行政院國家科學委員會專題研究計畫成果報告
Preparation of NSC Project Reports

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1、中文摘要

本計劃旨在研究一種適於光碟機之主動式偏心搖擺控制法則，其設計與實現之方法。本文探討此方法對於循軌伺服與短跨軌伺服性能之改善。　針對碟片偏心之干擾，本文提出一種切換於循軌伺服與短跨軌伺服之適應控制器，此法不僅可消除循軌穩態誤差，並可消除短跨軌之方向搖擺之不定性。　針對光碟機之特性，此法適合於碟片多種撥放倍速之固定角速度與固定線速度之要求。

關鍵詞：頻域適應控制、主動式搖擺隔絕、光碟機

Abstract

This research investigates the design and implementation of an active vibration isolation method, and the improvement it brings to the track-following and fine seeking in the optical disk drives. A control scheme is introduced to switch the adaptation between the track-following and fine seeking process. That leads to an efficient compensation of periodic disk runout vacillations both in track-following and seeking, thereby eliminating tracking errors as well as direction hysterics of the pick-up head. The proposed control strategy applies to the variable rotational speeds of constant angular and linear velocity modes in optical disk drives.

Keywords: frequency adaptive control, active vibration isolation, optical disk drive

2. Introduction

The high data transfer and short access time are two most important performance indices of the optical disk drive (ODD). Various attempts have been made to achieve these objectives such as to increase the disk rotational speed and to implement a fast seeking control. However, the increment of disk rotational speed to improve the data transfer rate raises up many serious problems in the servo control system, which controls the position and velocity of the laser spot relative to the rotating disk. Especially, the periodic vibration caused by deficiencies in track geometry and eccentric rotation of the disk is instinctive to all the optical disks and deteriorates the track-following and seeking servo system.

In general, to move the laser spot on the correct track of the disk, the pick-up head (PUH) assembly is maneuvered by two control strategies: seeking control and track-following control [1]. The seeking control moves the laser spot rapidly to a target track containing the information to be read, while the track-following control makes the laser spot follow the track closely in spite of the runout disturbance. However, the pull-in ability at the beginning of track-following is not always preserved due to the limitation in the bandwidth of the track-following system and the external runout disturbance. Furthermore, track miscounting occurs due to the risk of failure in generating the track-cross signals for fast PUH movement. In addition, Stan *et al.* [2] showed that, even for a given seeking length, the counts of track-crossed differed between the outside- and inside-oriented seeking. As a result, the locked track could not guaranteed to be the destination after one fast seeking operation and therefore, additional correction of short seeking becomes an imperative for accurate positioning. Thus, a two-stage seeking mechanism composed of coarse seeking and fine seeking is the most reliable method used in conventional optical disk drives. However, owing to the serious vibration disturbance caused by the high rotational speed of the disk and the limited bandwidth of the fine seeking, the velocity of the laser spot usually deviates from the profile during its slow velocity region. It usually leads to either a time-consuming fine seeking operation or a track-following failure at the end of the fine seeking.

In this research, a combined seeking and track-following servo structure is proposed with the capability of remarkably reducing the tracking error in the track-following process and improving the stable performance in seeking control in the high speed operation of rotational disks.

3. Frequency Adaptive Control Technique

Frequency adaptive control technique is a novel mechanism dealing with the vibration cancellation for both the CAV and CLV spindle modes of the optical disk drives with multi-playing speeds [3,4]. It is realized in a plug-in configuration as shown in Figure 1, in which the proposed algorithm of FACT is illustrated in Figure 2.

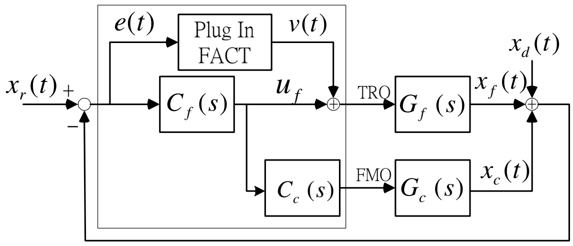

Figure 1. Plug-in frequency adaptive controller for track-following.

