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Specification

Title of the invention:

Disk-shaped recording medium, method of manufacturing a disk-shaped recording medium, recording and reproducing method, and disk drive



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2. Detailed Description of the Invention:

[0001]

2.1 Industrial Field of the Invention:

The present invention relates to a disk-shaped recording medium, a method of manufacturing a disk-shaped recording medium, a recording and reproducing method, and a disk drive, with improved yield and performance.

[0002]

2.2 Prior Art:

Disk drives employing magnetic disks as recording media have been evolving toward high capacities and high recording densities in recent years.

[0003]

As shown in FIG. 2, the soft error rate (SER) of a magnetic disk is positively correlated with increasing linear recording density, this density being the number of bits per unit length in the track direction (BPI: bits per inch), and the error rate is known to have risen with recently rising linear recording densities. The SER is indicated by the logarithm of the error count divided by the data count (number of samples). FIG. 2 indicates the change in SER as the linear recording density varies with respect to a predetermined linear recording density (1) on the horizontal axis. From FIG. 2, it can be seen that, for example, the SER is about -5 (an error rate of 10^{-5}) when the

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linear recording density is the predetermined linear recording density (1), but becomes about -6 (an error rate of 10^{-6}), the error rate decreasing by approximately one order of magnitude, if the linear recording density is decreased by ten percent with respect to the predetermined linear recording density.

[0004]

Methods of equalizing the linear recording density across the recording surface of the magnetic disk, in order to approximately equalize the SER over the entire recording surface of the magnetic disk, are being considered.

[0005]

For example, a disk drive according to the invention disclosed in Japanese Kokai Patent Publication No. 147059/1995 divides the recording surface of the magnetic disk into a number of areas (zones Z0, Z1, Z2, ...) in the radial direction, as shown in FIG. 3, and alters the number of data sectors recorded between servo sectors in each zone, according to its position in the radial direction, to equalize the linear recording density of the recording tracks in each zone.

[0006]

The SER can be substantially equalized over the entire recording surface of the magnetic disk by equalizing the linear recording density in this way.

[0007]

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To assure reliability, however, there is a set upper limit on the SER of a disk drive. A disk drive is generally provided with a plurality of recording surfaces, and a plurality of heads corresponding to the recording surfaces. The SER varies considerably, depending on the magnetic characteristics of the head and the magnetic disk. Therefore, in a disk drive having a plurality of recording surfaces, because the linear recording density is uniform on each recording surface, the SER differs on each recording surface.

[0008]

It has been customary to treat this type of disk drive as defective if there is even one recording surface having an SER exceeding the upper limit. A resulting problem is decreased yields and increased costs.

[0009]

The disk drive disclosed in Japanese Kokai Patent Publication No. 255412/1996 is a known example of a disk drive that solves this problem. In this disk drive, the SER of an entire recording surface is reduced by altering the zone boundaries on the recording surface and setting a track pitch within each zone, according to measured recording and reproducing characteristics.

[0010]

2.3 Problems to be Solved by the Invention:

Control of the disk drive disclosed in Japanese Kokai Patent Publication No. 255412/1996 is complex, however, because the zone boundaries differ on each recording surface; a particular problem was reduced performance, because the seek characteristics are degraded by the uneven track pitch.

[0011]

The present invention addresses these problems, with the object of providing a disk-shaped recording medium, a method of manufacturing a disk-shaped recording medium, a recording and reproducing method, and a disk drive that can contribute to improvements in yield and reductions in cost, while reducing complexity of control and inhibiting reductions in performance.

[0012]

3.4 Means of Solution of the Problems:

According to one aspect of the present invention there is provided a disk-shaped recording medium, comprising:

a first recording surface having a first linear recording density in a certain radial position; and

a second recording surface having a second linear recording density, different from said first linear recording density, in said certain position, wherein said first and second recording surfaces have a plurality of recording areas in which the recording frequency is constant regardless of position in the radial direction of the disk.

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According to another aspect of the present invention there is provided a method of manufacturing a disk-shaped recording medium, comprising the steps of:

measuring recording and reproducing characteristics of each recording surface of a disk-shaped recording medium having a plurality of recording surfaces; and

setting set plurality of recording surfaces to a first recording surface having a first linear recording density in a certain radial position and a second recording surface having a second linear recording density, differing from said first linear recording density, in said certain radial position, according to said recording and reproducing characteristics, wherein said first and second linear recording densities are set by providing a plurality of recording areas in which the recording frequency is constant, regardless of position in the radial direction of the disk, on the first recording surface, when said first recording surface is set.

According to still another aspect of the present invention there is provided in a recording and reproducing method for recording and reproducing on a disk-shaped recording medium possessing a first recording surface having a first linear recording density in a certain radial position, and a second recording surface having a second linear recording density, different from said first linear recording density, in said certain radial position, a recording and reproducing method comprising the steps of:

selecting recording surfaces on which to perform recording and reproducing according to commanded addresses;

changing the linear recording density of recording and reproducing according to the selected recording surface; and

performing recording and reproducing, changing the recording and reproducing characteristics according to the changed linear recording density.

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According to still another aspect of the present invention there is provided

a disk drive, comprising:

a disk-shaped recording medium having a first recording surface having a first linear recording density in a certain radial position, and a second recording surface having a second linear recording density, different from the first linear recording density, in said certain radial position;

a recording and reproducing means performing recording and reproducing on the disk-shaped recording medium;

a recording-surface selection means selecting recording surfaces on which to perform recording and reproducing, from commanded addresses;

a linear recording density alteration means changing the linear recording density according to the recording surface selected by the recording-surface selection means; and

a control means changing the recording and reproducing characteristics of said recording and reproducing means according to the linear recording density changed by the linear recording density alteration means, wherein said first and second recording surfaces have a plurality of recording areas in which the recording frequency is constant, regardless of position in the radial direction of the disk.

