960-7-168-C
IPOS

METHODS OF MONITORING OPERATING TEMPERATURES IN DISC DRIVES TO PREVENT THERMAL MISTRACKING

This invention relates generally to magnetic disc memory apparatus and particularly to temperature compensation in the transducer positioning system in a disc drive.

Disc drive machines record and reproduce information stored on concentric circular tracks recorded on magnetic discs. The tracks are written and read by a magnetic transducer that cooperates with the surface of the disc. Many disc drives today employ pulley band mechanisms driven by stepper motors to position the read/ write heads. For example, a detailed disclosure of a disc drive and especially the linear actuator for positioning the heads in alignment with a selected track on a disc is found in our U.S. Patent 4,323,939; a rotary actuator positioned by a stepper motor is found in our EP-A- 0162614A. Both are incorporated herein by reference.

Such drives convert rotary motion of the stepper motor shaft to linear or rotary motion of a carriage which moves the transducers carried on an end of the carriage across the disc to read and record data on concentric circular disc tracks. The drive band is wrapped around the motor shaft pulley attached to the shaft, and has its ends attached to the carriage. Rotation of the shafts wraps one end of the band on the pulley and

THIS SHEET HAS BEEN REPLACED

unwraps the other, causing the carriage to move the head from track to track.

Industry requirements for greater storage capacities in ever decreasing physical package sizes demand that the tracks be spaced as closely adjacent to one another as possible.

However, this creates the problem that the heads must be very accurately positioned relative to each track, so that the heads do not land on an incorrect track or too far from the center line of a desired track. A particularly difficult situation occurs in relatively low cost rigid disc drives; in order to achieve a significant reduction in cost and complexity as demanded by the competitive nature of the business, the head actuator which positions the transducer relative to the track does not incorporate any closed loop positioning control.

Therefore, it is an objective of this invention to provide a disc drive positioning mechanism which minimizes positioning error without any closed loop feedback control system.

Because of the wide range of operating environments in which a disc drive may be utilized, it has been found that one of the critical sources of mistracking error in positioning of the head relative to the desired track is thermal expansion and contraction of the various components with changes in the ambient temperature. This is due to the fact that it is very difficult to properly match thermal expansion coefficients of the different materials which must be used in the construction of the disc drive, particularly its baseplate, spindle motor and the transducer positioning actuator. As has been already noted, the thermal off-track problem is particularly severe in an open loop drive which is common to

This Sheet Has Been Replaced

the lower cost rigid disc industry; there is no track-following servo to insure that the head is centered on the desired track, or to indicate that this tracking has occurred. The mistracking problem which may be created by variations in ambient temperature does not become evident until data has been incorrectly read or written, and even then, no inherent self-correction means exist.

This invention provides a method of monitoring the operating temperature to prevent thermal mistracking in a disc drive comprising rotating a disk having a plurality of spaced circular tracks for storing recorded data and at least one test track, actuating means for accessing the data comprising a carriage, means for mounting a transducer at one end of the carriage, and means adjacent the periphery of the rotating disc for driving and positioning the carriage along a predetermined path to position the transducer relative to the disc and the tracks, comprising the steps of defining a selected test track and a reference track on at least one side of said test track on said disc, both at a location not accessible to the user; periodically sensing the ambient temperature of the disc drive, moving the transducer head to the test track in response to the sensing of a defined change in ambient temperature, after positioning of said transducer moving the transducer in predetermined incremental microsteps which are substantially smaller than the nominal track to track distance from said test track toward said reference track; detecting said reference signal; and operating on the number of steps carried out when said reference signal has been detected to determine the thermal shift of said transducer relative to said tracks on

