

DESCRIPTION**METHOD AND APPARATUS FOR
READING CD-ROMS OR THE LIKE
AT MATCHING SPEEDS DETERMINED
BY DISK ECCENTRICITIES****BACKGROUND OF THE INVENTION**

This invention relates to the recovery of data from rotating data storage disks such as, typically, compact disks (CDs) used as read-only memories (ROMs) in computer systems. More specifically, the invention concerns how to determine the optimum speed of rotation for reading each CD-ROM or like data storage disk according to the particular eccentricity of that disk.

Although originally developed for consumer audio reproduction in substitution for analog phonograph records, CDs have now found widespread commercial acceptance as compact, high-speed, large-capacity ROMs for computers. The only difference of CD-ROMs from audio CDs is that CD-ROMS are driven at speeds several times as high as the standard audio CD speed (1.2-1.4 meters per second).

There have been problems left unsolved in use of CD-ROMs with high-speed CD-ROM drives in computer systems. CD-ROMs are presently being made under the same design specifications and manufacturing standards as low-speed audio CDs. Inevitably, therefore, a substantial percentage of CD-ROMs on the market are not of truly satisfactory quality for use as high-speed computer data storage media. Some have their spindle holes cut eccentrically; others have their multiturn spiral tracks not centered at the geometric center of the disk.

Such eccentric disks, particularly eccentric hole disks, are easy to vibrate when driven at a speed as high as, say, twenty times the standard audio CD speed. The disk vibration can be resolved into horizontal and vertical components, it being understood that the disk is laid horizontally. The horizontal component can overload the tracking servo of the CD-ROM drive whereby the radial position of the beam spot on the disk is maintained in alignment with the spiral data track. The overloading of the tracking servo has resulted in the overheating of the voice-coil actuator for tracking control, in the degradation of its performance and, in

1 the worst case, in the burning of the actuator coil.

2 The vertical component of disk vibration, on the other hand, can
3 cause the overloading of the beam focusing servo of the CD-ROM drive,
4 again resulting in the overheating of the focusing actuator of voice-coil
5 construction, in the degradation of its performance and, in the worst case,
6 in the burning of the focusing actuator coil. The malfunctioning, not to
7 mention total destruction, of the tracking or the focusing servo must be
8 averted by any means because of ensuing read errors and retries, which
9 is a waste of time running counter to the objective of high speed data
10 recovery for which CD-ROMs are intended.

11 Disk vibration can give rise to additional inconveniences. A vi-
12 brating disk may cause vibration of the complete CD-ROM drive and, in
13 consequence, of the hard disk drive (HDD) in particular which is current-
14 ly being preferentially built into the computer system along with the CD-
15 ROM drive. The vibration of the HDD is just as undesirable, causing
16 both read and write errors, to the detriment of the reliability of the
17 complete computer system. Even if not so excessive as to cause read
18 and write errors, the vibration of the CD-ROM drive certainly gives a
19 shoddy image of the product to the user or to prospective buyers.

20 The reader might think that all such troubles and inconveniences
21 would not manifest themselves if only high quality CD-ROMs, altogether
22 free from the physical defects pointed out earlier, were used. CD-ROM
23 drive manufacturers cannot, and should not, expect their products to be
24 used only with such high quality disks, since in the current state of
25 affairs the existence of poor quality CD-ROMs must be more or less tak-
26 en for granted.

27 Fujimoto et. al. U.S. Pat. Appln. No. 08/890924, filed July 10, 1997,
28 teaches to check the eccentricity of each CD-ROM loaded into the disk
29 drive and to read the disk at a speed matching its particular eccentricity.
30 The maximum possible reading speed according to this prior related appli-
31 cation is assumed to be eight times the standard audio CD speed. More
32 recently, however, CD-ROMs have begun to be read at as high as twenty
33 or even thirty times the standard audio CD speed. The higher the
34 speed of rotation, the more will the disk vibrate if it is eccentric. A
35 more accurate determination of the amount, and "nature", as will be later
36 explained, of the eccentricity of each disk has proved necessary for read-

1 ing only high quality disks at such ultrahigh speeds, and other disks at
2 less speeds matching their particular eccentricities.

4 SUMMARY OF THE INVENTION

5
6 The present invention has it as an object to ascertain the amount
7 and nature of the eccentricity of each disk more accurately than hereto-
8 fore and to drive the disk at a speed suiting the particular eccentricity
9 of the disk.

10 Another object of the invention is to recover data from disks of
11 varying physical qualities at the highest possible speed suiting each par-
12 ticular disk without causing read errors or retries.

13 Still another object of the invention is to make utmost use of the
14 preexisting parts and components of CD-ROM drives or like apparatus in
15 order that the inventive concepts may be implemented in such apparatus
16 without any substantial alteration of its construction.

17 Briefly summarized in one aspect thereof, the present invention
18 concerns, in an apparatus for data recovery from rotating data storage
19 disks having varying degrees of hole eccentricity and track eccentricity, a
20 method of reading each disk at a speed suiting the particular hole eccen-
21 tricity of that disk. The method comprises making a first measurement of
22 the hole eccentricity and track eccentricity of a disk in rotation at a
23 first disk eccentricity check speed, and a second measurement of the hole
24 eccentricity and track eccentricity of the disk in rotation at a second
25 disk eccentricity check speed which is higher than the first. The sub-
26 traction of the first measurement from the second measurement provides
27 the hole eccentricity of the disk, according to which a matching speed of
28 rotation for reading the disk is determined.

29 Stated in another aspect thereof, the present invention provides an
30 apparatus for carrying the foregoing method of this invention into prac-
31 tice. A rotating disk data recovery apparatus, particularly a CD-ROM
32 drive, of standard design is readily adaptable for implementation of the
33 method.

34 The invention as summarized above is based upon the fact that
35 there are two types of disk eccentricities, namely, hole eccentricity and
36 track eccentricity. Hole eccentricity is such that the spindle hole is sit-

uated off the geometric center of the disk. In track eccentricity the data track is not centered at the geometric center of the disk. Usually, both hole eccentricity and track eccentricity coexist in each disk. It is, however, hole eccentricity that causes vibration of the disk and of the disk drive upon rotation of the disk, with the intensity or amplitude of vibration increasing with disk speed. Track eccentricity, on the other hand, is no inherent cause of disk vibration, and the vibration of a disk having only track eccentricity, if any, does not increase in intensity with disk speed.

Thus the present invention advocates to measure the hole eccentricity and track eccentricity of each disk at two different disk speeds. The subtraction of the eccentricity measurement at the lower disk speed from that at the higher results in the elimination of the track eccentricity, leaving only the hole eccentricity. The hole eccentricity thus detected is solely relied upon in determination of the speed for reading the disk with a minimum of vibration and therefore a minimum of read errors and retries.

The invention is particularly well applicable to optical disk drive as typified by CD-ROM drives, such devices having a transducer for reading data recorded on each optical disk along a multiturn spiral track thereon by irradiating the disk with a beam of light. The hole eccentricity of an optical disk manifests itself during disk rotation as periodic vibration of the disk and, in consequence, periodic departures of the light beam from the track to an extent proportional to the speed of disk rotation. The track eccentricity manifests itself during disk rotation as periodic departures of the light beam from the track to a constant extent regardless of the speed of disk rotation.

In optical disk drives, therefore, the hole eccentricity and track eccentricity of each disk are measurable from a tracking error signal or a tracking actuator drive signal, since these signals both include a component indicative of periodic departures of the light beam from the track. The tracking error signal and the tracking actuator drive signal may be utilized either individually or in combination for eccentricity measurement. Either way the eccentricity measurement from these signals is preferred to, for instance, the provision of an eccentricity or vibration sensor because the signals are both produced by parts of the standard tracking

1 servo incorporated in optical disk drives.

2 Optical disk drives have an additional source from which eccentric-
3 ity measurement is possible according to this invention. That source is
4 transducer output pulses each produced as the light beam crosses a track
5 turn. With the tracking servo turned off, the first and the second meas-
6 urements of the hole eccentricity and track eccentricity are made by
7 counting the transducer output pulses during at least one complete revo-
8 lution of the disk at the first and the second eccentricity check speeds,
9 respectively. The hole eccentricity of the disk is obtained by subtract-
10 ing the first measurement from the second. The counting of transducer
11 output pulses is also recommenced as it dispenses with an eccentricity or
12 vibration sensor.

13 The above and other objects, features and advantages of this in-
14 vention and the manner of realizing them will become more apparent, and
15 the invention itself will best be understood, from a study of the follow-
16 ing description and appended claims, with reference had to the attached
17 drawings showing some preferred embodiments of the invention.