According to still another aspect of the present invention there is provided in a disk drive having at least two recording surfaces, a disk drive comprising:

a first recording surface having a first linear recording density in a certain radial position; and

a second recording surface having a second linear recording density, different from said first linear recording density, in said certain radial position, wherein said first and second recording surfaces have a plurality of recording areas in which the recording frequency is constant regardless of position in the radial direction of the disk.

[0017]

3.5 Embodiments:

First embodiment

FIG. 1 is a block diagram showing the structure of a disk drive according to a first embodiment of the present invention.

[0018]

This disk drive comprises magnetic disks (disk-shaped recording media) 1 as recording media, heads 2 for recording and reproducing data on the magnetic disks 1, an arm electronics (AE) circuit that supplies recording signals to the heads 2 and picks up (amplifies) the output reproduced by the heads 2, a channel IC (recording/reproducing control means) 4 that carries out conversion between analog signals and digital data, and a hard disk controller (HDC) 5 that controls the operation of the entire apparatus, including the channel IC 4.

[0019]

This disk drive is provided with, for example, three magnetic disks 1. Each magnetic disk 1 has recording surfaces on both sides; heads 2 and arm electronics 3 are provided for each recording surface.

[0020]

As shown in FIG. 1, the channel IC 4 comprises a buffer 4a storing data from the HDC 5 and data to be sent to the HDC 5, an encoder/decoder (ENDEC) 4b that encodes data to be recorded and decodes reproduced data, a serial/parallel converter 4c that converts encoded record data to a serial signal, and converts a reproduced signal to parallel data, a clock generator 4d that generates a reference clock for recording and reproducing (a reference for RDWTCLK), a control unit 4e that controls the operation of the channel IC 4 as a whole, and a pulse detector 4g that reproduces servo signals.

[0021]

The HDC 5 comprises a control unit 5a having an MPU or the like, a memory 5b for caching record/reproduce data and storing various tables and the like used for control of operations, and a timing detector 5c that detects the record/reproduce timing when the recording or reproducing of data is commanded.

[0022]

As shown in FIG. 4, areas in which tracks 50 are recorded are formed concentrically, with a certain width, on the recording surfaces of the magnetic disk 1. Each area is provided with a servo area 51, in which servo sectors are recorded for performing tracking control, and a data area

52, in which data sectors are recorded. For simplicity, these are only partially shown in FIG. 4.

[0023]

The servo areas 51 are disposed at fixed angles of revolution (for example, 360°/66) on the surface of the magnetic disk 1. Physical servo sector information, including a servo pattern and identification information such as a cylinder ID (CYLID) and physical servo sector number (PHSN: Physical Sector Number) for identifying each individual physical sector, is recorded in these servo areas 51 at, for example, the time of manufacture.

[0024]

Servo sectors are recorded in the physical servo sectors of the servo areas 51 with a fixed-frequency clock, regardless of their radial position, at the time of manufacture, for example.

[0025]

As shown in FIG. 5, the data areas 52 are divided into several zones (physical zones) in the radial direction. To explain the concept, FIG. 5 is simplified to show 2.5 data sectors recorded per track in zone Z0, which is the outermost physical zone, with two data sectors per track in zone Z1, 1.5 data sectors per track in zone Z2, and one data sector per track in zone Z3. On an actual recording surface, ten zones (Z0 to Z9), for example, are provided in

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the radial direction, and one thousand tracks, for example, are recorded in each zone.

[0026]

One of the logical zones shown below in Table 1 is assigned to each physical zone.

Table 1

Logical Zone	Number of Logical Sectors
L0	400
L1	380
L2	360
L3	340
L4	320
L5	300
L6	280
L7	260
L8	240
L9	220
L10	200

As shown in Table 1, the number of data sectors recorded in each track in each logical zone (L0 to L10) is predetermined. Furthermore, with regard to one recording surface, logical zones with fewer sectors are assigned to inner physical zones.

[0027]

In the part of a data area 52 (physical servo sector) in one track, data sectors are recorded and reproduced with

a clock (reference clock) having a frequency responsive to the number of recorded data sectors.

[0028]

Although sixty-six physical servo sectors are provided, divided at certain angles of revolution by the servo areas 51, which are provided as explained above, the number of data sectors differs in each of the logical zones assigned to the physical zones, so the number of data sectors in a servo sector is not necessarily an integer; as shown in FIG. 5, data sectors may be divided at arbitrary positions, and may be recorded in plural servo sectors.

[0029]

The positions at which data sectors are divided in this way can be uniquely determined from the number of data sectors recorded in the data areas 52 provided in each zone (logical zone), and the positions of the individual data areas 52, which are indicated by the physical servo sector numbers (the values assigned to the individual servo sectors).

[0030]

Information indicating the positions at which the data sectors are divided (for example, information indicating that the n-th data sector in a zone is divided, with p bytes recorded in the m-th physical sector and q bytes recorded in the (m + 1)-th physical sector) is recorded, together with information indicating the position of each data sector and

whether or not it is divided, as a track format table, in a non-volatile memory in the HDC 5, for example, or in a predetermined area on the disk.

[0031]

In this disk drive, the length of a data sector is five hundred forty-six bytes, divisible at positions located at multiples of five bytes from the beginning of the sector, as shown in FIG. 6.

[0032]

The track format table therefore records information indicating in which physical servo sector the sector corresponding to the above-mentioned data sector number is located (the physical servo sector number PHSN of the physical servo sector), paired with information (an offset) indicating whether the data sector is divided or not, or if it is divided, how many bytes are recorded in the instant data area.

