The servo characteristics of single-phase spindle motor in DVD-ROM

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ABSTRACT

The single-phase DC motor has the low-cost advantage over 3-phase DC motor owing to its easy-assembling and high yield-rate, however, it has larger torque ripple and cogging torque. Single-phase DC motor is currently applied to low profit margin products such as cooling fan. In order to utilize single-phase DC motor to high precision system, for instance, DVD (Digital Versatile Disk), the vibration caused by torque ripple and cogging torque needs to be solved. In this paper, focusing error, tracking error, seeking ability and some velocity control performances are studied when single-phase DC motor is used in DVD related products.

Keywords: single-phase spindle motor , focusing servo, tracking servo, sled seeking

1. INTRODUCTION

In terms of the widespread use of multi-media devices and the remarkably demanding in high-density memory storage devices, there is a tendency that CD-ROM is being replaced by DVD-ROM. Because the prices of computer peripheral products are tending downward, DVD is no exception. As the maker's prices are approaches the cost, the cost-down of component parts becomes an important issue for the makers. The single-phase DC motor has the low-cost advantage over 3-phase DC motor owing to its easy-assembling and high yield-rate. If the single-phase DC motor can be applied to the DVD-ROM, it will become more competitive in the market.

Currently, a large portion of DVD-ROM is made in Taiwan. However, the key components like spindle motor, chip set and pick-up head rely on the supply from Japan. Taiwanese makers can only make little profit from assemble. In order to stop the long-term control from Japan, ITRI and SUNON developed the single-phase spindle motor to replace the traditional 3-phase 9-slot 12 pole design. SUNON has already had its single-phase DC motor patent, with SUNON's experience in making single-phase motor, the low-cost single-phase spindle motor will step into the DVD market. Figure. 1 shows the mechanical structures of the 3-phase and single-phase motor.

The DVD system was constituted with Toshiba's servo DSP TC9453F, pre-amplifier TA1293F, Sankyo's Mecha SF-HD2R, disk loader, single-phase motor and servo circuit developed by OES. This paper discusses a traditional three-phase spindle motor that is replaced by a single-phase motor applied in DVD-ROM. In Section 2, we describe the servo systems of focusing, tracking, sled and spindle. In Section 3, we show the implementation results of these servo systems. In Section 4, the experimental results are discussed.

2. DVD SERVO SYSTEM DESCRIPTION

Figure 2 shows the data are stored on the disk with uniform density so that the DVD-ROM system must rotate with constant linear velocity (CLV) for reading out the data. For reading out the data, the DVD servo system includes the focusing, tracking, sled and spindle servos [1], as shown in figure 2. The focusing and tracking servos adjust the vertical and radial positions of the pick-up head so that the data can be continuously and reliably read from the disc. The sled servo functions when the pick-up head is required to move with a significant distance radially. The spindle servo controls the disc angular velocity according to the position of the pick-up head so as to maintain CLV of the focusing spot on the disc.

2-1 Focusing servo system

When the disc is rotating, it may exhibit wobble up to $\pm 300\ \mu m$ and the allowable focusing error is $\pm 0.23\ \mu m$. It is impossible to maintain focus point on the disc without proper servo control. Thus, the focusing system is a closed loop control system. It consists of the focusing actuator, the optical system, a photo detector, a focusing error signal amplifier and a dynamic compensator. Figure 3 shows the block diagram of the DVD-ROM focusing servo system.

An astigmatism method [2][3] is used to sense the focusing error signal from the reflected laser beam. The focusing error signal is amplified before it is fed to the focusing servo control. The servo controller contains control algorithms that can generate control signals to drive the actuator drive the lens up and down to adjust the focusing spot. In most system configurations, the actuator is a voice coil motor and can be modeled by a second order dynamic system within the frequency bandwidth of interest. The servo controller is a phase lead/lag type compensator to compensate the actuator's dynamics. The servo controller is designed so that the desired closed loop system performance can be obtained.

2-2 Track following servo system

In order to read data from the DVD disc, the DVD-ROM has to keep the pick up head following the spiral track on the disc. As specified in the DVD Book, the track pitch on a DVD disc is 0.74 um. The tracking servo system has to perform track following within the precision requirement, while subjecting to disturbances and noises. Due to the disc run-out in rotation, the track of the disc will oscillate back and forth if viewed from a steady pick-up head. Without proper tracking error detection methods and servo designs, satisfactory track following can not be maintained.

