Track/Focus control of cantilever type near field optical head for high density and fast data transfer rate data storage device

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Abstract
A self-sensing cantilever is attached on the commercial optical disk drive system to verify feasibility of tracking and focusing optical recording head with a sub-wavelength aperture cantilever tip for the high areal density data recording and reading. In tracking control, a VCM head is controlled multi-offset by dividing photodiode signal into 16 levels. In focusing control, based on the frequency separation scheme, we controlled the VCM head to follow the low frequency surface profile and measured the gap between tip and sample at high modulation frequency, simultaneously.

Keyword : Track/Focus control, Near-field recording, Cantilever tip, Data storage.

1. Introduction

High-density data recording and fast data transfer rate are key issues in data storage devices [1-2]. One of the promising ways is optical recording with atomic force microscope (AFM) tip having a sub-wavelength aperture [3-4]. Through the aperture tip that is positioned in near field region, laser beam makes about 50~100 nm bit size data that matches more than 200 Gb/in^2 based on the principle of near field scanning optical microscopy (NSOM).

In the proposed system, a self-sensing cantilever (not aperture tip right now) is attached on the commercial optical disk drive system. This configuration takes the advantage of commercial optical pickup head for coarse tracking and focusing, and self-sensing cantilever tip for fine focusing to realize high areal data density.

The pickup head uses a voice coil motor (VCM) as an actuator and LD/PD optical tracking signal from land groove on the media. For one land-groove, only one tracking is possible. In this paper, we proposed multi-offset tracking control to achieve more tracks in each land-groove. The sinusoidal signal for a land-groove can be divided into several signal levels in order to make narrow track pitch in the point of cantilever tip.

In the optical pickup head, optical PD set cannot resolve under 1um along focus direction because of focal depth of the object lens. Above 1 μm, gap is controlled from focus signal of a DVD-ROM optical head set. Within 1 μm, with the self-sensing cantilever tip, we detect the atomic force between tip and the media surface and control the gap. In convention non-contact AFM gap control, oscillation PZT and gap control PZT is separated. However, the proposed frequency separation scheme, we apply the sum of modulation signal and gap profile signal .to VCM. VCM is mainly moves according to gap profile making cantilever resonated and the self-sensing cantilever sense the amplitude variation of modulation signal.

2. Principle and configuration of the system.

Figure 1 shows the schematic of the proposed system. A self-sensing cantilever is attached on the commercial optical disk drive system. To read and write data densely, self-sensing cantilever approaches to the media until it gets close below 100nm (near field region, $d << \lambda$ [5]) and is controlled precisely in tracking direction. Through the aperture tip, laser makes the near field optical spot similar to aperture size on the media (Figure 2). In tracking control, VCM head is controlled multi-offset using photodiode signal. In focusing control, however, since photodiode is not sensitive below 1 μm, a self-sensing cantilever takes the place of distance sensor between media and cantilever tip.

3. Multi-offset tracking control

For about 50 nm bit size data, the cantilever tip should be controlled every 50 nm in tracking direction. If head is tracked by every 50 nm offset from the center of the track, data areal density would be 250 Gb/in^2. Since VCM, inherently, has a capability of controlling several-nm resolution, we try to control cantilever head by 50 nm using VCM only. In order to get the minimum positioning resolution, we performed a basic experiment using function generator and capacitive sensor with the commercial VCM in DVD head. Figure 3 shows a potential of VCM below 10nm resolution, in our case, even if input voltage is limited by noise. This result gives a clue to control cantilever head by 50nm or less using VCM only in focusing and even tracking direction. VCM is used as a tracking actuator in DVD system of which track pitch is about 800 nm. In order to control by 50nm multi-offset tracking, we divide the full range sensor signal by 16 levels. Figure 4 is the experimental result of two up and down 20 nm-steps. As VCM head goes farther from the track center, PD signal noise level becomes higher, so that we cannot use the full range land-groove.

