"A method of estimating the clearance between a read/write transducer head and a magnetic recording disk"

THIS INVENTION relates to a method of estimating the clearance distance between a magnetic read/write transducer and a magnetic recording disk.

In data storage devices such as magnetic disk drives, both hard and floppy, and in tape storage systems the magnetic transducer head is positioned over the magnetic medium whilst data is read from or written onto the magnetic medium. Higher recording densities are obtainable by reducing the clearance between the magnetic transducer head and the magnetic medium. Magnetic recording technologies are achieving data storage densities in the region of 1Gb/in^2 and greater. However, with such high recording densities, it is difficult to maintain the low constant clearance required between the magnetic head and the magnetic disk.

Generally, a typical disk in a disk drive comprises a substrate, an underlayer, a layer of the magnetic medium, a protective layer and a layer of lubricant which comprises the effective surface of the disk. The term head-disk clearance is the distance between a magnetic transducer head and a magnetic disk.

The phenomena of contamination build-up were not as serious as they are now because the clearance was in the region of 100nm or above, and the build-up of contamination did not affect the clearance significantly. For head-disk clearances in the near contact region where the magnetic read/write transducer would have a chance of contacting the disk surface, the clearance between the magnetic read/write transducer and the magnetic disk is in the region of 15 to 40nm. At such low clearance the chance of lubricant coming into contact with the surface of the slider or being transferred from the disk surface to the slider increases significantly. It has been found that the contaminant on the transducer

can be as thick as 30nm or even more. Such build-up increases head-disk clearance significantly and as a result the recording performance will be affected. Since disk drives are now being routinely manufactured to operate within the near-contact region, there is a need for a method of estimating the variation of the clearance between the magnetic read/write transducer and the magnetic disk so that variations which could result in excessive degradation of the recording performance can be detected and start/stop operations initiated to remove or reduce the contamination build-up.

A number of methods are known for measuring the clearance between magnetic read/write transducers and a magnetic recording medium. For example, US-A-4 872 071 describes a method and apparatus of detecting abnormal operation of a magnetic disk drive by reading data from a pre-determined area of each track. The amplitude of the readback signals from each track are compared with a corresponding reference level. If the comparison indicates that the variation in the clearance is above a predetermined level, then an alarm signal is provided so that necessary actions can be taken to avoid the possibility of a head crash. However, this method does not allow for the fact that the amplitude of the readback signals varies when the magnetic head slider is not located perfectly along the centre line of a track.

US-A-4 777 544 describes a method and apparatus for the in-situ measurement of the clearance between a magnetic read/write transducer and a magnetic medium. A pre-written signal located at a predetermined area of the magnetic recording medium is readback at two different clearance levels. The Wallance Equation is used to measure the variation of the clearance. In a further embodiment, a signal is recorded which has a spectral content comprising a plurality of different frequencies, and read back signals are simultaneously sensed at two separate wavelengths. Such a method is not convenient for measuring the

variation of clearance between a magnetic read/write transducer and a magnetic disk during normal data read/write operations.

US-A-5 130 866 describes a method and circuitry for in-situ measurement of magnetic read/write transducer and magnetic medium clearance. Isolated transitions are pre-written on a magnetic medium. During a readout process, the width of readout signal of an isolated transition increases as the clearance increases. The pulse width is measured during a reading operation and is used to indicate the in-situ variation of clearance. However, the electronics required to implement this method are quite complicated compared with the read channel of present disk drives and are not easy to build into a disk drive system.

It is an object of the present invention to provide a simple in-situ method for detecting variations in the clearance between a magnetic read/write transducer and a magnetic recording disk in an operational magnetic disk drive or tape storage system.

Accordingly, the present invention provides a method of detecting variations in a clearance distance between a magnetic read/write transducer and a magnetic recording medium having a clearance detection burst recorded thereon, the clearance detection burst comprising at least two groups of bit patterns having different transition densities, the method comprising the steps of: obtaining a readback signal from the at least two groups of bit patterns, the readback signal being sensitive to variations in the clearance; detecting the amplitude of the readback signal of a first group; detecting the amplitude of the readback signal of a second group; comparing the amplitudes of the readback signals from the at least two groups of bit patterns to provide an indication of a variation in the clearance.

In order that the present invention may be more readily understood, embodiments thereof will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram of a magnetic read/write transducer positioned above a disk incorporating a magnetic recording medium;

Figure 2 is a graph illustrating the relationship between normalised readback amplitude as a function of recording density for a low and a high head-disk clearance;

Figure 3 is a schematic representation of one track on a disk which includes the servo sectors and data-blocks;

Figure 4 is a schematic representation of the current arrangement in each servo sector and data-block;

Figure 5 is a schematic representation of a servo sector embodying the present invention, with a clearance detection burst inserted;

Figure 6 is a graph illustrating the relationship between the amplitude of two readback signals from, respectively, a low transition density group and a high transition density group;

Figure 7 is a graph showing the transition amplitude ratio as a function of the clearance between the magnetic transducer head and disk calculated by $(A_{low}-A_{high})/A_{low}$; and

Figure 8 is a graph illustrating the transition amplitude ratio as a function of off-track distance.

