IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 3, March 2024

Design and Development of Feedback Controller for Scanning Probe Microscopy Applications

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Abstract: *The Scanning Probe Microscopy (SPM) techniques, mainly Scanning tunneling microscopy (STM) and atomic force microscopy (AFM) instruments have great important in surface science laboratories due to its high potential to achieve image at atomic scale resolution. SPM has revolutionized our ability to explore the nanoscale world enabling the imaging, manipulation and characterization of materials at the atomic and molecular level. The experimental designing and its analysis of feedback network system has proposed for scanning tunneling microscopy. Instability in feedback network could affect the measurements and accuracy in surface topology of material. Feedback network circuit controls the necessary arrangementfor proper functioning of STM. It Controls the STM operation like a regulator circuit in sealing fan even if input voltage changes, the output has controlled by the regulator. The working of each element of feedback network is well discussed and analysed. The interconnection between the different elements of feedback control network is analysed with mathematical equations.STM has the outstanding advantage from the biological perspective of allowing measurements has made with a resolution of nanometers in aqueous media. Hence, living cells, working enzyme systems etc. can be examined.[4] SEM also investigates 'Trichomes' which is present on both surfaces of leaf. [5].*

Keywords: Scanning Probe Microscopy

I. INTRODUCTION

Scanning probe microscopy (SPM) includes STM, AFM, and chemical force microscopy that have extensively applied in nanostructure characterization. Scanning Probe Microscopy (SPM) is device based on a new technique to investigate the structures at the atomic or molecular level.

Scanning Tunnelling Microscopy was first developed by Gerd Binnig and Heinrich Rohrer in 1981 and earned its inventors the Nobel Prize in Physics in 1986. STM has considered the godfather of all the other tip-based microscopy methods, including atomic force microscopy (AFM). It creates powerful surface images and characterization method, which have developed of our understanding of material, condensed matter and device operation at nanoscale. A key future of SPM is the nano sized probe, which interacts with the surface and produce the information used to create an image of the surface topography. [9]

After high success in providing high-resolution imaging, some limitation are still at the centre of researchers interests like low speed of imaging, limit of processes in real time, interpretation of complex data, issues related to tip-surface interaction. The sensing principle has remained unchanged since the development of SPM. This influences careful piezoelectric actuation for a raster scan of the sample surface while a feedback system senses the tip‑surface interaction in one of the many modes such as contact or contactless. It providing high-resolution imaging and information required for spectroscopy. Machine learning introduced some new technology to enhance performance data collection to improve traditional limitation and enhanced the quality of SPM. [9]

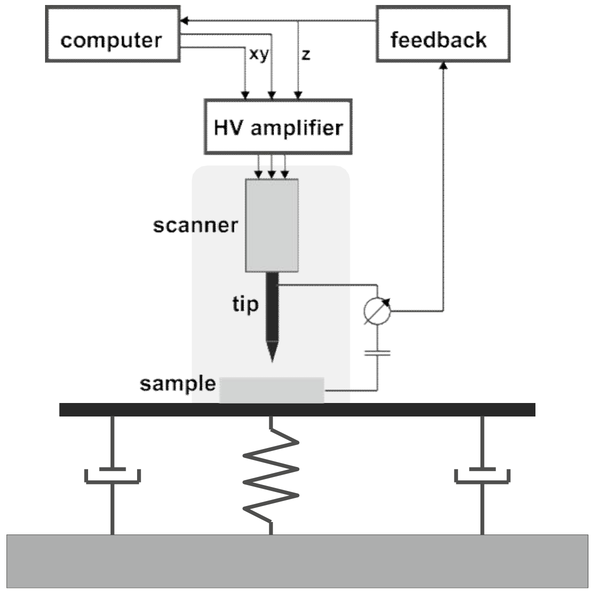

Figure 1.1: Schematic diagram of the scanning tunneling microscope

Scanning Tunnelling Microscopy (STM) is applicable to the conductive sample or the surface operating under different environment. STM operation has invented based on the mechanism of the quantum tunnelling effect. [3]

After building this microscope with increasing accuracy and complexity, we look towards to design a simple, cheap system that has to be useful for students and our research laboratory. An analogue control proportional feedback controller with sample and sharp conducting tip which has used to control the STM operation.The STM consists of a sharp metal tip, often made of Pt-Rh or tungsten and a conducting or semiconducting planer sample surface. When sample is clean and flat, even atoms canimaged. The distance between tip and sample control during data collection is change by synchronising the parameter of feedback loop. Instead of tip position, D- A convertor maintained velocity of tip to reduce generated noise. This will provide time delay for the collection of data. [2,18]

