Dual-Stage Actuator for HDD Achieving High-Accuracy Positioning and Wide-Bandwidth Servo Control

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In the latest hard disk drives (HDDs), advanced high-performance technologies for the actuator and servo control are required in order to achieve not only accurate positioning control on data tracks with a pitch of less than 100 nm but also high-speed access onto another data track within a few milliseconds.
To realize higher recording density of HDDs, Toshiba has developed a prototype dual-stage actuator (DSA) with piezoelectric elements (Pb [Zr, Ti] O3 : PZT) attached to the suspension. Experiments on the prototype DSA confirmed that it achieves an improvement of about 30% in positioning accuracy and about 1.7 times wider servo bandwidth compared with conventional single-stage actuators (SSAs).

1. Introduction

Demand for large-capacity high-performance hard disk drives (HDDs) for servers is increasingly growing due to the recent trends toward high performance mobile terminals and cloud computing. The rotation per minute (RPM) of HDDs for servers is generally 10,000 to 15,000 rpm, which is higher than that of HDDs for mobile devices, such as notebook PCs, which is generally 5,400 to 7,200 rpm. For this reason, head positioning accuracy of server HDDs is more likely to degrade than that of mobile HDDs due to the vibration of magnetic heads caused by the air turbulence generated by the high-speed rotation of disks. In addition, there is strong demand for server HDDs with high-speed access performance, which generally requires actuators with a wider servo bandwidth than those for HDDs for mobile devices.
To solve these issues, a dual-stage actuator (DSA), in which a precise actuator mechanism is integrated near the magnetic heads separately from the voice coil motor (VCM) used to drive the overall actuator, was proposed and has been studied. Meanwhile, due to improvements in the performance of conventional single-stage actuators (SSAs) and servo technology, DSA has not been widely applied to HDD products. However, requirements for server HDDs have become even higher, and it is becoming difficult for conventional SSAs to support improvements in recording density.
To realize higher performance HDDs for servers, Toshiba has developed a prototype DSA with piezoelectric elements (Pb [Zr, Ti] O3: PZT) attached to its suspension.
This article will discuss the mechanical design and servo technology applied to the prototype DSA, as well as the results of an evaluation of it.

2. Structure of DSAs

Figure 1 shows the structure of a server HDD that uses a conventional SSA. In order to prevent the degradation of positioning accuracy due to the air turbulence generated by the high-speed rotation of the disks, squeeze plates (shown with a dotted line) are integrated between the disks. In addition, dampers are attached to the arms to reduce residual vibration generated by high-speed access. These designs are generally applied to server HDDs and is not used for HDDs for mobile devices.
Figure 2 shows the frequency response function (FRF)

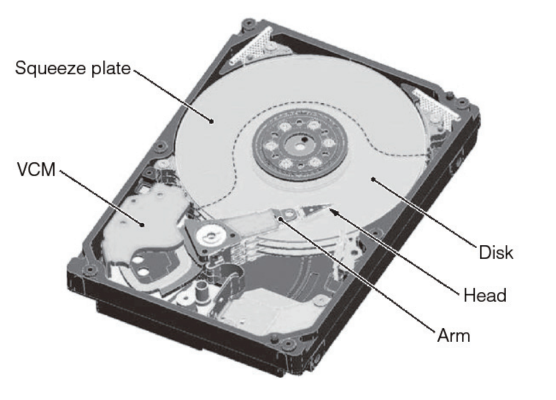

Figure1. Structure of conventional server HDD —
Additionally technology is installed to HDDs for enterprise market compared to HDDs for mobile application.

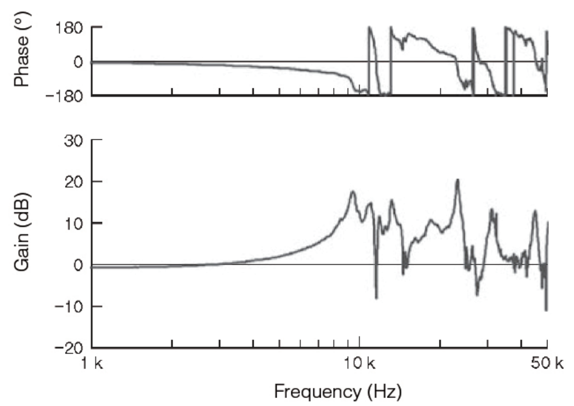

Figure 2. Frequency response function (FRF) of conventional SSA —
Main resonance mode of 9kHz limits performance improvement.

