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TITLE OF THE INVENTION

METHOD AND APPARATUS FOR MEASURING MAGNETIC HEAD

BACKGROUND OF THE INVENTION

5 The present invention relates to a magnetic head measuring apparatus for measuring a magnetic head.

A magnetic force microscope (MFM) is often used in inspecting a magnetic head. For example, the following inspection method used in a thin-film magnetic head wafer inspection process is known. That
10 is, with a plurality of thin-film magnetic heads formed on a wafer, a groove is formed in a surface on which a medium and the head gap of each thin-film magnetic head are in contact with each other. A probe of the MFM is inserted into this groove to inspect the
15 shape of the head gap surface and the electromagnetic conversion characteristic of the thin-film magnetic head.

The MFM is a kind of a scanning probe microscope (SPM), and is an apparatus which detects a dynamic
20 interaction between a pointed probe (MFM probe) which is a magnetic material, or a nonmagnetic material to which a magnetic material is adhered, and a magnetic field generated from a sample to be measured. The resolution is as very high as several tens of nm,
25 although it depends upon the measurement method and the probe shape. Therefore, this MFM is very effective in magnetic characteristic evaluation on

submicron order.

The MFM probe is supported by a leaf spring called a cantilever and has a mechanical resonance frequency determined by the mass of the MFM probe and the spring constant of the cantilever. Accordingly, in MFM measurements in a normal mode, responses at frequencies higher than this mechanical resonance frequency (generally a few tens of kHz to a few hundred kHz) cannot be measured in the case where the response is measured by applying sinusoidal wave.

In the above inspection method, the MFM measurement is performed while applying a sinusoidal high-frequency electric current to the recording head. However, no desired response can be obtained from the measured MFM signal owing to the above limitation; a high-frequency component is contained in a DC signal. Also, the DC component of the measured MFM signal contains contribution from factors other than the head, e.g., an MFM interaction caused by a DC magnetic field generated from the head magnetic pole. Under the measurement conditions like this, the distribution of a true magnetic field generated from the magnetic head cannot be measured. In other words, strict magnetic head inspection is difficult to perform.

Furthermore, in MFM measurements, measurement values vary owing to tip variations when the MFM

probes are changed (in some cases measurement values vary even for the same magnetic head as a sample to be measured). One reason is that the conditions (e.g., the shape, film thickness, and contamination) of a magnetic material at the tip of the MFM probe more or less change from one probe to another. Other reasons are variations in an optical system alignment for measuring the deflection of the cantilever supporting the MFM probe, and detection sensitivity variations caused by a difference in reflectance between thin metal films adhered to the back surface of the cantilever and required in the optical system alignment.

When the foregoing facts are taken into consideration, it is necessary to compensate for the influence of tip variations in the process of inspecting a large amount of magnetic heads. However, the above-mentioned references do not describe any method of solving this problem.

As described above, the conventional methods have the problems that no true high-frequency magnetic field can be measured, and the obtained measurement data have measurement variations caused by tip variations.

Also, electromagnetic conversion measurement for a magnetic head is conventionally performed using, e.g., a spin stand. This measurement must be

performed with a magnetic head in the form of HGA (Head Gimbals Assembly). That is, since magnetic heads including defective ones are measured in the form of HGA, the yield cannot be improved unlimitedly.

5 From the foregoing, the presentation of a magnetic head inspection technology that can reduce measurement variations caused by tip variations and which can improve the yield is desired.

10 In the meantime, a magnetic recording-head as a sample to be measured by a magnetic head measuring device is, e.g., an inductive type thin-film head and has a magnetic gap that generates a recording magnetic field corresponding to a signal current applied to a coil. The magnetic head measuring device applies
15 a high-frequency signal current to (the coil) of a head as a sample, and measures the distribution of a magnetic field generated from the magnetic gap. One practical measurement method is to detect the phase or deflection (dynamic interaction resulting
20 from a head magnetic field) of a cantilever vibrating and, on the basis of this detection result, measure the force gradient or force acting between the probe and the sample. In this method, measurement is performed using the relationship that the phase of the
25 cantilever approximates the force gradient and the deflection of the cantilever approximates the force.

 This measurement method has wide variations.

For example, R. Proksch et al., "Measuring the gigahertz response of recording heads with the magnetic force microscope", (Digital Instruments et al.), Applied Physics Letters, Vol. 74, No. 9, March 5 1999, pp. 1308-1310 (to be referred to as prior art 1 hereinafter) discloses a technique which applies an amplitude-modulated electric current to a magnetic recording-head and matches the modulation frequency to the resonance frequency of the cantilever, thereby 10 detecting the resonance frequency component of the deflection (or force) of the cantilever vibrating. This technique improves the sensitivity by using the Q value of the mechanical resonance frequency of the cantilever.

15 Also, Hiroyuki Ohmori, "Techniques of Evaluating and Analyzing Recording and Reproduction Heads", SONY CORP., Journal of Japan Applied Magnetism Society, Vol. 23, No. 12, 1999, pp. 2111-2117 (to be referred to as prior art 2 hereinafter) discloses a technique 20 which applies a high-frequency sinusoidal wave to a magnetic recording-head and measures the DC component of the phase change (force gradient) of the cantilever, resulting from a magnetic field generated around the head.

25 In prior art 1, however, the deflection of the cantilever is detected as magnetic field strength. Therefore, the vibration amplitude of the cantilever

is not constant during probe scanning. In the case of the measurement which detects dynamic deflection of the cantilever such as the measurement in prior art 1, detected interaction on the probe depends on the
5 cantilever amplitude, probe-sample distance, magnetic field and so on. Therefore, cantilever amplitude and probe-sample distance need to be constant during probe scanning, since magnetic field decays non-linearly. So an image reflecting a magnetic field cannot be
10 measured. In addition, the sensitivity is improved by using the Q value of the mechanical resonance frequency of the cantilever. However, a high Q value may produce a response delay in a change of the cantilever.

15 On the other hand, prior art 2 measures the DC component of the phase change (force gradient) of the cantilever, resulting from a magnetic field generated around a head. However, this DC component contains contributions other than the high-frequency component,
20 so the obtained data is difficult to analyze.

In either method, the frequency of a magnetic field generated from a magnetic recording-head is on the MHz order, i.e., much higher than the cantilever mechanical resonance frequency which determines the
25 response speed of the scanning probe microscope. This makes it difficult to extract only a high-frequency response and measure this response at high sensitivity

and high resolution.

From the foregoing, the presentation of a magnetic recording-head measurement technique capable of measuring a high-speed response at high sensitivity and high resolution is desired.

BRIEF SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a magnetic head measuring apparatus capable of measuring a high-speed response at high sensitivity and high resolution, and a magnetic head measuring method.

