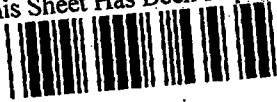


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CALIBRATION OF PES CURVES IN DISK DRIVES

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Field of Invention

This invention relates to the determination of position error signal (PES) calibration curves for disk drive assemblies. The invention has particular application to
10 hard disk drives having spaced read and write heads on a transducer unit. Such disk drives include high track-density drives in which thin film inductive (TFI) elements are used to write digital data onto the disk, and magnetoresistive (MR) sensors read the data.

15

Background Art

The use of dual head transducer units, often referred to as sliders, introduces a radial offset between the write and read centres which varies depending on the skew of the slider's rotary actuator. The prior approach has been to do the PES calibration on the
20 servo-writer itself and this was done after the servo-writing. This approach is convenient because the servo-writer is well equipped to give the radial off-track position of the slider on any track. However, this process requires a significant amount of expensive servo-writer time.

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Magnetoresistive sensor heads are prone to sensitivity variations in the long term due to various factors, and periodic re-calibration is necessary if disk failures caused by such variations are to be prevented. At present, it is not possible for users to conduct periodic self calibration of the MR head in their disk drives, due to the need for precision equipment to provide off-track position information required for calibration.

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Summary of the Invention

It is an object of the invention to facilitate determination of the PES calibration curve without any external position reference.

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According to a first aspect, the invention accordingly provides a method of deriving inputs for determination of a PES calibration curve for a disk drive assembly

having spaced read and write heads on a transducer unit moveable across the tracks of a data storage disk. The disk is rotated and the read head servo-aligned with respect to a set of servo data bursts on a servo sector of the disk to determine a track on the disk for the transducer unit. One or more pseudo servo bursts are then servo-written
5 onto a clear area of a data sector of the disk as the transducer unit follows this track. With the transducer unit set on the track, the read head is utilised to read and obtain a read response value from the or each of the pseudo servo bursts. These steps are repeated for other tracks and other pairs of servo and data sectors on the disk and the resultant read response values are stored or output with associated positional data for
10 the transducer unit, such associated read response values and positional data being useful as inputs for determination of a PES calibration curve for the disc drive assembly.

Preferably the repeating of the servo aligning, servo-writing and reading steps
15 includes repeating the servo aligning and servo-writing steps for further servo and data sector pairs on a particular track before effecting the reading step for the initial and further servo and data sector pairs.

The pseudo servo bursts are preferably erased from the data sector after the
20 reading step. It may also be desirable to erase an area for the pseudo servo bursts in one or more data sectors.

Preferably, for each track and associated pairs of servo and data sectors, the data sector immediately follows the servo sector.
25

Write signals for the pseudo servo bursts are preferably phase-correlated to the servo transition fields so that their downtrack positions are identical to that of the associated servo burst transitions.

30 The speed of rotation of the disk is advantageously adjusted according to the radial position of the transducer unit so that the fly-height of the unit does not change with different tracks on the disk.

In a preferred aspect of the invention, a PES calibration curve is computed
35 utilising said associated read response values and positional data. The positional data may include skew angle from a pre-determined reference and the separation of the read

and write heads. A radial offset between the read and write heads of the transducer unit may be determined.

Where the disc drive assembly has plural data surfaces, the respective steps are preferably repeated for all the data surfaces.

To verify the new PES curve, it is translated into a set of PES bias voltages, required to microposition the read-head above the pseudo servo bursts on a set of tracks. By injecting those voltages to a closed-loop track following system, the read head can be repositioned (or micropositioned) above the pseudo bursts and the corresponding amplitudes of the pseudo burst signals read by the read head can be verified.

In a third aspect, the invention provides a disk drive assembly having a data storage disk, and, a transducer unit moveable across the tracks of a data storage disk, the transducer unit including spaced read and write heads, means for rotating the disk, and a control means coupled to the rotating means and to the transducer unit, characterised in that the control means includes a selectable operating program for deriving inputs for determination of a PES calibration curve for the assembly, including sub routines for effecting the steps of the method of the first aspect of the invention.

