

"APPARATUS FOR TRACKING ERROR VERIFICATION
FOR A DISC DRIVE APPARATUS"

The present invention relates to an alignment disk for a magnetic disk driving apparatus which enables high precision tracking when a head carriage drive of the magnetic disk driving apparatus is positioned to a
5 predetermined position along a track diameter, and particularly when a drive of a magnetic disk having a bit density of more than 96 or 100 tracks per inch (TPI) is positioned, and to method and apparatus for verifying a tracking error of the magnetic disk driving apparatus.

10 A prior art alignment disk is explained. JP-B-59-7142 discloses an example of the prior art alignment disk. An index mark and a track diametric positioning signal are recorded on the disk. The positioning signal of the alignment disk is supplied to a magnetic disk
15 driving apparatus, reproduced by a magnetic head and displayed on an oscilloscope. In this manner, the track diametric positioning is attained.

However, the above prior art alignment disk does not have all of track diameter adjust signal,
20 index timing adjust signal and azimuth adjust signal, which are necessary for data interchangeability. The adjustment by the oscilloscope is of low resolution and assures the data interchangeability between magnetic disk driving apparatuses of a class of 48 PTI, but it is

1 hard to assure the data compatibility between the
magnetic disk driving apparatuses of a higher bit density,
i.e. 96 TPI or 100 TPI.

Another example of the prior art alignment
5 disk is explained with reference to Fig. 1. An index
timing adjust signal 21 is provided on an outer track of
an alignment disk 1. A track diameter adjust signal 36
is provided on a center track between an inner track and
the outer track. The signal 36 comprises a larger
10 diameter signal 37 which is eccentric from a center of
rotation 2 by a predetermined distance $\epsilon = 0.1$ mm and
larger than a reference diameter by $\delta/2 = 0.075$ mm, and
a smaller diameter signal 38 which is also eccentric
from the center of rotation 2 by the distance ϵ and
15 smaller than the reference diameter by $\delta/2$. These signals
37 and 38 are detected by a so-called cat eye signal.
A CW (clockwise) signal 31 and a CCW (counter clockwise)
signal 32 are provided on the inner track as an azimuth
adjust signal 30. The same signals are recorded on a
20 back side of the alignment disk 1 so that two upper and
lower heads are tracked.

In the tracking adjustment by using the
alignment disk, the alignment disk 1 is loaded to the
magnetic disk driving apparatus, a head carriage is
25 moved to a particular track of the disk, and the adjust
signals are reproduced and displayed on the oscilloscope.

In the index timing adjust, a time period T
from an index timing detection point IDX to the index

1 timing adjust signal 21 is measured, and the position
of the index detection sensor is adjusted such that the
time period T is within a predetermined period.

In the track diameter adjustment, the stepping
5 motor is finely adjusted such that output voltages of
the larger diameter signal 37 and the smaller diameter
signal 38 become same. In the azimuth adjustment, the
head inclination is adjusted such that a ratio of the
four signals 31 and 32 is within a predetermined range.

10 By using the above alignment disk, the index
timing adjustment and the azimuth detection of the
magnetic disk driving apparatus are attained. However,
the resolution attained by the track diameter adjustment
by the cat eye signal is low and it is hard to assure
15 the data interchangeability of the driving apparatus the
high density magnetic disk such as 96 TPI or 100 TPI.

Further, it is not possible to determine a
chucking error based on a format of the reproduced
signal.

20 The data interchangeability of the high density
magnetic disk driving apparatus explained. Because a
plurality of magnetic disk driving apparatuses on which
magnetic disks are loaded and unloaded record and
reproduce data, there is an error (called an off-track)
25 between a predetermined track diametric position on the
disk and an actual position at which the magnetic head
is positioned by the magnetic disk driving apparatus.
Major causes therefor are:

- 1 (1) Position adjust error of the carriage
- (2) Positioning error of the carriage
- (3) Chucking error (eccentricity) caused when the
magnetic disk is chucked to the magnetic disk
5 driving apparatus
- (4) Difference in expansion and shrinkage of the
magnetic disk and the magnetic disk driving
apparatus by temperature and humidity change

As to the index timing and the azimuth, there
10 are also errors between two magnetic disk driving apparatuses.

In the 96 TPI magnetic disk driving apparatus
a tolerance X of the off-track relates to a magnetic head
R/W gap width $W = 165 \mu\text{m}$ and an erase core width $E_r = 100$
15 μm , and X is approximately $50 \mu\text{m}$. The tolerance $X = 50 \mu\text{m}$
is distributed into the error items (1) to (4) so that
the total of the errors of the items (1) to (4) is within
 $50 \mu\text{m}$, in order to assure the data interchangeability.
However, the expansion/shrinkage error by the temperature
20 and humidity in the item (4) is hard to reduce because
of a large affect by a property of matter of the material.

The error items (1) to (3) are analyzed.

- (1) The carriage position adjust error is an error
caused when the head and a carriage transmission system
25 are assembled into the carriage. This error closely
relates to the assemble and adjust time. In order to
reduce the error, the adjust time must be significantly
lengthened.

