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MAGNETICALLY PROPELLED MICROPOSITIONERS

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Performed experiments presented here resulted in easy implementation of magnetic micropositioner and some useful data on friction forces. The most important point of such a micropositioner — the step size has been calculated from data derived from experiments as well as measured directly after applying the micropositioner in a scanning tunneling microscope.

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1. Introduction

The ability to position a specimen to within several nanometers is important in high resolution microscopy such as scanning tunneling microscopy (STM) [1]. The restricted range of piezopositioners makes the approach to the required tunneling gap a striking technical problem.

Manual and step motorized movement using screws, springs and levers [2, 3] are simple and easy to handle but at the cost of mechanical coupling and vibration. One method of approaching the tip towards the sample is called inertial translating. Although there are many articles in this field, all of them require high skill of operator and therefore are not user-friendly.

We designed and performed some experiments on magnetic translators which is a promising idea for the restricted laboratory. Experiments were focused on two designs of micropositioners, which simplify the STM design.

2. Design and construction of first translator

Magnetic microtranslators which use magnetic field directed vertically to the plane of current were previously made by Smith and Elrod [1]. A well-defined, low friction contact with a glass slide provided by three ball bearings rigidly attached to a smaller slide which carry a samarium cobalt magnet was the main idea of their design (Fig. 1). Current pulsing through the coil attached below the glass slide forces the sample holder to move backwards or forwards depending on the direction of current. The force on the sample holder is perpendicular to both direction of current and magnetic field. However the slider can easily make a sideways motion and vibrational immunity is very low.

In our design two microscope slides were glued inside of aluminum strap with a V-section. The assembly was fixed to a glass plate by means of two L-sectioned straps (see

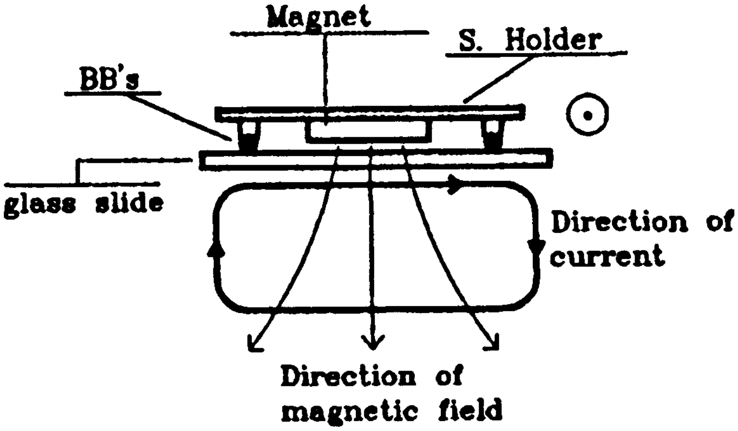

Fig. 1. Schematic diagram proposed in Ref. [1].

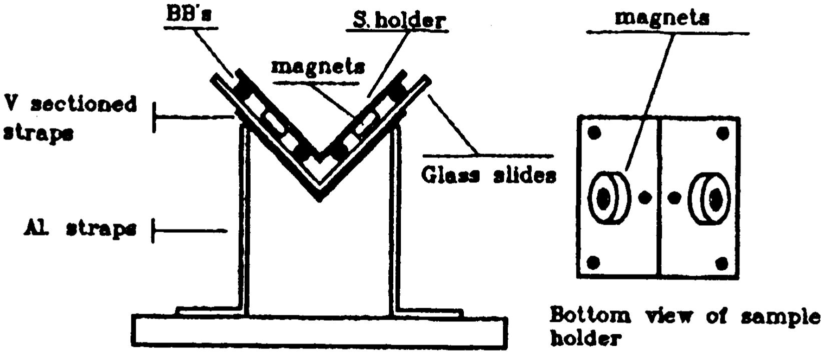

Fig. 2. The design of micropositioner proposed by author.