The tracking servo system is quite similar to the focusing servo system. The major difference is that the tracking servo system has two actuators[4][5]. As shown in Figure 4, Actuator 1 is the fine actuator and Actuator 2 is the coarse actuator. The coarse actuator is usually a sled motor on which the fine actuator is installed.

The frequently used method for DVD tracking error sensing is Differential Phase Detection (DPD). The DPD method utilizes the fact that the tracks on the disc behave as a diffraction grating and generate multiple diffraction orders in the reflected light spot. Analyzing the laser light reflected from the disc, we can get a phase difference varies while the spot is at different place of the track.

In general, the closed loop system with the fine actuator has bandwidth much larger than the one with the coarse actuator. This is because the fine actuator is designed mainly for high precision track following, while the coarse actuator is used to "zero" the reaction force from the suspension of the fine actuator and to perform long distance track seeking. However, in most system configurations, the fine actuator is suspended by springs and can only move the pick-up head within a small radial distance (about $\pm$ 0.6 mm).

2-3 Track seeking servo system

The access time is one of the most important DVD-ROM performance indices, and the seeking time represents the most significant part of the access time. For accessing data quickly from the disc, reliable and efficient seeking servo system is major concern. The seeking servo design is strongly related to software control and hardware function of the DVD_ROM chip set and pick-up head design.

Figure 5 shows the block diagram of a seeking servo system. We see that the system shares the dual actuators with the tracking servo system. The seeking servo system is to drive the pick-up head to a desired track location specified by the host or system controller. When the DVD_ROM performs seeking control, the system CPU calculates the direction and number of tracks to be "jumped" to get to the target address. Based on the number of tracks to be crossed, the CPU determines a seeking mode to move the pick-up head.

For short distance track jumps, the system might have to use only the fine actuator. For long distance track jumps, the sled motor will be used to swiftly move the pick-up head. Since the sled motor can only bring the pick-up head to a location near the target address, it provides only "rough seek". Usually, the CPU will provide a sled velocity profile for sled motor to follow. The velocity profile depends on the number of tracks to be crossed, and the acceleration/braking capability of the sled motor. This velocity profile can be converted into a voltage versus track number profile. For better sled control, some pick-up heads are equipped with photo sensor to provide sled velocity and position feedback. This allows the sled motor to better follow the desired velocity profile under the framework of feedback control.

2.4 Spindle servo system

The DVD-ROM system needs to read data from the disc with constant bit rate regardless of the disc constant linear velocity (CLV) values. One robust approach to maintain constant data rate is to use the on-line sync pattern for spindle CLV control. In Figure 6, a crystal oscillator is used as the reference of channel bit rate (26.16 MHz/sec. at single speed). The rate of the RF signal from the optical system depends on the spindle angular velocity. After channeling and demodulation process, one can obtain the synchronized data pattern. The difference in frequency and phase between the reference clock and the synchronized data rate is used to drive the CLV controller, usually a phase-locked loop (PLL) circuit. From the system-control point of view, we have a closed loop system that follows the reference signal (frequency in our case). By properly designing the PLL circuit, CLV control can be achieved. For DVD-ROM players that can operate in multi-speed modes, one needs to adjust the reference clock rate to accommodate the desired data bit rates.

3. IMPLEMENTATION AND RESULTS

DVD-ROM system needs to read out the data fast, stably and accurately from the disk, so the cross frequency of the tracking and focusing system is up to several KHz, the rotation speed of the spindle is also within this bandwidth. Due to the larger torque ripple of the single-phase spindle motor than the 3-phase one, the system bandwidth is required to increase in order to overcome the vibration. DVD servo systems are quite complicated, although the internal control loops can be designed separately, the integration of these systems for data read-out is required. The setting of parameters for focusing, tracking, sled and spindle and control strategy will influence the performance. It is hard to judge the whole servo system by individual servo system.

Figure 7 shows the open-loop gain of focusing loop under the rotation of single-phase spindle motor. The cross frequency of focusing loop is 2.4 kHz which is larger than the standard cross frequency 2 kHz in the DVD-ROM specification book. Due to the higher cross frequency of focusing loop, the focusing error can be reduced to the 0.23 um. Similarly, Figure 8 shows the open-loop gain of tracking loop. The cross frequency of tracking loop is 4.5 kHz which is larger than the standard cross frequency 2.4 kHz in the specification book. The tracking error can reach the standard value in the DVD-ROM specification book.