Brief Description of Drawings

The invention will now be further described, by way of example only, with reference to the accompanying drawings, in which:-

Figure 1 is a diagram of the principal components of a hard disk drive assembly according to an embodiment of the invention;

Figure 2 depicts the relationship between radial offset and skew angle at the transducer unit;

Figure 3 is a simple greatly magnified diagrammatic plan view of a segment of the hard disk data surface straddling a servo sector and a following data sector, showing an exemplary arrangement of pseudo servo bursts as seen by the read head, utilised in practising an embodiment of the method of the invention; and

Figure 4 is an exemplary position error signal (PES) calibration curve derived in accordance with the invention.

Description of Preferred Embodiments

The hard disk drive 10 illustrated in Figure 1 includes a hard disk 12 rotatable on a spindle 14 by a suitable motor (not shown). A transducer unit 16 is swept generally radially over data surface 13 by a servo-actuator 18. Transducer unit 16 is a dual element slider with spaced write and read heads 20, 21. For this application, the write head 20 is typically a Thin Film Inductive (TFI) element. It will be appreciated from Figure 1 that at one position the heads 20,21 are aligned with a centre track of the disk, but that there will be an increasing radial offset between the two as the transducer unit sweeps radially either way from the centre line. The radial offset o is directly related to the skew angle δ as shown by Figure 2.

Both the servo-actuator 18 for transducer unit 16 and the motor for disk spindle 14 are controlled by a controller 25 which includes a control program in firmware, including control algorithms for the servo-actuator, write and erase functions. An interface 40 between the controller 25 and the read and write heads 20,21 amplifies read data and provides for both buffering of write signals and transmission of erase signals. Amplified data signals are passed to memory 42 via an analogue-to-digital converter (ADC) 44.

The hard disk is a typical high track-density disk of 20K tracks per inch (TPI) corresponding to a recording density of 5Gb/square inch at 250K bits per inch (bpi) bit density. In this environment with a 2.5μ separation s between heads 20,21, the radial offset between read and write centres can approach half a track-pitch and the skew span may be up to $\pm 15^\circ$. For the purposes of this invention, it is preferred that the track density be at least about 20,000 per inch : for smaller track densities (or large track widths, in other words), the maximum value of o attainable will not be large enough to obtain the entire range of data points to be sufficient to construct the PES curve.

Controller 25 is provided with a selectable program in memory for executing a sequence of write and read steps in accordance with an embodiment of the invention. This sequence is described as follows, with reference to Figures 2 and 3,

Step 1. On the target disk surface 13, the equivalent of a servo-sector area 30 is d.c. erased in all the data sectors 32 immediately after each servo-sector 34, but leaving the servo sectors intact. Figure 3 illustrates just one exemplary segment of data surface 13 straddling a servo sector 34 and a data sector 32 with boundary at 33.

- Step 2. Any selected track (preferably starting with one lying in the outer diameter (OD) or the inner diameter (ID) marginal zones 35-Figure 1) is track-followed (i.e. servo aligned) with the MR read at mid-track 50 by null-seeking on the transitions 51 between a pair of adjacent servo data bursts A, B in a servo sector 34. If the disk is being calibrated for the first time, the null-seeking is done by assuming a fixed position error gain (or PES slope) on all the tracks. An error integrator included in the controller 25, ensures proper track-following by minimizing the steady-state error.
- Step 3. As the selected servo sector 34 ends and the slider 16 starts flying above the cleared area 30 of the immediately following data sector 32, the equivalent of a servo data burst C', i.e. a pseudo servo burst, is servo-written on the data sector as the read head 21 of the slider follows the track centred at 50. Since this is done without re-positioning the slider, the TFI write element actually writes off-track with a radial offset o from the track-centre 50, which is derivable from the sine of the corresponding skew-angle δ . Such pseudo servo-transitions are subsequently written on all data sectors of track 50. The offset may of course be positive or negative: Figure 2 shows one direction of skew.
- Step 4. Steps 2 and 3 are then repeated by null-seeking on the B/A servo bursts on the adjacent track 50' so that the slider can now write pseudo servo burst D', one track pitch away from C' and again in the data sector area 30, on all the data sectors of track 50'. Here, write signals for the C'/D' bursts are properly phase-correlated to the servo transition fields so that their down-track positions are identical to that of the "original" A/B transitions. These "pseudo" servo bursts C'/D' in the data sector 32 are radially offset from the centre of the C/D burst area by o (see Figure 3), by virtue of the slider-skew δ .
- Step 5. In a similar manner, track following by C/D and D/C bursts respectively, the A' and B' pseudo bursts are also written on every data sector down the track.
- Step 6. By repeating the above steps for the other tracks, a pattern of pseudo servo transitions with varying degrees of radial offset from the respective servo transitions may be written all over the disk surface 13. Near the zero skew area or central part of the data area 13, the pseudo bursts A', B', C' and D' would not have any radial mis-alignment with the servo-bursts A, B, C and D. As one

proceeds to the inner diameter or the outer diameter, the mis-alignment increases with the skew angle.

