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TITLE OF THE INVENTION

DISK DRIVE HAVING A MAGNETIC HEAD FOR PERPENDICULAR
MAGNETIC RECORDING

BACKGROUND OF THE INVENTION

5 The present invention relates to a disk drive
having a perpendicular magnetic recording system.

 Generally speaking, in a small-type disk drive in
particular, a magnetic head for performing data
read/write operation on a disk medium is mounted on a
10 rotary type actuator. The rotary type actuator is so
operated as to allow the write operation magnetic head
to swing in a radial direction over a turned disk
medium and, by doing so, the head is located to a
target position.

15 Where the rotary type actuator is used, the
magnetic head located over the disk medium involves a
so-called skew angle and encounters an interval
variation relative to an adjacent track corresponding
to the radial position over the disk medium. In more
20 detail, an increase in screw angle results in a
decrease in the effective track width (effective data
track width).

 Where a greater number of tracks are formed on
the disk medium surface, a variable track pitch system
25 for varying a track pitch according to the radial
position over the disk medium has been proposed as a
method of increasing the track recording density so as



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to consider the skew angle (see JPT PAT APPLN KOKAI
PUBLICATION NO. 11-25609).

5 In a disk drive of a perpendicular magnetic
recording system, a magnetic head is mounted on a
slider with a data read only read head and
perpendicular magnetic recording type write head
separated thereon. The write head performs the
perpendicular magnetic recording on the disk medium at
the bottom surface of a main magnetic pole structure
10 for generating a perpendicular recording magnetic
field. In the so-called footprint recording, that is,
in the recording made at the bottom surface of the
main magnetic pole structure, as the skew angle
becomes larger, it exerts a greater adverse effect on
15 an adjacent track.

In the disk drive of the perpendicular magnetic
recording system, if use is made of a write head
having a bevel angle defined by working the main
magnetic pole structure to a trapezoidal or triangular
20 shape, there is a tendency, on the other hand, that,
as the skew angle becomes larger, the effective track
width becomes greater. If, on one hand, the bevel
angle becomes larger, the area of the main magnetic
pole structure is decreased and the perpendicular
25 magnetic recording capability is lowered. In the disk
drive of the perpendicular magnetic recording system
it is not possible to enhance the track recording

density of the disk medium simply by using a variable track pitch configuration capable of a track pitch variation on the basis of the skew angle.

BRIEF SUMMARY OF THE INVENTION

5 It is accordingly the object of the present invention to provide a disk drive of a perpendicular magnetic recording system which can realize an effective variable track pitch configuration for a perpendicular magnetic recording system and realize a
10 higher track recording density.

 In one aspect of the present invention there is provided a disk drive comprising a disk medium configured to allow perpendicular magnetic recording; a magnetic head configured to include a read head for
15 reading out perpendicular magnetic recording data from the disk medium and a write head for effecting the perpendicular magnetic recording on the disk medium, the write head having a main magnetic pole structure with a bottom surface formed to trapezoidal or
20 triangular shape and facing the disk medium; and a rotary type actuator having a mounted magnetic head and configured to move it over the disk medium in a radial direction, in which those tracks recorded by the write head on the disk medium are such that, with
25 respect to a bevel angle defined relative to the bottom surface and a skew angle of the magnetic head located by the rotary type actuator over the disk

medium, a track pitch set based on the size of the
bottom surface of the main magnetic pole structure,
skew angle and bevel angle is variable in a radial
position over the magnetic medium where the skew angle
5 $\geq$ the bevel angle.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

The accompanying drawings, which are incorporated
in and constitute a part of the specification,
illustrate embodiments of the invention, and together
10 with the general description given above and the
detailed description of the embodiments given below,
serve to explain the principles of the invention.

