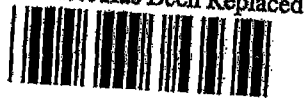
USING RADIAL RUNOUT CANCELLATION TO REDUCE TRACKING ERROR IN CD/DVD SYSTEMS

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 as an indication of an error signal for a radial actuator.

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DESCRIPTION OF PRIOR ART

In an optical or magneto-optical disk apparatus, during disk rotation, the information tracks on the disk are 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 spot position needs to be controlled in the disk radial direction for adjustment so that the beam spot is 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.

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 operation into the track position of the object. Optical disk 608 is a magneto/optic disk with recording medium 608.

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Motor 609 rotates and drives the disk and support base 6010 supports the above apparatus.

The ideal data storage disk contains a plurality of concentric data tracks that are perfectly circular or spiral. However, when installed into the playback unit and rotated, the center of concentric data tracks rarely coincides with the center of rotation of the disk due to limitation in mechanical alignment such as, for example, where a disk tray is used to load the disk into the playback unit. The lack of coincidence between the center of concentric data tracks and the center of rotation of the disk is known in the industry as eccentricity.

As a result of eccentricity, during rotation of the disk, data tracks move radially inwards and outwards repeatedly at a period equal to the period of rotation of the disk. This is a phenomenon known as repeatable radial runout in the industry. If it is too great, the radial position control system may not have adequate reacting capability to respond while maintaining data interfacing registry within a deep-sub-micron tolerance.

Radial position control is typically performed by feedback control operation of sensing the relative displacement, for example tracking error, between the information track on the optical disk and

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the beam spot by the method of passing the tracking error signal through the phase compensating circuit, thereafter feeding it into the radial actuator driving circuit to drive the actuator. The phase compensating circuit is a circuit for improving stability of the feedback controlling system.

As illustrated in Fig. 12, a feedback circuit is used to correct for errors in tracking. This, feedback circuit 1240 includes a track error detecting circuit 1220, which inputs a feedback error signal X_E and outputs a TE signal indicating the tracking error measure based on the track crossings. This TE signal is input to an output-feedback controller 619, which converts the TE signal into electric signals for the radial driver 607. The electrical signals are output from the output-feedback controller 1210 and input into the radial driver 670 in order to drive the radial actuator 605. The radial actuator 605 outputs the beam spot radial displacement X_A. This beam spot relative radial displacement X_E from the track center is the difference between beam spot radial displacement X_A and track radial displacement X_R, herein symbolically represented by subtracting circuit 1230. During tracking, X_E is much smaller in magnitude than either X_R and X_A such that $X_A \approx X_R$. Hence

$$X_E = X_R \times L_r^{-1} \qquad \text{Equation 1}$$

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where L_r is equal to the open loop gain magnitude at the disk rotation frequency. Typically, $L_r < (\omega_0/\omega_L)^2$, as Fig. 13 illustrates. For example, with a radial runout of 70 microns amplitude and a rotation frequency ω_R of 150 Hz and a unity gain frequency ω_0 of 2 kHz, the residual tracking error is:

$$X_E > 70 \text{ microns}/178 = .39 \text{ microns}, \qquad \text{Equation 2}$$

which exceeds the maximum tolerance tracking error of 0.025 microns.

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. However, the residual tracking error becomes greater as the tracking disturbance frequency becomes higher. This frequency becomes higher as disk is rotated faster, as is often the case in computer applications. This problem was in the past solved by increasing the unity-gain frequency ω_0. However, due to inherent imperfection in the construction of the lens holder and spring system, parasitic resonance exists in the radial actuator above 10kHz, and it becomes difficult to stabilize the feedback control system as a result. There is therefore a need to solve this problem in a fundamental way.

