

A DISK RECORDING SYSTEM AND A METHOD OF CONTROLLING
THE ROTATION OF A TURNTABLE IN SUCH A DISK
RECORDING SYSTEM

The present invention relates to a disk recording
5 system, for recording a disk such as a compact disk.
The present invention also relates to a method of
controlling the rotation of a turntable relative to a
recording head in a disk recording system.

Many systems are known in which information is
10 recorded on a disk-shaped medium and may subsequently
be played back. Generally the information is arranged
either in substantially circular rings or in a
continuous spiral track on the disk. An example of
the former arrangement is the magnetic floppy disk or
15 hard disk, where the information is divided into
sectors lying in concentric tracks. Examples of the
latter arrangement include the conventional gramophone
record carrying sound information in analog form in
the spiral groove in its surface, the optically read
20 videodisk carrying video information in analog form in
a series of pits arranged spirally on the surface (or
on an interfacial boundary) of the disk, and the
compact optical disk carrying audio or other
information in digital form in a series of spirally-

arranged pits. The gramophone record, the videodisk and the compact disk are all examples of media available to the consumer which cannot normally be recorded on by the consumer; recording takes place on
5 a master disk which is subsequently replicated by various processes such that the disks bought by the consumer are close copies of the geometry and the information content of the master disk.

The process of recording information on any of
10 these media usually shares in common the fact that the disk or master disk is rotated at a speed typically anywhere between 16 $\frac{2}{3}$ r.p.m. (for some gramophone records) and 1,800 r.p.m. (or even higher for some videodisks) while the point of recording (which may be
15 a magnetic head, a mechanical stylus, or a focused light beam) is traversed between the inside and outer edge of the disk at a slower rate. Normally it is a requirement of the recording system that the rotational motion of the disk may vary only slowly, if
20 at all; generally this is easily ensured by the inertia of the disk itself, together with that of the mechanism which rotates it. The radial motion of the point of recording on the disk is, however, not so easily controlled. In the case of magnetic disk
25 recording, it is usual that the recording head must move in discrete steps between the separate concentric tracks; by contrast, in the cases of gramophone records, videodisks, or compact disks, the recording

head must move continuously relative to the disk in a generally radial direction in order to lay out the information in a spiral track, and it is characteristic of these cases that the smoothness of the radial motion is more important than the absolute accuracy of radial positioning. With a gramophone record, for example, any radial motion having significant energy in the audio frequency band, even if it represents only a small fraction of the average groove spacing, will appear as a corresponding lateral movement of the pickup when the final record copy is played, and this will be audible as a noise superimposed on the recorded audio signal. With videodisks and compact disks there is not only the possibility that any sudden radial motions of the recording head will cause the player to fail to follow the track on the final disk, but also the more serious likelihood that such motions will be dangerous simply because they will result in significant changes in spacing between successive turns of the spiral track. Since this spacing is typically only $1.6\text{-}1.7\mu\text{m}$, and any reduction in spacing has the effect of increasing the crosstalk between tracks (resulting in interference in the picture from a videodisk, or an increased likelihood of bit errors with a compact disk) it is desirable to maintain a tolerance of at most $\pm 0.1\mu\text{m}$ in the track spacing, and preferably a much closer tolerance than this.

To obtain the necessary radial tracking motion, it is usual to move the recording head along a straight line which passes through the axis of the disk, in other words radially. When recording
5 gramophone record masters this is commonly achieved by mounting the recording head on a linear slide or rolling mount and moving it by means of a rotating leadscrew and nut. Satisfactory performance is achieved by careful engineering; the stiffness of the
10 leadscrew drive is great enough to overcome residual friction in the mounting. In videodisk and compact disk mastering (recording) a similar technique may be used, in which the optics which produce the focused beam are moved over the rotating master disk. To
15 avoid the disadvantage that part of the optics are thus movable while the remainder (owing to the size of the light source, normally a laser) have to be fixed, it is alternatively possible to move the entire turntable (which carries the master disk) together
20 with its rotary bearing along a straight line, using a leadscrew, while the recording head remains fixed.

In long-playing optical videodisks, or optical compact disks used for audio or other data in digital form, a constant linear velocity mode of recording is
25 normally used because it allows the maximum recording time consistent with operation at the optimum linear velocity (which determines the bandwidth of the signal which can be recorded) throughout the recording.