5 **Step 7.** After completing step 5, but not necessarily waiting until after step 6, track 50 is revisited. It is track-followed by null-seeking on the A/B bursts and as the slider 16 just starts flying above the pseudo transitions, the Automatic Gain Control (AGC) circuit is disabled and the MR head read response values are obtained for each of the pseudo servo bursts A', B', C', D', utilising read head 21 with transducer unit 16 on a track 50. The readings are stored in the computer 10 memory along with the corresponding value of ϕ which is computed from the skew angle δ and the read-write separation s . This data will be used for the off-line computation of the position error using the known absolute area detection method. This computation is known in the art and an example is disclosed e.g. in Sacks, A.H., "Position Signal Generation in Magnetic Disk Drives", Ph.D 15 dissertation, Carnegie Mellon University, Pittsburgh 5 September 1995, ps 24-31. More data is generated by track-following on C/D, B/A and D/C bursts.

20 **Step 8.** Step 7 is repeated on the necessary number of tracks for various values of ϕ as the track number (and hence the skew angle) changes. The position error can be computed in each case, the various outputs pieced together against ϕ , and the PES curve thereby obtained.

25 In relation to the matter of sequence, once the pseudo bursts are written on the particular data sector on a particular track, one can either remain at the same radial position to take the MR head readings, or go to any other sector or track (which is not necessarily the adjacent one) to repeat the experiments. However, when it comes to the write/read operations to be performed on the same track, it is advantageous to carry out these steps one after the other as the disk is spinning, since this approach minimises repositioning of the slider.

30 Figure 4 illustrates an exemplary PES curve derived in accordance with the invention.

35 While doing steps 2 to 8, the spindle speed should preferably be constantly adjusted so that the slider fly-height does not change with respect to the track number. This requires knowledge of the profile of slider fly-height variations with respect to the spindle speed and skew angle, so that the fly-height can be actively controlled

throughout the calibration by controlling the spindle speed. It is also desirable that sufficient vibration-isolation can be provided to the disk-file during the calibration. Even if this is not the case, methods of averaging can be applied to the data while post-processing to eliminate any noise effects.

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As the PES profiles are expected to repeat every second track, it is possible to group the tracks accordingly and do steps 2 to 8 for each group, to determine the various profiles. it would be sufficient enough if 10 data points are available per profile for its "faithful" reconstruction.

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For disk drives having plural data surfaces, Steps 1 to 8 are repeated on all the data surfaces.

After completing the calibration, a check sequence can be initiated by loading
 15 the new PES curves into the system-memory and doing a read operation on all the tracks. This would mean that the read element will be repositioned each time when it crosses over the servo sector to the pseudo-servo burst area in the data sector. This micro-positioning is effected by the controller, by adding a PES "bias" voltage corresponding to the read/write offset σ into the servo loop which in turn is obtained
 20 from the PES curves newly derived through steps 1 to 8. On a number of tracks, the pseudo burst-amplitudes are taken and cross-checked for the anticipated values. Also it may be useful to switch between A/B and C/D bursts for track-following, while still reading the A/B/C' /D' bursts. It helps to gain more data points, for cross-checking with the previous data collected during step 7. After satisfactory completion of the
 25 task, the pseudo servo bursts in the data sectors, and thus the "pseudo" transitions, are d.c. erased.

For executing the above sequences, additional micro codes are embedded in the servo control algorithm of controller 25. Also it may be preferable to have additional
 30 timing features in the servo-sector field to precisely clock the write operation. Time-synchronism becomes important if full-width transitions of the servo bursts cannot be written during a single pass.

