DESIGN OF A DISK FILE HEAD-POSITIONING SERVO

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Abstract: The engineering design of a head-positioning system for an interchangeable media disk file is considered. Particular emphasis is placed upon three specific functions within the positioning system: (1) encoding and demodulation of information from the dedicated servo surface, (2) compensation and dynamics of the track-following control system, and (3) implementation of control electronics for a quasi-time optimal track-accessing control system. The examples used are taken from the IBM 3340 Disk Storage Facility.

INTRODUCTION

The head-positioning servo system of a modern disk file provides many functions in addition to maintaining the data heads located over their respective positions on the recording surfaces. It must furnish a clock signal synchronized with the disk rotation to the recording channel so that all tracks will contain the same number of bits in the presence of spindle speed variations.

It must also provide an index mark and rotational position information for the data channel, as well as a means of recalibration of the access mechanism to data track 0 on start up or after errors. These requirements must be satisfied when choosing the encoding of the servo disk.

SERVO SURFACE ENCODING AND DEMODULATION

The head-positioning system requires an error signal which indicates the radial position of the heads relative to the desired recording track location on the data disks. This is the primary function of the prerecorded servo disk, servo head, and associated electronics. They will now be examined in greater detail.

To meet the requirements for a stable and accurate feedback control system, the error signal transducer must provide a signal which is not only zero when the head is properly positioned "on track", but also linearly proportional to the size and polarized as to the direction of misposition distance when "off track". The tranducer transfer function, expressed as output volts per unit of input radial misposition distance, should be a constant, independent of distance off track,* head signal amplitude variation, head-disk spacing variation, etc. These requirements may be accomplished by utilizing the property of a magnetic recording head which makes the amplitude of the electrical read signal proportional to the fractional width of the head over a recorded track. This is illustrated in Figs. 1 and 2a, where the head width h is the same as the track width.

The servo head signals are processed such that a resulting signal (which we shall call the "positive signal") is generated:

$$\text{Position signal} = k(B-A), \tag{1}$$

$B \triangleq$ portion of head signal due to track B,

$A \triangleq$ portion of head signal due to track A,

$k \triangleq$ gain parameter adjusted to make $k(A+B) =$ constant. (2)

Electronics suitable for generating the position signal described by Fig. 2b and Eqs. (1) and (2) are shown by the design block diagram of Fig. 3.

*Within limits of ± 1/2 track pitch distance at least.

It is evident from Figs. 2 and 3 that the position transducer system consists of a modulator-multiplexer (the encoded servo tracks and servo head), communications channel (the head signal), and demodulator-demultiplexer (electronics of Fig. 3). When choosing the best encoding method for the servo disk, the possible alternatives come from two major categories: frequency division multiplexing and time division multiplexing. Frequency division multiplexing would encode A tracks with one continuously recorded frequency and B tracks with a different frequency. The demodulator channels would then consist of appropriate bandpass filters, followed by envelope detectors. Time division multiplexing for this application might be better described as pulse position encoding in which a sync character is coincidently recorded in both A and B tracks, followed by two mutually nonoverlapping time periods containing pulses only in A tracks or B tracks, respectively. A comparison of these two systems is made in Table 1.

Practically implementable solutions were quickly found for the problems shown as disadvantages for pulse position encoding. Much of the work done in implementing this class of encoding for the previously developed IBM 3330 disk file proved to be directly usable. On the other hand, acceptable solutions to the frequency response and filter stability problems (disadvantages (1) and (2), Table 1) of frequency division systems have proved to be unattainable at competitive cost with electronics technology available in 1970.*

*The outcome might well be different with the linear integrated circuit technology avialable in 1974, however.

Therefore, a pulse position servo encoding was chosen for use in the 3340, and engineering efforts were concentrated upon finding a particular pulse code that would both improve performance and reduce cost and complexity, compared to the system used in 3330. The code shown in Fig. 4, was to my knowledge first proposed by Muller[1]. It has become known as the tri-bit pattern, for somewhat obvious reasons.

In reference to Fig. 3 and 4, sync information is contained in the leading edge 50% level of the sync pulse, which starts a monostable timing circuit or produce logic gates at A pulse and B pulse times. These logic signals are used to control identical gated peak detectors for the A and B channel demodulators, respectively. This system has proven to be very effective in practice and its advantages result from the following features.

The A and B channel demodulator electronics are identical and, furthermore, the code is such that off-track errors due to the electronics can only be caused by differences between the A and B channels. This feature can exploit the inherent matching of components on an integrated circuit, yet not require precise parameter values which are very difficult to achieve. It can be seen from Fig. 3 that, to have the same slope of the position signal at every null point (required to maintain negative feedback in the servo loop), an inversion of polarity is necessary on every other track. This may be accomplished in any system by swapping the outputs of the A and B demodulators; but in the tri-bit system where the demodulators are identical, only simple logic gating of the A and B gate signals is required, not a selectable analog gain of -1 which is a source of potential error and complexity.

Sync recovery with tri-bits requires only a level comparator for the -50% of the head signal since the sync pulse amplitude never varies as a function of off-track location. Since the spacing between sync pulses in this implementation was chosen to be two data-channel byte times, the pulses are well separated and index encoding is easily accomplished by adding an additional sync pulse between the A and B pulses only at index time. Thus, index detection and the data channel oscillator reference can be obtained very accurately with only simple electronics rather than the complex phase-locked oscillator required by most pulse-position encoding systems. The price paid for this feature is, of course, a large percentage of channel capacity being devoted to sync information, but the required servo transducer bandwidth is so low that this is a very profitable trade off.

The only significant disadvantage found with the tri-bit system is a sensitivity to asymmetrical pulse shapes in the magnetic recording system. If trailing edges of the pulses are longer than the leading edges, then any adjacent pulse interference makes the A pulse smaller (it is preceeded by a negative sync) and the B pluse larger (it is preceeded by a positive A pulse). Thus, the resultant null points are always shifted toward A tracks, making the minimum distances between null points (data track centers) smaller. So long as the pulse shape is reproducible and constant, this effect may be minimized by precompensation of the written track locations where the servo disk is recorded. This has proven to be an effective solution for the 3340.

SERVO DYNAMICS

When analyzing the head-positioning servo dynamics, the structure consisting of the heads and their supporting arms, carriage and bearings providing rectilinear motion, and the moving armature portion of the actuate motor may be considered essentially an inertia with both viscous and sliding friction negligible in effect. The type of actuator motor used has a moving coil armature attached to the carriage and a permanent magnet stator (the so called "voice coil motor" from analogy with permanent magnet loudspeakers).

The force produced by such a motor is directly proportional to armature current, while the armature voltage has a component proportional to velocity (the "back emf"), as well as the voltage drop due to current flow in the resistive and inductive impedance of the armature. Thus, the ouput impedance of the power amplifier used to drive the motor has a considerable effect upon system dynamics.

With a very low output impedance voltage mode amplifier, the armature current and, thus, force are affected by the armature voltage, producing not only damping due to the back emf, but also a current rise time dependent upon the armature L/R time constant. On the other hand, a high output impedance current-mode amplifier is able to set the armature current independent of the armature voltage (within the limits imposed by its power supply voltages). Thus, with a current mode driver, the current and force rise times are much faster and are independent of the temperature sensitive R of the armature but there is no inherent viscous damping resulting from the back emf.

The advantage of a faster force rise time is very significant while the loss of inherent motor damping can easily be made up by a compensation network in the servo electronics. Thus, nearly all designers choose current-mode drive, and the 3340 is no exception. A block diagram of the track-following servo of the 3340 using Laplace transform operational notation is shown in Fig. 5.

The open-loop transfer function G of Fig. 5 is given in Eq. 3.

$$G = \frac{K_c(S)}{S^2} \cdot \frac{K_1 K_A K_F}{M}. \tag{3}$$

Without the compensator $K_c(S)$, this is a classical second-order type 2 positioning servo[2]. It is capable of maintaining zero static misposition, but without compensation is a simple harmonic oscillator with no damping. The classical compensator for such a system is a lead-lag network $K_c(S)$ described by Eq. 4.

$$K_c(S) = \frac{\omega_1^2 \; M \left(\dfrac{S}{\left(\frac{\omega_1}{\sqrt{\gamma}}\right)} + 1 \right)}{\sqrt{\gamma} \; K_1 \; K_A \; K_F \left(\left(\dfrac{S}{\sqrt{\gamma}\,\omega_1}\right) + 1 \right)} \tag{4}$$

and substitution in Eq. 3 yields

$$G = \frac{\omega_1^2 \left(\frac{s}{\left(\frac{\omega_1}{\sqrt{\gamma}}\right)} + 1 \right)}{\sqrt{\gamma}\, s^2 \left(\frac{s}{\left(\sqrt{\gamma}\,\omega_1\right)} + 1 \right)} . \tag{5}$$

The open-loop transfer function G of Eq. 5 (which includes the compensator) is shown on the Bode diagram of Fig. 6 as an aid to seeing the effect of the compensator parameters γ and ω_1.

ω_1 is the radian frequency at which the open-loop gain is unity; it sets the bandwidth of the system. γ is the ratio of pole and zero frequencies $\sqrt{\gamma}\,\omega_1$ and $\frac{\omega_1}{\sqrt{\gamma}}$, respectively, of of the compensator; it controls the size of the phase lead at ω_1 and thus the amount of damping in the closed-loop system. A value of $\gamma = 7.5$ yields a phase lead of about 50°. This results in a system whose time response to a step displacement input has a single overshoot of less than 10%, and is usually considered to be a most desirable settling characteristic.

The closed-loop system bandwidth is set by ω_1 and increasing it while holding other system parameters constant reduces the track-following error due to (1) radial runout of the tracks at the disk rotation frequency ω_R, (2) static forces produced by imperfections in the carriage bearings or (3) cooling air circulating past the carriage. Increasing bandwidth also reduces settling time after a move between tracks and thus reduces access time, but the upper limit on bandwidth is controlled by the need to maintain stability in the presence of high-frequency mechanical-structural resonances such as shown in Fig. 6. If the bandwidth is increased sufficiently, the open-loop gain at frequency ω_M exceeds unity and most likely results in instability and oscillation. It is, of course, desirable to correct this by mechanical design improvements which lower the magnitude or increase the frequency of the resonance, but further improvements soon prove very costly.

In the 3340 track-following servo, a sharp cutoff second-order active low-pass filter was added to the compensator to help attenuate this resonance and permit a larger stable bandwidth. By placing the filter cutoff frequency ω_F at $5\omega_1$ and making its damping factor a very small $\zeta = .25$, the peaking at ω_F was limited to about 6 db and the phase loss at ω_1 to about -7°. By simultaneously increasing γ from 7.5 to 9, the system damping, transient overshoot, and gain margin at ω_M have remained nearly unchanged while increasing ω_1 (and thus the closed loop bandwidth) by 40%. There are at least two significant hazards in adopting this filter in other systems; it takes only a small amplitude unexpected structure resonance near ω_F to cause oscillation at that frequency and, secondly, the asymptotic slope of the magnitude function at high frequency is now - 60 db/decade; so only a small decrease in ω_M due to mechanical tolerances can greatly decrease the stability margin.

Before leaving the subject of compensators, a note should be added on hardware implementations. The final compensator and filter described above is shown in Fig. 7a, together with a power amplifier having an input voltage offset

V_s (an undersired error term) and transconductance of K_A amp/volt. The realization shown in Fig. 7b has the same transfer function as that shown in 7a. However, with implementation (b) the offset voltage V_S when refered to the position signal input is clearly only $1/\gamma$ times as large as in (a), a reduction of nearly an order of magnitude for $\gamma = 9$!

ACCESSING CONTROL SYSTEM

It has already been noted that the position transducer for the track-following servo, described by Figs. 2 and 3, is useful only over distances of about $\pm$ 1/2 track and, thus, is incapable of controlling head motion over distances of many tracks. Furthermore, the objective of an accessing servo is achieving minimum move time between any two tracks on the disk, rather than best accuracy in following a specific track. Thus, the control circuits of the accessing servo are much different than those of the track-following servo even though they both use the same power amplifier, actuator motor, and mechanical system components.

To design the accessing servo controller, time optimal control theory is used[3]. In simple terms the control strategy is to initially apply full forward power to the actuator until some point at which there is a switch to full reverse power until motion stops, hopefully at exactly the center of the desired destination track. However, implementation of such a system which also has the desired reliability is prohibitively expensive, so a slight compromise is made in the control. Full forward power is still initially applied, but as soon as the system velocity and position correspond with a trajectory defined by the control circuits, reverse power is applied under closed-loop control to keep the system flowing this trajectory the remaining distance to the target track. Since the control trajectory is constructed such that a machine with worst case performance can just follow with maximum reverse power, all other machines operate at less than maximum reverse power but still take no longer than the worst machine and are assured of reaching the correct target.

For systems with negligible actuator motor inductance, the control trajectory is parabolic of the form

$$\text{control velocity} = \text{constant} \times (\text{remaining distance})^{1/2}. \quad (6)$$

Operation of this system is illustrated in Fig. 8.

Input commands to the accessing servo are in the form of a direction and incremental track difference count. This difference is loaded into a down counter which is decremented by the zero crossings of the track-following position signal shown in Fig. 2. Thus, the track-position information is constantly available as a binary number in the counter, while velocity is measured by an analog electronic tachometer. A conventional way to implement the control trajectory is shown in Fig. 9 together with the improved method used in the 3340.

The maximum track difference of 350 requires a 9-bit binary word, but the only portion of the control trajectory with any significant slope or curvature is the last 63 tracks. Using logic to force the DAC to full scale whenever any of the three more significant bits of the counter are on permits use of a much simpler 6-bit DAC without significant change in performance. In addition, putting the diode function generator in feedback to the reference input of the DAC permits a curve fit to the required square root function with a series of curved line segments rather than the straight line segments obtained with the conventional cascaded function generator. This combination has not only permitted generation of a more accurate control trajectory (the error in the derivation of velocity with respect to position is much smaller), but also reduced the number of segments required in the function generator and thus its cost and complexity.

CONCLUSION

Several design improvements for disk file head-positioning servos have been presented in both the conceptual design form and the final implementation used in a current product. Since there is a notable lack of previously published applications literature in this field, it is hoped that this paper will have been enlightening to the reader and help stimulate his innovation of still better control systems for the future.

REFERENCES

1. U.S. Patent 3,691,543, September 12, 1972.

2. G. J. Thaler and R. G. Brown, Analysis and Design of Feedback Control Systems, McGraw-Hill 1960.

3. George Leitmann, An Introduction to Optimal Control McGraw-Hill 1966.

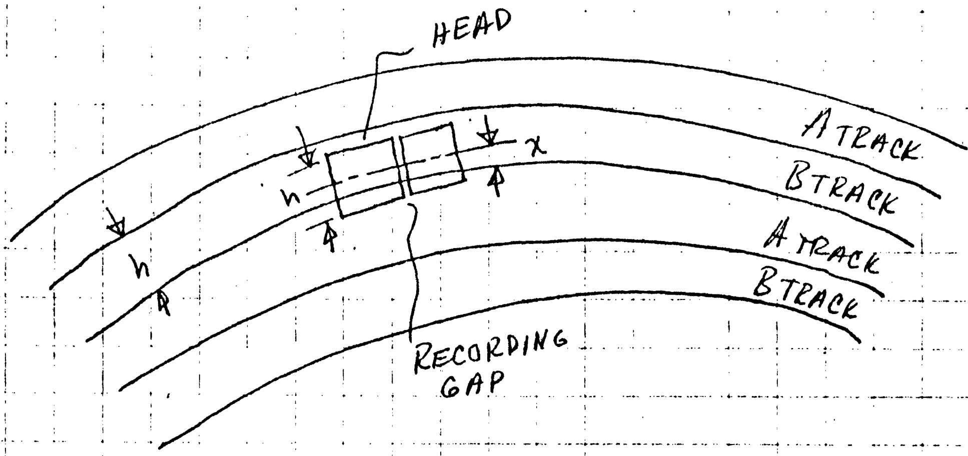
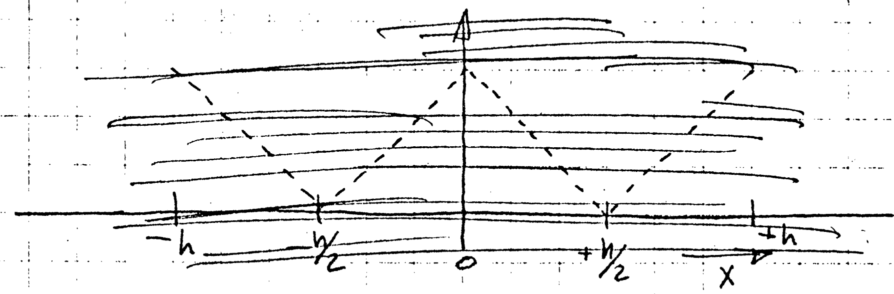