Constant linear velocity recording, however, adds complications to the system, because neither the speed of rotation of the disk, nor the speed of radial motion of the recording or playback head relative to the disk is constant. In a playback-only system this may be no great problem because both rotational and radial motions are normally controlled by servos governed by the information already laid down on the disk. Record/playback systems (for example read/write data recording systems) using pre-grooved disks are also simply implemented by servos of this type. However, in the case of a master recording system for videodisk or compact disk, where the master disk is initially devoid of groove structure, there is a problem in generating the required motions as it were from first principles.

If information is to be recorded in a spiral track of pitch P at a linear velocity v then, if the instantaneous radius is R and the rotational speed is ω (radians/sec.) at time t ,

$$\omega = \frac{v}{R} \quad \text{Equation 1}$$

$$\text{and} \quad \frac{dR}{dt} = \frac{P\omega}{2\pi} \quad \text{Equation 2}$$

$$\text{from which} \quad \frac{dR}{dt} = \frac{Pv}{2\pi R} \quad \text{Equation 3}$$

EP-A-011495 discloses, in the context of defining or following a plurality of substantially circular and concentric information tracks, an arrangement in which

the relationship of Equation 1 is obtained by generating a signal dependent on the radius R , and generating therefrom an alternating current signal of frequency inversely proportional to the radius R . The
5 angular rotational speed ω of the turntable is then synchronised to that alternating current signal. The same alternating current signal is used to control the radial velocity $\frac{dR}{dt}$, in accordance with Equation 2

10 using a lead screw drive. A similar method is described in EP-A-011493, in which an alternating current signal with a frequency inversely proportional to the radius R is generated, in this case by a digital division process.

15 It may be noted that the methods disclosed in EP-A-011495 and EP-A-011493 both require that an alternating current signal is generated first, to which the turntable rotation has to be synchronised.

Furthermore, EP-A-0013903 discloses a disk
20 recording system in which the radial displacement of the recording head relative to the axis of rotation of the turntable carrying the disk is determined. The measurement of the radial displacement is then used to control the rotational speed of the turntable, and
25 hence the disk, so that the relative velocity of the recording head and the disk are constant.

From Equation 3, if $R = 0$ at time t_0 , then Equation 4 below holds:

$$R = \left\{ \frac{Pv}{\pi} (t-t_0) \right\}^{\frac{1}{2}} \quad \text{Equation 4}$$

From this, it follows that:

$$\omega = \left\{ \frac{P}{\pi v} (t-t_0) \right\}^{-\frac{1}{2}} \quad \text{Equation 5}$$

Thus, both R and ω are non-linear functions of time.

It would be possible to generate these functions of time in a digital computer, and feed the functions to digital to analog converters to obtain voltages representative of the required values of R and ω . It would then be possible to use those voltages to control servo systems governing the radial and rotational motions. However, such an arrangement has the disadvantage that the values of R and ω thus obtained necessarily change in a stepwise manner, the magnitude of those steps depending on the resolution of the digital to analogue converters.

It would also be possible to use a digital computer to generate a value of the rate of change of radius R , given by equation 6 below.

$$\frac{dR}{dt} = \left(\frac{Pv}{4\pi(t-t_0)} \right)^{\frac{1}{2}} \quad \text{Equation 6}$$

This value, together with the value of ω derived by Equation 5, could be used to derive values which could then be output via digital to analog converters and fed to servos controlling the radial and rotational velocities. A single digital to analogue converter could be used for both values, since they have the same time dependence. Such an arrangement

would have the advantage that there are not the stepwise variations in R , but only in its rate of change $\frac{dR}{dt}$ and the effect on the recorded disk is

5 much less severe. However, the provision of an appropriate computing system means that complexity is high.

The present invention therefore seeks to obtain the necessary relationships between R and ω by analog
10 means. At its most general, the present invention proposes that signals are generated corresponding to R and ω ; the product of these two signals is then used to control the rotation of the turntable in dependence on the difference between that product and a reference
15 value.

