FOCUS PLANT IDENTIFICATION OR CHARACTARIZATION METHOD FOR OPTICAL DISK SYSTEM

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

This invention relates to improvements in dynamic information storage or retrieval systems and methods, and more particularly to improvements in such systems and methods for the storage or retrieval of arbitrarily variable information which is retained in a storage medium by variation of a optical characteristic thereof by sensing a variation of a physical characteristic of the storage medium by a transducer having relative motion along a continuous path, and still more particularly to improvements in such systems and methods for identifying or characterizing the parameters of the focus plant of an optical disk system.

2. RELEVENT BACKGROUND

In the construction of optical disk apparatuses, it is often important to characterize the parameters of the apparatus, including the focus plant. The term "plant" is generally regarded to be the "black box" to be controlled, with a controllable input and an observable output. More particularly, the "focus plant" is the portion of the optical pickup assembly and electrical control elements that contains and controls the focus lens that focuses the light source onto the optical disk to read data therefrom, and would typically encompass the focus coil, the focus lens, and the focus error generator portions of the optical disk apparatus.

The identification or characterization of the focus plant may be used to determine its transfer function. To first order, the focus plant has a 2nd order transfer function, which is uniquely

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determined by a quality factor Q, a resonance frequency f_o and a DC gain K_o.

In a typical compact disk (CD) or digital video disk (DVD) system, a data sensing transducer, or head or pickup assembly, is provided to read data patterns, frequently organized in groups, or sectors, that have been previously recorded on a data disk, usually in the forms of lands and grooves along radially arranged concentric tracks in the reflective surface of the disk. The pickup is constructed to contain a focusing lens to focus a laser beam to a spot on the optical disk. The reflected beam is modulated by the data pattern present on the reflective surface of the disk, and is used for data and positioning detection. After being reflected from the disk, the reflected light reenters the pickup through the lens and is reflected by one or more partially reflective mirrors to impinge on a photodetector array. The photodetector array then converts the received light energies into electric signals.

The focusing lens is typically held in a lens holder attached to the pickup body by a spring mechanism. Wire coils attached to the lens holder carry electric currents that generate magnetic forces that interact with permanent magnets mounted on the pickup body to move the lens holder relative to the pickup body to position the lens. Generally two coils are provided, a focusing coil, to provide the necessary focusing control, and a radial coil, to provide the necessary radial positioning control, respectively.

More particularly, the control of the focusing coil is based on a focus error signal that detects the distance of laser focal point from the highly reflective data layer. The focusing control thus works to minimize the focus error signal magnitude, thereby keeping the laser beam focused on the data layer. Still more particularly, with reference now to Figure 1, typically an optical disk assembly 5 is used in conjunction with an optical disk 10, which is rotated, for example, by a spindle motor 24. A plurality

of tracks (not shown) are formed in a radial direction on the optical disk 10.

An optical head assembly 12 is movably arranged with respect to the optical disk 10, and a head driving motor 26 moves the optical head assembly 12 in a radial direction of the optical disk 10. The optical head assembly 12 emits a light beam 14 that is focused into a spot on the optical disk 10 for reading information from and/or writing information to the optical disk 10.

A semiconductor laser 28 is provided as a light source within the optical head assembly 12. A light beam emitted from the semiconductor laser 28 is directed to an objective lens 36 via a collimator lens 30, a deflection beam splitter 32, and a quarter wave plate 34. The objective lens 36 converges the light beam into a beam spot on the optical disk 11. A reflected beam from the optical disk 10 is reflected in a perpendicular direction by the deflection beam splitter 32 onto a 4-segment photodetector 40 via a condenser lens 38.

A focus actuator 42 is provided for adjusting the focal position of the spot on the optical disk 10 by moving the objective lens 36 of the optical head 12 up and down. In addition, a track actuator 44 is provided for supplying drive signals to coil 37 to control the tracking of the beam by moving the objective lens 36 in a direction that is perpendicular to the tracks on the optical disk 11.

The focus actuator 42 is controlled by a focus servo circuit 46, which drives the focus actuator 42 so that a focus error signal, FE, which is derived from an output light detection signal of the 4-segment photodetector 40, becomes a minimum. The circuit 46 derives its inputs from the various segments of a photodetector array 40 in known fashion.

