DETECTION AND SUPPRESSION OF LENS VIBRATION IN RADIAL DIRECTION DURING SEEK OPERATION ON DC/DVD DISK

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 involving optical servo systems for controlling the tracking of an optical data sensing transducer and for detecting and reducing vibrations or oscillations lens elements of the data sensing transducer.

2. RELEVANT BACKGROUND

In a typical compact disk (CD) or digital video disk (DVD) system, a data head or pickup assembly is provided to read data patterns, frequently organized in groups, or sectors, 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 lens to focus a laser beam in a beam spot on the optical disk. The beam is reflected, and is modulated by the data pattern present on the reflective surface of the disk.

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More particularly, with reference now to Figure 1, a typical conventional optical disk assembly 5 is used in conjunction with an optical disk 10, which is rotated, for example, by a spindle motor 24. An optical head 12 is movably arranged with respect to the optical disk 10, and a head driving motor 26 moves the optical head 12 in a radial direction of the optical disk 10. The optical head 12 emits a light beam 14 that is focused onto 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 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 $\lambda/4$ plate 34. The objective lens 36 converges the light beam into a beam spot on the optical disk 10. 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 plurality of tracks are formed in a radial direction on the optical disk 10. The radial track position, however, may deviate, for instance, by eccentricities of the optical disk 10 or due to positioning errors when the data is written. In addition, the focal position of the beam spot may deviate by undulations of the optical disk 10. Nevertheless, the beam spot, which may have a diameter of 1 μm or less, must follow the track, despite such deviations in the track and the focal positions.

Hence, a focus actuator 42 is provided for adjusting the focal position of the spot by moving the objective lens 36 of the optical head 12 up and down. In addition, a track

actuator 44 is provided for controlling the tracking of the beam by moving the objective lens 36 in a direction that is perpendicular to the tracks on the optical disk 10.

The focus actuator 42 is controlled by a focus servo circuit 46, which drives the focus actuator 42 so that a focus error signal, FES, which is derived from an output light detection signal of the 4-segment photodetector 40, becomes a minimum.

The track actuator 44 is controlled by a tracking servo circuit 48 during a tracking servo operation in which the light beam is controlled to follow the target track. On the other hand, the track actuator 44 is controlled by a velocity control circuit 50 during a track jump operation in which the light beam jumps to an arbitrary track for making a new access.

Random accesses of data require that the beam spot be readily movable to an arbitrary track or land/groove in a "seek" operation. This involves moving the pickup 12 and the lens 36 together, as an entire assembly. However, since the lens 36 is held in a suspension system inside the pickup, generally with springs or other linear resilient structures (not shown), the lens position may oscillate in response to abrupt acceleration or deceleration of the pickup. In the extreme, when the pickup is accelerated or decelerated very quickly, the lens suspension may be stretched beyond its elastic limit and sustain permanent damage.

In the past, attempts have been made to hold the lens in the center of the pickup using a magnetic force created by a current circulated in a radial coil 37 in the pickup. Finding the difference in the velocity of the pickup and the velocity of the beam spot senses the lens velocity,

relative to the pickup. The velocity of the pickup may be measured by external means. The beam spot velocity is derived from track crossing pulses. A track crossing pulse is created in the reflected laser beam each time the spot that is focused on the disk crosses a data track, or land/groove. Once the lens velocity relative to the pickup is determined, referred to herein as lens vibration, a negative feedback control loop can be provided to develop an appropriate radial coil drive signal to reduce the relative velocity.

This method of vibration detection and suppression has several major drawbacks. The method implicitly assumes that the track crossing pulses are due only to beam spot motion. In fact, in a rotating disk, track crossing pulses may be generated even if the beam spot is stationary. This is due to eccentricity between the center of rotation of the disk and the center of the circular data track. This results in a phenomenon called "runout" or "radial runout". Thus, circuits previously used may falsely detect vibration at the radial runout frequency, and, in trying to reduce the apparent vibration, such circuits and methods may actually cause the lens to vibrate at the radial runout frequency.

Therefore, what is needed is a method and apparatus for controlling the lens that is enabled to detect lens vibration by detecting track crossing velocity and subtracting it from the pickup velocity and the radial runout, thereby reducing error caused by radial runout, and also to that is enabled to detect and compensate for a condition in which there is little or no relative movement between the optical pickup and lens, but in which the optical pickup is experiencing an acceleration.

