

CHARACTERISTIC EVALUATION METHOD FOR MAGNETIC DISK MEDIUM

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

The present invention relates to a characteristic evaluation method for a magnetic disk medium. More particularly, it relates to a method of quantitatively evaluating the nonlinear transition shift, the partial erasure or the like nonlinear distortion of a recorded signal attributed to the fact that bits are adjacently recorded in a high-density record medium.

2. DESCRIPTION OF THE RELATED ART

As signal processing in the read channel of a magnetic disk device, a PRML (Partial Response Maximum Likelihood) scheme has become the present-day mainstream instead of a conventional peak detection method. The PRML method is the scheme wherein PR equalization in which a head signal waveform is equalized to a predetermined PR target by an equalizer is combined with an ML method in which NRZ data are reproduced from bit data sampled at a channel rate, by maximum-likelihood decoding. When a bit interval narrows, the interference of waveforms occurs, and bit detection becomes difficult with

the peak detection method. In contrast, since the PRML method positively utilizes the waveform interference, the bit detection of a higher line record density is possible. However, when a line record density becomes conspicuously high (the bit interval becomes conspicuously narrow), the nonlinear distortion of a head signal increases, and the performance of the bit detection in the PRML method degrades. This is because the PR equalization is based on the linear superposition of signals. In the development of a high-record-density medium, therefore, it becomes important to precisely evaluate the magnitude of the nonlinear distortion.

The nonlinear distortion includes the two sorts of a nonlinear transition shift and a partial erasure. In a case where two magnetization transitions have been recorded in proximity, the magnetization transition recorded later is influenced by a leakage magnetic field from the magnetization transition recorded before, and a position at which the former magnetization transition is formed shifts forward of its original position. This is called the "nonlinear transition shift".

Besides, in the case where the two magnetization transitions have been recorded in proximity, the amplitude

of a reproduced pulse waveform based on each of the magnetization transitions becomes smaller than an amplitude in the case where the reproduced pulses of isolated waveforms are linearly superposed. This is called the "partial erasure". The partial erasure includes the following two factors: One of them is ascribable to the fact that a head magnetic field undergoes interference on account of a demagnetic field from an adjacent bit, so the magnetization transition width of a recorded bit spreads. The other is ascribable to the fact that a region where magnetization is divided appears within a bit cell on account of the interaction between grains constituting a recorded layer, resulting in the decrease of the total magnetization.

Various methods have heretofore been proposed for measuring the nonlinear distortion. They are classified into a time domain method and a frequency domain method. The time domain method includes a method stated in IEEE Trans. Magn., Vol. 23, pp. 2377-2379, 1987. This method is such that pseudo-random signals are recorded on a disk, that the dibit response of a reproduction system is obtained by the inverse convolution calculations between the input pseudo-random signals and the reproduced signal waveform thereof, and that the magnitude of the nonlinear distortion is obtained from the amplitude value of an echo on a dibit response waveform

attributed to a nonlinearity. The method has the advantage that all sorts of nonlinearities can be analyzed. However, it has the problems that the processing of the calculations for obtaining the dibits is complicated, and that an extreme measurement error arises when a DC offset exists in the reproduced signal waveform.

Besides, the frequency domain method includes a method called a "Harmonic Elimination method" stated in IEEE Trans. Magn., Vol. 27, No. 6, pp. 5316-8, 1991. This method is such that a periodic pattern which contains dibits and isolated bits and in which specified odd-numbered order higher harmonic components become zero in a case where a nonlinear component is zero, and a reference pattern which contains only isolated bits are respectively written into a disk, that the reproduced signal waveforms of the patterns are frequency-analyzed to obtain the odd-numbered order higher harmonic components of the respective waveforms, and that the nonlinear transition shift is evaluated in terms of the ratio between the magnitudes of the higher harmonic components. The method has the advantage that the processing is comparatively simple and easy of performance. However, it has the problem that the partial erasure and the nonlinear transition shift cannot be separated, so the nonlinear transition shift becomes larger than an actual magnitude,

under the influence of the partial erasure. Besides, the method assumes that the nonlinear transition shift is sufficiently smaller than a bit interval, and it therefore has the problem that the measurement precision of the nonlinear transition shift degrades under a condition in which the assumption does not hold true.