4. Focusing control with frequency separation scheme.

A self-sensing cantilever is a good candidate for sensing the gap between tip and sample. It does not need optical alignment. Since near field data read/write is possible within 100nm tip-sample distance, gap control in case of data storage application could be coarser than AFM image application. . In convention non-contact AFM gap control, oscillation PZT and gap control PZT is separated. However, if we apply the sum of modulation signal and gap profile signal .to VCM, VCM is mainly moves to the low frequency gap profile making cantilever resonated at modulation frequency even with small movement of VCM. At the same time, the resonated self-sensing cantilever senses the amplitude variation of modulation signal. We call this ‘frequency separation scheme’. In order to explain in detail, we make mathematical model of VCM with a cantilever tip (figure 5(a)). Followings are dynamic equation and transfer function of the system.

$$\begin{aligned} M\ddot{x}_v + b_v\dot{x}_v + k_v x_v + b_c(\dot{x}_v - \dot{x}_c) + k_c(x_v - x_c) &= F \\ m\ddot{x}_c + b_c(\dot{x}_c - \dot{x}_v) + k_c(x_c - x_v) &= 0 \end{aligned} \quad \text{..} \quad (1)$$

$$\begin{aligned} \frac{X_v(s)}{F(s)} &= \frac{ms^2 + b_c s + k_c}{mMs^4 + (Mb_c + m(b_c + b_v))s^3 + (Mk_c + b_v b_c + m(k_c + k_v))s^2 + (b_v k_c + k_v b_c)s + k_c k_v} \\ \frac{X_c(s)}{F(s)} &= \frac{b_c s + k_c}{mMs^4 + (Mb_c + m(b_c + b_v))s^3 + (Mk_c + b_v b_c + m(k_c + k_v))s^2 + (b_v k_c + k_v b_c)s + k_c k_v} \\ \frac{X_v(s) - X_c(s)}{X_v(s)} &= \frac{ms^2}{ms^2 + b_c s + k_c} \end{aligned} \quad \text{................} \quad (2)$$

where, F is applied force to VCM, x_v, M, b_v, k_v are displacement, mass, damping coefficient, spring constant of VCM, respectively and x_c, m, b_c, k_c are displacement, mass, damping coefficient, spring constant of cantilever, respectively.

In figure 5(b), frequency response function (FRF) shows that VCM motion is attenuated a lot at the cantilever resonance frequency, making cantilever resonated with small oscillation of VCM. Figure 5 (c),(d) verify the simulation result by experiment. Since VCM is suspended by four-wire guidance, it, in real, has more resonance at higher frequency, still having attenuated motion.

Based on the proposed frequency separation scheme, we can control VCM head to follow the surface profile and can measure the gap between tip and sample, simultaneously (Figure 6). With frequency separation scheme, we measure the gap distance and modulation frequency amplitude variation (Figure 7). As it is well known, the closer the tip approaches, the larger the amplitude variation is. And setting the regulation point, we control VCM head to stay at a constant height from sample with PI control algorithm. Figure 8 is the experimental result of gap control performance. Figure 8(a) is the z-directional sample motion of 150nm sinusoid. Figure 8(b)-(f) is the control performance according to the frequency of sample motion that simulate the scanning speed. Slow scanning gives more correct following than fast scanning. It depends on control speed. And slow scanning result shows errors because of low sensor sensitivity at this regulating point. In order to get more sensitive result, regulating point must be close to the sample that result harder gap control. Therefore, there is a room for improvement.

5. Conclusion

The idea of combining self-sensing and VCM head is proposed. Multi-offset tracking performance of 20nm gives insight to control multi-track with only one land-groove without changing commercial optical head. To control cantilever tip to follow the track with constant height, frequency separation scheme is applied. Small oscillation of VCM at cantilever resonance frequency makes the self-sensing cantilever sense the modulation amplitude according to the gap between tip and sample. Closed loop gap control is performed utilizing frequency separation schemed gap sensing. To give more precise and fast focusing performance, regulating point should be closer to the sample, and control gain should be higher to response to the sample height variation quickly.