1 (2) The carriage positioning error is caused by
a stepping motor (STM) positioning error due to precision
errors of parts of the STM and its drive system, and
a positioning error due to precision errors of parts of
5 the STM drive force transmission system. However, in
the drive of the high density magnetic disk, the manu-
facturing precisions of the STM, drive system and
transmission system have reached the limits, and if the
precision is to be more improved, the yield is reduced,
10 which will lead to the cost increase and quality
instability.

(3) Major causes of the chucking error are a
precision of parts of the chunk unit of the magnetic
disk, and a precision of parts of the chunking unit of
15 the magnetic disk driving apparatus. The precision of
the parts in the high density magnetic disk driving
apparatus reached its limit, and if the precision is to
be improved, the yield is reduced which leads to the
increase of cost and the instability of quality.

20 As described above, in the high density
magnetic disk driving apparatus, the precision for the
components is at their limits, and in order to assure
the data interchangeability between the magnetic disk
driving apparatuses on which a plurality of disks are
25 loaded and unloaded, it is necessary to improve the
precision of components which leads to the cost increase,
or to improve the precision of the position adjustment
of the head carriage driver. Those cause problems in

the manufacturing efficiency and reliability.

In the prior art apparatus, the positioning error of the stepping motor, hysteresis error and accumulated error of the transmission system, which are to be detected
5 in the tracking adjustment to assure the data interchangeability, are not detected as a result, the off-track increase in the tracks other than the adjusted track or in the innermost and outermost tracks and the read/write error occurs. Further, the prior art apparatus cannot
10 measure the chucking error between the magnetic disk driving apparatus and the magnetic recording medium, and the off-track increases by the eccentricity due to the chucking error and the tracking error occurs.

It is an object of the present invention to
15 overcome the above referred to problems in the prior art structure.

According to the present invention there is provided apparatus for tracking error verification for a magnetic disk drive apparatus having magnetic head means
20 for recording and reproducing data on or from a magnetic recording medium, a head carriage for carrying said magnetic head means, and head carriage drive means having a stepping motor for driving said head carriage relative to said magnetic recording medium so as to radially cross a
25 plurality of tracks of said magnetic recording medium, said magnetic head means being capable of being adjusted in its position radially of a predetermined track from an adjust signal read by said head means which is recorded on an

alignment disk, said alignment disk being loaded and unloaded to and from said magnetic disk drive apparatus, said alignment disk having a set of track diameter adjust signal pairs recorded on a predetermined number of tracks of said alignment disk, the total number of tracks in the plurality of tracks equal to or larger in number than the number of phases of said stepping motor, the predetermined number of tracks respectively corresponding to at least the phases of said stepping motor, a set of track diameter adjust signal pairs being recorded on at least a track in the vicinity of at least one of an innermost track and an outermost track; said apparatus including:

(a) filter means for filtering the adjust signal read by said magnetic head means when said alignment disk is loaded to said magnetic disk drive apparatus and providing an output indicative thereof;

(b) A/D conversion means for digitizing the output of said filter means and providing an output indicative thereof;

(c) memory means for storing the output of said A/D conversion means;

(d) control means for supplying a control signal to said head carriage drive means to drive said head carriage;

(e) calculation means for calculating, based on the data stored in said memory means, at least an error which is accumulated through the movement of said head means from the inner track to the outer track of said

alignment disk, said error including a positioning error of said drive means, a hysteresis error depending on the direction of drive of said carriage, and an eccentricity error of the disk; and

5 (f) display means for displaying a result of said calculation means;

said control means controlling said head carriage to move from the outer track to the inner track and from the inner track to the outer track so that said magnetic head means scans the track corresponding to at least the phases of the stepping ^{motor,} for driving said carriage ~~head~~.

The present invention will now be described in greater detail by way of example with reference to the accompanying drawings, wherein:-

15 Fig.1 shows a front view of a prior art alignment disk,

Fig. 2 shows a front view of an embodiment of an alignment disk of the present invention,

20 Fig. 3 shows a signal write apparatus for the alignment disk,

Fig. 4 shows a perspective view of a magnetic disk driving apparatus,

Fig. 5 is a characteristic chart illustrating a positioning error of a stepping motor,

25 Fig. 6 shows arrangement of adjust signals in the alignment disk of the present invention,

Fig. 7 is a characteristic chart illustrating an off-track when the stepping motor is assembled into the

magnetic disk driving apparatus,

Fig. 8 shows a block diagram of one embodiment of a tracking verification apparatus for the magnetic disk driving apparatus in accordance with the present invention,

5 Figs. 9 and 10 show waveforms of adjust signals reproduced from the alignment disk,

1 Fig. 11 shows an example of display on a CRT
of the adjust signal reproduced from the alignment disk,

 Figs. 12 to 14 show other examples of display
on the CRT of the adjust signal reproduced from the
5 alignment disk, and

 Fig. 15 shows a flow chart of a tracking adjust
method of the present invention.