A signal V_R corresponding to the radius R is generated, as is a signal representative of and proportional to the rotation velocity ω . The former is preferably a voltage signal and the latter is
20 preferably a frequency signal. Such a frequency signal may be produced by a slotted strobe disk attached to a shaft of the disk recording system, which may be sensed by suitable optical means. The signal V_R and the frequency signal may then be combined
25 in a multiplying discriminator circuit which generates a suitable signal proportional to the product $R\omega$. This product may be a voltage signal, which may then be compared with a reference voltage V_0 representative of the desired linear velocity. The difference in

voltages may then be used to drive a servo amplifier, which in turn drives a motor which rotates a turntable of the disk recording system.

Thus, with the second aspect of the present invention, it is possible to form a servo loop which tends to hold the product $R\omega$ constant and equal to the desired linear velocity. A separate discriminator circuit may also be used to derive from the frequency signal a voltage V_c representative of the quantity

10 $\frac{P\omega}{2\pi},$

where P is the desired track pitch. This voltage V_c may then be compared with a voltage V_s derived from the voltage V_R , which represents the quantity $\frac{dR}{dt}$.

15

The difference between the voltages V_c and V_s may then drive a servo amplifier whose output causes radial motion. Thus, the action of this second servo loop is such as to tend to hold $V_s = V_c$ and thus to

20 hold the radial velocity $\frac{dR}{dt}$ equal to the desired value $\frac{P\omega}{2\pi}.$

Preferably the disk recording system is used for optical recording or videodisks or audio or data compact disks.

25

An embodiment of the present invention will now be described in detail, by way of example, with

reference to the accompanying drawings, in which:

Fig. 1 is a schematic view of a disk recording system according to an embodiment of the present invention;

5 Fig. 2 illustrates a linear dashpot which may be used in the present invention;

 Figs. 3a and 3b illustrate a first rotary dashpot which may be used in the present invention, Fig. 3a being a sectional view and Fig. 3b being a detail of
10 the dashpot mechanism;

 Figs. 4a and 4b illustrate a second rotary dashpot which may be used in the present invention, Fig. 4a representing a sectional view and Fig. 4b illustrating a detail of the dashpot mechanism;

15 Fig. 5 illustrates an arrangement using a spring for applying a the torque to the shaft of the main air bearing in an embodiment of the present invention, together with a means for monitoring the rotation of the end of the spring remote from the shaft;

20 Figs. 6a and 6b illustrate another arrangement using a spring for applying a torque to the shaft of the main air bearing in the embodiment of the present invention, together with a means for monitoring the strain on the spring, Fig. 6a being a perspective view
25 of the arrangement and Fig. 6b being a detailed view of part the arrangement of Fig. 6a;

 Fig. 7 shows a local servo loop for controlling the motor arrangement of Fig. 5 or Figs 6a/6b of the

first embodiment of the present invention;

Figs. 8a and 8b illustrate a capacitive electrical sensing device for use in the embodiment of the present invention, Fig. 8a being a sectional view
5 and Fig. 8b being an exploded view of the disks of Fig. 8a;

Fig. 9 is a block diagram of an electrical circuit for processing the output of the sensing device of Figs. 8a and 8b;

10 Fig. 10 shows the variation of the output V_0 from the circuit of Fig. 9;

Fig. 11 shows a differentiating circuit for generating a further output voltage from the output circuit of Fig. 9;

15 Fig. 12 shows a servo amplifier for use in the present invention;

Fig. 13 shows the servo system for the disk recording system of Fig. 1; and

Fig. 14 shows a multiplying discriminator which
20 may be used in the servo system of Fig. 13.

Fig. 1 illustrates the general structure of a disk recording system being an embodiment of the present invention. A master disk 1 is supported on a turntable 2 which in turn is mounted on a shaft 3.
25 That shaft is the inner element of a turntable bearing 4 (or is an extension of the inner element). The turntable bearing 4, which carries the turntable 2, is

mounted on a bracket 5 held by arms 6,7 which arms 6,7 are supported by the shaft 8 of a main bearing 9. The turntable bearing 4 and the main bearing 9 are, in this embodiment, rotary air bearings, and their axes
5 are vertical.

Furthermore, a recording head 10 is mounted so as to be located above the turntable 2 and hence above the disk 1. In this embodiment, the recording head 10 is fixed, and the relative motion in the horizontal
10 plane of the disk 1 and recording head 10 is achieved by rotation of the turntable 2 and movement of the arms 6,7.