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of actuators used for conventional server HDDs. The main resonance mode appears at around 9 kHz, but it is desirable that the actuators' FRF remain flat up to a high frequency bandwidth to improve access performance. However, this main resonance mode cannot be improved above the resonance frequency determined by the mass of the actuator and the spring stiffness of the pivot bearing, and the performance improvement of actuators has been close to this limit.

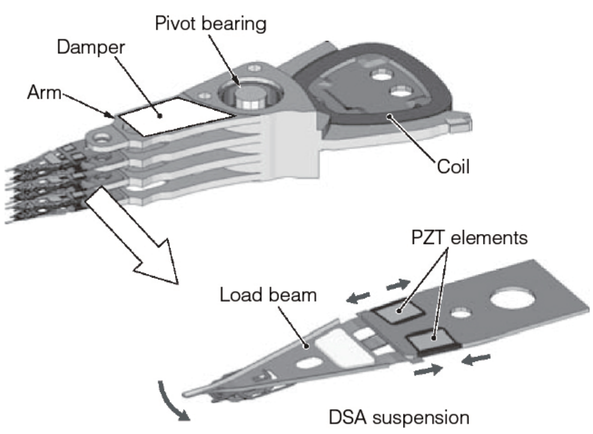

Figure 3. Configuration of DSA —
The second-stage actuator is added to the tip of the first-stage actuator.

Figure 3 shows the structure of Toshiba's prototype DSA. With the second-stage actuator driven by a higher resonance frequency suspension added to the tip of the first-stage conventional VCM drive actuator, this DSA achieves higher-speed performance with higher positioning accuracy than conventional models. Two PZT elements are mounted on the DSA suspension. When a voltage is applied to each of the left and right PZT elements, they expand and contract in opposite phases to each other, which, as a result, displaces the magnetic heads at the tip of the actuator in the direction of the tracks. Because only the load beam section at the tip of the actuator is driven, this DSA has the advantage that an actuator with a lightweight drive part and a high resonance frequency can be achieved.

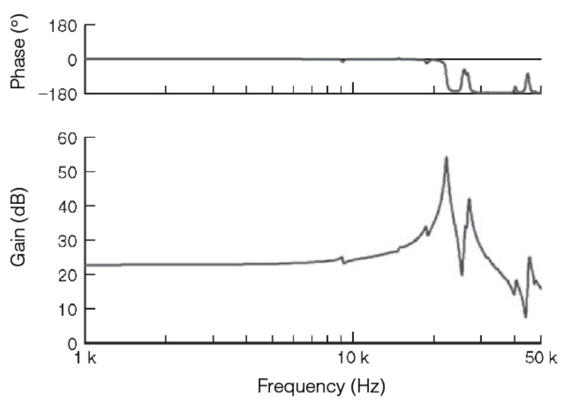

Figure 4. FRF of DSA suspension (simulation data) —
The resonance frequency is 22 kHz.

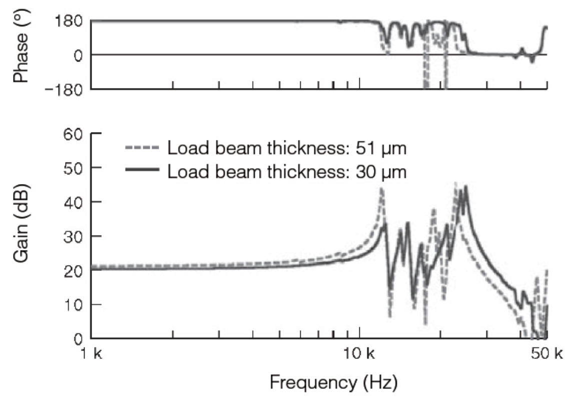

Figure 5. FRF of DSA (simulation data) —
The main resonance is improved.

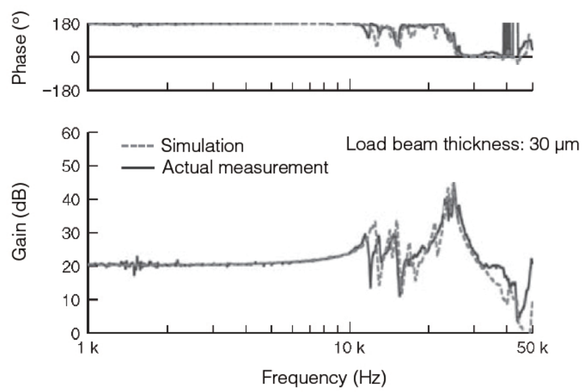

Figure 6. FRF of DSA (actual measurement) —
Favorable characteristics that are close to the simulation wave obtained.