18

19 *BRIEF DESCRIPTION OF THE DRAWINGS*

20

21 FIG. 1 is a block diagram of the CD-ROM drive constructed in ac-
22 cordance with the novel concepts of this invention for carrying out the
23 disk eccentricity check method, the CD-ROM drive being shown together
24 with a computer with which it is incorporated;

25 FIG. 2 is a schematic electrical diagram showing in more detail the
26 transducer, tracking servo circuit, and focusing servo circuit of the FIG.
27 1 CD-ROM drive;

28 FIG. 3 is an equivalent block diagram of the system controller in-
29 cluded in the FIG. 1 CD-ROM drive, showing in particular the means pos-
30 sessed by the controller for implementation of the disk eccentricity check
31 method according to the invention;

32 FIG. 4 is a schematic electrical diagram showing the lowpass filter
33 of the FIG. 3 system controller in more detail;

34 FIG. 5, consisting of (A) and (B), is a waveform diagram showing
35 the track eccentricity components included in the tracking error signal of
36 the FIG. 1 CD-ROM drive when the disk is driven at two different

1 speeds for eccentricity measurement;

2 FIG. 6 is a plan view of a CD-ROM having hole eccentricity;

3 FIG. 7 is a plan view of a CD-ROM having track eccentricity;

4 FIG. 8 is a flow chart of the disk eccentricity check program ac-
5 cording to the present invention, to be executed in the FIG. 1 CD-ROM
6 drive;

7 FIG. 9 is a block diagram of another preferred form of CD-ROM
8 drive according to the invention;

9 FIG. 10 is an equivalent block diagram of the system controller
10 included in the FIG. 9 CD-ROM drive, showing in particular the means
11 possessed by the controller for implementation of a modified disk eccen-
12 tricity check method according to the invention;

13 FIG. 11 is an equivalent block diagram of a system controller for
14 use in the FIG. 9 CD-ROM drive in substitution for the FIG. 10 system
15 controller, showing in particular the means possessed by this alternate
16 controller for implementation of another modified disk eccentricity check
17 method according to the invention;

18 FIG. 12 is a block diagram of a yet another preferred form of
19 CD-ROM drive according to the invention;

20 FIG. 13 is an equivalent block diagram of the read circuit and the
21 system controller included in the FIG. 12 CD-ROM drive, showing in par-
22 ticular the means possessed by the read circuit and the system controller
23 for implementation of a further modified disk eccentricity check method
24 according to the invention; and

25 FIG. 14 is a schematic electrical diagram of an analog lowpass fil-
26 ter for use in place of digital lowpass filters used in the foregoing em-
27 bodiments.

28

29 *DESCRIPTION OF THE PREFERRED EMBODIMENTS*

30

31 *Apparatus*

32

33 The present invention is believed to be best embodied in the
34 computer system diagramed in FIG. 1, which shows a computer 1 connected
35 to a CD-ROM drive 2 by way of a bus 3. The CD-ROM drive 2 is
36 shown loaded with a CD-ROM or optical data storage disk 4. The CD-

1 ROM 4 will be hereinafter referred to as the disk, and the CD-ROM
 2 drive 2 as the disk drive, for simplicity. The disk 4 is shown disposed
 3 in a preassigned data recovery position by receiving in its center hole 17
 4 a drive spindle 16 shown as an armature shaft of an electric disk drive
 5 motor 5. As far as the present invention is concerned, the disk 4 is
 6 "loaded" in the disk drive 2 when it is on the drive spindle 16, as pic-
 7 tured in FIG. 1, and "unloaded" when it is moved out of engagement
 8 with the drive spindle.

9 Other primary components of the disk drive 2 include an optoelec-
 10 tric transducer or pickup 6, a transducer transport means 7, a disk drive
 11 motor servo circuit 8, a read circuit 9, an interface circuit 10, a system
 12 controller 11 which may take the form of a microprocessor or digital sig-
 13 nal processor, a disk drive motor speed sensor 12, a focusing servo cir-
 14 cuit 13, a tracking servo circuit 14, and an analog to digital converter
 15 (ADC) 15 for use in detection of the eccentricity of each loaded disk 4
 16 according to this invention.

17 As depicted diagrammatically in FIG. 2, the disk 4 can be of the
 18 standard CD-ROM design having data prerecorded thereon in the form of
 19 minute bumps or pits impressed into the disk surface along a multiturn
 20 spiral track 18. Ideally, the data track 18 is centered about the spindle
 21 hole 17, and this spindle hole is at the geometric center of the disk.
 22 Practically, however, the data track may not be centered about the spin-
 23 dle hole or about the geometric center of the disk, and the spindle hole
 24 may not be centered on the disk. The present invention seeks to find
 25 the speed of rotation matching the hole eccentricity, rather than the track
 26 eccentricity, of each disk. More will be said presently about such track
 27 eccentricity and hole eccentricity.

28 In CD-ROMs, as in audio CDs, the current practice is to record
 29 data at constant linear velocity (CLV), rather than at constant angular
 30 velocity (CAV), and to read the data at either CLV or CAV. For CLV
 31 reading of the disk the angular velocity of the disk is increased as the
 32 disk track is scanned radially outwardly by the transducer.

33 As shown in detail also in FIG. 2, the transducer 6 is of prior
 34 art construction having a light source such as a diode laser 19, a dif-
 35 fraction grating 20, a beam splitter 21, a collimator lens 22 for providing
 36 parallel rays of light, a quarter wavelength plate 23, an objective lens 24,

1 a semicylindrical lens 25 disposed on the path of the light that has been
 2 reflected back from the disk 4 and subsequently separated from the inci-
 3 dent light by the beam splitter 21, a photodetector 26, a focusing actua-
 4 tor 27, and a tracking actuator 28.

5 Converged by the objective 24, the light from the laser 19 hits
 6 the surface of the disk 4. It is understood that in the illustrated trans-
 7 ducer 6, the diffraction grating 20 creates a primary beam, used for both
 8 reading and focusing control, and two auxiliary beams for tracking control.
 9 FIG. 2 shows only the primary beam spot on the disk 4 at 34, and the
 10 two auxiliary beam spots at 34a and 34b. The unmodulated primary beam
 11 on hitting the disk surface will be modulated by the pattern of optical
 12 pits representative of data, and this modulated primary beam, as well as
 13 the reflected auxiliary beams, will be directed by the beam splitter 21
 14 into the photodetector 26 via the semicylindrical lens 29. The arrow des-
 15 ignated 29 indicates the reflected primary beam thus irradiating the pho-
 16 todetector 26, and the arrows 29a and 29b the two reflected auxiliary
 17 beams for tracking control purposes.

18 Capable of translating the incident light beams into electric signals,
 19 the photodetector 26 is shown to have a closely packed group of four
 20 photosensitive sections designated A, B, C and D, both for data recovery
 21 and for focusing control, and two other separate photosensitive sections E
 22 and F for tracking control. The photodetector sections A and B, as well
 23 as the sections C and D, are divided along a line extending essentially
 24 tangentially of the disk track 18, as indicated by the arrow 30. The
 25 other two photodetector sections E and F are aligned in the direction of
 26 the arrow 30. The reflected primary beam 29 irradiates the sections A-D,
 27 and the reflected auxiliary beams 29a and 29b the sections E and F,
 28 respectively.

29 The focusing actuator 27 is shown as a voice coil actuator com-
 30 prising a moving coil 31 coupled to the objective 24, and a permanent
 31 magnet 32. The objective 24 moves back and forth perpendicular to the
 32 disk surface, as indicated by the double headed arrow 33, in response to
 33 bidirectional current flow through the moving coil 31. The beams will
 34 thus be kept focused on the disk surface.

35 The tracking actuator 28, which functions to maintain the read
 36 beam spot 34 in centerline alignment with the disk track 18, is also

1 shown as being of voice coil construction comprising a moving coil 35
 2 coupled to the objective 26, and a permanent magnet 36. The objective
 3 26 moves back and forth parallel to the disk surface, as indicated by the
 4 double headed arrow 37, in response to bidirectional current flow through
 5 the moving coil 35. The tracking actuator 28 serves the additional pur-
 6 pose of jumping the beam spot to a desired track position during seek
 7 operations. Such spot jumping will take place as a jumping signal is
 8 applied from the system controller 11, FIG. 1, to the moving coil 35 via
 9 the tracking servo circuit 14.

10 The four photodetector sections *A-D* are all connected to the fo-
 11 cusing servo circuit 13 and thence both to the moving coil 31 of the fo-
 12 cusing actuator 27 and, via an adder 53, to the read circuit 9, FIG. 1.
 13 The focusing servo circuit 18 comprises two adders 38 and 39, a sub-
 14 tracter 40, an on-off switch 41, and a phase compensator and driver cir-
 15 cuit 42. The adder 38 adds the outputs from the photodetector sections
 16 *A* and *C*, and the other adder 39 the outputs from the photodetector sec-
 17 tions *B* and *D*. The subtracter 40 subtracts the output from the adder
 18 39 from the output from the adder 38. The resulting output from the
 19 subtracter 40 is a focusing control signal, which is applied via the
 20 switch 41 and phase compensator and driver circuit 42 to the moving coil
 21 31 of the focusing actuator 27. The objective 24 will thus be moved
 22 toward or away from the disk surface to keep the read beam focused
 23 thereon.

24 The focusing method set forth above is known to the specialists
 25 as the astigmatic method. The switch 41 is operated by a signal sup-
 26 plied from the system controller 11 over a conductor 43, and the phase
 27 compensator and driver circuit 42 by a signal supplied from the system
 28 controller over a conductor 44.