FIG. 1 is a block diagram showing an arrangement
of a disk drive according to an embodiment of the
15 present invention;

FIG. 2 is a view for explaining a structure of a
magnetic head according to the present embodiment;

FIGS. 3A and 3B are views for explaining a main
magnetic pole structure of a write head according to
20 the present embodiment;

FIG. 4 is a view for explaining a positional
relation showing a write head relating to the present
embodiment which is mounted on an actuator;

FIGS. 5A and 5B are views for explaining a
25 practical example of a variable track pitch relating
to the present embodiment;

FIG. 6 is a view for explaining a relation

between a track pitch relating to the present
embodiment and a skew angle;

FIG. 7 is a view for explaining a relation
between a track pitch relating to the present
5 embodiment and a track density;

FIG. 8 is a view explaining a process of deriving
a relation equation between a track pitch relating to
the present embodiment and respective parameters of a
main magnetic pole structure;

10 FIG. 9 is a view for explaining a process of
deriving a relation equation between a track pitch
relating to the present embodiment and respective
parameters of a main magnetic pole structure; and

FIG. 10 is a view for explaining a process of
15 deriving a relation equation between a track pitch
relating to the present embodiment and respective
parameters of a main magnetic pole structure.

DETAILED DESCRIPTION OF THE INVENTION

An embodiment of the present invention will be
20 explained below with reference to the drawings.

(Structure of Disk Drive)

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

The disk drive 10 of the present embodiment is
25 comprised of a hard disk drive using a disk medium 11
capable of perpendicular magnetic recording. The disk
medium 11 is fixed in place on a spindle motor (SPM)

13 and it is incorporated within a disk drive 10 to allow high speed rotation. The disk medium 11 is comprised of, as shown in FIG. 2, a laminate structure, on a nonmagnetic substrate, of a soft
5 magnetic layer 112, an intermediate nonmagnetic layer 111 and a perpendicular recording layer 110. The perpendicular recording layer 110 is an area for magnetically recording data corresponding to a perpendicular recording magnetic field from a write
10 head 12W as will be set out below.

Here, a greater number of tracks are provided on the disk medium 11 for data recording by a write head 12W. In the present embodiment, as will be set out below, the track pitch of a track-to-track interval is
15 varied in accordance with a radial position over the disk medium 11.

The disk drive 10 has a magnetic head 12 including, relative to the disk medium 11, a read head 12R for reading out data (servo information and user
20 data) and a write head for writing data. The magnetic head 12 is mounted on an actuator 14 driven by a voice coil motor (VCM) 15. The VCM 15 has its drive current supplied from a VCM driver 21 so as to be driven under control. The actuator 14 is a head moving mechanism
25 driven under control of a microprocessor (CPU) 19 to allow the magnetic head 12 to be located to a target position (target track) of the disk medium 11.

In addition to the head disk assembly, the disk drive 10 also has a preamplifier circuit 16, a signal processing unit 17, a disk controller (HDC) 18, CPU 19 and memory 20.

5 The pre-amplifier circuit 16 has a read amplifier for amplifying a read data signal which is output from the read head 12R of the head 12 and a write amplifier which supplies a write data signal to the write head 12W. The signal processing unit 17 is comprised of a
10 signal processing circuit for processing a read/write data signal (including a servo signal corresponding to the servo information) and also called a read/write channel.

 HDC 18 has an interface function between the
15 drive 10 and a host system 22 (for example, a personal computer and various kinds of digital devices). The HDC 18 executes the transfer control of read/write data between the disk 11 and the host system 22.

 The CPU 19 is comprised of a main controller of
20 the drive 10 and executes the head positioning control and normal read/write operation of the user data under control. That is, the CPU 19 is comprised of a practical means which, in order to allow the track pitch of the tracks on the disk medium 11, to vary,
25 effects the head positioning control and data write operation control.

 The memory 20 includes, in addition to a flash

memory (EEPROM) of a nonvolatile memory, a RAM, ROM, etc., and retains various kinds of data and program necessary to control the CPU 19.