In the past, two characterization or identification techniques have been used. The first conventional technique is a closed-loop

identification technique. Since focus error has a small linear region, typically within several micrometers, conventional frequency response measurement methods resort to maintaining the distance between focal plane and data layer to within this linear region, while simultaneously injecting a swept sinusoidal or white-noise disturbance and detecting the focus error response.

In the swept sine method, the focus error response of the same frequency content as the injected sinusoidal excitation is extracted mathematically for each frequency, while the frequency is varied across the whole range of interest.

In the white noise method, a white noise excitation is injected and the frequency response of the focus plant is obtained as the quotient between the focus error response power spectral density and that of the excitation.

Both of the swept sine and white noise methods suffer when there is extra disturbances bigger or comparable to the intended excitation, such as a vibration of the recording layer in the focal direction. This problem is further compounded by the fact that the intended excitation must be limited to be small in order to maintain the focal system within the small linear region. The combined result is poor signal-to-noise ratio of the measurement method, aside from the large computational effort that is required.

The second conventional technique is the triangular wave open-loop technique for characterizing the dc gain of the plant, which is illustrated in Figure 2. According to this method the focus actuator is driven with a triangular wave signal 60 to obtain focus error S-curves 62. A focus error S-curve is the plot of focus error signal when the focus plane sweeps towards and past the data layer on the optical disk. The focus error signal magnitude is negligible when the focus plane is far away from the reflective data layer, for example greater than 50μm. As it moves towards the data layer, it acquires greater magnitude, while retaining the same polarity,

until it reaches a peak. Then it rapidly declines towards zero as it reaches the data layer, continuing past zero towards a peak of opposite polarity shortly after passing through the data layer. Then it declines in magnitude, while retaining the new polarity, as it moves further away from the data layer.

The frequency of the triangular wave is much lower than the resonance frequency of the focus plant, typically 1/10 or even less, so that the actual mechanical movement of the focus lens 36 closely approximates the triangular input. The DC gain is obtained as the quotient between the slope 64 of the focus error S-curve in it linear region to the slope 66 of the triangular drive signal. The linear region is approximately that part of the S-curve between positive and negative peaks that approximates a straight line, as shown.

The triangular wave open-loop method, however, cannot produce the resonance frequency or the quality factor of the focus plant. The low speed at which the focus plane sweeps through the focus error linear region also makes the gradient small, effectively making the signal-to-noise ratio poor in the presence of axial disturbances.

What is needed, therefore, is a method for focus plant identification or characterization that can tolerate extraneous disturbances, such as vibrations of the recording layer in the focal direction, which allows larger excitation signals, and which can produce the quality factor (Q) and the resonance frequency of the focus plant.

SUMMARY OF THE INVENTION

In light of the above, therefore, an object to provide an improved method for focus plant identification or characterization.

It is another object an improved method of the type described that can tolerate extraneous disturbances, such as vibrations of the recording layer in the focal direction.

It is another object an improved method of the type described which allows larger excitation signals than previous typical in-system closed-loop identification techniques.

It is another object an improved method of the type described which can produce the quality factor (Q) and the resonance frequency of the focus plant.

These and other objects, features, and advantages will become apparent to those skilled in the art from the following detailed description, when read in conjunction with the accompanying drawings and appended claims.

Thus, according to a broad aspect of the invention, a focus plant identification or characterization method is provided for an optical disk system. The method uses a large sine wave drive signals to drive the focus lens from which focus S-curve timings are measured and used to obtain phase delay through the focus plant. The natural resonance frequency and quality factor are derived from this information. The gain factor is then obtained using the sine wave drive signal biased appropriately such that the focus S-curves occur at equal time intervals apart. AC-gain at the sine wave frequency is obtained from the ratio between the linear region gradient of the focus error S-curves and the steepest gradient of the drive signal. DC gain is finally obtained from this AC-gain at the measured resonance frequency divided by the measured quality factor.

BRIEF DESCRIPTION OF THE DRAWING

The invention is illustrated in the accompanying drawings, in which:

Fig. 1 is an electrical schematic diagram of an optical disk assembly including a focus plant, in accordance with the prior art.

Fig. 2 shows a triangular wave excitation voltage curve and resulting focus error S curves produced by a focus plant, in accordance with the prior art.

Fig. 3 is a block diagram of a system for generating a focus error (FE) signal for use in practicing the method, according to a preferred embodiment of the invention.