In scanning tunnelling microscopy (STM), where a small tunnelling current has measured between probing tip and sample. Various operation modes such as constant tunnelling and constant height modes as well as tunnelling spectroscopy had described and application are given. [10] By using combination of a coarse approach and piezoelectric transducers, a sharp, metallic probing tip has brought into close proximity with the sample.The surface contact between tip and sample is only a few angstrom units, which implies that the electron wave functions of tip and sample start to overlap. [16,17]

II. BACKGROUND AND DESIGNING OF PREAMPLIFIER

There are three major part of STM device. It contains head stainless steel with differential screw and piezo tube for scanning. [2]Scan area has limited by the choice of the piezoelectric scanner and the maximum output voltage V_{max} of the high voltage amplifier. In the driver amplifier of piezo, we can use op-amps. The scan tube sensitivity is 30nm/V for X and Y and 5 nm/V for Z. The tunnel current converted in to a voltage for feedback system by using pre amplifier with a 10^8 Ω and OPA 128.The signal is amplified 10 times to get a 1 V/nA. Preamplifier has mounted at base of head to reduce mechanical noise. Since the current is exponential dependence tip-sample distance. The current has linearized with logarithmic amplifier. This voltage has apply to feedback controller, which is the difference amplifier. The output voltage of the log amplifier has compared with set reference, which decides the value of the tunnel current desired. Feedback circuit generated proportional voltage depending on error signal. [1,14]

To achieve constant tunnel current, this proportional signal has applied to the Z electrode of the piezo, which is in corresponding to reference voltage. For this rules and condition, we assume that tunnel current locked by applying voltage to the XY electrode of the piezo, the surface has scanned in a raster pattern. At the same time, output of the feedback controller is gain by the data acquisition system. The software produced then a grey scale image, which is image of the sample topography.[16]

The preamplifier circuit converts small current through the high impedance tunnel junction into low impedance voltage signal. It has two stages, Op amp 1 has used as current to voltage converter.The tunnel current is of the order of 1 nA with an impedance of a few MΩ range. Here, the Op amp OPA 128 has used, which has high input impedance ($10^{12}\Omega$). The tunnel signal has amplified by the instrumentation amplifier AD 524 with variable gain. The proper selection of feedback resistor is necessary since the increase in R_f will increase signal to noise ratio but will decrease band-width the system. Infrequency response, gain picking has observed at a particular frequency. Here no drift has observed in the output.[14]

III. FEEDBACK CONTROLLER NETWORK

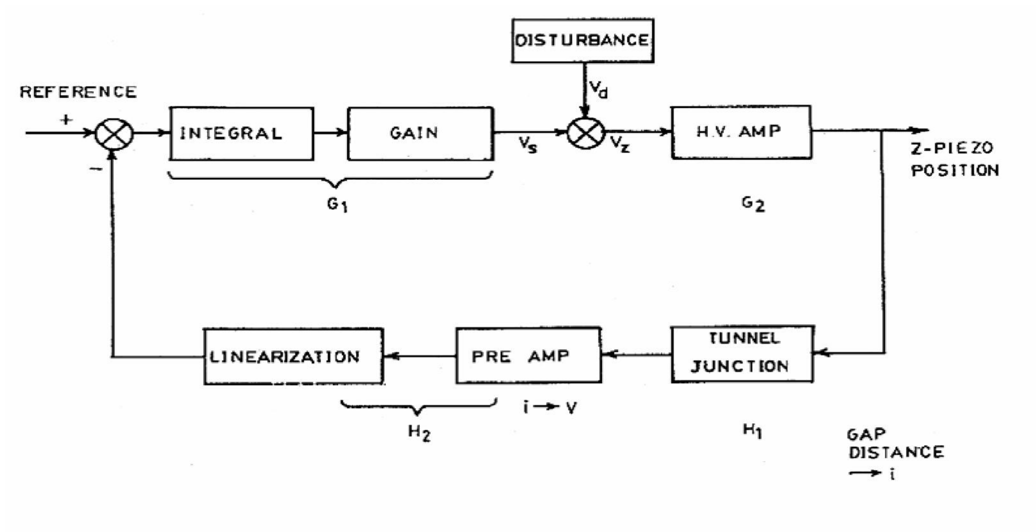

Figure 3.1: Block diagram of feedback controller network

The important and central part of a scanning tunneling microscope electronic system is the feedback controller network. For every system should be controlled system. In STM system, it is necessary that the Z piezo-electric element and tip-sample is in contact. The tunneling current is exponential function of tip-sample separation. The logarithmic amplifier is used to linearized the tunneling current. [1,5,13]

In figure 3.1, block diagram shows the control system in constant current scan the gap separation has set by comparing the tunneling current to the demanded current and has compensated by a negative feedback loop. Before designing feedback circuit, it is necessary to analyze it.[4,11,12].