Figure 1. Servo Disk Format



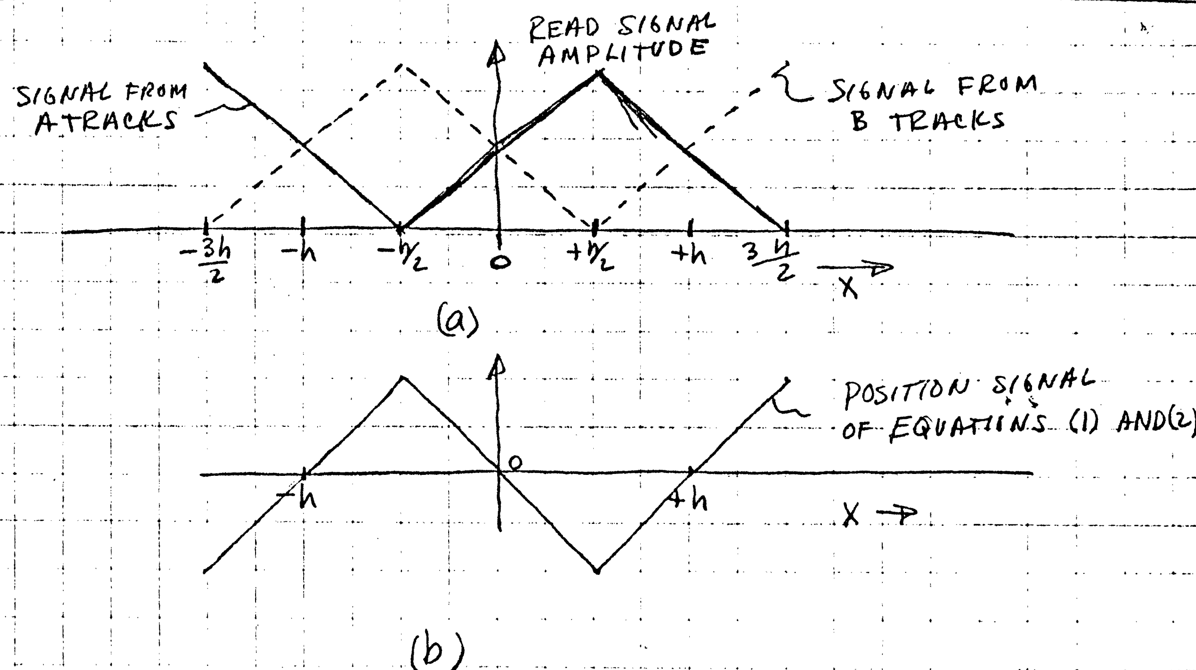


Figure 2 Servo Head Signals

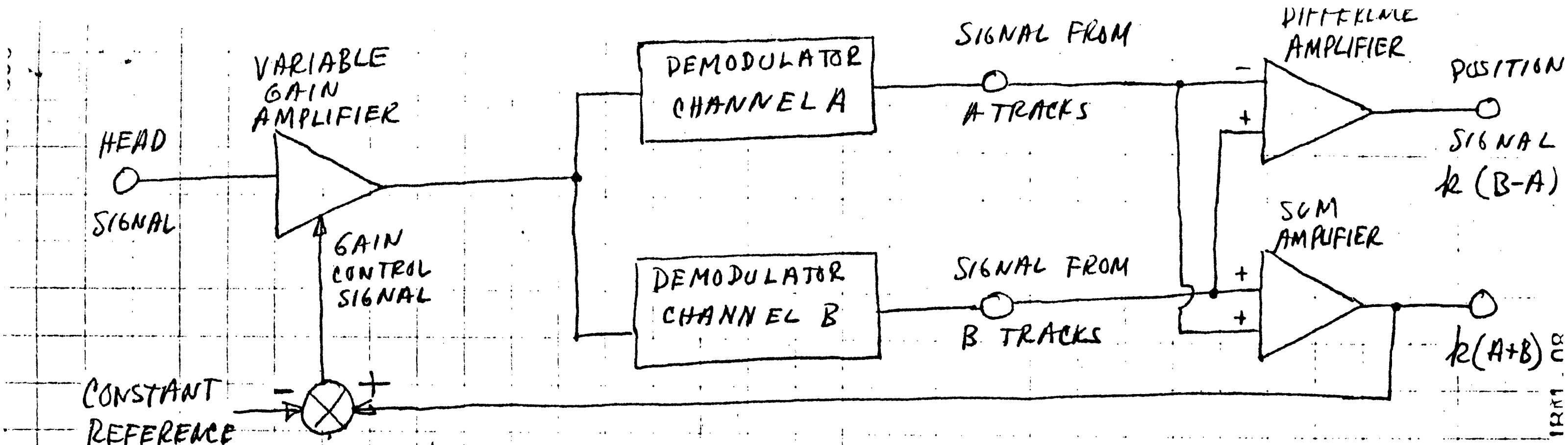


Figure 3. Demodulation Electronics

SYSTEM	ADVANTAGES	DISADVANTAGES
FREQUENCY DIVISION	1.) Time synchronization between A and B tracks not required. 2.) No need to regenerate sync information for demodulator. 3.) Impulse noise rejection can be very good. 4.) Demodulator is very simple	1.) Frequency dependant amplitude variations cause off track error. 2.) Filter amplitude and frequency stability difficult to achieve. 3.) May require AC biased recording to avoid wide harmonic spectrum in read back signal. 4.) Index encoding usually adds considerable complexity to electronics.
PULSE POSITION	1.) Can utilize same recording and read back components as data channel. 2.) Frequency response variations don't cause off track error. 3.) Demodulator sync directly usable as data write oscillator sync. 4.) Index encoding easy to add to existing sync information.	1.) Sync information sensitive to impulse noise. 2.) Sync recovery and gated demodulator electronics may be complex. 3.) Accurate time syncronization required between recorded A and B tracks 4.) More sensitive to small disk coating defects.

TABLE 1. ENCODING SYSTEMS

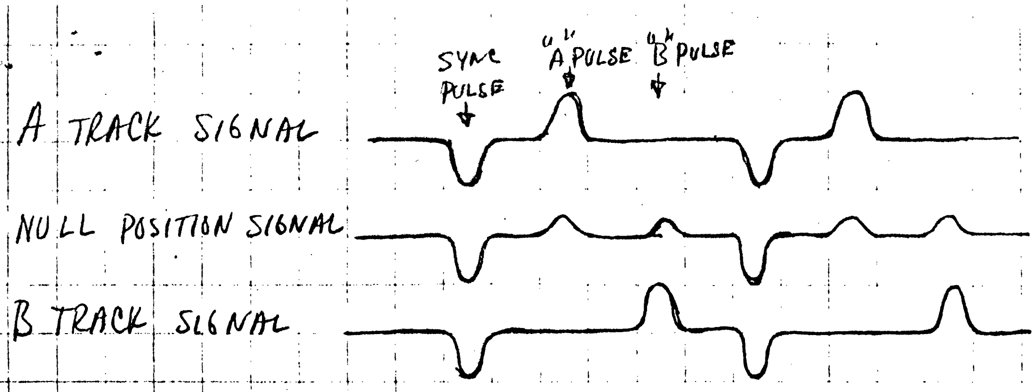


Figure 4. Read back signals, tri-bit encoding.

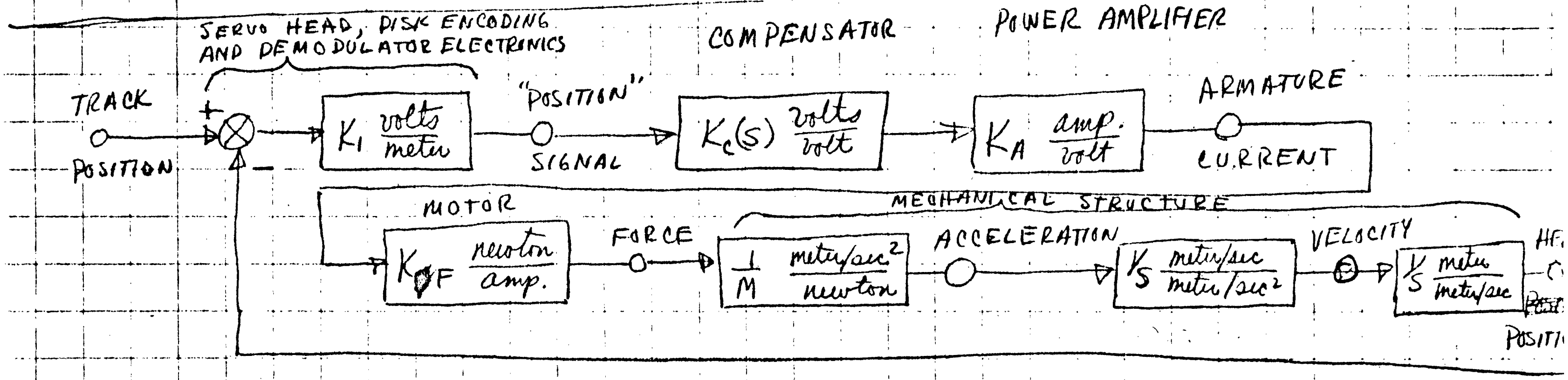


Figure 5. Track following servo block diagram

Figure 6. (on graph)