THIS SHEET HAS BEEN REPLACED

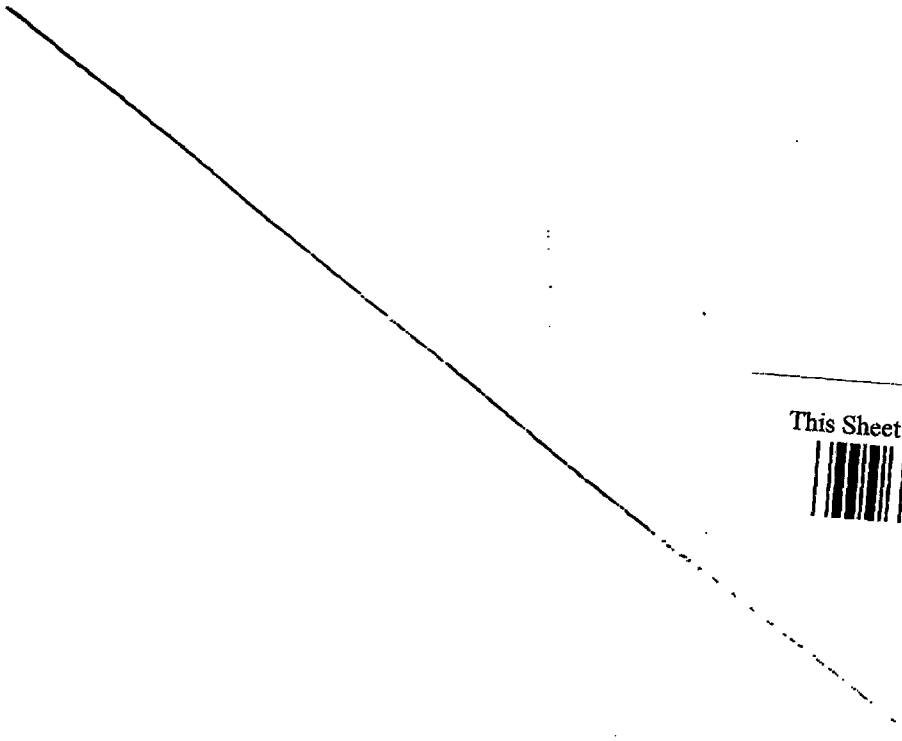
said disc and applying the data of said determined thermal shift to subsequent seeks to user accessible data tracks.

The method may further comprise the steps of periodically sensing the ambient temperature of the disc drive, and moving the transducer head to the test track in response to the sensing of a defined change in ambient temperature.

The invention can be better understood together with its advantages and features by reference to the accompanying drawings wherein:

Figure 1 is a plan view of a stepper motor driven actuator and data recording disc in which this invention may be incorporated;

Figure 2 is a layout of an example of the thermal text track and adjacent data tracks used in the thermal compensation system of this invention;



This Sheet Has Been Replaced

FIG 3 is a simple block diagram of the electrical elements in the disc drive controller system used to carry out the operating sequence of this invention; and

FIG 4 is a flow diagram of the sequence of steps which is utilized to carry out the thermal compensation and correction features of this invention.

Referring particularly to FIG 1, it shows a transducer 10 which is mounted on a flexure 20 attached to an actuator arm 21 to be positioned by a movement of a drive arm 32 on any data track of a disc 12. The disc 12 is driven in constant rotation by a spindle motor 25. The positioning of the actuator is carried out by the stepper motor 30 which drives a pulley 36 connected through a flexible band 38 to the head portions 19a, 19b of the actuator arm 32. With rotation of the motor pulley 36, the portion of flexible band 38 wind and unwind on the pulley 36, moving the transducer 10 from track to track. This is accomplished under control of the microprocessor 40 shown schematically in the corner of the disc drive; this provides the control signals to the stepper motor 30 in response to externally received seek commands. Such seek commands are received whenever the transducer is to be moved from its current position to a newly addressed track.

Referring to FIG 2, a thermal test track is defined at an area of the disc surface not accessible to the user of the disc, in this example, outside of track 0 (i.e., toward the outer diameter of disc 12). As shown in detail in FIG 2, the thermal test track in this example is track -3. A constant frequency level, selected in this case to be 1.8 MHz is written) track distance away from the center of the thermal test track on each side of the track.