SUMMARY OF THE INVENTION

An advantage of the present invention is that the method and apparatus for controlling the lens is in enabled to detect lens vibration by detecting track crossing velocity and subtracting it from the pickup velocity and the radial runout, thereby reducing error caused by radial runout.

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.

According to a broad aspect of the invention, a circuit is presented for detecting a vibration of a lens of an optical pickup that is used in detecting signals along radially arranged tracks of an optical disk. The circuit includes a track crossing velocity detector and a radial velocity detector. The track crossing velocity detector produces an output signal that represents a velocity at which a lens of the pickup crosses the tracks, and the radial velocity detector produces an output signal that represents a radial velocity of the optical pickup. A radial runout velocity detector produces an output signal that represents a velocity of a radial runout of a track of the optical disk. A circuit is provided to subtract the output signal representing a radial velocity of the optical pickup and the output signal representing a velocity of a radial runout of a track of the optical disk from the output signal representing a velocity at which a lens of the pickup crosses the tracks to produce a control signal to control a radial actuator to position the lens.

Additionally provided is a feed-forward circuit to calculate an acceleration of the optical pickup and add it

to the output of the radial actuator, to provide for the case where there is no relative motion between the lens and the optical pickup, yet in which the lens is off-center within the optical pickup.

According to another broad aspect of the invention, method is presented for detecting a vibration of a lens of an optical pickup that is used in detecting signals along radially arranged tracks of an optical disk. The method includes determining a track crossing velocity at which a lens of said pickup crosses said tracks, and subtracting a radial velocity of said optical pickup and a radial runout velocity from said track crossing velocity to produce a radial actuator control signal. Additionally, a signal may be added to said radial actuator control signal that represents an acceleration of said optical pickup to control the movement of the lens when there is no relative motion between the lens and the optical pickup.

BRIEF DESCRIPTION OF THE DRAWINGS

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

Figure 1 is a block diagram of a typical optical head or transducer unit for use in conjunction with an optical disk, or the like, according to the prior art.

Figure 2 is a block diagram of a circuit for controlling the lens vibration of an optical pickup, in accordance with a preferred embodiment of the invention.

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

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

According to the present invention, a circuit and method are provided for controlling a lens in an optical pickup, and, more particularly, for detecting and

controlling lens vibration by detecting track crossing velocity and subtracting it from the pickup velocity and the radial runout, thereby reducing error caused by radial runout.

The radial runout velocity is derived from radial runout calibration data, which may be obtained, for example, by one of various methods. Two methods which may be used are shown in copending patent application serial number 09/083,001, filed _____, (Attorney docket number TI-26887) entitled USING RADIAL RUNOUT TO CALIBRATE RADIAL ACTUATOR FREQUENCY RESPONSE IN A CD/DVD PICKUP, by the inventor hereof, and assigned to the assignee hereof, said patent application being incorporated herein by reference.

In a first measurement method calibration data is stored in a lookup table and the radial runout velocity is calculated from time to time as the difference in radial runout displacements divided by a time interval. This first method is referred to as the constant linear velocity, or CLV, method. In a second measurement method, if data is stored as magnitude A and phase Φ of the radial runout of the expression (CAV) $y = A\sin(\phi + \theta)$, then the radial runout is obtained by the formula $y' = A\phi'\cos(\phi + \theta)$, where Φ' is the disk angular velocity. As will become apparent, the vibration detection and control method of the invention is valid whichever radial runout velocity estimation method is used.

More particularly, the lens vibration may be controlled by detecting track crossing velocity and subtracting from it the pickup velocity and runout velocity using a circuit 55, as shown in Figure 2, to which reference is now made.

The circuit 55 includes a track crossing velocity detector 58, and a pickup velocity detector 60. The track crossing detector 58 may operate, for example, to develop the reciprocal of the track crossing pulse period produced by the reflected light beam. On the other hand, the pickup velocity detector 62 may detect the velocity of the pickup by known means, such as a Hall sensor, or the like, on the pickup sled, or other pickup moving mechanism that produces pulses that can be timed by an associated DSP, or the like.