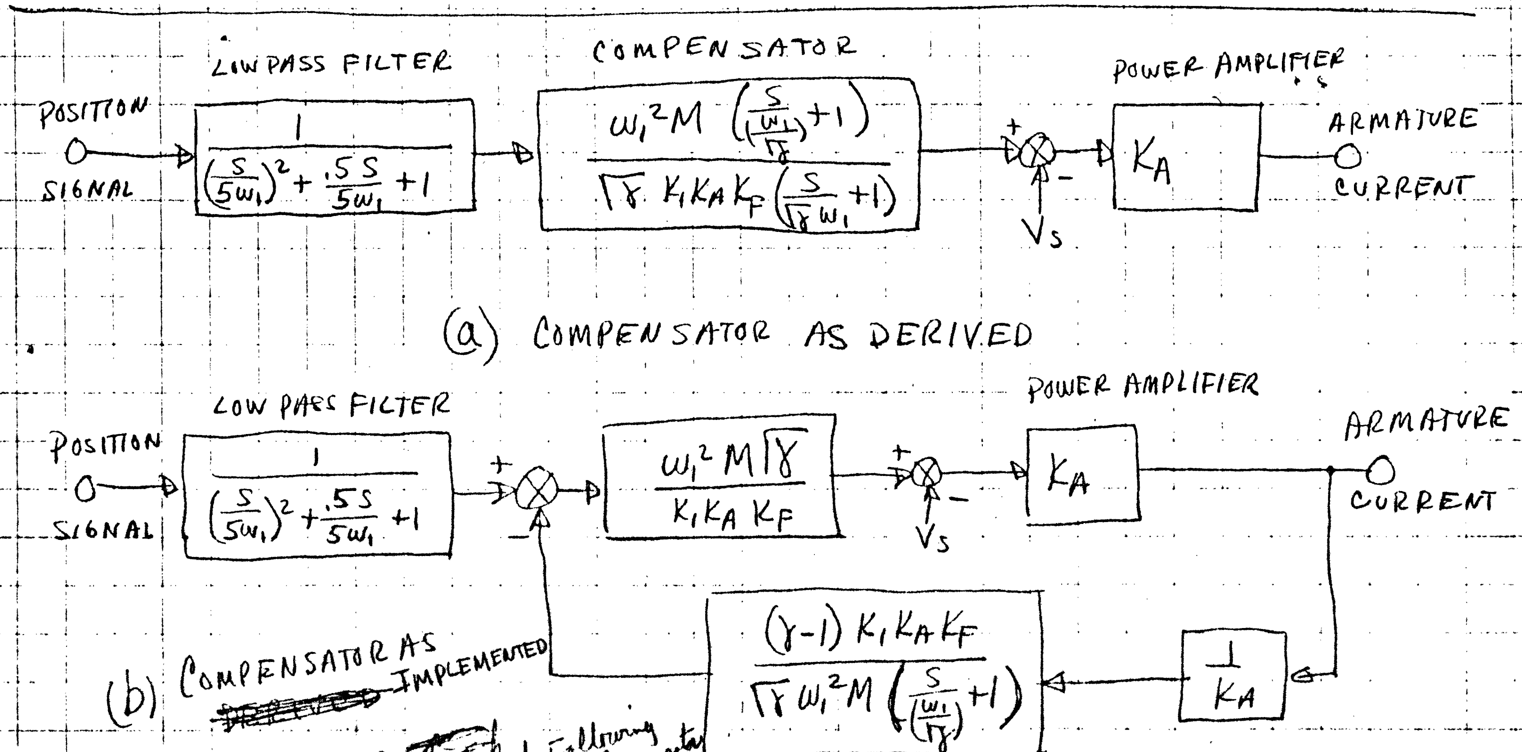


FIGURE 7 ~~Track~~ Track Following Compensator

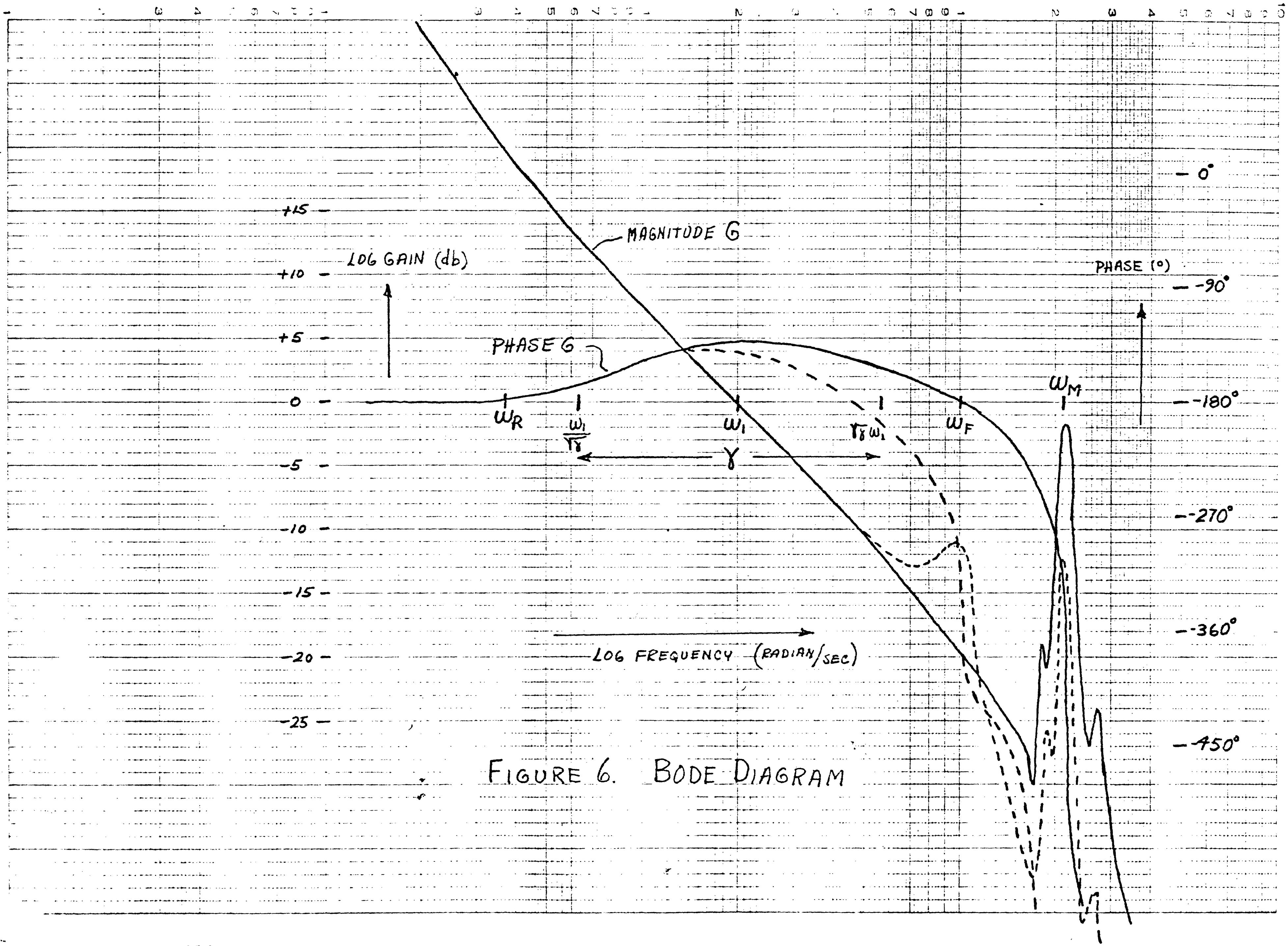


FIGURE 6. BODE DIAGRAM

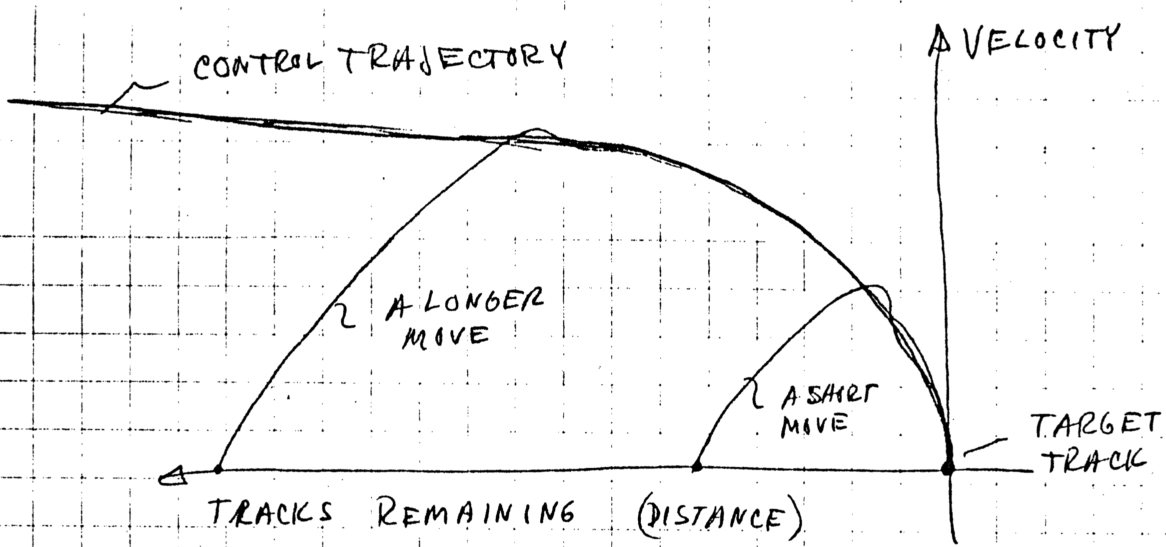
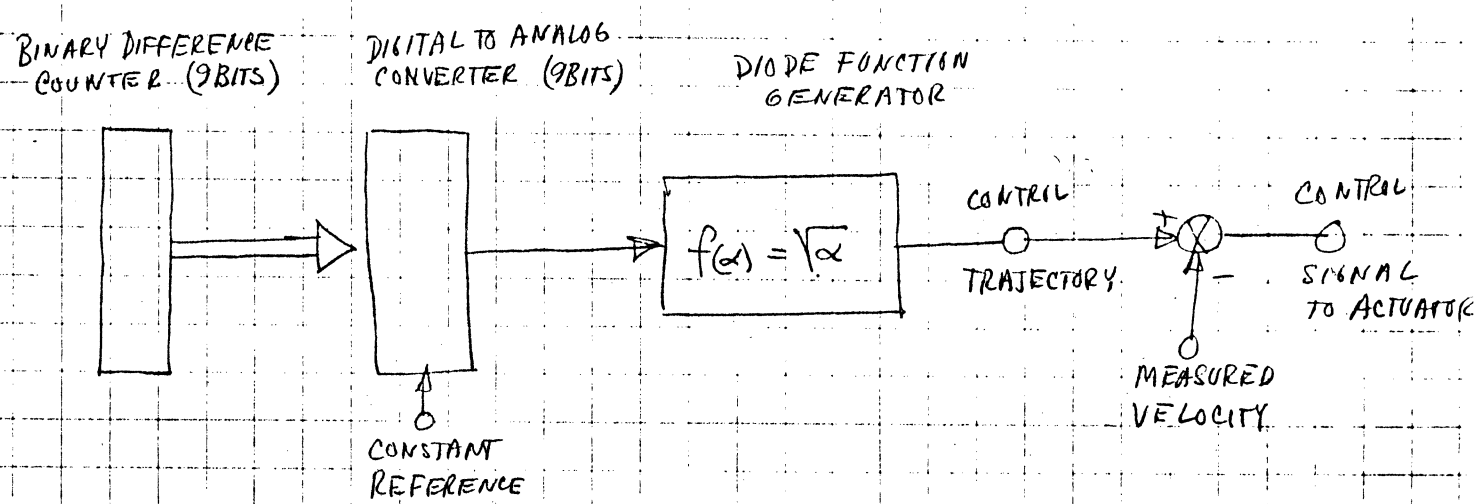


Figure 8. Access control trajectory



(a) CONVENTIONAL METHOD.

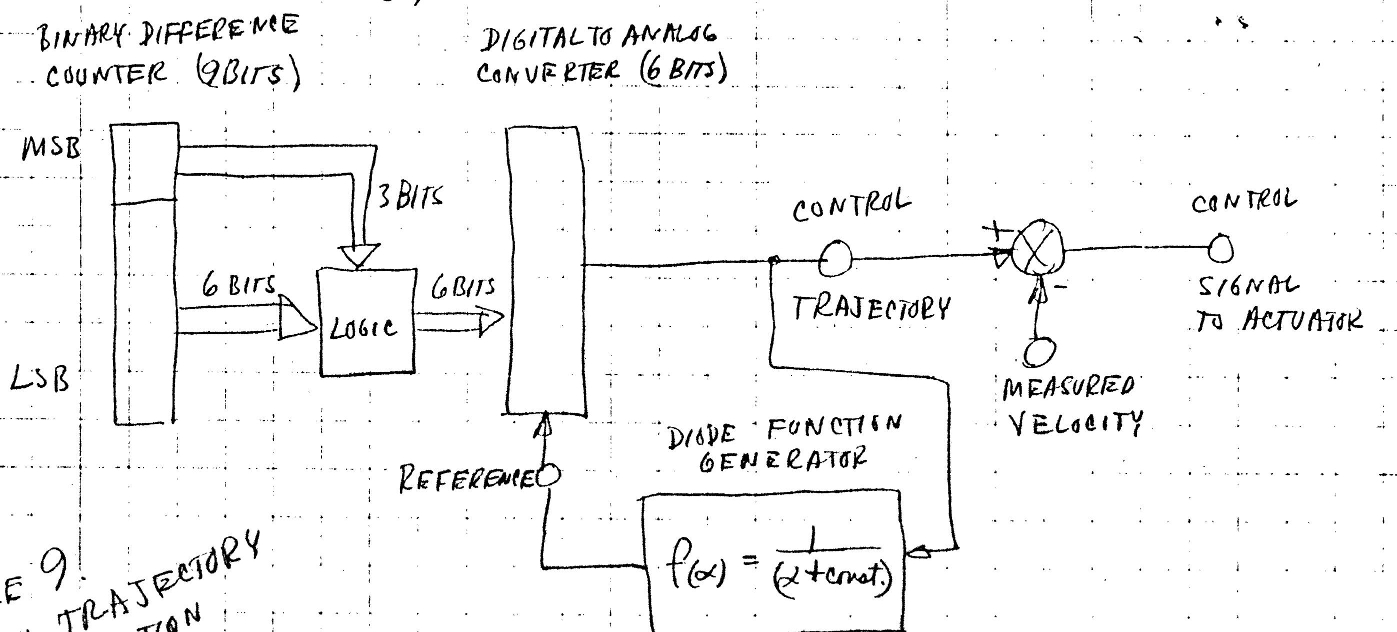


FIGURE 9
CONTROL TRAJECTORY GENERATION

(b) METHOD USED IN 2240.

United States Patent Office

3,534,344

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3,534,344

METHOD AND APPARATUS FOR RECORDING AND DETECTING INFORMATION

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Int. Cl. G11b *5/00, 5/48, 23/18*
U.S. Cl. 340—174.1 26 Claims

ABSTRACT OF THE DISCLOSURE

Method and apparatus for recording and detecting information and deriving therefrom position information for use with a track following servo system. Alternate odd and even servo tracks are magnetically recorded with oppositely-poled, constant fluxes, subject to periodically-occurring data-frequency flux reversals. The flux reversals may be of opposite phase for odd and even tracks and are physically alternated along the direction of motion. A servo read head is properly centered when it is located half way between adjacent tracks such that the data frequency signals received from the tracks are equal. The data frequency pulse signals as read are separated according to the polarity of the flux reversals and compared. The net signal resulting from the comparison is the servo position error information.

BACKGROUND OF THE INVENTION

Field of the invention

The invention relates to methods and apparatus for recording and detecting information, and more particularly to methods and apparatus for recording and detecting position information.

Description of the prior art

Track following servo systems and position-detecting means are becoming more important and requirements thereof becoming more exacting in many fields, such as machine tool control. Another field, one which is now beginning to realize and employ the advantages of track following servo systems, is the field of data processing, and more particularly, data storage.

As data storage systems have developed, each improvement thereto has been directed to optimizing the compromise between increasing the areal density of data, lowering the access time required to find desired data, and cost reduction. As a result of this development, most data storage devices employ a storage medium comprising a surface upon which may be recorded parallel linear tracks of data. This data is recorded or reproduced by means of one or more transducers with means for causing relative movement between the transducer or transducers and the storage medium, such that a transducer follows along a corresponding track.

Data storage systems employed as part of data processing apparatus require very high areal densities. To attain such high densities, the tracks are made closer and closer together with each new development and made narrower in width, so that a great number of tracks may be fitted onto a single storage medium. Prior art data storage systems hold the transducer in a fixed lateral position with respect to a track by mechanical means. In all applications where the media are interchangeable or the transducer may be moved laterally from track to track, the mechanical positioning means may not always accurately align the transducer with the desired track. Therefore, the tracks must be spaced apart sufficiently to allow for misalignment caused by manufacturing tolerances.

The distance between tracks should be sufficiently great to prevent the transducer from reading an adjacent track along with the desired track when so misaligned. To allow the tracks to be placed closer together, present development is moving toward closed-loop, track following servo systems to maintain the transducer positioned along the corresponding track.

Previously, track following servo systems have not been advantageous in data storage systems due to the high cost thereof. The high cost is a result of the special equipment required and the critical characteristics of the equipment. Many possible servo systems have been proposed, but all suffer from the excessive cost required to implement the system properly.

Many examples of such prior service systems are evident in the art. One example is a system employing odd and even servo tracks of differing frequencies. A servo transducer is centered when it is located half way between adjacent tracks such that the signals received from the tracks are equal. In such a system, the servo transducer cannot be an ordinary data transducer because of the wide and precision frequency response necessary to provide accurate servo signals. Likewise, the circuitry for separating and detecting the two frequencies and for determining the relative amplitudes thereof must be accurately balanced and provide a precision response for each of two different frequencies. Satisfying these requirements necessitates the use of expensive transducers and circuitry.

In another example, the odd and even servo tracks are recorded at the same frequency, but in opposite phase. Extreme precision is thus required to record each track so as to be continually exactly opposite in phase to the adjacent track. Further, precision timing means is required to detect the phase of the predominant signal and determine the direction to drive the servo transducer to properly center it between the servo tracks. Again, the equipment required must be extremely expensive.

In still another example, bursts of servo data are recorded at alternate times along the odd and even tracks and a separate timing track and transducer are provided. The timing track and transducer operate appropriate gating circuitry to indicate whether a detected burst signal is that of an odd or an even track. This system allows use of a data servo transducer, but still requires precision in recording the various tracks so that all bursts are properly aligned with the corresponding time signals on the timing track. An additional cost requirement is that two separate transducers are required, one being the movable servo transducer and the other being a fixed transducer for detecting the timing track. Additionally, complex circuitry is required for properly gating, under control of the timing signals, the various bursts of data to the proper side of a comparison circuit, depending upon whether the servo transducer is between an odd and an even track, or between an even and an odd track. This is required to determine the proper direction to move the servo transducer to properly center it between the servo tracks. Again, the additional transducer and associated circuitry, plus the complex switching circuitry required, makes the system quite expensive.

Still other systems have been described by the prior art, but all are rather expensive to implement in physical hardware, or are subject to great inaccuracy when not properly implemented.

SUMMARY

An object of the present invention is to provide simple and less expensive means for providing position information of the accuracy required for use in a track following servo system of a data storage device.

Another object of the present invention is to provide a simplified method for generating accurate position information.

Briefly, the invention comprises a method and apparatus for generating position signals. The apparatus comprises a plurality of tracks, each track having a normal predetermined polarity subject to periodically occurring sets of polarity reversals, adjacent tracks being of opposite predetermined polarity. Transducing means is provided for detecting the polarity reversals, wherein the amplitude of the detection is directly related to the later distance of the transducer from the center of the track having the polarity reversal. Conversion means converts each set of polarity reversals into signals of positive or negative polarity depending upon the direction of the first polarity reversal of the set of polarity reversals. Comparison means compares the amplitudes of the positive and negative polarity signals and generates position signals indicating the polarity and amplitude of the difference between positive and negative polarity pulses.

The method comprises a plurality of steps including fashioning a plurality of adjacent tracks, such that a line centered between two adjacent tracks represents a constant positional indication, and each track is generated with a predetermined normal polarity subject to periodically occurring sets of polarity reversals, adjacent tracks having opposite predetermined polarity. Another step comprises sensing, along a line essentially parallel to the centered line, the polarity reversals of the adjacent tracks wherein the sensing amplitude is directly dependent upon the lateral distance from the sensing line to the center of the track having the sensed polarity reversal. The sets of polarity reversals are then separated into signals of opposite polarity dependent upon the first polarity reversal of each set. The oppositely-poled signals are then compared to derive a net difference, the amplitude and polarity of the difference thereby indicating the distance and direction of the distance of the sensing line from the centered line.

The primary advantage of the present invention is that the tracks do not need to be made with exact phase precision and alignment as do the prior servo tracks. Rather, the sets of phase reversals only need be generally interlaced without precise alignment.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is diagrammatic illustration of data storage apparatus having a track following servo system including an embodiment of the subject invention;

FIG. 2 is a representation of reference patterns arranged in accordance with the present invention;

FIG. 3 is a block diagram of circuitry for analyzing the reference patterns of FIG. 2;

FIG. 4 illustrates waveforms at various points in the circuitry of FIG. 3;

FIGS. 5 and 6 illustrate various waveforms of the circuitry of FIG. 3 obtained by scanning different paths along the reference patterns of FIG. 2;

FIG. 7 is a block diagram of alternative circuitry for analyzing the reference patterns of FIG. 2;

FIGS. 8A–8D schematic diagrams of the gated peak detector of FIG. 7;

FIG. 9 is a schematic diagram of the sum and filter network of FIG. 7; and

FIG. 10 is a schematic diagram of circuitry for recording the reference patterns of FIG. 2.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

As discussed above, track following servo systems and position-detecting means are becoming more important in many fields. Further, the uses of such systems expand, the requirments thereof become far more exacting. Examples of position detecting systems abound. The example chosen for illustratiton of the invention is that of a data storage system employing a disk file **10**. Other examples of data storage devices comprise tape drives, drums and strip files. The subject invention may be utilized with any of these data storage systems employing relative motion between a transducer and a data storage medium for recording and reading one or a plurality of parallel tracks. The subject invention may also be utilized with any other position detection system where applicable.

An embodiment of a disk file **10** employing the subject invention is shown in FIG. 1. In the arrangement shown, the disk file **10** comprises a central shaft **11** which supports disks **12** and **13** perpendicular to the axis thereof and axially aligned therewith. A motor (not shown) rotates shaft **11** in the direction of arrow **14**. The disks **12** and **13** comprise a planar aluminum substrate coated on both sides with a thin magnetizable film. A ganged transducer head assembly **15** includes a plurality of separate transducers **16** for the magnetic recording and reproducing of data on the associated surfaces of disks **12** and **13**. Also included in head assembly **15** is a separate servo transducer head **17**. All of the transducers are suspended by support arms **18** from carriage **19** so as to be accurately aligned with one another and with respect to disks **12** and **13**. An example of a disk file having plural transducers and recording surfaces is the IBM 2311 Disk Storage Drive with an IBM 1316 Disk Pack. The 1316 Disk Packs are interchangeable and may be removed from one storage drive and placed on another.

With the carriage **19** stationary, the transducers **16**, **17** each trace along a circular track on the corresponding disk surface. The tracks all lie in a common cylinder having a central axis concentric with shaft **11**. Movement of carriage **19** along a radial line extending from shaft **11** changes the radius of the cylinder traced by the tranducers **16**, **17**. Accurate positioning of the carriage **19** is determined from the servo positioning signals detected by servo transducer **17**, as will be explained hereinafter. These signals are supplied to position error detection circuitry **20**. Two examples of this circuitry will be described hereinafter. The circuitry provides as an output a position error signal indicating the direction and amplitude of the position error. This output is supplied to a servo driver **21**. The servo driver provides an output current I proportional to the voltage output of the detection circuitry **20**. Current from the servo driver **21** drives a servo actuator **22**. The servo actuator **22** may be of any suitable type for moving carriage **19** toward or away from shaft **11** in response to the output current from servo driver **21**. The position error servo system operates to cause the ganged transducers **16**, **17** to accurately follow the desired servo track on the servo surface of disk **12**. Hence, servo transducer **17** and the corresponding data transducer **16** are maintained in alignment with the servo track.

The accessing of a particular servo track is accomplished by a separate accessing servo system which forms no part of the present invention.