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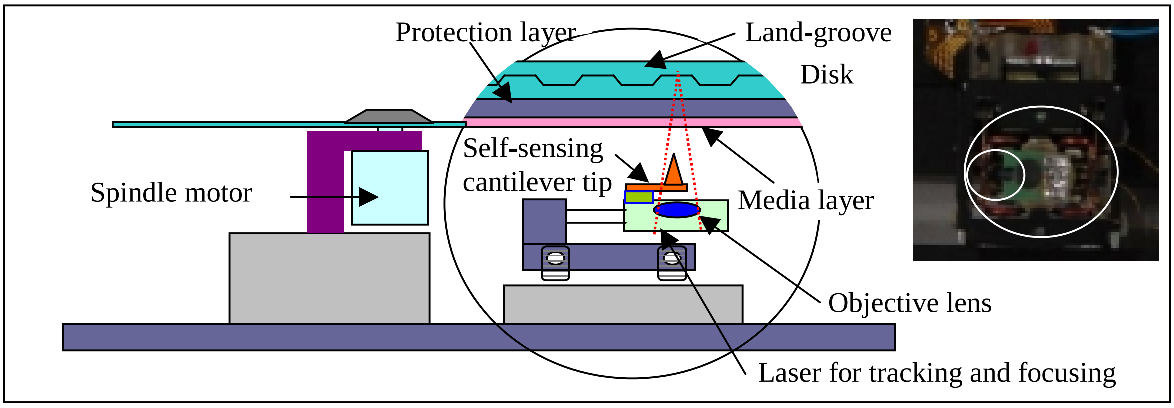

Figure 1. Schematic of cantilever type near field optical head

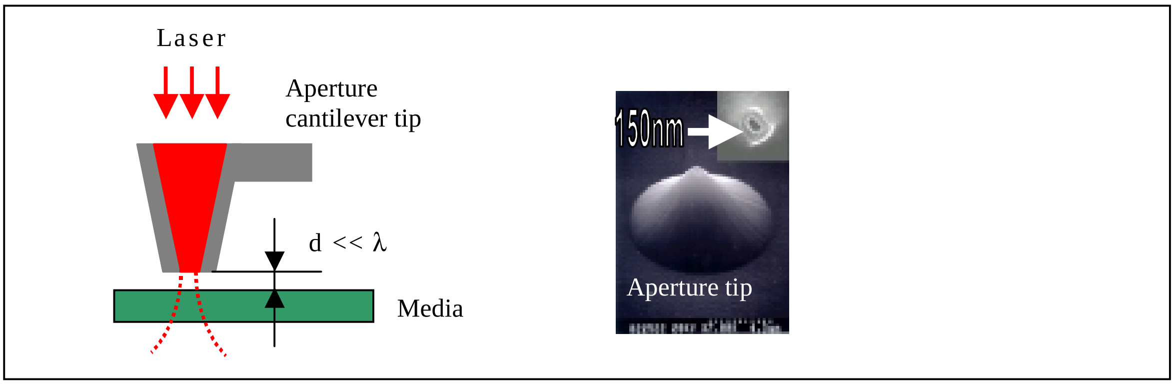

Figure 2. Near field Scanning Optical Microscope (NSOM)