Fig. 2). Two rectangular coils removed from a junked piece of CD player were glued at the bottom of the slides. The sample holder was made from the same piece of V-sectioned aluminum strap and this point is very important for angular compatibility. 3 holes having diameters of 2.5 mm were drilled on each side of the V, and ball bearings of 3 mm were attached. The sample holder slides inside the V groove by touching at three points on each side. Two samarium cobalt magnets were fixed at the bottom of the sample holder.

A very well controlled motion is obtained by pulsing current through the coils. The pulse width and the frequency depend on the step size and speed of motion requirements. Typical value of pulse width is from 100 to 500 μs. Typical frequency lies between 100 to 1000 Hz. The relations between pulse width, frequency and step size should be presented with details in the following sections. The minimum step size obtained with this translator was around 100 Å.

3. Design and construction of second translator

First translator worked perfectly, but it could not operate vertically. To overcome this problem, a magnetic walker, which operates vertically inside a glass tube, was designed. A round piece of aluminum which has an extension at the bottom for housing a donut shaped samarium cobalt magnet was used as the sample holder.

Six 2.5 mm diameter holes were drilled round the carriage for housing all bearings (see Fig. 3). Owing to its kinematic design, the sample holder does not need to not be precisely machined. When ball bearings larger than 2.5 mm were housed in the holes, it could be easily understood that the length of ball bearings which rested on the surface was a function of hole diameters, not hole depths.

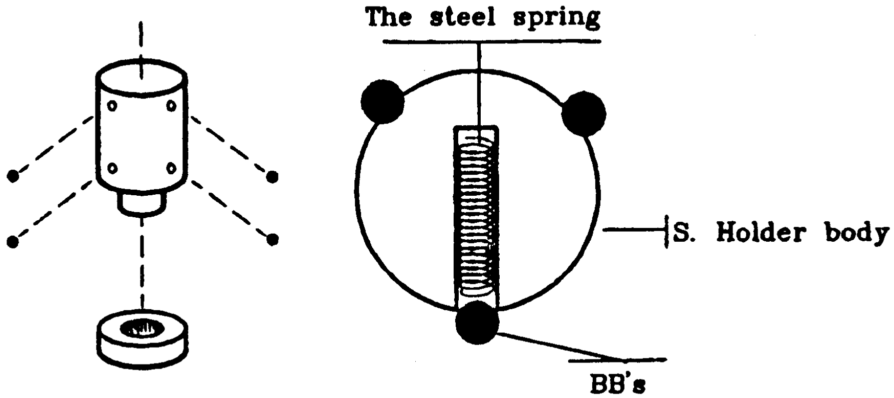

Fig. 3. The details of translator for vertical motion.

All holes were drilled to a depth of 2 mm at the beginning of the machining. Two holes resting on the same plane, which was parallel to the axis, were enlarged to 3 mm and were drilled to a depth of 6 mm for the purpose of housing small springs. After all ball bearings were fitted to a position with super-glue, the springs were positioned inside the remaining two holes. The 3 mm diameter ball bearings were added at the top of springs. After the magnet was locked into the position the assembly was located inside a glass tube.

If the inner diameter of glass tube satisfies the equation:

$$D = 2[r + \sqrt{r^2 - (h/2)^2} + \sqrt{(d/2)^2 - (h/2)^2}],$$

the carriage should perfectly rest in place no matter how imprecisely machined it is (here D is the inner diameter, d is the diameter of sample holder, r is the radius of ball bearing, h is the diameter of holes drilled).

If the diameter does not obey the formulation above, the sample holder should rest tilted which should not allow proper operation. Of course, it is impossible to find the exact diameter of glass tube and ball bearings, but by making an approximation it should be available to keep the holder in appropriate position.

The glass tube was located inside a solenoid removed from an electrically controlled valve. Due to the characteristic of applied magnetic field the sample holder may operate outside of the solenoid. Pulses of 500 μs to 3 ms at 24 V were applied to the solenoid and motion with minimum step sizes of 250 Å was obtained. The step sizes obtained and relations with pulse width, applied voltage and frequency are presented in the next section.