 One embodiment of the alignment disk for the
10 magnetic disk driving apparatus is explained with refer-
ence to Fig. 2.

 The alignment disk shown in Fig. 2 has, for
example, 40 tracks, only six of which are shown in Fig. 2
for a sake of simplification. On the center of the 26th
25 track T_{25} of the adjust signal tracks of the alignment
disk 1, a track diameter adjust signal including a
pair of inner signal 11 and outer signal 12 extending
alternately inward and outward from the center of the
track are recorded. The 4 - 96 pairs (8 pairs in the
20 present embodiment) of diameter adjust signal 10 are
arranged on the center of the track T_{25} symmetrically
with respect to the rotation axis 2 of the disk 1. A
timing signal 21 is arranged, as an index timing adjust
signal 20, on the center of the adjust signal track T_{25}
25 at a position corresponding to a predetermined time T
after an index timing detection point (IDX) 22. An
azimuth adjust signal 30 including preferably a pair of

1 CW signal 31 recorded by a signal write head 65 inclined
 by predetermined angles α and α' clockwise with respect
 to a radial line ℓ extending from the rotation axis 2
 and a pair of CCW signals 32 recorded by a signal write
 5 head 65 inclined by the angle α and α' counterclockwise
 with respect to the line ℓ , are arranged on the center
 of the adjust signal track T_{25} . The azimuth adjust
 signal may include only one CW signal and one CCW signal
 each inclined by the same angle α or α' . The 4 to 96
 10 (8 in the present embodiment) azimuth adjust signals 30
 are arranged alternately to the track diameter adjust
 signal pairs. The index timing signal and the azimuth
 adjust signal may be separately arranged on other tracks
 than the track diameter adjust signal track.

15 The diameter adjust signals are also recorded
 on the tracks which are equal to or larger than the
 number of phases of a stepping motor for driving the head
 carriage, and each of which corresponds to at least one
 phase of the stepping motor assuming that the stepping
 20 motor in the present embodiment has four phases, for
 example, eight pairs of track diameter adjust signal are
 recorded on each of three tracks in addition to the track
 T_{25} , for example, the 17th, 20th and 23rd tracks T_{16} ,
 T_{19} and T_{22} .

25 Further, eight pairs of track diameter adjust
 signal are recorded on at least one of the tracks close
 to the outermost track and the innermost track. In
 the present embodiment, they are recorded on the first

1 track T_0 and the 38th track T_{37} where the stepping motor phases are identical.

In Fig. 2, only the first, second, third, 20th, 26th and 40th tracks T_0 , T_1 , T_2 , T_{19} , T_{25} and T_{39} are shown although the track diameter adjust signals are also recorded on the tracks T_{16} , T_{22} and T_{37} .

Fig. 2 shows a front surface of the alignment disk 1. The same signals are recorded on a rear surface.

The signals are recorded on the alignment disk 1 by a signal write apparatus 40 shown in Fig. 3. As shown in Fig. 3, the signal write apparatus 40 comprises a table 41, a carriage 43 carrying magnetic heads 44, a guide 42 for moving the carriage 43 radially of the alignment disk 1, a direct drive (DD) motor 45 for rotating the disk 1 and a microscope 49 for detecting position of a center of a spindle 45a of the DD motor 45 and a center of a R/W gap of the magnetic heads 44.

The signals are written into the alignment disk 1 in the following manner. The disk 1 is mounted on the DD motor 5 through a disk mount mechanism 46, and the microscope 49 is moved radially of the disk and the center of rotation 45a of the DD motor 45 is detected by watching the microscope. Then, the magnetic head 44 is moved to the center T_a of the track which is spaced from the center of rotation 45a by a distance L and on which the track diameter adjust signal is to be written. The head 44 is positioned while the read/write gap center 44a of the head 44 is watched through the micro-

1 scope 49 such that the read/write gap center 44a is
positioned to the track center Ta.

Then, the track diameter adjust signal, index
timing signal and the azimuth adjust signal are written
5 on the track center Ta of the disk 1 by applying these
signals to the heads 44 from a signal generator (not
shown) in an operation panel 51.

Construction and operation of the magnetic disk
driving apparatus adjusted and verified by the alignment
10 disk 1 are explained with reference to Fig. 4. The
magnetic disk 54 is chucked to a rotary bearing 64 of
a direct drive (DD) motor 63 by a collet 62 and rotated
by the DD motor at a constant speed. The carriage 58
which carries the magnetic head 59 is movable radially of
15 the track by the STM 55, and the head 59 is positioned
to a target track by the carriage 58 to record and
reproduce data on and from the magnetic disk 54. The
head positioning mechanism is explained. The STM 55
fixed to a chassis (not shown) changes its rotation angle
20 stepwise by a control signal supplied from an I/O circuit
108. Thus, the carriage 58 is linearly moved along a
rail 65 through a steel belt wrapped around a pulley 57.
Accordingly, the magnetic head 59 mounted on the carriage
58 is linearly moved stepwise at a constant pitch
25 radially of the magnetic disk 54. By setting the pitch
to a track pitch, the magnetic head 59 is positioned to
the track. The index direction which is the direction
of the rotation of the magnetic disk 54 is detected
by an index timing photo-emitter 60 and an index timing

1 photo-sensor 61.