The rotation of the turntable 2, about shaft 3, is governed by the turntable bearing 4, and the
15 movement of the arms 6,7 on the shaft 8 is governed by the main bearing 9. The arms 6,7 are positioned so that the recording head 10 will follow an arc-shaped path relative to the axis of the turntable bearing 4, extending between the centre and the periphery of that
20 disk 1.

The rotation of the turntable 2 on the shaft 3 is driven by a first motor 11, and the movement of the arms 6,7 on the shaft 8 are driven by a second motor 12. In this embodiment, both motors are
25 electronically commutated motors with permanent-magnet rotors; the rotors are mounted directly on the shafts 3,8 so that no separate bearings are required.

Also mounted on the shaft 3 is a slotted strobe

13, the rotation of which is sensed by an optical sensor 14. The sensor 14 generates two outputs which are square-wave signals in a quadrature relationship. These outputs are used in a servo system for
5 controlling the rotation speed of the turntable 2.

The main bearing 9 is supported by a vertical bracket 15 which in turn is supported from the underside of a horizontal mounting plate 16 by a bracket 17. Mounted on the upper side of mounting
10 plate 16 is a damper unit 18 which will be described in more detail later. Also mounted above or within the concave-topped element 33 from a bracket 19a is a position sensing unit 19 which will also be described in more detail later.

15 As has previously been mentioned, the present invention requires that the relative movement of the head and the turntable bearing be damped. In an embodiment where this relative motion is linear, this may be achieved by a linear dashpot, such as shown in
20 Fig. 2.

Such a dashpot may be provided in the case where there is linear motion, for example where a linear air bearing is used, by the use of a piston moving in a fluid-filled cylinder. It is important in the present
25 invention that all friction be avoided; therefore a conventional seal cannot be used to prevent leakage of fluid around the shaft of the piston, and instead (if the motion is to be horizontal) an arrangement

corresponding to that of Fig. 2 is best used, incorporating shrouding means to prevent dust from falling into the fluid.

Thus, Fig. 2 shows that a piston 20 is mounted in a container 21, which container 21 is filled with viscous fluid 22. The piston has a bracket 23 which extends out of the container 21 and is fixed to the object whose movement is to be damped. The dust cover 24 is fixed to the bracket, covering the opening 25 in the container through which the bracket 23 extends, to prevent the ingress of dust.

Preferably, however, the dashpot used in the present invention is a rotary one, and is used in connection with a rotary air bearing, the axis of which is vertical.

Fig. 3a shows the construction of a dashpot which consists of interleaved thin annulae.

In Fig. 3a, an annular mounting 30 supports a fixed damping element 31. The fixed damping element 31 surrounds a shaft 32 (which may e.g. correspond to shaft 8 in Fig. 1 so that the dashpot corresponds to the damper unit 18 of Fig. 1) and a moving damping element 33 is fixed to that shaft. The fixed damping element 31 is secured to the mounting 30 by a clamping member 34, which is pressed down by springs (not shown).

As shown in more detail in Fig. 3b static vanes 35 are provided in the fixed damping element 31, which

are interleaved with moving vanes 36 secured to the moving damping element 33. A viscous fluid 37 fills the resulting dashpot.

Figs. 4a and 4b illustrate an alternative dashpot arrangement, having interleaved concentric cylindrical sections. Components of Fig. 4a and 4b corresponding to those of Fig. 3a and 3b are indicated by the same reference numerals. As can be seen from Fig. 4b, however, the static cylindrical sections 38 are vertical, as are the moving vanes 39. Again, if this dashpot is used in the embodiment of Fig. 1, the shaft 32 may correspond to the shaft 8 so that the dashpot forms the damper unit 18.

The cylindrical geometry of Figs. 4a and 4b is preferred because it allows freedom of adjustment of the movable elements in a vertical direction and because it is easier to fill the structure with fluid without causing bubbles. Radial gaps may be left at intervals in one set of cylindrical sections, in order to allow the fluid to distribute itself evenly. A very high viscosity is required to control the very slow speeds of motion required for example in compact disk recording, but suitable fluids are readily obtainable, for example the fluids sold under the brand name "Hyvis" by British Petroleum Ltd. and available in a range of viscosities. In order to fill the structure with fluid, the viscosity of the fluid may be reduced by heating it. A further feature of

the use of a rotary bearing in conjunction with a rotary dashpot according to this embodiment of the present invention is that rapid changes to the position of the movable elements may be effected by
5 raising the clamp 34 to free the entire dashpot assembly so that the outer dashpot element 31 rotates within its mountings 30.

