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USING RADIAL RUNOUT TO CALIBRATE RADIAL ACTUATOR FREQUENCY RESPONSE IN A CD/DVD PICKUP

FIELD OF THE INVENTION

The present invention relates to sensing signals recorded on a disk, applying the sensed signals as an indication of track crossing and particularly for sensing signals recorded on an optical disk.

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DESCRIPTION OF PRIOR ART

In an optical disk apparatus or an optical magnetic disk apparatus, the disk medium is displaced in the lateral direction, namely, in the disk radius direction because of the eccentricity between the center of the tracks of the disk and the rotational center of the motor rotating the disk. Thus, the light beam position is controlled in the disk radial direction for adjustment so that the beam spot or the light beam may be always positioned on the information track by moving the beam spot or light beam to follow the displacement of the information track on the disk. Also, positioning controlling, for example, access controlling, is performed on the beam spot at a high speed with high accuracy to get the selectable tract of the entire disk radius zone.

Generally, among the well-known mechanism for beam spot control, there is a mechanism in which the objective lens supported by four leaf springs is driven vertically and laterally by a magnetic force, a mechanism which moves horizontally the lens by magnetic force to laterally displace the beam spot position or mechanism which drives an optical head, supported by the slide bearing, in the lateral direction by an magnetic force.

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The radial controlling operation is performed by feedback controlling operation of sensing the relative displacement, for example, radial error between the information track on the optical disk and the beam spot by the method of passing the radial error signal through the phase lead compensating circuit, thereafter feeding it into the radial actuator driving circuit to drive the actuator. The phase lead compensating circuit is a circuit for improving stability of the feedback controlling system.

Typical lens construction is a lens that is mounted as a spring mass. Typically, four wires, which are elastic but stiff and constructed of metal, such that the force imparted to the lens is a constant multiplied by a displacement. Additionally, a coil is mounted around the lens holder to conduct a current through this coil. Thus, the coil and lens holder move together in a direction in opposition to the spring force. Typically, the sum of these factors result in a delay in the movement of the lens. Thus, if the movement of the lens is represented by sinusoidal motion, the actual movement of the lens is again a sinusoidal but delayed in phase. This phase is important to anticipate the delay and correspondingly remove the delay of the lens.

Additionally, the lens may wear and the delay may change as a response to the wear.

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One of the difficulties in moving the lens arises from the eccentricity in disk rotation combined with approximately 1.6 μm for CD and 0.74 μm for DVD intertrack spacing.

When starting to play back a disk, optical disk players, such as CD players or DVD player, read and store beforehand TOC (Table of Contents) data from a read-in area of the currently set disk. Upon access to a desired track based on a search command, the micro-processor in the optical disk player first calculates the currently read sub-code Q-data to find the current track number and then the number desired tracks. The difference between the two track numbers allows the microcomputer to find the number of tracks to be jumped. Accordingly, the microcomputer drives the optical system of the player to jump the calculated number of tracks in order to reach the target track. The need to count the number of tracks jumped upon jump operations requires detecting the traverse operation of the optical pickup spot across tracks. With the spreading use optical disk drives units as an external storage for computers, the demand for a compact and high speed unit has increased.

Data storing disks employ circular or spiral tracks on which data is recorded. Transducers such as magnetic read/write heads, laser read/write assemblies, and the like, must maintain registry with those tracks within relatively close tolerances.

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The ideal data storage disk contains a plurality of concentric data tracks that are perfectly circular or spiral in character when established and remained that way indefinitely. Such ideal data tracks are rarely created in disk manufacture and even more rarely remain circular in contemporary operating environment.

The lack of circularity in the data tracks is known in the industry as runout or radial runout. If it is too great, the transducer controlling the lens may not have adequate reacting capability to response so as to maintain data interfacing registry. Further even though the disk itself may rotate at a constant velocity, the runout forces the lens to accelerate and decelerate rapidly to compensate for the runout.

Fig. 6 illustrates a optical disk unit 600 for a magneto/optic disk unit. Laser source 601 emits laser beam 602. The laser beam 602 is reflected through a mirror 603. The laser beam 602 is subsequently focused through objective lens 604. Actuator 605 provides focus controlling operation and radial controlling operation which drives the objective lens 604 vertically and laterally to follow and control the light spot position of the laser beam 602 on the record track of the disk record medium. Optical head 606 accommodates these optical systems. The linear motor 607 drives the optical head laterally to perform the radial controlling operation or the recorded access

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operation into the track position of the object. Optical disk 608 is a magneto/optic disk with recording medium 608. Motor 609 rotates and drives the disk and support base 6010 supports the above apparatus.