Factors of the positioning error by such a magnetic head positioning mechanism are;

- (1) a positioning error of the STM 55 and a
5 hysteresis error which depends on a load,
- (2) an accumulated error of the STM drive force transmission system which depends on circularity of the pulley 57, thickness of the steel belt 56 and manner of wrapping,
- 10 (3) chucking error representing eccentricity between the center of a disk and the center of the rotation axis of the motor, caused when the magnetic disk 54 is chucked, and
- (4) an error from a standard distance in the radial
15 direction of the disk between upper and lower magnetic heads.

The positioning error of the stepping motor 55 is explained with reference to Fig. 5. Assuming that the number of tracks is 40, the outermost track is numbered as
20 "00" and the innermost track is numbered as "39". A distance between the center of the designated track and the magnetic head 59 is represented as the positioning error of the stepping motor as shown in Fig. 5. It has been known that an error curve appears at a period corre-
25 sponding to the number of phases of the stepping motor (four phases in the present embodiment), and amount of errors of the tracks in the same phase is almost same. The phases 0, 1, 2 and 3 of the stepping motor are represented by ○, X, Δ and □, respectively.

1 In order to determine the positioning error of
the STM 55, the adjust signal track centers T_1 , T_{16} , T_{19} ,
 T_{22} and T_{25} of Fig. 2 are arranged to correspond to the
vicinity of the outermost track, the phases of the stepping
5 motor 55 and the vicinity of the innermost track, as shown
in Fig. 6, respectively.

Fig. 7 shows an off-track detected when the
STM 55 having the characteristic shown in Fig. 5 is
assembled into the magnetic disk driving apparatus. The
10 curve shows a combination of the positioning error of the
STM 55 and the accumulated error of the transmission
system. In general, the accumulated error does not finely
change. The adjust signal track centers (T_1 and T_{37} in
the present embodiment) are arranged in the vicinity of
15 the outermost track and the innermost track of the
alignment disk, and a gradient of the curve of Fig. 7 is
linear-approximated from the off-tracks in those two
tracks and the off-track in one of the tracks T_{16} , T_{19} ,
 T_{22} and T_{25} . In the present embodiment, the adjust signal
20 track center is set in the tracks T_1 and T_{37} of the same
phase (phase 1 in the present embodiment) so that it is
discriminated from the positioning error of the STM 55.
The tracks marked with 0 in Fig. 7 indicate the tracks
on which the adjust signals are recorded.

25 One embodiment of a tracking verification
apparatus for the magnetic disk driving apparatus in
accordance with the present invention is explained with
reference to Fig. 8.

As shown in Fig. 8, the tracking verification

1 apparatus comprises a magnetic disk driving apparatus 102,
a rectifier 103, a filter 104, an A/D converter 105, I/O
circuits 106 and 108 and a personal computer 107. The
personal computer 107 has a CRT 108 and a keyboard 109,
5 and also has a CPU, a ROM and a RAM (not shown).

The apparatus of Fig. 8 operates in the following
manner.

The alignment disk 1 having the track diameter
adjust signal, azimuth adjust signal and index timing
10 adjust signal recorded on predetermined tracks is loaded
to the magnetic disk driving apparatus 102. A control
signal is supplied to the head carriage drive apparatus or
the stepping motor of the magnetic disk driving apparatus
102 from the personal computer 107 through the I/O circuit
15 108 by manipulating the keyboard 109 so that the magnetic
head is moved to the reference outermost track. Then,
the magnetic head is moved to a predetermined track on
the alignment disk 102 having the adjust signals recorded
thereon. The adjust signal is reproduced from that track
20 by the magnetic head and it is converted to a DC voltage
containing a ripple component by the rectifier 103, and
the high frequency ripple component is eliminated by the
filter 104. The output of the filter 104 is converted
to a digital signal by the A/D converter 105, and the
25 digital data is written into the memory of the personal
computer 107 through the I/O circuit 106. Then, the off-
track, index timing and azimuth etc. are calculated based
on the data stored in the memory. The magnetic head is

1 then moved to an inner predetermined track of the align-
 ment disk 1 and the same process is carried out. The data
 are also read from the remaining predetermined tracks in
 the same manner, and the direction of movement is changed
 5 so that the magnetic head is moved from the inner track
 to the outer track, and the same process is repeated.
 After the data have been read and processed for the prede-
 termined tracks, the personal computer displays on the
 CRT the error or deviation in the radial direction between
 10 the upper and lower magnetic heads, positioning error of
 the STM, hysteresis error due to the direction of rotation
 of the STM, chucking error and accumulated error of the
 transmission system.