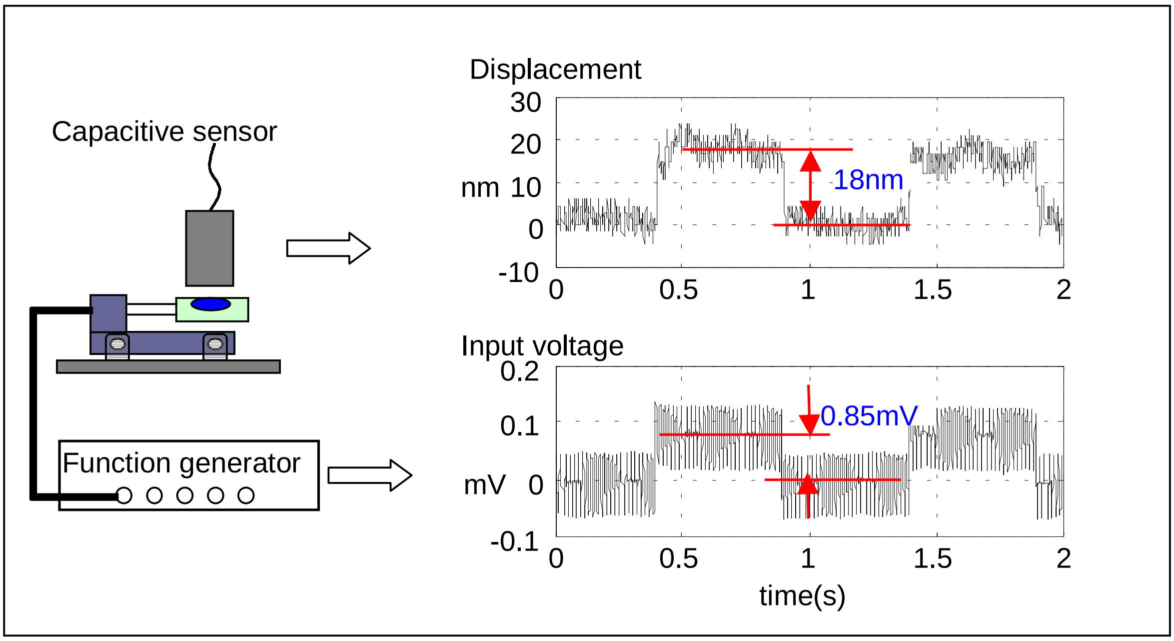

Figure 3. Minimum step motion of VCM (Resolution ~10nm)