29 The noted two photodetector sections *E* and *F* are both connected
 30 to the tracking servo circuit 14 and thence to the moving coil 35 of the
 31 tracking actuator 28. The tracking servo circuit 14 comprises a subtract-
 32 er 45, an on-off switch 46, and a phase compensator and driver circuit
 33 47. The subtracter 45 subtracts the output from the photodetector sec-
 34 tion *F* from the output from the photodetector section *E*. The resulting
 35 output from the subtracter 45 is a tracking error signal, which is applied
 36 via the switch 46 and phase compensator and driver circuit 47 to the

1 moving coil 35 of the tracking actuator 28, thereby causing the objective
2 24 to move parallel to the disk surface to keep the read beam spot 34
3 in centerline alignment with the disk track 18.

4 The above described method of tracking control is per se not new
5 in the art but has been known to the specialists as the three spots
6 method. Another possible method is the differential phase detection, also
7 conventional in the art, which creates a tracking error signal based on
8 the difference between the sum of the outputs from the photodetector
9 sections *A* and *C* and the sum of the outputs from the photodetector
10 sections *B* and *D*, dispensing with the diffraction grating 20 and the pho-
11 todetector sections *E* and *F*.

12 The switch 46 is turned on and off by a signal supplied from
13 the system controller 11, FIG. 1, over a conductor 48. The phase com-
14 pensator and driver circuit 47 includes phase compensation filter means
15 and gain control means, both not shown, which are controlled by a signal
16 fed from the system controller 11 over a conductor 49. The aforesaid
17 jumping pulses are supplied over another conductor 50 to the driver sec-
18 tion of the circuit 47. The three input conductors 48, 49 and 50 of
19 the tracking servo circuit 14 are shown as a single line in FIG. 1 for
20 simplicity of illustration. An output conductor 51 shown extending from
21 the subtracter 45 of the tracking servo circuit 14 is intended for deliv-
22 ery of the tracking error signal to the system controller 11 via the ADC
23 15, enabling the system controller to detect disk eccentricity according to
24 the present invention. The output from the tracking servo circuit 14 is
25 applied not only to the tracking actuator 28 but also to the transducer
26 transport means 7, FIG. 1, by way of a conductor 52 in order to enable
27 the transducer 6 to trace the spiral track on the disk 4.

28 It is apparent that the addition of all the outputs from the pho-
29 todetector sections *A-D* provides a read signal representative of the data
30 read out from the disk 4. The illustrated embodiment employs the adder
31 53 for adding together the outputs from the two adders 38 and 39 of
32 the focusing servo circuit 13, although, of course, the outputs from the
33 photodetector sections *A-D* could be directly added together. The read
34 signal thus obtained is sent over the conductor 54 to the FIG. 1 read
35 circuit 9.

36 In FIG. 1 the connections between the transducer 6, read circuit 9,

1 focusing servo circuit 13, and tracking servo circuit 14 are shown greatly
 2 simplified and so do not exactly reflect the connections indicated in FIG.
 3 2. Also, in FIG. 2, all or some of the adders 38, 39, and 53 and sub-
 4 tractors 40 and 45 could form parts of the transducer 6, that is, could
 5 be made movable with the optical reading system across the data tracks
 6 18 on the disk 14.

7 The transducer 6 is moved across the turns of the track 18 on
 8 the disk 4 by the transport means 7 typically comprising an electric
 9 motor and means such as a lead screw or a rack and pinion mechanism
 10 for translating the bidirectional rotation of the motor into the linear
 11 reciprocation of the transducer 6. The transport means 7 have two
 12 functions: (1) to move the transducer 6 to desired track positions on the
 13 disk 4 in response to a seek command sent from the system controller 11
 14 over a conductor 58; and (2) to enable the transducer to trace the spiral
 15 track on the disk in cooperation with the disk drive motor 5. For this
 16 latter function the transport means 7 detects the radial displacement of
 17 the beam spot 35 from the track 18 by directing into a low pass filter,
 18 not shown, the tracking control signal fed from the tracking servo circuit
 19 14 over the conductor 52, and controls the radial travel of the transducer
 20 6 accordingly.

21 Connected to the disk drive motor 5, controller 11, and motor
 22 speed sensor 12, the motor servo circuit 8 controls the motor for rotation
 23 at the speed indicated by the controller. For CLV reading of data that
 24 has been CLV recorded on the disk, the motor servo circuit 8 conven-
 25 tionally operates to vary the rotational speed of the motor according to
 26 the radial position of the read beam on the disk 4. The motor servo
 27 circuit 8 is also conventionally equipped to drive the motor at a constant
 28 speed for CAV reading.

29 The read circuit 9 is connected as aforesaid to the conductor 54
 30 for inputting the data that has been recovered from the disk 4. Con-
 31 ventionally comprising a wave shaping circuit, synchronization detector cir-
 32 cuit, demodulator circuit, error detection and correction circuit, etc., the
 33 read circuit 9 processes the input signal accordingly and puts out a data
 34 signal in a form suitable for delivery to the computer 1 via the interface
 35 10.

36 The system controller 11 is shown in FIG. 1 as comprising a cen-

1 tral processor unit (CPU) 55, a random access memory (RAM) 56 and a
2 read only memory (ROM) 57. The controller 11 has outputs connected to
3 the transducer transport means 7, the disk drive motor servo circuit 8,
4 the focusing servo circuit 13, and the tracking servo circuit 14 for con-
5 ventionally controlling them in order to retrieve data from the disk 4 as
6 dictated by commands from the computer 1. Additionally, the controller 11
7 is equipped to ascertain the eccentricity of each loaded disk and to de-
8 termine the matching speed of rotation for that disk accordingly, as will
9 be detailed hereafter.

10 Disk eccentricity is measured according to this invention by driv-
11 ing the disk at two different speeds, both less than the maximum possi-
12 ble speed of the disk drive motor 5, and by taking advantage of a sig-
13 nal used in the standard tracking control of the transducer 6. The two
14 different speeds at which the disk is driven for disk eccentricity meas-
15 urement will be hereinafter referred to as the disk eccentricity check
16 speeds, simply as the disk check speeds, or more simply as the check
17 speeds. If eccentric, the disk 4 on rotation will itself vibrate mechanical-
18 ly and so cause vibration of the disk drive motor 4 and the transducer
19 6, among other parts. Such vibration resolves itself into a "vertical"
20 component (i.e. component in the direction in which the drive spindle 16
21 extends) and a "horizontal" component at right angles with the vertical
22 component. It is the horizontal component that causes deviations of the
23 read beam spot 34 and two tracking beam spots 34a and 34b out of cen-
24 terline alignment with the track 18 on the disk 14. Such deviations,
25 commonly referred to as tracking errors, are therefore a measure of disk
26 eccentricity.

27 Tracking errors are represented by the output from the subtracter
28 45, FIG. 2, of the tracking servo circuit 14. The tracking errors as rep-
29 resented by the tracking error signal from the subtracter 45, however, are
30 only partly due, and partly not due, to disk vibration caused by disk
31 eccentricity. But, luckily, tracking errors due to disk eccentricity are
32 clearly distinguishable from those not due to that cause because the for-
33 mer have a periodicity that is coincident with each complete revolution of
34 the disk.

35 Thus the present invention advocates to measure disk eccentricity
36 by deriving the horizontal component of disk vibration due to disk eccen-

1 tricity from the tracking error signal produced by the subtracter 45.
 2 Toward this end the ADC 15, FIG. 1, is connected to the output conduc-
 3 tor 51 of the subtracter 45 for digitizing the tracking error signal pre-
 4 paratory to delivery to the system controller 11 over a conductor 59.

5 FIG. 3 is a schematic illustration of various means built into the
 6 controller 11 for deriving the eccentricity component from the incoming
 7 digital tracking error signal, for measuring the disk eccentricity, and for
 8 determining the speed at which that disk is to be read according to the
 9 measurement. The input conductor 59 is connected, first of all, to a
 10 digital lowpass filter 60 which functions to derive from the tracking error
 11 signal the periodic vibration component that varies with revolutions of the
 12 disk. Since disk eccentricity is measured at two different check speeds
 13 as aforesaid, the cutoff frequency of the LPF 60 must be varied as the
 14 disk speed is changed from one to the other. To this end the LPF60
 15 has an input connected by way of a conductor 62 to speed command
 16 means 78, which is also connected to the disk drive motor servo circuit
 17 8, FIG. 1, to cause disk rotation at either of the two disk eccentricity
 18 check speeds or at any chosen read speed.

19 As depicted highly schematically in FIG. 4, the digital LPF 60 may
 20 be envisaged as comprising an adder 63, a sample delay circuit 64, and a
 21 coefficient unit or multiplier 65, which are connected as shown. The
 22 adder 63 adds the digitized tracking error signal and its delayed signal.
 23 This construction permits a variety of modifications, however. For exam-
 24 ple, there may be provided two or more, instead of one, delay stages, or,
 25 as indicated by the dashed line, the output from the adder 63 may be
 26 input to the delay circuit 64 instead of the tracking error signal. Either
 27 way, the cutoff frequency of the LPF 60 may be changed by varying
 28 the coefficient of the multiplier 65.