Fig. 4 shows a sine wave excitation voltage curve and resulting focus error S curves produced by a focus plant for determining the phase delay between the focus drive input FOC and focus error output FE, according to a preferred embodiment of the invention.

And Fig. 5 shows a sine wave excitation voltage curve and resulting focus error S curves produced by a focus plant for determining DC gain, K_f, of the focus plant, according to a preferred embodiment of the invention.

In the various figures of the drawings, like reference numerals are used to denote like or similar parts.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

According to a preferred embodiment of the invention, a method to characterize or identify a focus plant of an optical disk system is presented. As mentioned, the term "plant" is generally regarded to be the "black box" to be controlled, with controllable input and observable output, and in the context of the invention is regarded to be the "focus plant" portion of the optical pickup that contains and controls the focus lens 36 that focuses the light source 28 onto the optical disk 10 to read data therefrom, encompassing, for example, the focus coil 37, the focus lens 36, and the focus error generator 46 portions of the optical disk apparatus 5.

A preferred embodiment of the invention accomplishes the focus plant characterization or identification using an open-loop identification using large excitation magnitude to obtain a large signal-to-noise ratio, two phase measurements to obtain ω_0 and Q, and one AC-gain measurement to determine magnitude response.

More particularly, with reference to Figures 3 and 4, the method uses a large sine wave 70 drive signal applied to the head positioning actuator 42 to generate the focus error signal (FE) 48,46 to drive the focus lens 37. The sine wave 70 is therefore applied to the focus coil 37, thus generating a sinusoidal current which, in turn, generates a sinusoidal magnetic flux to move the lens holder.

Through the application of the sine wave 70 to the head positioning actuator, the phase delay between the focus drive input FOC and the focus error output FE of the focus plant at any frequency f can be measured. This is accomplished by measuring the time delay t_d between the midpoint between two successive focus S-curves 72 and 74 and next preceding extremum 76 of the input sinusoidal wave. It should be noted that the next preceding extremum may have been the negative peak 78 if the two adjacent S-curves 74 and 80 had been chosen for calculation of the phase delay. It should also be noted that the phase calculation immediately next above described assumes that the disk 10 is a single layer disk. For a multi-layer disk, each focus S-curve is replaced by a group of closely spaced S-curves, which can easily e identified as a group.

Focus S-curve timings are then measured and used to obtain the phase delay through the focus plant and hence the natural resonance frequency and quality factor. The phase response of the focal plant, $\phi(f)$ is obtained by:

$$\phi(f) = \frac{2\pi * t_d}{T} = 2\pi f t_d \qquad \text{Equation 1}$$

the transfer function G(s) of the focus plant is described by a second order model:

$$G(s)=\frac{K_f}{\left[\left(\frac{s}{\omega_n}\right)^2+\frac{1}{Q^*}\left(\frac{s}{\omega_n}\right)+1\right]}$$ Equation 2

where ω_n is the natural resonance frequency of the plant, K_f is the DC gain, and Q is the quality factor.

Substituting jω for s:

$$G(j\omega)=\frac{K_f}{\left[1-\left(\frac{\omega}{\omega_n}\right)^2+j*\frac{1}{Q*}\left(\frac{\omega}{\omega_n}\right)\right]}$$ Equation 3

At the resonance frequency $\omega=2\pi f=\omega_n$

$$G(j\omega_n)=\frac{K_f}{\left[\frac{j*1}{Q}\right]}=-jQ*K_f$$ Equation 4

Since ω=0 at DC,

$$G(0)\equiv G_0=K_f$$ Equation 5

From Equation 4, $G(j\omega_n)=\frac{K_f}{\left[\frac{j*1}{Q}\right]}=-jQ*K_f$

Equation 4the phase response of the focus plant at resonance frequency $\omega_n = 2\pi f_n$ is -90°, i.e., a quarter-period of phase delay. The natural resonance frequency is therefore determined by adjusting the sinusoidal drive signal frequency until $t_d = \frac{1}{4}*T$.

The next determination is for Q.

From Equation 3, tan(ϕ) is given by:

$$\tan\phi=\frac{-\sigma}{\left[\left(1-\sigma^2\right)*Q\right]}$$ Equation 6

Hence,

$$Q = \frac{-\sigma}{\left[\left(1-\sigma^2\right) * \tan\phi\right]}$$ Equation 7

where $\sigma = \omega/\omega_n = f/f_n$.