According to one aspect of the present invention, there is provided a magnetic head measuring apparatus for measuring a magnetic head, comprising a calibrating magnetic field generating source which causes the magnetic head to generate a magnetic field having a constant strength and frequency; an electric current applying device which applies an amplitude-modulated electric current whose amplitude is modulated by a specified carrier wave frequency and modulation frequency, to the magnetic head from which the magnetic field is generated by the calibrating magnetic field generating source; and a magnetic head measuring device which measures a high-frequency magnetic field generated from the magnetic head by application of the amplitude-modulated electric current from the electric current applying device.

According to another aspect of the present invention, there is provided a method of inspecting a magnetic head, comprising setting the magnetic head; selecting an analysis item for which the magnetic head
5 is to be inspected; applying to the magnetic head an amplitude-modulated electric current whose amplitude is modulated by a specified carrier wave frequency and modulation frequency; measuring, in accordance with the selected analysis item, the magnetic head to which
10 the amplitude-modulated electric current is applied, by using a high-frequency magnetic force microscope; analyzing and evaluating data, obtained by the measurement, of the magnetic head; and determining success or failure of the magnetic head on the basis
15 of the evaluation result.

According to still another aspect of the present invention, there is provided a magnetic recording-head measuring apparatus for measuring a magnetic
recording-head, comprising an electric current
20 applying device which applies to the magnetic recording-head an amplitude-modulated electric current whose amplitude is modulated by a specified carrier wave frequency and modulation frequency; a cantilever to which a probe having a magnetic material is
25 attached; a vibrator which applies a vibration with specified vibration amplitude to the cantilever; and a measuring device which measures a dynamic interaction

which a magnetic field generated in the magnetic
recording-head by application of the
amplitude-modulated electric current from the electric
current applying means exerts on the probe vibrating,
5 wherein while the probe is scanned to measure the
dynamic interaction by the magnetic field, a vibration
range of the probe falls within a range from a surface
of the magnetic recording-head to a point at which the
probe does not interact with the magnetic field any
10 longer.

According to still another aspect of the present
invention, there is provided a method of measuring a
magnetic recording-head, comprising applying to the
magnetic recording-head an amplitude-modulated
15 electric current whose amplitude is modulated by a
specified carrier wave frequency and modulation
frequency; applying a vibration with specified
vibration amplitude to a cantilever to which a probe
having a magnetic material is attached; and measuring
20 a dynamic interaction which a magnetic field generated
in the magnetic recording-head by application of the
amplitude-modulated electric current exerts on the
probe which vibrates together with the cantilever,
wherein while the probe is scanned to measure the
25 dynamic interaction by the magnetic field, a vibration
range of the probe falls within a range from a surface
of the magnetic recording-head to a point at which the

probe does not interact with the magnetic field any longer.

Additional objects and advantages of the invention will be set forth in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention may be realized and obtained by means of the instrumentalities and combinations particularly pointed out hereinafter.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention, and together 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 the main components of a magnetic head measuring apparatus according to the first to fourth embodiments of the present invention;

FIG. 2 is a view showing the arrangement of the magnetic head measuring apparatus in more detail;

FIG. 3 is a view for explaining a case in which a calibrating magnetic field generating source is an annular conductor;

FIG. 4 is a view showing a configuration for

acquiring an MSM image in analysis and evaluation of
a certain analysis item;

FIGS. 5A and 5B are views showing
a two-dimensional image of a high-frequency magnetic
5 field when a magnetic head is viewed from the above,
and a line profile of the image;

FIG. 6 is a flow chart for explaining a magnetic
head inspection method according to the first
embodiment of the present invention;

10 FIG. 7 is a flow chart for explaining a magnetic
head inspection method according to the second
embodiment of the present invention;

FIG. 8 is a flow chart for explaining a magnetic
head inspection method according to the third
15 embodiment of the present invention;

FIG. 9 is a flow chart for explaining a magnetic
head inspection method according to the fourth
embodiment of the present invention;

FIG. 10 is a block diagram showing the
20 arrangement of a magnetic recording-head measuring
device according to the fifth embodiment of the
present invention;

FIG. 11 is a view for explaining the conditions
of a cantilever of the fifth embodiment;

25 FIG. 12 is a flow chart for explaining
a measurement method of the fifth embodiment;

FIGS. 13A to 13C are graphs showing a force

gradient image measurement example of the fifth embodiment;

FIGS. 14A to 14C are graphs showing a force image measurement example of the fifth embodiment; and

5 FIG. 15 is a view showing the relationship between the gap position and profile of a sample in the measurement examples of the fifth embodiment.

DETAILED DESCRIPTION OF THE INVENTION

Embodiments of the present invention will be
10 described below with reference to the drawings.

FIG. 1 is a block diagram showing the main parts of a magnetic head measuring apparatus according to the first to fourth embodiments of the present invention.

15 A magnetic head measuring (or inspecting) apparatus 10 includes a magnetic head measuring (or inspecting) device 12 for measuring (or inspecting) a magnetic head 11 as a sample, an interchangeable magnetic material probe 13 prepared
20 for the magnetic head measuring device 12, and a calibrating (or correcting) magnetic field generating source 14 for calibrating measurement variations of the magnetic head 11.

 The magnetic head 11 is supplied in the form of
25 a wafer of row bar, and fixed by a fixing jig of the magnetic head measuring apparatus 10. A "row bar" is a rectangular wafer piece obtained when a wafer is

processed into a slider in a magnetic head fabrication process. The magnetic head 11 can also be measured in the form of HGA.

5 The magnetic head measuring device 12 contains
a high-frequency magnetic force microscope (HF-MFM) as
one form of a scanning probe microscope (SPM).
A difference from a common MFM is that a frequency
response higher than the mechanical resonance
frequency of a cantilever can be measured. By the use
10 of this HF-MFM, it is possible to perform measurement
corresponding to a true high-frequency magnetic field
and accurately inspect a magnetic head. Note that the
HF-MFM can be constructed using technologies disclosed
in R. Proksch and P. Neilson, S. Austvold and
15 J.J. Schmidt, Applied Physics Letters 74 (1999) 1308
(Digital Instruments et. al.), and U.S. Patent
Application No. 09/811,771.

20 The magnetic head measuring device 12 can apply
an amplitude-modulated electric current to the
magnetic head 11. It is of course also possible to
apply other signals than this amplitude-modulated
electric current. The magnetic head measuring device
12 can also save and analyze data obtained by
measuring the characteristics of the magnetic head 12.

25 To measure the magnetic head 11 at high
resolution, the magnetic head measuring device 12
incorporates a magnetic material probe that is

a magnetic material or a nonmagnetic material to which a magnetic material is adhered. The interchangeable magnetic material probe 13 is used to replace this probe. Replacement is performed as needed.