As noted above, it would be impractical to determine the thermal compensation factor for every seek operation. This would greatly slow user accesses to the disc drive. Instead, there is a set of temperature sensing logic incorporated herein and shown generally as thermistor circuits 72 on FIG 3. Included in the thermistor circuits 72 is a thermistor or other temperature sensing device and associated circuitry for determining when a temperature change has occurred which exceeds a preselected significant range. This range, in the example, has been set at 5 intervals. When the temperature monitoring circuitry determines that the operating temperature has increased or decreased beyond this 5 range, a logic flag is set in the thermistor circuits 72 and remains set until acknowledged and cleared by the microprocessor 40. This acknowledgment will not occur until the host computer in the system employing the disc drive commands the disc drive to seek to a new track.

This sequence of events is perhaps best understood in conjunction with the flow diagram of FIG 4. Upon receipt of the seek command 70, the microprocessor will poll the logic flag in the thermistor circuits 72 to determine if the operating temperature of the disc drive has changed significantly (more than 5) since the last prior seek command (step 71). As the flow diagram of FIG 3 shows, if no significant temperature change has occurred (i.e., the flag is not set), the disc drive seeks to the addressed track (step 90) applying the thermal correction last obtained (step 92). If, however, the flag is set, the microprocessor then clears the flag (step 72) and enters the sequence to determine a new thermal compensation factor by initiating a special seek to the thermal test track 60 (step 73).

When the head is moved to the thermal test track 60 without any compensation made for thermal expansion or

contraction, it will still be positioned between the two test data tracks (62, 64 of FIG 2) prerecorded with the known frequency.

Once the head is landed at track 60, the first micro-step toward one of the special data track 62, 64 is taken as shown at block 74. The frequency discriminator 50 is read, as shown at step 76. If an up level is detected, the head has already reached the test data track 62 or 64 and the count used to reach that position is stored. As shown in the decision block 78, if no data has yet been read, a further step is taken and the sequence returns to block 74. Only four steps are taken in the search for the recorded data level because a series of four micro-steps, each equivalent to 3% of the track-to-track distance, will represent 12% of the distance between tracks (or 24% of the distance between the thermal test track 60 and the test data tracks 62, 64), and the mechanical design of the disc drive is such that greater errors cannot be thermally induced.

Closer examination of FIG 2 will yield a greater appreciation of this. In disc drives designed using current technology, a guard band is included between adjacent tracks which is approximately 20% of the track-to-track distance. If the test data tracks 62, 64 are thought of as normal data tracks, then the thermal test track 60 will be located at the center of the guard band between the two recorded known frequencies, with a maximum of 10% of this guard band on either side of the nominal position of the thermal test track.

After locating the first of the test data tracks, the microstepper proceeds to return to the thermal track 60 and step in the opposite direction looking for a written data track. This is shown at blocks 81, 82. Again, with each micro-step in the direction of the opposite

test data track, the frequency discriminator is read as shown at step 84 looking for an up level as shown at step 86. When the test data track is found, the count of micro-steps is stored. Based on the data stored from these sequences of transducer steps and readings generated by the frequency discriminator 50, a thermal correction can be calculated at 88.

The transducer 10 is now moved to the commanded track as shown in block 90. When the track is reached the developed thermal correction is applied as shown at step 92 to accurately position the transducer 10 over the track.

The seek sequence is now complete, and the thermal correction is stored so that until another significant shift in ambient temperature occurs, the same thermal correction can be applied in each instance.

A person of skill in the disc drive art who studies this invention disclosure may realize that modification can be made to the preferred embodiment which has been described above. For example, a track of test data may be written on only one side of the thermal test track 60, or the development of a thermal compensation constant may be carried out at regular intervals, rather than with significant changes in ambient temperature. Therefore, the scope of the present invention is to be limited only by the following claims.

