

AFM VIBRATION ISOLATOR WITH HIGH PERFORMANCE USING EDDY CURRENT DAMPING

Gyung-Hoon Chung, Dae-Gab Gweon, Hoi-Won Chung, Jong-Yup Shim

SAMSUNG DISPLAY DEVICES CO. LTD.

575, Shin-Dong,, Paldal-Gu Suwon City

Kyungki-Do, Korea 442-391

(FAX)+82-0331-210-7967

(e-mail) letshee@sdd.samsung.co.kr

1. INTRODUCTION

This article describes the design of a vibration isolation system for AFM(Atomic Force Microscope)⁽¹⁾ to reduce the external mechanical oscillation down to a subatomic scale. The AFM senses forces between the tip and the sample. In order to measure the sample with orders of sub-nanometer resolution, the reduction of floor vibration effecting to AFM is required to this ultra-precision system firstly. Because no distance change between tip and sample is the important thing to AFM as shown in Fig. 1.

Damping force is based on the interaction of eddy currents and a magnetic field usually induced in a moving part. Recently eddy current damping is used in many areas. Especially it is powerful to this AFM vibration isolator which has no friction and coincides modeling with experimental results well. But the eddy current modeling is maintained at the qualitative level only. Therefore this article will show more precise analysis.

The vibration isolator constitutes of two metal

plates suspended by coil spring and eddy current damper. It is designed symmetrically, so it can separate lateral mode and vertical mode. Also in order to reduce the leakage of magnetic flux greatly new concept of design is described calls 'closed loop eddy current damper'. And isolator is constructed by optimal design scheme.

The experimental results of the isolation performance are well explained by the analysis with figures. Thereby the progressive characteristics of eddy current damping

and vibration isolation are clarified.

2. THEORY OF VIBRATION ISOLATION FOR AFM

A. General consideration of vibration isolation

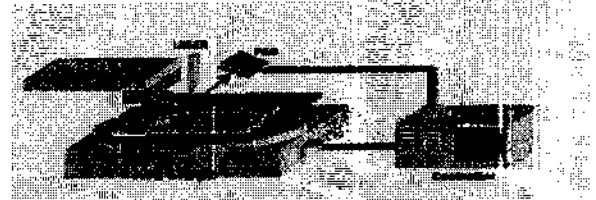


Fig. 1. AFM system

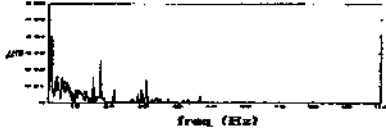


Fig. 2. Vibration amplitude on the floor

External vibrations coming along a building floor have wide varieties in their frequencies, amplitudes, and all of them change with time. Changes in displacement magnitude at the floor of the main building is shown in Fig. 2 as a function of mechanical oscillation frequency. The displacement magnitude reached the maximum of 40~50nm, which is far greater than an atomic scale. The level of the vibration amplitude to be achieved at the AFM is 1~10pm. Therefore vibration isolator is required in AFM.

B. The modeling of isolator and AFM

In order to simplify the principle of vibration isolation, we describe the isolator and the AFM assembly with two coupled oscillators having masses m_i , m_t and spring constants k_i , k_t without damping, as illustrated in Fig. 3. Equations of motion are given by

$$m_i \ddot{x}_i'' + (k_i + k_t) x_i = k_t x_t + k_i x_b \sin \omega t,$$

$$m_t \ddot{x}_t'' + k_t x_t = k_t x_i$$

where $x_b \sin \omega t$ is the displacement of the floor. The transfer function defined for the vibration isolator versus the floor $Z_i = 20 \log(x_i/x_b)$ and that defined for the AFM assembly versus the vibration isolator $Z_t = 20 \log[(x_t - x_i)/x_i]$ are curves I and II, respectively. The overall transfer function $Z = 20 \log[(x_t - x_i)/x_b]$ is shown as

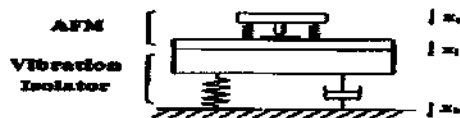
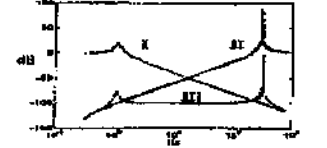


Fig. 3. The assembly of isolator and AFM



$$I: Z_i = 20 \log [x_i / x_b]$$

$$II: Z_t = 20 \log [(x_t - x_i) / x_i]$$

$$III: Z = 20 \log [(x_t - x_i) / x_b]$$

Fig. 4. Transmissibility of the modeling

curve III in Fig. 4. The peaks at two natural frequencies are easily reduced by adding damping to the systems. ⁽²⁾

In concluding, two important items should be noted. It is necessary to evaluate the floor vibration and design the vibration isolator being suitable for AFM in order to achieve the vibration amplitude of the AFM assembly down to pico-meter range. The overall isolation performance is improved by making the difference in the two natural frequencies larger and by making the slope of curve I above the natural frequency steeper.