The operation to adjust and verify the magnetic
 15 disk driving apparatus by using the alignment disk 1 is
 explained. Waveforms of $1/8$ period of adjust signals
 reproduced by scanning the track No. 25 corresponding to
 the adjust signal track center T_{25} by the magnetic head,
 and output waveforms from the filter 104 of Fig. 8 are
 20 shown in Fig. 9, in which (a) shows a signal reproduced by
 the upper head, (b) shows a filter output signal for the
 upper head, (c) shows a signal reproduced by the lower head,
 and (d) shows a filter output signal for the lower head.
 Symbols T_1 , T_2 , V_{RUA} etc. correspond to output values of
 25 the A/D converter 105 fetched into the computer 107.

(1) A positioning error between a radial position
 on the predetermined track and the lower (or upper) head
 is determined in proportion to a ratio V_{RLA}/V_{RLB} (or

1 V_{RUA}/V_{RUB}), that is, a ratio of a magnitude V_{RLA} (or V_{RUA}) of the inner track signal of the track diameter adjust signal 10 and a magnitude V_{RLB} (or V_{RUB}) of the outer track signal 12.

5 (2) The index timing is verified by detecting a time difference T_1 (or T_2) between a rise time point of the reproduced index timing adjust signal 21 detected by the lower (or upper) head and an index timing detection time point (IDX) 22. This time difference indicates a
10 position of the magnetic head in the rotational direction of the disk from the reference position. The index timing is adjusted and verified such that the time difference is within a predetermined allowable time T .

(3) The azimuth angle is verified by determining
15 a ratio $V_{\theta LA}/V_{\theta LB}$ (or $V_{\theta UA}/V_{\theta UB}$), that is, a ratio of a magnitude $V_{\theta LA}$ (or $V_{\theta UA}$) of the CW signal 31 of the azimuth adjust signal 30 detected by the lower (or upper) head and a magnitude $V_{\theta LB}$ (or $V_{\theta UB}$) of the CCW signal 32. This ratio indicates the azimuth angle of the magnetic
20 head. Whether the azimuth angle of the R/W gap of the lower or upper magnetic head is within an allowable range or not is verified based on this ratio.

Thus, the adjustment and verification of precision in the radial direction of the track, the
25 adjustment and verification in the index timing direction, and the adjustment and verification in the azimuth direction are simultaneously carried out.

Fig. 10 shows waveforms of the track diameter

1 adjust signal reproduced by the magnetic head 59 on
the track No. 1 (T_1) in the vicinity of the outermost
track, and filtered by the filter 104 of Fig. 8. In
Fig. 10, (a) shows a waveform reproduced by the upper
5 head, and (b) shows a waveform reproduced by the lower
head. Eight pairs of track diameter adjust signal for
one circle of track are shown in Fig. 10.

(1) A mean value ΔL (or ΔU) in each track of
positioning error between a radial position on the prede-
10 termined track and the lower (or upper) head is represented
by

$$\Delta L = \frac{1}{8} \cdot \sum_{i=1}^8 \frac{W}{2} \cdot \frac{(V_{RLA})_i - (V_{RLB})_i}{(V_{RLA})_i + (V_{RLB})_i}$$

$$\Delta U = \frac{1}{8} \cdot \sum_{j=1}^8 \frac{W}{2} \cdot \frac{(V_{RUA})_j - (V_{RUB})_j}{(V_{RUA})_j + (V_{RUB})_j}$$

where $(V_{RLA})_i$ and $(V_{RLB})_i$ (or $(V_{RUA})_j$ and $(V_{RUB})_j$) are
magnitudes of the inner track signal V_{RLA} (or V_{RUA}) and
the outer track signal V_{RLB} (or V_{RUB}) of each of the
15 eight pairs of the adjust signals, and W is the R/W gap
of the magnetic head 59. The error on each track can be
determined in the same manner, and the off-track error
due to the positioning error of the stepping motor,
the hysteresis error and the accumulated error for the
20 movement from the inner track to the outer track or from
the outer track to the inner track, and the assembly
error of the upper and lower heads of the magnetic head

1 can be verified and adjusted.

(2) The accumulated error can be linearly approximated as: $|\Delta_{37} - \Delta_1|$ when $(\Delta_{37} - \Delta_{25})$ and $(\Delta_{25} - \Delta_1)$ are of the same sign (both + or -), or a larger one of $|\Delta_{37} - \Delta_{25}|$ and $|\Delta_{25} - \Delta_1|$ when $(\Delta_{37} - \Delta_{25})$ and $(\Delta_{25} - \Delta_1)$ are of the opposite signs (one is + and the other is -),

where Δ_1 , Δ_{25} and Δ_{37} are position errors between the radial position on the track and the head in the tracks No. 1 (T_1), No. 25 (T_{25}) and No. 37 (T_{37}) which are of the same excitation phase of the STM 55. Thus, the accumulated error can be displayed and verified.

