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폐루프 외란 검출기를 통한 광디스크 외란 측정

Disturbance estimation of optical disc by closed loop output estimator

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ABSTRACT

The method for output disturbance estimation is proposed. In this method, output disturbance is estimated from the closed loop system dynamics using the output and control input signals. In the closed-loop output-disturbance estimator, precise system identification is required to reduce estimation error. The realization of estimator was done by the DSP board (DSP1103), and disturbance estimation in various environments was performed: change of rotation speed, media feature and spindle motor with (or without) auto-ball balancing system (ABS). From these experiments, the disturbance characteristics of ODD under various conditions are analyzed, and the desirable servo loop configuration based these results is proposed.

1. Introduction

ODD has become very popular since early 1980's CD invention because it has good portability, cheap media price, convenient storage feature, exchangeability, and so on. However, comparing to other storage systems such as HDD, ODD has lower storage capacity and data transfer rate. To develop ODD with features of higher density and data transfer rate, many researches were carried out in the field of new media, optical system design and more accurate servo system, etc. [1,2]

In the scope of the control system design, for higher density and data transfer rate, it is required to obtain higher loop gain in the open-loop transfer function and larger bandwidth in the closed-loop transfer function. However, increase of the loop gain and bandwidth results in the high cost. The main function of the control system is to reduce output disturbance below the available error, and the disturbance resulted depends on the media type. Thus, the adequate choice of the compensator depending on the disturbance of the media disc can make it possible to increase data transfer rates available without any change of the system.

Therefore, it is required to estimate the output disturbance when the specified closed-loop works for the disturbance suppression. In this paper, the method to estimate output disturbance using the control input and the output error signal of the closed-loop system is presented. This method requires precise identification of the system parameters to reduce estimation error. In this method, the precise measurement of actuator dynamics is performed to obtain the precise actuator model parameters and the loop gain adjustment technique is applied to obtain the precise sensor dynamics.

To verify the validity of the developed closed-loop output estimator (CLOE), the estimation signal and measurement signal using LDV were compared, and we could find that online estimation of the output disturbance had a good agreement to the LDV measurements.

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Using the developed estimator, the change of the output disturbance characteristics was investigated according to the change of mechanical properties of the media disc such as vertical deviation, eccentricity, unbalance, and so on, and we could find that the desired loop shape could be changed according to the specific media disc.

2. Closed-Loop Output Estimation

2.1 Principle of Closed-Loop Output Estimator (CLOE)

Servo loop in ODD can be described as Fig.1.

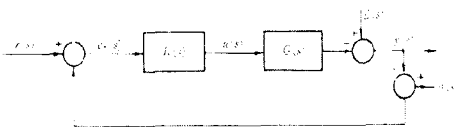

Fig. 1 Feedback control system of optical disc

Where,

d(s): mechanical disturbance
n(s): electrical noise
K(s): controller
G(s): Optical pick-up dynamics.

In this case, measurement y(s) can be expressed as,

$$y(s)=\frac{GK}{1+GK}r(s)-\frac{GK}{1+GK}n(s)+\frac{1}{1+GK}d(s) \quad (1)$$

In case of the regulation problem, the reference input, r(s), could be set to zero without loss of generality, then the disturbance can be stated as,

$$d(s)=G(s)K(s)(y(s)+n(s))+y(s) \quad (2)$$

Here, control input u(s) is given by

$$u(s)=-K(s)(y+n) \quad (3)$$

As a result, the disturbance value relating to the dynamics of system, measurement output and control input can be expressed as,

$$d(s)=y(s)-G(s)u(s) \quad (4)$$

Measurement y(s) and control input u(s) can be observed and dynamics of system can be obtained from the pick-up specification and experimental method of the pick-up. From (4), we can successfully estimate the disturbance if output of the closed-loop system and control input signal are measured.

In the optical pick-up sensing system, the electrical noise has a feature of DC offset. However, the DC disturbance is cancelled out in the estimation process, thus, we can only estimate AC value of the disturbance.

2.2 System Dynamics Modeling and LGA

From (4), we can infer that the accuracy of disturbance measurement depends directly on the accuracy of the mathematical model for the dynamics of pick-up, sensor and control input. The accurate value of control input u(s) can be obtained from drive IC terminal in ODD, but the dynamics of pick-up G(s) and measurement output y(s) should be more carefully obtained. Therefore, system dynamic G(s) should be evaluated experimentally and output measurement y(s) also should be calibrated by LGA.