3. DESIGN OF VIBRATION ISOLATION FOR AFM

A. Theory of eddy current damping force

Electromechanical braking is based on the interaction

of eddy currents and a magnetic field, with the former usually induced in a moving part. The absolute value of the braking force F acting on the moving sheet is as follows ⁽³⁾.

$$F = \sigma \delta u B_z^2 4hb \frac{2}{\pi} \left\{ \arctan \frac{h}{b} + \frac{1}{2} \left[\frac{h}{b} \ln \sqrt{1 + \left(\frac{b}{h}\right)^2} - \frac{b}{h} \ln \sqrt{1 + \left(\frac{h}{b}\right)^2} \right] \right\}$$

which has thickness δ , conductivity σ , velocity u ,

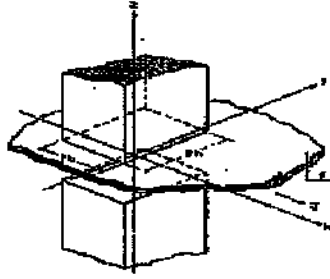


Fig. 5. The scheme of eddy current damping

magnetic flux density B_z , and b, h are the geometry of magnet as shown in Fig. 5.

B. Design Criteria of vibration isolator

Curve I in Fig. 4 shows the characteristics of the vibration isolation. Acquiring better effect of isolation by both making lower natural frequency of the curve I and steeper slope. The steeper slope means the lower damping. Regarding the simple first order system which has damping ratio ζ , mass m , and stiffness k . The undamped natural frequency ω_r is as follows

$$\omega_r = \omega_n \sqrt{1 - 2\zeta^2}$$

which $\omega_n = \sqrt{k/m}$. That means that two requirements of better isolation effect are in inverse proportion. Therefore we used an optimal design method, which is the design criteria of isolator for AFM.

4. EXPERIMENTAL RESULTS OF CONSTRUCTED ISOLATOR

A. System configuration

A schematic of the two-stage coil-spring suspension isolator for AFM is shown in Fig. 6. For minimize the leakage of magnetic flux from permanent magnet, the parts of damping are constructed as if closed loop type as shown in Fig. 6. Each end of the coil spring was terminated by a rubber ring in order to attenuate

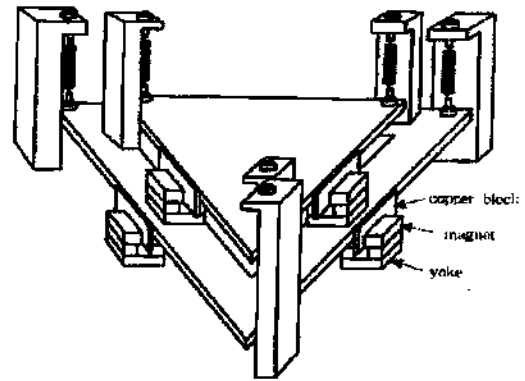


Fig. 6. Vibration isolator for AFM

the high frequency sound propagating along solid columns, plates, and coil springs. Eddy currents dampers consisting of copper blocks and permanent magnets also make the gravity center of the ends of the coil springs. The configuration prevents the translational motion along the gravity direction and the rotational motions around the gravity center. The triangle shape plate on which a AFM is placed enables easy access to wiring and simplifies the exchange procedure of samples and probing metal tips.

B. Effect of vibration isolation

The vibration amplitudes of the floor and on the isolator plate against frequencies are shown in Figs. 7(a) and 7(b) respectively. These show that the region of the above 5Hz frequencies is filtered by isolator.

C. Effect of vibration isolation in AFM and measured sample image

When AFM is placed on the vibration isolator, we regard the experimental results as shown in Fig. 4.. Curve I is the transmissibility of the isolator displacement amplitude versus floor. Curve II is the transmissibility of the tip-sample displacement change

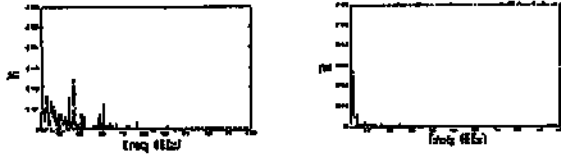


Fig. 7. (a) vibration of floor (b) vibration on the isolator

versus isolator. And Curve III is the transmissibility of the tip-sample displacement change versus floor amplitude. In regarding curve III, isolation effect of the tip-sample displacement change against floor vibration is about -50dB. Therefore it attenuates the floor vibration isolation into the tip-sample displacement change about 10^{-3} order. For example, 3nm of floor vibration is attenuated 30pm in the tip-sample displacement change.

The measured sample results in the no vibration isolation and with vibration isolation respectively are shown in the Fig. 8. Thereby we can conclude that the performance of AFM with vibration isolator is very good. Also the AFM with vibration isolator has very high resolution and repeatability performance.

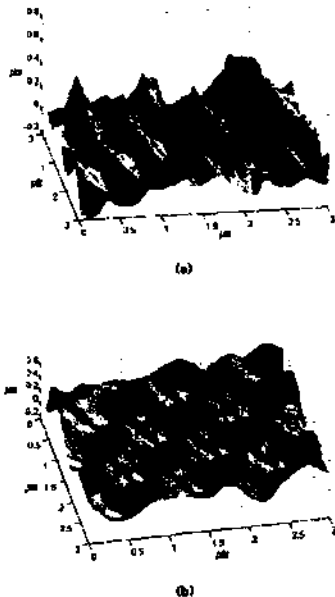


Fig. 8. AFM measurement (a) without (b) with the isolator

5. CONCLUSION

The technology of vibration isolation which suppresses the external perturbation down to a subatomic scale has been described. That is in making the natural frequency of the isolator lower and making the slope of isolator in the transmissibility steeper.

Surface atomic images were shown as an example of successful application of this vibration isolator with AFM.

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