Fig. 7 is a block diagram of the controlling system. In Fig. 7, reference X_D is the disk displacement reference at X_1 is the object lens displacement to indicate the amount of displacement of the radial actuator 605, X_E is a follow up error, reference D_E to indicate the error between the actual position and the target position of the lens and is a detector which converts the follow up error X_E into an electric signal, reference P is a phase compensating circuit for performing the stable control. Reference Go is an actuator for driving and displacing the object lens and reference Do is a driver for driving Go.

As can be seen, tracking is controlled by a closed loop feed back circuit which measures the tracking error and outputs a tracking control signal to move the track actuator to correct the signal error. The unevenness of the radial tracking due to radial runout

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introduces error and delay into the operation of the lens. The forces that effect the lens are:

$$\frac{d^2 X_E}{dt^2} = -kX_E - \frac{hdX_E}{dt} + au$$

- kX_E is the spring force
- hdX_E/dt is the friction force
+ au is the magnetic force on the lens mass

The radial actuator's frequency response should be known with sufficient accuracy so that the controller can be designed and tuned to produce the highest tracking and seek landing performance without risking stability.

This frequency response can be measured on the factory floor and subsequently the proper, optimal coefficient values for the controller is stored in a memory device. Unfortunately, such method has problems adapting to changing temperature, humidity, aging and different seating orientation of the drive. Thus, a method is needed that can measure this frequency response automatically under normal operation, such as when a disk is started.

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SUMMARY OF THE INVENTION

An object of the present invention is to measure the phase response of the radial actuator at any frequency up to the maximum rotation frequency of the disk. A second object of the present invention is to measure the magnitude response of the radial actuator and any frequency up to the maximum rotation frequency of the disk. The phase response is determined by obtaining the radial runout magnitude. The phase response is determined by using the nominal transfer function of the radial actuator. Then, calculate or determine the magnitude of a sinusoidal voltage signal to drive the actuator in order to move the radial actuator in the radial direction a distance of the radial runout magnitude divided by a fraction. Next, drive the radial actuator with a sinusoidal voltage with a magnitude equal to the calculated magnitude (A). Next, the phase of the sinusoidal voltage is adjusted so that the phase of the radial actuator is the same as the phase of the actual radial runout. This is the phase where the apparent radial runout is minimal. The apparent radial runout is the minimum apparent radial runout.

The maximum apparent radial runout is obtained by shifting the phase 180° from the phase of the apparent radial runout.

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Magnitude response is the ratio of the difference between the original or actual radial runout and the minimal apparent radial runout to the calculated magnitude A.

Phase response is the difference between the phase of the original or actual radial runout and the phase of the sinusoidal voltage at the minimal apparent radial runout.

This procedure is repeated for a set of predetermined disk rotation frequencies. Alternatively, the set of rotation frequencies can be determined online by, for instance, having denser spacing where phase response changes rapidly with respect to frequency.

This is the phase of the radial actuator to place the radial actuator in phase with the radial runout.

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BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates a diagram of the present invention;

Fig. 2 illustrates a circuit diagram of the present invention;

Fig. 3 illustrates another circuit diagram of the present invention;

Fig. 4 (a-i) Illustrates waveforms of the present invention;

Fig. 5 illustrates a waveform of the radial runout.

Fig. 6 illustrates a reproduction system.

Fig. 7 illustrates a feedback system.

Fig. 8 illustrates a response curve.

Fig. 9 illustrates a method of the present invention.

Fig. 10 illustrates a second method of the present invention.

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DETAILED DESCRIPTION OF THE INVENTION

The present invention measures both direction and magnitude of the radial runout and corrects the actuator based on the radial runout.

As illustrated in Fig. 1, a track 110 is centered about a track center 120. The offset of track 110 is due to radial runout. The track 110 is offset from the center of the disk 130 by an amount of the radial runout A. The pickup 100 moves along the track 110 from the center of the disk 130 by an angle θ.

Fig. 1 is a block diagram of a tracking servo system for controlling jump or radial runout operation.

In Fig. 2, the information recorded on disk 200 is read by pickup device 260 as an information signal. The pickup device 260 as a result of the read operation and in response to the information signal generates an RF signal which is input to the RF amplifier 210. Additionally, the pickup 260 sends the information signal on disk 200 to the TE signal generating circuit 270. The tracking error generating circuit 270 generates a tracking error (TE) signal based on the output of pickup 260. The TE signal has an 's' curve characteristic such as shown in Fig. 4c. The TE signal is input to the track traverse detecting circuit 220. Additionally, the RF signal is output from the RF amplifier 210 is input to the track traverse detecting

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circuit 220. Output from the track traversed detecting circuit 220 is a EFI signal which is input to micro-processor 230. The micro-processor 230 a dedicated circuit or DSP outputs a signal to the tracking controller 240. Accordingly, the tracking controller 240 operates a tracking actuator 250 to move the pickup 260 across the disk 200. Fig. 3 illustrates the RF signal and the TE signal which are sent to the MIRR generating circuit 320 and the TZC generating circuit 350, respectively.