5 The interchangeable magnetic material probe 13 can be used in replacement either manually or automatically. Although this interchangeable magnetic material probe 13 can be saved in the magnetic head measuring apparatus 10, it can also be supplied and
10 used in replacement where necessary, without being saved.

 The calibrating magnetic field generating source 14 causes the magnetic head 11 to generate a magnetic field having a constant strength and
15 frequency. This calibrating magnetic field generating source 14 can take any form as long as a uniform magnetic field can be generated. However, flatness that can be measured by the MFM is necessary, and the scanning range is limited (e.g., 50 μm square or
20 less). The calibrating magnetic field generating source 14 can apply either an alternate current or direct current to the magnetic head 11. From the calibrating magnetic field generating source 14, the magnitude of an actual magnetic field corresponding to
25 the applied electric current can be estimated. Practical examples of the magnetic field generating source are a microcoil, fine wire, and magnetic head

formed on general substrates such as Si, SiO₂, and silicon nitride.

If a large electric current is allowed to flow through the magnetic head measuring device 12 and
5 the calibrating magnetic field generating source 14, signal lines may be burnt out. Hence, the current density of an electric current to be applied is desirably 10^{-8} A/cm² or less.

FIG. 2 is a view showing the arrangement of the
10 magnetic head measuring apparatus 10 in more detail.

In addition to the interchangeable magnetic material probe 13 and the calibrating magnetic field generating source 14, the magnetic head measuring apparatus 10 includes a probe 101, a cantilever 102,
15 a piezoelectric element 103, signal generators 104 and 106, a current value monitor 107, a scanning piezoelectric element 108, a deflection detector 109, a phase sensitive detector 110, a synchronous detector 111, an amplitude/DC voltage converter (RMS-DC
20 circuit) 112, and a feedback circuit 113, as the constituent elements of the magnetic head measuring device 12. The magnetic head measuring apparatus 10 also includes a computer 114.

The probe 101 is an interchangeable MFM probe
25 that is made of a magnetic material or magnetized by adhering a magnetic material to a nonmagnetic material.

The cantilever 102 supports the probe 101.

The piezoelectric element 103 for supporting the cantilever 102 is attached to the side of the cantilever 102 away from the side to which the probe 101 is attached. This piezoelectric element 103 applies a vibration to the probe 101 and the cantilever 102.

The signal generator 104 applies a signal (resonance frequency: ω_r) to the piezoelectric element 103.

The signal generator 106 includes an AM signal generator for generating an amplitude-modulated electric current whose amplitude is modulated by a carrier wave frequency ω_c and a modulation frequency ω_m , a DC signal generator for generating a direct current, and a signal generator for generating an electric current which is the sum of a direct current and alternate current. This signal generator 106 applies an electric current to the magnetic head 11 to generate a magnetic field.

The current value monitor 107 measures the electric current flowing through the magnetic head 11.

The scanning piezoelectric element 108 determines three-dimensional relative positions of the probe 101 and the magnetic head 11.

The deflection detector 109 detects the deflection of the cantilever 102.

The phase sensitive detector 110 outputs a phase difference (phase shift) between an output from the signal generator 104 and an output from the deflection detector 109.

5 The synchronous detector 111 detects a component synchronized with the modulation component of the AM signal generator described above, from an output signal from the phase sensitive detector 110.

 The amplitude/DC voltage converter (RMS-DC
10 circuit) 112 outputs an effective value (root mean square) of an output from the deflection detector 109.

 The feedback circuit 113 controls the scanning piezoelectric element 108 such that the output from the amplitude/DC voltage converter 112 is equal to
15 a preset value (i.e., the probe-to-sample distance is constant).

 The computer 114 records and saves information of the high-frequency magnetic field obtained from the output from the synchronous detector 111 and
20 information of the surface shape obtained from the output from the feedback circuit 113, thereby controlling the whole apparatus 10 and monitoring various parameters. This computer 114 can also select analysis items and analyze and evaluate data
25 corresponding to the selected analysis items or determine success or failure of the magnetic head 11.

 Magnetic head measurement by the magnetic head

measuring apparatus 10 shown in FIG. 2 is basically performed following the procedure below.

First, an electric current whose amplitude is modulated (by the carrier wave frequency ω_c and the modulation wavelength ω_m) is applied to the magnetic head 11.

When the probe 101 is approached to the magnetic head 11, a high-frequency (ω_c) magnetic field component generated by the magnetic head 11 is converted into a low-frequency (ω_m) interaction component by the probe-sample interaction.

By setting the resonance frequency ω_r and the modulation frequency ω_m of the cantilever 102 supporting the probe 101 to meet the condition $\omega_m \ll \omega_r$, a component synchronized with the modulation frequency (ω_m) contained in a phase change (phase shift) or frequency change (frequency shift, T.R. Albrecht, P. Grutter, D. Horne, and D. Rugar, Journal of Applied Physics, 69 (1991) 668.) of cantilever vibration is measured while the amplitude of the cantilever 102 is held substantially constant at the mechanical resonance frequency (ω_r), regardless of the strength of the field, by using the piezoelectric element 103 and an external signal. In this way, a high-resolution, high-frequency magnetic field can be stably measured.

As described above, a true high-frequency

magnetic field can be measured by the application of the HF-MFM technology. Also, since the calibrating magnetic field generating source for compensating for tip variations is incorporated into the apparatus, measurement variations can be improved. Furthermore, the electromagnetic conversion characteristics can be measured in the form of a row bar without using any spin stand, and the yield can be improved.

FIG. 3 is a view for explaining a case in which the calibrating magnetic field generating source is an annular conductor. A calibrating magnetic field generating source 14a shown in FIG. 3 is an annular conductor. Letting r denote the radius of the formed circle and z denote the distance from the center of the circle to a point P, the strength of a magnetic field at this point P when an electric current I flows through the conductor is $H = Ir^2 / \{2(r^2 + z^2)^{3/2}\}$ (AT/m).

Although FIG. 3 illustrates the annular calibrating magnetic field generating source, it is of course also possible to use some other shape, e.g., a linear shape.

FIG. 4 is a view showing an example of a configuration for acquiring an MSM (Magnetoresistive Sensitive Mapping) image in analysis and evaluation of a certain analysis item. For MSM, refer to "Magnetoresistive Sensitive Mapping" (G.A. Gibson and

S. Shultz, IEEE Trans. Magn. 28, 2310 (1992)).

As shown in FIG. 4, while the signal generator 104 is applying a signal to the piezoelectric element 103, a direct current flowing through the magnetic head 11 is extracted through a differential amplifier. Lock-in processing is performed for this extracted signal and the signal from the signal generator 104 to acquire an MSM image.

As shown in FIGS. 5A or 5B, this MSM image is acquired in the form of an image or graph. FIG. 5A shows a two-dimensional image of a high-frequency magnetic field when the magnetic head is viewed from the above. FIG. 5B shows a line profile of this two-dimensional image.