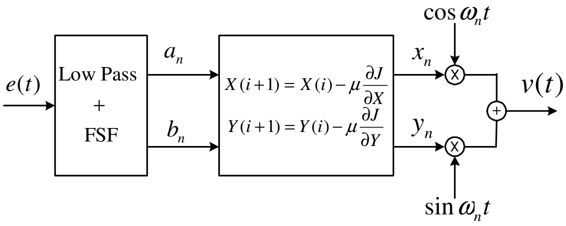

Figure 2. Algorithm of the plug-in FACT

The variables *TRO* and *FMO* are the control inputs to $G_f(s)$ and $G_c(s)$, respectively. The feedback controller $C_f(s)$ and $C_c(s)$ are designed so that the closed-loop system is stable and the laser spot follows the track trajectory $x_r(t)$ in the presence of the external runout vibration $x_d(t)$. Among the signals $x_r(t)$, $x_f(t)$, $x_c(t)$, $x_d(t)$ and $e(t)$, only the tracking error signal $e(t)$ is measurable and is commonly abbreviated as TES.

3.1 Periodic Runout Identification

Let ω_1 be the fundamental frequency of $e(t)$, then the periodic tracking error $e(t)$ can be expressed as

$$e(t)=\sum_{n=1}^{M}(a_n\cos\omega_n t+b_n\sin\omega_n t) \qquad (2)$$

where M is the highest harmonic order, $\omega_n = n\omega_1$, and a_n and b_n are unknown variables to be identified. The time series $e(k)$ depicts the sampled values from the N equal-spaced points per period of $e(t)$. Define

$$\begin{aligned}H_n(z)&=\frac{1-z^{-N}}{1-W_N^n z^{-1}}\\&=1+W_N^n z^{-1}+W_N^{2n}z^{-2}+\cdots+W_N^{n(N-1)}z^{-(N-1)}\end{aligned}$$

where $W_N^n=\exp(j\frac{2\pi n}{N})$ and $n=0,1,\cdots,N-1$.

The input $e(k)$ through each elementary filter $H_n(z)$ produces an output expressed as

$$\xi_n(k)=H_n(z)e(k)=\frac{N}{2}(\alpha_n+j\beta_n) \qquad (3)$$

Then, the parameters a_n and b_n describing the measurable signal $e(t)$ in equation (2) are then identified on-line through

$$\begin{cases}a_n=\alpha_n\cos\omega_n t+\beta_n\sin\omega_n t\\ b_n=\alpha_n\sin\omega_n t-\beta_n\cos\omega_n t\end{cases} \qquad (4)$$

3.2 Adaptation Formulation

The transfer function from the adaptation signal $v(t)$ to the tracking error $e(t)$ can be expressed as

$$\frac{e}{v}=\frac{G_f}{1+G_fC_f}\cong W(s) \qquad (5)$$

The frequency response of $W(s)$ at ω_n can be denoted as $[W_r(\omega_n)+j\,W_i(\omega_n)]$, where $W_r(\omega_n)$ and $W_i(\omega_n)$ are the real and imaginary parts of $W(\omega_n)$, respectively. Define the output $v(t)$ as

$$v(t)=\sum_{n=1}^{M}(x_n\cos\omega_n t+y_n\sin\omega_n t) \qquad (6)$$

the on-line adaptation of variables x_n and y_n are formulated as

$$\begin{cases} x_n(i+1) = x_n(i) - \mu[W_r(\omega_n)a_n + W_i(\omega_n)b_n] \\ y_n(i+1) = y_n(i) - \mu[-W_i(\omega_n)a_n + W_r(\omega_n)b_n] \end{cases}$$

(7) with $n=1, 2, \ldots, M$.

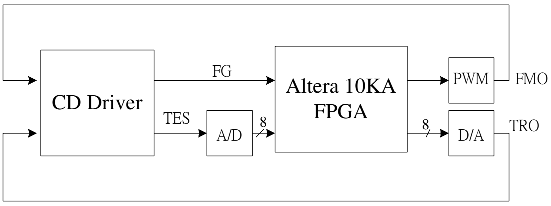

Figure 3. Experimental setup

3.3 Implementation of FACT

A single ALTERA EPF10KA FPGA device is used to implement the track-following controllers *Cf(s)* and *Cc(s)* as well as the FACT algorithms as shown in Figure 3. The experimental results of the vibration rejection in the track-following system are explained in the following. Figure 4 illustrates the TES waveforms around 4 revolutions of the disk from the original feedback system; where ch1 represents the TES with a large peak-to-peak amplitude corresponding to a maximum $0.1\mu m$ position error, while its FFT waveform depicted in ch2 shows that the TES be dominated by the first three harmonics. After the implementation of the FACT, the waveforms of TES are shown in Figure 5 where the first three harmonics are cancelled successfully.