The driving force to produce the relative motion of moving and fixed parts may, as stated above, be
10 generated by a direct-drive electric motor using the moving-coil, moving-magnet, induction or hysteresis principles. In accordance with the principles expressed above the motor must not contribute any friction to the relative motion; this is readily
15 achieved if the moving part of the motor has no bearings of its own but is mounted directly on the shaft 8 of the rotary air bearing. If commutation of the drive current is required (as in conventional moving-coil d.c. motors) then it should be generated
20 electronically by any of a variety of known means, rather than by mechanical switching.

Alternatively, it has been found possible to exert the necessary torque on the moving system by means of a spring, for example a coil spring whose
25 further end is secured, for example, to the output shaft of a reduction gearbox, the input shaft of which is driven by a conventional d.c motor. It is apparent that even if the said output shaft is held in a fixed

position, the spring will exert a torque which changes only slowly as the moving parts of the air bearing and damper assembly rotate; thus it is in the nature of this arrangement to produce a substantially constant
5 relative motion by purely passive means, and any adjustments to the speed of relative motion can be performed by driving the gearbox in a relatively crude manner.

Thus, Fig. 5 shows that the shaft 8 of the main
10 bearing 9 in Fig. 1 is connected to a spring 40, which in turn is connected to the output shaft 41 of a gearbox 42, which gearbox 42 connects the shaft 41 to a motor 43. It is found advantageous to place the motor/gearbox assembly in an inner servo loop having
15 a relatively short response time. In order to make this possible, the shaft 41 also extends to a rotary potentiometer 44. Thus, the output signal V_p of the potentiometer 44 corresponds to the position of the shaft 41.

20 Figs. 6a and 6b illustrate an alternative arrangement, in which the strain in the spring itself is sensed in order to drive the inner servo loop. Components which correspond to those of Fig. 5 are indicated by the same reference numerals. In Fig. 6a,
25 the spring 45 has a flat section, and a strain gauge 46 is mounted thereon. As is shown in more detail in Fig. 6b, the strain gauge is connected via flexible connections 47 to an output amplifier 48, which

generates an output signal V_p .

Fig. 7 shows the inner servo loop referred to above. In Fig. 7, the gearbox shaft position sensor (from Fig. 5) or the spring torque sensor (from Figs. 5 6a and 6b) is shown at 50. The output signal V_p from this sensor is fed to a differential amplifier 51. That differential amplifier 51 also receives a control voltage V_0 and generates an output 52 which drives the gearbox motor 43. Thus this inner servo loop causes 10 the sensor output V_p to follow the control voltage V_0 .

The signal V_0 is generated by a further servo loop (which will be discussed in more detail later) which has a slow response, so that the position of the gearbox output shaft, and hence the torsion in the 15 spring and hence the speed of motion of the movable elements (namely the main air bearing rotor, the movable part of the dashpot and the complete turntable bearing assembly), is controlled by comparing an external control voltage V_c with a voltage V 20 representative of the speed of motion and obtained from position sensing means for example as described below.

Turning now to the means of sensing the position of the movable parts, which may form the sensor unit 25 19 in Fig. 1, it is proposed that a capacitive electrical sensing device is provided as in Fig. 8a and 8b. In the arrangement illustrated, the shaft 8 of the main bearing 9 carries an insulating disk-

shaped rotor 60. This rotor carries on both its surfaces conducting sectors 61 occupying part of each surface. This rotor is mounted between insulating plates 62,63 attached to the fixed framework, each of which carries on its inward-facing surface conducting sectors (A,B) separated by narrow gaps. The number of such sectors depends on the angular range of rotation which it is desired to sense, but in the arrangement illustrated there are eight sectors allowing a maximum movement of 45° . The rotor 60 carries on each face four sectors 61, each subtending 45° at the centre and equally spaced apart so that the spaces between them also subtend 45° . The conducting sectors 61 on the two faces of the rotor 60 are aligned together and are all electrically connected to a conducting cylinder 65 and a flexible lead 64. The conducting sectors on the two fixed plates 62,63 are aligned in opposite-facing pairs which are electrically connected, and in addition alternate sectors on each plate are electrically connected, so that there are in all two sets of alternate sectors (A and B) each sharing a common electrical connection on the two fixed plates 62,63.