The mirror signal generating circuit 320 generates an heightened level signal as illustrates in Fig. 4b by detecting a mirror face between tracks (pit area) on the disk 200. The MIRR signal is a signal that goes high when the optical spot is irradiated at the disk mirror face (area between tracks or pit arrays) and which goes low when the optical spot is irradiated at a track. The TZC signal as illustrated in Fig. 4d is generated as the sine signal of the TE signal is captured, the TE represents the deviation of the optical spot from any of the tracks or from any mirror area therebetween. When the TE signal is zero, for example, when the optical spot is located precisely on a track or on a mirror face, the TZC signal goes from high to low or vice versa.

During a traverse operation, a TZC edge signal, as illustrated in 4e, is generated at a time when a mid-point is reached between a high and a low period of the MIRR signal by edge detecting circuit 340. This TZC edge signal occurs substantially 90° between a change in the MIRR signal.

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Furthermore, the MIRR edge signal occurs substantially 90° between a change in the TZC signal. However, delays in digitizing the TE signal and delays resulting from the sampling by the A/D converter combine to delay the MIRR signal in phase. Likewise, delays in digitizing the TE signal and delays resulting from the sampling by the A/D converter combine to delay the TZC system in phase.

The TZC signal generating circuit 350 generates the TZC signal by detecting the zero crossing of the TE signal. The TZC signal is input to the edge detecting circuit 340. The TZC edge as illustrated in Fig. 4d is input to the micro-processor 230. Additionally, the MIRR signal is output by the MIRR signal generating circuit 320 and input to the edge detecting circuit 330. The edge detecting circuit 330 detects the leading and trailing edges of the MIRR signal. The output of the edge detecting circuit is the MIRR edge signal as illustrated in Fig. 4f and is input additionally into the micro-processor 230.

Fig. 5 illustrates a graph illustrating the motion of the beam 100 with radial runout of the pickup 260. The radial motion or radial runout can be modeled as simple harmonic motion where $y = A \sin \theta$ and the velocity, $v = dy/dT = (2\pi/T) A \cos \theta$ where y is the radial displacement from the center of motion or the lens, v = radial velocity, T = period of rotation of the disk and A = ½ of the peak to peak runout magnitude. θ equals the

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angle of rotation away from the orientation where the motion starts going outwards from the center of motion.

In actuality, θ can be measured from a center of the motor driving the disk. The motor shaft typically includes hall sensors, for example typically 3 hall sensors, located around the shaft at each 30° increment. Additionally, a clock generator used with the hall sensors may be used to determine a more precise location of the shaft and may be set to generate 360 clock pulses for a given complete revolution of the motor and disk. Thus, θ can be accurately measured.

The peak-to-peak magnitude,

n is timer count (instances)

N is a timer count between successive hall sensor pulses

$$D\theta = \frac{360^{\circ}}{18} X \frac{n}{N}$$

of the radial runout can be determined by rotating the disk at a constant angular velocity. The pickup device 260 remains stationary in the radial direction, and the magnitude of the radial runout can be measured by either using the TZC signal and the MIRR signal. A count pulsing circuit or a DSP circuit can be used to count the number of high pulses of the

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TZC signal per disk rotation and the radial runout magnitude is equal to (half) ½ the number. Alternatively, a pulse counting or DSP could count the number of MIRR pulses from the MIRR signal per disk rotation and again the radial runout magnitude would be half this number. Alternatively, a pulse counting circuit or DSP could count the number of TZC high pulses or, but not both, MIRR high pulses that occur between the direction reversal of track crossings. The polarity phase difference, (phase (MIRR) - phase (TZC) = ± 90) indicates track crossing direction.