The output of the pickup velocity detector 62 is subtracted from the output of the track crossing velocity detector 60 by a differential amplifier 64. The output of a runout velocity detector 66, which may be constructed according to the aforementioned copending patent application serial number 09/083,001, is subtracted from the output of the differential amplifier 64 by a second differential amplifier 68. The output of the differential amplifier 68 is used to control a vibration controller 70, which may be constructed in a manner similar to that described in USP 5,673,240, which is incorporated by reference herein. The output of the vibration controller 70 causes the lens radial actuator 72 to oppose the detected velocity.

It should be noted that although the circuit 55, and method performed thereby, represent improvements over the prior art, nevertheless, the controller output may have a zero output level when the relative velocity is zero, even though the lens may not be centered in the pickup. Thus, during steady-state operation when the lens has zero velocity relative to the pickup, there is no magnetic force to keep accelerating the suspension springs to hold it in position. The amount of stretching is directly proportional

to the acceleration of the pickup. In cases where extremely fast seek is attempted, the amount of stretching might exceed the elastic limit of the suspension spring and cause permanent deformation of the spring.

Accordingly, a feed-forward controller 80 is provided, which has an output that is added to the output of the radial actuator 72 by an adder circuit 82. The frequency response of the radial actuator can be represented by the transfer function equation:

$$G(s)=\frac{K}{s^2+as+b},$$

where s = j2πf, and f is frequency.

This can be rewritten as a 2nd order ordinary differential equation that governs the radial movement of the lens:

$$\frac{d^2y}{dt^2}=Kx-a\frac{dy}{dt}-by$$

where:

y = the radial displacement of the lens from the center of equilibrium,

and x= the radial actuator input signal.

Hence Kx is the amount of lens radial acceleration due to the radial actuator.

The feed-forward controller thus calculates its output:

$$x=\left[\frac{d^2y}{dt^2}\right]_{estimate}\bullet K^{-1}.$$

Thus, the feed-forward controller 80 can obtain its input signal from the pickup velocity detector 62,as shown, or, alternatively, from a look-up table, such as in a servo controller ROM or RAM 82, as denoted by the dotted line.

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 detecting a vibration of a lens of an optical pickup that is used in detecting signals along radially arranged tracks of an optical disk, comprising:

determining a track crossing velocity at which a lens of said pickup crosses said tracks;

subtracting a radial velocity of said optical pickup and a radial runout velocity from said track crossing velocity to produce a radial actuator control signal.

2. The method of claim 1 further comprising adding a signal to said radial actuator control signal that represents an acceleration of said optical pickup.

3. The method of claim 2 wherein said adding a signal to said radial actuator control signal comprises developing an acceleration signal from said pickup velocity.

4. The method of claim 2 wherein said adding a signal to said radial actuator control signal comprises developing an acceleration signal from a lookup table.

5. A circuit for detecting a vibration of a lens of an optical pickup that is used in detecting signals along radially arranged tracks of an optical disk, comprising:

a track crossing velocity detector to produce an output signal representing a velocity at which a lens of said pickup crosses said tracks;

a radial velocity detector to produce an output signal representing a radial velocity of said optical pickup;

a radial runout velocity detector to produce an output signal representing a velocity of a radial runout of a track of said optical disk; and

a circuit for subtracting said output signal representing a radial velocity of said optical pickup and said output signal representing a velocity of a radial runout of a track of said optical disk from said output signal representing a velocity at which a lens of said pickup crosses said tracks to produce a radial actuator control signal.

6. The circuit of claim 5 further comprising a vibration controller circuit connected to receive said radial actuator control signal to produce a vibration control signal, and a radial actuator connected to receive said vibration control signal to produce a radial actuating signal connected to control a radial positioning coil disposed to control a radial position of said lens.

7. The circuit of claim 5 further comprising a feed-forward circuit to produce an output signal representing an acceleration of said optical pickup, and an adder to add said output signal representing an acceleration of said optical pickup to said radial actuating signal.

8. The circuit of claim 7 wherein said feed-forward circuit is connected to develop said signal representing an acceleration of said optical pickup from said pickup velocity signal.

9. The circuit of claim 7 wherein said feed-forward circuit is connected to develop said signal representing an

acceleration of said optical pickup from a value in a lookup table.