Appendix G

N92-14909

Differential Spot-Size Focus Servo

T.D. Milster, M.S. Wang, F.F. Froehlich, J.L. Kann, J.P. Treptau, and K.E. Erwin
Optical Sciences Center, University of Arizona, Tucson, Arizona, 85721

Abstract

We describe performance of a differential spot-size (wax-wane) focus servo. Cross talk from the tracks are analyzed in the single detector and differential focus circuits. Magnitude of the cross talk is reduced by a factor of three in the differential circuit. A false FES signal is present when the spot crosses sector marks at an angle.

2. Introduction

There are several techniques that can be used for focus-error detection in an optical data storage device. Astigmatic, knife-edge, critical-angle prism, pupil obscuration, and spot-size detection are common techniques (1)(2)(3). These methods sense the focus error by manipulating reflected light from the disk and creating an electrical focus-error signal (FES) with sectioned detectors. If a continuously pregrooved disk is used, the reflected light also contains diffracted orders that are used to provide a tracking-error signal (TES). It is difficult to completely separate the focus-error information from the tracking-error information, regardless of the focus-error detection method. The residual amount of TES observed in the FES is called cross talk. Other kinds of pattern noise, such as diffraction from sector marks, beam motion, and partial obscuration, can also lead to false FES signals. Prikryl (4) has modeled the sensitivity of several focus-error detection methods to sources of cross talk. Cohen (1) and Stahl (5) have modeled cross talk sensitivity of astigmatic focus-error detection. In this paper, we discuss the characteristics of a differential spot-size measurement technique, which has better cross-talk rejection than the single-detector spot-size measurement technique. Similar differential techniques have been presented in the literature (6), but they have not been analyzed with respect to cross talk.

Our differential spot-size technique is illustrated in Figure 1. Reflected light from the objective lens is focused through a polarizing beam splitter onto two quadrant detectors. Detector 1 is slightly inside focus, and detector 2 is slightly beyond focus. Representations of spot sizes through focus are sketched in Figure 2. For the in-focus condition, the spots are approximately the same size, but they are displaced slightly from the center of the detector. Displacement on detector 1 is opposite from the displacement on detector 2. As the disk moves outside of focus (farther away from the objective lens), the spot on detector 1 becomes smaller, and the spot on detector 2 becomes larger. As the disk moves inside of focus (closer to the objective lens), the spot on detector 1 becomes larger, and the spot on detector 2 becomes smaller. An error signal is generated from :

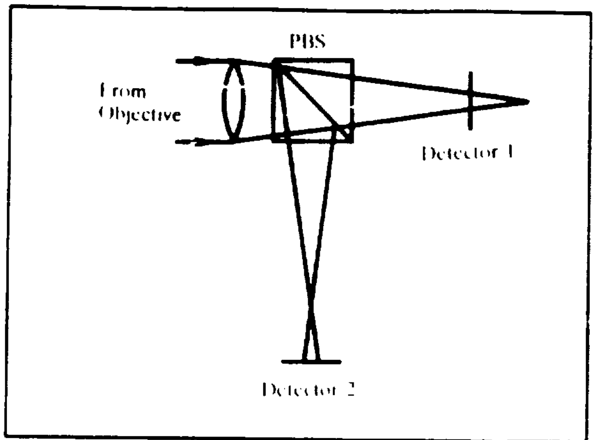

Figure 1. Detector optics layout for the differential spot size technique.

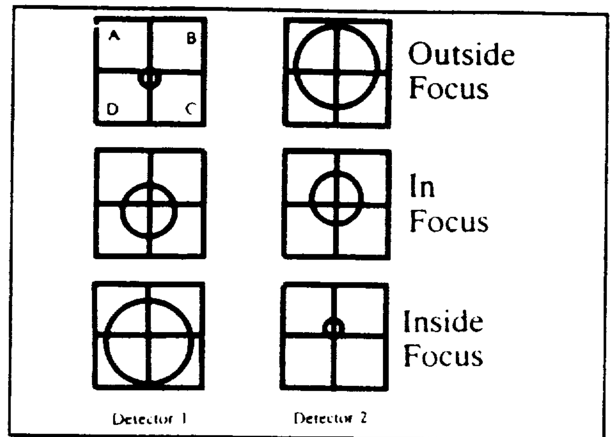

Figure 2. Spot shapes on the quad detectors for three different focus conditions.