(Structure of Magnetic Head)

5 FIG. 2 is a view for explaining a structure of the magnetic head 12 relating to the present embodiment.

 The magnetic head 12 is comprised of a structure mounted on a slider, not shown, with the write head
10 12W and read head 12R separated. The read head 12R is constructed of a read only head and, normally, a GMR (giant magnetoresistive element).

 Write head 12W is comprised of a single pole type head suitable to the perpendicular magnetic recording
15 and has a main magnetic pole structure (recording magnetic pole structure) 120, a return yoke having a trailing-side magnetic pole structure 121 corresponding to auxiliary magnetic pole structure, and exciting coil 122. The write head 12W is such
20 that, in the running direction (the right direction of FIG. 2) of the disk medium 11, a trailing-side magnetic pole structure 121 is set at the rear end side and the main magnetic pole 120 is set on the leading end.

25 The main magnetic pole structure 120 is comprised of a soft magnetic material of a relatively high magnetic permeability, allowing the excitation of a

perpendicular write magnetic field corresponding to a write current flowing through the exciting coil 122. In the present embodiment, as will be set out below, the main magnetic pole structure 120 is of such a type that the bottom surface facing the surface of the disk medium 11 is worked to have a trapezoidal or triangular shape.

(Main Magnetic Pole Structure)

Referring to FIGS. 3A to 10, an explanation will be made below about the structure of the main magnetic pole structure 120 at the write head 12W of the present embodiment.

FIGS. 3A and 3B are views showing a bottom surface 120W, facing the surface of the disk medium 11, at the main magnetic pole structure 120 of the write head 12W of the present embodiment. Further, the bottom surface 120W may be worked to have a triangular shape.

Here, those parameters on the main magnetic pole structure 120 are: PW, the upper base width of the bottom surface 120W; PT, the main magnetic pole length, and PWB, the lower base width, as shown in FIG. 3A. And, as shown in FIG. 3B, Ba represents a bevel angle based on the upper base width PW, main magnetic pole length PT and lower base width PWB.

FIG. 4 is a view showing that, in a state mounted on the actuator 14, a positional relation of a read

element 120R of the read head 12R and bottom surface
120W of the main magnetic pole structure 120 over the
disk medium. In FIG. 4, respective parameters are
defined with a skew angle H_a given in the case where,
5 over the disk medium, the magnetic track width of the
write head 12W is represented by MWW and the magnetic
read width of the read head 12R by MRW.

Here, in general, the magnetic track width MWW
and upper base width PW of the main magnetic pole
10 structure 120 have a relation of $[MWW \geq PW]$. And the
magnetic read width MRW and read width RW of the read
element 120 have a relation of $[MRW \geq RW]$. And the
magnetic head length of the write head 12W and main
magnetic pole length PT have a relation of $MT \geq PT$.

15 In a state with the skew angle H_a given to the
magnetic head 12, as shown in FIG. 4, eMWW represents
the effective track width relative to the magnetic
track width MWW, and eMRW, the effective read width
relative to the magnetic read width MRW.

20 (Main Magnetic Pole Structure and Variable Track
Pitch Configuration)

In the write head 12W of the present embodiment,
even if the skew angle H_a becomes larger by working
the bottom surface 120W of the main magnetic pole
25 structure 120 to a trapezoidal or triangular shape and
giving the bevel angle B_a as set out above, the
effective track width becomes larger as will be set

out below, therefore it is possible to realize a higher track density. If, on the other hand, the bevel angle Ba is made larger, the area of the bottom surface 120W of the main magnetic pole structure 120 is decreased, thus causing a fall in the magnetic recording capability.

The present embodiment provides a variable track pitch structure for realizing a higher track recording density (TPI) while maintaining a magnetic recording capacity.