(3) The chucking error S which is the eccentric component error caused when the magnetic disk is chucked is represented by (for the lower head)

$$2S = \frac{W}{2} \cdot \left\{ \left(\frac{(V_{RLA})_i - (V_{RLB})_i}{(V_{RLA})_i + (V_{RLB})_i} \right)_{\max} - \left(\frac{(V_{RLA})_i - (V_{RLB})_i}{(V_{RLA})_i + (V_{RLB})_i} \right)_{\min} \right\}$$

15 where $(V_{RLA})_i/(V_{RLB})_i$ or $(V_{RUA})_j/(V_{RUB})_j$ is the ratio of the eight pairs of track diameter adjust signals on one circle of track.

Those errors are displayed on the CRT 108 of the personal computer of Fig. 8 as shown in Fig. 11.

20 Diamonds a_1 to a_8 represent the error between the radial position on the track and the head, chucking error and hysteresis error etc. in the tracks No. 16 (T_{16}), No. 19 (T_{19}), No. 22 (T_{22}) and No. 35 (T_{25}), $a_1 - a_4$

1 represent the errors produced when the lower head scans
 the rear side (side 0) of the alignment disk 1, and
 $a_3 - a_8$ represent the errors produced when the upper head
 scans the front side (side 1) of the disk 1. The side
 5 l_1 (or l_2) in each track is represented by plotting the
 eight values $(V_{RLA})_i / (V_{RLB})_i$ or $(V_{RUA})_j / (V_{RUB})_j$. In each
 diamond, the left side l_1 represents the error produced
 when the head is moved inward, and the right side l_2
 represents the error produced when the head is moved
 10 outward. Accordingly, the hysteresis error is represented
 by a vertical axis length H of a side l_3 connecting the
 side l_1 and the side l_2 . The chucking error is represented
 by one half length of the side l_1 or side l_2 . The radial
 direction error produced when the upper head and the lower
 15 head of the magnetic head 59 are assembled is represented
 by a difference between vertical axis lengths of the
 diamonds a_1 and a_5 for the same track (for example, track
 No. 16 (T_{16})) on the front side and the rear side of the
 disk 1.

20 The variation of the positioning errors for
 the respective excitation phases of the STM can be grasped
 from the vertical axis positions of the diamonds $a_1 - a_4$.
 A sum of the accumulated error and the track radial
 position error is represented by a rectangle a_9 , where
 25 l_6 represents a maximum track radial position error in
 the four tracks shown on the right, and l_4 and l_5
 represent the accumulated errors for the outermost
 track T_1 , the track T_{25} and the innermost track T_{37} ,

1 and λ_4 and λ_5 correspond to one of $(\Delta_{37} - \Delta_{25})$ and
 5 $(\Delta_{25} - \Delta_1)$. A sum of $\lambda_4 - \lambda_6$ represents a sum of the
 track radial direction positioning errors of the magnetic
 disk driving apparatus determined by the alignment disk
 1. Based on this sum, whether the position adjustment of
 the head carriage drive apparatus is within the allowable
 range or not can be determined. When a high density
 magnetic disk driving apparatus is to be verified, the use
 of λ_4 and λ_5 for the determination is very important in
 10 suppressing the error within the allowable range.

The verification results for the index timing
 and the azimuth angle may be numerically or graphically
 displayed as required.

The tracking method of the magnetic disk
 15 driving apparatus of the present invention is explained.
 In Fig. 4, the carriage 58 which carries the magnetic
 head 59 is moved by the stepping motor 55 through the
 steel belt 56. In order to maintain the data inter-
 changeability which is important to the magnetic disk
 20 driving apparatus, the tracking is required. The
 alignment disk 1 having the track diameter adjust signal
 10 recorded on the predetermined track center is loaded
 to the magnetic disk driving apparatus 102, the track
 diameter adjust signal 10 is read by the magnetic head
 25 59, the stepping motor 55 is finely adjusted to the
 track radial direction P or Q to position the magnetic
 head to maintain the data interchangeability of the
 magnetic disk driving apparatus.

1 A method for adjusting the off-track by the
tracking of the present embodiment is explained with
reference to Figs. 12, 13 and 14. A tracking verifi-
cation apparatus (see Fig. 8) which measures the off-track
5 between the alignment disk 1 having the track diameter
adjust signal 10 recorded on the tracks corresponding to
the excitation phases of the stepping motor 55 (4-phase
excitation stepping motor in the present embodiment)
 T_{16} , T_{19} , T_{22} and T_{25} , and the magnetic head is used to
10 display the off-track of the respective tracks on the
CRT as shown in Figs. 12 - 14.

A maximum off-track 110 on one track produced
when the head is moved from the inner track to the outer
track on the front side (side 0) of the disk is represented
15 by ●, and a minimum off-track on one track produced when
the head is moved from the outer track to the inner
track is represented by o. A maximum off-track 112a on
one track produced when the head is moved from the inner
track to the outer track on the rear side (side 1) of
20 the disk is represented by o, and a minimum off-track on
one track produced when the head is moved from the outer
track to the inner track is represented by ●. The
stepping motor is finely adjusted radially of the track
so that the maximum off-track 110a or 112a is within the
25 allowable range 10b ($\pm 20 \mu\text{m}$ for 96 TPI, and $\pm 15 \mu\text{m}$ for
135 TPI).