29 Diagramed at (A) and (B) in FIG. 5 are analog equivalents of the
 30 outputs (horizontal vibration components) from the LPF 60 when an eccen-
 31 tric disk is driven at the two eccentricity check speeds. The periods
 32 T_a and T_b of vibrations in these diagrams correspond to each complete
 33 revolution of the disk at the two check speeds. It will be noted that,
 34 even though the disk is the same, the amplitude of vibration is greater
 35 when the speed of disk rotation is higher, as at (B), than when the
 36 speed is lower as at (A).

1 Before proceeding further with the description of the FIG. 3
2 means built into the system controller 11, let us briefly study what exact-
3 ly is meant by so called "eccentric" disks. Such disks can be broadly
4 classified into two categories. One of them is what is herein called an
5 eccentric hole disk, shown in FIG. 6 and therein labeled 4a, having a
6 spindle hole 17 situated off the geometric center of the disk. The other
7 is typified by a FIG. 7 disk 4b which has a spindle hole 17 in the
8 right position on the disk but in which the multiturn spiral track 18 is
9 not centered at the geometric center of the disk. Such a disk 4b is
10 herein referred to as an eccentric track disk. Of course, in practice,
11 both hole eccentricity and track eccentricity may coexist in one disk;
12 more exactly, most disks may possess both types of eccentricities in var-
13 ious quantities. FIGS. 6 and 7 are meant purely to illustrate the two
14 types of defects, and the defects are, needless to say, shown greatly
15 exaggerated.

16 The instant invention is based upon the finding that, being dy-
17 namically unbalanced about the spindle hole 17, the eccentric hole disk 4a
18 vibrates more with an increase in the speed of rotation, causing periodic
19 deviations of the beam spot from the track to extents that are dependent
20 upon the disk speed. The eccentric track disk 4b, on the other hand,
21 causes periodic departures of the beam spot from the track as a direct
22 result of its track eccentricity. However, the intensity of vibration, if
23 any, of the eccentric track disk 4b is totally independent of the speed
24 of disk rotation, this disk being dynamically balanced about its spindle
25 hole 17. It is therefore necessary to make a clear distinction between
26 hole eccentricity and track eccentricity of any given disk, to accurately
27 measure its hole eccentricity, and to determine the fitting read speed for
28 that disk solely on the basis of the hole eccentricity.

29 From these considerations the present invention utilizes the afore-
30 said tracking error signal produced by the subtracter 45, FIG. 2, of the
31 tracking servo circuit 14, for accurate detection and measurement of the
32 hole eccentricity of each loaded disk. The tracking error signal contains
33 both a component representative of hole eccentricity and a component rep-
34 resentative of track eccentricity. The hole eccentricity of any disk is
35 detectable by driving the disk at two different check speeds and by
36 eliminating from the tracking error signal the component representative of

1 track eccentricity.

2 With reference back to FIG. 3 the LPF 60 of the system control-
3 ler 11 is connected to an amplitude detector circuit 70 which detects the
4 peak amplitude of the output from the LPF, that is, the difference be-
5 tween the positive peak V_{p1} , FIG. 5, and negative peak V_{p2} of the LPF
6 output. In other words, the amplitude detector circuit 70 measures the
7 intensity of periodic vibration of the disk 4 due to both hole eccentrici-
8 ty and track eccentricity.

9 The output from the amplitude detector 70 is directed through a
10 selector switch 71 to a memory 73. Operating under the direction of a
11 switch control circuit 72, the selector switch 71 functions to send the
12 amplitude detector output to two different parts 73a and 73b of the me-
13 mory 73 depending upon whether the disk is being driven at one or the
14 other of the two disk check speeds. Thus, during disk rotation at the
15 first check speed, a first amplitude (i.e. eccentricity) measurement TE_1
16 made by the amplitude detector circuit 70 will be written via the switch
17 contact a on the first part 73a of the memory 73. A second amplitude
18 (i.e. eccentricity) measurement TE_2 will be written via the switch contact
19 b on the second memory part 73b during disk rotation at the second
20 check speed. In practice this memory 73 can be part of the RAM 56,
21 FIG. 1, built into the system controller 11.

22 A subtracter 74 has its two inputs shown connected to the two
23 parts 73a and 73b of the memory 73 for computing the hole eccentricity
24 E_1 of the disk by subtracting the first eccentricity measurement TE_1 from
25 the second TE_2 ; that is, $E_1 = TE_2 - TE_1$.

26 The hole eccentricity output E_1 from the subtracter 74 is sent
27 into the positive input of a comparator 75, the negative input of which
28 is connected to reference means 76 for inputting a reference value Ref_2 .
29 The reference means 76 may be part of the ROM 57, FIG. 1. The out-
30 put from the comparator 75 indicates whether the hole eccentricity E_1 is
31 not less than the reference Ref_2 or not.

32 Inputting this output from the comparator 75, the speed determina-
33 tion means 77 determines the speed at which the disk is to be driven,
34 according to whether its hole eccentricity E_1 is not less than the refer-
35 ence Ref_2 or not. The disk is judged to be of poor quality if the hole
36 eccentricity E_1 is equal to or more than the reference Ref_2 , and of good

1 quality if not. The speed determination means 77 produces a signal in-
 2 dicative of a speed less than the maximum possible speed of rotation of
 3 the disk drive motor 5 if the disk has proved to be of poor quality,
 4 and of the maximum possible motor speed if the disk has proved to be
 5 of good quality.

6 Instead of the comparator 75, however, another subtracter could be
 7 connected between subtracter 74 and speed determination means 77 for
 8 speed determination according to the difference between hole eccentricity
 9 E_1 and reference Ref_2 . In this case any one of several different speeds
 10 (e.g. two, four, eight, sixteen, and twenty times the standard audio CD
 11 speed) may be chosen for each disk loaded. As another alternative, the
 12 subtracter 74 could be connected directly to the speed determination
 13 means 77, causing the latter to determine the disk speed according to the
 14 hole eccentricity E_1 .

15 The speed determination means 77 informs the aforementioned speed
 16 command means 78 of the chosen disk speed. Connected to the disk
 17 drive motor servo circuit 8, FIG. 1, by way of 62 conductor, the speed
 18 command means 78 causes disk rotation at the chosen speed.

19 As an ancillary feature of this invention, the FIG. 3 system con-
 20 troller is provided with additional means for determination of the second
 21 disk check speed according to the first amplitude measurement TE_1 . Such
 22 means include a comparator 79 having one input connected the first part
 23 73a of the memory 73, and reference means 80, such as part of the ROM
 24 57, connected to another input of the comparator 79. The comparator 79
 25 causes the speed command means 78 to make the second disk check speed
 26 lower when the first eccentricity measurement TE_1 proves greater than a
 27 reference Ref_1 .

28

29

Method

30

31 Flowcharted in FIG. 8 is the disk eccentricity check routine ac-
 32 cording to the method of this invention which is to be factory prepro-
 33 grammed on the ROM 57 of the controller 11. The routine starts at S_0
 34 when a CD-ROM disk 4 is loaded on the drive spindle 16. The first
 35 block S_1 indicates driving of the disk at the first check speed of, say,
 36 four times the standard audio CD speed. Further, with both tracking and

1 focusing servos set into operation, the transducer 6 is positioned on the
2 inmost turn of the data track 18 on the disk 4 where the table of con-
3 tents is customarily recorded. Experiment has proved that disks of any
4 possible eccentricities are readable at four times the standard audio CD
5 speed (1950 revolutions per minute).

6 Then the first eccentricity measurement is done according to the
7 block S_2 . As has been set forth with reference to FIG. 3, the disk
8 eccentricity is measured by the amplitude detector circuit 70, and the
9 first eccentricity measurement TE_1 is written on the first part 73a of the
10 memory 73.

11 The next block S_3 dictates driving of the disk at a second ec-
12 centricity check speed. This second check speed may be predetermined
13 but, as has also been mentioned in connection with FIG. 3, is preferably
14 variously determined according to the first eccentricity measurement TE_1
15 in the illustrated embodiment. The first eccentricity measurement TE_1 is
16 compared with the Ref_1 by the comparator 79. The second check speed
17 may be set at 50 percent of the maximum possible motor speed (e.g. 20
18 times the standard audio CD speed, or approximately 10,000 rpm) if TE_1 is
19 not more than Ref_1 , and at 40 percent of the maximum possible motor
20 speed if TE_1 is more than Ref_1 . Variable second check speeds are pre-
21 ferred to a fixed second check speed because overly eccentric disks
22 might develop too much vibration when driven at the fixed speed.

23 Then the eccentricity of the disk is measured again at the second
24 check speed according to the block S_4 . The second eccentricity check is
25 also done by the amplitude detector circuit 70, and the second eccentrici-
26 ty measurement TE_2 is written on the second part 73b of the memory 73.

27 Then the difference E_1 between the two eccentricity measurements
28 TE_1 and TE_2 is computed according to the block S_5 . This difference E_1
29 represents as aforesaid the hole eccentricity of the disk.