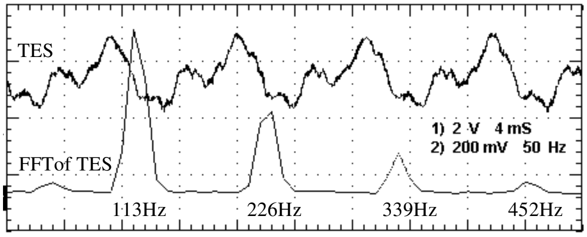

Figure 4. The waveforms of TES without FACT function for CAV-24X.

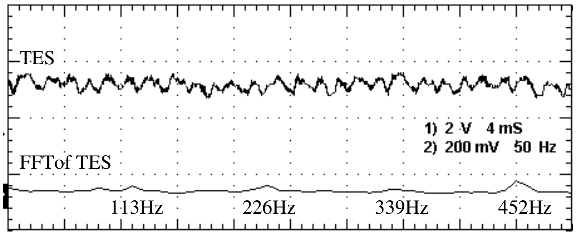

Figure 5. The waveforms of TES with FACT added in for CAV-24X

4. Active Free Vibration Configuration

The proposed FACT provides a promising solution to the vibration cancellation by a simple setup linking the fine seeking and track-following subsystems. Figures 6 and 7 show the block diagrams of the proposed configuration.

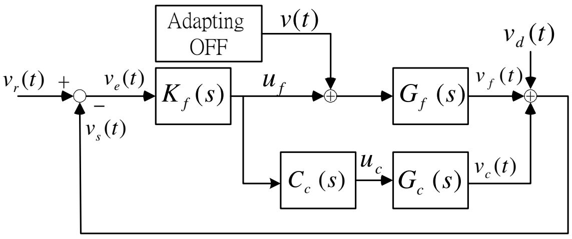

Figure 6. FACT controller for fine seeking.

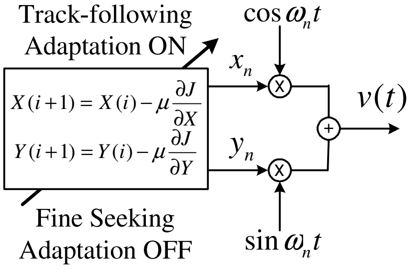

Figure 7. Adaptation ON for track- following while Adaptation OFF for fine seeking.

The FACT was applied to the track-following control phase, and successfully compensated the disk runout with drastically reduced tracking errors. Then, the adaptation function is turned off as soon as the system is switched from the track-following to the fine seeking process, and the well-tuned coefficients x_n and y_n in equation (7) obtained during the track-following are retained to cancel the disk vibration during the fine seeking. In this way, by adding the output *v(t)* during the fine seeking, the disk vibration source $v_d(t)$ will be completely cancelled, resulting in a vibration free environment.

During the fast CAV-24X mode, examined is the fine seeking operation moving outward for 8 tracks to the target track and the operation begins at the instant when the disk vibration has a maximum inward velocity as shown in Figure 8. It is clear that, owing to the significant inward vibration velocity, the direction of seeking goes inward as soon as the seeking operation is initialized. As a result, the extra effort has to be made until the lens is led to the accurate direction and the target is eventually reached.

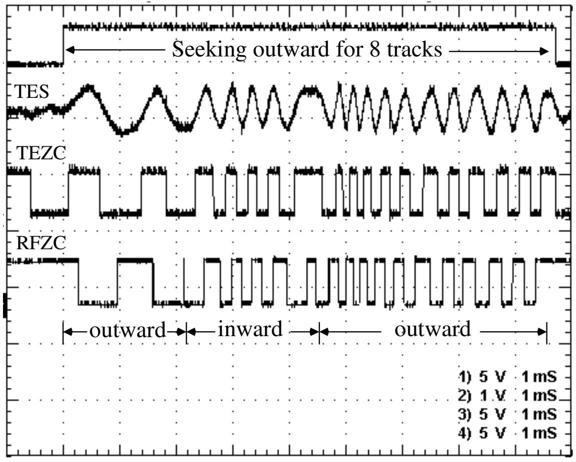

Figure 8. Fine seeking to outward for 8 tracks at CAV-24X without FACT.