Figure 4 shows the FRF of a DSA suspension when the magnetic heads are driven by the PZT elements. When compared with the resonance frequency of approximately 9 kHz shown in Figure 2, the resonance frequency shown in Figure 4, 22 kHz, is about 2.5 times higher.

Figure 5 shows an FRF when the DSA suspensions with the characteristics shown in Figure 4 are mounted on the tip of the first-stage actuator arms and the magnetic heads are driven by the PZT elements. It can be seen from the figure that new resonance peaks have been excited at around 10 to 20 kHz, which were not present in the FRF for the DSA suspension only. The dotted line indicates an FRF when the load beam thickness is 51 μm, the same as that in conventional server HDDs, and the solid line indicates an FRF when the load beam thickness is 30 μm, which is thinner than that in conventional server HDDs. This is caused by the excitation difference of the first-stage actuator arms as a reaction to the driving of the DSA suspensions. Since the reaction of a lighter 30 μm thickness load beam is smaller than that of a 51 μm thickness load beam, the peak FRF of the 30 μm thickness load beam is lower by at least 10 dB. If the peaks of FRF are up to those of the 30 μm thickness load beam, it is possible to fully bring out a DSA performance by the DSA control method described below.

Figure 6 shows the actual FRF measurements for Toshiba's

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prototype DSA developed based on the above mentioned study results by using a load beam with a thickness of 30 µm. As shown in the figure, favorable characteristics that are close to the simulation were obtained. We consider that the resonance peaks in a range between 10 and 20 kHz are lower than those in the simulation due to the effects of the dampers attached to the arms.

3. Dual-stage Servo

A head positioning control using a DSA is called a dual-stage servo. **Figure 7** shows block diagrams for each of the conventional control (single-stage servo) and a dual-stage servo. In DSAs, the VCM and milli actuator (MA) are connected in parallel, and therefore the head positioning error is a sum of the output of each actuator. The controllers for VCM and MA, Cv and Cm, respectively, can also be expressed by connecting them in parallel, and generate the control inputs uv and um,for VCM and MA respectively, based on the head positioning error. In dual-stage servos, each controller for VCM and MA is designed so that the low-frequency band is controlled by the VCM, which has a wider range of movement, and the high-frequency band is controlled by a high-speed MA. In this way, an overall wider bandwidth control system can be realized without being restricted by low resonant frequencies in the VCM.

Figure 8 shows the open-loop transfer function of a dual-stage servo. The figure shows that the gain cross over frequency in the open-loop transfer function (the frequency at which the gain crosses through 0 dB), or the target control bandwidth, is approximately 4 kHz. While the control bandwidth that can be realized by conventional SSAs is approximately 2.2 to 2.4 kHz, the DSA has achieved a bandwidth about 1.7 times wider than that.

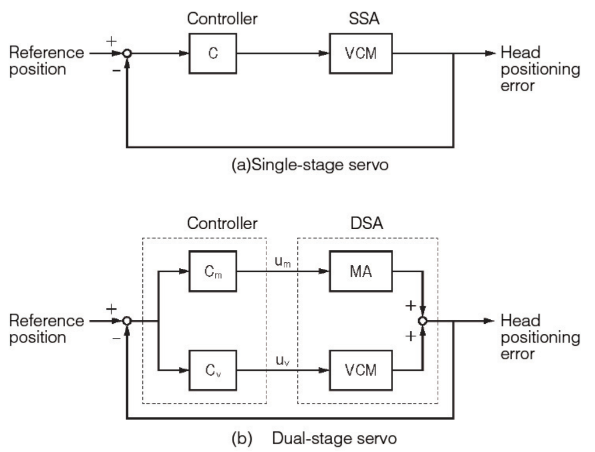

Figure 7. Block diagram of singled-sage and dual-stage servos —
the servo controller for DSA has parallel structured controllers.