Data transducers **16** each detect data recorded on the corresponding surface of rotating disks **12** or **13**. A specific transducer is selected by means of switching circuitry **25**. The switching circuitry may comprise any suitable switching network for selectively interconnecting the output wires of one of the transducers **16** to line **26**. Line **26** is connected to a read amplifier **27**, which amplifies the output of switching means **25**. The amplified signal is then supplied to a data separator **28**. The data separator **28** comprises circuitry for analyzing the output of read amplifier **27** and decoding those signals into binary "ZERO" or "ONE" data bits at a specified clocking rate. An example of such a data separator is presented in U.S. Pat. 3,197,739, E. G. Newman, "Magnetic Recording System" issued July 27, 1965.

The output of data separator **28** is transmitted to a storage means **29**. Storage means **29** comprises any suitable means for storing the data received from data separator **28** until its transmission is requested by a receiving device. The storage device **29** may receive and transmit the data serially or, alternatively, may receive the serial data and convert it to parallel data which is transmitted. Many examples of such storage registers exist in the prior art. The receiving device operates the controlling input **30** of a gate circuit **31** to transmit the data from storage means **29** to the receiving device over data output **32**.

FIG. 2 shows a representation of position-indicating reference patterns arranged in accordance with the present invention. Three position-indicating tracks **35–37** are illustrated. Those tracks represent three of a plurality of alternating odd and even circular concentric servo tracks recorded on the lower surface of disk **12**. Various portions of track **35**, for example, are marked with either a plus (+) or a minus (−). Each positive portion represents an area of magnetization of the surface of disk **12** in a first direction with respect to servo transducer **17**, and the minus portions represent areas recorded in the opposite direction. The vertical lines dividing the plus and minus portions of track **35** therefore represent transitions between the two states. Tracks **35** and **37** are odd tracks and have a normally positive flux, subject to periodically-occurring sets of two flux reversals, represented by the vertical lines such as lines **38**. The even tracks, however, are normally of minus magnetic polarity, subject to periodically-occurring sets of two flux reversals, also shown by vertical lines such as lines **39**. The sets of flux reversals of the even tracks are arranged to alternate with respect to the sets of flux reversals of the odd tracks.

The servo transducer **17** is shown superimposed over the recorded servo tracks in FIG. 2. The servo transducer is ideally positioned when it traces a path **40** midway between an odd and an even servo track. When so positioned, the amplitudes of the transistions of the adjacent odd and even tracks as detected by the servo transducer should be equal. If the path traced by the servo transducer moves to one side or the other of the centered path **40**, the detected amplitudes of the transitions of one track will rise and those of the other track will fall. Hence, the relative amplitudes indicate the distance the servo transducer is from the center path **40** and the polarity of the stronger transitions indicates the lateral direction of the servo transducer from the centered path.

An example of circuitry for making such a detection is shown in FIG. 3. In FIG. 3, the servo transducer **17** is represented as a coil having a grounded center tap. The signals detected by the servo transducer are applied to terminals **50** and **51** of double-ended amplifier **52**. The outputs of the amplifier are supplied to integrating circuits **53** and **54**, respectively. The resultant integrated signals are then rectified by rectifiers **55** and **56** into signals of the same actual polarity, representing the opposite polarity phases of amplifier **52**. The amplitudes of the resultant signals are detected, respectively by detectors **57** and **58**. These amplitudes are then compared by summing circuit **59**, which subtracts the output of detector **58** from the output of detector **57** and supplies the net differnce to output terminal **60**.

Operation of the circuit when centered between an odd and an even track is illustrated by the waveforms of FIG. 4. The waveforms of FIGS. 4A and 4B represent, respectively, the outputs of head **17** as they appear on lines **50** and **51**. Referring to FIG. 4A, peak **61** represents the detection of the first transition **38** from positive to negative magnetic polarity on track **35** and peak **62** represents the following transition **38** from negative to positive magnetic polarity. Negative peak **63** then represents the transition **39** from negative to positive polarity of track **36** and peak **64** represents the following transition **39** from positive to negative polarity. It is seen that the set of signals representing the detection of the sets of two transitions for, respectively, the odd and even tracks are the same in amplitude and in shape, but of opposite polarity. The waveform of FIG. 4B is thus the same as that of 4A, but of opposite polarity.

The wave forms of FIGS. 4A and B are integrated, respectfully, by integrators **53** and **54** to provide as outputs the waveforms of FIGS. 4C and **D.** As shown by waveform **4**C, the peaks **61** and **62** of waveform **4A** integrate into the signal positive peak **70**. Likewise, the integration of peaks **63** and **64** forms negative peak **71**. In this manner, the set of transitions **38** of the odd track **35** have integrated into a positive peak **70**, and the set of transitions **39** of the even track **36** have integrated into a negative peak **71**. The opposite result is true for waveform **4D** as the result of integration of the wavefore **4B**. There, the peaks **65** and **66** integrate into negative peak **72** and peaks **67** and **68** integrate into positive peak **73**.

The waveforms 4C and D are then rectified, respectively, by half-wave rectifiers **55** and **56**. The rectified signals are shown as waveforms **4E** and F. As a result of the rectification, only the positive peaks **70** and **73** are transmitted. The transmitted signals are applied to detectors **57** and **58**. These detectors are peak detectors that charge to the amplitude of the input peak and discharge very slowly until again charged to the following peak. These detectors thus provide output signals of nearly constant amplitude, wherein the amplitude represents the amplitude of the peaks **70** and **73**, respectively. The outputs of detectors **57** and **58** comprise wave forms 4G and H, respectively. These two signals are applied to summation circuit **59** which detects the difference therebetween, if any, and supplies the difference to output terminal **60**. Since, in the example employed, the servo transducer **17** is centered between the odd and even tracks **35** and **36**, the outputs of detectors **57** and **58** are equal and no net difference appears at output terminal **60**.

The net signal appearing at terminal **60** of FIG. 3 comprises the position error output of detection circuitry **35** of FIG. 1.

The waveforms of FIG. 5 represent the outputs of servo transducer **17** on line **50** for various paths of the servo transducer with respect to the odd and even tracks **35** and **36**. For example, waveform **5A** illustrates the signal appearing on line **50** from servo transducer **17** when the transducer traces the path **75** shown in FIG. 2. The path **75** is positioned towards the center of odd servo track **35** and away from the desired path **40** centered between odd servo track **35** and even servo track **36**. As shown by the waveform of FIG. 5A, the servo transducer detects this position by responding to the transitions **38** of odd track **35** by producing high amplitude peaks **76** and **77**. The transducer **17** is of such distance from even track **36** that the transitions **39** therein produce no noticeable output from servo transducer **17**.

FIG. 5B illustrates the waveform on line **50** of FIG. 3 produced by servo transducer **17** when tracing path **78** of FIG. 2. The servo transducer thus detects the transitions **38** of odd track **35** fairly strongly and provides the signal having peaks **79** and **80** on line **50**. The amplitudes of the peaks **79** and **80** of FIG. 5B are slightly less than peaks **76** and **77** of FIG. 5A due to the increased distance of the transducer from the center of track **35**. The servo transducer is somewhat closer to even track **36** and therefore detects the transitions **39** of the even track and supplies a signal having peaks **81** and **82** on line **50**.

The waveform of FIG. 5C represents the signals produced on line **50** by servo transducer **17** when accurately centered between the odd track **35** and the even track **36**, along path **40**. The resultant signal produced is identical to that of FIG. 4B, wherein peaks **83** and **84** represent the detected transitions **38** and peaks **85** and **86** represent detected transitions **39**. The waveform of FIG. 5D represents the output on line **50** of the servo transducer as it traces path **87** in FIG. 2. In FIG. 5D, peaks **88** and **89**, representing the detection of transitions **38**, are weak, and peaks **90** and **91**, representing detection of transitions **39**, are relatively strong. The relative amplitudes are caused by the distance of path **87** from the center of track **35** and the closeness of even track **36**. This is brought out more emphatically by the waveform of FIG. 5E, representing the output on line **50** of the servo transducer **17** when tracing path **92**. This path is relatively close to the center of even track **36** and, hence, does not even detect transitions **38** of odd track **35**. The sole output signal is represented by peaks **93** and **94** which are the output of the servo tranducer from its detection of transitions **39**.

The waveforms of FIG. 6 illustrate the results of integration of the waveforms of FIG. 5. The signals of line **50** as amplified by amplifier **52** are integrated by integrator **53** and then transmitted to rectifier **55**. The waveforms of FIG. 6 therefore represent the output of integrator **53**.

As shown by FIG. 6A the signals **76** and **77** of FIG. 5A are integrated by integrator circuit **53** to thereby produce the single peak **95**. The amplitude of the integrated peak **95** is proportional to the distance of servo transducer **17** from the center of odd track **35** and upon detection thereby of transitions **38**. FIG. 6B illustrates the integration of peaks **79** and **80** of FIG. 5B to the single peak **96** and the peaks **81** and **82** into the single peak **97**. The relative amplitudes of the peaks **96** and **97** therefore represent the relative distances of the servo transducer **17** from the center of odd track **35** and even track **36** respectively. The peaks **98** and **99** of the waveform of FIG. 6C represent respectively the integration of peaks **83**, **84** and of peaks **85**, **86** of FIG. 5C. The peaks **98** and **99** are of equal amplitude and therefore indicate that the servo transducer **17** is tracing path **40** half way between odd track **35** and even track **36**.

FIG. 6D represents the integration of signals **88**, **89** and **90**, **91** of FIG. 5D into single peaks **100** and **101**. The waveform illustrates the output of integrator **53** when the servo transducer **17** traces path **87** which is offset from desired path **40** towards the center of even track **36**. FIG. 6E illustrates the integration by integrator **53** of the waveform **93**, **94** of FIG. 5E into the single peak **102**. The large amplitude of peak **102** with no signal representing detection of transitions **38** of odd track **35** signals that the servo transducer **17** is tracing path **92** near the center of even track **36**.

Referring to FIG. 3, the output waveforms resulting from the operation of integrator **54** is substantially identical to the waveforms shown in FIG. 6 except that the corresponding waveforms are each inverted such that positive peak **95** becomes a negative peak of similar shape and amplitude. Rectifiers **55** and **56** rectify the outputs of the corresponding integrators and thereby transmit only the positive pulses to corresponding detectors **57** and **58**. In this manner, rectifier **55** transmits peaks **95**, **96**, **98** or **100** to detector **57** and rectifier **56** transmits peaks **97**, **99**, **101** or **102** to detector **58**. As shown with respect to FIG. 4, the detectors **57** and **58** charge to the amplitudes of the supplied peaks and provide output signals of nearly constant amplitude to summation circuit **59**. Therefore, the output of detector **57** is at a nearly constant amplitude and is the amplitude of either peak **95**, **96**, **98** or **100**. Likewise, the output of detector **58** is constant and is at the amplitude of either peak **97**, **99**, **101** or **102**. The outputs of detectors **57** and **58** are compared by summation circuit **59** and the net difference supplied to output terminal **60**.

Referring to FIGS. 2, 3 and 6, as servo transducer **17** traces path **75**, the output of summation circuit **59** is equal in amplitude to that of peak **95** and is of positive polarity. As the servo transducer traces path **78**, the output of the summation circuit is equal to the difference between the amplitudes of peaks **96** and **97** and is positive in polarity. As the servo transducer traces path **40** which is centered between odd track **35** and even track **36**, the net amplitude from summation circuit **59** is zero. Upon the servo transducer tracing path **87**, the output of the summation circuit is equal to the difference between peaks **100** and **101** and is negative in amplitude, since peak **101** is the greater of the two. Likewise, upon servo transducer **17** tracing path **92**, the output of summation circuit **59** at terminal **60** is equal to the amplitude of peak **102** and is negative in polarity.

Hence, the output signal appearing at terminal **60** from summation circuit **59** indicates by means of its polarity and amplitude the relative position of servo transducer **17** with respect to a path **40** intermediate odd servo track **35** and even servo track **36**.

Referring to FIG. 1, the output at terminal **60** comprises the output of detection circuitry **20**. This output is transmitted to servo driver **21** and operates the driver to provide a current I to actuator **22**. This current is proportional in amplitude and the same polarity as the output from detection circuitry **20**. The current drives the actuator **22** to move the servo transducer **17** towards the desired path. In the example given, the desired path lay between odd track **35** and even track **36**. Hence, the output of detection circuitry **20** is of proper polarity to control the actuator **22** so as to center the servo transducer **17**. However, should it be desired to position the servo transducer **17** intermediate the even servo track **36** and the odd servo track **37**, the polarity of the output signal from summation circuit **59** would be the opposite of that required to center the servo transducer. Therefore, a second input **103** is provided to servo driver **21**. A signal is provided on this line by track addressing or accessing circuitry (which forms no part of the present invention) when the desired position of servo transducer **17** is between an even and an odd track, such as tracks **36** and **37**. No signal is provided when the desired position of servo transducer **17** lies between an odd and an even track, such as between tracks **35** and **36**.

Application of a signal on line **103** causes servo driver **21** to reverse the polarity of the output current I. The servo driver therefore provides a current of the same polarity as the position error signal when no signal is supplied on line **103** and supplies a current having a polarity opposite to that of the position error signal when a signal is supplied on line **103**. The apparatus of FIG. 1, including the detection circuitry of FIG. 3, therefore continually operates actuator **22** to maintain servo transducer **17** intermediate two adjacent servo tracks.

Alternative apparatus comprising detection circuitry **20** is shown in FIG. 7. In FIG. 7 the servo transducer **17**, its outputs **50** and **51**, and the double-ended amplifier **52** are the same as shown previously in FIG. 3. The two, opposite-polarity signals from amplifier **52** are transmitted via lines **105** and **106** to gate detector **107**, and via lines **108** and **109** to gated peak detector **110**. The gate detector **107** detects positive excursions of signals appearing on either line **105** or line **106** and supplies corresponding signals to single shots **111** or **112**, respectively. Each single shot responds to an applied signal by supplying an output of predetermined duration. The output from single shot **111** is transmitted to input **113** of gated peak detector **110** and also to inverter **114**. The output of single shot **112** is likewise transmitted to the input **115** of gated peak detector **110** and also to inverter **116**. The inverters **114** and **116** are connected to, respectively, inputs **117** and **118** of gated peak detector **110**.

Referring to the operation of gate detector **107**, signals on input lines **105** and **106** are shown essentially by FIGS. 4A and 4B, respectively. The waveforms of FIGS. 4A and 4B are generally identical but of opposite polarities. Voltage divider **120**, **121** maintains the base connections of transistors **122** and **123** at a voltage exactly intermediate the instantaneous voltages of the waveforms of FIGS. 4A and 4B. As shown by FIG. 7, the gate detector **107** is arranged such that transistor **122** conducts when the signal on line **105** is negative and the input on line **106** is positive. Likewise, transistor **123** conducts when the signal on line **106** is negative and the signal on line **105** is positive. Hence, referring additionally to FIGS. 4A and 4B, gate detector **107** responds to peak **61** on line **105** and peak **65** on line **106** by the conduction of transistor **123**. Conversely, the gate detector responds to negative peak **62** on line **105** and positive peak **66** on line **106** by the conduction of transistor **122**. Conduction by either transistor **122** or **123** causes the corresponding single shot **111** or **112** to provide a positive output pulse of duration T. These output pulses are supplied via lines **113**, **115**, inverters **114**, **116** and lines **117**, **118** to gated peak detector **110**. The gated peak detector and the supplied waveforms are shown in FIG. 8.

Referring to FIG. 8A, a gating network including input **113**, transistor **125**, resistor **126** and diodes **127**, **128** responds to pulses **130** and **131** from single shot **111** by blocking transmission of signals appearing from line **108**. Only in the event no signal appears at line **113** does transistor **125** cease conducting so as to transmit the signal appearing at line **108**. Such a signal is illustrated by peak **61** which is transmitted to the base input of transistor **132**. The transistor then charges capacitor **133** to the peak value of the input voltage. The capacitor essentially maintains its charge, discharging only very slowly via controlled current flow to ground at terminal **134**. In discharging, the voltage across the capacitor drops no more than 10% before the following peak **61** is transmitted to transistor **132** to again charge the capacitor. The voltage appearing across capacitor **133** is transmitted to output terminal **135** by emitter follower **136**.

The circuitry of FIG. 8B is identical to that of FIG. 8A, including gating circuitry **140–143**, charging transistor **144**, capacitor **145**, discharge terminal **146**, emitter follower **147** and output terminal **148**. The sole differences are that input diode **142** is connected to line **109** and the base of gate transistor **140** is connected to line **115** from single shot **112**. The gating circuit therefore blocks pulses **65**, **66** and **68** and transmits signal **67** to charge capacitor **145**.

The cricuitry of FIG. 8C is similar to that of the two prior circuits but is of the opposite polarity. Inverted pulses **155** and **156** are supplied at input **118** from inverter **116** to transistor **157**. As before, transistor **157** comprises part of a gating circuit which also includes resistor **158** and diodes **159** and **160**. The gating circuit responds to negative pulses **155** and **156** to block transmission of signals **61**, **62** and **64**, but transmits signal **63** to transistor **161** which charges capacitor **162** to the peak negative value of signal **63**. The capacitor slowly discharges to gradually become less negative by means of current from terminal **163** until the capacitor is again charged to the peak negative value of the next incoming signal **63**. The voltage of capacitor **162** is transmitted by emitter follower **164** to output terminal **165**.