In general, there are 2 indices for DVD performance: (1) data read-out jitter. (2) time for pick-up head to read out data from target track. Figure 9 shows the jitter value of read-out data is 4.09 ns. It is larger than the standard jitter 3.8 ns in the specification book. Figure 10 shows the pick-up head crossing 25,000 tracks to the target track will takes 0.32 s and the maximum track-crossing velocity is 240 kHz.

4. CONCLUSION

In this paper, single-phase spindle motor is used to replace the traditional 3-phase spindle motor. Although the single-phase spindle motor will cause larger torque ripple than the 3-phase motor, we can increase the focusing and tracking bandwidth to overcome the vibration caused by torque ripple. From above experiments, jitter value of read-out data and pick-up head crossing 25,000 tracks show that the single-phase spindle motor has the same performance as the 3-phase motor.

5. REFERENCES

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Figure 1 Mechanical structures of the 3-Phase and 1-Phase motor.

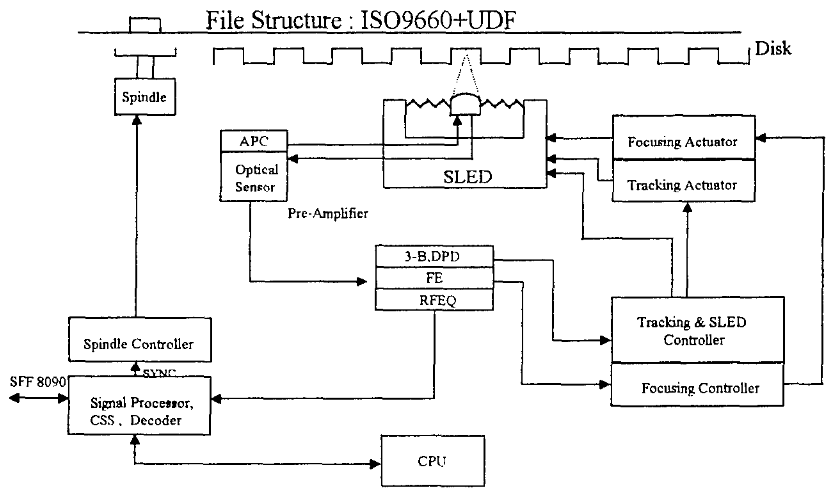

Figure 2. DVD-ROM servo system structure.

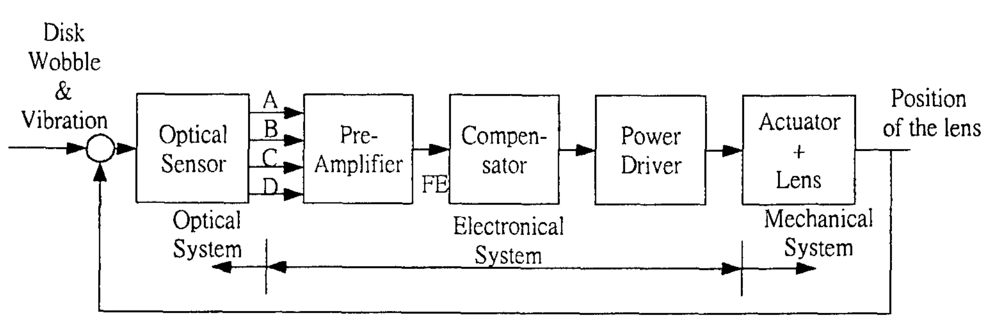

Figure 3. Block diagram of DVD-ROM focusing servo system.