Besides, regarding a method in which the nonlinear transition shift and the partial erasure are separately measured, there is a method stated in IEEE Trans. Magn., Vol. 31, No. 6, pp. 3021-6, 1995. This method is such that the partial erasure is first obtained alone by employing a square wave signal which is not influenced by the nonlinear transition shift, while the total nonlinear distortion is obtained by the above harmonic elimination method. In addition, the nonlinear transition shift is obtained from both the obtained results. It is a method which is excellent in the point that the nonlinear distortion can be separated. For the above reason, however, it has the problem that the measurement precision of the nonlinear transition shift degrades under the condition in which the assumption of the nonlinear transition shift being sufficiently smaller than the bit interval does not hold true.

Besides, another method in which the nonlinear

transition shift and the partial erasure are separately measured is a method stated in Patent JP-A-10-269511. This method is the improved method of the harmonic elimination method based on the fifth order harmonic. It is such that a periodic pattern of 30 bits containing dibits and isolated bits is employed as a measurement pattern, that the fifth order harmonic ratio between the measurement pattern and a reference pattern which is caused to contain only the isolated bits by successively changing the bit intervals of the dibits is obtained, and that the partial erasure is obtained from the minimum value of the ratio. Further, the value of the nonlinear transition shift is obtained by employing the relational formula between the fifth order harmonic ratio and the partial erasure as well as the nonlinear transition shift. Since, however, this method necessitates means for finely adjusting the intervals of the dibits at a high precision, it is not easy of realization.

Here, a measurement principle for the nonlinear transition shift as is based on the prior-art harmonic elimination method stated in IEEE Trans. Magn., Vol. 27, No. 6, pp. 5316-8, 1991 will be elucidated in order to supplement the embodiment of the present invention as will be described later.

Fig. 3 shows a periodic pattern containing dibits and isolated bits, for use in the harmonic elimination method, and the reproduced signal waveform thereof. This pattern is composed of the dibits P and the succeeding isolated bits Q. Here, the term "dibit" signifies a pattern in which magnetization transitions succeed two bits. This pattern is represented by an NRZI (Non-Return to Zero Invert) notation, as given below. Incidentally, the "NRZI notation" is a method in which the existence of the magnetization transition is noted as "1", whereas the nonexistence of the magnetization transition is noted as "0".

1100...(m 0's)100...(n 0's)1100... (m 0's)100... (n 0's)

Here, $m = 6p$ and $n = 6q$ (where p and q denote natural numbers) hold true. The number of bits of this pattern is $N = 2m + 2n + 6$, and the period thereof is $(2m + 2n + 6)T$ (where T denotes the bit period of the dibits). It will be indicated below that, in a case where the nonlinear distortion is nonexistent, the specified odd-numbered order higher harmonics of the reproduced signal waveform become zero.

As shown in Fig. 4, the pattern in Fig. 3 is decomposed into three periodic patterns (a) - (c) of isolated bits. Accordingly, the reproduced signal waveform $y(t)$ is expressed as follows:

Formula 1

$$y(t) = x(t) - x(t - (n + 1)T) + x(t - (n + 2)T)$$

Here, "x(t)" denotes the temporal waveform of the periodic pattern (a) in Fig. 4.

The frequency spectrum $Y(\omega)$ of the reproduced signal waveform is expressed as:

Formula 2

$$Y(\omega) = X(\omega) - X(\omega) \cdot e^{-j\omega(n+1)T} + X(\omega) \cdot e^{-j\omega(n+2)T}$$

Here, a fundamental frequency ω_0 is expressed as:

Formula 3

$$\omega_0 = \frac{2\pi}{NT} = \frac{\pi}{(m + n + 3)T}$$

The k th order harmonic component is expressed as:

Formula 4

$$\begin{aligned} Y(k \omega_0) &= X(k \omega_0) - X(k \omega_0) \cdot e^{-jk\omega_0(n+1)T} + X(k \omega_0) \cdot e^{-jk\omega_0(n+2)T} \\ &= X(k \omega_0) - X(k \omega_0) \cdot e^{-j\frac{n+1}{m+n+3}k\pi} + X(k \omega_0) \cdot e^{-j\frac{n+2}{m+n+3}k\pi} \end{aligned}$$

In case of $k = 2p + 2q + 1$, the k th order harmonic

component becomes zero as indicated below:

Formula 5

$$\begin{aligned}
Y(k \omega_0) &= X(k \omega_0) \cdot \left(1 - e^{-j \frac{n+1}{m+n+3} k\pi} + e^{-j \frac{n+2}{m+n+3} k\pi}\right) \\
&= X(k \omega_0) \cdot \left(1 - e^{-j \frac{2q+1}{6p+6q+3} (2p+2q+1)\pi} + e^{-j \frac{2q+2}{6p+6q+3} (2p+2q+1)\pi}\right) \\
&= X(k \omega_0) \cdot \left(1 - e^{-j \frac{6q+1}{3} \pi} + e^{-j \frac{6q+2}{3} \pi}\right) \\
&= X(k \omega_0) \cdot \left(1 - e^{-j \frac{1}{3} \pi} + e^{-j \frac{2}{3} \pi}\right) = 0
\end{aligned}$$

Here, "k" is always an odd number, and k = 5 holds true in case of p = q = 1 by way of example.