For the measurement of dynamics of pick-up dynamics G(s), Voltage amp (Gain 1,Bandwith 20kHz), signal analyzer (HP 35670A) and LDV equipment are used. From these experiments, the dynamics of several pick-ups for DVD-ROM is measured and their results are presented in Fig.2.

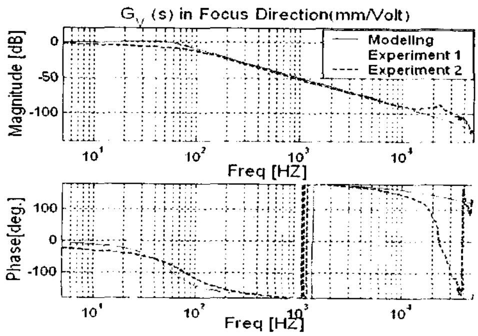

Fig. 2 Dynamics of experimented optical pick-up

The amount of sensing signal comes to be changed about same physical amount: distance between the beam spot and pits on the disc. This result mainly is generated from the variation of the sensor gain and variation of the reflection rate of the disc. The sensor gain's variation of the nominal plant is ± 50%, and reflection rate depends on the kinds of disc and state of disc. Thus, compensation to get the nominal sensor gain is necessary.

To solve this problem, the method to change sensor gain for according with the target open loop is used. If nominal dynamics is known, the disturbance having specific frequency inserts to the close loop of system, and output value through actual plant is obtained. Then this value goes to the specific bandpass filter. After the calculated phase of nominal plant on the specific disturbance frequency is compared with phase of actual system, the sensor gain is tuned to have the same phase. This is the LGA. With this method, we can get the compensated nominal sensor gain though variation of disc reflection and sensor gain exist, Thus, LGA in both the focusing and the tracking was done in this experiment.

3. Experimental Setup & Test DVD Disc

3.1 Experimental Setup for CLOE

The disturbance in ODD depends on the rotation speed, physical characteristic of disc, drive set, working environment and so on. For the change of the measurement conditions, some samples of test DVD disc series having specific physical characteristics are used and rotation speed is varied. The schematic diagram for the experimental setup and the procedure of the disturbance estimation are shown in Fig.3.

As shown in the Fig.3 the estimated disturbance outputs are analyzed in time domain and frequency domain, and scaled to the each DVD servo specification (Focus 0dB:0.23 μm . Tracking 0dB:0.022 μm). [7]

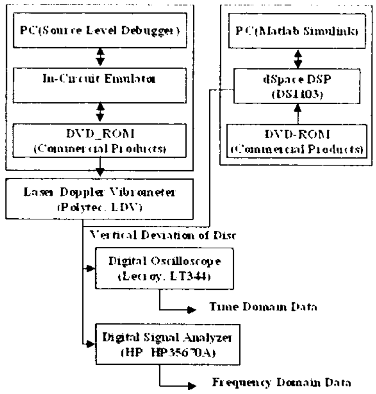

Fig. 3 Schematic diagram for CLOE

For realization of CLOE, the analysis of pick-up dynamics and sensor gain model block are constructed in Simulink blockset environment, then CLOE is realized by the DSP board using RTW (Real Time workshop) and RIT (Real Time Interface,). DSP board used in this experiment is DSP1103 model (Dspace inc.) and sampling frequency f_s is 100kHz. CLOE parameter setting and monitoring are done in the Control Desk. Constructed block diagram of CLOE is shown in Fig.4.

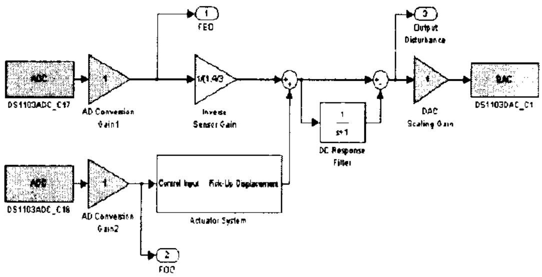

Fig. 4 Block diagram of CLOE construction

3.2 Test DVD Disc

Test DVD discs are selected from the products of ABEX test DVD disc series. The mechanical features of these can be divided as three categories: Deviation; Eccentricity; Unbalance. [9]

Its summary table is shown in Table1.