Again, the circuitry of FIG. 8D is identical to that of FIG. 8C, including gating circuitry **170–173**, charging transistor **174**, capacitor **175**, discharging terminal **176**, emitter follower **177** and output **178**. The sole differences are that the base of gating transistor **170** is connected by input line **117** to inverter **114** so as to respond to pulses **179** and **180** therefrom, and diode **172** is connected to input line **109**. The circuitry thus blocks signals **66–68** and charges capacitor **175** to the peak negative value of signal **65** and transmits this value to output terminal **178**.

Referring additionally to FIGS. 4A and 4B, the circuitry of FIG. 8A supplies the positive value of peak **61** at output terminal **135**, the circuitry of FIG. 8D supplies the negative value of peak **65** to output terminal **178**, the circuitry of FIG. 8B supplies the positive value of **67** to output terminal **148** and the circuitry of FIG. 8C supplies the negative value of peak **63** to output terminal **165**. Referring to FIGS. 7 and 9, the voltages appearing at output terminals **135**, **148**, **165** and **178** are supplied to sum and filter network **185**, shown in FIG. 9.

In FIG. 9, terminals **135** and **165**, resistors **186** and **187** and junction **188** comprise a first summing network terminating in output line **189**. Terminals **148** and **178**, resistors **190** and **191** and junction **192** comprise a second summing network terminating in output line **193**. Capacitor **194** filters the output waveform.

The first summing network **186-189** detects the difference in amplitude between the outputs of the peak detector of FIG. 8A and the peak detector of FIG. 8C. Referring additionally to FIGS. 2 and 4, the comparison of the outputs of the circuits of FIGS. 8A and 8C comprises the comparison of the voltage of peak **61** of the waveform of FIG. 4A, representing the amplitude of transition **38** of odd track **35**, with the amplitude of negative peak **63** of the waveform of FIG. 4A, representing transition **39** of even track **36**. Hence, the resultant difference comprises an indication of the relative distance of transducer **17** from the center of odd track **35** with respect to the center of even track **36**.

Similarly, the summation network **190–193** compares the outputs of the circuits of FIGS. 8B and 8D. This comparison is of the amplitude of positive peak **67** of FIG. 4B, representing transition **39** of even track **36** with respect to the amplitude of negative peak **65** of the waveform of FIG. 4B, representing transitions **38** of odd track **35**. Thus, the result of this comparison likewise indicates the relative position of servo transducer **17** with respect to the center of odd track **35** versus the center of even track **36**. Hence, the amplitude of the outputs of the two summing networks are equal, but of opposite polarity. The voltage between output lines **189** and **193** is therefore approximately twice the amplitude of the voltage at either junction point **188** or **192** with respect to ground.

As described with respect to the apparatus of FIG. 3, the output of the sum and filter network **185** comprises the output of detection circuitry **20**. This output is transmitted to servo driver **21** to transmit corresponding current to actuator **22** to drive servo transducer **17** to the desired path intermediate adjacent odd and even servo tracks. Also, as before, the direction of movement of the actuator **22** is controlled by input line **103** to servo driver **21**.

FIG. 10 illustrates an example of apparatus which may be utilized to record the servo tracks of FIG. 2 on the servo surface on disk **12** of FIG. 1. In FIG. 10, the disk **12** is mounted so as to rotate synchronously with a clock disk **200**. The clock disk **200** includes two tracks **201** and **202**. Track **201** is a clock track having a continuous string of clock signals recorded thereon. Track **202** comprises only a single index signal per revolution. Two fixed transducers are provided, a clock head **203** for reading clock track **201**, and an index head **204** for reading index track **202**. The output of clock head **203** is amplified and shaped by amplifier **205**, and the output of index head **204** is amplified and shaped by amplifier circuit **206**. The resultant clock signals from amplifier **205** and the index pulse from amplifier **206** are then transmitted to data generation circuitry **207**. The data generation circuitry supplies servo signals to a write driver **208** and recording head **209** to thereby write servo tracks on the surface of disk **12**. Step motor logic **210**, operating under the control of stepping pulses from input terminal **211** controls the operation of stepping actuator **212** to properly position the recording head **209** for recording each of the servo tracks. Stepping pulse input **211** also controls the operation of write gate **213**, after initialization by start disk input **214**, to control the gating of write driver **208**.

The start disk input **214** is connected to the "set" input of trigger **215** and to the "set" input of trigger **216**. A set pulse operates trigger **215** so as to provide an "off" output signal on line **217** to data generation circuitry **207**. The "off" output signal represents an odd servo track, but the trigger will be switched before the first servo track, which is an event track, is recorded.

The data generation circuitry **207** includes a dual bit ring **220** having two synchronously operating bit rings comprising bit trains **221** and **222**. The bit trains comprise the specific bits shown in the drawing. The even bit train **221** comprises the data required to record an even servo track and the odd bit data **222** comprises the information required to record an odd servo track. The dual bit ring is reset by an index pulse from index transducer **204** appearing at "reset" input **223**. Resetting the dual bit ring **220** causes it to assume the exact bit sequences shown. The dual bit ring then responds to pulses received from clock transducer **203** to advance one bit position for each clock pulse.

The index pulse detected by index transducer **204** is also transmitted to AND circuit **225**, AND circuit **226**, AND circuit **227** and to the "off" input of trigger **216**.

After the initial start disk signal is received on input **214**, the initiali stepping pulse is received at input **211**. This pulse is transmitted to delay **230**, to step motor logic **210**, and to trigger **215**. The pulse operates step motor logic **210** so as to supply the proper signals to stepping actuator **212** to cause recording transducer **209** to be stepped to the first servo track. Delay **230** is of sufficient time to allow for the motion of recording head to be completed before the transmitting the stepping pulse to single shot circuit **231**. The single shot then supplies an enabling pulse to AND circuit **225**. This enabling pulse is of duration greater than one revolution of the disks and less than two revolutions. The stepping pulse also operates trigger **215** so as to switch to the opposite state and thereby supply an "on" output signal on line **217**. As mentioned before, the output of trigger **215** now represents an even servo track. This signal is transmitted to the enabling input of AND circuit **226**, the enabling input of AND circuit **232**, and to inverter **233**. The output of inverter **233** is therefore switched to the "off" state, which signal is supplied to the enabling input of AND circuit **227** and to the enabling input of AND circuit **234**. The operation of trigger **215** and inverter **233** therefore causes AND circuits **226** and **232** to be enabled and AND circuits **227** and **234** to be disabled.

Operation of the system then awaits the first subsequent index pulse detected by index transducer **204**. This pulse is transmitted as before to the "reset" input **223** of dual bit ring **220** to AND circuts **225**, **226**, and **227**, and to the "off" input of trigger **216**. The pulse again resets dual bit ring **20**. Since trigger **216** has already been reset "off" the pulse appearing at the "off" input thereto has no effect. Further, the input to AND circuit **225** which is now enabled by the signal from single shot **231** is therefore transmitted to the "on" input of trigger **216**. This causes the trigger to be reset "on" and supply a write gate signal to write driver **208**. This allows any subsequent data appearing on line **235** to be transmitted to the recording transducer **209**. As stated previously, AND circuit **226** has been enabled while AND circuit **227** has been disabled. Therefore, the index pulse is transmited by AND circuit **226** to the reset input of trigger **236**. This causes the trigger to be reset "off" and supply an "off" signal on line **235** to write driver **208**. The write driver therefore writes a signal of negative magnetic polarity on the even servo track. This area of negative magnetic polarity is shown by the area having a minus (−) designation as shown by even track **36** in FIG. 2.

Then, subsequent clock pulses detected by clock transducer **203** are supplied to the dual bit ring **220** to advance the ring one bit position for each clock pulse. The outputs of the even bit train are supplied to AND circuit **232** and the inputs of the odd bit train are supplied to AND circuit **234**. As stated previously, trigger **215** and inverter **233** have caused the enabling of AND circuit **232** and the disabling of AND circuit **234**. Therefore, the output of even train **221** is transmitted by AND circuit **232** to OR circuit **237**.

The "zero" outputs of even train **221** have no effect on trigger **236**. The first "one" bit, however, causes the trigger to change state and produce an "on" output on line **235**. This output signal causes the write driver **208** and recording transducer **209** to switch polarity and record a positive (+) magnetic polarity signal on the servo track. The immediately following bit from even train **221** is also a "one," causing the trigger **236** to again change state. Hence, the write driver again switches magnetic polarity and causes the transition of the recorded signal back to negative magnetic polarity. The recording of the even servo track thus continues to produce a signal of normally negative magnetic polarity subject to periodically occurring sets of two flux reversals or transitions **39** as shown in FIG. 2.

Upon completion of one revolution of the disks and completion of the recording of the even servo track, index transducer **204** again detects an index pulse. This pulse again resets the dual bit ring **220**, and again appears at the "off" input of trigger **216**, thereby resetting the trigger off and terminating the write gate signal to write driver **208**. The index pulse is also transmitted to the "reset" input of trigger **236**. The resetting of trigger **236** has no effect on the servo surface since the termination of the write gate to write driver **208** prevents further writing of data on the disk surface.

Operation of the system is thus suspended until the next stepping pulse is received at input **211**. The stepping pulse is then again supplied to delay **230**, trigger **215** and step motor logic **210**. The step motor logic causes the stepping actuator to move the recording transducer **209** to the next servo track. The trigger **215** then switches to the "off" state, representing an odd servo track, and thereby disables AND circuits **226** and **232**. Inverter **233** responds by then enabling AND circuits **227** and **234**. After the recording head **209** is positioned at the next servo track, relay **230** supplies the stepping pulse to single shot **231**. The single shot then enables AND circuit **225** for the predetermined time period. Subsequently, index transducer **204** supplies an index pulse to AND circuit **225**, which is thereby transmitted to again turn on trigger **216**. The trigger then supplies a write gate signal to write driver **208**, causing the driver to transmit data to recording transducer **209**. The index pulse is also transmitted by enabled AND circuit **227** to set trigger **236** to the "on" state. This signal causes the right driver **208** and recording transducer **209** to record the servo track at a positive magnetic polarity (shown as a plus sign in odd servo track **35** of FIG. 2). In addition, the index pulse resets the dual bit ring **220**. Subsequently, the clock signals detected by clock transducer **203** step the dual bit ring. Since AND circuit **234** is enabled, the odd train **222** of bits is transmitted by the AND circuit and by OR circuit **237** to trigger **236**. As before, the "zero" bits have no effect on the trigger. The first "one" bit, however, causes the trigger to change to the "off" state and thereby causes recording transducer **209** to switch to the negative magnetic polarity. The immediately following "one" bit of the odd train **222** then switches trigger **236** back to the "on" state and switches recording transducer **209** to the positive magnetic polarity. This action is shown by reference to the odd servo track **35** of FIG. 2 wherein the track comprises normally positive magnetic polarity subject to periodically occurring sets of two flux reversals **38**.

The recording of alternate odd and even servo tracks therefore continues until all tracks have been recorded. At this time the system is shut down and the recorded servo disk **12** removed.

It is seen that by use of a clocking disk **200** which rotates synchronously with the servo surface, and the dual bit ring **220**, the sets of transitions of the odd servo tracks occur at approximately the midway point between the corresponding sets of transitions of the even servo tracks over the entire servo surface.

It should be obvious to those skilled in the art that other means of recording the servo tracks in the manner shown may easily be employed.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention.

We claim:

1. In a system for indicating position with respect to a predetermined path, means for marking said path, comprising:
  a first track adjacent one side of said path, said track comprising a designation of a first type interrupted by relatively short designations of a second type, and
  a second track adjacent the other side of said path, said track comprising a designation of said second type interrupted by relatively short designations of said first type, said short designations appearing opposite said designations of said first type of said first track.

2. The means of claim 1 for marking said path, additionally including means for marking a second path parallel to said first path, wherein:
  said second track lies between said paths and is adjacent to both; and including
  a third track adjacent the other side of said second path, said track comprising said designation of said first type interrupted by relatively short designations of said second type, and said short designations appearing opposite said designations of said second type of said second track.

3. The apparatus of claim 1 wherein:
  said tracks comprise magnetically recorded tracks,
  said designations of said first type comprise a magnetic flux of a first directional orientation; and
  said designations of said second type comprise a magnetic of a second directional orientation.

4. The apparatus of claim 1 wherein:
  said tracks comprise magnetically recorded tracks,
  said designations of said first type comprise a magnetic flux of a first polarity; and
  said designations of said second type comprise a magnetic flux of the opposite polarity.

5. The apparatus of claim 1 wherein:
  said short designations are separated by a distance greater than three times the normal length of said short designations; and
  each of said short designations of said second track appear generally half-way between the two nearest of said short designations of said first track.

6. The apparatus of claim 1 wherein:
  said first track comprises a designation of said first type interrupted by sets of at least one relatively short designation of said second type; and
  said second track comprises a designation of said second type interrupted by sets of at least one relatively short designation of said first type, said sets of short designations of said second track appearing opposite said designations of said first type of said first track.

7. The apparatus of claim 1 wherein:
  said first track comprises a magnetic flux of a first polarity subject to periodically occurring sets of polarity reversals; and
  said second track occurring opposite said first polarpolarity subject to periodically occurring sets of polarity reversals, said sets of polarity reversals of said second track occurring opposite said first polarity magnetic flux of said first track.

8. The apparatus of claim 7 for marking said path, additionally including means for marking a second path parallel to said first path, wherein:
  said second track lies between said paths and is adjacent to both; and including
  a third track adjacent the other side of said second path, said track comprising said first polarity magnetic flux subject to periodically occurring sets of polarity reversals, said sets of polarity reversals occurring opposite said reverse polarity magnetic flux of said second track.

9. The apparatus of claim 7 wherein: each said set of polarity reversals comprises a plurality of flux reversals occurring at data bit density.

10. The apparatus of claim 7 for marking a plurality of said predetermined paths additionally including: a plurality of said first tracks and a plurality of said second tracks, said tracks situated alternately across a surface and defining said paths between said tracks, said sets of polarity reversals of each said first track occurring opposite said reverse polarity magnetic flux of said second tracks that are immediately adjacent said first track, and said sets of polarity reversals of each said second track occurring opposite said first polarity magnetic flux of said first tracks that are immediately adjacent said second track.

11. The apparatus of claim 7 wherein: each of said sets of polarity reversals comprises an even number of polarity reversals.

12. The apparatus of claim 11 wherein: each said set of polarity reversals comprises two polarity reversals.

13. The apparatus of claim 12 wherein:
  said sets of polarity reversals are separated by a distance greater than three times the normal distance between the polarity reversals comprising each said set; and
  each of said polarity reversal sets of said second track appear generally intermediate the two nearest of said polarity reversal sets of said first track.

14. Apparatus for generating an indication of position with respect to a predetermined path, comprising:
  a first track adjacent one side of said path, said track comprising a designation of a first type interrupted by relatively short designations of a second type; and
  a second track adjacent the other side of said path, said track comprising a designation of said second type interrupted by relatively short designations of said first type, said short designations appearing opposite said designations of said first type of said first track;
  transducing means for detecting said designations of said tracks, wherein the amplitude of detection of each track and of the output therefrom is related to the lateral distance of said transducer from said track;
  separation means responsive to said detected designations for separating said output from said transducing means into two types of signals representing, respectively, said first and second tracks; and
  comparison means for comparing the amplitudes of said two types of signals and supplying an indication of the stronger of the two types of signals and the amplitude of the difference therebetween, said indication thereby representing the lateral direction and distance of said path from said transducing means.

15. The apparatus of claim 14 wherein:
  said first track comprises a magnetic flux of a first polarity interrupted by periodically occurring sets of polarity reversals;
  said second track comprises a magnetic flux of reverse polarity interrupted by periodically occurring sets of polarity reversals, said sets of polarity reversals of said second track occurring opposite said first polarity magnetic flux of said first track;
  said transducing means detects said polarity reversals of said tracks and provides output signals indicating the direction of each detected polarity reversal, wherein the amplitude of each output signal is related to the lateral distance of the transducer from the track containing said polarity reversal; and
  said separation means is responsive to said detected porality reversals for separating said transducing means output into said two types of signals.

16. The appaartus of claim 15 arranged to generate an

indication of positon with respect to a selected one of two predetermined paths, wherein:

said second track lies between said paths and is adjacent to both; and said apparatus additionally includes:

a third track adjacent the other side of said second path, said track comprising said first polarity magnetic flux interrupted by sets of polarity reversals, said sets of polarity reversals occurring opposite said reverse polarity magneic flux of said second track;

means causing said transducing means to be positioned approximately at said selected one of said two predetermined paths; and

orientation means responsive to said selection for causing said indication to be properly oriented.