[0033]

The position PHSN indicates the servo sector number of the servo sector to which the beginning of the data sector belongs. The offset value is 00h if the data sector is not divided, and is the quotient of the number of bytes of data recorded in the first data area 52 divided by five (01h to 6Dh [= 545/5 = 109 in decimal]) if it is divided.

[0034]

This table requires a minimum of eight hundred bytes in total, because from Table 1, the maximum number of data sectors per track is four hundred, and two bytes are necessary per data sector (one byte for the PHSN and one byte for the quotient value; if the data sector number is stored as an address pointer, the data sector number itself does not have to be stored).

[0035]

A track format table is provided for each above-mentioned logical zone, because the number of data sectors per track differs for each logical zone. This table is recorded in a predetermined area on the disk, or in a ROM in the HDC 5 or elsewhere, and is read into, for example, the memory 5b of the HDC 5 during operation.

[0036]

In commanding this hard disk drive to record or reproduce data, a personal computer, workstation, or other information-processing device specifies an LBA (logical block address), rather than the cylinder ID, physical servo sector number, and data sector. LBAs are assigned as serial numbers, from recordable positions, so a table that converts them to the corresponding cylinder ID, physical servo sector number, and data sector number is needed.

[0037]

This hard disk drive accordingly carries out the conversion of LBAs and data sector numbers using an address

conversion table such as the one shown in FIG. 8. This address conversion table also specifically includes data, not shown in the drawings, used in finding other parameters indicating positions on the magnetic disks (Z--zone, H--head, C--cylinder), indicating relationships to the other parameters.

[0038]

Incidentally, this address conversion table does not necessarily have to be stored as a table, but can be calculated from the given LBA, the zone assignment table described below, and other information.

[0039]

As shown in the address conversion table in FIG. 8, the assignment of data sectors to LBAs in this disk drive is carried out so that after data sectors in tracks having the same CYLID on a plurality of recording surfaces have been assigned, the assignment proceeds to data sectors in the sequentially adjacent tracks. When zone boundaries have been changed as described below, however, the order of assignment of data sectors to LBAs is changed; the details will be more fully explained in the description of the operation.

[0040]

In this address conversion table, the logical head number indicates the logical head where the data sector assigned to the corresponding LBA exists, and the data

which the track format table is rewritten increases, access to the memory 5b appears to become slower. For these reasons, an increase in the number of times the table is rewritten can become a factor reducing the performance of the disk drive.

[0077]

Therefore, in this disk drive, the assignment of disk sectors to LBAs is changed when the physical zone boundaries are moved, to inhibit the reduction of performance.

[0078]

Specifically, logical head numbers are first assigned consecutively to the heads other than heads with a reduced linear recording density (head HD3 in the example in FIG. 13). Logical head numbers 0, 1, 2, 3, 4 are thereby assigned to heads HD0, HD1, HD2, HD4, HD5 (the first group).

[0079]

The assignment of data sectors to LBAs is carried out in the sequence of logical head numbers, the recording surfaces corresponding to heads HD0, HD1, HD2, HD4, and HD5 being taken in sequence, and the CYLID being increased successively so that data sectors are distributed over these recording surfaces.

[0080]

At predetermined intervals, for example, at intervals of a certain number of LBAs or a certain number of tracks, data sectors are assigned consecutively to recording tracks

having consecutive CYLIDs on recording surfaces corresponding to the remaining heads (the second group), in this case HD3 (on a number of recording tracks in the second group corresponding to the tracks to which data sectors have been assigned in the first group). Data sectors are now assigned in, for example, sequentially decreasing order of CYLID.

[0081]

When the assignment is completed, the combination of head, CYLID, and data sector corresponding to each LBA is recorded in a non-volatile memory provided in the HDC 5, for example, or in a predetermined area on the disk, as the address conversion table shown above in FIG. 8, or as mathematical formulas equivalent to this table.

[0082]

When access is performed in a disk drive in which the above-described type of data sector assignment has been carried out, the number of times the track format table is rewritten is reduced, as shown in FIG. 14, for example. Accordingly, overhead due to table rewriting is reduced, and the performance of the disk drive is enhanced.

[0083]

Furthermore, the successive increase in the CYLID when data sectors are assigned on the first group (the recording surfaces corresponding to heads HD0, HD1, HD2, HD4, HD5) and the successive decrease in the CYLID when data sectors are

assigned on the second group (HD3) can reduce the number of comparatively long seeks (the seek between track n and track n + 3 in FIG. 14) and shorten the seek time, further contributing to the enhancement in performance. This effect becomes prominent as the number of groups of recording surfaces with different physical zone boundaries increases.

[0084]

In the description above, a case in which the zone boundaries of only one recording surface differed from the other recording surfaces was described; when the zone boundaries of two or more recording surfaces differ from the other recording surfaces, LBAs are assigned as follows.

[0085]

If the recording surfaces (the second group) having zone boundaries different from the other recording surfaces (the first group) have mutually identical zone boundaries, first, consecutive logical head numbers are first assigned to the heads in the first group, and consecutive logical head numbers are assigned to the heads in the second group.

[0086]

Data sectors in the first group and data sectors in the second group are assigned in turn at predetermined intervals: for example, at intervals of a certain number of LBAs or tracks, as described above. During this assignment, the CYLID increment in the first group is the reverse of that in the second group.

[0087]

When access is performed in a disk drive in which this type of assignment of data sectors to LBAs has been carried out, the number of times the track format table is rewritten can be reduced, as shown in FIG. 15.

[0088]

When the recording surfaces in the second group have differing zone boundaries, first, sectors are assigned in the first group, with the CYLID successively increasing; at predetermined intervals, for example, at intervals of a certain number of LBAs or tracks, data sectors are assigned to each of the recording surfaces in the second group, changing the CYLID increment alternately at each recording surface.