Table.1. Physical Characteristic of Test DVD Discs:

Species	DVD Media	Disc Structure
Vertical Deviation	TDV-551 (0.4 ± 0.05mm) : at Chapter No.16	Single Layer
	TDV-533 (1.0 ± 0.05mm) : at Chapter No.16	
Eccentricity	TDV-510 (0^{+10}_{-0} μm)	
	TDV-511 (50 ± 5 μm)	
	TDV-515 (150 ± 5 μm)	
Unbalance	SVD-5574: 0.30 $g \cdot cm$	
	SVD-5574: 0.50 $g \cdot cm$	

3.4 Validity Proof of Closed Loop Estimator

In using CLOE, the validity for it should be confirmed first. The validity was proved in focusing direction by LDV. With LDV and CLOE, disturbance measurements on the same position are measured at the same time. Then, the measured disturbance data was compared. From this compared result, validity of CLOE was proved. One example of results is shown in Fig.5.

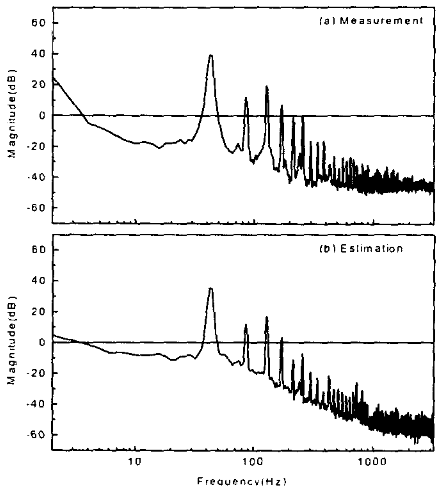

Fig. 5 Measurement results (a) LDV, (b) Estimator

4. Experiment Procedure & Results

The disturbance in ODD depends on the rotation speeds, physical characteristic of disc, with (or without) ABS and so on. Therefore, we experimented the disturbance estimation by the various experiment setting.

Experiments conditions are presented in Table.2.

Table.2. Experiment Combination in CLOE

Species	With ABS	Without ABS
	Focusing/Tracking Direction Speed Setting: CAV Mode	
Vertical Deviation	4X, 6X, 8X	4X, 6X, 8X
Eccentricity	4X, 6X, 8X	4X, 6X, 8X
Unbalance	4X, 6X, 8X	4X, 6X, 8X

Here, ABS is the device using metal ball to compensate the unbalance mass. To find the ABS effect, the experiment was done by the change of spindle motor. As the rotation speed increases, the unwanted disturbance force caused by unbalance mass grows up rapidly and this phenomenon leads to more mechanical vibration and noise problem. [4,5,6] As compensation amount by ABS is affected by various conditions, we have a difficulty in quantifying the compensation amount in the experiment. But, we can find the quantitative feature of reducing disturbance.

To convert disturbance data from time domain to frequency domain, the estimated output disturbance signal was analyzed by HP35670A. In FFT process, Hanning window was selected for preventing signal leakage, and enough average to get rid of transient signal was done.

In many experiment results, some representative results are presented in Fig.6–Fig.10.