17. The apparatus of claim **15** wherein:

each of said sets of polarity reversals comprises an even number of polarity reversals;

said separation means responds to said output of said transducing means to convert said detected polarity reversals into two classes of signals, the class being dependent upon the direction and sequential position of each said polarity reversal, each class of signal thereby representing one of said tracks and the amplitude thereof being related to the amplitude of the corresponding detected polarity reversal, said two classes of signals representing, respectively, said first and second tracks; and

said comparison means compares said amplitudes of said two classes of signals and supplies an indication of the stronger of the two classes of signals and the amplitude of the difference therebetween, said indication thereby representing the lateral direction and distance of said path from said transducing means.

18. The apparatus of claim **17** arranged to center said transducing means laterally with respect to said predetermined path, said apparatus additionally comprising: drive means for moving said transducing means laterally with respect to said path, said drive means being responsive to said indication from said comparison means to move said transducing means in the direction of and with a force related to the amplitude of said indication.

19. The apparatus of claim **18** additionally arranged as a track-following servo system to align a plurality of data transducers with respect to corresponding data paths, wherein: said predetermined path is aligned with respect to said data paths such that said centering of said transducing means laterally with respect to said predetermined path causes said data transducers to each be approximately centered with respect to the corresponding data path.

20. The apparatus of claim **19** arranged as a track-following servo system in a rotating disk file data storage system, wherein said system additionally includes:

a plurality of magnetic disk surfaces concentrically mounted with respect to a central axis and rotated synchronously about said axis and wherein;

each of said paths comprise a circular path on a different one of said magneic disk surfaces so that said paths define a right cylindrical surface having an axis coextensive with said central axis, and

said transducing means and said data transducers are aligned so as too be parallel to said axis of said cylindrical surface, and said transducing means and said data transducers are arranged to cooperate with said corresponding predetermined path and data paths, respectively, such that said centering of said transducing means laterally with respect to said predetermined path causes said data transducers to each be approximately centered with respect to the corresponding data path.

21. The apparatus of claim **17** wherein:

said separation means responds to said output of said transducing means to separate said detected polarity reversals into two classes of signals, the class being dependent upon the direction and sequential position of each said polarity reversal, each class of signal thereby representing one of said tracks;

said apparatus additonally comprises:

peak detection means for detecting the amplitudes of selected peaks of said classes of signals and supplying at output terminals approximately D.C. representations of the ampiltudes of said peaks; and wherein:

said comparison means compares said D.C. representations from said output terminals of said peak detection means to thereby provide an indication of the stronger of the two classes of signals and the amplitude of the difference therebetween, said indication thereby representing the lateral direction and distance of said path from said transducing means.

22. The apparatus of claim **21** wherein:

said transducing means provides on two output lines, separate output signals of equal amplitude and opposite polarity for each detected polarity reversal, each such signal comprising a complete A.C. waveform; and

said separation means comprises:

integration means for separately integrating from said output lines said output signals of said transducing means to thereby convert said output signals into half-wave waveforms;

first half-wave rectifier means for transmitting out of those of said half-wave waveforms resulting from output signals of one of said two output lines, only those of one polarity and blocking those of the other polarity, said transmitted waveforms comprising said first class; and

second half-wave rectifier means for transmitting out of those of said half-wave waveforms resulting from the second of said two output lines, only those of one polarity and blocking those of the other polarity, said transmitted waveforms comprising said second class of signals.

23. The apparatus of claim **22** arranged to generate an indication of position with respect to a selected one of a plurality of predetermined paths, additionally comprising:

a plurality of said first tracks and a plurality of said second tracks, said tracks situated alternately across a surface and defining said paths between said tracks, said sets of polarity reversals of each said first track occurring opposite said reverse polarity magnetic flux of those second tracks that are immediately adjacent said first track, and said sets of polarity reversals of each said second track occurring opposite said first polarity magnetic flux of those first tracks that are immediately adjacent said second track;

accessing means for approximately positioning said transducing means at said selected path; and

orientation means responsive to said selection for selectively inverting the direction of said indication.

24. A method of generating position indicating signals comprising the steps of:

fashioning a plurality of adjacent tracks, such that a line centered between two adjacent tracks represents a constant positional indication, wherein each track is fashioned with a predetermined normal polarity subject to periodically occurring sets of polarity reversals, adjacent tracks having opposite predetermined normal polarity;

sensing, along a line essentially parallel to said centered line, said polarity reversals of said tracks immediately adjacent said centered line, wherein the sensing amplitude is dependent upon the lateral distance from the sensing line to the center of the track having the sensed polarity reversal;

separating said sensed polarity reversals into two categories dependent upon the direction and sequential position of each said detected polarity reversal, each of said categories thereby representing one of said two immediately adjacent tracks; and

comparing the peak amplitudes of said two categories of detected polarity reversals to derive a net difference, the amplitude and polarity of said net difference thereby indicating the lateral direction and distance of said centered line from said sensing line.

25. The method of claim **24** for additionally centering a sensing means laterally with respect to said centered line, wherein:

said sensing step is accomplished by said sensing means; and

additionally including the step of:

moving said sensing means laterally in response to said net difference derived by said comparison.

26. The method of claim **25** for centering said sensing means laterally with respect to a selected one of a plurality of said centered lines, comprising the additional steps of:

initially positioning said sensing means at a point laterally closer to said selected centered line than any other one of said centered lines; and

orienting, in response to said selection, said net difference derived by said comparison by selectively inverting said net difference.

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U.S. Cl. X.R.

179—100.2

Disclaimer

3,534,344.—*George R. Santana*, Saratogo, Calif. METHOD AND APPARATUS FOR RECORDING AND DETECTING INFORMATION. Patent dated Oct. 13, 1970. Disclaimer filed Aug. 9, 1971, by the assignee, *International Business Machines Corporation.*

Hereby enters this disclaimer to claims 1, 2, 3, 4, 6, 7, 8, 10, 11 and 12 of said patent.

[*Official Gazette November 2, 1971.*]

Oct. 13, 1970 G. R. SANTANA 3,534,344

METHOD AND APPARATUS FOR RECORDING AND DETECTING INFORMATION

Filed Dec. 21, 1967 3 Sheets-Sheet 1

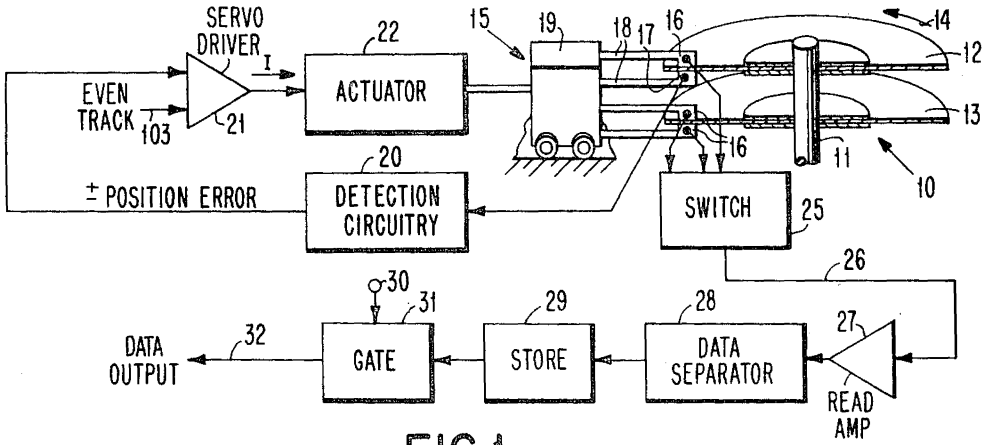

FIG.1

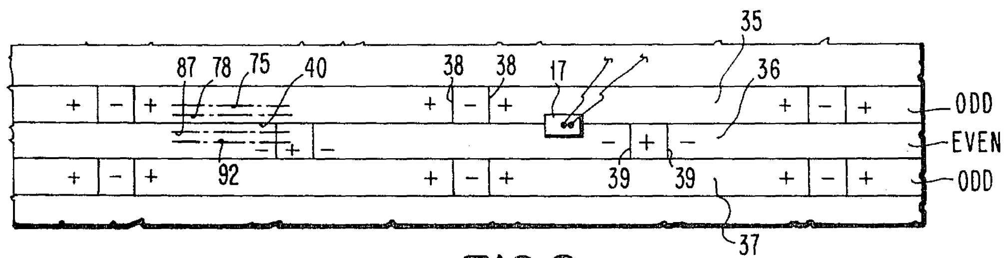

FIG.2

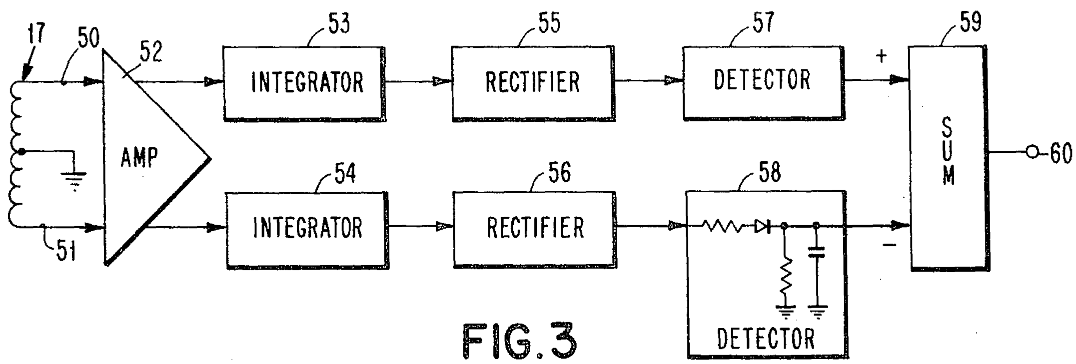

FIG.3

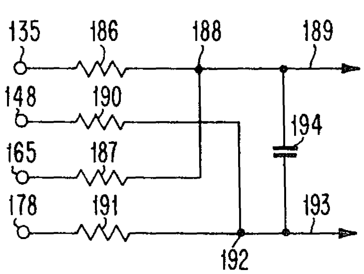

FIG.9

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METHOD AND APPARATUS FOR RECORDING AND DETECTING INFORMATION

Filed Dec. 21, 1967 3 Sheets-Sheet 2

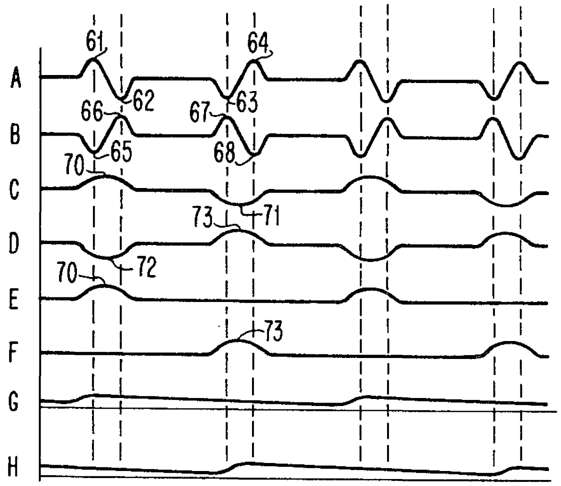

FIG. 4

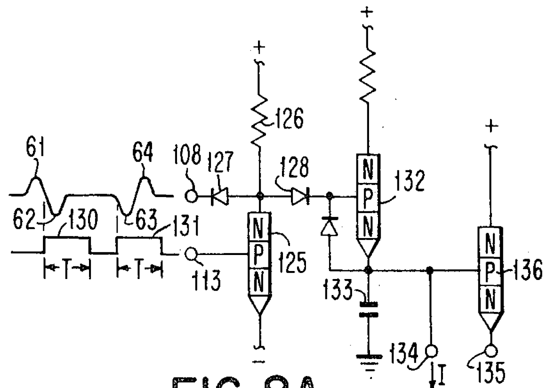

FIG. 8A

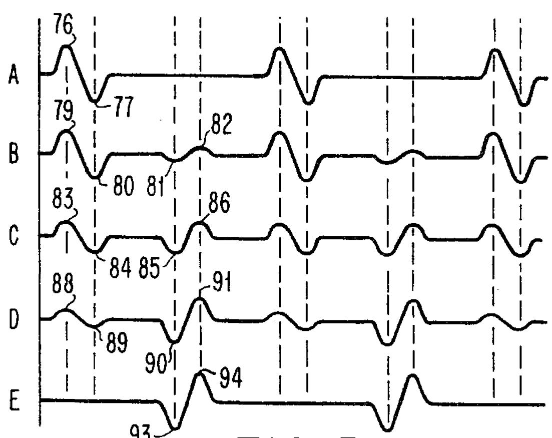

FIG. 5

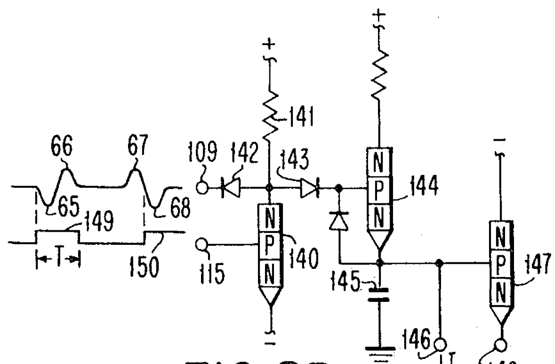

FIG. 8B

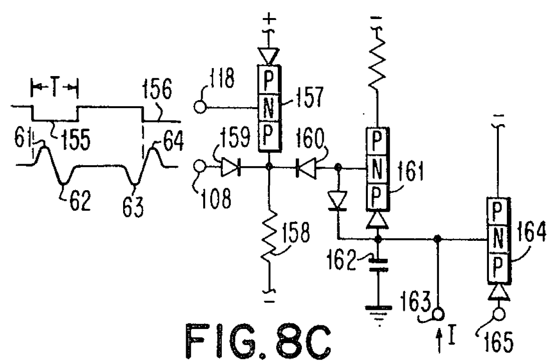

FIG. 8C

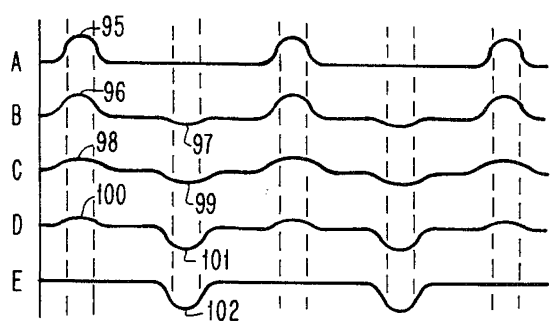

FIG. 6

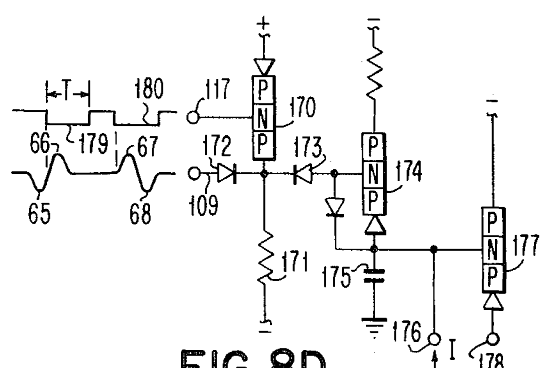

FIG. 8D

METHOD AND APPARATUS FOR RECORDING AND DETECTING INFORMATION

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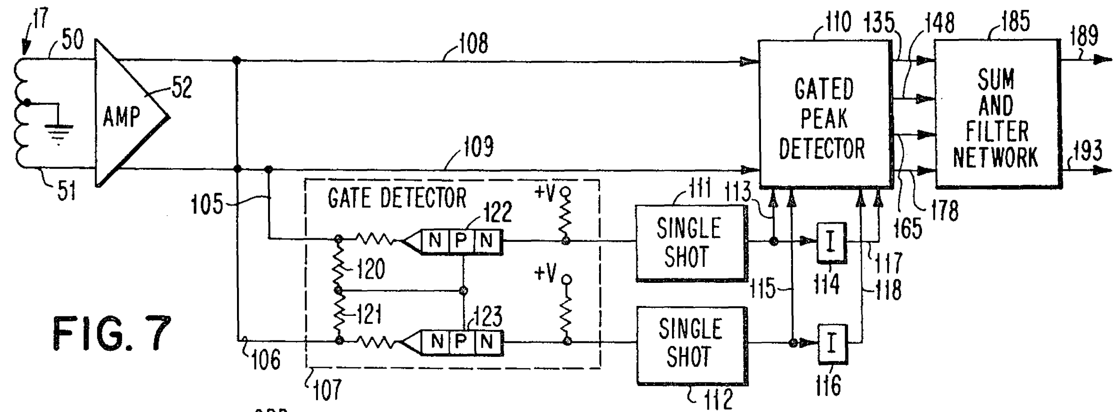