$$\epsilon_1 = \frac{2(A+B)-(C+D)}{A+B+C+D}$$
$$\epsilon_2 = \frac{(A+B)-2(C+D)}{A+B+C+D} \qquad [1]$$
$$\epsilon = \epsilon_1 - \epsilon_2 \quad ,$$

where *A, B, C,* and *D* are detector voltages, ϵ_1 and ϵ_2 are FES signals for detectors 1 and 2, and ϵ is the differential FES. This method can also be considered as a differential wax-wane focus scheme. We subtract the combined quadrant signals from each detector to generate the magneto-optic read-back signal.

The following paragraphs describe modeling and experiment used to evaluate the differential spot-size technique.

3. Modeling

Our model is a scalar diffraction implementation of the servo path from the disk to the detectors. We use a Fresnel approximation to describe the propagation from disk to objective lens and from detector lens to detectors. The *A, B, C,* and *D* signals are found by integrating the squared absolute value of the amplitude over detector quadrants.

An important consideration for servo design is gain, G, expressed in volts per micron. If one assumes a uniform beam, an expression for G in spot-size focus detection is given by

$$G = \frac{\Delta \epsilon}{\Delta z} = G_g \times \frac{0.976}{l} \times \left(\frac{f_{det}}{f_o}\right)^2 \quad ,$$

Table I

	Single spot size servo	Differential spot size servo
Gain (measured)	0.36V/μm	0.71V/μm
Gain (calculated)	0.37V/μm	0.74V/μm
Residual FES (p-p)	0.14V	0.085V
Crosstalk (p-p)	0.38μm	0.12μm

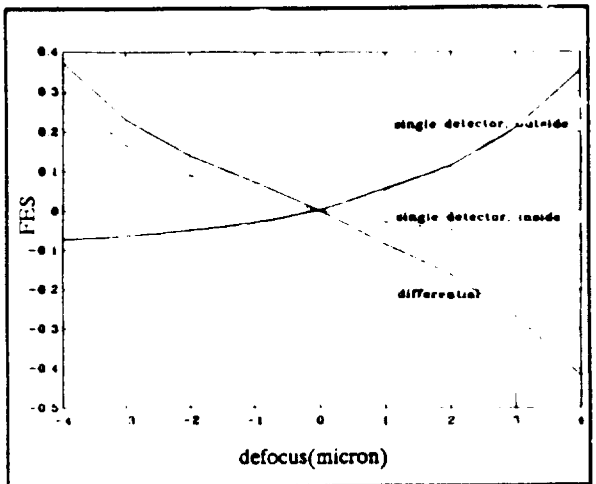

Figure 3. Calculated FES curves for single detector and differential circuits.

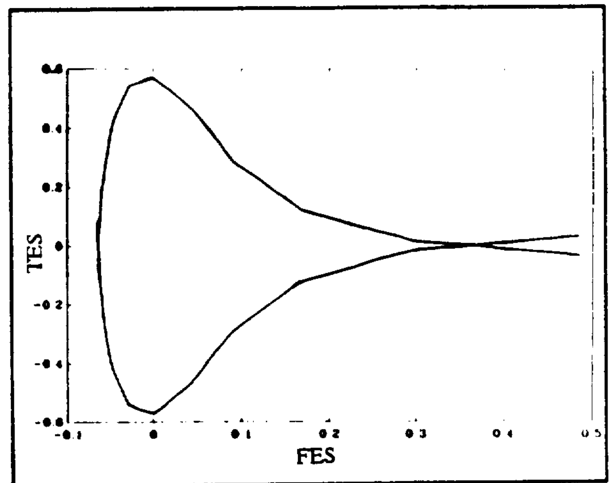

Figure 4. Calculated Lissajous envelope for the single-detector circuit.

where G_E is electronic gain (5), l is distance from detector to nominal focus (11 mm), f_{det} is focal length of the detector lens (124 mm), f_o is focal length of the objective lens (4.3 mm), and Δz is disk displacement. Our calculated G is 0.37 V/μm, which corresponds well to the measured value of 0.36 V/μm. Gain for the differential spot-size focus technique is twice G, or 0.74 V/μm. The measured differential gain is 0.71 V/μm. Table I summarizes these results.