A method for adjusting the off-track by the
tracking method using the four-phase adjust signal is

1 explained with reference to Fig. 13. The off-track in
 Fig. 3 is represented in the same manner as that of
 Fig. 12 but a mean value 117 of the off-tracks for all
 tracks is represented in Fig. 13. The mean value is
 5 obtained by averaging ΔL and ΔU for the tracks T_{16} , T_{19} ,
 T_{22} and T_{25} .

When the maximum off-track exceeds 20 μm , the
 stepping motor is finely adjusted radially of the track
 to set the mean value 117 to the vicinity of the prede-
 10 termined track center of the alignment disk 1 to bring
 the maximum off-track within 20 μm . In accordance with
 the present embodiment, the off-tracks of the magnetic
 head for all tracks is smaller than 20 μm and the
 positioning precision of the magnetic head is improved.

15 A method for adjusting the off-track by other
 tracking method is explained with reference to Fig. 14.

In Fig. 14, the track diameter adjust signals
 on the tracks T_{16} , T_{19} , T_{22} and T_{25} as well as at least
 one of the innermost and outermost tracks T_{37} and T_{01}
 20 are used, and the mean value 117 of the off-tracks for
 the tracks T_{01} , T_{10} , T_{19} , T_{22} , T_{25} and T_{37} is calculated
 and displayed. If the maximum off-track exceeds 20 μm ,
 the stepping motor is finely adjusted radially of the
 track to set the mean value 117 to the vicinity of the
 25 predetermined track center of the alignment disk 1 to
 bring the maximum off-track within 20 μm . In accordance
 with the present embodiment, the positioning precision
 of the magnetic head for all tracks including the inner-
 most and outermost tracks is improved and the reliability

1 is improved. If the maximum off-track exceeds the allowable range, whether it is mainly due to the error of the stepping motor or the error in the assembly work is determined by checking the chucking error, radial direction error between the upper and lower heads and hysteresis error etc. displayed on the CRT, and so the error in the next assembly can be brought within the allowable range. Thus, the productivity is improved.

A flow chart of the tracking method of the present embodiment is explained with reference to Fig. 15.

In a step 200, the alignment disk 1 is loaded to the magnetic disk driving apparatus 102. In a step 202, the head is sought to the track No. 00 (T_0). In a step 204, the stepping motor 55 is set to seek the head inward. In a step 206, the carriage 58 which carries the magnetic head 59 is sought to the target track. In a step 208, the adjust signal is reproduced by the magnetic head.

The steps 206 and 208 are sequentially repeated to the tracks corresponding to the excitation phases of the stepping motor (T_{16} , T_{19} , T_{22} and T_{25} in the present embodiment) to read the data. In a step 210, whether the seeking from the outer track to the inner track and from the inner track to the outer track has been completed for the tracks T_{16} , T_{19} , T_{22} and T_{25} or not is checked, and if the decision is NO, the process proceeds to a step 212 where the head is sought to the innermost track T_{39} .

1 In a step 214, the stepping motor 55 is set to seek the head outward. In a step 206, the carriage 58 is sought to the target track and the data is read. In this manner, the tracks T_{25} , T_{22} , T_{19} and T_{16} are sequentially
5 sought and the data are read.

 When the seeking in the inward and outward directions and the reading of the data for all tracks are completed, the off-track on the target track is displayed on the CRT 108 in a step 216 as shown in Figs. 12 and 13.
10 In a step 218, whether the maximum off-track exceeds the allowable range or not is checked, and if it exceeds, it is displayed. If the maximum off-track exceeds the allowable range (approximately $\pm 20 \mu\text{m}$ for the 5-inch 96 TPI alignment disk), the positioning is adjusted so that the
15 off-track is brought within the allowable range.

 The predetermined tracks T_1 and T_{37} in the vicinity of the outermost track and the innermost track may be sought and the data thereof may be read and displayed as shown in Fig. 14. The hysteresis error
20 positioning error of the STM, radial direction error between the upper and lower heads, accumulated error and the chucking error may be displayed as shown in Fig. 11.

 In accordance with the present embodiment, whether the off-track is large due to the positioning
25 error of the stepping motor and the hysteresis error, or it is due to the chucking error S, accumulated error or radial direction error between the upper and lower heads can be determined, and the productivity is improved.