In contrast to such an unpleasant case, however, a better result is obtained by means of FACT. The relative movement of lens with respect to the disk maintains in-phase with the disk vibration as if there were no vibration, and a steady and regular seeking motion is achieved at the high disk speed as shown in Figure 9.

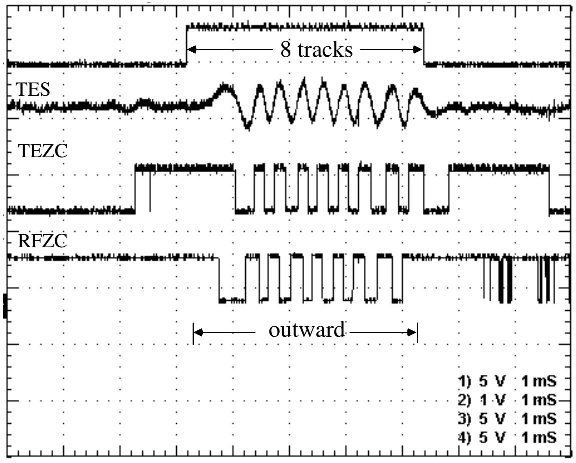

Figure 9. Fine seeking to outward for 8 tracks at CAV-24X with FACT.

Due to the periodicity of the sinusoidal vibration, there are two maximum vibration velocity instances for each rotation of the disk. In order to show the vibration-free mechanism is a feasible scheme to deal with the maximum vibration velocity, a seeking operation experiment is conducted where the seeking period covers the entire interval of one complete disk rotation. By the implementation of FACT, figure 10 shows a uniform movement of the fine seeking without vibration, where the seeking period is same as the time interval of one complete disk rotation when the disk is running at the speed of CAV-24X.

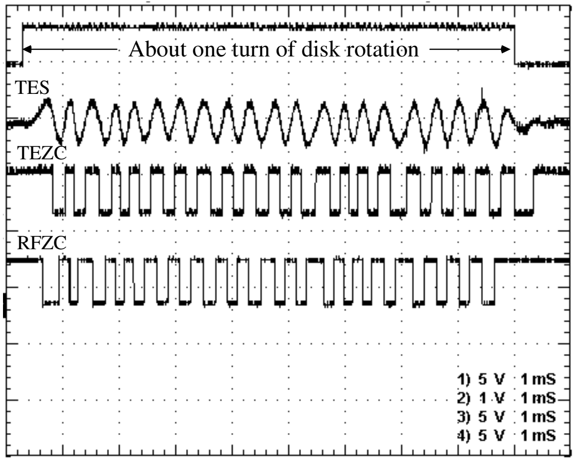

Figure 10. Vibration free result when the seeking period equals to the time interval of one complete disk rotation for disk running at CAV-24X.

5. Conclusion

This research presents an active vibration compensation method for the track-following and fine seeking control in the optical disk drives. The vibration compensation performs well in the fine seeking, and the PUH operates as if there were no runout vacillation. Extension of the same application to the CD-ROM, CD-RW or DVD-ROM drives is also expected.

References

[1] K. C. POHLMNN 1992 *The Compact Disc Handbook*. A-R Editions, Inc.

[2] S. G. STAN, H. VAN K EMPEN, G. L EENKNEGT, and T. H. M. AKKERMANS 1998 *IEEE Transactions on Consumer Electronics* 44, 178--186. Look-ahead seek correction in high-performance cd-rom drives.

[3] J. J. LIU and Y. P. YANG 2002 *Proceedings of the 41st Conference on Decision and Control*, *Las Vegas, Nevada*, Frequency adaptive control technique of compact disk drives for rejecting periodic vibration.

[4] J. J. LIU and Y. P. YANG *will publish on Control Engineering Practice*, Frequency adaptive control technique for rejecting periodic runout.

附件：封面格式

行政院國家科學委員會補助專題研究計畫成果報告

碟片偏擺對光碟機跨軌伺服性能之分析與控制

計畫類別：□個別型計畫　　□整合型計畫
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執行期間：　90 年 8 月　1 日至　91 年　7 月　31 日

計畫主持人：陽毅平
共同主持人：
計畫參與人員：

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- □出席國際學術會議心得報告及發表之論文各一份
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執行單位：國立台灣大學機械工程學系

中　華　民　國　　91 年　10　月　31 日