FIG. 7

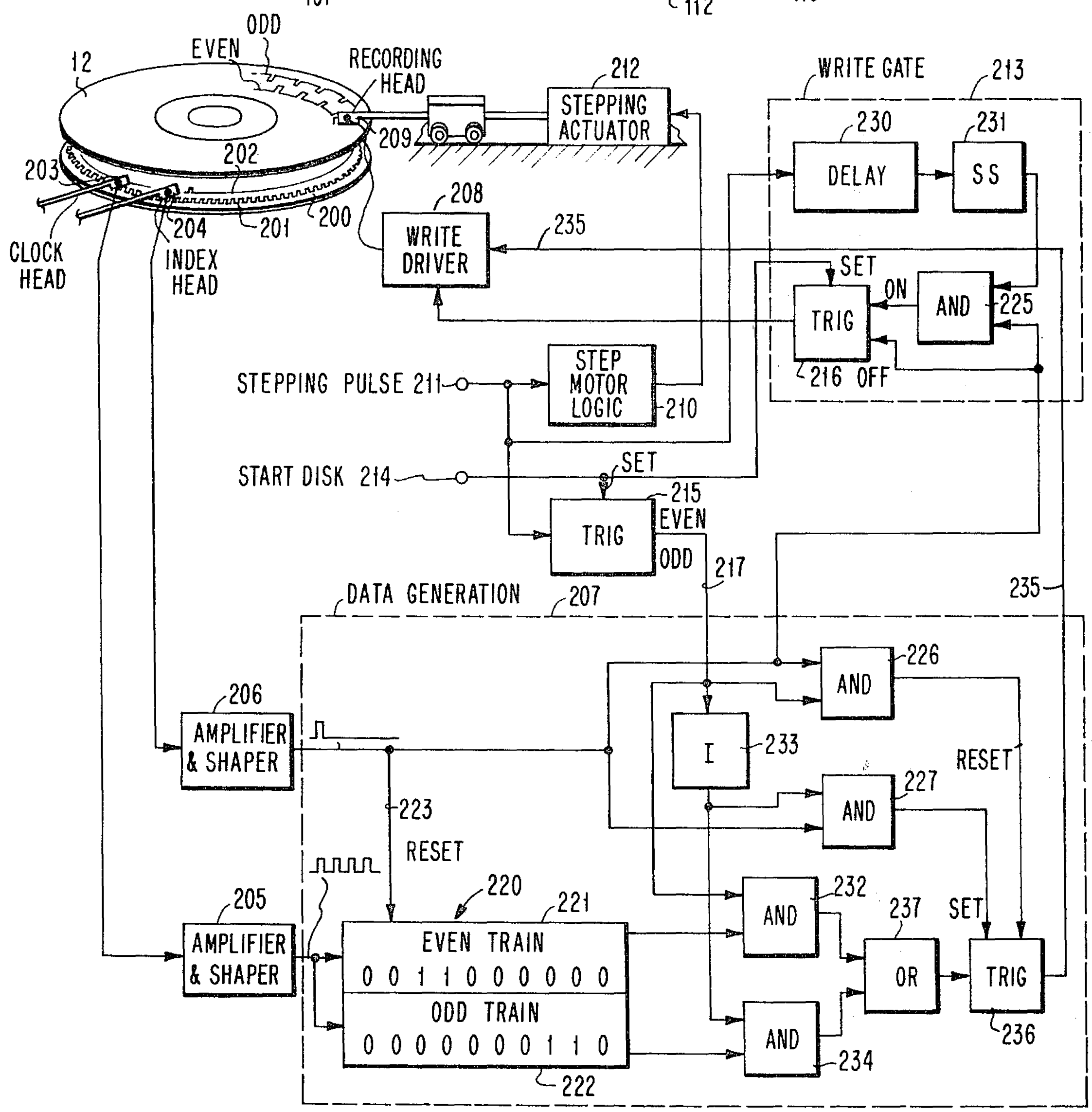

FIG. 10

United States Patent

Mueller

[15] **3,691,543**

[45] **Sept. 12, 1972**

[54] **POSITIONING SYSTEM INCLUDING SERVO TRACK CONFIGURATION AND ASSOCIATED DEMODULATOR**

[72] Inventor: **Francis E. Mueller**, San Jose, Calif.

[73] Assignee: **International Business Machines Corporation**, Armonk, N.Y.

[22] Filed: **Feb. 8, 1971**

[21] Appl. No.: **113,484**

[52] **U.S. Cl.** ....**340/174.1 B**

[51] **Int. Cl.** **G11b 5/02**

[58] **Field of Search**..340/174.1 G, 174.1 H, 174.1 B, 340/174.1 C

[56] **References Cited**

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Primary Examiner—Vincent P. Canney
Attorney—Hanifin & Jancin and Edward M. Suden

[57] **ABSTRACT**

The invention relates to a positioning system which provides a series of adjacent servo tracks, the boundary between adjacent servo tracks defining a path for the servo system to follow. The servo track configuration generating an output signal in a transducer which has positive pulses for synchronization and negative pulses for positioning information and gain control information. A demodulator is used for separating the synchronization signal from the position and gain control signals. The synchronization signal is used to separate portions of the positioning and gain control signal so as to generate a positioning signal that is indicative of the position of the transducer with respect to the servo tracks and for generating an automatic gain control signal for the demodulator itself.

10 Claims, 12 Drawing Figures

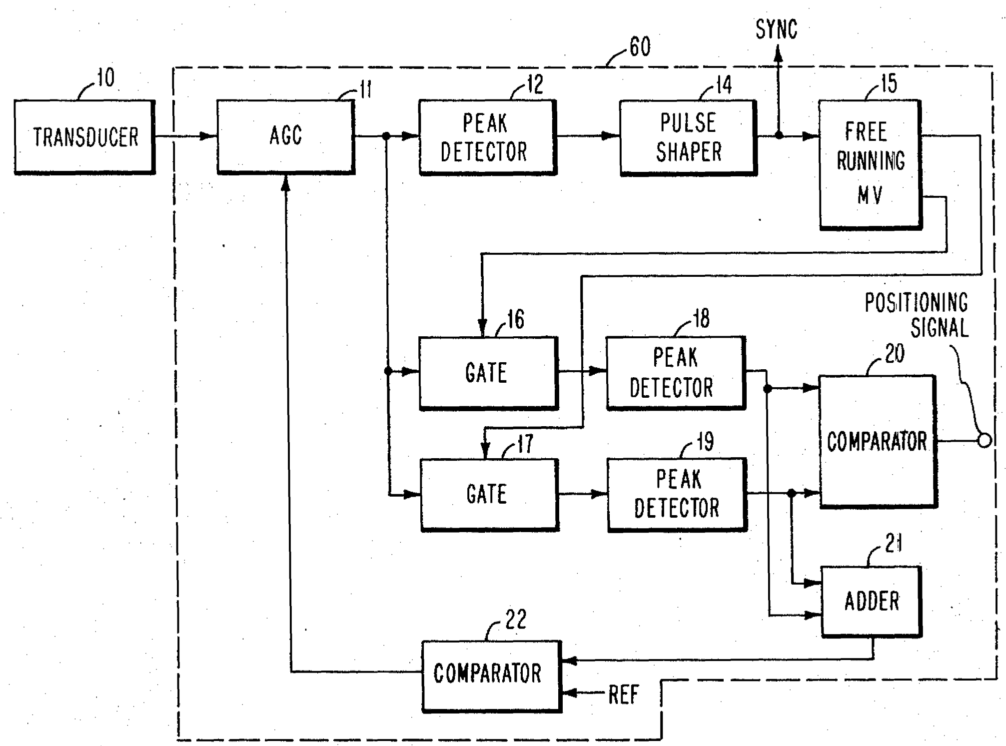


FIG. 1

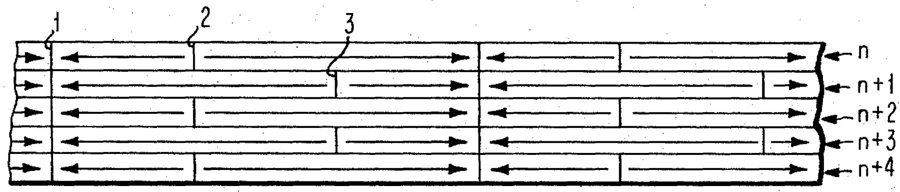


FIG. 2

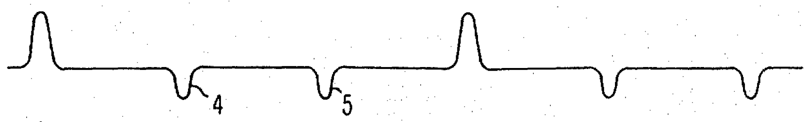


FIG. 3

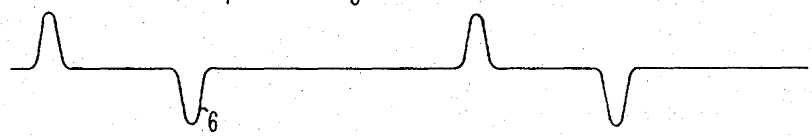


FIG. 4

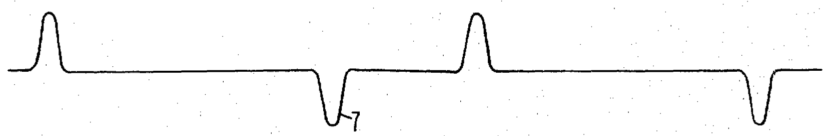
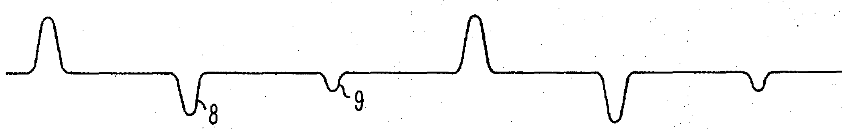


FIG. 5



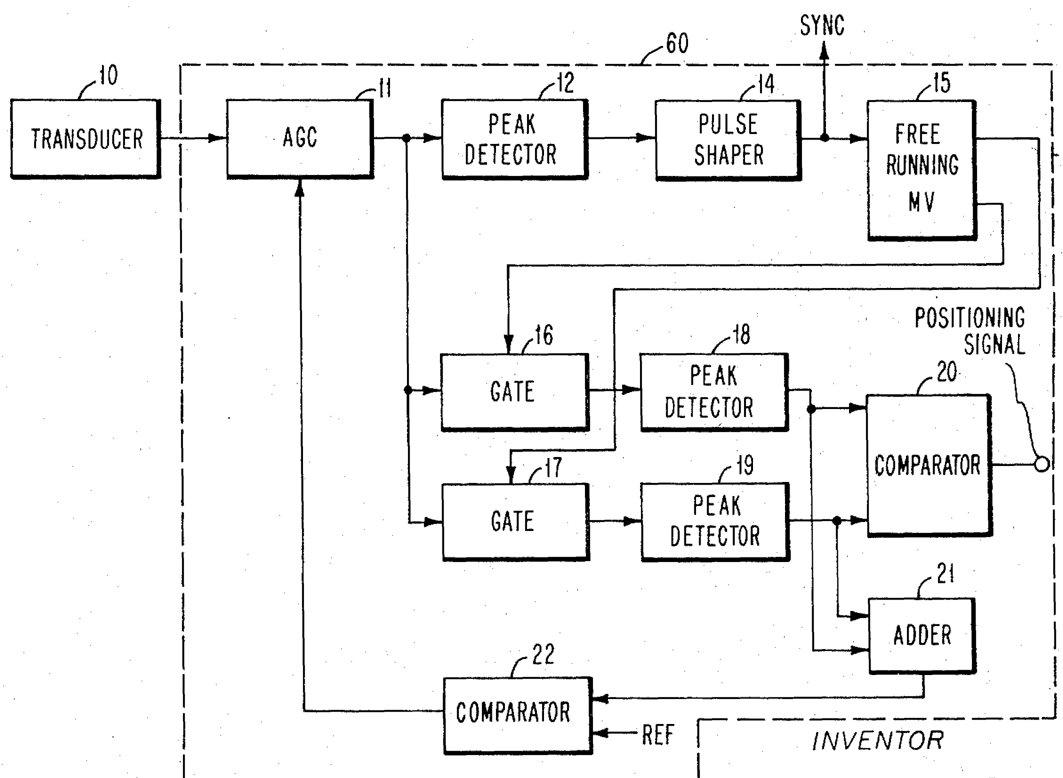


FIG. 6

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FIG.7

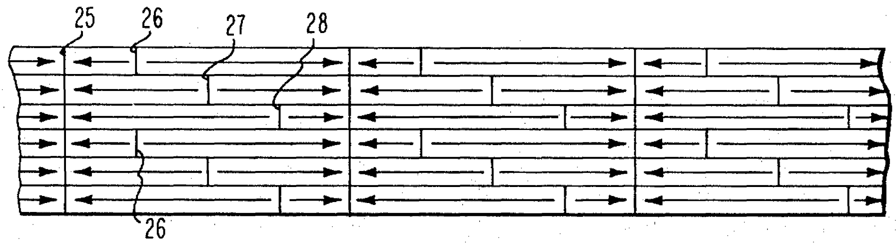


FIG.8

FIG.9

FIG.10

FIG.11

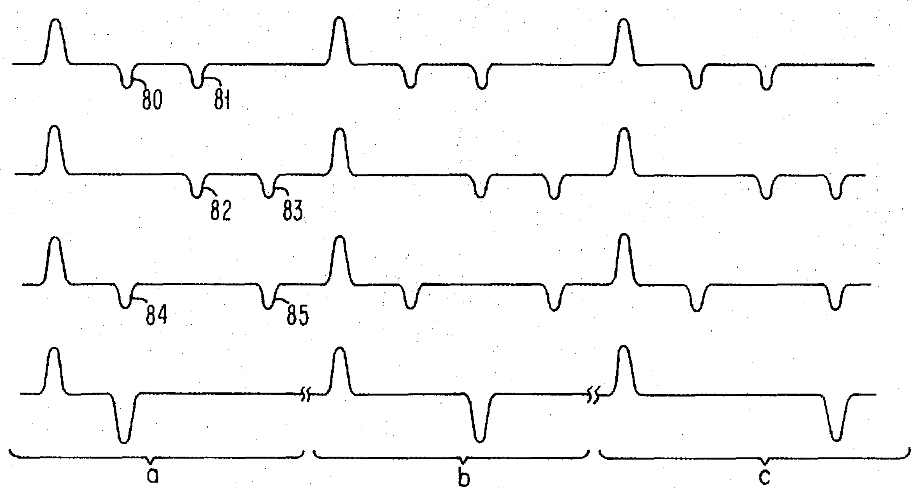
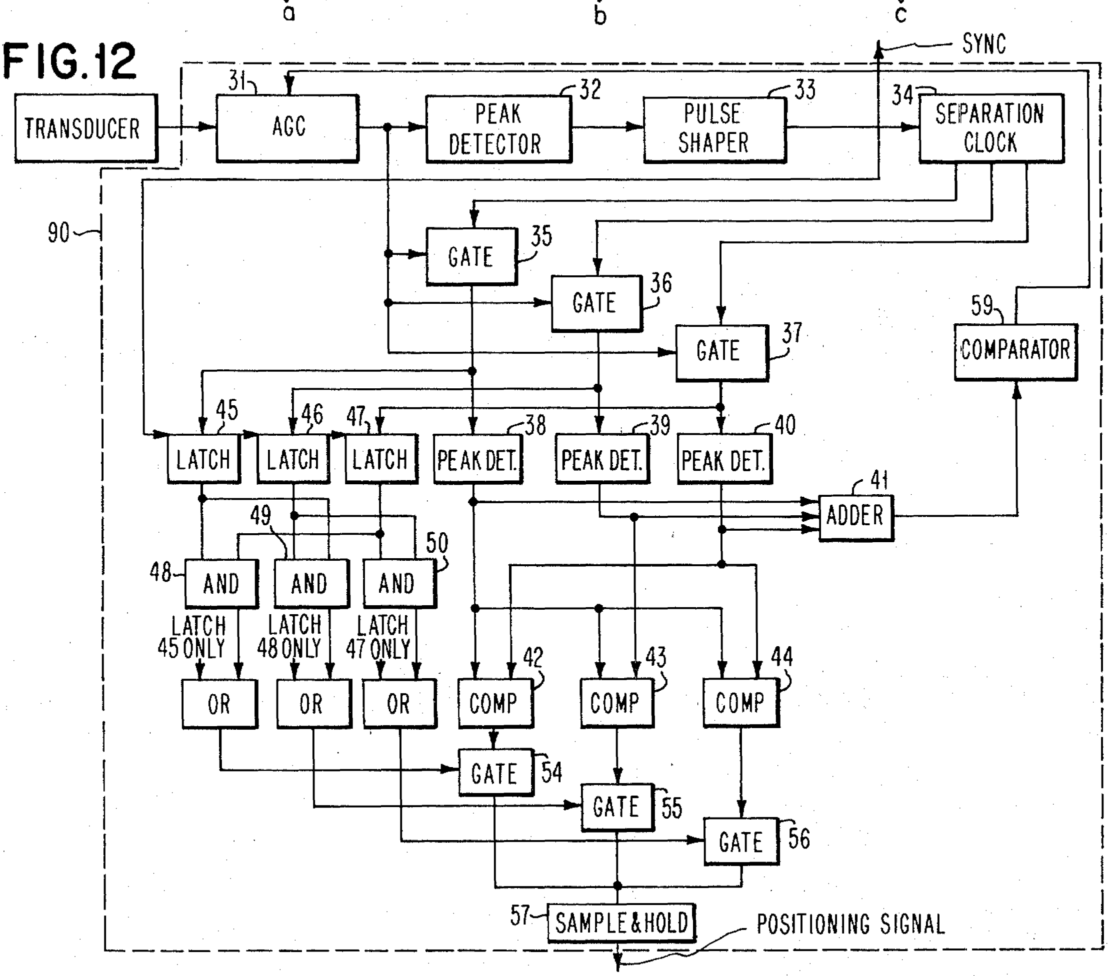


FIG.12



POSITIONING SYSTEM INCLUDING SERVO TRACK CONFIGURATION AND ASSOCIATED DEMODULATOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to information recording and reproducing systems, and more particularly to random access memory systems which require the accurate positioning of a transducer relative to the information to be recorded or reproduced.