1 The result of verification of the index timing
and the azimuth angle may also be displayed.

In accordance with the present invention,

(1) precision of positioning
5 (2) positioning error of the stepping motor,
hysteresis error and accumulated error of the transmission
system, and

(3) chucking error of the magnetic disk and radial
deviation between the lower head and the upper head can
10 be collectively displayed on the CRT. Accordingly, by
verifying a product, part by part, such as a magnetic disk
driving apparatus in which the precision of the components
has reached the limit and which is designed taking the
required precision of each component into account in a
15 probability distribution manner, the allowable range or
required precision of the positioning error of the head
carriage drive unit is determined for each magnetic disk
drive apparatus. By adjusting the drive with necessary
and sufficient precision, unnecessary and wasteful
20 adjusting time is saved and the productivity, reliability
and stability are improved. If the maximum off-track
exceed the allowable range, the chucking error and the
hysteresis error, positioning error of the stepping motor,
radial direction error between the upper and lower heads
25 and accumulated error etc. are checked based on the
display on the CRT so that the component in trouble or
the assembly process in trouble is determined. By
adjusting the component in trouble in the next assembly,

the productivity and reliability are improved.

In addition to the adjustment and verification in the radial direction of the track, the adjustment and verification in the direction of index timing, that is, the direction of rotation of the magnetic disk, by the use of the index timing adjust signal, and the adjustment and verification in the direction of the R/W gap inclination by the use of the azimuth adjust signal can be numerically done, and high precision adjustment and verification are attained, and the reliability for the high density disk drive apparatus is improved.

Attention is drawn to our Patent Application No. 8703534 (Serial No. 2,187,878) from which this Application has been divided and also our Patent Application No. 8926034 (Serial No. 2,226,179) which is also a divisional application of parent application 8703534.

CLAIMS:

1. ~~According to the present invention there is~~
provided Apparatus for tracking error verification for a
magnetic disk drive apparatus having magnetic head means
5 for recording and reproducing data on or from a magnetic
recording medium, a head carriage for carrying said
magnetic head means, and head carriage drive means having a
stepping motor for driving said head carriage relative to
said magnetic recording medium so as to radially cross a
10 plurality of tracks of said magnetic recording medium, said
magnetic head means being capable of being adjusted in its
position radially of a predetermined track from an adjust
signal read by said head means which is recorded on an
alignment disk, said alignment disk being loaded and
15 unloaded to and from said magnetic disk drive apparatus,
said alignment disk having a set of track diameter adjust
signal pairs recorded on a predetermined number of tracks
of said alignment disk, the total number of tracks in the
plurality of tracks equal to or larger in number than the
20 number of phases of said stepping motor, the predetermined
number of tracks respectively corresponding to at least the
phases of said stepping motor, a set of track diameter
adjust signal pairs being recorded on at least a track in
the vicinity of at least one of an innermost track and an
25 outermost track; said apparatus including:

(a) filter means for filtering the adjust signal
read by said magnetic head means when said alignment disk



is loaded to said magnetic disk drive apparatus and providing an output indicative thereof;

(b) A/D conversion means for digitizing the output of said filter means and providing an output
5 indicative thereof;

(c) memory means for storing the output of said A/D conversion means;

(d) control means for supplying a control signal to said head carriage drive means to drive said head
10 carriage;

(e) calculation means for calculating, base don the data stored in said memory means, at least an error which is accumulated through the movement of said head means from the inner track to the outer track of said
15 alignment disk, said error including a positioning error of said drive means, a hysteresis error depending on the direction of drive of said carriage, and an eccentricity error of the disk; and

(f) display means for displaying a result of said
20 calculation means;

said control means controlling said head carriage to move from the outer track to the inner track and from the inner track to the outer track so that said magnetic head means scans the track corresponding to at least the
25 phases of the stepping^{motor,} for driving said carriage head.

2. Apparatus for tracking error verification according to claim 1, wherein said control means controls



said head carriage to move from the outer track to the inner track and from the inner track to the outer track so that said magnetic head means scans the tracks corresponding to the excitation phases of said stepping motor as well as at least one of the tracks in the vicinity of the outermost track and the innermost track.

3. Apparatus for tracking error verification according to claim 1, wherein said alignment disk further has an index timing adjust signal for detecting a position of said magnetic head means in the direction of disk rotation and an azimuth adjust signal for detecting an inclination of a read/write gap of the magnetic head means, recorded thereon as said adjust signal, and the index timing adjust signal and the azimuth adjust signal are read and processed to display the inclination of said magnetic head means and the position of said magnetic head means from a reference position in the direction of disk rotation.

4. Apparatus for tracking error verification according to claim 1, wherein said set of track diameter adjust signal pairs each have an inner track signal and an outer track signal extending inward and outward from a centre of the track, the inner and outer track signals of respective pairs having the same size in the circumferential and radial directions, said set of track diameter adjust signals pairs being arranged symmetrically



around a rotation axis of said alignment disk.

5. Apparatus for tracking error verification according to claim 1, said apparatus further comprising means for obtaining a ratio of output signals of a pair of track diameter adjust signals read by said magnetic head means,

wherein said set of track diameter adjust signal pairs each have an inner track signal and an outer track signal extending inward and outward from the centre of a track, said inner and outer track signals being substantially equal in width in directions perpendicular to the track and spaced along the track with a distance therebetween, said set of track diameter adjust signal pairs being arranged symmetrically around a rotation axis of said disk, and

said display means includes means for displaying the obtained ratios thereby indicating a direction of displacement of said head means from a track and an amount of the displacement.