Next, it will be indicated that, in the existence of the nonlinear transition shift, the value thereof can be obtained from the kth order harmonic components of the respective reproduced signal waveforms of the periodic pattern containing the dibits and the isolated bits and the periodic pattern of the isolated bits.

In the existence of the nonlinear transition shift, the temporal waveform $\hat{y}(t)$ (the reproduced signal waveform of the periodic pattern containing the dibits and the isolated bits) is expressed as follows, when Δ denotes the nonlinear transition shift:

Formula 6

$$\hat{y}(t) = x(t) - x(t - (n+1)T + \Delta) + x(t - (n+2)T + \Delta)$$

Here, owing to $x(t + \Delta) \cong x(t) + \Delta x(t) / dt$, the following is obtained:

Formula 7

$$\begin{aligned} \hat{y}(t) &= x(t) - x(t - (n+1)T + \Delta) + x(t - (n+2)T + \Delta) \\ &= x(t) - x(t - (n+1)T) - \Delta \cdot x(t - (n+1)T) / dt + x(t - (n+2)T) \\ &\quad + \Delta \cdot x(t - (n+2)T) / dt \end{aligned}$$

Here, “ $y(t)$ ” is let denote the temporal waveform of the periodic pattern containing the dibits and the isolated bits, in the nonexistence of the nonlinear transition shift, and an error signal $e(t)$ is defined as follows:

Formula 8

$$\begin{aligned} e(t) &= \hat{y}(t) - y(t) \\ &= -\Delta \cdot x(t - (n+1)T) / dt + \Delta \cdot x(t - (n+2)T) / dt \end{aligned}$$

The frequency spectrum $E(\omega)$ becomes:

Formula 9

$$E(\omega) = -\Delta \cdot \omega X(\omega) \cdot e^{-j\omega(n+1)T} + \Delta \cdot \omega X(\omega) \cdot e^{-j\omega(n+2)T}$$

The k th order harmonic component is expressed as follows:

Formula 10

$$\begin{aligned}
E(k\omega_0) &= -\Delta \cdot k\omega_0 X(k\omega_0) \cdot e^{-jk\omega_0(n+1)T} + \Delta \cdot k\omega_0 X(k\omega_0) \cdot e^{-jk\omega_0(n+2)T} \\
&= -\Delta \cdot k\omega_0 X(k\omega_0) \cdot e^{-j\frac{2p+2q+1}{(6p+6p+3)}(6q+1)\pi} + \Delta \cdot k\omega_0 X(k\omega_0) \cdot e^{-j\frac{2p+2q+1}{(6p+6p+3)}(6q+2)\pi} \\
&= -\Delta \cdot k\omega_0 X(k\omega_0) \cdot e^{-j(2q+\frac{1}{3})\pi} + \Delta \cdot k\omega_0 X(k\omega_0) \cdot e^{-j(2q+\frac{2}{3})\pi} \\
&= -\Delta \cdot k\omega_0 X(k\omega_0) \cdot (e^{-j\frac{1}{3}\pi} - e^{-j\frac{2}{3}\pi}) \\
&= -\Delta \cdot k\omega_0 X(k\omega_0)
\end{aligned}$$

Here, from the following:

Formula 11

$$E(k\omega_0) = \hat{Y}(k\omega_0)$$

(where $\hat{Y}(k\omega_0)$ denotes the k th order harmonic component of the reproduced signal waveform $\hat{y}(t)$ of the periodic pattern containing the dibits and the isolated bits), the nonlinear transition shift Δ eventually becomes:

Formula 12

$$\Delta = \frac{|E(k\omega_0)|}{k\omega_0 |X(k\omega_0)|} = \frac{|\hat{Y}(k\omega_0)|}{k\omega_0 |X(k\omega_0)|}$$

In this manner, the nonlinear transition shift is evaluated as the ratio between the magnitudes of the k th order harmonic components of the respective reproduced signal waveforms of the periodic pattern containing the dibits and the isolated bits, and the periodic pattern of the isolated bits.