[0089]

Specifically, data sectors in the first group (on the recording surfaces corresponding to HD0, HD1, HD2, and HD4) are assigned with successively increasing CYLIDs, data sectors on the recording surface corresponding to head HD5 in the second group are assigned with successively decreasing CYLIDs, and data sectors on the recording surface corresponding to head HD3 in the second group are assigned with successively increasing CYLIDs, as shown in FIG. 16.

[0090]

When access is performed in a disk drive in which this type of data sector assignment has been carried out, the

sector number indicates the data sector number of the data sector assigned to the corresponding LBA.

[0041]

In this disk drive, the time required for switching heads 2 by switching in the arm electronics 3 (for example, the time occupied by ten physical servo sectors) is shorter than the time required for seeking the heads to the adjacent track (for example, eighteen physical servo sectors), so performing the type of assignment shown in FIG. 8 enhances the performance of the disk drive.

[0042]

When this disk drive is manufactured, a test of the soft error rate (SER) is carried out on each recording surface and paired head.

[0043]

Previously, a disk drive passed only if the SERs of all of its recording surfaces were within the specification limit; the disk drive was considered defective if there was even one recording surface on which the SER exceeded the specification limit.

[0044]

When this disk drive is manufactured, however, if the SERs of all recording surfaces are within the specification limit, the linear recording density (BPI: bits per inch) is made uniform on all recording surfaces, but if there is a recording surface on which the SER exceeds the specification

limit, the linear recording density of this recording surface is reduced, reducing its SER. The track pitch is constant in this case.

[0045]

To show this specifically, if the upper limit of the SER is -5 (equivalent to an error rate of 10^{-5}, because in the SER, the error rate is indicated as a logarithm to the base ten), and if among six recording surfaces, the SER of the recording surface corresponding to head HD3 is -4.8, exceeding the specification limit, as shown in FIG. 9, for example, then if this SER is within an allowable range (for example, if the SER is -4 or less, when the allowable range is one order of magnitude), the physical zone boundaries on the recording surfaces are changed.

[0046]

As was seen in FIG. 2 above, the SER decreases by approximately one order of magnitude if the linear recording density is reduced by about ten percent, so if the linear recording density is reduced by about ten percent on the recording surface with a poor SER (the recording surface corresponding to head HD3), it can be anticipated that the SER of this recording surface will become approximately -5.8, which is within the specification limit.

[0047]

One method of reducing the linear recording density is to lengthen the period of the clock used in recording and

reproducing, but in this disk drive, the physical zone boundaries are changed to reduce the linear recording density, as shown in FIG. 10.

[0048]

FIG. 11 indicates the change in linear recording density (BPI) on the entire recording surface when the physical zone boundaries are moved while the relationship between physical zones and logical zones is left unchanged. The horizontal axis indicates the movement of the zone boundaries in units of the track pitch, the positive direction indicating the state in which they are moved toward the outer perimeter of the magnetic disk 1. The vertical axis indicates the percent change in the linear recording density. According to this, if the zone boundaries are moved outward by about one thousand five hundred tracks (equivalent to 1.5 zones), the linear recording density can be reduced by ten percent.

[0049]

It is necessary, however, to obtain a predetermined total disk capacity, so if the capacity of recording surface HD3 is reduced by ten percent, in proportion to its linear recording density, this reduction must be made up for by increasing the capacity of the other recording surfaces.

[0050]

Therefore, in this example, the positions of the zone boundaries on the other recording surfaces (HD0 to HD2, HD4,

HD5) are altered to increase the linear recording density by two percent. In this way, a capacity similar to the total capacity of a disk drive in which the zone boundaries have not been changed can be obtained.

[0051]

Increasing the linear recording density on the other recording surfaces (HD0 to HD2, HD4, HD5) by two percent in this way does not increase the SER very much, and as shown in FIG. 9 above, the SER on these recording surfaces was low before their zone boundaries were changed, so the SER after the zone boundary change is also within the specification limit.

[0052]

After the change of zone boundaries is carried out as described above, a table (zone boundary table) indicating the boundaries of the physical zones on each disk recording surface is recorded in a ROM in the HDC 5, or in a predetermined area on the magnetic disk 1. Alternatively, a function equivalent to the zone boundary table can be implemented in the above-described address conversion table or by an equivalent logic design (mathematical formulas).

[0053]

If necessary, the above-described address conversion table can also be created and recorded in the ROM in the HDC 5, or in a predetermined area on the magnetic disk 1.

Alternatively, mathematical formulas equivalent to the address conversion table may be set, as mentioned above.

[0054]

Thus, a product that was formerly treated as defective can be redeemed as good, leading to improved yields and reduced costs.

[0055]

There was already a disk drive that altered the track pitch according to recording and reproducing characteristics (corresponding to the above SER), as disclosed in Japanese Kokai Patent Publication No. 255412/1996, but no consideration was given therein to keeping the recording capacity of the disk drive as a whole constant. It is also thought that the seek characteristics of that disk drive may be degraded because of the non-uniform track pitch.

[0056]

In contrast thereto, with this disk drive, it is possible to obtain the same total disk drive capacity as when the zone boundaries are not moved. Moreover, the track pitch is constant in this disk drive, so there is no degradation of seek characteristics due to non-uniform track pitch.

[0057]

In the description above, a case in which the SER of one recording surface exceeded the specification limit was described, but if there are two or more recording surfaces

with SERs above the specification limit, the linear recording densities of these recording surfaces can be similarly reduced, while the linear recording density of the other recording surfaces is increased. Yields can thereby be further improved.