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Typical lens construction is a lens that is mounted on a spring mass. Typically, four wires, which are elastic but stiff and constructed of metal, such that the spring force imparted to the lens is a constant multiplied by a displacement. Additionally, a coil is wound around the lens holder to conduct a current through this coil, and a stationary permanent magnet is mounted on the pickup body. The two terminals of the coil is typically brought outside of the pickup body so that a voltage applied across these two terminals result in a current directly proportional to the voltage applied. The magnetic force exerted on the lens holder is directly proportional to the current in the coil, thus providing a means for externally controlling the additional force applied to the lens and lens holder. Furthermore, between the lens holder and the stationary pickup body there is typically provided damping material to provide frictional force opposing the motion of the lens holder relative to the pickup body. The equation of motion of the lens is:

$$m\frac{d^2y}{dt^2} = -ky - h\frac{dy}{dt} + au$$

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where

m = total mass moving together with the lens

$k.y$ = spring force

$h.dy/dt$ = frictional force

au = magnetic force on the lens mass

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A salient characteristic of the equation of motion is that output displacement y is not directly proportional to applied force au. In fact, there is a delay from input to output that varies with input frequency. Unless the delay through the radial actuator is precisely known, there is difficulty to applying feed forward control to move the lens in a predetermined phase even if the radial runout to be followed is precisely known. Hence there is a need to identify the phase delay through the radial actuator.

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SUMMARY OF THE INVENTION

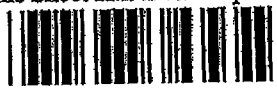
The present invention provides a method and apparatus for detecting and accurately measuring the magnitude and phase of radial runout by employing signals indicating the track crossings. These track crossings may be represented by either TZC or MIRR signals. Additionally, the direction of the track crossings can be determined from the interaction of two signals. In particularly, these two signals could be the TZC signal or the MIRR signal. The present invention uses the phase difference between the TZC signal and the MIRR signal to determine a reversal of direction of the track crossings.

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. An additional 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. This phase response and magnitude response of the radial actuator is used to calibrate the actuator to reduce the tracking error of the lens.

The phase response is determined by using the function of the radial actuator. Then, calculate or determine the magnitude of a

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sinusoidal voltage signal to drive the actuator in order to move the radial actuator in the radial direction a distance of a fraction of the radial runout magnitude. Next, the radial actuator is driven 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 apparent radial runout is minimal. This is where the phase of the radial actuator is the same as the phase of the actual radial runout. The phase response of the actuator is obtained as the difference between the phase of the actual radial runout and the phase of the sinusoidal voltage.

The magnitude response is determined by obtaining the difference between radial runout magnitude before and after activating the lens in and out of phase with the actual runout and further divide by two.

The present invention measures and compensates for radial runout by activating the radial actuator in such a way as to match the actual radial runout both in magnitude and phase.

The present invention provides a feed forward circuit to work in conjunction with the feedback circuit to provide for more accurate control of the radial actuator after the frequency response of the radial actuator and the magnitude response has been determined.

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A feed forward runout canceller determines a feed forward correction signal to cancel the effects of the radial runout during tracking. This feed forward correction signal is used in combination with a feedback signal in order to provide for more accurate control of the radial actuator.

Additionally, for a system which rotates the disk at a different frequency, the magnitude and phase response of the radial actuator is determined for a finite number of frequencies and a calibration number for a feed forward canceller is input to a look-up table. During actual rotation, the actual frequency is measured and the calibration is obtained from the look-up table as used as a feed forward and again combined with the feedback control to provide a more accurate control of the radial actuator.

Additionally, the actuator magnitude and phase response may be characterized by a simple formula for which coefficients are determined by measuring the magnitude and phase response of the radial actuator and finding the best value of the coefficients to fit the measured response values. This equation is then used to calculate phase and magnitude of the radial actuator to accurately match the radial runout thus effecting a feed forward canceller.

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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;

Fig. 11 illustrates a feed forward circuit;

Fig. 12 illustrates a feedback circuit; and,

Fig. 13 illustrates a response diagram.

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DETAILED DESCRIPTION OF THE INVENTION

The present invention measures both phase and magnitude of the radial runout, and the magnitude and phase response of the actuator, and corrects the actuator based on the radial runout and the actuator frequency response.

Fig. 2 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) signals based on the output of pickup 260. The TE signal has an sine 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 circuit 220. Output from the track traverse detecting circuit 220 are TZC and MIRR signals which are input to micro-processor 230. The microprocessor 230 outputs a signal to the tracking controller 240. Accordingly, the tracking controller 240

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operates a tracking actuator 250 to move the pickup 260 across the disk 200. Fig. 4 illustrates the RF signal and the TE signal are sent to the MIRR generating circuit 320 and the TZC generating circuit 350, respectively.

The mirror signal generating circuit 320 generates a 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. Furthermore, the MIRR edge signal occurs substantially 90° between a change in the TZC signal.