Next, a measurement procedure for the nonlinear transition shift based on the prior-art harmonic elimination method will be described.

The periodic pattern is assumed to have $m = 6$, $n = 6$, the number of bits $N = 30$, and the bit period T . On this occasion, the fundamental frequency becomes $\omega_0 = 2\pi/NT$, and the higher harmonic to be eliminated becomes the fifth order harmonic.

First, the periodic pattern containing the dibits and the isolated bits:

110000001000000110000001000000

is recorded on a magnetic disk at the bit period T .

Subsequently, the periodic pattern containing the dibits and the isolated bits is read, and the magnitude $|Y(5\omega_0)|$ of the fifth order harmonic component is obtained by a

frequency analysis.

Subsequently, the periodic pattern of the isolated bits:

10000000000000010000000000000000

is recorded on the magnetic disk at the bit period T .

Subsequently, the isolated-bit periodic pattern is read, and the magnitude $|X(5\omega_d)|$ of the fifth order harmonic component is obtained by a frequency analysis.

In addition, the nonlinear transition shift Δ is evaluated as $\Delta = |Y(5\omega_0)| / (5\omega_0 \times |X(5\omega_0)|)$.

As stated above, in the prior-art harmonic elimination method, the approximation $x(t + \Delta) \cong x(t) + \Delta x(t)/dt$ is made assuming that the nonlinear transition shift is sufficiently smaller than the bit period T . Therefore, this method has the problem that the measurement precision degrades under the condition in which the assumption does not hold true. Besides, this method cannot separate the partial erasure, so that the nonlinear transition shift becomes larger than its actual magnitude in the existence of the partial erasure.

Also the method stated in IEEE Trans. Magn., Vol. 31,

No. 6, pp. 3021-6, 1995 as separately measures the partial erasure and the nonlinear transition shift assumes that the nonlinear transition shift is sufficiently smaller than the bit period T , and it has the same problem as that of the harmonic elimination method.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a method which can separately measure a nonlinear transition shift and a partial erasure in the measurement of the nonlinear distortion of a magnetic disk, in which a measurement precision does not degrade even at a high record density where the nonlinear transition shift is not negligible relative to a bit period, and which can quantitatively evaluate the nonlinear distortion without requiring fine adjustment means for the bit interval of a periodic pattern to-be-recorded.

The invention is characterized by comprising the steps of recording a first periodic signal which contains dibits and isolated bits, into a magnetic disk in synchronism with a clock signal which is synchronous to a rotation of the magnetic disk and which is generated on the basis of a trigger signal synchronous to the rotation of the magnetic disk; sampling a read signal of the first periodic signal recorded

on the magnetic disk, in accordance with a sampling clock which is synchronous to a rotation of the magnetic disk and which is generated on the basis of the trigger signal; Fourier-transforming those sampling data of the first periodic signal which have been obtained by the sampling, thereby to obtain a predetermined odd-numbered order harmonic component with respect to a fundamental frequency; recording a second periodic signal which contains only isolated bits, into the magnetic disk in synchronism with the clock signal; sampling a read signal of the second periodic signal recorded on the magnetic disk, in accordance with the sampling clock; Fourier-transforming those sampling data of the second periodic signal which have been obtained by the sampling, thereby to obtain the odd-numbered order harmonic component; and calculating a partial erasure and a nonlinear transition shift of the magnetic disk from the obtained odd-numbered order harmonic component of the first periodic signal and the obtained odd-numbered order harmonic component of the second periodic signal.

Advantageously, the first periodic signal has positions and periods of the dibits and the isolated bits determined so that the predetermined odd-numbered harmonic component may become zero in nonexistence of a nonlinear component, that the second periodic signal is a signal which has a period

equal to that of the first periodic signal and which contains only the isolated bits, and that positions of the isolated bits of the second periodic signal are equal to those of the isolated bits of the first periodic signal.

According to the invention, the partial erasure and the nonlinear transition shift can be separately evaluated. Further, an approximation operation in which the terms of the second and higher degrees of the nonlinear transition shift are discarded is not executed unlike in the prior-art harmonic elimination method, so that the measurement precision of the nonlinear transition shift does not degrade even under a condition in which the nonlinear transition shift is not negligible relative to the bit period.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram of a read/write tester which is used for measuring a nonlinear distortion in the present invention;

Fig. 2 is a flow chart showing a procedure for measuring the nonlinear distortion in the invention;

Fig. 3 is a diagram showing a periodic pattern which is used in a harmonic elimination method; and

Fig. 4 is a diagram showing waveforms in which a periodic

pattern waveform in Fig. 3 is decomposed into three isolated pulses.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Now, an embodiment of the present invention will be described. First, the basic principle of a measurement method for a nonlinear distortion in the invention will be elucidated below.