[0058]

The amount by which the zone boundaries are moved can also be varied according to the SER values that are out of specification. For example, if it suffices to reduce the linear recording density by five percent, then from the above FIG. 11, one can see that it suffices to move the zone boundaries outward by seven hundred seventy-five tracks. In this case, the linear recording density of the other recording surfaces only has to be increased by one percent.

[0059]

Alternatively, the zone boundaries can be preset to increase the linear recording density on all recording surfaces, on the presumption that the linear recording density will be reduced on one or several recording surfaces with poor SERs, and the zone boundaries of the recording surfaces with poor SERs can be changed at the time of manufacture. A contribution can thus be made toward a simplification of the manufacturing process and a reduction of manufacturing costs.

[0060]

Furthermore, since there is generally some variation in the SERs of the recording surfaces, even when there is no recording surface with an SER that exceeds the specification limit, a contribution toward an improvement in SER for the disk drive as a whole, and toward an increase in reliability, can be made by reducing the linear recording density of the recording surface with the worst SER, reducing its SER.

[0061]

The operation of a disk drive with the structure described above will be explained below.

[0062]

From an LBA (logical block address) at which recording or reproducing is commanded from an external device, using the address conversion table for obtaining data sector numbers from logical block addresses, which is stored in the memory 5b, control unit 5a derives parameters ZCHS (Z--zone, H--logical head, C--cylinder (CYLID), S--disk sector) indicating a position on a magnetic disk. Alternatively, these parameters can be derived from set mathematical formulas, as mentioned above.

[0063]

Control unit 5a furthermore reads the above-described track format table corresponding to the derived zone, and stores it in a predetermined area on the memory 5b. It also finds the actual head (physical head) corresponding to the

derived logical head, and controls the switching of the heads 2 by the arm electronics 3 through control unit 4e so that the output of this physical head is supplied to the serial/parallel converter 4c and clock generator 4d.

[0064]

Control unit 5a also controls a seek control system (not visible) according to the derived cylinder (CYLID), causing the heads 2 to move to the target track.

[0065]

Moreover, using the track format table for obtaining actual recording positions from data sector numbers, control unit 5a determines the actual recording position from the data sector derived as described above, and controls the operation of the timing detector 5c.

[0066]

The timing detector 5c thereby controls the record/reproduce timing through control unit 4e, according to control from control unit 5a, and recording/reproducing is carried out at the position on the recording surface of the disk 1 corresponding to the appropriate LBA.

[0067]

The operation will now be described in more detail.

[0068]

During the reproduction of a physical servo sector, the clock generator 4d reproduces a reference clock and servo data from the reproduced output of the recorded track, which

is supplied from the arm electronics 3. The reproducing of this reference clock and the servo data can be carried out using the channel IC 4, or by the HDC 5, using signals supplied from the pulse detector 4g.

[0069]

During recording in a data area 52, the record data is supplied from the HDC 5 in parallel (eight bits), for example, and this data is temporarily stored in the buffer 4a. The ENDEC 4b reads a certain number of bits of data according to control from control unit 4e, and performs 8-9 encoding, for example, to avoid continuous runs of 0's or 1's. The clock generator 4d generates the clock (RDWTCLK) used for reproducing and recording data. The serial/parallel converter 4c converts the data encoded by the ENDEC 4b to a serial signal according to the reference clock, and supplies it through the arm electronics 3 to the head 2.

[0070]

During the reproducing of a data area 52, the reproduced signal from the head 2 is supplied through the arm electronics 3 to the channel IC 4. The serial/parallel converter 4c recovers a clock from the reproduced output of the head 2, and converts the serial signal (reproduced output) to parallel data according to the reference clock generated by the clock generator 4d according to the recovered clock. The reproduced output that has been

converted to parallel data is decoded by the ENDEC 4b, and supplied through the buffer 4a to the HDC 5.

[0071]

If there is a recording surface with a poor SER and the physical zone boundaries have been changed as described above, the relationship between logical heads and physical heads is changed, and the assignment of data sectors to LBAs is changed.

[0072]

If the physical zone boundaries have not been changed, after data sectors have been assigned to LBAs on tracks having the same CYLID across a plurality of recording surfaces, the assignment proceeds to the sequentially adjacent tracks.

[0073]

When this type of data sector assignment has been performed, during recording/reproducing operations, after tracks having the same CYLID have been accessed successively through the six heads from HD0 to HD5, the tracks having the next CYLID are accessed through heads HD0 to HD5, and access proceeds in this way, the CYLID increasing sequentially, as shown in FIG. 12.

[0074]

In the case illustrated in FIG. 12, on the recording surface corresponding to each head from HD0 to HD5, the physical zones agree with the logical zones assigned to the

physical zones, and the physical zone boundaries agree, so if tracks have the same CYLID, they can be accessed on each recording surface using a single track format table.

[0075]

When there is a recording surface with different physical zone boundaries, however, even in access to tracks having the same CYLID, the logical zone may differ, depending on the recording surface, as described above. If access similar to that in FIG. 12 is performed in this condition, it is necessary to rewrite the track format table before and after access to the recording surface with differing logical zones. In the case shown in FIG. 13, for example, on tracks with CYLIDs of n + 1 and n + 2, it is necessary to rewrite the track format table during the switchover from head HD2 to head HD3 and the switchover from head HD3 to head HD4, because the zone boundaries of the recording surface corresponding to HD3 differ from the zone boundaries of the other recording surfaces.

[0076]

In comparison to the switching time in the arm electronics 3, the rewriting of the track format table is not negligible, because as noted above, the length of this table is about eight hundred bytes. Moreover, during recording/reproducing, the memory 5b is also used as a record/reproduce buffer, and is used by the control program executed by the control unit 5a, so if the frequency with

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number of times the track format table is rewritten can be reduced, as shown in FIG. 16.