Alternatively, a circuit or DSP could measure the period of time between successive track crossings. The period should vary in a periodic fashion reaching a maximum of twice per disk rotation and additionally reaching a minimum per disk rotation. The DSP then counts the number of track crossings between successive maximum or between successive minimum, This number is the radial runout magnitude. Alternatively, a track count circuit that counts up or down depending on the inward/outward track crossings the DSP or an appropriate hardware circuit detects the maximum and minimum of track count. The difference between the maximum and minimum is the radial runout magnitude. To determine the direction of the radial runout, Figs. 4G, H, and I illustrate a procedure. The direction can be determined by evaluating the edge pulses from both the edge detecting circuit 330 and the edge detecting circuit 340. The edge detecting circuit 330 provides an indication of an edge of the TZC signal by generating a TZC edge signal. The edge detecting circuit

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340 as illustrated in Fig. 4g provides an indication of an edge of MIRR signal by generating a mirror edge signal. The edge pulse from the edge detecting circuit 330 indicated by an 't' should alternate with respect to the edge pulses from the edge detecting circuit 340 and indicated in Fig. 4g by the symbol 'm'. For example, the series of edge pulses m t m t m t indicates that the direction has not changed. In contrast as illustrated in Fig. 4h, a sequence m t t t m indicates a direction change. More specifically, the two successive 'tt' indicate that the radial runout has reversed direction. Likewise, in Fig. 4i, the sequence is m t m t m m t. The successive two edges 'm' and 'm' indicate a reversal in the direction. Thus, we have seen how the magnitude of the radial runout can be determined.

The radial runout magnitude, Y, and the direction θ, is obtained in accordance with the above procedure. The transfer function, for example the response characteristic of the actuator to an input signal is supplied by a manufacturer and can be used by the present invention by storing the transfer function in a memory that is located in and accessed by the CPU 230.

The phase measurement of radial runout is determined using one of the following methods:

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Curve 930 represents the output of radial actuator under minimal radial runout condition. The phase of curve 930 must agree with the phase of actual or original radial runout.

Curve 902 is the input validity signal to the radial actuator which is known.

This transfer function is typically expressed in terms of magnitude and phase of frequency response. Using the transfer function of the radial actuator from the manufacture, calculate the magnitude of a sinusoidal voltage signal to be input into the radial actuator to move the radial actuator in a radial direction a distance, Y/2. (Y is the magnitude of the radial runout.) While Y/2 is chosen for the present invention, any fraction of Y could be chosen. This is magnitude B(B = Y/2). Next, the radial actuator is driven with a sinusoidal voltage having a peak magnitude B, and the apparent radial runout magnitude C is determined. Because of radial runout the lens will not move a distance Y/2 but a distance C. As illustrated in Fig. 9, the phase is adjusted by moving curve 900 to the position of curve 920 and then to the position of the curve 930. This could be performed by a degree by degree procedure by measuring the distance D between first curve 900 and 910, then between curve 920 and 930 and lastly between curve 930 and 910. When the curve 910 has been adjusted to curve 930, it is noted that the maximum of 930 is directly under the

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maximum of curve 910. Consequently, the distance D is the smallest distance. Thus, the phase difference between curve 930 and 902 is the phase response of radial actuator at a given frequency of the actuator input. Curves 900, 920 and 930 represent output of radial actuator given different amount of phase delay of voltage input of the radial actuator. This is measured by the number of degrees θ needed to move curve 900 to curve 930.

To determine the magnitude response of the radial actuator, a similar method is employed. First, the disk is rotated at a given frequency. Next, the radial runout magnitude, for example, Y, is determined. The amplitude, D of a sinusoidal voltage signal to be "input" into the radial actuator, is determine by using the transfer function of the radial actuator by calculating the magnitude to move the radial actuator in the radial direction with a distance Y/2.

As described above, measure the apparent radial runout magnitude by adjusting the phase until the apparent radial runout magnitude E is minimum.

Curve 930 is moved along the 'x' axis until positioned as illustrated by curve 940 is obtained. The movement is accomplished the same way as previously explained. Next, as illustrated in Fig. 10, the phase difference between curve 940 and curve 950 is 180° and a

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maximum apparent radial measurement F is obtained by measuring the distance between the two curves (940 and 950). The distance F is the maximum distance between the curve 940 and curve 950. Thus, the magnitude response equal track pitch times the max apparent radial runout F minus the minimum apparent radial runout E divided by 2A. Thus, this magnitude and phase is input to the radial actuator in order to bias the lens to avoid the displacement of the lens due to radial runout.

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CLAIMS

1. A circuit to detect radial runout, comprising:

a disk subject to radial runout and having at least one track;

a circuit to detect a magnitude of said radial runout based on said at least one tracking crossing;

a circuit to detect a phase of said radial runout for a device based on said magnitude of said radial runout.

2. A circuit to detect radial runout as in Claim 1 whereas:

said phase is determined by a phase difference between the phase of the device and a maximum apparent radial runout.

3. A circuit to detect radial runout, as in Claim 1, whereas:

said circuit to detect a phase including a circuit to detect a magnitude.

4. A circuit to detect radial runout as in Claim 1, whereas:

said phase of said device is moved forward to a maximum apparent radial runout.

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