In more detail, with MWW_0 , MRW_0 and MT representing the magnetic track width, magnetic read width and magnetic head length, respectively, when the skew angle $Ha = 0^\circ$, the track pitch Tp is set as indicated by an equation (A) bellow.

$$2Tp = MWW_0 \cdot \cos Ha + MT \sqrt{1 + \tan^2 Ba} \cdot \sin (Ha - Ba) + MRW_0 \cdot \cos Ha \cdots (A)$$

provided that, $Ha \geq Ba$

Or the track pitch Tp may be so set as to satisfy the relation indicated by the following equations (B) and (C).

$$MWW_0 \cdot \cos Ha + MT \sqrt{1 + \tan^2 Ba} \cdot \sin (Ha - Ba) + MRW_0 \cdot \cos Ha \leq 2Tp \cdots (B)$$

$$2Tp \leq MWW_0 \cdot \cos Ha + MT \sqrt{1 + \tan^2 Ba} \cdot \sin (Ha - Ba) + MRW_0 \cdot \cos Ha + 60 \cdots (C)$$

provided that, $Ha \geq Ba$

By referring to FIGS. 8 to 10, an explanation will be made below about the process of deriving an equation showing the relation between the track pitch Tp and respective parameters of the main magnetic pole structure 120.

As shown in FIG. 8, the magnetic track width MWW can be calculated from $\cos(Ha)$ when the magnetic track width = MWW_0 at $Ha = 0^\circ$. Thus, the bevel angle Ba of the main magnetic pole structure 120 and magnetic head length MT can be expressed by the relation shown in FIG. 9.

As shown in FIG. 10, the following equation D of calculating the effective track width eMWW can be derived from the relation between the skew angle Ha and the bevel angle Ba.

$$eMWW = MWW_0 \cdot \cos Ha + MT \sqrt{1 + \tan^2 Ba} \cdot \sin(Ha - Ba) \quad \dots(D)$$

When the effective read width eMRW can be derived as the following equation (E) from $\cos(Ha)$ when the magnetic read width = MRW_0 at $Ha = 0^\circ$.

$$eMRW = MRW_0 \cdot \cos Ha \quad \dots(E)$$

Here, the effective track width eMWW can be derived from the following equation (F) at $Ha > Ba$.

$$eMWW = MWW_0 \cdot \cos Ha \quad \dots(F)$$

provided that, $Ha > Ba$

When, on the other hand, the skew angle $Ha \leq$ the bevel angle Ba, the pole of the main magnetic pole structure 120 projects out to an extent given by the

following equation:

$$MT\sqrt{1+\tan^2 Ba} \cdot \sin(Ha - Ba) \quad \dots(G)$$

provided that, $Ha \leq Ba$

By the deriving process above it is possible to
5 derive the effective track width eMWW from the
equation (D) above. It is possible to, from the
equations (D) and (E), derive the equation (A) for
setting the track pitch Tp. It is also possible to
derive the relation equations (B) and (C).

10 FIG. 5 is an explanatory view showing a practical
case of respective parameters applied on the present
embodiment and its associated track recording density.

Now suppose a disk drive 10 in which, as shown in
FIG. 5A, at a target areal density of 300 Gbps, the
15 radial value of a disk medium 11 is 15 to 30 mm, the
skew angle Ha is -13° for the radius of 15 mm, or 13°
for the radius of 30 mm, and the track group is
equidistantly divided into 20 zones.

In this disk drive 10, respective parameters of
20 the main magnetic pole structure 120 are set to be:
PW = 100 nm, PT = 300 nm, RW = 500 nm, MWW = PW + 30 =
130 nm, MRW = RW = 50 nm, and MT = PT = 300 nm.

Here, FIG. 6 shows a relation between the skew
angle Ha and an optimal track pitch Tp. The track
25 pitch Tp is calculated out from a relation equation
[$2Tp - eMWW - eMRW > 40$]. In FIG. 6, the solid line
60 shows the characteristic when, the bevel angel Ba,

one of the paramators of the main magnetic pole structure 120, is 7° . On the other hand, the dotted line 61 shows the characteristic at the bevel angle $Ba = 9^\circ$. As shown in FIG. 6, the track pitch T_p is constant in a range of a relatively small skew angle Ha over the disk medium 11.