THIS SHEET HAS BEEN REPLACED

CLAIMS

1. A method of monitoring the operating temperature to prevent thermal mistracking in a disc drive comprising rotating a disk (12) having a plurality of spaced circular tracks for storing recorded data and at least one test track, actuating means for accessing the data comprising a carriage, means for mounting a transducer (10) at one end of the carriage, and means adjacent the periphery of the rotating disc (12) for driving and positioning the carriage along a predetermined path to position the transducer relative to the disc and the tracks, comprising the steps of:

defining a selected test track and a reference track on at least one side of said test track on said disc (12), both at a location not accessible to the user;

periodically sensing the ambient temperature of the disc drive, moving the transducer head to the test track in response to the sensing of a defined change in ambient temperature,

after positioning of said transducer (10) moving the transducer in predetermined incremental microsteps which are substantially smaller than the nominal track to track distance from said test track toward said reference track;

detecting said reference signal; and

operating on the number of steps carried out when said reference signal has been detected to determine the thermal shift of said transducer relative to said tracks on said disc (12) and applying the data of said determined thermal shift to subsequent seeks to user accessible data tracks.

2. A method as claimed in Claim 1 further

* C L M S *

This Sheet Has Been Replaced

THIS SHEET HAS BEEN REPLACED

comprising the steps of:

periodically sensing the ambient temperature of the disc drive, and

moving the transducer head to the test track in response to the sensing of a defined change in ambient temperature.

* C L M S *

This Sheet Has Been Replaced

ABSTRACT:

METHODS OF MONITORING OPERATING TEMPERATURES IN DISC DRIVES TO PREVENT THERMAL MISTRACKING

A thermal test track (-3) is provided outside the user-accessible area on the disc. A track complete of a known frequency is then written on either side of this thermal test track, preferably half the usual track separate distance away. To develop a thermal compensation constant, the transducer (10) is moved to the thermal test track with no compensation applied. This way, any thermally induced off-track error, which would affect seeks to user-accessible data tracks, will be reflected in the off-track from the nominal position of the thermal test track. The transducer is now moved in a series of defined increments (e.g. 5) smaller than normal track-to-track steps, or "micro-steps", away from the uncompensated position of the thermal track toward one of the tracks written with the known frequency. When the data on the written track to the side of the thermal test track is detected, a note is made of the number of micro-steps the transducer has been moved. The transducer (10) is then micro-stepped incrementally in the opposite direction until the data written on the other side of the thermal test track is detected. A simple comparison of these two micro-step counts will yield the existing thermal shift, which can be converted into a thermal compensation constant for the transducer positioning mechanism by means of a simple look-up table.

(Figure 2 to accompany Abstract when published)