[0091]

In a disk drive according to this embodiment, as described above, yields can be improved by reducing the linear recording density on recording surfaces with a poor SER, thereby improving their SER, and disk drive performance can be enhanced by changing the order of assignment of data sectors to LBAs.

[0092]

2nd embodiment

A disk drive according to the second embodiment of the present invention is configured as in FIG. 1, described above.

[0093]

In the first embodiment described above, the physical zone boundaries of recording surfaces with poor SERs were moved in the direction that reduced their linear recording density, but in a disk drive according to the second embodiment, the linear recording density is reduced and the SER improved by changing the logical zones assigned to the physical zones on a recording surface with a poor SER, without moving the physical zone boundaries.

[0094]

Specifically, when the disk drive is manufactured, a soft error rate (SER) test is carried out on each recording surface and its paired head, as in the first embodiment.

[0095]

Moreover, the logical zones corresponding to the physical zones are changed on recording surfaces with poor SERs.

[0096]

To show this specifically, if the upper limit of the SER is -5 (equivalent to an error rate of 10^{-5}, because in the SER, the error rate is indicated as a logarithm to the base ten, as stated above), and if among six recording surfaces, the SER of the recording surface corresponding to head HD3 is -4.8, exceeding the specification limit, as shown above in FIG. 9, for example, then if this SER is within an allowable range (for example, if the SER is -4 or less, when the allowable range is one order of magnitude), logical zones one rank lower than on other surfaces, for example, are assigned to the physical zones on the recording surface corresponding to this head HD3.

[0097]

That is, as shown in FIG. 17, on the recording surfaces corresponding to heads other than head HD3, the logical zones L0, L1, ... listed in Table 1 are assigned to physical zones Z0, Z1, ... from the outer diameter to the inner diameter, but on the recording surface corresponding to head

HD3, the logical zones L1, L2, ... in Table 1 are assigned to physical zones Z0, Z1, ... from the outer diameter to the inner diameter.

[0098]

From the above FIG. 11, performing this type of assignment of logical zones to physical zones reduces the linear recording density by about 6.5%, and from FIG. 2, the SER is reduced by about 0.7, so it can be anticipated that the SER of the recording surface corresponding to HD3 will become -5.5, which is within the specification limit.

[0099]

As in the first embodiment, the above-described assignment of logical zones to physical zones is recorded as an address conversion table in a ROM in the HDC 5, or in a predetermined area on the magnetic disk 1. Alternatively, it can be implemented as a logic design (mathematical formulas) equivalent to an address conversion table.

[0100]

In this embodiment, accordingly, as in the first embodiment described above, yields can be improved and product costs reduced by reducing the linear recording density on recording surfaces with poor SERs, thereby improving their SERs.

[0101]

To achieve a predetermined capacity for the disk drive, it is also necessary to compensate for the capacity

shortfall due to the reduction of the linear recording density. In the first embodiment, the capacity could be finely adjusted, because the zone boundaries were moved. Fine adjustment of the capacity is difficult in the second embodiment, however, because the logical zones assigned to physical zones are changed; accordingly, the zone boundaries should be preset on the assumption that that logical zones will be changed, so that the capacity shortfall due to the reduction of the linear recording density on recording surfaces with a poor SER is assigned to other recording surfaces, having a good SER.

[0102]

Instead of assigning logical zones to physical zones on a one-to-one basis, it is also possible to change the assignment as called for to preserve a fixed capacity, for example, to assign logical zones (L0, L1), (L1, L2), ... to physical zones Z0, Z1, ...

[0103]

Alternatively, it is possible to pre-design, for example, the number of data sectors recorded in the tracks in each logical zone on the assumption that the linear recording density will be reduced on recording surfaces with poor SERs, and to make the logical zones assigned to physical zones on the recording surface with the worst measured SER differ from the other recording surfaces.

[0104]

Performing this type of design can contribute to a simplification of the manufacturing process and a reduction of manufacturing costs. It can also contribute to an improvement in SER for the disk drive as a whole, and an increase in reliability, by reducing the linear recording density of the recording surface with the worst SER, thereby reducing its SER, even when there is no recording surface with an SER that exceeds the specification limit.

[0105]

The operation of a disk drive with the structure described above will be explained below.

[0106]

In this disk drive, logical head numbers 0 to 6 are assigned sequentially to heads HD0 to HD6, and after data sectors on tracks having the same CYLID have been assigned to LBAs across a plurality of recording surfaces, the CYLID is sequentially increased and a similar assignment of data sectors is performed, as in the above-described FIGs. 12 and 13.

[0107]

When access is performed on a disk drive in which data sectors have been assigned in this way, as shown in FIG. 18, each time a track is reproduced, it is necessary to rewrite the above-described track format table at the switchover from HD2 to HD3 and the switchover from HD3 to HD4.

[0108]

If this type of rewriting of the track format table is performed, access can be carried out with a head switching order similar to the conventional order.

[0109]

The control load increases, however, if the track format table is rewritten in response to head switchovers in every track. Moreover, the performance of the disk drive may be reduced if track format table rewrites are performed frequently, as explained above.

[0110]

Therefore, two track format tables may be placed on the memory 5b, the table to use being selected according to the switching of heads. The frequency of rewriting of the track format table can thereby be reduced, leading to an enhancement in performance.

[0111]

As explained above, however, the size of the track format table is comparatively large, and if the capacity of the memory 5b is limited, it may be difficult or inefficient to store two tables.

[0112]

If this is the case, performance can be improved by changing the logical head numbers.

[0113]

Specifically, logical head numbers 0 to 4 are assigned consecutively to heads HD0 to HD2, HD4, and HD5, for

example, omitting head HD3, which corresponds to a recording surface with reduced linear recording density; then logical head number 5 is assigned to head HD3, and the assignment of disk sectors to LBAs is carried out in the manner described above, in order of logical head number.