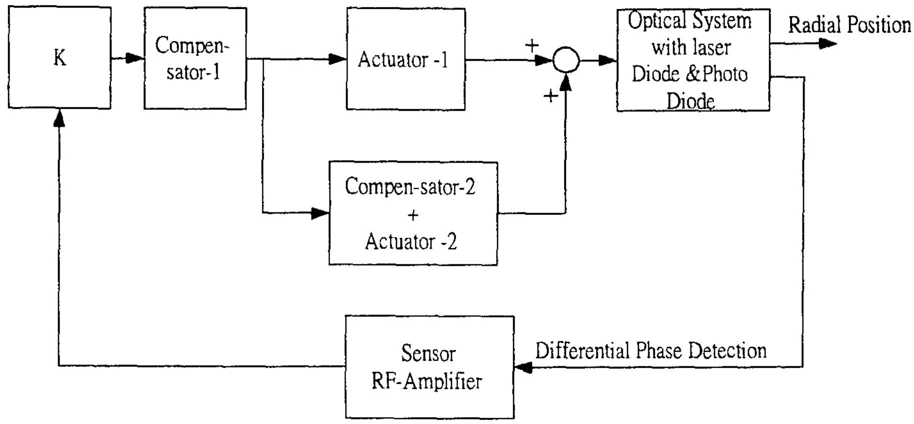

Figure 4. Block diagram of DVD-ROM track following system.

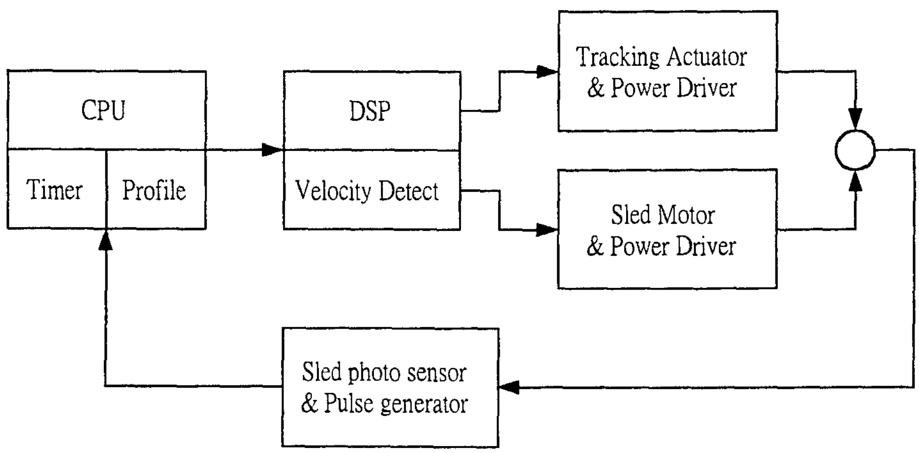

Figure 5. Block diagram of seeking servo system.

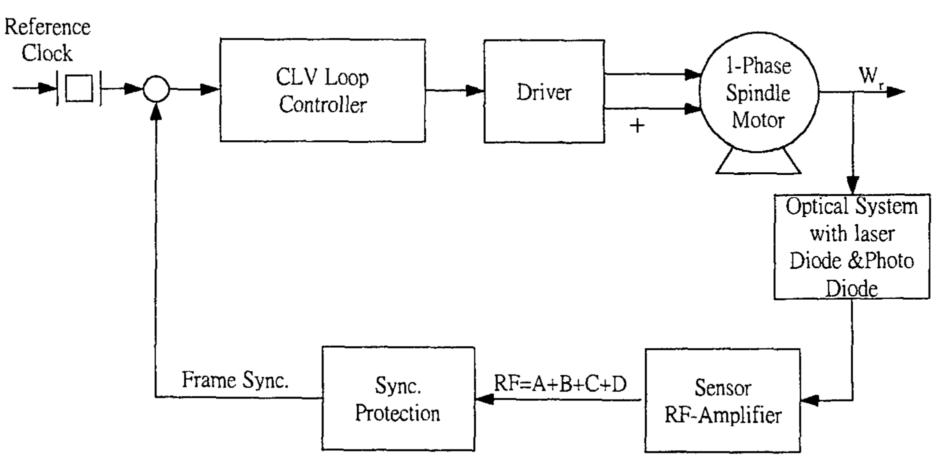

Figure 6. The block diagram of the spindle servo system.