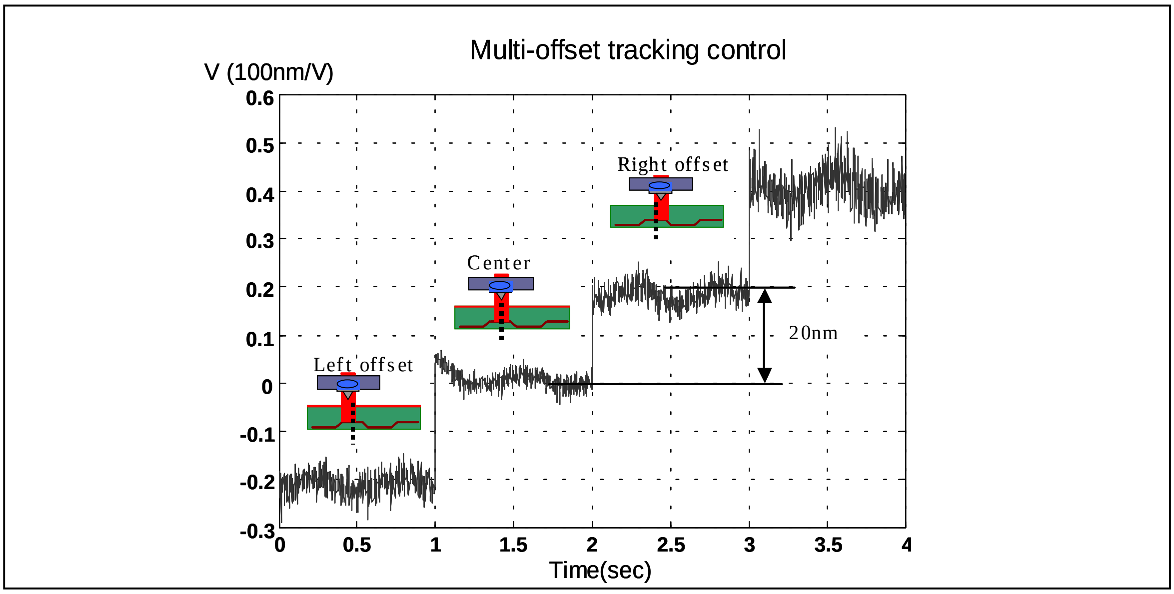

Figure 4. Experimental result of 20nm multi-offset tracking control

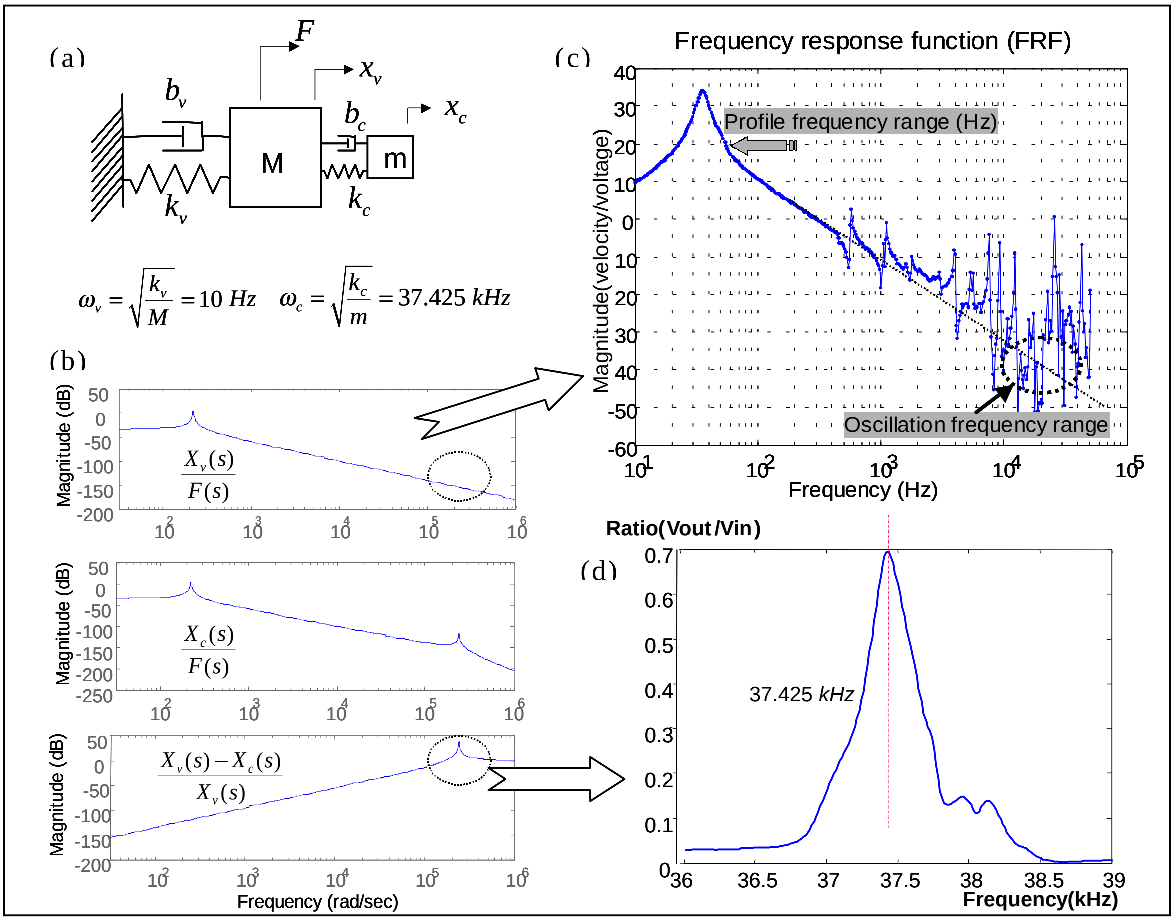

Figure 5. Modeling and frequency responses of VCM with cantilever
(a) dynamic modeling, (b) simulation (c-d) experimental result

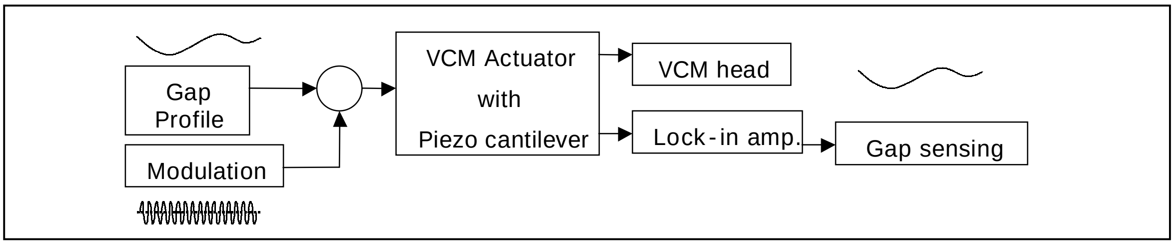

Figure 6. Frequency separation scheme: Gap profile and modulation signal is fed to VCM head, Lock in amp detect amplitude variation of modulation frequency