[0114]

When access is performed on a disk drive in which data sectors have been assigned in this way, as shown in FIG. 19, it becomes unnecessary to rewrite the track format table in, for example, the switchover from head HD3 on track n + 2 to head HD0 on track n + 3. The frequency of rewriting of the track format table can thereby be reduced, restraining the reduction in performance.

[0115]

Moreover, in the switchover from head HD3 to head HD0 in each track, the seek to the adjacent track is carried out at the same time as the rewriting of the track format table, so the time margin is a little greater than in switchovers between other heads. There is accordingly comparatively less reduction in performance when the rewriting of the track format table is carried out during this switchover.

[0116]

Furthermore, if the drive is configured for storing two track format tables in the memory 5b, the reduction in performance can be further restrained.

[0117]

It is also possible to perform the assignment of data sectors to LBAs as shown in FIG. 14 above, by first assigning data sectors to tracks having the same CYLID on recording surfaces on which the linear recording density has not been reduced, then proceeding to assign data sectors while successively increasing the CYLID, but assigning data sectors at predetermined intervals to adjacent tracks on a recording surface on which the linear recording density has been reduced, while decreasing the CYLID.

[0118]

It is also possible, incidentally, to reduce the linear recording density of two or more recording surfaces, when the SERs of two or more recording surfaces exceed the specification limit. In this case, logical head numbers 0 to 3, for example, are assigned consecutively to heads HD0 to HD2 and HD4, on which the recording density is not reduced, as shown in FIG. 20; logical head numbers 5 and 4 are assigned to heads HD3 and HD5, which correspond to recording surfaces with reduced linear recording densities; and when data sectors are assigned to LBAs, the assignment of data sectors is performed in order of logical head number.

[0119]

If the assignment of logical head numbers is performed in this way, as shown in FIG. 20, the frequency of rewriting of the track format table during access can be reduced and

the performance penalty due to rewriting can be reduced, contributing to the prevention of performance reduction.

[0120]

It is also possible to assign data sectors to LBAs as in the above-described FIG. 15, by first assigning data sectors to tracks having the same CYLID on recording surfaces on which the linear recording density has not been reduced, then proceeding to assign data sectors while successively increasing the CYLID, but assigning data sectors at predetermined intervals to tracks having the same CYLID on recording surfaces on which the linear recording density has been reduced, while decreasing the CYLID.

[0121]

2.6 Effect of the Invention:

In the present invention, a disk-shaped recording medium has a structure with a first recording surface and a second recording surface, the linear recording density of which differs from that of the first recording surface according to recording and reproducing characteristics, so media that were conventionally treated as defective, when the linear recording density was set uniformly on each recording surface, can be redeemed, yields can be improved, and costs can be reduced.

[0122]

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Reductions in disk drive performance can also be inhibited by the use of this type of disk-shaped recording medium in a disk drive.

4. Brief Explanation of the Drawings:

FIG. 1 is a block diagram showing the structure of a disk drive according to a first embodiment of the present invention.

FIG. 2 illustrates the relationship between the linear density of data recorded on a magnetic disk and the error rate.

FIG. 3 shows an example of the recording format on a magnetic disk in a conventional disk drive.

FIG. 4 shows an example of the recording format on a magnetic disk in a disk drive according to a first embodiment of the present invention.

FIG. 5 shows an example of zones provided in the radial direction on a magnetic disk.

FIG. 6 shows an example of the recording format of a data sector recorded on a magnetic disk.

FIG. 7 shows an example of a track format table showing the correspondence between data sector numbers and actual recording positions on a magnetic disk.

FIG. 8 shows an example of an address conversion table showing the correspondence between logical block addresses and data sector numbers.

FIG. 9 shows an example of the positions of physical zone boundaries.

FIG. 10 shows an example of the positions of physical zone boundaries.

FIG. 11 illustrates the relationship between the positions of physical zone boundaries and the SER.

FIG. 12 shows an example of the operation of a disk drive.

FIG. 13 shows an example of the operation of a disk drive.

FIG. 14 shows an example of the operation of a disk drive.

FIG. 15 shows an example of the operation of a disk drive.

FIG. 16 shows an example of the operation of a disk drive.

FIG. 17 shows an example of the logical zones assigned to physical zones in a disk drive according to a second embodiment of the present invention.

FIG. 18 shows an example of the operation of a disk drive.

FIG. 19 shows an example of the operation of a disk drive.

FIG. 20 shows an example of the operation of a disk drive.

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Reference Numerals:

1	magnetic disk
2	head
3	arm electronics
4	channel IC
4a	buffer
4b	ENDEC
4c	serial/parallel converter
4d	clock generator
4e	control unit
4g	pulse detector
5	HDC
5a	control unit
5b	memory
5c	timing detector

Claims:

1. A disk-shaped recording medium, comprising:

a first recording surface having a first linear recording density in a certain radial position; and

a second recording surface having a second linear recording density, different from said first linear recording density, in said certain position, wherein said first and second recording surfaces have a plurality of recording areas in which the recording frequency is constant regardless of position in the radial direction of the disk.

2. The disk-shaped recording medium of claim 1, wherein:

said first and second linear recording densities are set with the positions of the boundaries of the recording areas on said second recording surface, in the radial direction of the disk, differing from the positions of the boundaries on said first recording surface.

3. The disk-shaped recording medium of claim 1, wherein:

said first and second recording surfaces have a plurality of recording areas in which the recording frequency is constant regardless of position in the radial direction of the disk; and

said first and second linear recording densities are set by setting different recording frequencies for recording areas in the same position, in the radial direction of the disk, on said first recording surface and said second recording surface.