4. Electronics

The pulse generator circuit was established around a 555 timer IC. Addition of two diodes in charge and discharge path allows the pulse width and the frequency to be independently adjusted. The circuit is shown in Fig. 4. The output of pulse generator is boosted by a fast power transistor (BUX84). Also, an ultrafast diode connected inversely to the ends of coil assembly stops the negative going pulses caused by coil's self-reactance.

The actual circuit is equipped with a decade set of potentiometers for adjusting the frequency in an extended range. Also for easy operation a remote control button is used to enable and disable the system.

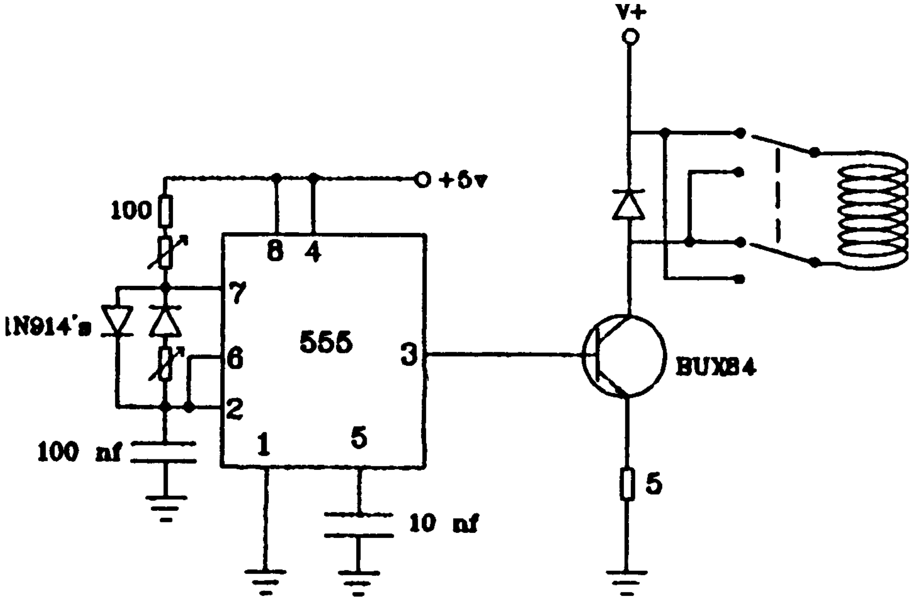

Fig. 4. The pulse generator circuit.

5. Analysis of the motion

The step sizes were calculated by measuring the time in which the sample holder was observed to move as large distance as 3 mm with the help of an optical microscope.

It can be easily understood that

$$S = x/tf,$$

where S is the step size, x is the distance covered, t is the measured time, f is the frequency.

Figure 5 illustrates the pulse width and step size relationship in the first translator. Figure 6 is the plot of step size versus voltage. All data was acquired by using the method explained above.

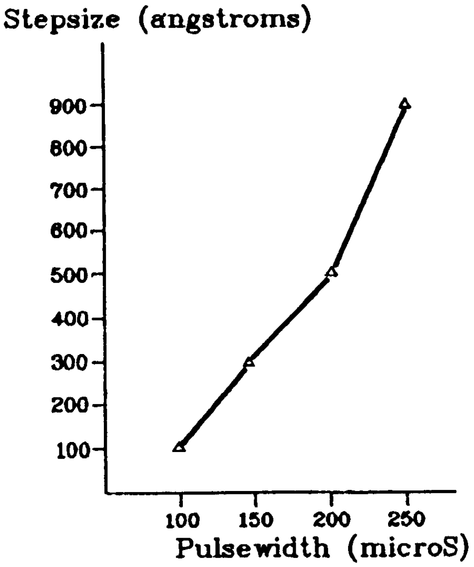

Fig. 5. The dependence of size of single step on current pulse width obtained for first translator.