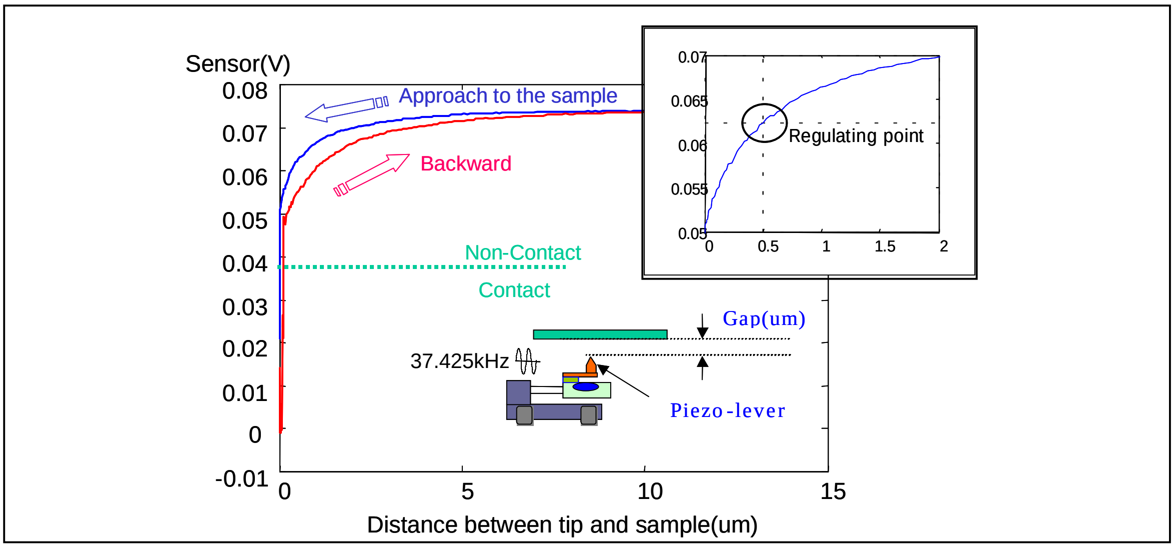

Figure 7. Tip approach curve: the closer tip moves to the surface, the more sensitive sensor is.

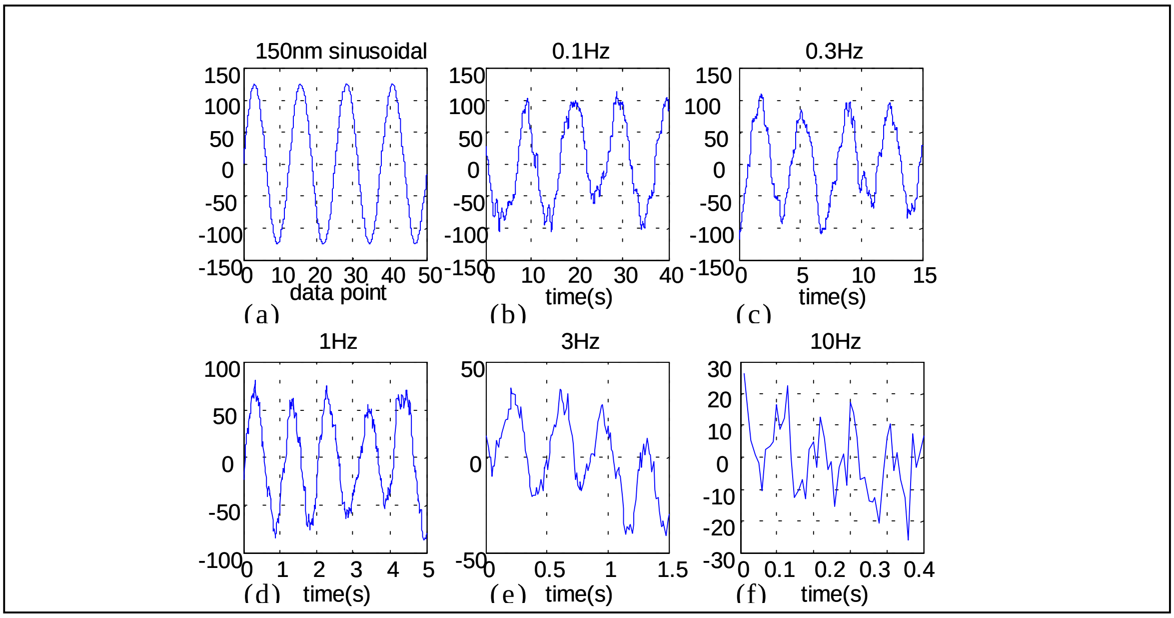

Figure 8. Gap control performance according to the scanning frequency