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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 DSP or dedicated track counter 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 330 is the MIRR edge signal as illustrated in Fig. 4f and is input additionally into the DSP or dedicated track counter 230.

Figs. 1a and 1b illustrate the radial motion of the track near the beam spot 100. The radial motion or radial runout can be modeled as simple harmonic motion where the radial displacement of the track is

$$y = A \cdot \sin(\theta - \phi)$$

and the radial velocity,

$$v = \frac{dy}{dt} = \frac{2\pi}{T} A \cdot \cos(\theta - \phi)$$

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where

T = period of rotation of the disk.

A = ½ of the peak to peak runout magnitude.

θ = the instantaneous phase of rotation of the disk.

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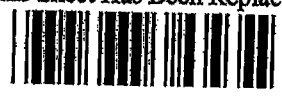
ϕ = the phase of rotation of the disk where tracks attain outermost radial displacement.

In actuality, θ can be measured from a center of the motor driving the disk. The motor shaft typically includes hall sensors, for example three hall sensors, located around the shaft at equal spacing between successively north poles. Typically, there are 6 north poles on the circular permanent magnet. Thus, each hall sensor generates 6 pulses per motor rotation resulting in 18 total pulses per motor rotation or 360/18 = 20° between pulses. 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 20 clock pulses between successive hall sensor pulses. In this case, each clock pulse would correspond to 1° of θ. Typically, a higher number of pulses would be used for greater accuracy in determining shaft position or θ. Thus, θ can be accurately measured.

The magnitude 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 or the MIRR signal or both. A count pulsing circuit or a DSP circuit can be used to count the number of high pulses of the TZC signal per

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disk rotation and the radial runout magnitude A is equal to (quarter) 1/4 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 one fourth 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 rotation, and again the radial runout magnitude would be half this number. Direction reversal of track crossing is detected by observing the phase lag/lead of TZC signal with respect to MIRR signal.

Alternatively, a circuit or DSP could measure the period of time between successive track crossings. The period should vary in a periodic fashion reaching maximum twice per disk rotation and additionally reaching minimum twice per disk rotation. The DSP then counts the number of track crossings between successive maximum or between successive minimum, and again the radial runout magnitude A would be half this number.

Alternatively, a track count circuit that counts up or down depending on the inward/outward track crossings the DSP or an

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appropriate hardware circuit detects the maximum and minimum of track count, and again the radial runout magnitude A would be half this number.

The phase ϕ of the radial runout is determined from the track crossing pulse periods. As defined earlier, ϕ = the angle of rotation of the disk where tracks attain outermost radial displacement. Furthermore, track crossing pulse periods reach their maximum twice per disk rotation when track velocity reaches zero—once when the tracks attain outermost radial displacement, and once when the tracks attain innermost radial displacement. The radial runout phase is determined by finding the two disk rotation angles where track crossing period reaches maximum, and then further by distinguishing between these two angles which one corresponds to when tracks reach their outermost radial displacement.

Fig. 5a illustrates two possible outcomes. The solid line represents first possible radial runout, and the second is a second possible radial runout, 180° out of phase with the first possible radial runout. The solid line has the outer period maximum arriving at point 525 and the inner period maximum arriving at point 527. The second possible radial runout has the inner period maximum at point 529 and the outer period maximum at point 531. The true solid runout can only be either the first possible radial runout or the

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second possible radial runout. If the first is true, the radial runout phase is t_1; if the second is true, the radial runout phase is t_2. The true radial runout should be identified for use with the present invention.

To uniquely determine the true radial runout, the radial actuator is activated to follow the first possible radial runout. The runout magnitude determined by comparing with the actual runout magnitude. If the magnitude is less than the actual runout magnitude, then, the true radial runout is the first possible radial runout. If the magnitude is greater than the actual runout magnitude, then, the true radial runout is the second possible radial runout.

Using the approximate transfer function of the radial actuator from the manufacturer, 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 actual radial runout.) While Y/2 is chosen for the present invention, any fraction of Y could be chosen.

The disk is rotated as constant angular velocity at a frequency substantially below the resonance frequency of the radial actuator so that the phase lag from the input to the output of the radial actuator

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at this frequency is substantially below 180 degrees. This ensures that, by making the input sinusoidal signal to the radial actuator follow the first radial runout, the radial actuator also follows the first radial runout without much delay.