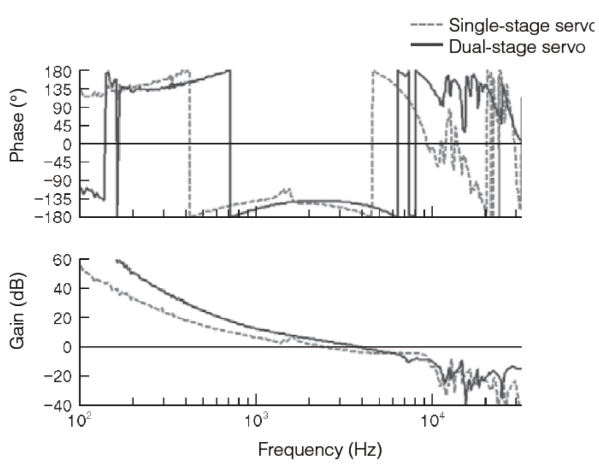

Figure 8. Open-loop transfer functions of single-stage and dual-stage servos —
The band width was improved about 1.7times wider thatn SSA.

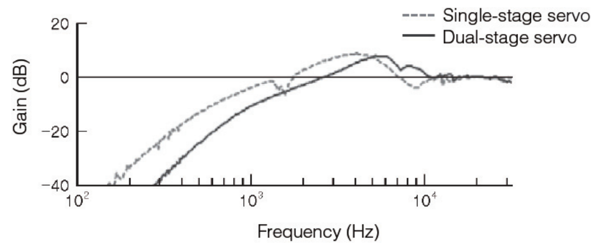

Figure 9. Gain characteristics of sensitivity functions of single —
stage and dual-stage servos – Compression ratio was improved more than 10 dB low frequency band

Figure 9 shows the gain characteristics of the sensitivity function. This is a performance index of the servo system in regard to compression of the disturbance components in the device. Widening the bandwidth of the control system will compress mainly the disturbance components in the low frequency band, which will in turn improve the head positioning accuracy.

Figure 10 shows the time history waveform (a time

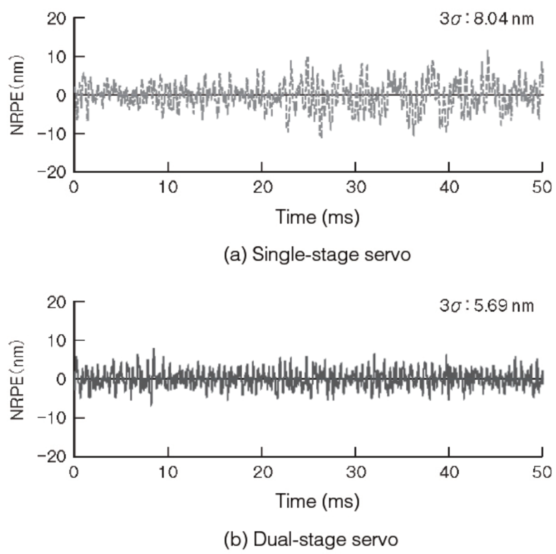

Figure 10. Head positioning accuracies of single-stage and dual-stage servos (time history) —
Positioning errors was reduced.

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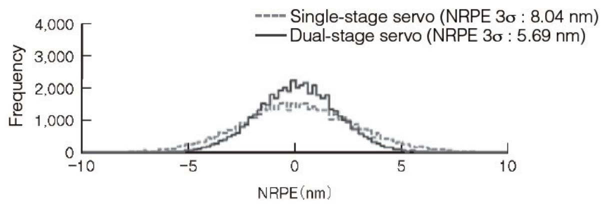

Figure 11. Head positioning accuracies of single— stage and dual-stage servos(non-repeatable positioning error [NRPE] histogram – NRPE was decreased by about 30%.

response waveform) of the head positioning errors for both of the SSA and DSA. **Figure 11** shows a statistical improvement with regard to non-repeatable positioning errors (NRPEs), an index for positioning performance. It can be seen that the NRPE distribution (3σ value) has improved about 30% in the case of the dual servo system compared with the conventional system. This value corresponds to the positioning accuracy required for devices in three generations ahead.

4. Conclusion

The prototype DSA that Toshiba has developed can significantly improve positioning accuracy and control bandwidth compared with conventional SSAs. Currently, Toshiba has been evaluating its practical performance with an eye toward the integration of the DSA into the next model of server HDDs.

Toshiba will continue to promote the development of high performance actuators and control technologies that can contribute to high recording densities.

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