30 Then a maximum allowable speed of rotation for the particular
31 disk 4, now on the drive spindle 16, is determined at the block S_6 on
32 the basis of the hole eccentricity E_1 ascertained as above. The thus
33 determined maximum allowable disk speed is retained on the RAM 56 until
34 the disk is ejected. With the disk eccentricity check routine completed
35 at S_7 , the disk is read thereafter at a speed not exceeding the maximum
36 allowable speed.

The determination of a maximum allowable speed for each disk on the bases of eccentricity measurements at two different check speeds according to the invention may be theoretically explained as follows: The tracking servo signal normally contains both a component TE_a due to disk vibration by the FIG. 6 hole eccentricity of the disk and a component TE_b due to the FIG. 7 track eccentricity of the disk. However, if the first disk check speed is sufficiently low to cause practically no disk vibration, the first eccentricity measurement TE_1 approximately equals the track eccentricity component TE_b .

$$TE_1 = TE_b$$

If the second disk check speed is sufficiently high to cause disk vibration, the second eccentricity measurement TE_2 can be defined as:

$$TE_2 = TE_a + TE_b$$

Since the present invention teaches to set a read speed for each disk according to the difference E_1 between the two eccentricity measurements TE_1 and TE_2 , as in the block S_8 of the FIG. 8 flowchart,

$$E_1 = TE_2 - TE_1 = TE_a + TE_b - TE_b = TE_a$$

In other words, to compute the difference E_1 is to ascertain the hole eccentricity TE_a of the disk.

Possibly, the first eccentricity measurement TE_1 may include a vibration component due to the FIG. 6 hole eccentricity. The track eccentricity component is the same, however, for both first and second eccentricity measurements TE_1 and TE_2 , so that the subtraction of TE_1 from TE_2 will eliminate the track eccentricity component and yield only the hole eccentricity component.

It is the hole eccentricity of each disk that needs accurate measurement to anticipate its vibration during high speed rotation. The present invention meets this requirement by eliminating the track eccentricity component and relying only on the hole eccentricity to determine the optimum read speed for each disk.

1 This embodiment of the invention gains the following additional
2 advantages:

1. Disk eccentricity is measured using no vibration sensors or equivalent means.

2. As the optimum read speed for each disk is determined preparatory to data recovery therefrom, the disk will not vibrate to such an extent as to bring about read errors through tracking errors and focusing errors. A reading of poor quality disks at the maximum motor speed would inevitably cause read errors and retries, increasing the time for reading a unit amount of data. Less errors will occur when a poor quality disk is read at a lower speed that suits the particular hole eccentricity of that disk; indeed, errors will occur so much less that a much shorter read time will be required than when the disk is read at a higher speed.

15 3. The tracking servo coil and focusing servo coils are kept from
16 destruction with the reduction of disk vibration.

17 4. The driving of a low quality disk at a reduced speed causes
18 less vibration of the disk, of the disk drive, and of other device such
19 as an HDD.

20 5. The two disk eccentricity check speeds are both less than the
21 maximum possible speed of the disk drive motor, so that the eccentricity
22 check routine of FIG. 8 can be carried out while the motor is being
23 energized toward its maximum speed prior to the commencement of data re-
24 covery from the disk that has been just loaded.

Second Form

28 The hole eccentricity of each disk is detected from the tracking
29 error signal in the foregoing embodiment. The tracking error signal may,
30 however, be of such low magnitude that it may be difficult to derive the
31 eccentricity component solely from the tracking error signal in the case of
32 disks that are only very slightly hole eccentric. Thus, in an alternate
33 embodiment of the invention shown in FIGS. 9 and 10, disk eccentricity is
34 detected from the drive signal for the moving coil 35, FIG. 2, of the
35 tracking actuator 28 when the tracking error signal is of low level.

36 Generally, even disks that are infinitesimally eccentric may develop

1 inconveniently great vibration when driven at a speed as high as from
 2 twenty to thirty times the standard audio CD speed. Fairly large disk
 3 eccentricities are accurately detectable from the tracking error signal.
 4 Infinitesimal disk eccentricities are not necessarily so, because then the
 5 tracking error signal is so small in amplitude. The tracking actuator
 6 drive signal is of much greater voltage magnitude than the tracking error
 7 signal, so that the eccentricity component is far more accurately detect-
 8 able from the former than from the latter. From these considerations the
 9 alternate CD-ROM drive includes means for detecting disk eccentricity
 10 from the tracking actuator drive signal in addition to those from the
 11 tracking error signal.

12 In the alternate CD-ROM drive 2a shown in FIG. 9 the output
 13 conductor 52 of the tracking servo circuit 14 is connected to a second
 14 ADC 83 (the first ADC being seen at 15) and thence to a system control-
 15 ler 11a by way of a conductor 84. It will be recalled that the first
 16 ADC 15 is for digitizing the tracking error signal prior to delivery to
 17 the system controller. The second ADC 83, then, digitizes the drive sig-
 18 nal for the moving coil 35, FIG. 2, of the tracking actuator 28 prelimi-
 19 nary to application to the system controller 11a, which is correspondingly
 20 modified from the FIG. 3 controller 11 as shown in FIG. 10. The alter-
 21 nate disk drive 2a is akin to the FIG. 1 device 2 in all the other de-
 22 tails of construction.

23 With reference to FIG. 10 the modified system controller 11a in-
 24 cludes a second digital LPF 85 connected to the second ADC 83 by way
 25 of the conductor 84. Similar in construction to the first LPF 60, shown
 26 in detail in FIG. 4, the second LPF 85 functions to derive from the
 27 tracking actuator drive signal the component representative of the hole
 28 eccentricity of the disk.

29 In order to ascertain the hole eccentricity from the tracking actua-
 30 tor drive circuit the system controller 11a is shown in FIG. 10 as compris-
 31 ing, in addition to the second LPF 85, a second amplitude detector cir-
 32 cuit 90, a second selector switch 91, a second memory 92, a second sub-
 33 tractor 93, a second comparator 94, and second reference means 95. The
 34 means for detecting the hole eccentricity from the tracking error signal,
 35 also included in the system controller 11a, are of the same construction as
 36 in FIG. 3, so that their components are therefore identified by the same

reference characters as used to denote their FIG. 3 counterparts. Furthermore the system controller 11a includes speed determination means 77a to which there are input the hole eccentricities as detected from both the tracking error signal and the tracking actuator drive signal.

Connected to the second LPF 85, the second amplitude detector circuit 90 detects the amplitude of the eccentricity component of the tracking actuator drive signal. The second selector switch 91 is controlled jointly with the first selector switch 71 by the switch control circuit 72 for directing the amplitude detector output (first eccentricity measurement) TD_1 at the first disk check speed into the first part 92a of the second memory 92, and the amplitude detector output (second eccentricity measurement) TD_2 at the second check speed into the second memory part 92b.

The eccentricity measurements TD_1 and TD_2 derived from the tracking actuator drive signal are akin to the eccentricity measurements TE_1 and TE_2 made from the tracking error signal. The first measurement TD_1 mostly represents the FIG. 7 track eccentricity of the disk whereas the second measurement TD_2 represents both FIG. 6 hole eccentricity and FIG. 7 track eccentricity. Consequently, a subtraction of TD_1 from TD_2 provides the hole eccentricity E_2 of the disk. Possibly, like the first measurement TE_1 of the tracking error signal, the first measurement TD_1 of the tracking actuator drive signal may also contain a hole eccentricity component. Both measurements TD_1 and TD_2 contain the same amount of track eccentricity component, however, so that the difference E_2 therebetween is free from the track eccentricity component.

The second subtracter 93 has its two inputs coupled to the two memory parts 92a and 92b for computing the difference E_2 between the two eccentricity measurements TD_1 and TD_2 . The second comparator 94 compares the difference E_2 with a reference Ref_2 and provides a signal indicative of the results of the comparison.

Inputting the outputs from both first and second comparators 75 and 94, the speed determination means 77a determines the disk speed as follows:

1. If the difference E_1 is equal to or greater than the reference Ref_2 , the disk is of great hole eccentricity, so that a relatively low first speed N_1 (e.g. not more than four times the standard audio CD

1 speed) is set for the disk.

2 2. If the difference E_1 is less than the reference Ref_a , and the
3 other difference E_2 equal to or greater than the reference Ref_a , the disk
4 is of medium hole eccentricity, so that a higher second speed N_1 (e.g.
5 from five to sixteen times the standard audio DC speed) is set for the
6 disk.

7 3. If the difference E_1 is less than the reference Ref_a , and the
8 other difference E_2 less than the reference Ref_a , the disk is of minimal
9 hole eccentricity, so that a third speed N_3 of the highest possible disk
10 drive motor speed (e.g. from seventeen to thirty times the standard audio
11 CD speed) is set for the disk.

12 The disk speed N_1 , N_2 or N_3 determined as above is sent from
13 speed determination means 77a to speed command means 78 whereupon the
14 latter signals the motor servo circuit 8, FIG. 9, to rotate the disk at the
15 required speed for reading. The disk will be read with a minimum of
16 vibration whatever its hole eccentricity may be.