<First Embodiment>

A magnetic head inspection method according to the first embodiment will be explained below with reference to FIG. 6.

First, the magnetic head 11 as a sample is set in the magnetic head measuring apparatus 10 (step S101), and an analysis item for which the magnetic head measuring device 12 inspects the magnetic head 11 is selected (step S102). As this analysis item, not only estimation of a high-frequency magnetic field distribution and local high-frequency magnetic field strength, but also reconstructing calculations of a high-frequency leakage magnetic field and horizontal

magnetic field component and prediction of various electromagnetic conversion characteristics are prepared, and an arbitrary item can be selected.

Next, an amplitude-modulated electric current
5 having the carrier wave frequency ω_c and the modulation frequency ω_m is applied to the magnetic head (step S103), and a high-frequency magnetic field is measured with a high-frequency magnetic force microscope (step S104). A surface shape can also be
10 measured as well as the high-frequency magnetic field. In this case, a magnetic field generation position corresponding to the surface shape can be confirmed.

The data obtained by the measurement of the high-frequency magnetic field is analyzed and
15 evaluated (step S105), and success or failure is determined on the basis of the result (step S106). If the product has passed the inspection, acceptable product processing is performed (step S107); if the product has failed the inspection, rejected product
20 processing is performed (step S108).

Finally, whether to terminate the measurement is checked (step S109). If the measurement is not to be terminated, the above steps are repeated; if the measurement is to be terminated, this magnetic head
25 inspection is terminated.

In this first embodiment, a magnetic head can be inspected before incorporated into an HGA. This can

greatly improve the HGA yield.

<Second Embodiment>

5 A magnetic head inspection method according to the second embodiment will be explained below with reference to FIG. 7.

This second embodiment includes processing for obtaining characteristics, e.g., the shape and sensitivity of a reproducing portion and a saturated magnetic field phenomenon, not obtained in the first
10 embodiment (FIG. 6) described above.

First, the magnetic head 11 as a sample is set in the magnetic head measuring apparatus 10 (step S201), and an analysis item for which the magnetic head measuring device 12 inspects the magnetic head 11 is
15 selected (step S202). As this analysis item, not only estimation of a high-frequency magnetic field distribution and local high-frequency magnetic field strength, but also reconstructing calculations of a high-frequency leakage magnetic field and horizontal
20 magnetic field component and prediction of various electromagnetic conversion characteristics are prepared, and an arbitrary item can be selected.

Next, an amplitude-modulated electric current having the carrier wave frequency ω_c and the
25 modulation frequency ω_m is applied to the magnetic head (step S203), and a high-frequency magnetic field is measured with a high-frequency magnetic force

microscope (step S204). A surface shape can also be measured as well as the high-frequency magnetic field. In this case, a magnetic field generation position corresponding to the surface shape can be confirmed.

5 The data obtained by the measurement of the high-frequency magnetic field is analyzed and evaluated (step S205). Also, whether to perform evaluation other than the measurement of the high-frequency magnetic field is checked (step S206).

10 If evaluation other than the measurement of the high-frequency magnetic field is to be performed, an evaluation/analysis method is selected (step S207), and the evaluation is performed by the selected method (step S208). Examples of the evaluation/analysis
15 method are the measurement and analysis of magnetic head characteristics not obtained by the high-frequency magnetic field alone, such as the measurement of the shape or sensitivity or a reproducing portion by Magnetoresistive Sensitive
20 Mapping (G.A. Gibson and S. Schultz IEEE Trans. Magn. 28, 2310 (1992)), and the analysis of a saturation phenomenon of a recording portion.

 Next, success or failure is determined on the basis of the analysis/evaluation result (step S209).
25 If the product has passed the inspection, acceptable product processing is performed (step S210); if the product has failed the inspection, rejected product

processing is performed (step S211).

Finally, whether to terminate the measurement is checked (step S212). If the measurement is not to be terminated, the above steps are repeated; if the
5 measurement is to be terminated, this magnetic head inspection is terminated.

This second embodiment has the effect of performing total evaluation including a reproducing head and magnetic saturation characteristics, in
10 addition to the effects obtained in the first embodiment.

<Third Embodiment>

A magnetic head inspection method according to the third embodiment will be described below with
15 reference to FIG. 8.

When measurements are repeatedly performed, no specified inspection results can be obtained in some instances owing to deterioration of the MFM probe, e.g., deterioration of the resolution and a reduction
20 in the S/N ratio of a measurement signal. This "deterioration" herein mentioned includes physical rounding of the probe tip during measurements, peeling of a magnetic film from a probe having the magnetic film attached, and unsuccessful magnetization of
25 a probe. In cases like these, the MFM probe must be replaced with a new one. By taking this into consideration, the third embodiment includes a process

of exchanging MFM probes.

First, whether it is necessary to replace the probe mounted on the magnetic head measuring device 12 is checked (step S301). If replacement is necessary, the probe is replaced (step S302). Note that this replacement of the probe can be performed either manually or automatically. Note also that a probe for replacement can be saved in the magnetic head measuring apparatus 10 or supplied where necessary without being saved.

Next, the magnetic head 11 as a sample is set in the magnetic head measuring apparatus 10 (step S303), and an analysis item for which the magnetic head measuring device 12 inspects the magnetic head 11 is selected (step S304). As this analysis item, not only estimation of a high-frequency magnetic field distribution and local high-frequency magnetic field strength, but also reconstructing calculations of a high-frequency leakage magnetic field and horizontal magnetic field component and prediction of various electromagnetic conversion characteristics are prepared, and an arbitrary item can be selected.

Subsequently, an amplitude-modulated electric current having the carrier wave frequency ω_c and the modulation frequency ω_m is applied to the magnetic head (step S305), and a high-frequency magnetic field is measured with a high-frequency magnetic force

microscope (step S306). A surface shape can also be measured as well as the high-frequency magnetic field. In this case, a magnetic field generation position corresponding to the surface shape can be confirmed.

5 The data obtained by the measurement of the high-frequency magnetic field is analyzed and evaluated (step S307). Also, whether to perform evaluation other than the measurement of the high-frequency magnetic field is checked (step S308).

10 If evaluation other than the measurement of the high-frequency magnetic field is to be performed, an evaluation/analysis method is selected (step S309), and the evaluation is performed by the selected method (step S310). Examples of the evaluation/analysis
15 method are the measurement and analysis of magnetic head characteristics not obtained by the high-frequency magnetic field alone, such as the measurement of the shape or sensitivity or a reproducing portion by Magnetoresistive Sensitive
20 Mapping (G.A. Gibson and S. Schultz IEEE Trans. Magn. 28, 2310 (1992)), and the analysis of a saturation phenomenon of a recording portion.