Specific reference is made in the following description to a magnetic disk drive system. However, it is to be appreciated that the present invention is applicable to other forms of magnetic recording media such as both hard and floppy magnetic disk drives and tape storage systems.

Figure 1 shows part of the structure of a magnetic disk drive system and, in particular, a part of a disk 1 and a slider 2 having a transducer 2a. In operation, the slider 2 flies above the surface of the rotating disk 1 upon an air bearing created by the high relative speed between an air bearing surface of the slider 2 and the disk 1. The distance by which the transducer 2a is spaced apart from the surface of the disk 1 is termed the head-disk clearance.

The disk structure comprises a disk substrate 3, an underlayer 4 laid over the substrate 3, a magnetic layer 5, a protective layer 6 laid over the magnetic recording medium 5 and a lubricant layer 7.

The slider 2 supports the magnetic transducer 2a for reading and writing data from and onto the magnetic recording layer 5. As the disk 1 rotates with respect to the slider 2, contaminants such as debris and lubricant build-up on the underside of the slider 2. Such build-up of contaminant particles 9 can cause significant changes in the clearance 8 between the magnetic transducer 2a and the magnetic disk 1. This problem is exacerbated for clearances 8 below 50nm which are necessary to achieve high magnetic recording densities above $1Gb/in^2$.

Previous disk drive systems did not encounter this problem because the clearance 8 was significantly greater than the layer of contamination so the build-

up of contaminant particles 9 did not result in significant changes in the clearance. The effect of such contaminant build-up only had a negligible effect on the read/write performance of this system. However, it has been discovered that contaminant build-up 9 on more advanced disk drive systems having a clearance 8 below 50nm can be as thick as 30nm or even more. This represents a significant portion of the clearance between the magnetic read/write transducer 2a and the magnetic disk 1 and will strongly affect the read/write performance and reliability of the disk drive system.

Figure 2 shows the relationship between normalised readback amplitude as a function of recording density for a low head-disk clearance (0.9 microinch) and a high head-medium clearance (1.4 microinch).

Referring to Figure 2, the horizontal axis represents the recording density or transition density in units of thousands of flux changes per inch (KFCPI) and the vertical axis represents the readback amplitude normalised at one thousand flux changes per inch. It can be seen that in the range of low recording densities less than 20 KFCPI, the normalized readback amplitude for the two head-disk clearances, 1.4 microinch and 0.9 microinch respectively, are almost the same. However, in the range of high recording densities, 80 KFCPI for example, there is a marked difference between the normalised readback amplitude for the lower head-medium clearance (0.9 microinch) and that of the higher head-medium clearance (1.4 microinch). Thus the difference of the normalised values with different transition densities can be used to present the relative change or variation in the head-disk clearance.

It is known that contamination build-up can be removed or partially removed through a number of start/stop operations.

It is, therefore, important that a detection system be provided which can detect those changes or variations in clearance, which could result from contaminant 9 being transferred to the slider 2, so that, if the variation in clearance is not within an acceptance range, operations, such as a number of contact start/stop operations, can be initiated to remove the contaminant build-up.

The magnetic recording layer 5 of the disk 1 is divided into a number of concentric tracks 10, each track 10 being divided into a number of servo sectors 11 and data-blocks 12 as shown in Figure 3. A schematic map of a conventional servo sector 11 is shown in Figure 4. A conventional servo sector 11 comprises four field patterns: an automatic gain control (AGC) field 13; a servo timing mark (STM) or synchronisation pattern 14; an address mark 15; and a sector servo burst 16. A servo sector 11 for use with a method embodying the present invention is shown in Figure 5 and is similar to a conventional servo sector 11 but includes an additional field 17 located after the sector servo burst 16 and preceding the data block 12. The additional field 17 comprises a so-called head-disk clearance detection burst or bit pattern. The clearance detection burst 17 is pre-written onto the magnetic recording medium simultaneously with the sector servo burst 16 and any other control information in the servo sector 11. Each servo sector 11 is not written over during normal read/write operations of the disk drive.

Each clearance detection burst 17 comprises a series of bits nominally divided into at least two groups. Each group has its own transition density.

One preferred embodiment of a clearance detection burst or bit pattern is based on two groups of transitions, with one group having a low transition density (corresponding to the flat part of the curves in Fig.2) and another group having a high transition density (corresponding to the falling part of the curves in Fig.2). If there is no clearance change, the amplitude ratio $((A_{low}-A_{high})/A_{low})$ of the readback

signals from the two groups will be the same, where A_{high} is the amplitude of high transition density readback signals and A_{low} is the amplitude of low transition density readback signals. Contamination build-up on the transducer surface increases the head-disk clearance 8 and the amplitude ratio of two readback signals from the two transition groups also increases. The amount of increase is proportional to the clearance 8 increase, as illustrated in Fig. 7 and can be used to detect the change in clearance 8.

Figure 6 gives an example of the amplitude relationship between two different transition density groups which are very sensitive to the variation of head-disk clearance 8.