17 The eccentricity check method implemented in the FIGS. 9 and 10
18 disk drive is substantially analogous with that of the preceding embodi-
19 ment and therefore as analogously represented by the FIG. 8 flowchart.
20 The two eccentricity measurements from the tracking actuator drive signal
21 are made concurrently with those from the tracking error signal at the
22 blocks S_2 and S_4 .

23 Besides gaining all the advantages set forth in connection with the
24 first disclosed embodiment, this second embodiment offers the strength of
25 far more accurately detecting minute disk eccentricities from the tracking
26 actuator drive signal than from the tracking error signal.

28 Third Form

29
30 Shown in FIG. 11 is a slight modification of the FIG. 10 system
31 controller. The FIG. 11 system controller differs from that of FIG. 10 in
32 having no comparators 75 and 94 and no reference means 76 and 95 and
33 in having, instead, a modified speed determination means 77b. The two
34 subtracters 74 and 93 are therefore coupled directly to the modified
35 speed determination means 77b.

36 Inputting both difference E_1 between the eccentricity measurements

1 TE_1 and TE_2 made from the tracking error signal and difference E_2 be-
 2 tween the eccentricity measurements TD_1 and TD_2 made from the tracking
 3 actuator drive signal, the speed determination means 77b computes the
 4 equation, $E_3 = aE_1 + E_2$, where a is a correction coefficient, and deter-
 5 mines the quality of the disk and the fitting speed therefor according to
 6 whether the sum E_3 is greater than a reference or not. The disk is of
 7 large hole eccentricity if E_3 is greater than the reference, so that a
 8 relatively low speed is chosen for the disk. If E_3 is not more than the
 9 reference, on the other hand, then the disk is of small hole eccentricity,
 10 so that the disk is read at the maximum motor speed.

12 Fourth Form

14 In the CD-ROM drive 2b shown in FIG. 12, the disk eccentricity
 15 is measured on the basis of the number of track turns traversed by the
 16 read beam spot 34, FIG. 2, during each complete revolution of the disk,
 17 with the tracking servo turned off during such eccentricity measurement.
 18 Thus the disk drive 2b has neither the ADC 15 of the FIG. 1 disk drive
 19 1 nor the ADC 83 of the FIG. 9 disk drive 2a; instead, as shown in
 20 FIG. 13, the wave shaping circuit 97 customarily included in the read cir-
 21 cuit 9 is connected by way of a conductor 96 to a modified system con-
 22 troller 11b detailed in the same figure. Connected to the output conduc-
 23 tor 54 of the transducer 6, the wave shaping circuit 97 operates to re-
 24 shape the transducer output into a rectangular waveform.

25 The modified system controller 11b has eccentricity detector means
 26 98 in substitution for the LPF 60 and amplitude detector circuit 70 of
 27 the FIG. 3 system controller. The eccentricity detector means 98 is
 28 shown as comprising a counter 99 having an input IN connected to the
 29 wave shaping circuit 97, and a frequency divider 100 connected to the
 30 reset input R of the counter. Reset by an output pulse of the frequen-
 31 cy divider 100 when the apparatus is in eccentricity check mode, the
 32 counter 99 counts the pulses from the wave shaping circuit 97.

33 The frequency divider 100 is connected to the disk drive motor
 34 speed sensor 12, FIG. 12 by way of a conductor 101. It is understood
 35 that the speed sensor 12 is of conventional make capable of producing
 36 six pulses with each complete revolution of the disk 4. The frequency

1 divider 100 puts out a pulse each time it inputs six pulses from the
 2 speed sensor 12; in other words, it puts out a pulse with each complete
 3 revolution of the disk. Thus the counter 99 counts the pulses incoming
 4 from the wave shaping circuit 97 during each complete revolution of the
 5 disk.

6 The focusing servo of the disk drive 2b is set in operation by
 7 closing the focusing servo switch 41, FIG. 2, and the tracking servo is
 8 set out of operation by opening the tracking servo switch 46, for disk
 9 eccentricity check according to the invention. When the disk is read
 10 under these conditions, the wave shaping circuit 97 will produce a pulse
 11 each time the read beam spot traverses the track 18. The beam spot
 12 will cross the track only once for each complete disk revolution in the
 13 case of a noneccentric disk. If the disk has some FIG. 6 hole eccentrici-
 14 ty, however, the beam spot will cross the track more than once by rea-
 15 sons of disk vibration and beam spot displacement radially of the disk.
 16 The beam spot will cross the track more than once if the disk is track
 17 eccentric as in FIG. 7, too.

18 Thus the number of times the beam spot crosses the track per
 19 unit length of time is a measure of disk eccentricity. It will therefore
 20 be apparent that the output pulses of the wave shaping circuit 97 might
 21 be counted during any preset period of time other than that of each
 22 complete disk revolution.

23 In this FIGS. 12 and 13 embodiment, too, disk eccentricity is
 24 checked at two different speeds. In the FIG. 13 system controller 11h,
 25 therefore, the counter 99 is shown connected via the selector switch 71
 26 to the two different parts 73a and 73b of the memory 73. The first
 27 eccentricity count N_a is stored on the first memory part 73a, and the
 28 second eccentricity count N_b on the second memory part 73b. The sub-
 29 tracter 74 subtracts the first eccentricity count N_a from the second N_b
 30 and sends the difference N_c therebetween to speed determination means
 31 77c. Like the two eccentricity measurements TE_1 and TE_2 of the forego-
 32 ing embodiments, the eccentricity counts N_a and N_b contain information on
 33 the track and hole eccentricities of the disk, so that the difference N_c
 34 therebetween represents only the hole eccentricity of the disk.

35 Inputting the difference N_c , the speed determination means 77c
 36 determines the disk speed accordingly. For example, the disk speed may

1 be set at the maximum motor speed (e.g. twenty times the standard audio
2 CD speed) if N_c is not more than two, at 80 percent of the maximum
3 motor speed (e.g. sixteen times the standard audio CD speed) if N_c is
4 three, and at 50 percent of the maximum motor speed (e.g. ten times the
5 standard audio CD speed) if N_c is four. Data recovery from the disk is
6 then commenced at the chosen speed.

7 Notwithstanding the foregoing detailed disclosure it is not desired
8 that the present invention be limited by the exact showing of the draw-
9 ings or the description thereof; rather, the invention should be construed
10 broadly and in a manner consistent with the fair meaning or proper scope
11 of the attached claims. The following is a brief list of possible modifi-
12 cations of the illustrated embodiments which are all believed to fall with-
13 in the scope of this invention:

14 1. The digital LPFs 60 and 85 could be replaced each by an ana-
15 log LPF shown at 60a in FIG. 14, which comprises a buffer 112, an in-
16 ductance (or resistor) 113, a capacitor 114 and a variable capacitance diode
17 115. The variable capacitance diode 115 is controlled by the analog volt-
18 age output from a digital to analog converter 110 on the output conductor
19 62 of the speed command means 78, FIGS. 3, 10 and 11. The output
20 from the analog LPF 60a is directed through an ADC 116 to the ampli-
21 tude detector circuit 70 or 90.

22 2. The invention could be applied to devices for CAV servo read-
23 ing of CAV disks, and CAV reading of CLV disks. Incidentally, in the
24 illustrated embodiments of the invention, it is understood that a radially
25 inward region of the disk is read at CAV, and a radially outward region
26 at CLV.

27 3. In the FIGS. 10 and 11 embodiments the hole eccentricity of
28 each disk could be detected solely from the tracking actuator drive sig-
29 nal, instead of from both tracking actuator drive signal and tracking
30 error signal.

31 4. The various hole eccentricity data supplied to the speed deter-
32 mination means in FIGS. 10, 11 and 13 could be employed in various other
33 combinations for determination of the fitting speed for each disk.

34 5. The photodetector 26 could be split into two sections instead
35 of six as in the illustrated embodiments.

36 6. The invention could be applied to not only optical, but also

1 magnetic, disk drives.