A periodic pattern containing dibits and isolated bits, for use in the invention is identical to the pattern of the prior-art harmonic elimination method stated in IEEE Trans. Magn., Vol. 27, No. 6, pp. 5316-8, 1991. That is, it is the periodic pattern indicated below.

1100... (m 0's) 100... (n 0's) 1100... (m 0's) 100... (n 0's)

Here, as stated before, $m = 6p$ and $n = 6q$ (where p and q denote natural numbers) hold true, and a period is represented by $(2m + 2n + 6)T$ (where "T" denotes a bit period).

The temporal waveform of a reproduced signal in the existence of the nonlinear distortion (a partial erasure and a nonlinear transition shift) can be expressed as follows:

Formula 13

$$y(t) = x(t) - (1-\alpha) \cdot x(t - (n+1)T) + (1-\alpha) \cdot x(t - (n+2)T + \Delta)$$

Here, " Δ " denotes the nonlinear transition shift, " α " the partial erasure, and " $x(t)$ " the temporal waveform of the isolated pulse shown at (a) in Fig. 4.

Letting the frequency spectra of $x(t)$ and $y(t)$ be $X(\omega)$ and $Y(\omega)$, respectively,

Formula 14

$$Y(\omega) = X(\omega) - (1 - \alpha)X(\omega) \cdot e^{-j\omega(n+1)T} + (1 - \alpha)X(\omega) \cdot e^{-j\omega(n+2)T + \Delta}$$

Here, a fundamental frequency ω_0 is expressed as follows:

Formula 15

$$\omega_0 = \frac{2\pi}{NT} = \frac{\pi}{(m + n + 3)T}$$

Accordingly, the k th order harmonic component becomes:

Formula 16

$$Y(k\omega_0) = X(k\omega_0) - X(k\omega_0) \cdot (1 - \alpha) \cdot e^{-j\frac{2\pi k(n+1)}{N}} + X(k\omega_0) \cdot (1 - \alpha) \cdot e^{-j\frac{2\pi k(n+2+\Delta/T)}{N}}$$

Here, the following formulas hold true:

Formula 17

$$\begin{aligned}
 \frac{2\pi k(n+1)}{N} &= \frac{2\pi(2p+2q+1) \cdot (6q+1)}{2m+2n+6} \\
 &= \frac{2\pi(2p+2q+1) \cdot (6q+1)}{2(6p+6q+3)} \\
 &= \frac{\pi}{3}
 \end{aligned}$$

Formula 18

$$\begin{aligned}
 \frac{2\pi k(n+2+\Delta/T)}{N} &= \frac{2\pi(2p+2q+1) \cdot (6q+2+\Delta/T)}{2m+2n+6} \\
 &= \frac{2\pi(2p+2q+1) \cdot (6q+2+\Delta/T)}{2(6p+6q+3)} \\
 &= \frac{\pi}{3} (6q+2+\frac{\Delta}{T})
 \end{aligned}$$

Accordingly, the following formula holds true:

Formula 19

$$\begin{aligned}
 Y(k \omega_0) &= X(k \omega_0) - X(k \omega_0) \cdot (1 - \alpha) \cdot e^{-j\frac{\pi}{3}} + X(k \omega_0) \cdot (1 - \alpha) \cdot e^{-j\frac{\pi}{3}(6q+2+\frac{\Delta}{T})} \\
 &= X(k \omega_0) - X(k \omega_0) \cdot (1 - \alpha) \cdot e^{-j\frac{\pi}{3}} + X(k \omega_0) \cdot (1 - \alpha) \cdot e^{-j\frac{\pi}{3}(2+\frac{\Delta}{T})} \\
 &= X(k \omega_0) - X(k \omega_0) \cdot (1 - \alpha) \cdot (\frac{1}{2} - j\frac{\sqrt{3}}{2}) \\
 &\quad + X(k \omega_0) \cdot (1 - \alpha) \cdot (\cos \frac{\pi}{3} (2 + \frac{\Delta}{T}) - i \cdot \sin \frac{\pi}{3} (2 + \frac{\Delta}{T}))
 \end{aligned}$$

Here, when

Formula 20

$$\theta_d = \frac{\pi}{3} \left(2 + \frac{\Delta}{T} \right)$$

is put, the following formula is obtained:

Formula 21

$$\begin{aligned} Y(k \omega_0) / X(k \omega_0) &= 1 - (1 - \alpha) \cdot \left(\frac{1}{2} - i \cdot \frac{\sqrt{3}}{2} \right) + (1 - \alpha) \cdot (\cos \theta_d - i \cdot \sin \theta_d) \\ &= 1 - (1 - \alpha) \cdot \left(\frac{1}{2} - \cos \theta_d \right) + j \cdot (1 - \alpha) \cdot \left(\frac{\sqrt{3}}{2} - \sin \theta_d \right) \end{aligned}$$

Here, when

Formulas 22

$$\operatorname{Re}[Y(k \omega_0) / X(k \omega_0)] = R, \quad \operatorname{Im}[Y(k \omega_0) / X(k \omega_0)] = I$$

are put, the following formulas are obtained:

Formula 23

$$R = 1 - (1 - \alpha) \cdot \left(\frac{1}{2} - \cos \theta_d \right)$$

Formula 24

$$I = (1 - \alpha) \cdot \left(\frac{\sqrt{3}}{2} - \sin \theta_d \right)$$

When these formulas are solved as to $\cos \theta_d$ and $\sin \theta_d$, the following formulas are obtained:

Formula 25

$$\cos \theta_d = \frac{2R - 1 + (1 - \alpha)}{2(1 - \alpha)}$$

Formula 26

$$\sin \theta_d = \frac{(1 - \alpha)\sqrt{3} - 2I}{2(1 - \alpha)}$$

Formula 27

$$\left[\frac{2R - 1 + (1 - \alpha)}{2(1 - \alpha)} \right]^2 + \left[\frac{\sqrt{3}(1 - \alpha) - 2I}{2(1 - \alpha)} \right]^2 = 1$$

Accordingly, the partial erasure α becomes:

Formula 28

$$\therefore \alpha = \frac{R^2 + I^2 - 2R + 1}{R - 1 - \sqrt{3} \cdot I} + 1 \quad \cdots \text{Equation (5. 1)}$$

The nonlinear shift Δ becomes:

Formula 29

$$\therefore \Delta = \left(\frac{3}{\pi} \theta_d - 2 \right) = \frac{3}{\pi} \cos^{-1} \left(\frac{2(R - 1) + (1 - \alpha)}{2(1 - \alpha)} \right) - 2 \quad \cdots \text{Equation (5. 2)}$$

In this manner, when the values of the real part and imaginary part of the ratio between the k th order harmonic spectra of the reproduced signal waveforms of the periodic pattern containing the dibits and the isolated bits and the isolated-bit periodic pattern are found, the partial erasure can be obtained by Equation (5. 1), and further, the nonlinear transition shift can be obtained from the value of the partial erasure by Equation (5. 2). In this regard, however, the phases of the reproduced signal waveforms of the periodic pattern containing the dibits and the isolated bits and isolated-bit periodic pattern must be in complete agreement. Otherwise, the ratio between the respective k th order harmonic components becomes erroneous, and the partial erasure and the nonlinear transition shift cannot be evaluated precisely. In the method of the invention, therefore, the positions of the respective isolated bits of the periodic pattern containing the dibits and the isolated bits and the isolated-bit periodic pattern are brought into agreement, and the write processing into the disk and the read processing from the disk are performed in synchronism with timing signals which are generated by disk rotations.

Next, a practicable measurement method for a nonlinear distortion in the invention will be described. Fig. 1 shows a read/write tester 100 for performing the measurement of the nonlinear distortion. A magnetic disk 101 is fixed to the rotary shaft of a spindle motor 102, and it is rotated and controlled by a motor driver 103. A head 104 is fixed to a head positioning mechanism 105 through a suspension arm 113, and it is moved in the radial direction of the magnetic disk 101 while floating over the record surface of the magnetic disk 101, during the rotation of the magnetic disk 101. A data generator 108 generates write data 131 corresponding to a data pattern programmed beforehand. The write data 131 are converted by a write amplifier 106 into a write current whose direction changes in accordance with the pattern, and which causes the change of the magnetic flux of the unshown record element of the head 104. Thus, the data are recorded into the magnetic disk 101.

The data recorded on the magnetic disk 101 are read out by the head 104. A signal read out from the head 104 is amplified by a read amplifier 107, and a read signal 122 being the output of the read amplifier 107 is inputted to a data acquisition unit 109. The data acquisition unit 109 samples the read signal 122, and stores sampling data in an internal waveform memory (not shown). A digital storage oscilloscope

which is commercially available can be used as the data acquisition unit 109.