The feedback circuit uses integrator. If $V_i$and V_0 are the input and output of the integrator, R is the input variable resistance 500KΩand C is the capacitance, 0.22 µf across the integrator, then the output of an integrator is given as

$$V_0 = -\frac{1}{RC}\int V_i\,dt$$

The amplifier is adjusting the gain of the feedback circuit to match with piezo electric devices. The next circuit is summing amplifier, which allow the addition of external voltage to the control signal. The output of it has connected to high voltage amplifier, which is necessary in order to get larger movable range for the Z tip. The problem of perfect tuning of the controller to match to the system is common. Initially system has locked for required tunneling current. Therefore, error signal from differential amplifier is zero; which indicates Z control signal Vz is set. [15,19]

At time t=0 sec, the Z piezo is raised up or lowered by step input Vd, which simulates the disturbances created by scanning the STM tip laterally. The changing the tip–sample distance produces finite the error signal that makes the feedback operation to recover the initial Vz.

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After the feedback loop stabilizes, all outputs from each stage have returned to the initial values before disturbances except V_s to the summing amplifier. [12]By simply monitoring the response of V_s to the disturbances V_d on an oscilloscope, we can easily adjust the loop gain**.**

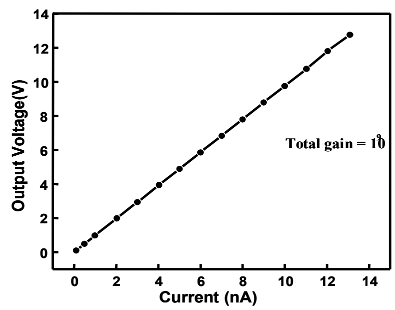

Figure-3.2 Graph of pre-amplifier

For Op-Amp, IC1, 3140, if V_{in}< Vref, the negative feedback will moves the tip in upward direction. It acts as buffer circuit. When V_{in} increases the output of IC1 is negative and if $V_{in\ decreases}$ of IC1 is the output is positive. IC2 is integrator when V_{in}< Vref, then output is positive. The output of integrator is negative. It is gain amplifier and no phase change in it. For IC3 output is negative. It has feed to IC4 and now its output is positive. IC5 is unity gain amplifier of gain 2. It is inverting amplifier and output is negative. [11]

IC6 removes the noise and output is negative. V_Z is negative and tip moves in downword direction. Tunnel current increasing and now V_{ref} = V $_{in.}$.Feedback controller is tested by changing $V_{in}$for fixed vale of V_{ref} and Output is monitored.

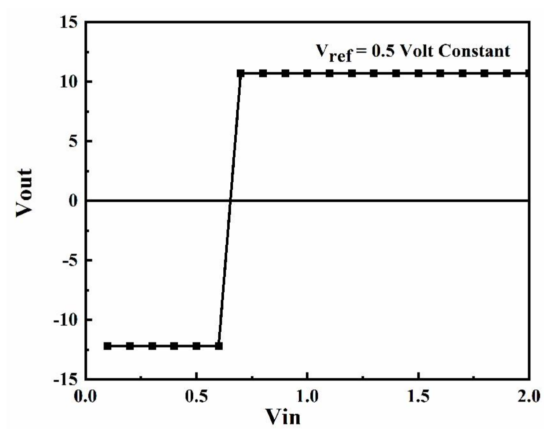

Figure- 3.2Graph of V_{in} against $V_{o/p,}$ for $V_{ref.}$ = 0.5 Volt Constant.

We have been able to obtained the stability region of an STM analytically using the all the possible element in feedback loop. We have use theoretical and mathematical model for each element of feedback loop and we have solve the problems by using logical and technical way. It is possible to achieve real condition of stability of loop. The parameter permits us a to achieve the highly accurate and stable condition for imaging.

ACKNOWLEDGMENTS

This work was possible by the support of institutes like research center of Department of physics, Ahmednagar College, Ahmednagar and research center, Department of physics, New Arts, Commerce and science college, Parner, Ahmednagar. The author wants to thank for helpful discussion for this project.

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