5 It will be appreciated that the afore- described embodiments exploit the fact that the four PES profiles derived from "A/B", "C/D", B/A" and "D/C" servo burst combinations for adjacent pair of tracks and for a particular head-media assembly are more or less identical all over the disk surface in spite of the varying skew-angle conditions of the slider. the embodiments also entail a reasonable assumption that distribution of the read and write offset values o over the disk surface can be computed either by knowing the values of s and $\delta_{\max}$ or by measuring the RMS error rates at the maximum skewed conditions of the slider.

10 It will be understood that the invention disclosed and defined herein extends to all alternative combinations of two or more of the individual features mentioned or evident from the text or drawings. All of these different combinations constitute various alternative aspects of the invention.

15 It will also be understood that the term "comprises" or its grammatical variants as used herein is equivalent to the term "includes" and is not to be taken as excluding the presence of other elements or features.

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Claims

1. A method of deriving inputs for determination of a PES calibration curve for a disk drive assembly having spaced read and write heads on a transducer unit moveable
5 across the tracks of a data storage disk, characterised by:

rotating the disk;

- 10 servo aligning the read head with respect to a set of servo data bursts on a servo sector of the disk, to determine a track on the disk for the transducer unit;

servo-writing one or more pseudo servo bursts onto a clear area of a data sector of the disk as the transducer unit follows said track;

- 15 with the transducer unit set on said track, utilising the read head to read and obtain a read response value from the or each of said pseudo servo bursts;

repeating the aforementioned steps for other tracks and other pairs of servo and data sectors on the disk; and

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storing or outputting the resultant read response values with associated positional data for the transducer unit, such associated read response values and positional data being useful as inputs for determination of a PES calibration curve for the disk drive assembly.

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2. A method according to claim 1 further characterized in that said repeating of the servo aligning, servo-writing and reading steps includes repeating the servo aligning and servo-writing steps for further servo and data sector pairs on a particular track before effecting said reading step for the initial and further servo and data sector pairs.

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3. A method according to claims 1 or 2 further characterized by erasing the pseudo servo bursts from the data sector after said reading step.

- 35 4. A method according to any preceding claims further characterised by erasing an area for said pseudo servo bursts in one or more data sectors.





5. A method according to any preceding claim further characterised in that, for each track and associated pairs of servo and data sectors, the data sector immediately follows the servo sector.
- 5 6. A method according to any preceding claim further characterised in that write signals for the pseudo servo bursts are phase-correlated to the servo transition fields so that their downtrack positions are identical to that of the associated servo burst transitions.
- 10 7. A method according to any preceding claim further characterized by adjusting the speed of rotation of the disk according to the radial position or skew angle of the transducer unit so that the fly-height of the unit does not change with different tracks on the disk.
- 15 8. A method according to any preceding claim further characterized by computation of a PES calibration curve utilising said associated read response values and positional data.
- 20 9. A method according to claim 8 further characterized in that the positional data includes skew angle from a pre-determined reference and the separation of the read and write heads.
10. A method according to any preceding claim further characterized by determining a radial offset between the read and write heads of the transducer unit.
- 25 11. A method according to any preceding claim further characterized by repeating the respective steps for all data surfaces of the disk drive assembly.
- 30 12. A method according to any preceding claim further including storing the determined PES calibration curve(s) and utilising the PES data for off-track micropositioning of the read-head, whereby to verify the PES curve(s).
- 35 13. A disk drive assembly having a data storage disk, and a transducer unit moveable across the tracks of a data storage disk, the transducer unit including spaced read and write heads, means for rotating the disk, and a control means coupled to the rotating means and to the transducer unit, characterised in that the control means includes a selectable operating program for deriving inputs for determination of a PES

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calibration curve for the assembly, including sub routines for effecting the following steps:

- rotating the disk;
- 5 servo aligning the read head with respect to a set of servo data bursts on a servo sector of the disk, to determine a track on the disk for the transducer unit;
- 10 servo-writing one or more pseudo servo bursts onto a clear area of a data sector of the disk as the transducer unit follows said track;
- with the transducer unit set on said track, utilising the read head to read and obtain a read response value from the or each of said pseudo servo bursts;
- 15 repeating the aforementioned steps for other tracks and other pairs of servo and data sectors on the disk; and
- 20 storing or outputting the resultant read response values with associated positional data for the transducer unit, such associated read response values and positional data being useful as inputs for determination of a PES calibration curve for the disk drive assembly.

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