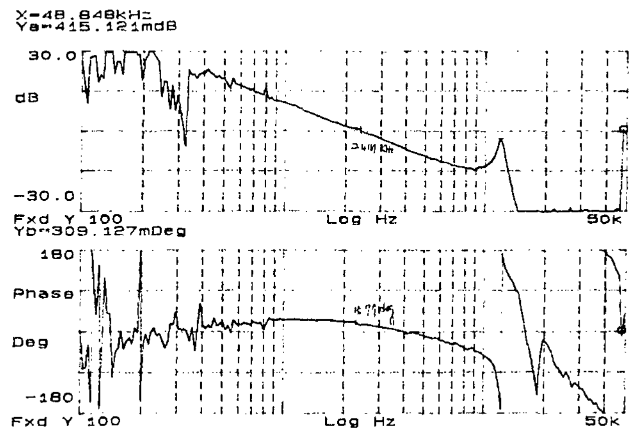

Figure 7. The open-loop gain of focusing loop

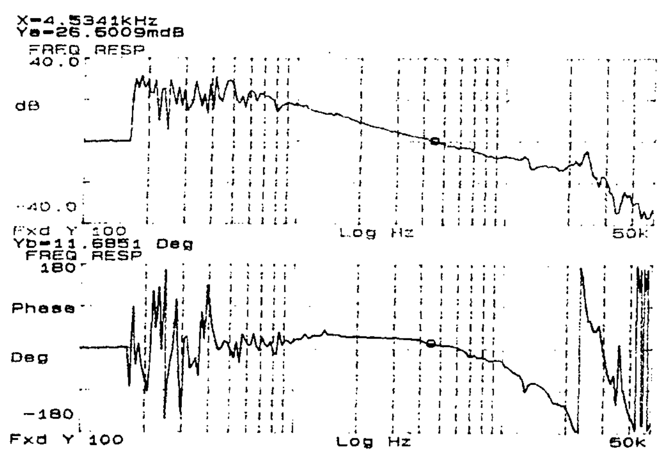

Figure 8. The open-loop gain of tracking loop.

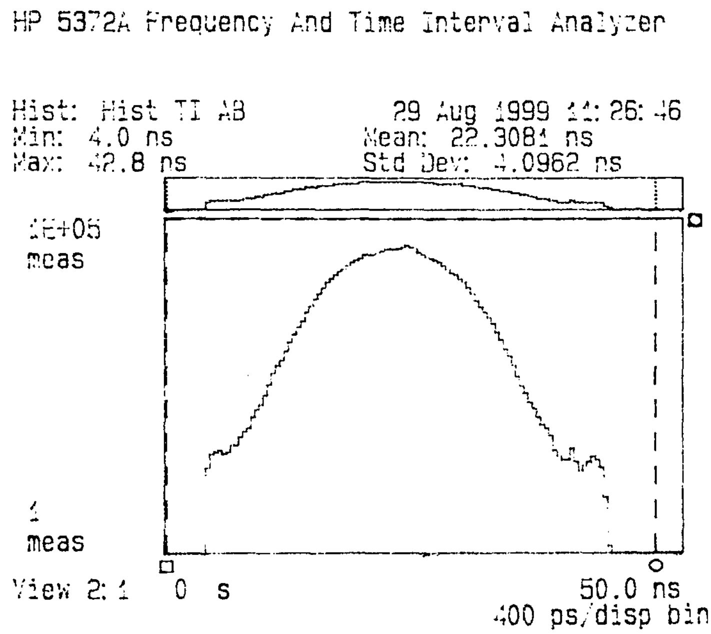

Figure 9. Data read-out jitter signal.

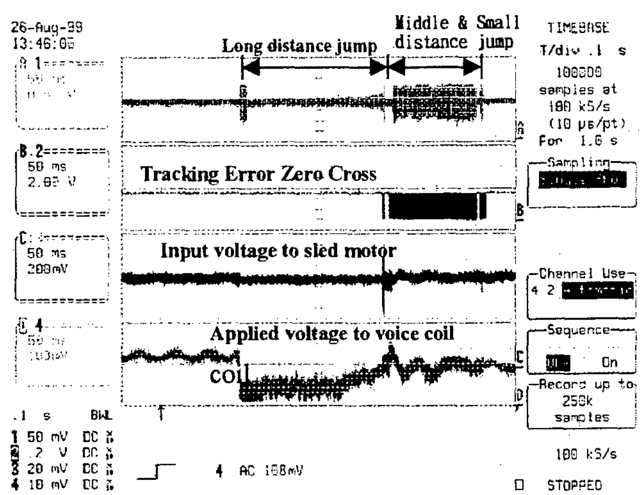

Figure 10. The long-distance seeking profile