 Next, success or failure is determined on the basis of the analysis/evaluation result (step S311).
25 If the product has passed the inspection, acceptable product processing is performed (step S312); if the product has failed the inspection, rejected product

processing is performed (step S313).

Finally, whether to terminate the measurement is checked (step S314). If the measurement is not to be terminated, the above steps are repeated; if the measurement is to be terminated, this magnetic head inspection is terminated.

This third embodiment has the effect of avoiding deterioration of a probe caused by repetitive measurements, because probes can be exchanged, in addition to the effects obtained in the second embodiment.

<Fourth Embodiment>

A magnetic head inspection method according to the fourth embodiment will be described below with reference to FIG. 9.

When measurements are performed while probes are exchanged as described in the third embodiment (FIG. 8), experimental results before and after the probes are exchanged are sometimes different (even when a magnetic head as a sample to be measured remains the same). As a consequence, specified inspection cannot sometimes be properly performed in a process of inspecting a large amount of magnetic heads. One reason is that the conditions (e.g., the shape, film thickness, and contamination) of a magnetic material at the tip of the MFM probe more or less change from one probe to another.

Other reasons are variations in an optical system alignment for measuring the deflection of the cantilever supporting the MFM probe, and variations in the detection sensitivity caused by a difference in reflectance between thin metal films adhered to the back surface of the cantilever and required in the optical system alignment. These variations are called tip variations.

To compensate for tip variations, it is necessary to calibrate the sensitivity of the probe and normalize the obtained measurement signal. Therefore, this fourth embodiment includes a process of inspecting a large amount of magnetic heads while performing sensitivity calibration.

First, whether it is necessary to replace the probe mounted on the magnetic head measuring device 12 is checked (step S401). If replacement is necessary, the probe is replaced (step S402). Note that this replacement of the probe can be performed either manually or automatically. Note also that a probe for replacement can be saved in the magnetic head measuring apparatus 10 or supplied where necessary without being saved.

Next, the magnetic head 11 as a sample is set in the magnetic head measuring apparatus 10 (step S403).

Whether to execute calibration for eliminating measurement variations caused by tip variations is

checked (step S404). If it is necessary to perform this calibration for eliminating measurement variations, a calibration process is performed (step S405).

5 Subsequently, an analysis item for which the magnetic head measuring device 12 inspects the magnetic head 11 is selected (step S406). As this analysis item, not only estimation of a high-frequency magnetic field distribution and local high-frequency
10 magnetic field strength, but also reconstructing calculations of a high-frequency leakage magnetic field and horizontal magnetic field component and prediction of various electromagnetic conversion characteristics are prepared, and an arbitrary item
15 can be selected.

 An amplitude-modulated electric current having the carrier wave frequency ω_c and the modulation frequency ω_m is applied to the magnetic head (step S407), and a high-frequency magnetic field is
20 measured with a high-frequency magnetic force microscope (step S408). A surface shape can also be measured as well as the high-frequency magnetic field. In this case, a magnetic field generation position corresponding to the surface shape can be confirmed.

25 The data obtained by the measurement of the high-frequency magnetic field is analyzed and evaluated (step S409). Also, whether to perform

evaluation other than the measurement of the high-frequency magnetic field is checked (step S410).

If evaluation other than the measurement of the high-frequency magnetic field is to be performed,
5 an evaluation/analysis method is selected (step S411), and the evaluation is performed by the selected method (step S412). Examples of the evaluation/analysis method are the measurement and analysis of magnetic head characteristics not obtained by the
10 high-frequency magnetic field alone, such as the measurement of the shape or sensitivity or a reproducing portion by Magnetoresistive Sensitive Mapping (G.A. Gibson and S. Schultz IEEE Trans. Magn. 28, 2310 (1992)), and the analysis of a saturation
15 phenomenon of a recording portion.

Next, success or failure is determined on the basis of the analysis/evaluation result (step S413). If the product has passed the inspection, acceptable product processing is performed (step S414); if the
20 product has failed the inspection, rejected product processing is performed (step S415).

Finally, whether to terminate the measurement is checked (step S416). If the measurement is not to be terminated, the above steps are repeated; if the
25 measurement is to be terminated, this magnetic head inspection is terminated.

This fourth embodiment has the effect of

performing measurements by reducing the influence of tip variations, in addition to the effects obtained in the third embodiment.

As described in detail above, the invention
5 expressed by the first to fourth embodiments can provide a magnetic head measuring apparatus and magnetic head inspection method capable of reducing measurement variations caused by tip variations and improving the yield.

10 <Fifth Embodiment>

The fifth embodiment of the present invention will be described below with reference to FIGS. 10 to 15.

(Arrangement of Magnetic recording-head Measuring
15 device>

FIG. 10 shows the arrangement of a magnetic recording-head measuring device according to the fifth embodiment of the present invention.

This magnetic recording-head measuring device
20 contains a high-frequency magnetic force microscope (HF-MFM) as one form of a scanning probe microscope (SPM). Also, this measuring device allows a magnetic recording-head as a sample to generate an AM signal (amplitude-modulated signal), and measures
25 a high-frequency (MHz to GHz) magnetic field as the force (magnetic force) acting on a probe. At the same time, the apparatus measures a topographical image of

the sample.

As shown in FIG. 10, this measuring device includes a probe 201, a cantilever 202, a sample 203, a scanning piezoelectric element 204, an actuating
5 piezoelectric element 205, a signal generator 206, a deflection detector 207, a switch 208, a synchronous detector 209, a phase sensitive detector 210, a synchronous detector 211, an amplitude/DC voltage converter (RMS-DC circuit) 212, a feedback
10 circuit 213, a first signal generator 214, a second signal generator 215, an AM signal generator (amplitude-modulated signal generator) 216, a current value monitor 217, a computer 218, and a switch 219.

The probe 201 is magnetized by coating of
15 a magnetic substance and attached to the front end of the cantilever 202.

The cantilever 102 supports the probe 201 and has a mechanical resonance frequency ω_r .

The sample 203 is a magnetic recording-head and
20 generates a high-frequency magnetic field under specific conditions.

The scanning piezoelectric element 204 controls the driving of the sample 203 in the X-, Y-, and Z-axis directions, thereby changing the relative
25 positional relationship between the probe 201 and the sample 203.

The actuating piezoelectric element 205 is

attached to the rear end of the cantilever 202 and applies a vibration to the cantilever 202.

The signal generator 206 drives the actuating piezoelectric element 205 to apply a vibration with
5 specified vibration amplitude to the cantilever 202.

The deflection detector 207 includes a laser light source, photodiode, and the like, and detects the deflection of the cantilever 202.

The switch 208 switches the output destinations
10 of a detection signal from the deflection detector 207 in accordance with whether to perform force measurement or force gradient measurement.