Figure 7 shows the relationship between the head-disk clearance 8 and the amplitude ratio of the two transition groups. The amplitude ratio increases proportionally as the clearance increases. Therefore, the variation of amplitude ratio can be used to indicate the variation in the head-disk clearance 8.

If the clearance identified in the above manner is not within a predetermined acceptable range, then a control operation can be initiated to stop read/write operations and conduct one or more start/stop operations to remove accumulated contaminant particles from the air-bearing surface of the slider. The system would then return to the interrupted read/write operations.

A further embodiment of the method according to the present invention includes using a clearance detection burst incorporating three groups of transitions. From the readback signals from these three groups of transitions, similar techniques used with two groups of transitions can be used to estimate the variation of clearance between the slider 2 and the disk 1.

One of the main advantages of this invention is that the ratio of two readback signals from the two transition groups is not sensitive to off-track variations of the magnetic transducer. Since the above prescribed method detects the relative variations in amplitudes of the readback signals from the clearance detection patterns, so the ratio of variation of readback signals is not sensitive to the magnetic transducer 2a being slightly off the centre line of a particular track. Thus, off-track distance is not a variable when detection of the variation of clearance is concerned. Figure 8 shows the relationship between the off-track distance and the amplitude ratio. It can be seen that the ratio can be considered as a constant when the magnetic head is positioned at an offset above 10% of the track width.

The clearance detection bursts are pre-written in a conventional pre-writing operation thereby avoiding the need to re-write or erase this area of each sector during normal read/write operations.

The present method can be based on existing circuitry and apparatus available in present disk drives. Thus, there is no need to incorporate a lot of additional electronic circuitry to identify the variations in the clearance between the magnetic head transducer 2a and the disk 1.

CLAIMS:

1. A method of detecting variations in a clearance distance between a magnetic read/write transducer and a magnetic recording medium having a clearance detection burst recorded thereon, the clearance detection burst comprising at least two groups of bit patterns having different transition densities, the method comprising the steps of: obtaining a readback signal from the at least two groups of bit patterns, the readback signal being sensitive to the variations in said clearance; detecting the amplitude of the readback signal of a first group; detecting the amplitude of the readback signal of the second group; comparing the amplitudes of the readback signals from the at least two groups of bit patterns to provide an indication of a variation in the clearance.

2. A method according to Claim 1, wherein the clearance detection burst comprises two groups of bit patterns and the method comprises the further steps of calculating the difference between the amplitudes of the readback signals from the first group and the second group; and dividing the amplitude difference by the amplitude of the readback signal from the group having the lower transition density of the two groups, the resultant ratio being indicative of a variation in the clearance.

3. A method according to Claim 1, wherein the clearance detection burst comprises two groups of bit patterns and the method comprises the further steps of calculating the difference between the amplitudes of the readback signals from the first group and the second group; and dividing the amplitude difference by the amplitude of the readback signal from the group having the higher transition density of the two groups, the resultant ratio being indicative of a variation in the clearance.

4. A method according to Claim 1, wherein the clearance detection burst comprises two groups of bit patterns and the method comprises the further step of performing a mathematical calculation as a function of: the amplitude of readback signal from the first group, the amplitude of the readback signal from the second group, and the difference between the amplitudes of the first and the second group so as to get a figure being indicative of a variation in the clearance.

5. A method according to any one of Claims 1 to 4, wherein the clearance detection burst comprises three or more groups of bit patterns.

6. A method according to any preceding claim, wherein the clearance detection burst is recorded in a control zone of a sector of the magnetic recording medium.

7. A method according to any preceding claim, wherein the clearance detection burst is pre-recorded onto a predetermined area of the magnetic recording medium.

8. A method according to Claim 7, wherein the clearance detection burst is pre-recorded onto the magnetic recording medium at the same time as a sector servo burst is pre-recorded on the magnetic recording medium.

9. A method according to any preceding claim, wherein each of the groups of bit patterns have different transition densities.

10. A method according to any preceding claim, wherein if the variation in the amplitudes of the groups of bit patterns from the clearance detection bit pattern is indicative of a variation in the clearance distance above a predetermined threshold, then a detection signal is generated.

11. A method according to Claim 10, wherein the detection signal terminates read/write operations and initiates a start/stop operation to remove contaminant particles from the magnetic head slider.

12. A method according to any preceding claim, wherein the magnetic recording medium is divided into a plurality of sectors and the clearance detection burst is located at substantially the beginning of each sector or part of a sector.

13. A method according to any one of Claims 1 to 11, wherein the magnetic recording medium is divided into a plurality of sectors and the clearance detection burst is located substantially at the end of each sector or part of a sector.

14. A method according to any one of Claims 1 to 10, wherein the magnetic recording medium is divided into a plurality of sectors and the clearance detection burst is located in each sector or part of each sector or some of the sectors.

15. A clearance detection burst comprising at least two groups of bit patterns having two different transition densities, a readback signal from the at least two groups of bit patterns from the clearance detection burst being sensitive to variations in a clearance distance between a magnetic transducer and a magnetic recording medium.

16. A disk drive system incorporating a magnetic recording medium having recorded thereon a pattern in accordance with Claim 14.