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CLAIMS

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3 1. In an apparatus for data recovery from rotating data stor-
4 age disks having varying degrees of hole eccentricity and track eccen-
5 tricity, a method of reading each disk at a speed suiting the particular hole
6 eccentricity of that disk, which method comprises:

7 (a) driving a data storage disk at a first disk eccentricity check
8 speed;

9 (b) making a first measurement of the hole eccentricity and track
10 eccentricity of the disk in rotation at the first disk eccen-
11 tricity check speed;

12 (c) driving the disk at a second disk eccentricity check speed
13 which is higher than the first disk eccentricity check
14 speed;

15 (d) making a second measurement of the hole eccentricity and track
16 eccentricity of the disk in rotation at the second disk ec-
17 centricity check speed;

18 (e) ascertaining the hole eccentricity of the disk by subtracting the
19 first measurement from the second measurement; and

20 (f) determining a matching speed of rotation for reading the disk on
21 the basis of the above ascertained hole eccentricity thereof.
22

23 2. In an apparatus for data recovery from rotating optical data
24 storage disks having varying degrees of hole eccentricity and track eccen-
25 tricity, the apparatus having a transducer for reading data recorded on
26 each such disk along a track thereon by irradiating the disk with a
27 beam of light, the hole eccentricity of each disk manifesting itself during
28 disk rotation as periodic vibration of the disk and, in consequence, peri-
29 odic departures of the light beam from the track to an extent proportion-
30 al to the speed of disk rotation, the track eccentricity manifesting itself
31 during disk rotation as periodic departures of the light beam from the
32 track to a constant extent regardless of the speed of disk rotation, a
33 method of reading each disk at a speed suiting the particular hole eccen-
34 tricity of that disk, which method comprises:

35 (a) driving an optical data storage disk at a first disk eccentricity
36 check speed;



- 1 (b) making a first measurement of the hole eccentricity and track
- 2 eccentricity of the disk in rotation at the first disk eccen-
- 3 tricity check speed in terms of the resulting periodic de-
- 4 partures of the light beam from the track;
- 5 (c) driving the disk at a second disk eccentricity check speed
- 6 which is higher than the first disk eccentricity check
- 7 speed;
- 8 (d) making a second measurement of the hole eccentricity and track
- 9 eccentricity of the disk in rotation at the second disk ec-
- 10 centricity check speed in terms of the resulting periodic
- 11 departures of the light beam from the track;
- 12 (e) ascertaining the hole eccentricity of the disk by subtracting the
- 13 first measurement from the second measurement; and
- 14 (f) determining a matching speed of rotation for reading the disk on
- 15 the basis of the above ascertained hole eccentricity thereof.
- 16

17 3. The method of claim 2 wherein the apparatus includes a

18 tracking servo for holding the spot of the light beam on the track on

19 the disk, the tracking servo including means for providing a tracking er-

20 ror signal representative of the departures of the beam spot from the

21 track, and wherein the first and the second measurements of the hole ec-

22 centricity and track eccentricity of the disk are each made by:

- 23 (a) deriving from the tracking error signal a component that varies
- 24 periodically with each complete revolution of the disk; and
- 25 (b) detecting the amplitude of the derived component of the track-
- 26 ing error signal.
- 27

28 4. The method of claim 2 wherein the apparatus includes a

29 tracking servo for holding the spot of the light beam on the track on

30 the disk, the tracking servo including means for providing a tracking ac-

31 tuator drive signal for driving a tracking actuator so as to keep the

32 beam spot on the track, and wherein the first and the second measure-

33 ments of the hole eccentricity and track eccentricity of the disk are each

34 made by:

- 35 (a) deriving from the tracking actuator drive signal a component
- 36 that varies periodically with each complete revolution of the



1 disk; and

2 (b) detecting the amplitude of the derived component of the track-
3 ing actuator drive signal.
4

5 5. In an apparatus for data recovery from rotating optical data
6 storage disks having varying degrees of hole eccentricity and track eccen-
7 tricity, the apparatus having a transducer for reading data recorded on
8 each such disk along a track thereon by irradiating the disk with a
9 beam of light, the hole eccentricity of each disk manifesting itself during
10 disk rotation as periodic vibration of the disk and, in consequence, peri-
11 odic departures of the light beam from the track to an extent proportion-
12 al to the speed of disk rotation, the track eccentricity manifesting itself
13 during disk rotation as periodic departures of the light beam from the
14 track to a constant extent regardless of the speed of disk rotation, the
15 apparatus further including a tracking servo for holding the spot of the
16 light beam on the track on the disk, the tracking servo including means
17 for providing a tracking error signal representative of the departure of
18 the beam spot from the track, and means responsive to the tracking error
19 signal for providing a tracking actuator drive signal for driving a track-
20 ing actuator so as to keep the beam spot on the track, a method of
21 reading each disk at a speed suiting the particular hole eccentricity of
22 that disk, which method comprises:
23

24 (a) driving an optical data storage disk at a first disk eccentricity
25 check speed;

26 (b) making a first measurement of the hole eccentricity and track
27 eccentricity of the disk in rotation at the first disk eccen-
28 tricity check speed by deriving from the tracking error
29 signal a component that varies periodically with each com-
30 plete revolution of the disk and by detecting the amplitude
31 of the derived component of the tracking error signal;

32 (c) concurrently with step (b), making a second measurement of the
33 hole eccentricity and track eccentricity of the disk in rota-
34 tion at the first disk eccentricity check speed by deriving
35 from the tracking actuator drive signal a component that
36 varies periodically with each complete revolution of the
disk and by detecting the amplitude of the derived compo-



1 nent of the tracking actuator drive signal;

2 (d) driving the disk at a second disk eccentricity check speed
3 which is higher than the first disk eccentricity check
4 speed;

5 (e) making a third measurement of the hole eccentricity and track
6 eccentricity of the disk in rotation at the second disk ec-
7 centricity check speed by deriving from the tracking error
8 signal a component that varies periodically with each com-
9 plete revolution of the disk and by detecting the amplitude
10 of the derived component of the tracking error signal;

11 (f) concurrently with step (e), making a fourth measurement of the
12 hole eccentricity and track eccentricity of the disk in rota-
13 tion at the second disk eccentricity check speed by deriv-
14 ing from the tracking actuator drive signal a component
15 that varies periodically with each complete revolution of the
16 disk and by detecting the amplitude of the derived compo-
17 nent of the tracking actuator drive signal;

18 (g) subtracting the first measurement from the third measurement;

19 (h) subtracting the second measurement from the fourth measurement;
20 and

21 (i) determining a matching speed of rotation for reading the disk on
22 the bases of the remainders of subtraction of the first
23 measurement from the third measurement and of subtraction
24 of the second measurement from the fourth measurement.

25
26 6. The method of claim 5 wherein the speed of rotation for
27 reading the disk is set at a first value when the remainder of subtrac-
28 tion of the first measurement from the third measurement is equal to or
29 greater than a first reference, at a second value, which is higher than
30 the first value, when the remainder of subtraction of the first measure-
31 ment from the third measurement is less than the first reference and, at
32 the same time, the remainder of subtraction of the second measurement
33 from the fourth measurement is equal to or greater than a second refer-
34 ence, and at a third value, which is higher than the second value, when
35 the remainder of subtraction of the first measurement from the third
36 measurement is less than the first reference and, at the same time, the



1 remainder of subtraction of the second measurement from the fourth meas-
2 urement is less than the second reference.

3
4 7. The method of claim 5 wherein the speed of rotation for
5 reading the disk is determined according to the sum of the remainders of
6 subtraction of the first measurement from the third measurement and of
7 subtraction of the second measurement from the fourth measurement.

8
9 8. In an apparatus for data recovery from rotating optical data
10 storage disks having varying degrees of hole eccentricity and track eccen-
11 tricity, the apparatus having a transducer for reading data recorded on
12 each such disk along a track thereon by irradiating the disk with a
13 beam of light, and a tracking servo for holding the spot of the light
14 beam on the track on the disk, a method of reading each disk at a
15 speed suiting the particular hole eccentricity of that disk, which method
16 comprises:

17 (a) turning the tracking servo off;

18 (b) driving an optical data storage disk at a first disk eccentricity
19 check speed;

20 (c) making a first measurement of the hole eccentricity and track
21 eccentricity of the disk in rotation at the first disk eccen-
22 tricity check speed in terms of the number of times the
23 light beam crosses the track during at least one complete
24 revolution of the disk;

25 (d) driving the disk at a second disk eccentricity check speed
26 which is higher than the first disk eccentricity check
27 speed;

28 (e) making a second measurement of the hole eccentricity and track
29 eccentricity of the disk in rotation at the second disk ec-
30 centricity check speed in terms of the number of times the
31 light beam crosses the track during at least one complete
32 revolution of the disk;

33 (f) ascertaining the hole eccentricity of the disk by subtracting the
34 number of times the light beam crossed the track at the
35 first eccentricity measurement from the number of times the
36 light beam crossed the track at the second eccentricity



1 measurement; and

2 (g) determining a matching speed of rotation for reading the disk
3 on the basis of the above ascertained hole eccentricity
4 thereof.

5
6 9. The method of claim 8 wherein the first and the second
7 measurements of the hole eccentricity and track eccentricity of the disk
8 are each made by counting output pulses of the transducer.

9
10 10. An apparatus for data recovery from rotating data storage
11 disks having varying degrees of hole eccentricity and track eccentricity,
12 wherein the improvement resides in the combination of:

13 (a) drive means for imparting variable speed rotation to a data stor-
14 age disk;

15 (b) speed command means connected to the drive means for com-
16 manding speeds at which the disk is to be rotated, the
17 speed command means being capable of commanding disk
18 rotation at a first and a second disk eccentricity check
19 speed, the first disk eccentricity check speed being lower
20 than the second disk eccentricity check speed;

21 (c) eccentricity measurement means for making a first measurement of
22 the hole eccentricity and track eccentricity of the disk in
23 rotation at the first disk eccentricity check speed, and a
24 second measurement of the hole eccentricity and track ec-
25 centricity of the disk in rotation at the second disk eccen-
26 tricity check speed;

27 (d) subtracter means connected to the eccentricity measurement means
28 for ascertaining the hole eccentricity of the disk by sub-
29 tracting the first measurement from the second measurement;
30 and

31 (e) speed determination means connected between the subtracter
32 means and the speed command means for determining a
33 matching speed of rotation for reading the disk on the
34 basis of the above ascertained hole eccentricity thereof.