A PLL circuit "A" 127 and a PLL circuit "B" 128 multiply the index pulse signal 124 of the spindle motor 102, thereby to create the write clock signal 129 and the sampling clock signal 130, respectively. Accordingly, the write clock signal 129 and the sampling clock signal 130 are synchronous. The write clock signal 129 is fed as the basic clock of the data output of the data generator 108, and the sampling clock signal 130 as the sampling clock of the data acquisition unit 109. Here, the frequency of the sampling clock signal 130 is about 8 - 16 times the frequency of the write clock signal 129.

In writing the data, the write data corresponding to the programmed pattern are outputted from the data generator 108, with the index pulse signal 124 of the spindle motor 102 as a trigger and in synchronism with the write clock signal 129, thereby to be written into the disk 101. On the other hand, in reading out the data, the data acquisition unit 109 samples the read signal 122, with the index pulse signal 124 as a trigger and in synchronism with the sampling clock signal 130. Thus, the phases of the data in the cases of writing and reading out the data can be always brought into agreement.

Besides, the portions of the read/write tester 100 are controlled by various control signals which a computer 111 generates. The control signals are, for example, the control signal of positioning for the head positioning mechanism 105, and the control signal of the data output for the data generator 108. In addition, the sampling data of the data acquisition unit 109 are transferred to the computer 111 through a signal line 126. Besides, a program (not shown) for computing the nonlinear distortion from the sampling data is stored in the computer 111.

Next, a measurement procedure for the nonlinear distortion will be described. First, as preprocessing, the peripheral track of a measurement track 112 on the magnetic disk 101 is AC-erased by the head 104. The AC erase is performed in such a way that a square wave signal on the order of 300 - 500 MHz is written into the magnetic disk 101 in correspondence with one round of a track. Here, the AC erase is performed for the reason that, when the disk is erased in a specified direction, a nonlinear distortion (hard transition shift) ascribable to the erase appears to become the error of the nonlinear distortion ascribable to the adjacency of bits to be actually measured.

A further succeeding procedure is shown in the flow

chart of Fig. 2. First, at a step 201 in Fig. 2, a periodic pattern containing dibits and isolated bits is written into the measurement track on the magnetic disk 101, in synchronism with the index signal 124. In order to write the periodic pattern, the following dibit periodic pattern of 30 bits is programmed in the data generator 108 in correspondence with predetermined periods:

110000001000000110000001000000

This pattern corresponds to a case where $p = q = 1$ is put in the periodic pattern containing the dibits and the isolated bits as stated before, and the fifth order harmonic wave thereof becomes zero in the nonexistence of the nonlinear distortion. Here, the number of the periods of the pattern to be programmed should preferably be larger because a measurement precision is enhanced more. However, when the number of the periods is too large, the time period of data processing increases. Approximately 100 is suitable as the number of the periods though this number depends also upon a bit period T .

Subsequently, the programmed write data are outputted from the data generator 108, with the index signal 124 as a trigger and in synchronism with the write clock signal 129. In addition, the data are written by the head 104.

Subsequently, at a step 202, the read signal of the periodic pattern containing the dibits and the isolated bits, on the magnetic disk 101 is sampled with the index signal 124 as a trigger, thereby to obtain the fifth order harmonic component. In order to perform the sampling, the periodic pattern containing the dibits and the isolated bits, on the magnetic disk 101 is first read out by the head 104, and the resulting read signal 122 is sampled by the data acquisition unit 109, with the index signal 124 as a trigger and in synchronism with the sampling clock signal 130. In addition, the resulting sampling data are transferred to the computer 111. The computer 111 subjects the sampling data to a Fourier transform, thereby to obtain the fifth order harmonic component $Y(5\omega_0)$ of a frequency spectrum.

Here, " ω_0 " denotes a fundamental frequency, and it is given as $\omega_0 = 2\pi/30T = \pi/15T$. Accordingly, the fifth order harmonic becomes a component at a frequency of $\pi/3T$. Here, " T " denotes the period of the write clock signal 129.

Subsequently, at a step 203, a periodic pattern consisting only of isolated bits is written into the measurement track on the magnetic disk 101, in synchronism with the index signal 124. In order to write the periodic pattern, the periphery of the measurement track on the

magnetic disk 101 is first AC-erased in preprocessing. In addition, the following isolated-bit periodic pattern of 30 bits is programmed in the data generator 108 in correspondence with predetermined periods: Approximately 100 is suitable as the number of the periods as in the case of the periodic pattern containing the dibits and the isolated bits. Incidentally, those positions (the 9th bit and 24th bit) of the isolated-bit periodic pattern at which the isolated bits appear need to agree with those of the periodic pattern containing the dibits and the isolated bits. Otherwise, a phase shift occurs, and the measurement cannot be made correctly.