The synchronous detector 209 constructs a force measurement system and detects the vibration
15 amplitude (the AC component of deflection) of the cantilever 202.

The phase sensitive detector 210 constructs a force gradient measurement system together with the synchronous detector 211, and detects a phase
20 difference (phase shift) between the vibration amplitude of the signal generator 206 and the vibration amplitude of the cantilever 202.

The synchronous detector 211 constructs the force gradient measurement system together with the phase
25 sensitive detector 210, and detects the AC component (the sideband component of AM modulation) of an output from the phase sensitive detector 210.

Note that in the force gradient measurement system, a feedback loop may be formed by deflection detector 207 → signal generator 206 → actuating piezoelectric element 205 → cantilever 202 to measure
5 an amount (frequency shift) corresponding to a change in resonance frequency while the cantilever 202 is vibrating at specified amplitude (frequency detecting method).

The amplitude/DC voltage converter 212 measures
10 the effective value of the deflection detector 207.

The feedback circuit 213 drives the scanning piezoelectric element 204 on the basis of an output from the amplitude/DC voltage converter 212 to perform control such that the output from this amplitude/DC
15 voltage converter 212 is constant. Also, the feedback circuit 213 drives the scanning piezoelectric element 204 to move the sample 203 in the X-, Y-, and Z-axis directions, and outputs to the computer 218 a signal (digital data) indicating a topographical image of the
20 sample 203 on the basis of the output from the amplitude/DC voltage converter 212.

The signal generator 214 sets a sideband frequency (modulation frequency) ω_m of an AM signal, and generates a signal to which ω_m is set.

25 The signal generator 215 sets a carrier wave frequency ω_c ($\gg \omega_r$) of an AM signal, and generates a signal to which ω_c is set.

The AM signal generator 216 generates an AM signal based on the output signals from the signal generators 214 and 215.

5 The current value monitor 217 has a function of measuring the value of an electric current applied from the AM signal generator 216 to the sample 103, and adjusting this electric current.

10 The computer 218 controls the overall measuring device. This computer 218 has a function of inputting and saving the conditions of an electric current generated from the AM signal generator 216, and a function of monitoring and controlling the states of the AM signal generator 216 and the current value monitor 217. The computer 218 also has a function of
15 saving, in the same file, the conditions of an electric current to be applied to the sample 203 and measurement data in one-to-one correspondence with each other.

20 Furthermore, the computer 218 has a function of calculating differences between a plurality of obtained images to specify a magnetic field position, and effectively displaying the contrast of that portion. For example, the computer 218 performs subtraction for images different in the value of
25 an electric current to be applied to the sample 203, thereby specifying a portion where a change in the magnetic field strength is large. In addition, the

computer 218 can visually display a magnetic field generation position by changing the contrast of that portion.

Also, the computer 218 measures a force image on
5 the basis of an output signal from the synchronous detector 209 constructing the force measurement system, and measures a force gradient image on the basis of an output signal from the synchronous detector 211 constructing the force gradient
10 measurement system (a display process and saving process are included). The force image and the force gradient image are high-frequency head images relating to the magnetic force of a high-frequency magnetic field generated by a magnetic recording-head. The
15 computer 218 selectively performs force measurement and force gradient measurement by switching the switches 208 and 219.

The switch 219 collaborates with the switch 208 to switch signal input destinations in accordance with
20 whether to perform force measurement or force gradient measurement.

(Conditions of Cantilever)

FIG. 11 is a view for explaining the conditions of the cantilever.

25 To improve the spatial resolution during measurements, as shown in FIG. 11, it is desirable to set a vibration amplitude A_{cant} in the direction of

height (Z direction) of the cantilever 202 as large as possible provided that the probe 201 does not hit the surface of the sample 203. That is, the difference between the square value of a distance h from the surface of the sample 203 to the vibration center of the cantilever 202 and the vibration amplitude A_{cant} of the cantilever 202 is desirably as close to 0 as possible, that is,

$$2h - A_{cant} \rightarrow 0 \quad \dots (1)$$

where, $A_{cant} < 2h$

Note that the distance h can be adjusted by moving the scanning piezoelectric element 204 in the Z-axis direction (direction of height).

However, if the probe 201 is moved too close to the surface of the sample 203 in order to improve the spatial resolution (i.e., if an interval (probe-to-sample distance) z between the sample 203 and the probe 201 is too small), the tip of the probe 201 is attracted to the sample 203 (the probe-to-sample distance when this attraction occurs changes in accordance with the material of the sample 203 and the type of excitation field).

That is, if a Van der Waals force gradient acting on the probe 201 becomes larger than the spring constant of the cantilever 202, this cantilever 202 can no longer support the probe 201. As a consequence, the probe 201 jumps onto the surface of the sample 203 to

make measurement difficult (Seizo Morita, K BOOKS
SERIES 83, "All About Scanning Probe Microscope"
(KOGYO CHOSAKAI) 1992). Accordingly, a spring
constant k_{cant} of the cantilever 202 is desirably
5 larger than the Van der Waals force gradient as
indicated by

$$k_{cant} > \delta F_{vdw} / \delta z \quad \dots (2)$$

where F_{vdw} is the Van der Waals force acting on the
probe 201, and z is the probe-to-sample distance.

10 In a dynamic mode in which a dynamic interaction
caused by a magnetic field is measured while the
cantilever 202 is vibrating, this dynamic interaction
is represented by the average of the probe 201 and the
magnetic force of the magnetic field at each point of
15 vibration (F.J. Giessibl, Physical Review B56 (1997) 16010).
Therefore, if the vibration amplitude A_{cant}
is larger than an attenuation distance α_{mag} , a place
where the probe 201 does not interact with
the magnetic field exists, so no efficient measurement
20 can be performed. The "attenuation distance" is the
distance from the surface of the sample 203 to a point
at which the probe 202 does not interact with the
magnetic field any longer.

Accordingly, to further increase the efficiency
25 of detection of the dynamic interaction, it is
necessary to eliminate the place where the probe 201
does not interact with the magnetic field. In other

words, while the probe 201 is scanned to measure the dynamic interaction caused by the magnetic field, it is necessary to set the vibration range of this probe 201 within the range from the surface of the sample 203 to the point at which the probe 201 does not interact with the magnetic field any longer. To this end, the vibration amplitude A_{cant} of the cantilever 202 must be made smaller than the attenuation distance α_{mag} of the magnetic field as indicated by

$$A_{cant} < \alpha_{mag} \quad \dots (3)$$

Since the attenuation distance α_{mag} of the magnetic field is about 50 nm, the vibration amplitude A_{cant} of the cantilever 202 is desirably set to less than 50 nm.

When the cantilever 202 is set under the conditions as described above, a high-frequency response can be stably measured with high resolution. (Measurement Method)

A measurement method of this embodiment will be explained below with reference to FIG. 10 and a flow chart in FIG. 12.