Figure 3 displays FES versus defocus for both detectors individually and the differential FES. Single-detector FES is a nonlinear function of position. The differential FES is more linear.

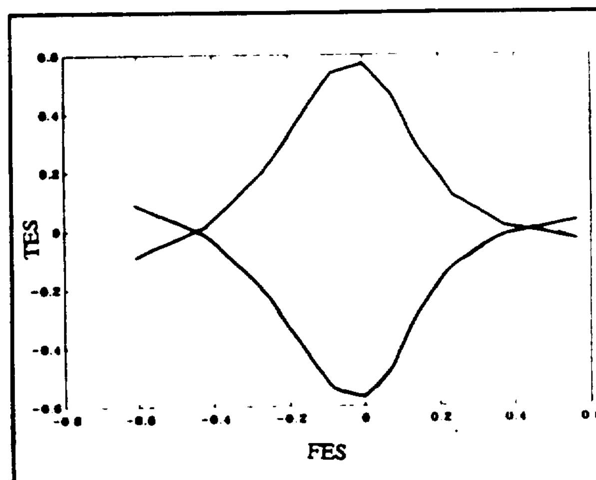

Figure 5. Calculated Lissajous envelope for the differential circuit.

We studied the interaction of focus and tracking signals by calculating the envelope of the Lissajous pattern formed between the FES and the TES. Figure 4 displays the Lissajous pattern for the single-detector case. Due to nonlinear gain of the FES, the TES signal approaches zero rapidly as the system goes out of focus in one direction. In the opposite focus direction, the TES falls off more slowly. The envelope of the differential FES is displayed in Figure 5, which is nearly symmetrical around best focus.

4. Experimental Procedure and Results

The measurement of cross talk on the FES (focus error signal) requires knowledge of the focus servo gain and the peak-to-peak voltage fluctuation of the FES as a result of track crossings. The servo gain is measured on the linear region of the open-loop FES. The actuator-to-disk spacing is varied by translating the optical head with a micrometer screw, and the change in open-loop FES voltage at a fixed time reference is noted. The time

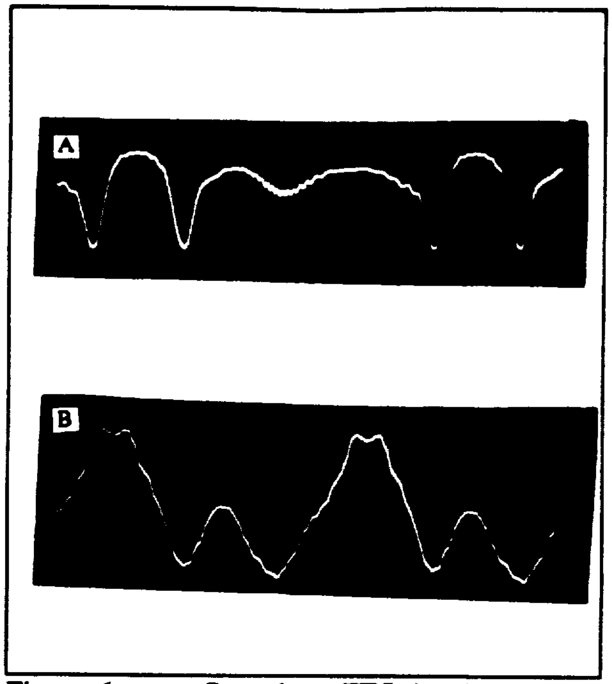

Figure 6. Open loop FES signals. A: single detector, B: differential circuit. X: 10ms/div, Y: 5V/div.