Alternative, but functionally equivalent methods of construction will of course be apparent to those skilled in the art, for example to form either the fixed conducting sectors, or the moving ones, or both, from metallic material in ways other than by forming

them on the surface of an insulating material, and in particular for all the moving sectors to form one self-supporting piece of metal.

Then equal and opposite alternating electrical
5 voltages (V_A and V_B) are applied to the two sets of fixed sectors. Preferably, these voltages are square waves of amplitude for example 30 volts peak-to-peak. As a result of capacitance between the conducting sectors on the rotating disk 60 and the sectors on the
10 fixed plates 62,63, an alternating voltage appears on the conducting sectors on the disk 60, of waveform similar to that of the voltages applied to the sectors of the fixed plates 62,63 and of magnitude and phase depending on the azimuthal position of the said
15 conducting sectors on the rotating disk 60 in relation to the sectors on the fixed plates 62,63. This voltage may be buffered (and optionally amplified) by, for example, an operational amplifier of low gain and high input impedance, connected by the flexible lead
20 64, and forms the input to a phase-sensitive detector (essentially a multiplier followed by a low-pass filter) whose reference input is the waveform applied to one set of the fixed sectors as shown in Fig. 9. From this phase-sensitive detector a d.c. output V_θ ,
25 is obtained, which is representative of the orientation (θ) of the moving sectors relative to the fixed sectors.

It may readily be shown that the d.c. voltage V_θ

is substantially proportional to

$$\frac{C_A - C_B}{C_A + C_B},$$

where C_A and C_B are the capacitances between the
 5 movable sectors and one or other set of fixed sectors
 respectively. If the disk and the fixed plates are
 flat and parallel at all times then these capacitances
 are in turn proportional to the areas of overlap
 between the movable sectors and the respective fixed
 10 sectors. If the sectors have circular inner and outer
 edges, then these areas are linear functions of the
 azimuthal angle θ , and $C_A + C_B$ is a constant. It can
 then be seen that the d.c. voltage V_θ is a
 substantially linear function of θ , except near the
 15 points (θ_A and θ_B) at which the rotating sectors are
 aligned with one or other set of fixed sectors. Fig.
 10 shows the dependence of V_θ on θ for the case where
 the sectors subtend 45° at the centre. Owing to its
 symmetrical construction, the sensing device of Figs.
 20 8a and 8b is tolerant of situations where the rotor 60
 is not exactly equidistant from, or parallel to, the
 fixed plates 62, 63.

Clearly this rotation sensing device may be
 modified in a number of ways obvious to those skilled
 25 in the art. For example, the number of sectors may be
 increased so as to subtend less than 45° ; the
 sensitivity, i.e. the rate of change of V_θ with θ , is
 then increased but the linear working range ($\theta_B - \theta_A$)
 becomes less.

When this rotation sensing means is applied to the embodiment of the invention shown in Fig. 1 so as to measure the azimuthal position of the swinging turntable bearing assembly in its arclike motion, it may be objected that, although the voltage V_θ is a substantially linear function of θ , it is not thereby a linear function of the distance of the recording head from the centre of the master disk. The latter distance may be expressed as $2R_c \sin \left(\frac{\theta - \theta_0}{2} \right)$,

where R_c is the radius of the motion of the turntable bearing assembly on its swinging arm and θ_0 is the value of θ when the recording head lies over the centre of the master disk (assuming that the system is aligned so that there is such a position), and

$$\sin \left(\frac{\theta - \theta_0}{2} \right)$$

is not a linear function of θ . However, a geometry may be chosen for which the linearity is adequately good for the present purpose. For example, if $R_c = 200$ mm and it is desired to record compact disks with a radius of 60 mm, then $(\theta - \theta_0) = 17^\circ$ maximum, and at this maximum excursion the voltage V_θ differs by only 0.4% from the value linearly extrapolated from small values of $(\theta - \theta_0)$. A correction for this error may be made electronically if necessary.

In general it will be found desirable to position the rotation sensing means such that a zero value of V_θ does not correspond to zero recorded radius (i.e.

the position where the recording head lies directly over the axis of the turntable). A voltage V_R which does so correspond may be obtained by adding a suitably chosen fixed reference voltage (V_{OFFSET}) as
 5 shown in Fig. 9.