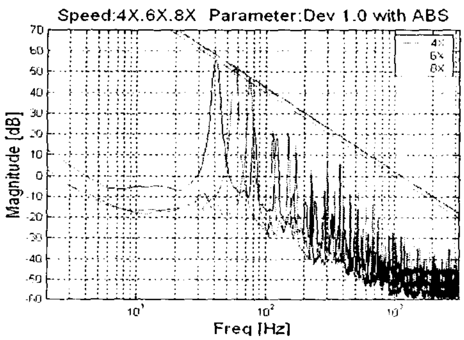

Fig. 6 Deviation disc: focusing direction

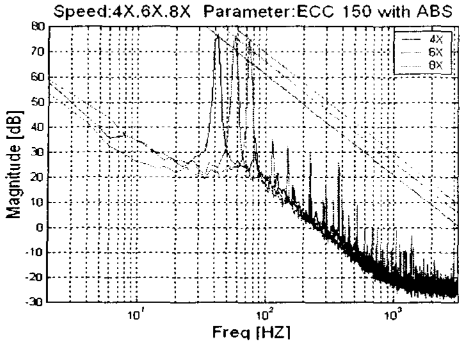

Fig. 7 Eccentricity disc: tracking direction

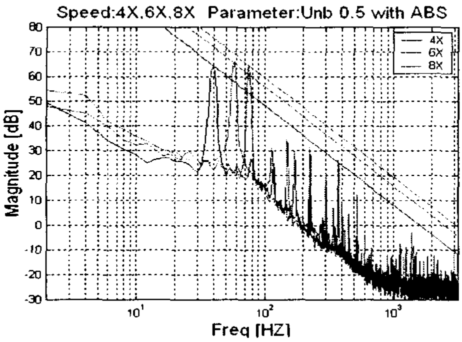

Fig. 8 Unbalance disc with ABS: tracking direction

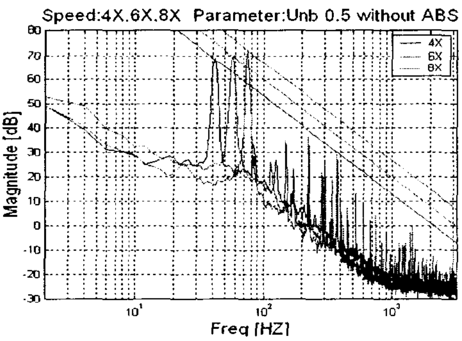

Fig. 9 Unbalance disc without ABS: tracking direction

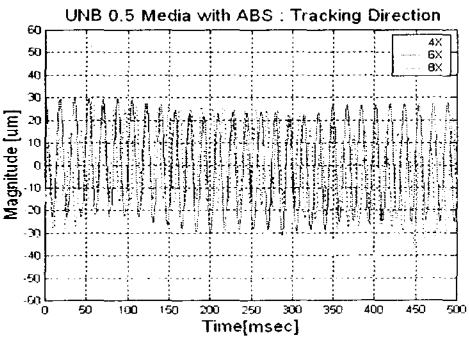

Fig. 10 Disturbance in time domain: tracking direction

5. Disturbance Analysis and Desirable Shape of Open Loop

From various test conditions, we can find that disturbance characteristic depends on each rotation speed, physical feature of disc and the existence of ABS.

Some common and different features of disturbance are summarized as below.

•The disturbance depending on the test DVD physical features is observed. Deviation and eccentricity disc has the large disturbance in each direction. In case of the unbalance disc, we can find the feature of disturbance increase as rotation speed increases. This phenomenon is clear in the absence of ABS.
•The magnitude of disturbance at rotation frequency is larger than the other harmonic disturbance.
•As rotation speed increases, ratio of the harmonic disturbances to the fundamental disturbance increases.

Focusing Direction

•As the rotation speed increases, the peaks of disturbance decrease.
•The magnitude of disturbance increases as pick-up moves outward.
•The effects of chucking condition are small.

Tracking Direction

•The conditions of disc chucking affect the magnitude of disturbance, which is dominant in the tracking direction.
•The tendencies of disturbance related with speed variations are obvious.
•Comparing with focusing direction, the ratio of high disturbance to the main peak disturbance is low.
•Low frequency variation of disturbance at 2 to 5Hz is observed, and this result is shown in Fig.10. The cause of low frequency variation is the effect of coarse actuator. Thus, this phenomenon cannot be found in focusing direction.

With (or Without) ABS

In the absence of ABS, more disturbances are observed as rotation speed increases and this phenomenon is dominant in the disc with large unbalance. This result is shown in Fig.8 and Fig.9.

But, disturbance characteristic in the others is rather good, when ABS is not used.

From experiment, ABS has the good compensation feature in large unbalance disc, but the compensation amount is not equal each case. It can be known that compensation of unbalance is dependent on kind of the disc, rotating speed and operation conditions.

Now, we change the concern from the disturbance to the controller design. If the disturbance of ODD generated by the various causes are known exactly, controller design to suppress the disturbance is easy. Thus, based on the measurement results, we can find the some important things to design the controller for the ODD.

To suppress the disturbance, the open loop should have a larger value than that of disturbance. Hence, the optical pick-up and the others; controller, driver and etc. should have the proper loop shape. Because optical pick-up has -40dB/dec slope over 1^{st} resonance frequency, the open loop has the dynamics of optical pick-up.

Like as Fig.6-Fig.10, most of the disturbance are generated in the low frequency region, and some gap which exists between the -40dB/dec line from the main peak and the disturbance is shown. From the above result, we could find that the servo loop means the disturbance itself.

In case of unbalance disc, 2nd and 3rd harmonic peaks of disturbance are relatively large to the main peak, and larger values above -40dB/dec line exist in some case. Thus, a careful design should be done in the region of 2nd and 3rd disturbance peaks, when combination case (deviation-unbalance, and, eccentricity-unbalance) happens.

6. Conclusion

By the proposed CLOE, disturbance characteristics of the ODD were experimented and analyzed. For this, we proved the validity of CLOE by LDV and used the LGA function.

From the experiment results under the various conditions, we found the common and different features of the disturbance in the ODD. Based on the results, we found that the servo loop means the disturbance itself, and proposed that the careful design should be done in the region of 2^{nd} and 3^{rd} disturbance peaks.

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