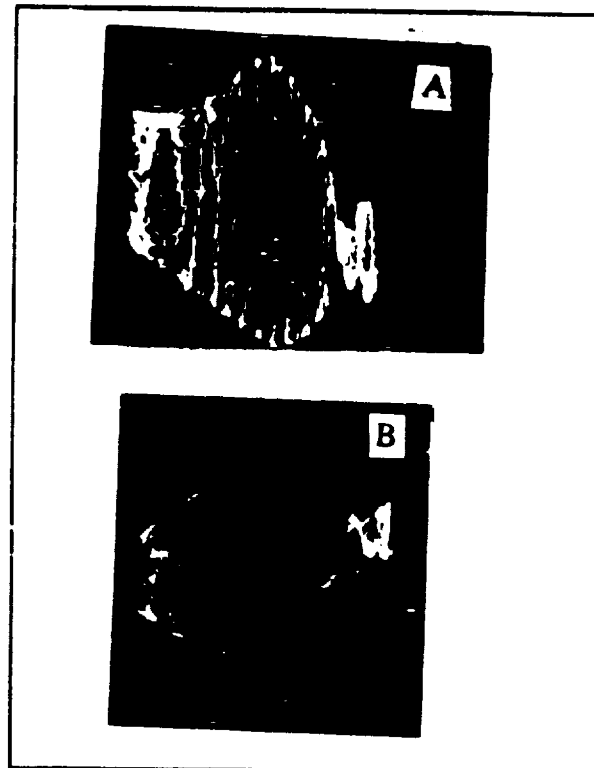

Figure 7. Lissajous patterns. A: single-detector X=1V/div, B: differential circuit X=2V/div. X: FES, Y: TES 1V/div.

reference is established relative to the synch pulse from the disk spindle. The gain is then computed as the change in open-loop FES voltage for a given displacement of the actuator and is expressed in volts per micron. The peak-to-peak voltage fluctuation of the FES is measured directly on an oscilloscope with the focus servo locked and the tracking servo unlocked. The peak-to-peak cross talk is then calculated by

$$\text{Cross talk } (\text{um}_{pp}) = \frac{\text{FES Voltage (Vpp)}}{\text{Servo Gain (V/um)}}$$

We made most measurements on a glass substrate magneto-optic disk spinning at 1800 rpm. Figure 6 displays the open-loop FES signals for the single-detector and differential circuits. Figure 7 displays the Lissajous patterns for single-detector and differential circuits. The single-detector Lissajous pattern consists of nominally straight lines with small oscillations. Vertical lines correspond to small values of cross talk (7). The nonlinearity of the gains corresponds to the envelope predicted in Figure 4. At this time we have no

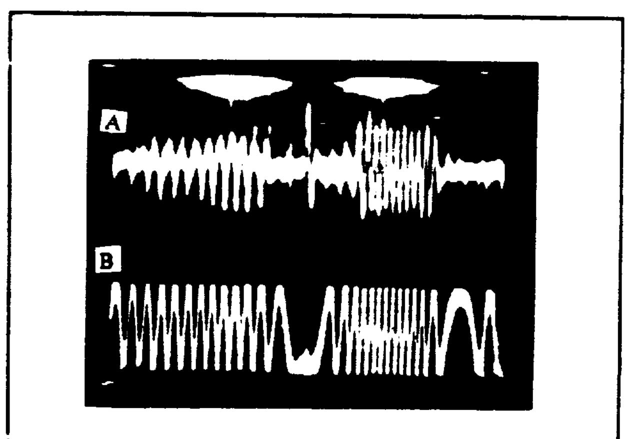

Figure 8. Open-loop TES servo signals from the differential circuit. A: differential FES, Y=0.1V/div. B: TES, Y=2 V/div. X=2ms/div.

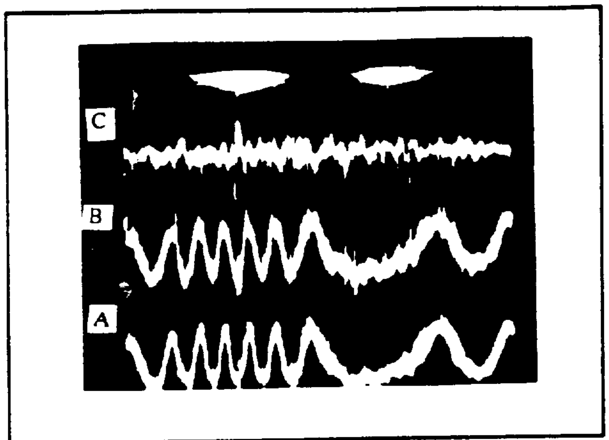

Figure 9. Cancellation of cross talk for the differential spot size technique. A: detector 1, B: detector 2, C: differential circuit. X=1 ms/div, Y=0.1 V/div.