It is found experimentally that a very good signal-to-noise ratio may be obtained with this arrangement, and in particular that it is possible to obtain electronically a second output voltage V_s which
 10 is adequately representative of the rate of change of V_r (in other words, representative of the speed of radial motion, $\frac{dR}{dt}$ of the recording head relative to

the master disk) to be used in a servo loop to control
 15 the radial motion. The second output voltage V_s may be obtained by a differentiating circuit as shown in Fig. 11. As discussed above in connection with V_r , there is a small radius-dependent error in V_s (owing to the geometry of the swinging arm in the embodiment of Fig
 20 1), which may be corrected electronically if necessary.

The differentiating behaviour of this circuit is primarily determined by C_1 and R . The optional components R_2 and C_2 each serve to limit the high-
 25 frequency response of the circuit by introducing first-order low-pass responses with time constants R_2C_1 and R_1C_2 , thus reducing the high frequency noise which appears in the output. It has been found possible to

control the said speed of radial motion in a system for recording compact disks in the manner herein described, notwithstanding that the said speed is only of the order of a few microns per second.

5 Fig. 12 shows the structure of a suitable servo amplifier for controlling the speed of the radial motion. The voltage V_s representative of the speed of radial motion is compared with a control voltage V_c representative of the desired speed, and the
10 difference $(V_s - V_c)$ forms the input to an amplifier. The output V_o of this amplifier controls the speed of radial motion, for example by controlling the torque applied to a rotary bearing system damped by a dashpot, for example by a direct-drive electric motor
15 or alternatively by rotating the one end of a coil spring whose other end is attached to the movable element. The action of the servo system is such as to tend to maintain V_s equal to V_c . The servo amplifier shown in Fig. 12 has an integrating response, and by
20 adjusting the values of the resistors r and the capacitor C the overall response time of the servo system may be set to a suitable value, for example 5 to 10 seconds, such a value being found to be a good compromise between a long response time causing the
25 system to be too slow in settling down and a short response time allowing too much noise from the rotation sensor to be impressed onto the radial motion.

Fig. 13 shows a servo system for controlling the disk recording system of Fig. 1. In Fig. 13, a radius sensor 108 generates both a radius voltage V_R and a radial velocity voltage V_s . The sensor 108 thus may
 5 operate on the basis of information from the position sensing unit 19 of Fig. 1 which has been discussed in detail with reference to Figs. 8, 9, 10 and 11. In a similar way, the rotation of the turntable 2 in Fig. 1 is monitored by the turntable strobe 13 and sensor
 10 14, which generates a pulse train signal 102 (ideally a square wave) representative of ω and a delayed pulse train signal 104. These signals 102, 104 are both passed to two multiplying discriminators 110, 112. The first discriminator 110 also receives the radius
 15 voltage signal V_R from the radius sensor 108. From V_R and the signals 102, 104, the discriminator 110 generates a voltage V_1 which is proportional to $V_R \omega$. That voltage V_1 is compared with a reference voltage V_0 representative of the desired linear velocity. The
 20 comparison is carried out by a servo amplifier 110, and this generates an output acting as the DC drive to the motor 11 which rotates the turntable 2.

In a similar way, the second discriminator 112 receives the signals from the sensor 14, and also a
 25 reference voltage 113. The discriminator 112 is used to derive from the said pulse train a voltage V_c proportional to ω alone, which is compared with the voltage V_s which is representative of and substantially

proportional to $\frac{dR}{dt}$.

The difference between the voltages V_c and V_s drives a servo amplifier 114 whose output causes radial motion.

5 Thus the action of this second servo loop is such as to tend to hold V_s equal to V_c . If the sensitivity of the discriminator circuit is suitably chosen in proportion to the desired track pitch P , then V_c can be made representative of the quantity $\frac{P\omega}{2\pi}$, whereupon

10 the action of this second servo loop is such as to hold the radial velocity $\frac{dR}{dt}$ equal to the desired value $\frac{P\omega}{2\pi}$

15 In the arrangement of Fig. 13, suitable adjustment of the gains and frequency responses of the servo amplifiers 111 and 114 will normally be necessary, in a manner known to persons skilled in the art, to ensure a suitably accurate overall response consistent with stability. In particular the amplifier 114 may have the characteristics discussed above in connection with Fig. 12.