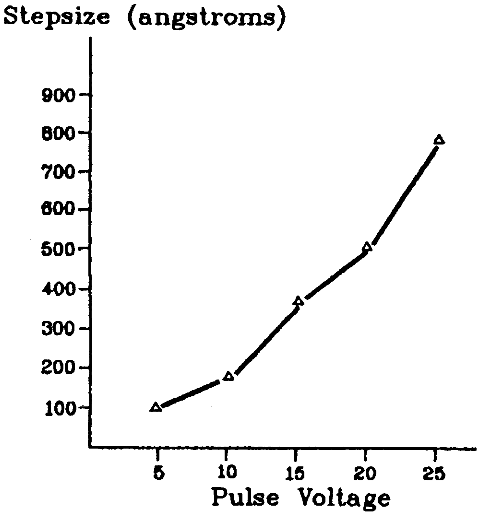

Fig. 6. The length of single step of translator versus applied pulse voltage.

While the first two graphs are typical in this kind of work, Fig. 7 is not. We noted some hysteresis between frequency and step size, although this seems impossible at first glance — some measurements showed the fact. As shown in Fig. 7 the step size is stable till 1600 steps per second, but above this limit the estimated step sizes get smaller. In fact this is not true. When the sample holder receives the second pulse of force, before it stops, it continues its way rather than going step by step. For controllable motion the operation must be done on the plateau.

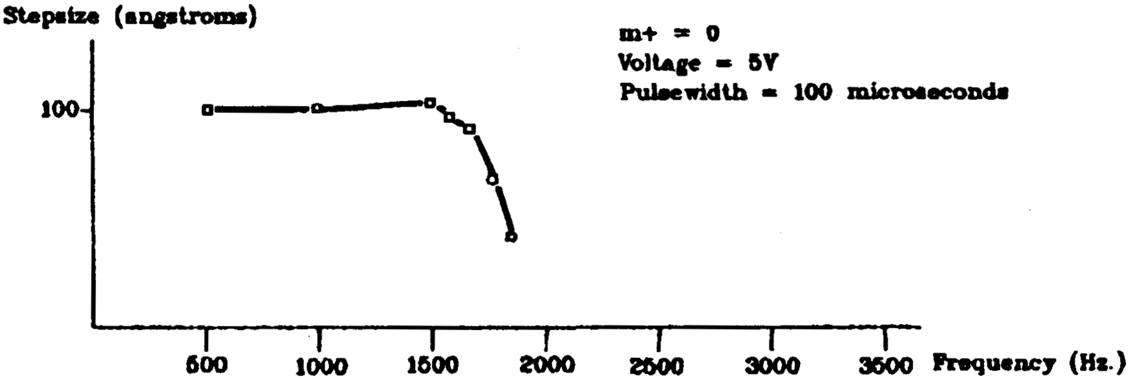

Fig. 7. Calculated step size versus frequency of applied pulses. Above 1500 Hz the system gets unstable.

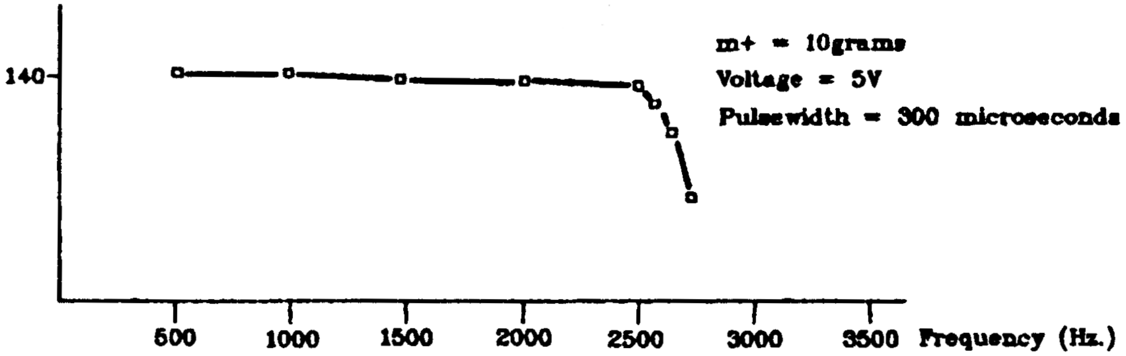

Fig. 8. Additional mass extends the range of stability up to 2500 Hz.