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Subsequently, the programmed write data are outputted from the data generator 108, with the index signal 124 as a trigger and in synchronism with the write clock signal 129. In addition, the data are written by the head 104.

Subsequently, at a step 204, the read signal of the periodic pattern consisting only of the isolated bits, on the magnetic disk 101 is sampled with the index signal 124 as a trigger, thereby to obtain the fifth order harmonic component. The processing of this step is similar to that of the step 202 stated above. Here, the fifth order harmonic

component obtained is set as $X(5\omega_0)$.

Subsequently, at a step 205, the partial erasure and the nonlinear transition shift are evaluated from the fifth order harmonic component of the periodic pattern containing the dibits and the isolated bits, and the fifth order harmonic component of the periodic pattern consisting only of the isolated bits. In order to perform the evaluations, a ratio $Y(5\omega_0)/X(5\omega_0)$ is first obtained from the fifth order harmonic component $Y(5\omega_0)$ of the periodic pattern containing the dibits and the isolated bits, and the fifth order harmonic component $X(5\omega_0)$ of the periodic pattern consisting only of the isolated bits. In addition, the ratio is divided into a real part R and an imaginary part I . Besides, the partial erasure α is obtained in conformity with Equation (5. 1). Further, the nonlinear transition shift Δ is obtained in conformity with Equation (5. 2). Then, the measurement of the nonlinear distortion is completed.

As described above, owing to the application of the method of the invention, the partial erasure and the nonlinear transition shift can be separately evaluated. Further, an approximation operation in which the terms of the second and higher degrees of the nonlinear transition shift are discarded is not executed unlike in the prior-art harmonic

elimination method, so that the measurement precision of the nonlinear transition shift does not degrade even under a condition in which the nonlinear transition shift is not negligible relative to the bit period.

Although this embodiment has been described as to the case of using the periodic pattern which contains the dibits and the isolated bits and from which the fifth order harmonic wave is eliminated in the nonexistence of the nonlinear component, a usable period pattern containing dibits and isolated bits is not restricted to the described periodic pattern, but any periodic pattern containing dibits and isolated bits may be used as long as it satisfies the conditions stated before.

Besides, although this embodiment has been described as applicable to the case where the write clock in the data writing mode and the sampling clock in the data sampling mode are created from the index pulse of the spindle motor, these signals may well be created by another method. By way of example, the write clock and the sampling clock can also be created on the basis of a synchronizing signal of predetermined length as is written into a specified position within the measurement track by the head beforehand.

What is claimed is:

1. A characteristic evaluation method for a magnetic disk medium, comprising the steps of:

recording a first periodic signal which contains dibits and isolated bits, into a magnetic disk in synchronism with a clock signal which is synchronous to a rotation of the magnetic disk and which is generated on the basis of a trigger signal synchronous to the rotation of the magnetic disk;

sampling a read signal of the first periodic signal recorded on the magnetic disk, in accordance with a sampling clock which is synchronous to a rotation of the magnetic disk and which is generated on the basis of the trigger signal;

Fourier-transforming those sampling data of the first periodic signal which have been obtained by the sampling, thereby to obtain a predetermined odd-numbered order harmonic component with respect to a fundamental frequency;

recording a second periodic signal which contains only isolated bits, into the magnetic disk in synchronism with the clock signal;

sampling a read signal of the second periodic signal recorded on the magnetic disk, in accordance with the sampling clock;

Fourier-transforming those sampling data of the second periodic signal which have been obtained by the

sampling, thereby to obtain the odd-numbered order harmonic component; and

calculating a partial erasure and a nonlinear transition shift of the magnetic disk from the obtained odd-numbered order harmonic component of the first periodic signal and the obtained odd-numbered order harmonic component of the second periodic signal.

2. A characteristic evaluation method for a magnetic disk medium as defined in claim 1, wherein the first periodic signal has positions and periods of the dibits and the isolated bits determined so that the predetermined odd-numbered harmonic component may become zero in nonexistence of a nonlinear component, the second periodic signal is a signal which has a period equal to that of the first periodic signal and which contains only the isolated bits, and positions of the isolated bits of the second periodic signal are equal to those of the isolated bits of the first periodic signal.