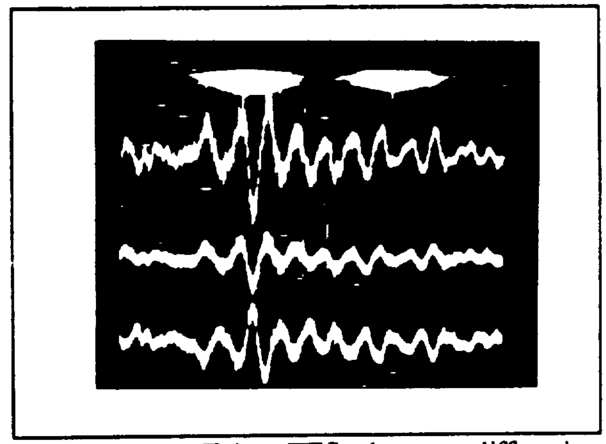

Figure 10. False FES due to diffraction from the sector marks.

explanation for the oscillations or the skew of the pattern. The differential-detector Lissajous pattern is more symmetric, but there is still some asymmetry due to a small imbalance in the gains. The lines making up the patternare nearly vertical, and there are no observable oscillations.

Oscilloscope traces of servo error signals for the single-detector spot size technique are shown in Figure 8. The lower trace is the open-loop TES (tracking error signal), and the upper trace is the closed-loop FES showing cross talk. The cross talk was minimized by rotational and lateral alignment of the quad detector. The cross talk was found to be 0.38 μm_{pp}.

The improved cross talk performance for the differential spot size technique is illustrated in Figure 9. The lower two traces are individual FES signals from quad detectors 1 and 2. Track crossings are in phase on these signals. The upper trace is the differential FES, which shows cancellation of the track crossings. The residual cross talk was 0.12 μm_{pp}, which is a factor of three improvement over the single-detector technique.

In the course of measuring the cross talk for the differential technique on a plastic disk, we discovered an FES signal generated by sector marks. This excitation yields the focus servo response shown in Figure 10. The response acted like a true focus error, thus the individual FES signals are out-of-phase, and the response is doubled in the differential FES. We believe that this response is due to diffraction as the spot crosses the sector mark.

5. Conclusions

We have analyzed a differential spot-size (wax-wane) focus error technique for sensitivity to cross talk from track crossings. The single-detector circuit exhibited cross talk of 0.38μm_{pp}. The differential circuit exhibited cross talk of 0.12μm_{pp}, which is approximately a factor of three improvement. An undesired signal was discovered as the spot crosses a sector mark. It is believed that diffraction from the sector mark causes a false FES signal. We are investigating how to minimize this effect.

6. References

1. D. K. Cohen, "Analysis of methods for detecting focus error in optical data storage systems," Ph.D. Dissertation, University of Arizona, Tucson, Arizona (1987).

2. M. Irie, T. Fujita, M. Shinoda, and M. Kondo, "Focus sensing characteristics of the pupil obscuration method for continuously grooved disks," *Proc. Int. Symp. on Optical Memory, 1987 Japanese Journal of Applied Physics*, vol. 26, pp.183-186 (1987) supplement 26-4.

3. M. Yamamoto, A. Watabe, and H. Ukita, " Optical Pregroove dimensions: design considerations," *Appl. Opt.*, vol 25, 22, pp. 4031-4034 (1986).

4. I. Prikryl, "Optical servo cross talk," *SPIE 1078 Optical Data Storage Topical Meeting*, pp. 244-255 (1989).

5. R.P. Stahl, "Modeling optical feedtrough of track crossings into the focus error signal in an optical storage device," Master's Report, Department of Optical Sciences, University of Arizona, Tucson, Arizona (1990).

6. M. Oka, A. Fukumoto, K. Osato, and S. Kubota, "A new focus servo method for magneto-optical disk systems," *Proc. of the Int. Symp. on Optical Memory, 1987, Japanese Journal of Applied Physics*, vol. 26, pp. 187-190 (1987) supplement 26-4.

7. S.L. Grove, K.W. Getreuer, and D.L. Schell, "Lissajous analysis of focus cross talk in optical disk systems," to be published in SPIE Proceedings 1499.

Muster