35
36 11. An apparatus for data recovery from rotating optical data



1 storage disks having varying degrees of hole eccentricity and track eccen-
2 tricity, the apparatus having a transducer for reading data recorded on
3 each such disk along a track thereon by irradiating the disk with a
4 beam of light, the hole eccentricity of each disk manifesting itself during
5 disk rotation as periodic vibration of the disk and, in consequence, peri-
6 odic departures of the light beam from the track to an extent proportion-
7 al to the speed of disk rotation, the track eccentricity manifesting itself
8 during disk rotation as periodic departures of the light beam from the
9 track to a constant extent regardless of the speed of disk rotation,
10 wherein the improvement resides in the combination thereof with:

11 (a) drive means for imparting variable speed rotation to an optical
12 data storage disk;

13 (b) speed command means connected to the drive means for com-
14 manding speeds at which the disk is to be rotated, the
15 speed command means being capable of commanding disk
16 rotation at a first and a second disk eccentricity check
17 speed, the first disk eccentricity check speed being lower
18 than the second disk eccentricity check speed;

19 (c) eccentricity measurement means for making a first measurement of
20 the hole eccentricity and track eccentricity of the disk in
21 rotation at the first disk eccentricity check speed, and a
22 second measurement of the hole eccentricity and track ec-
23 centricity of the disk in rotation at the second disk eccen-
24 tricity check speed, both in terms of the resulting periodic
25 departures of the light beam from the track;

26 (d) subtracter means connected to the eccentricity measurement means
27 for ascertaining the hole eccentricity of the disk by sub-
28 tracting the first measurement from the second measurement;
29 and

30 (e) speed determination means connected between the subtracter
31 means and the speed command means for determining a
32 matching speed of rotation for reading the disk on the
33 basis of the above ascertained hole eccentricity thereof.
34

35 12. The apparatus of claim 11 wherein the apparatus has a tracking
36 servo for holding the spot of the light beam on the track on the disk,



1 the tracking servo including means for providing a tracking error signal
2 representative of the departures of the beam spot from the track, and
3 wherein the eccentricity measurement means comprises:

4 (a) means for deriving from the tracking error signal a component
5 that varies periodically with each complete revolution of the
6 disk; and

7 (b) means for detecting the amplitude of the derived component of
8 the tracking error signal.

9
10 13. The apparatus of claim 11 wherein the apparatus has a
11 tracking servo for holding the spot of the light beam on the track on
12 the disk, the tracking servo including means for providing a tracking ac-
13 tuator drive signal for driving a tracking actuator so as to keep the
14 beam spot on the disk, and wherein the eccentricity measurement means
15 comprises:

16 (a) means for deriving from the tracking actuator drive signal a
17 component that varies periodically with each complete revo-
18 lution of the disk; and

19 (b) means for detecting the amplitude of the derived component of
20 the tracking actuator drive signal.

21
22 14. An apparatus for data recovery from rotating optical data
23 storage disks having varying degrees of hole eccentricity and track eccen-
24 tricity, the apparatus having a transducer for reading data recorded on
25 each such disk along a track thereon by irradiating the disk with a
26 beam of light, the hole eccentricity of each disk manifesting itself during
27 disk rotation as periodic vibration of the disk and, in consequence, peri-
28 odic departures of the light beam from the track to an extent proportion-
29 al to the speed of disk rotation, the track eccentricity manifesting itself
30 during disk rotation as periodic departures of the light beam from the
31 track to a constant extent regardless of the speed of disk rotation, the
32 apparatus further having a tracking servo for holding the spot of the
33 light beam on the track on the disk, the tracking servo including means
34 for providing a tracking error signal representative of the departure of
35 the beam spot from the track, and means responsive to the tracking error
36 signal for providing a tracking actuator drive signal for driving a track-



1 ing actuator so as to keep the beam spot on the track, wherein the im-
2 provement resides in the combination thereof with:

3 (a) drive means for imparting variable speed rotation to an optical
4 data storage disk;

5 (b) speed command means connected to the drive means for com-
6 manding speeds at which the disk is to be rotated, the
7 speed command means being capable of commanding disk
8 rotation at a first and a second disk eccentricity check
9 speed, the first disk eccentricity check speed being lower
10 than the second disk eccentricity check speed;

11 (c) first eccentricity measurement means for making a first measure-
12 ment of the hole eccentricity and track eccentricity of the
13 disk in rotation at the first disk eccentricity check speed,
14 and a second measurement of the hole eccentricity and
15 track eccentricity of the disk in rotation at the second
16 disk eccentricity check speed, both by deriving from the
17 tracking error signal a component that varies periodically
18 with each complete revolution of the disk and by detecting
19 the amplitude of the derived component of the tracking
20 error signal;

21 (d) second eccentricity measurement means for making a third
22 measurement of the hole eccentricity and track eccentricity
23 of the disk in rotation at the first disk eccentricity check
24 speed, and a fourth measurement of the hole eccentricity
25 and track eccentricity of the disk in rotation at the second
26 disk eccentricity check speed, both by deriving from the
27 tracking actuator drive signal a component that varies peri-
28 odically with each complete revolution of the disk and by
29 detecting the amplitude of the derived component of the
30 tracking actuator drive signal;

31 (e) first subtracter means connected to the first eccentricity meas-
32 urement means for subtracting the first measurement from
33 the second measurement;

34 (f) second subtracter means connected to the second eccentricity
35 measurement means for subtracting the third measurement
36 from the fourth measurement; and



1 (e) speed determination means connected between the first and the
2 second subtracter means and the speed command means for
3 determining a matching speed of rotation for reading the
4 disk on the bases of the remainders of subtraction of the
5 first measurement from the second measurement and of sub-
6 traction of the third measurement from the fourth measure-
7 ment.

8
9 15. The apparatus of claim 14 wherein the speed determination
10 means determines the speed of rotation for reading the disk at a first
11 value when the remainder of subtraction of the first measurement from
12 the second measurement is equal to or greater than a first reference, at
13 a second value, which is higher than the first value, when the remainder
14 of subtraction of the first measurement from the second measurement is
15 less than the first reference and, at the same time, the remainder of sub-
16 traction of the third measurement from the fourth measurement is equal to
17 or greater than a second reference, and at a third value, which is higher
18 than the second value, when the remainder of subtraction of the first
19 measurement from the second measurement is less than the first reference
20 and, at the same time, the remainder of subtraction of the third measure-
21 ment from the fourth measurement is less than the second reference.

22
23 16. The apparatus of claim 14 wherein the speed determination
24 means determines the speed of rotation for reading the disk according to
25 the sum of the remainders of subtraction of the first measurement from
26 the second measurement and of subtraction of the third measurement from
27 the fourth measurement.

28
29 17. An apparatus for data recovery from rotating optical data
30 storage disks having varying degrees of hole eccentricity and track eccen-
31 tricity, the apparatus having a transducer for reading data recorded on
32 each such disk along a track thereon by irradiating the disk with a
33 beam of light, and a tracking servo for holding the spot of the light
34 beam on the track on the disk, a method of reading each disk at a
35 speed suiting the particular hole eccentricity of that disk, which method
36 comprises:



- 1 (a) drive means for imparting variable speed rotation to an optical
2 data storage disk;
- 3 (b) speed command means connected to the drive means for com-
4 manding speeds at which the disk is to be rotated, the
5 speed command means being capable of commanding disk
6 rotation at a first and a second disk eccentricity check
7 speed, the first disk eccentricity check speed being lower
8 than the second disk eccentricity check speed;
- 9 (c) means for turning the tracking servo on and off;
- 10 (d) eccentricity measurement means for making a first measurement
11 of the hole eccentricity and track eccentricity of the disk
12 in rotation at the first disk eccentricity check speed, and
13 a second measurement of the hole eccentricity and track
14 eccentricity of the disk in rotation at the second disk ec-
15 centricity check speed, both with the tracking servo turned
16 off, and both in terms of the number of times the light
17 beam crosses the track during at least one complete revolu-
18 tion of the disk at each check speed;
- 19 (e) subtracter means connected to the eccentricity measurement means
20 for ascertaining the hole eccentricity of the disk by sub-
21 tracting the number of times the light beam crossed the
22 track at the first eccentricity measurement from the number
23 of times the light beam crossed the track at the second
24 eccentricity measurement; and
- 25 (f) speed determination means connected between the subtracter
26 means and the speed command means for determining a
27 matching speed of rotation for reading the disk on the
28 basis of the above ascertained hole eccentricity thereof.

29
30 18. The apparatus of claim 17 wherein the eccentricity meas-
31 urement means include a counter for making the first and the second
32 measurements of the hole eccentricity and track eccentricity of the disk
33 by counting output pulses of the transducer.
34
35
36