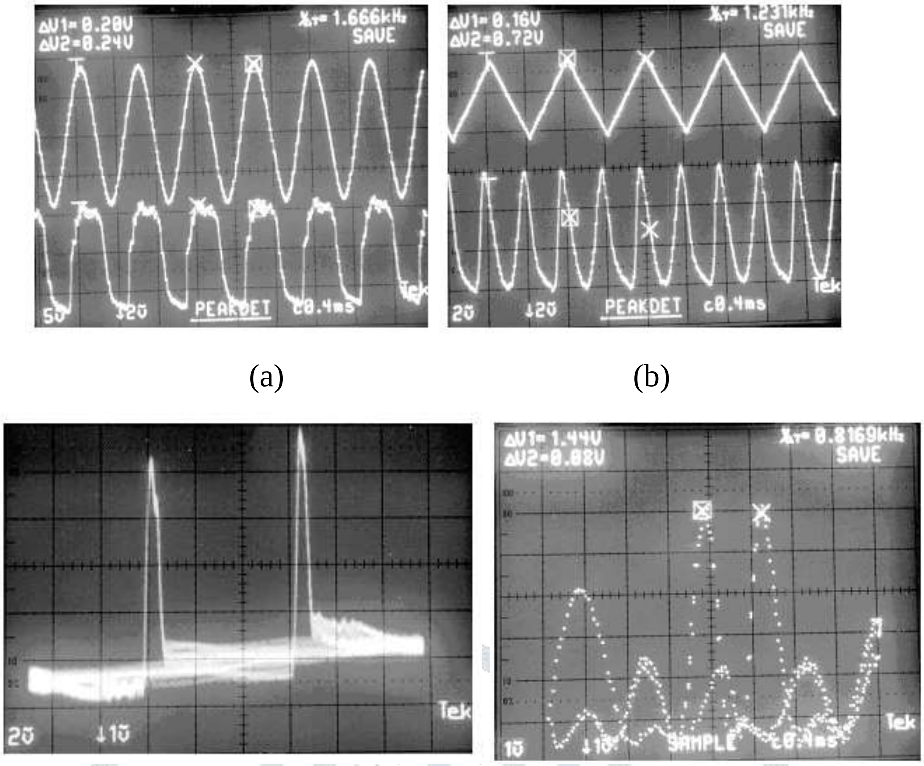


Fig. 6. Dc response PZT.

i) Measurement of piezo tube response: - The piezo is mounted on Michelson interferometer which is subjected to high voltage between the inner and outer electrode resulting in the elongation or contraction along the length to tube which in turn causes shift in the fringes. For the dc measurement voltage was varied manually and the number of fringes displayed was measured. Figure (6) shows a plot of displacement versus applied voltage. It can be seen that the piezo exhibits hysterisis curve. For ac measurement the output of the amplifier was connected across the inner and outer electrodes and the response was observed on the laser detector as shown in figure (7a, b). It shows the response of detector for sinusoidal and triangular waveforms, clearly establishing the fact that the instrument response and resolution was more than sufficient to detector the shift in the fringes. In order to measure the displacement, the output of detector was connected to y-axis of the oscilloscope while the ramp voltage to the x-axis of the oscilloscope. Figure (7c) show x-y display of such measurement, the distance between the two peaks the value 60 A^0/volt was obtained for the ac response. It was found that the response A^0/volt depends on the frequency excitation. In figure (7d) shows the variation of piezo tube response with frequency. The maximum being near the response frequency.



(a) (b)

(c) (d)

Fig. 7. (a) Response of detector for sine waveform, (b) Response of detector for triangular waveform, (c) x-y displacement with x as ramp voltage and y as detector output for displacement measurement, (d) Ac response of PZT near resonant frequency.

Discussion and conclusion:

The significant results of the present work in the observation figure (8) that the response depends on the frequency excitation. The response is constant up to 10 Hz, as the driving frequency is increased about 10 Hz the travel of the actuators drops sharply, and near 100 Hz it about 1/4th of its low frequency value. Above 100 Hz the travel increases and attends maximum at 1 kHz. Although, we ware unable to measure the response above this frequency because of the phase shift in forward and backward travel, resulting in the phase difference between x and y setting which in turn upsets the synchronization.

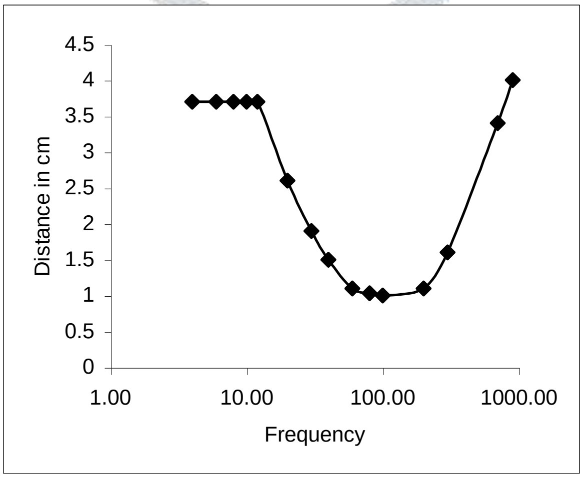


Fig. 8. Relation between displacement versus applied frequency.

Conclusion:

In conclusion we have designed and developed an elaborate experimental setup for dynamic and static characterization of piezoelectric actuators, using the same we have obtained important results on piezoelectric response as well as the effect of factors such as hysterisis, creep and fatigue on performance of actuators. The result was important in the context of development of piezo based micropositioning devices for scanning tunneling microscope (STM).

References:

1. Catlog; *“Inchworm Systems”* Burleigh Instruments Inc Burleigh Park, Fishern, NY- 14453.
2. Ch. Geber, G. Binning, H. Fuchs, O. Marti, and Rohrer, *Rev. Sci. Instrum,*. 57, 221 (1986).
3. Y. Kuk and P. J. Silvarman, *Rev. Sci. Instrum.*, 60, 165 (1989).
4. G. Binning, C. F. Quate andCh Gerber, *Phys. Rev. Lett.*, 56, 930 (1986).
5. J. S. Foster and D. Reger, *App. Phys. Lett.*, 42, 869 (1983).
6. G. Basile, A. Bergamin, G. Cavagnero, G. Mana and G. Zosi, *IEEE Trans. Int. Meas.*, 38, 210 (1989).
7. G. Binning and H. Roher, *Phys. Acta.*, 55, 726 (1982).
8. G. Binning, H. Roher, Ch. Gerber and E. Weibel, Phys. Rev. Lett., 50, 120 (1983).
9. P. K. Hansma and J. Tersof, *J. Appl. Phys.*, 61, R1 (1987)
10. Born M. and Wob E, *“Principles of Optics”*, Oxford Pergamon Press, (1959).
11. Hariharan P., *“Optical Interferometry”,* Academic Press, Son Diego, (1985).
12. Heem, F. and Zajac, A *“Optics”*, Addison Welsey Reading, Massachusette, (1987).
13. Yariv, A. *“Introduction to Optical Electronics”* IInd Edition, New York. Hoot, Reinchart and winstor, (1976).
14. K. D. Stampf, *“Read Time Interferometer”,* Eng, 18, 648, 653 (1979).
15. *“Review of Scientific Instrument”*, 58, 2193 (1987).
16. R. W. Borebow and T. D. Cocks, *J. Of Physics Instru,ents*, 13, 840 (1987).
17. S. s. Charschan *“Laser in Industry”*, Van Nortrand Reinhold Company, London, USA.
18. Elion, H. A., *“Laser system and Application”*, Oxford Pergamon Press.