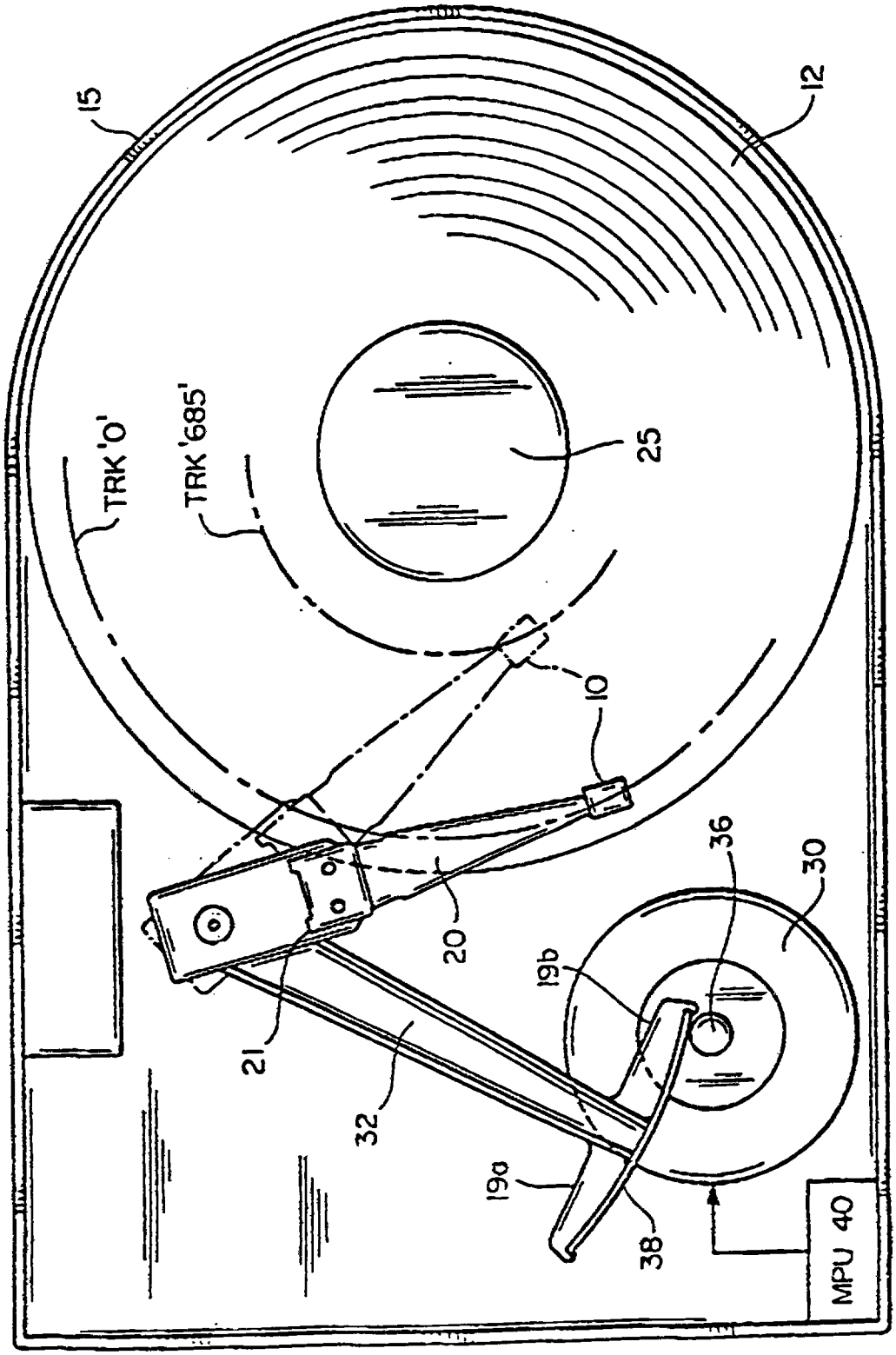


FIG_1

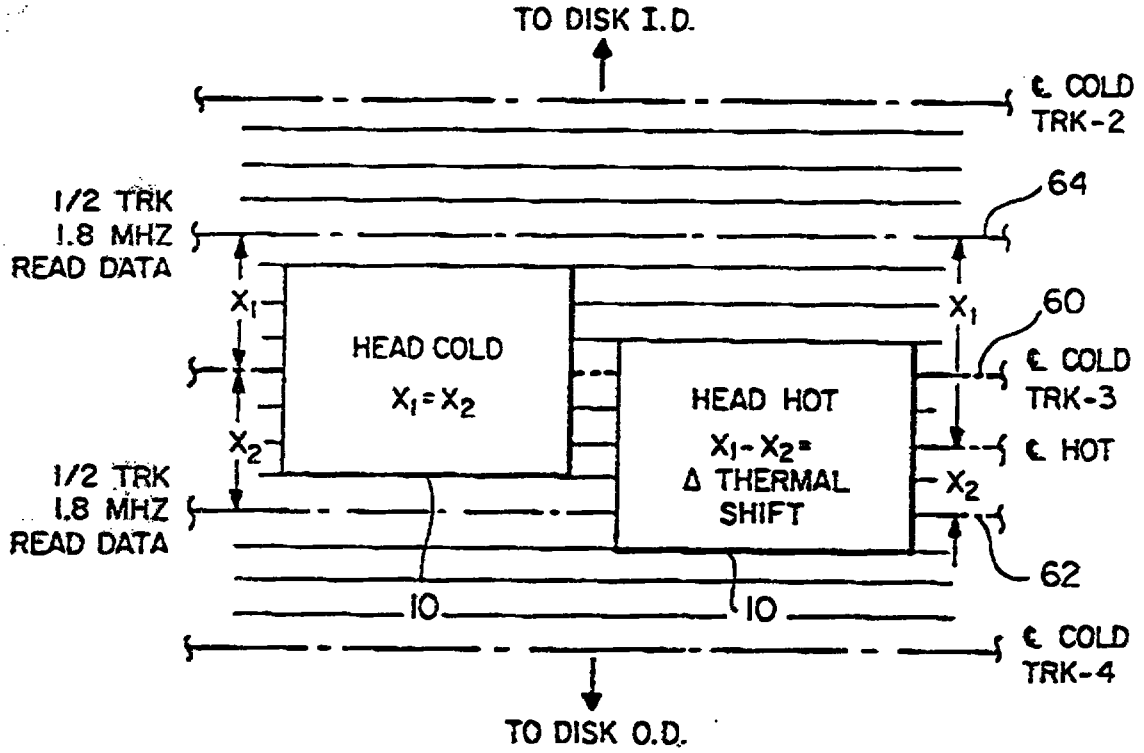

TO DISK I.D.
℄ COLD TRK-2
64
1/2 TRK 1.8 MHZ READ DATA
X1
X2
HEAD COLD
X1=X2
HEAD HOT
X1-X2= Δ THERMAL SHIFT
60
℄ COLD TRK-3
℄ HOT
62
1/2 TRK 1.8 MHZ READ DATA
10
10
℄ COLD TRK-4
TO DISK O.D.