4. The disk-shaped recording medium of any of claims 1 to 3, wherein said first and said second linear recording densities are set according to recording and reproducing characteristics of said recording surfaces.

5. A method of manufacturing a disk-shaped recording medium, comprising the steps of:

measuring recording and reproducing characteristics of each recording surface of a disk-shaped recording medium having a plurality of recording surfaces; and

setting said plurality of recording surfaces to a first recording surface having a first linear recording density in a certain radial position and a second recording surface having a second linear recording density, differing from said first linear recording density, in said certain radial position, according to said recording and reproducing characteristics, wherein said first and second linear recording densities are set by providing a plurality of recording areas in which the recording frequency is constant, regardless of position in the radial direction of the disk, on the first recording surface, when said first recording surface is set.

6. The method of manufacturing a disk-shaped recording medium of claim 5, wherein said first and second linear recording densities are set by:

providing a plurality of recording areas in which the recording frequency is constant, regardless of position in the radial direction of the disk, on the second recording surface, when said second recording surface is set, and setting the positions of the boundaries of the recording areas in the radial direction of the disk in positions differing from the boundaries of the recording areas on said first recording surface.

7. The method of manufacturing a disk-shaped recording medium of claim 5, wherein said first and second linear recording densities are set by:

providing a plurality of recording areas in which the recording frequency is constant, regardless of position in the radial direction of the disk, on the first recording surface, when said first recording surface is set; and

providing a plurality of recording areas in which the recording frequency is constant, regardless of position in the radial direction of the disk, on the second recording surface, when said second recording surface is set, the recording frequency of each recording area differing from the recording area in the same radial position on said first recording surface.

8. The method of manufacturing a disk-shaped recording medium of any of claims 5 to 7, wherein the soft error rate of each said recording surface is used as said recording and reproducing characteristics.

9. In a recording and reproducing method for recording and reproducing on a disk-shaped recording medium possessing a first recording surface having a first linear recording density in a certain radial position, and a second recording surface having a second linear recording density, different from said first linear recording density, in said certain radial position, a recording and reproducing method comprising the steps of:

selecting recording surfaces on which to perform recording and reproducing according to commanded addresses;

changing the linear recording density of recording and reproducing according to the selected recording surface; and

performing recording and reproducing, changing the recording and reproducing characteristics according to the changed linear recording density.

10. A disk drive, comprising:

a disk-shaped recording medium having a first recording surface having a first linear recording density in a certain radial position, and a second recording surface having a second linear recording density, different from the first linear recording density, in said certain radial position;

a recording and reproducing means performing recording and reproducing on the disk-shaped recording medium;

a recording-surface selection means selecting recording surfaces on which to perform recording and reproducing, from commanded addresses;

a linear recording density alteration means changing the linear recording density according to the recording surface selected by the recording-surface selection means; and

a control means changing the recording and reproducing characteristics of said recording and reproducing means according to the linear recording density changed by the linear recording density alteration means, wherein said first and second recording surfaces have a plurality of recording areas in which the recording frequency is constant, regardless of position in the radial direction of the disk.

11. The disk drive of claim 10, wherein:

said first and second linear recording densities are set with the positions of the boundaries of the recording areas of said second recording surface, in the radial direction of the disk, in different positions from said first recording surface;

said linear recording density alteration means changes the linear recording density according to the recording surface selected by said recording-surface selection means; and

said control means changes the recording and reproducing frequency of said recording and reproducing means according to the linear recording density changed by the linear recording density alteration means and the recording area in which recording and reproducing are performed.

12. The disk drive of claim 11, wherein:

there are a plurality of said first recording surfaces;

there are one or more of said second recording surfaces;

said recording and reproducing means performs recording and reproducing in the recording areas of each said recording surface in data recording units of a predetermined length (data storage);

the disk drive has an address conversion means for obtaining the data sectors corresponding to said commanded addresses in each said recording area; and

when assigning data sectors to said addresses, the address conversion means assigns data sectors sequentially in the same position in the radial direction in said plurality of first recording surfaces, then performs assignments while successively varying the position in the radial direction, and assigns data sectors in consecutive positions in the radial direction in said second recording surfaces at predetermined intervals, the variation in position in the radial direction being opposite to that when data sectors are assigned in said first recording surfaces.

13. The disk drive of claim 10, wherein:

said first and second recording surfaces have a plurality of recording areas in which the recording frequency is constant, regardless of position in the radial direction of the disk;

said first and second linear recording densities are set with the recording frequencies of the recording areas of said second recording surface differing from the recording frequencies of the recording areas in the same radial positions on said first recording surface;

said linear recording density alteration means changes the linear recording density according to the recording surface selected by said recording-surface selection means; and

said control means changes the recording and reproducing frequency of said recording and reproducing means according to the linear recording density changed by the linear recording density alteration means and the recording area in which recording and reproducing are performed.

14. The disk drive of claim 13, wherein:

there are a plurality of said first recording surfaces;

there are one or more of said second recording surfaces;

said recording and reproducing means performs recording and reproducing in the recording areas of each said recording surface in data recording units of a predetermined length (data sectors);

the disk drive has an address conversion means for obtaining the data sectors corresponding to said commanded addresses in each said recording area; and

when assigning data sectors to said addresses, the address conversion means assigns data sectors sequentially in the same position in the radial direction in said plurality of first recording surfaces, then assigns data sectors sequentially in the same position in the radial direction in said second recording surfaces.

15. In a disk drive having at least two recording surfaces, a disk drive comprising:

a first recording surface having a first linear recording density in a certain radial position; and

a second recording surface having a second linear recording density, different from said first linear recording density, in said certain radial position, wherein said first and second recording surfaces have a plurality of recording areas in which the recording frequency is constant regardless of position in the radial direction of the disk.