2. Prior Art

With the advent of the use of flux transition to generate servo information as taught by U.S. Pat. No. 3,534,344 entitled "Method and Apparatus for Recording and Detecting Information", the field of positioning servo systems has been greatly expanded.

Servo systems of this type have the inherent problem that each servo track generates both positive and negative pulses and therefore in order to obtain accurate positioning information from the servo signal generated in the servo head, a demodulator must be designed to separate the positive and negative transitions of adjacent tracks and for comparing the magnitude of the pulses in adjacent tracks to obtain accurate positioning information. Since both positive and negative transitions are used to generate positioning information, the amplifiers used must be carefully designed such that positive and negative transitions of the same magnitude will obtain the same amplification so that no error would be introduced into the system by the amplifier.

Another problem within servo systems of this type is the problem of obtaining a synchronization signal for controlling the timing of the servo system. In the past, separate synchronization or timing tracks have been used.

It is the object of this invention to provide a novel track configuration which provides synchronization information, positioning information and gain control information.

A further object of this invention is to provide the synchronization information as pulses of only one polarity and for all positioning information and gain control information to be pulses of the other polarity.

Still another object of this invention is to provide a demodulator for separating the synchronization signal from the positioning and gain control signal in the servo signal generated by the servo transducer and for generating a fine positioning signal for the servo system and an automatic gain control signal for the demodulator.

SUMMARY OF THE INVENTION

Briefly, the invention is directed toward a servo positioning system having a servo track configuration and its associated demodulator. The servo track configuration will generate pulses of one polarity for synchronization in the servo transducer and pulses of the other polarity, the amplitude of which is indicative of the transducer's position with respect to the servo track, in the servo transducer. The position pulses induced in the servo transducer also contain automatic gain control information. A demodulator is provided for receiving the signal generated in the servo transducer, using the synchronization pulses to separate the position pulses such that the position pulses may be properly compared to obtain positioning information and further may be properly combined to obtain the automatic gain control signal for the demodulator.

The advantage of such a track configuration and demodulator is that the amplifier design criteria are greatly reduced since the critical positioning information is now carried by pulses of a single polarity at the point where their amplitudes are equal, and therefore inherent amplifier non-linearity will not cause off-track error in the servo system.

Another advantage of the system is that synchronization information is presented by the same servo transducer that is generating servo information therefore making the timing of the read/write data system more reliable.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention as illustrated in the accompanying drawings.

FIG. **1** is a illustration of the novel servo track configuration, the configuration repeating every two servo tracks.

FIG. **2** shows the waveform generated in the servo transducer when the servo transducer covers two adjacent servo tracks equally.

FIG. **3** shows the waveform generated in the servo transducer when the servo transducer is positioned only on even servo tracks.

FIG. **4** shows the servo signal generated in the servo transducer when the servo transducer is positioned only on the odd servo tracks.

FIG. **5** shows the signal generated in the servo transducer when the servo transducer is positioned unequally over two adjacent servo tracks.

FIG. **6** shows the demodulator for demodulating the information generated in the servo head from the track configuration of FIG. **1**.

FIG. **7** is an illustration of the track configuration of the invention where the configuration repeats every three servo tracks.

FIG. **8** shows the waveform generated in the servo transducer when the servo transducer is centered over the boundary between servo tracks n and $n+1$.

FIG. **9** shows the signal generated in the servo transducer when the servo transducer is positioned on the boundary between servo tracks $n+1$ and $n+2$.

FIG. **10** shows the signal generated in the servo transducer when the servo transducer is positioned on the boundary between tracks $n+2$ and $n+3$.

FIG. **11** (*a–c*) shows various waveforms generated in the servo transducer when the servo transducer is positioned only over track n as shown in *a*, only over track $n+1$ as shown in *b*, and only track $n+2$ as shown in *c*.

FIG. **12** is a block diagram of the demodulator used for separating the synchronization signal and position and gain control signal generated in the servo transducer from the track configuration as illustrated in FIG. **7**.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The preferred embodiment of the invention is a combination of the track configuration shown in FIG. **1** and its associated demodulator shown in FIG. **6**.

With reference to FIG. **1**, the track configuration of the invention is shown. It should first be noted that all positive transitions **1** occur at the same position on all servo tracks. Further the requirement for the track configuration is that negative transitions on adjacent servo tracks occur at different positions. By viewing track *n*, *n*+1, and *n*+2, it can be seen that negative transitions **2** and **3** on tracks *n* and *n*+1 occur at different times. Further, it can be realized that the position of the negative transitions is repetitive and appears in a fixed sequence.

A servo transducer centered on the boundary between tracks *n* and *n*+1 will generate a servo signal as shown by the waveform in FIG. **2**. The negative transitions **2** and **3** generate negative pulses **4** and **5** of equal amplitude in the waveform of FIG. **2**. If the servo transducer was positioned so as to receive only signals from even tracks represented by tracks *n*, *n*+2, etc. the waveform shown in FIG. **3** would be generated in the servo transducer. Under this condition, only one negative pulse **6** would be generated because only negative transition **2** would be sensed by the servo transducer. Similarly, if the servo transducer was positioned entirely over odd tracks represented by *n*+1, *n*+3, the signal generated in the servo transducer would appear as the waveform in FIG. **4**. Again, it can be seen that only one negative pulse **7** will occur in the waveform which is generated by the negative transition **3** on the odd servo tracks. When the servo transducer is positioned so as to receive components both from odd and even servo tracks, the signal generated in the servo transducer is exemplified by the waveform shown in FIG. **5**. Under these conditions, the servo transducer is not centered on the boundary between adjacent servo tracks and therefore the negative pulses **8** and **9** generated by the negative transitions **2** and **3** will not have the same amplitude.

It should further be noted that in all waveforms shown in FIGS. **2**, **3**, **4** and **5**, all positive pulses were of the same magnitude. This result is achieved by having all positive transitions **1** on all servo tracks aligned such that the signal generated in the servo transducer will be the same regardless of the position of the servo transducer with respect to the servo track. Therefore, as the servo transducer moves across the servo track, the positive transitions will maintain constant amplitude while the negative transitions will vary in amplitude.

With reference to FIG. **6**, a demodulator **60** is shown receiving the servo signal from the servo transducer **10**. The automatic gain control circuit **11** receives the servo signal generated in the servo transducer **10** and amplifies the servo signal. The output of the automatic gain control circuit is fed to positive peak detector **12** and to gates **16** and **17**. Positive peak detector **12** passes the positive pulses of the amplified servo signal to pulse shaper **14**. Pulse shaper **14** shapes the positive pulses and synchronizes the free running multivibrator **15** to the frequency of the occurrence of the positive pulses.

Gates **16** and **17** are controlled by the synchronized free-running multivibrator **15** such that the negative transitions that are associated with even tracks will pass through gate **17** and the negative transitions associated with the odd servo tracks will pass through gate **16**. Peak detectors **18** and **19** hold the peak value of the negative transitions that are passed by gates **16** and **17**, respectively. Comparator **20** compares the output of peak detectors **18** and **19** and generates a positioning signal that is a function of the difference between the magnitude of the output of peak detectors **18** and **19**.

The output of peak detectors **18** and **19** are also added together by adder **21** and compared against a reference by comparator **22**. The output of comparator **22** is an automatic gain control signal which is fed back to the automatic gain control circuit **11** for controlling the gain of the automatic control circuit **11**. It should be noted that the summation of the outputs of peak detectors **18** and **19** should be a constant value and any departure from that constant value would indicate a correction would be needed in the gain of the automatic gain control circuit **11**. The reference voltage to comparator **22** is the constant value that would be expected from the summations of the output of peak detectors **18** and **19**.

It should further be noted that the output of pulse shaper **14** can be used for synchronization purposes in other parts of the servo system.

The second preferred embodiment is shown by the combination of the track configuration shown in FIG. **7** and the demodulator shown in FIG. **12**.

The track configuration as shown in FIG. **7** is similar to the track configuration as shown in FIG. **1** except that the sequence of negative transitions occurs every third track rather than every second track. The arrows in each area of each track symbolize the orientations of the magnetic domains in that area. As can be seen from FIG. **7**, all positive transitions **25** still occur at the same position across all servo tracks. The criteria that negative transitions do not occur at the same position on adjacent servo tracks is still maintained. Negative transitions **26**, **27** and **28** on servo tracks *n*, *n*+1, and *n*+2, respectively, are positioned so as to maintain the negative transition criteria and show the sequence of negative transitions that will be repeated every three servo tracks.

If the servo transducer was centered over the boundary between servo tracks *n* and *n*+1, the servo signal generated in the servo transducer would be of the waveform as shown in FIG. **8**. The negative pulses **80** and **81** are generated by the negative transitions **26** and **27**, respectively. No negative pulse is caused by transition **28** on servo track *n*+2 since the servo transducer receives no contribution from that servo track.

If the servo transducer was centered over the boundary between servo tracks *n*+1 and *n*+2, the resulting servo signal generated in the servo transducer would be of the waveform shown in FIG. **9**. Here the negative pulses **82** and **83** would be generated from the negative transitions **27** and **28** occurring in servo tracks *n*+1 and *n*+2, respectively. Again, it should be noted that no negative pulse is seen since no contribution is made by negative transition **26** on servo track *n* or *n*+3.

If the servo transducer were centered over the boundary between servo tracks *n*+2 and *n*+3, the servo signal generated in the servo transducer would be of the waveform as shown in FIG. **10**. Here negative pulses **84** and **85** are generated as a result of negative transitions **27** and **28** that occur in servo tracks n+2 and n+3, respectively. Again, it should be noted that the magnitude of the positive transitions remains a constant, regardless of the position of the servo transducer with respect to the servo tracks. This is because the servo transducer will always see the same magnitude of transition regardless of its position with respect to any servo track.

FIG. **11**(a) shows in portion a the waveform that would be generated in the servo transducer when the servo transducer is centered over track n and only the negative transition **26** generates a negative pulse. Similarly, the waveform shown in sections (b) and (c) of FIG. **11** show the waveforms that would be generated if the servo transducer were centered over servo tracks n+1 and n+2, respectively, and the negative pulses are generated by negative transitions **27** and **28**, respectively.

Again, it should be noted that the magnitude of the negative transitions and waveforms shown in FIGS. **8, 9** and **10** will vary as the servo transducer moves from its center position over the boundary between adjacent tracks. The magnitude of the negative pulses represents the position of the servo transducer with respect to one of the boundaries between two adjacent tracks. The time occurrence of two negative pulses gives information as to which boundary the servo transducer is attempting to follow.

With reference to FIG. **12**, the demodulator **90** receives the servo signal from servo transducer **30**. Here again, the servo signal is amplified by automatic gain control circuit **31** and fed to positive peak detector **32** and negative peak detector **33**. The output of the positive peak detector **32** is fed to pulse shaper **33**. The output of pulse shaper **33** is used as a reset line for latches **45, 46** and **47** and to start the separation clock **34**. A separation system is provided which includes separation clock **34** and gates **35, 36**, and **37**. The pulses passed to gates **35, 36** and **37** are separated by means of the separation clock **34**. The output of gates **35, 36** and **37** are fed to peak detectors **38, 39** and **40**, respectively, which store the magnitude of the last negative transition that was passed through gates **35, 36** and **37**. The output of peak detectors **38, 39** and **40** are fed to adder **41** for generating an automatic gain control signal for controlling the gain of the automatic gain control circuit **31**. It should be noted that only two of the three peak detectors will have an output at any given time. The output of adder **41** is fed to comparator **59** to be compared against a known constant reference voltage for the generation of the automatic gain control signal.

Since the system does not know which of the two peak detectors will have a given output at any given instant of time, the output of the three possible usable combinations are compared by means of comparators **42, 43** and **44**. The output of comparators **42, 43** and **44** are gated as the positioning errors by means of gates **54, 55** and **56** to sample and hold circuit **57**.

It should be realized that with two of the three peak detectors **38, 39** and **40** being activated, that an output will be present at all three comparators **42, 43** and **44** since at least one active output is fed into each of the three comparators. In order to determine which output of which comparator is the true positioning signal, it is necessary to determine the position of the negative pulses that occurred between two adjacent positive pulses, that is to say, which boundary between which two adjacent tracks is the servo transducer attempting to follow. This is accomplished by means of latches **45, 46** and **47** which will store the occurrence of a pulse being transmitted through gates **35, 36** and **37**, respectively. It is possible for only two of the three latches **45, 46** and **47** to be latched. AND circuits **48, 49** and **50** determine which of the three possible boundaries the servo transducer can be attempting to follow. If AND circuit **48** is activated, then the pulses received are associated with negative transitions **26** and **27** on tracks n and n+1 of FIG. **7**. If AND circuit **49** is activated, then negative pulses associated with negative transitions **28** and **29** on servo track n+1 and n+2 have been sensed. If AND circuit **50** is activated, then negative transition **26** and **28** have been sensed on servo track n+3 and n+2, respectively, as shown in FIG. **7**. Therefore, the output of AND circuits **48, 49** and **50** determine which boundary condition is being sensed by the magnetic transducer. OR circuits **51, 52** and **53** take into account the possibility that the servo transducer is positioned directly over one of the three servo tracks and that only one negative pulse will occur. This is shown by the input to OR circuits **51, 52** and **53** of an input labeled latch **45** only, latch **46** only, and latch **49** only, respectively. The logic necessary to determine whether only latch **45** or **46** or **47** was activated at a given instant of time is well within the state of the art. The output of OR circuits **51, 52** and **53** controls gates **54, 55** and **56**, respectively, such that the proper error signal generated by comparators **42, 43** and **44**, respectively, will be fed and sampled by sample and hold circuit **57** which will generate the positioning signal from the demodulator to be used by the servo system.

It should further be noted that the output of shaper **33** is the synchronization output to be used by other portions of the servo and data recovery systems.

It can readily be realized that any sequence of negative transitions across any given number of tracks may be used. It is possible to call for a discrete negative transition for each track such that by decoding the occurrence of two negative transitions, the address of the boundary between adjacent tracks that the servo transducer is attempting to follow can be readily decoded. It is readily within the skill of the art that such a system may readily be used as an addressing means for addressing the boundary to be followed by the servo transducer.

It should be obvious to those skilled in the art that this means of synchronization is applicable to magnetic storage systems such as tape drives, disk files, and magnetic drums.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention.

What I claim is:

1. In a system for indicating position with respect to a predetermined path, means having a code member for marking *n* paths,

said code member being of the type wherein a plurality of series of pattern areas are arranged for line readout of information representative of displacement of said code member from a nominal position, said code member comprising:

$n + 1$ adjacent tracks, the boundary between any two adjacent tracks defining one of said n paths;

at least one first transition of a first polarity occurring on each of said tracks, each said first transition occurring at the same position on all said tracks;

a second transition of the opposite polarity of said first transition occurring after each of said first transitions on each of said tracks, said second transitions occurring at a position other than the position of the occurrence of a second transition on an adjacent one of said tracks; and

said second transitions occurring in a defined sequence across said tracks.

2. The system as set forth in claim **1** wherein said sequence is repetitive.

3. The system as set forth in claim **2** wherein said sequence repeats every two tracks.

4. The system as set forth in claim **1** wherein each of said tracks are of the same width.

5. The system as set forth in claim **4** further comprising:

a transducer having an active width dimension equal to or less than the width of one of said tracks, said transducer generating an output signal in response to said first and second transitions, said output signal being indicative of the position of said transducer to one of said *n* paths, and further providing synchronization and gain control information.

6. The system as set forth in claim **5** wherein said synchronization information of said output signal is generated out from said first transition sensed by said transducer.

7. The system as set forth in claim **5** wherein said positioning information is generated only from said second transition sensed by said transducer.

8. The system as set forth in claim **5** wherein said gain control information is generated only from said second transition sensed by said transducer.

9. The system as set forth in claim **5** further comprising:

a demodulator for receiving said output signal from said transducer for generating a synchronization signal, a position signal and a gain control signal from said output signal.

10. The system as set forth in claim **9** wherein said demodulator comprises a separation circuit controlled by said synchronization signal, said separation circuit separating said second transitions, said separated second transitions being used to generate said position signal and said gain control signal, said gain control signal controlling the gain of said demodulator.

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