First, the sample 203 as a magnetic recording-head to be measured is placed on a specific member to be driven by the scanning piezoelectric element 204.

The sideband frequency ω_m and the carrier wave frequency ω_c of an AM signal to be generated from the AM signal generator 216 are set (step S501).

An AM signal current whose amplitude is modulated by these ω_c and ω_m is generated from the AM signal generator 216 and applied to the sample 203 (step S502).

5 In the above settings, the sideband frequency ω_m is set under the condition " $\omega_m \ll \omega_r$ ". In this case, the sideband frequency ω_m is preferably set to be 1/10 the resonance frequency ω_r of the cantilever 202 or less. This is so because there is the limitation
10 in modulation theory and circuit configuration that the maximum frequency of an AC component detected by the phase sensitive detector 210 is approximately 1/10 the resonance frequency of the cantilever or less.

 Also, the carrier wave frequency ω_c is set
15 to a value (a few MHz to GHz) higher than the resonance frequency ω_r of the cantilever 202. If measurement is performed by setting this carrier wave frequency ω_c in the vicinity of the resonance frequency ω_r of the cantilever 202, the cantilever
20 202 itself stores energy acting on the probe 201. This makes accurate image measurement impossible. Furthermore, if the carrier wave frequency ω_c is set to be smaller than the resonance frequency ω_r , no high-frequency measurement can be performed any
25 longer.

 Next, the cantilever 202 is set under the conditions meeting expressions (1) to (3) above and

vibrates, and the surface of the sample 203 is scanned by the probe 201 while the relative positional relationship between the probe 201 and the sample 203 are changed (step S503). During the scan, the
5 cantilever 202 is actuated at specified vibration amplitude by applying a specific signal (e.g., a signal having a frequency close to the resonance frequency ω_r of the cantilever 202) from the signal generator 206 to the actuating piezoelectric
10 element 205.

Consequently, a dynamic interaction caused by a magnetic field generated from the sample 203 acts on the probe 201. More specifically, a force and force gradient having a low-frequency AC component (ω_m
15 component) act on the probe 201. This ω_m component contains a high-frequency ω_c component. The value of ω_m is much smaller than the resonance frequency of the cantilever 202 and hence can be detected relatively easily. Therefore, the high-frequency
20 magnetic field distribution of the sample 203 can be measured by setting the value of the carrier wave frequency ω_c at a few MHz to GHz. That is, the high-frequency component (carrier wave component) of the dynamic interaction acting on the probe 201 can be
25 measured by converting this high-frequency component into the low-frequency component (sideband component).

The deflection detector 207 detects the force

and force gradient as the deflection of the
cantilever 202. The computer 218 receives a signal of
a topographical image of the sample 203 from
the measurement system including the deflection
5 detector 207, the amplitude/DC voltage converter 212,
and the feedback circuit 213, thereby measuring this
topographical image. In addition, the computer 218
selectively measures the force image and force
gradient image by controlling the switches 208
10 and 219.

If the computer 218 connects the switch 208 to
the phase sensitive detector 210 (PD) ("PD" in step
S504), this phase sensitive detector 210 and the
synchronous detector 211 generate a signal of the
15 force gradient. If the computer 218 connects the
switch 208 to the synchronous detector 209 (SD) ("SD"
in step S504), this synchronous detector 209 generates
a signal of the force image.

The force gradient image signal generated by the
20 phase sensitive detector 210 and the synchronous
detector 211 is loaded into the computer 218 via the
switch 219 ("Gradient" in step S507). The force image
signal generated by the synchronous detector 209 is
loaded into the computer 218 via the switch 219
25 ("Force image" in step S507).

The computer 218 measures the force gradient
image when loading the force gradient image signal

(step S508), and measures the force image when loading the force image signal (step S509).

As described above, this measuring device can measure the topographical image of the sample 203 and at the same time can selectively measure the force image and the force gradient image. Also, by switching the switches 208 and 219, a high-frequency force image and force gradient image in the same field of view can be compared under the same conditions.

Note that in high-frequency magnetic field measurement, if the strength of the magnetic field from the magnetic recording-head is too large, the surface shape is influenced by this magnetic field. When this is the case, the vibration frequency or vibration amplitude of the cantilever 202 is preferably controlled on the basis of the contrast of the obtained surface shape. For example, the vibration frequency of the cantilever 202 is shifted from the resonance frequency ω_r or the vibration amplitude of the cantilever 202 is increased by adjusting the actuating piezoelectric element 205 or the signal generator 206. Accordingly, measurement can be performed with the influence of the strong magnetic field reduced.

In the measuring device of the fifth embodiment described above, while the conditions of the cantilever 202 are appropriately set,

an amplitude-modulated, high-frequency electric
current is applied to a magnetic recording-head to be
measured, thereby generating a magnetic field. This
can realize measurement of a high-frequency response
5 with improved spatial resolution.

FIGS. 13A to 14C are graphs showing measurement
examples when a force gradient image and a force image
of a magnetic recording-head are measured using the
measuring device of the above embodiment.

10 FIG. 13A is a force gradient image as a
high-frequency head image obtained by the force
gradient measurement system of the measuring device of
the embodiment. FIGS. 13B and 13C depict line
profiles. As shown in FIG. 15, the magnetic
15 recording-head (sample 203) to be measured has a gap
51 between magnetic poles 50. Also, the value
(amplitude) of a signal current applied from the
current value monitor 17 to the sample is 20 mA.
Furthermore, the carrier wave frequency of
20 an AM signal for generating this signal current is
" $\omega_c = 2\pi \times 10 \text{ MHz}$ ", and the sideband frequency of
this AM signal is " $\omega_m = 2\pi \times 300 \text{ Hz}$ ". The operation
range of the probe 201 is " $5 \mu\text{m} \times 5 \mu\text{m}$ ". A range 30
in FIG. 13A corresponds to the position of the gap 51
25 of the magnetic recording-head, meaning that a
high-frequency magnetic field is large in this
portion. FIG. 13B is a line profile (corresponding to

a line 52 in FIG. 15) indicating that the magnetic field is large in the vicinity of the gap position. FIG. 13C is a line profile (corresponding to a line 53 in FIG. 15) indicating peaks 31 presumably generated by the effect of loss by excess current on the edges of the gap.