Using an arbitrarily value $\phi_1 = \phi$, for example, $\phi_1 = -\pi/4$, or a one-quarter period delay, and computing $\tan(\phi_1)$, in this case $\tan(\phi_1) = -1$, the frequency $f_1 < f_n$ of the sinusoidal drive signal is determined such that $\phi = \phi_1$. In this case, $\phi = \pi/4$. From equation 7, Q may then be determined as

$$Q = \frac{-\sigma}{\left[\left(1-\sigma_1^2\right) * \tan\phi_1\right]}$$ Equation 8

when, when $\phi_1 = -\pi/4$, reduces to

$$Q = \frac{-\sigma}{\left(1-\sigma_1^2\right)}$$ Equation 9

To this point, both ω_n and Q of equation 2 have been determined, leaving only $K_f = G_0$, the DC gain undetermined.

Gain at the sine wave frequency is then obtained as the ratio between the linear region gradient of the error S-curves and the steepest gradient of the drive signal. The linear region is approximately that part of the S-curve between positive and negative peaks that approximates a straight line. The gradient of the focus error at the linear region is determined as $\Delta FE/\Delta t$. Δt is arbitrarily chosen so that it encloses an interval that is within the linear region of S-curve. It should be noted that the linear region is unique as long as there is only one reflective layer, for example, such as exists in a single-layer disk. In dual-layer disks, there are multiple S-curves, each corresponding to one reflective layer being passed by the focal plane. DC gain is finally obtained from this AC-gain at the measured resonance frequency divided by the measured quality factor.

More particularly, the DC gain factor is then obtained using the sine wave drive signal 70′ at frequency f that is biased appropriately such that each focus S-curve occur an equal time intervals apart, as shown in Figure 5. Again, if a multi-layer disk is used, S-curve groups are used.

The ratio $r(\omega)$ of the gradient of the focus error in the linear region of the S-curve to the maximal gradient of the input sinusoidal signal 70′ is equal to the absolute value of $G(j\omega)$. Thus one can obtain $r(\omega_n)$ from measurements of the aforementioned gradients for any particular frequencyω_n and obtain K_f subsequently from equation 3.

In particular, if $\omega_1 = \omega_n$, then

$$|G(j\omega)| = |G(j\omega_n| = r(\omega_n) = Q * K_f \qquad \text{Equation 10}$$

Hence,

$$K_f = \frac{r(\omega_n)}{Q} \qquad \text{Equation 11}$$

With this, the identification of the focus plant of the optical disk system is complete.

The complete identification method is simple, and, for instance, can be implemented on a microprocessor to identify the focus plant from time-to-time to cope with variations of the plant parameter values due to variations in temperature, humidity, aging, etc.

Although the invention has been described and illustrated with a certain degree of particularity, it is understood that the present disclosure has been made only by way of example, and that numerous changes in the combination and arrangement of parts can be resorted to by those skilled in the art without departing from the spirit and scope of the invention, as hereinafter claimed.

CLAIMS:

1. A method for focus plant identification, comprising:

determining a phase delay through the focus plant;

determining a resonance frequency and a quality factor of the focus plant from the phase delay;

determining an AC gain at the resonant frequency; and

obtaining a DC gain by dividing the AC gain by the quality factor.

2. The method of claim 1 wherein said phase delay is determined by driving a focus lens with a sine wave signal having a sine wave frequency, measuring focus S-curve timings produced as a result of the sine wave signal, and determining said phase delay from the measured S-curve timings.
wherein said.

3. The method of claim 2 wherein said determining said phase delay from the measured S-curve timings comprises determining a midpoint between successive S-curves, determining an immediately next preceding extremum of said sine wave signal between said midpoint, and determining a time difference between said midpoint and an said extremum.

4. The method of claim 1 wherein said determining an AC gain at the resonance frequency comprises determining a ratio between a linear region gradient of the focus error S-curve and a steepest gradient of a focus plant drive signal.

5. The method of claim 1 wherein said obtaining a DC gain factor is obtained by determining a bias necessary for a sine wave drive signal to cause the focus S-curves to occur at equal time

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intervals apart, determining a ratio of a gradient of a focus error in a linear portion of the S-curve to a maximal gradient of the input sinusoidal signal, and dividing the ratio by the quality factor.