FIG_2

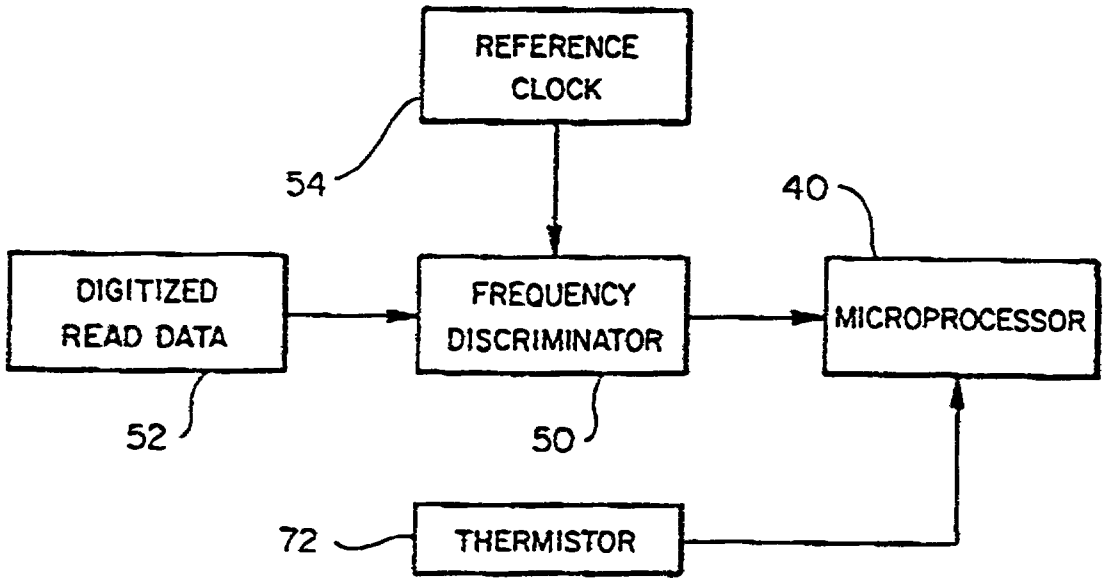

REFERENCE CLOCK
54
40
DIGITIZED READ DATA
FREQUENCY DISCRIMINATOR
MICROPROCESSOR
52
50
72
THERMISTOR

FIG_3

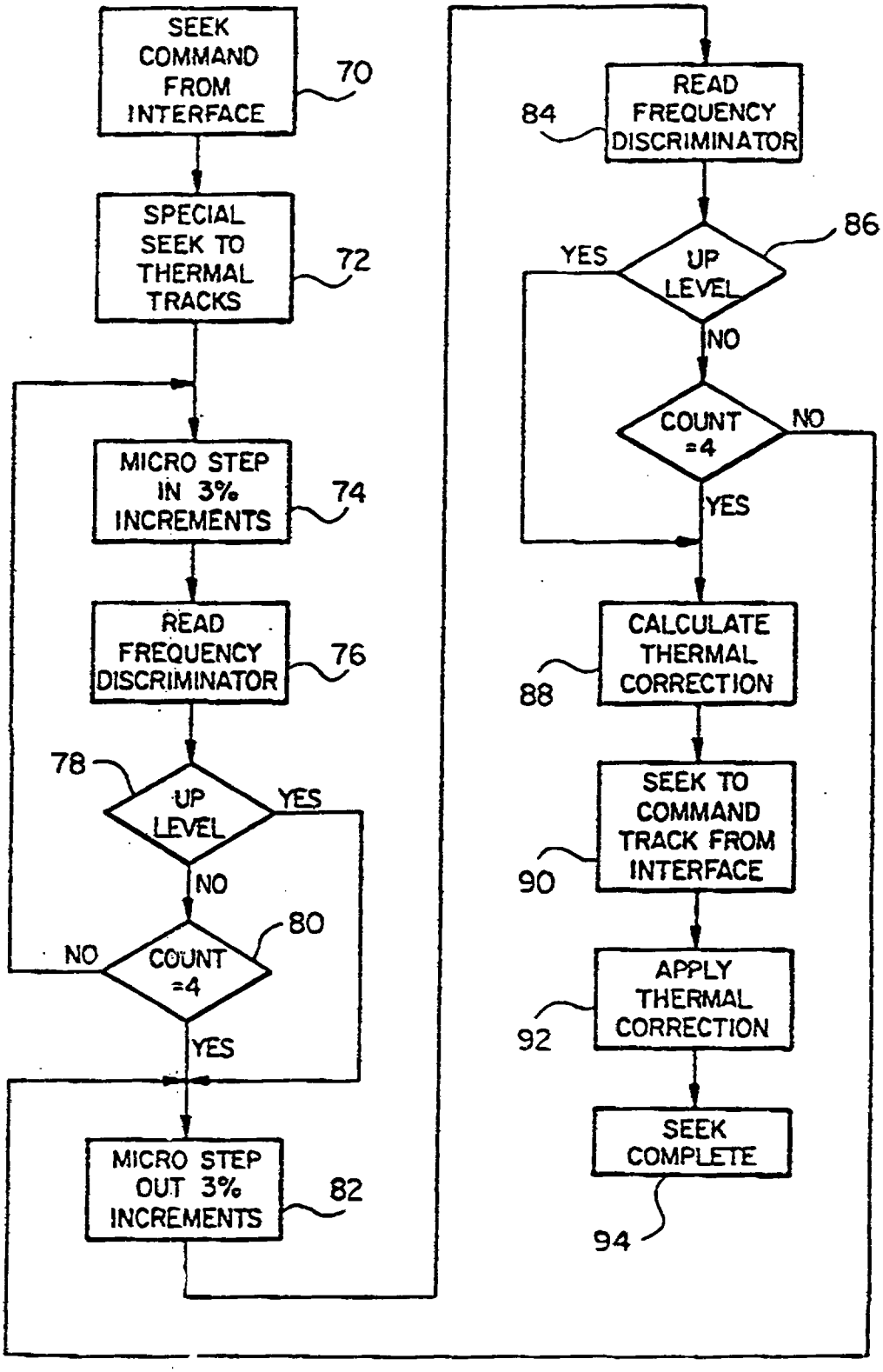

SEEK COMMAND FROM INTERFACE
70
SPECIAL SEEK TO THERMAL TRACKS
72
MICRO STEP IN 3% INCREMENTS
74
READ FREQUENCY DISCRIMINATOR
76
78
UP LEVEL
YES
NO
80
NO
COUNT =4
YES
MICRO STEP OUT 3% INCREMENTS
82
84
READ FREQUENCY DISCRIMINATOR
86
YES
UP LEVEL
NO
COUNT =4
NO
YES
CALCULATE THERMAL CORRECTION
88
SEEK TO COMMAND TRACK FROM INTERFACE
90
APPLY THERMAL CORRECTION
92
SEEK COMPLETE
94

FIG_4

REPLACEMENT SHEET
12 OCT 1999

unwraps the other, causing the carriage to move the head from track to track.