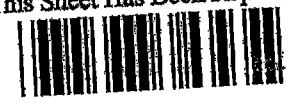
As a further refinement of the precise angles where period maxima occur, the 4 angles (t_A, t_B, t_C, t_D) at which track-crossing pulse period crosses a certain period value (T_1) somewhat less than the maximum period (T_m) are determined ($T_1 < T_m$). As illustrated in Fig. 5b, the two precise angles at which maximum period occur are given by

$$t_1 = \frac{t_A + t_B}{2}$$

and

$$t_2 = \frac{t_C + t_D}{2}$$

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The radial runout magnitude, Y, and the phase ϕ, are thus obtained in accordance with the above procedure. These data are in turn used in the following procedure to determine magnitude and phase response of the radial actuator.

The transfer function, namely the response characteristic of the actuator to an input signal, is typically represented below and is uniquely determined by the values of the 3 coefficients K, ω_o, and Q:

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$$G(s) = \frac{K}{s^2 - \frac{\omega_0}{Q}s + \omega_0^2}$$

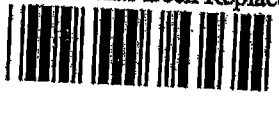
Using the nominal values of K, ω_o, and Q from the manufacturer, the peak magnitude B of a sinusoidal voltage signal to be input into the radial actuator to move the lens in a radial direction a distance, Y/2. (Y is the magnitude of the radial runout.) While Y/2 is chosen for the present invention, any fraction of Y could be chosen. B can be pre-calculated and stored in the microprocessor memory, for example.

Next, the radial actuator is driven with a sinusoidal voltage having a peak magnitude B, and the resultant apparent radial runout magnitude is determined. This is repeated until the minimal apparent radial runout is found.

Fig. 9 illustrates the phase relationship between the lens motion and the actual radial runout during this search operation. Curve 910 represents the actual radial runout, while curves 900, 920 and 930 are three different lens motion trajectories. While the phase of the sinusoidal voltage is adjusted, lens motion trajectories changes from curve 900 to curve 920 and then to curve 930. When the lens motion trajectory has been adjusted to curve 930, it is noted that the maximum of curve 930 is directly under the maximum of curve 910. Consequently, the apparent radial runout is minimal.

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This is where the lens motion phase agrees with the actual radial runout phase which is already determined by aforementioned procedure. The phase delay through the radial actuator is obtained by subtracting the phase of the actual radial runout from the phase of the radial actuator input sinusoidal voltage where minimal apparent radial runout occurs. Thus, the radial actuator phase response at this particular frequency is obtained.

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 Y is determined. The amplitude B 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 lens in the radial direction with a distance Y/2.

As described above, measure the apparent radial runout magnitude while adjusting the phase of the radial actuator input sinusoidal voltage until the minimal apparent radial runout magnitude is obtained. Represent this magnitude by E. This corresponds to lens motion trajectory curve 930 whose phase agrees with the actual radial runout. Next, adjust the phase of the input sinusoidal voltage until maximal apparent radial runout is obtained. Represent this magnitude by F. As illustrated in Fig. 10, this

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corresponds to lens motion trajectory curve 940 which is 180° out of phase with the actual radial runout. Thus, the magnitude response equals track pitch times the maximum apparent radial runout F minus the minimum apparent radial runout E divided by 2A. Track pitch for CD is given as 1.6 μm, and DVD as 0.74 μm.

The magnitude and phase response of the radial actuator are thus obtained in accordance with the above procedure. These data are in turn used in the following procedure perform radial runout cancellation and thus reduce tracking error.

As illustrated in Fig. 11, the track error detecting circuit 1220 outputs a TE signal to the radial runout detector 1130 and the output-feedback controller 1140. The MIRR generator 320 outputs a MIRR signal to the radial runout detector 1130. The track error detector 1120 outputs a TZC signal to the radial runout detector 1130. As discussed above, the radial runout detector 1130 computes the actual and apparent radial runouts. These are input to the feed forward runout calculator 1120. The disk orientation detector 1110 detects the rotation phase of the disk and outputs a signal θ to the feed forward runout canceller 1120.