As shown in FIG. 5B, if, at $Ba = 7^\circ$, calculation is made to obtain the same surface capacity when the variable track pitch is not used, then the average linear density (kBPI) and average track density (kTRI) become 1459 kBPI and 206 kTPI, respectively. When, on the other hand, the variable track pitch is used, the average linear density (kBPI) and average track density (kTPI) become 1341 kBPI and 224 kTPI, respectively.

Likewise, at $Ba = 9^\circ$, when the variable track pitch is not used, then the average linear density (kBPI) and average track density (kTPI) become 1397 kBPI and 215 kTPI, respectively. When, on the other hand, the variable track pitch is used, the average linear density (kBPI) and average track density (kTPI) become 1317 kBPI and 228 kTPI, respectively. That is, the difference of the linear densities when the variable track pitch is not used is 118 kBPI. When, on the other hand, the variable track pitch is used, the corresponding difference is 24 kBPI only. If the variable track pitch is used, a higher track density

(TPI) can be achieved without giving any relative high bevel angle B_a . That is, it is possible to obtain a high recording density without exerting any adverse effect on the magnetic head 12 and disk medium 11.

5 FIG. 7 shows a variation of the track density (TPI) in the radius direction on the disk medium. In FIG. 7, the dotted line 71 shows the characteristic when the variable track pitch is not used, that is, the track pitch is constant. And the solid line 70
10 shows the characteristic when the variable track pitch is used. As indicated by the solid line 70 in FIG. 7, a given high track density is involved at an intermediate circumferential portion of the disk medium 11 in a relatively small skew angle H_a range,
15 and a track pitch is set variable at those inner and outer circumferential portions to allow the track density to vary.

 As set out above, a track structure is realized based on the relation equation (A) and equation (B) or
20 (C), that is, it is realized with the use of a variable track pitch T_p , taking into consideration the skew angle B_a and bevel angle B_a over the magnetic head 12 which is a parameter of the main magnetic pole structure 120. For such track structure on such disk
25 medium 11, it is possible to achieve a relatively high track density (TPI) on the disk medium 11 while retaining a recording capacity of the main magnetic

pole structure.

In other words, in order to achieve a higher track density (TPI) at a higher skew angle H_a in the perpendicular magnetic recording, the bottom surface 120W of the main magnetic pole structure 120 is worked to a trapezoidal or triangular shape to provide a bevel angle B_a and, by doing so, even if a relatively high bevel angle B_a is not provided, it is possible to achieve the higher track density (TPI) at the variable track pitch on the disk medium 11. It is to be noted that, if the skew angle H_a is lower than the bevel angle B_a , the track pitch T_p may be constant.

According to the present embodiment, for the disk drive using a perpendicular recording system write head having a bevel angle given by working the main magnetic pole structure to a trapezoidal or triangular shape, it is possible to achieve an effective variable track pitch configuration without lowering a perpendicular magnetic recording capability and to achieve a high track recording density.

Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details and representative embodiments shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as

defined by the appended claims and their equivalents.

WHAT IS CLAIMED IS:

1. A disk drive comprising:

a disk medium configured to allow perpendicular magnetic recording;

5 a magnetic head configured to include a read head for reading out perpendicular magnetic recorded data from the disk medium and a write head for effecting the perpendicular magnetic recording onto the disk medium, said write head having a main magnetic pole
10 structure with a bottom surface formed to a trapezoidal or triangular shape and facing the disk medium; and

a rotary type actuator having a mounted magnetic head and configured to move it over the disk medium in
15 a radial direction, in which those tracks recorded by the write head on the disk medium are such that, with respect to a bevel angle defined relative to said bottom surface and a skew angle of the magnetic head located by the rotary type actuator over the disk
20 medium, a track pitch set based on the size of said bottom of the main magnetic pole structure, skew angle and bevel angle is variable in a radial position over the disk medium where the skew angle $\geq$ the bevel angle.