Industry requirements for greater storage capacities in ever decreasing physical package sizes demand that the tracks be spaced as closely adjacent to one another as possible.

However, this creates the problem that the heads must be very accurately positioned relative to each track, so that the heads do not land on an incorrect track or too far from the center line of a desired track. A particularly difficult situation occurs in relatively low cost rigid disc drives; in order to achieve a significant reduction in cost and complexity as demanded by the competitive nature of the business, the head actuator which positions the transducer relative to the track does not incorporate any closed loop positioning control.

US-A-4 485 418 discloses a system for locating the centre of a track on a magnetic storage disc. The system includes a transducer for recording and replaying signal information on the disc and a motor is attached to the transducer for moving the transducer over a nominal position of the track and moving the transducer in increments along the positive and negative slope of the sides of the signal amplitude of the track. A computer processor having memory storages connected to the motor and the processor, on receiving a calibration command, causes the motor to move the transducer a small increment across the track width. An offset measuring system is connected to the transducer and the processor for determining if the signal received at each increment stage is greater than a reference level.

REPLACEMENT SHEET
12 OCT 1999

Because of the wide range of operating environments in which a disc drive is utilized, it has been found that one of the critical sources of mistracking error in positioning of the head relative to the desired track is thermal expansion and contraction of the various components with changes in the ambient temperature. This is due to the fact that it is very difficult to properly match thermal expansion coefficients of the different materials which must be used in the construction of the disc drive, particularly its baseplate, spindle motor and the transducer positioning actuator. As has been already noted, the thermal off-track problem is particularly severe in an open loop drive which is common to

REPLACEMENT SHEET
12 OCT 1999

said disc to provide a thermal correction for use in positioning the transducers for subsequent seeks to user accessible data tracks.

In one particular method according to the invention characterised in that the ambient temperature of the disc drive may be sensed periodically and the transducer moved to the text track in response to the sensing of a change in ambient temperature in excess of a predetermined amount.

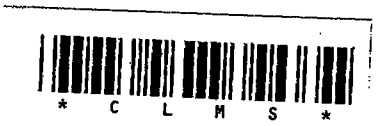
In an alternative method characterised in that the ambient temperature may be sensed at regular intervals.

The invention can be better understood together with its advantages and features by reference to the accompanying drawings wherein:

Figure 1 is a plan view of a stepper motor driven actuator and data recording disc in which this invention may be incorporated;

Figure 2 is a layout of an example of the thermal text track and adjacent data tracks used in the thermal compensation system of this invention;

REPLACEMENT SHEET
12 OCT 1999



CLAIMS

1. A method of monitoring operating temperatures to prevent thermal mistracking in a disc drive which comprises a rotary disc having a plurality of spaced circular tracks for storing recorded data and at least one test track, a transducer for accessing data mounted at one end of a carriage and means adjacent the periphery of the rotary disc for positioning the carriage along a predetermined path to position the transducer relative to the disc and the tracks; the method comprising the steps of:

defining on a disc in a location not accessible by the user a selected test track and a reference track on at least one side of the test track;

sensing ambient temperature of the disc drive, and moving a transducer to the test track in response to the sensing of a defined change in ambient temperature;

after positioning of said transducer at said test track moving the transducer in predetermined incremental microsteps which are substantially smaller than the nominal track to track distance from said test track toward said reference track; and

detecting when said transducer reaches said reference track; characterised in that the method includes operating on the number of steps carried out when said reference signal has been detected to determine the thermal shift of said transducer relative to said tracks on said disc to provide a thermal correction for use in positioning the transducer for subsequent seeks to user accessible data tracks.

2. A method of monitoring as claimed in Claim

REPLACEMENT SHEET
12 OCT 1999

1, characterised in that the ambient temperature of the disc drive is sensed periodically and the transducer moved to the test track in response to the sensing of a change in ambient temperature in excess of a predetermined amount.

3. A method of monitoring as claimed in Claim 1, characterised in that the ambient temperature is sensed at regular intervals.