After a determination of the frequency response and the magnitude response of the radial actuator, the feed forward runout

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canceller recalculates the amplitude and the phase of the sinusoidal signal to make the lens motion exactly follow the radial runout. The signal is output from the feed forward runout canceller and is indicated generally by reference U2. The output from the output feedback controller 1140 represented generally by the symbol U1 is input to summer 1150 along with the output from the feed forward runout canceller 1120. These two signals U_1, U_2 are summed and input to the radial driver 607 as described previously. Thus, a smaller tracking error is obtained by letting radial runout be cancelled by the feed forward canceller and the feedback controller only needs to cancel a smaller residue tracking error. The above description is sufficient for a constant velocity or frequency disk system to rotate at different speeds.

However, at times, the frequency of the disk can be varied to rotate at different speeds. Since the radial actuator magnitude and phase responses are functions of the frequency of input sinusoidal voltage, their exact values must be applied in the feed forward runout canceller at each frequency. In such a system, the above procedure is repeated for many frequencies at which the disk is expected to operate. These frequencies could be incremented by 5 Hertz. The results of the above procedures at different speeds could be stored in a look-up table which would store the disk frequency with a corresponding feed forward runout signal U2. Alternatively,

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the phase and magnitude responses of the radial actuator can be stored in the look-up table and the signal U2 computed therefrom during runtime. This look-up table could be stored in the memory storage 232 of the microprocessor 230. During actual tracking, additionally, the rotational speed or frequency of the disk is measured and corresponding feed forward runout signal is obtained from the look-up table and input to summer 1150.

Alternatively, from the radial actuator frequency response calibration, as described above, K, Q and ω_0 of the radial actuator transfer function can be determined. Next, the radial actuator magnitude and phase can be calculated on-the-fly for any sinusoidal input frequency by the microprocessor 230 using the above transfer function. At any rotation frequency, the actual radial runout phase subtracted by the actuator phase response gives the required canceller output phase. The actual radial runout magnitude is divided by the calculated magnitude response and this is the required canceller output magnitude. The canceller output is input to summer 1150.

The coefficients in the radial actuator transfer function, K, Q and ω_0, are determined using the following equations:

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$$G(s)=\frac{K}{s^2-\frac{\omega_o}{Q}s+\omega_o^2}$$

$$G(j\omega)=\frac{K}{-\omega^2-j\frac{\omega_o\omega}{Q}+\omega_o^2}$$

$$|G(j\omega)|=\frac{K}{\sqrt{\left|\omega^2-\omega_o^2\right|^2+\frac{\omega_o^2\omega^2}{Q}}}$$

$$\angle G(j\omega)=\arctan\left[\frac{\omega_o\omega}{Q(\omega^2-\omega_o^2)}\right]$$

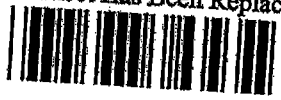
and

$$\omega=\omega_o \Leftrightarrow \angle G(j\omega)=90^\circ$$

So find ω where $\angle G(j\omega)=90^\circ$. This ω is ω_0. Then find another speed, say $\omega_1=1.5\omega_0$. Then Q is given by,

$$Q=\frac{\omega_o\omega_1}{\left(\omega_1^2-\omega_o^2\right)\tan<G(j\omega_1)}$$

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Finally, K is given by:

$$K=|G(j\omega_1)|\cdot\sqrt{\left|\omega_1^2-\omega_o^2\right|^2+\frac{\omega_o^2\omega_1^2}{Q}}$$

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* C L M S *

IN THE CLAIMS

1. A circuit to determine tracking error, comprising;

a disk;

a circuit to determine a feed forward runout signal from radial runout;

a circuit to determine a track error signal;

a circuit to combine said feed forward runout signal and said track error signal;

a radial driver to provide a drive signal based on said combined feed forward runout signal and said track error signal;

a radial actuator responsive to said drive signal to move a pick up device along said disk.

2. A circuit to determine tracking error as in Claim 1, wherein said circuit to determine said feed forward runout signal uses a lookup table.

3. A circuit to determine tracking error as in Claim 1, wherein said circuit to determine said feed forward runout signal is based on a transfer function of said pickup device.

4. A circuit to determine tracking error as in Claim 1, wherein said circuit to determine said feed forward runout signal's based on a phase of a radial runout signal.

5. A circuit to determine tracking error as in Claim 1, wherein said circuit to determine said feed forward runout signal is based on a magnitude of a radial runout signal.

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