25 2. A disk drive according to claim 1, in which, in a radial position over the disk medium where the skew angle is less than the bevel angle, the track is

so configured that the track pitch is constant.

3. A disk drive according to claim 1, in which,
with MWW_0 representing a magnetic track width of the
write head when the skew angle H_a is 0° ; MRW_0 , a
5 magnetic read width of the read head; MT , a magnetic
head length of the write head; and T_p , a track pitch
 T_p , the track is so configured as to satisfy the
following equation:

$$10 \quad 2T_p = MWW_0 \cdot \cos H_a + MT \sqrt{1 + \tan^2 B_a} \cdot \sin (H_a - B_a) + MRW_0 \cdot \cos H_a \cdots (H)$$

provided that, $H_a \geq B_a$

4. A disk drive according to claim 1, wherein,
with MWW_0 representing a magnetic track width of the
write head at a skew angle $H_a = 0^\circ$; MRW_0 , a magnetic
read width; MT , a magnetic head length of the write
15 head; and T_p , a track pitch, the track is so
configured as to satisfy the following equations:

$$MWW_0 \cdot \cos H_a + MT \sqrt{1 + \tan^2 B_a} \cdot \sin (H_a - B_a) + MRW_0 \cdot \cos H_a \leq 2T_p \cdots (I)$$

$$20 \quad 2T_p \leq MWW_0 \cdot \cos H_a + MT \sqrt{1 + \tan^2 B_a} \cdot \sin (H_a - B_a) + MRW_0 \cdot \cos H_a + 60$$

$$\cdots (J)$$

provided that, $H_a \geq B_a$

5. A magnetic head applied to a disk drive using
a disk medium allowing perpendicular magnetic
recording, comprising:

a read head configured to read out perpendicular
25 magnetic recorded data from the disk medium; and
a write head configured to effect perpendicular

magnetic recording on the disk medium, said write head having a main magnetic pole structure with a bottom surface formed to a trapezoidal or triangular shape and facing the disk medium, and in which, with respect to a bevel angle defined relative to said bottom surface and a skew angle located over the disk medium, those tracks recorded on the disk medium are formed at a variable pitch in a radial position on the disk medium where the skew angle $\geq$ the bevel angle, the size of the bottom surface of the main magnetic pole structure and bevel angle matched to the track pitch are set.

6. A magnetic head according to claim 5, in which, with MWW_0 representing a magnetic track width of the write head when the skew angle $H_a = 0^\circ$; MRW_0 , a magnetic read width of the read head; MT , a magnetic head length of the write head and T_p , the track pitch, the following equation is satisfied:

$$2T_p = MWW_0 \cdot \cos H_a + MT \sqrt{1 + \tan^2 B_a} \cdot \sin(H_a - B_a) + MRW_0 \cdot \cos H_a \cdots (K)$$

provided that, $H_a \geq B_a$

7. A magnetic head according to claim 5, in which, with MWW_0 representing a magnetic track width of the write head when the skew angle $H_a = 0^\circ$; MRW_0 , a magnetic read width of the read head; MT , a magnetic head length of the write head; and T_p , a track pitch, the following equations (L) and (M) are satisfied:

$$MWW_0 \cdot \cos H_a + MT\sqrt{1 + \tan^2 B_a} \cdot \sin (H_a - B_a) + MRW_0 \cdot \cos H_a \leq 2T_p \cdots (L)$$

$$2T_p \leq MWW_0 \cdot \cos H_a + MT\sqrt{1 + \tan^2 B_a} \cdot \sin (H_a - B_a) + MRW_0 \cdot \cos H_a + 60$$

5

$\cdots (M)$

provided that, $H_a \geq B_a$