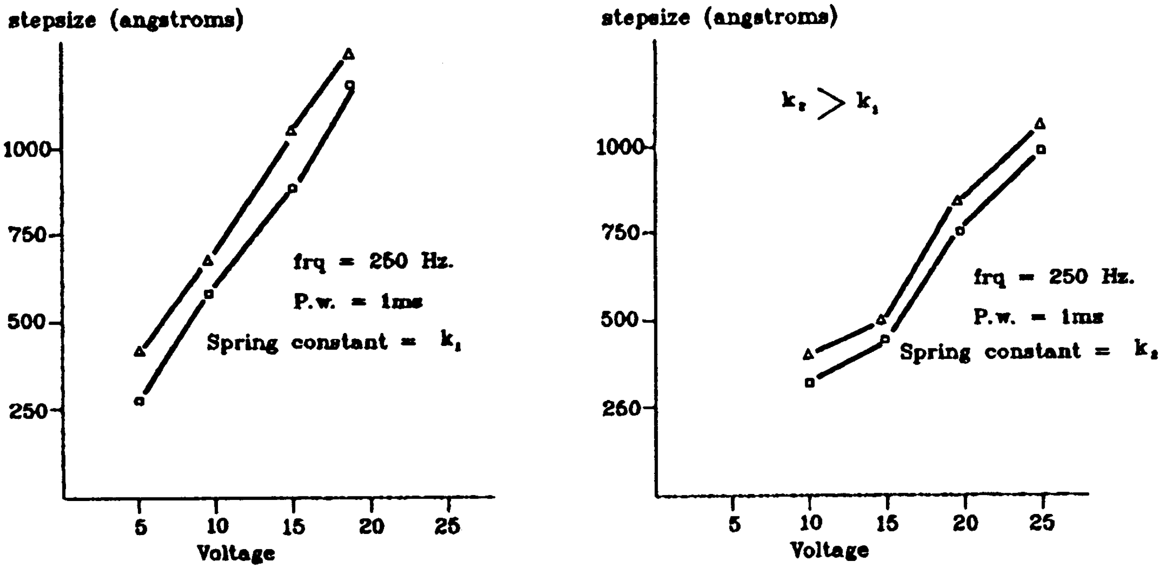

Fig. 9. The influence of gravity: the step sizes for motion up (□) and down (△) obtained for two different spring constants.

As shown in Fig. 8, the extra mass added to the sample holder reduces both the step size and the gliding time, and this results in longer plateau of operation.

The step sizes of up and down motion in the second translator differ for each other because of gravity. As the performance is graphically illustrated in Fig. 9 it can be noted that a harder spring results in smaller step sizes and smaller differences in up and down steps.

It was observed that as the sample holder went up the stepsizes got smaller because of the decaying magnetic field. The operating range of micropositioner depends on the structure of the coil.

6. Conclusion

After the system was applied to a tunneling microscope it was observed that each step is not strictly the same as others from controlled loop measurements. When the feedback loop is active and monitors the voltage applied to the Z electrode of the scanning system, each step of the micropositioner may be measured by voltage changes. But this is not so important since there are many steps in the dynamic range of the piezopositioner. The situation may be improved by using sapphire balls and glass tubes made from higher glass quality.

Both systems can be constructed with very limited sources. Also electronics can be formed by cheap and easy to find components. STM design can be significantly simplified by mounting a tube scanner inside the glass tube. The system is suitable for both cryogenic and UHV work.

The only limitation of magnetic walkers is that they cannot be used under external magnetic fields.

For the second translator, magnetic propulsion is not necessary. Keeping the kinematic structure of the sample holder, the other types of propulsion methods should work as well as the original one.

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