Fig. 14 illustrates a structure which may be used 25 for the discriminator 110. The structure of discriminator 112 may be similar, with the reference voltage 113 replacing the signal V_R .

In Fig. 14, an electronic switch 101 is controlled by the pulse train 102 from the sensor 14. 30 The switch 101 generates a voltage signal 103 which alternates between the radius voltage V_R and ground, at

the frequency of the pulse train 102. The voltage transitions of the waveform of the signal 103 cause current pulses to flow through a capacitor 105 to a second electronic switch 106, which is controlled by
 5 the delayed strobe signal 104 from the turntable strobe. That delay should be less than half a cycle. The delayed strobe signal 104 may be generated by a second optical sensor acting on the strobe disk 13, but may alternatively be generated by electronically
 10 delaying the strobe signal 102. As a result, the delayed strobe signal 104 gates the current pulses arriving from the capacitor 105, that gating being alternately between ground and the input of an amplifier 107. Thus, a mean voltage V_1 appears at the
 15 output of the amplifier 107 which is proportional both to V_R and to the repetition rate of the strobe signal 102. Hence, V_1 is proportional to $V_R\omega$.

The capacitor 115 serves to attenuate the transitions in the waveform of the voltage V_1 , which
 20 are due to the current pulses arriving from the capacitor 105.

The discriminator 112 may be the same as that of Fig. 14 except that in place of V_R it uses a reference voltage 113 which does not vary with radius, but which
 25 may be set in proportion to the desired track pitch P so as to obtain an output voltage representative of $\frac{P\omega}{2\pi}$.

CLAIMS

1. A method of controlling the rotation of a turntable (2) relative to a recording head (10) in a disk recording system, in which a first signal is generated corresponding to the radial displacement of the recording head (10) relative to the turntable axis:

characterised in that:

a second signal is generated corresponding to the rate of rotation of the turntable (2),

the product of the first and second signals is generated, and the rotation of the turntable (2) is controlled in dependence on the difference between that product and a reference value.

2. A method according to claim 1, wherein the first signal is a voltage signal and the second signal is a frequency signal.

3. A method according to claim 1 or claim 2, wherein the product is a voltage signal.

4. A method according to any one of the preceding claims, wherein the generation of the product of the first and second signals includes generation of pulses proportional in magnitude to the first signal and at a frequency depending on the second signal.

5. A method according to claim 4 wherein at least some of the pulses are passed to an amplifier (107) which generates the average amplitude of those pulses, representing the product.

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED



6. A method according to any one of the preceding claims, wherein a signal corresponding to the radial velocity of the head is compared with the second signal for controlling radial motion of the recording
5 head (10) relative to the turntable (2).

7. A disk recording system comprising:
a recording head (10),
a turntable (2) for supporting a disk (1)
adjacent the recording head (10) the turntable (2)
10 being rotatable relative to the recording head (10);
means for moving the recording head (10) relative
to the axis of the turntable (2), and
means for generating a first signal corresponding
to the radial displacement of the recording head from
15 the turntable axis:

characterised in that:

the system further includes:

means for generating a second signal
corresponding to the rate of rotation of the
20 turntable,

means for generating the product of the first and
second signals, and

means for controlling the rotation of the
turntable in dependence on the difference between that
25 product and a reference value.

8. A disk recording system according to claim 7,
having a gate network comprising first and second
gates (101, 106) connected by a capacitor (105), the

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED



first gate (101) and the capacitor (105) being arranged to generate pulses of a magnitude proportional to the first signal and of a frequency proportional to the second signal, and the second gate
5 (106) being arranged to pass at least some of those pulses.

9. A disk recording system according to claim 8 wherein the second gate (106) is adapted to be controlled on the basis of the second signal, thereby
10 to pass pulses of one polarity only.

10. A disk recording system according to claim 7 or claim 16, having an amplifier (107) connected to the second gate (106) for generating the average amplitude of the pulses passed by the second gate.

15 11. A disk recording system according to any one of claims 7 to 10, further including means for comparing a signal corresponding to the radial velocity of the head with the second signal, and for controlling the head movement means in response to that comparison.



* C L M S *

THIS SHEET HAS BEEN
REPLACED