FIG. 14A is a force image as a high-frequency head image obtained by the force measurement system of the measuring device of the embodiment. FIGS. 14B and 14C depict line profiles (corresponding to the lines 52 and 53, respectively, in FIG. 15). The magnetic recording-head 203 to be measured and the probe 201 are the same as in the measurement example in FIGS. 13A to 13C. The measurement conditions are also the same except that the sideband frequency of the AM signal is " $\omega_m = 2\pi \times 47.2 \text{ kHz} (= \omega_r)$ ". A range in FIG. 14A corresponds to the gap position of the magnetic recording-head, meaning that a high-frequency magnetic field is large in this portion. FIG. 14B is a line profile indicating that the magnetic field is large in the vicinity of the gap position. A change in the contrast is moderate compared to FIG. 13B, indicating that the resolution is low. FIG. 14C shows that there are no peaks 31, shown in FIG. 13C, presumably generated by the effect of loss by an excess current on the edges of the gap.

From the above measurement results, the force

gradient measurement system has a higher resolution
than that of the force measurement system and,
therefore, can measure an image well reflecting
a high-frequency magnetic field generated from
5 a magnetic recording-head.

As described in detail above, the invention
expressed by the fifth embodiment can provide
a magnetic recording-head measuring device capable of
measuring a high-frequency response at high
10 sensitivity and high resolution.

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
15 shown and described herein. Accordingly, various
modifications may be made without departing from the
spirit and scope of the general inventive concept as
defined by the appended claims and their equivalents.

WHAT IS CLAIMED IS:

1. A magnetic head measuring apparatus for measuring a magnetic head, comprising:

a calibrating magnetic field generating source
5 which causes the magnetic head to generate a magnetic field having a constant strength and frequency;

an electric current applying device which applies an amplitude-modulated electric current whose amplitude is modulated by a specified carrier wave
10 frequency and modulation frequency, to the magnetic head from which the magnetic field is generated by the calibrating magnetic field generating source; and

a magnetic head measuring device which measures a high-frequency magnetic field generated from the
15 magnetic head by application of the amplitude-modulated electric current from the electric current applying device.

2. The apparatus according to claim 1, wherein the magnetic head measuring device includes an
20 interchangeable magnetic material probe partially or entirely made of a magnetic material.

3. The apparatus according to claim 1, wherein the electric current applying device is capable of applying a direct current.

25 4. The apparatus according to claim 1, wherein the electric current applying device is capable of applying an alternate current.

5. The apparatus according to claim 1, wherein the electric current applying device applies an electric current having a current density of not more than 10^{-8} A/cm².

5 6. The apparatus according to claim 1, wherein the calibrating magnetic field generating source includes an annular conductor and is capable of applying an electric current to the magnetic head.

10 7. The apparatus according to claim 1, wherein the calibrating magnetic field generating source includes a linear conductor and is capable of applying an electric current to the magnetic head.

15 8. The apparatus according to claim 1, wherein the calibrating magnetic field generating source is capable of applying an electric current and from which the magnitude of a magnetic field corresponding to the applied current is capable of being estimated.

20 9. The apparatus according to claim 1, wherein the calibrating magnetic field generating source includes a magnetic head.

10. The apparatus according to claim 1, wherein the calibrating magnetic field generating source is capable of applying a direct current to the magnetic head.

25 11. The apparatus according to claim 1, wherein the calibrating magnetic field generating source is capable of applying an alternate current to the

magnetic head.

12. The apparatus according to claim 1, wherein
the calibrating magnetic field generating source
applies an electric current having a current density
5 of not more than 10^{-8} A/cm².

13. The apparatus according to claim 1, further
comprising:

a direct current application source which applies
a direct current to the magnetic head;

10 a voltage measuring unit which measures a voltage
of the magnetic head to which the direct current is
applied by the direct current application source; and

a synchronous detector which synchronously
detects a specified frequency component of an output
15 voltage from the voltage measuring unit.

14. The apparatus according to claim 1, further
comprising:

an electric current application source which
applies to the magnetic head an electric current which
20 is a sum of a direct current and an alternate current;
and

a synchronous detector which synchronously
detects at a specified frequency a specific signal
output from the magnetic head measuring device.

25 15. A method of inspecting a magnetic head,
comprising:

setting the magnetic head;

selecting an analysis item for which the magnetic head is to be inspected;

applying to the magnetic head an amplitude-modulated electric current whose amplitude
5 is modulated by a specified carrier wave frequency and modulation frequency;

measuring, in accordance with the selected analysis item, the magnetic head to which the amplitude-modulated electric current is applied, by
10 using a high-frequency magnetic force microscope;

analyzing and evaluating data, obtained by the measurement, of the magnetic head; and

determining success or failure of the magnetic head on the basis of the evaluation result.

15 16. The method according to claim 15, further comprising:

applying a constant current to the magnetic head;
and

measuring a voltage of the magnetic head to which
20 the constant current is applied.

17. The method according to claim 15, further comprising synchronously detecting a specified frequency component of an output voltage obtained by the measurement.

25 18. The method according to claim 15, further comprising exchanging probes for use in measurement of the magnetic head.

19. The method according to claim 15, further comprising calibrating measurement variations of the magnetic head.

20. A magnetic recording-head measuring apparatus
5 for measuring a magnetic recording-head, comprising:

an electric current applying device which applies
to the magnetic recording-head an amplitude-modulated
electric current whose amplitude is modulated by a
specified carrier wave frequency and modulation
10 frequency;

a cantilever to which a probe having a magnetic
material is attached;

a vibrator which applies a vibration with
specified vibration amplitude to the cantilever; and

15 a measuring device which measures a dynamic
interaction which a magnetic field generated in the
magnetic recording-head by application of the
amplitude-modulated electric current from the electric
current applying means exerts on the probe vibrating,

20 wherein while the probe is scanned to measure the
dynamic interaction by the magnetic field, a vibration
range of the probe falls within a range from a surface
of the magnetic recording-head to a point at which the
probe does not interact with the magnetic field any
25 longer.

21. The apparatus according to claim 20, wherein
the vibration amplitude of the cantilever is less than

50 nm.

22. The apparatus according to claim 20, wherein a spring constant of the cantilever is larger than a Van der Waals force gradient acting on the probe.

5 23. The apparatus according to claim 20, wherein the vibrator is capable of adjusting at least one of the vibration frequency and vibration amplitude of the cantilever.

24. A method of measuring a magnetic recording-
10 head, comprising:

applying to the magnetic recording-head an amplitude-modulated electric current whose amplitude is modulated by a specified carrier wave frequency and modulation frequency;

15 applying a vibration with specified vibration amplitude to a cantilever to which a probe having a magnetic material is attached; and

measuring a dynamic interaction which a magnetic field generated in the magnetic recording-head by
20 application of the amplitude-modulated electric current exerts on the probe which vibrates together with the cantilever,

wherein while the probe is scanned to measure the dynamic interaction by the magnetic field, a vibration
25 range of the probe falls within a range from a surface of the magnetic recording-head to a point at which the probe does not interact with the magnetic field any

longer.

25. The method according to claim 24, wherein the vibration amplitude of the cantilever is less than 50 nm.

5 26. The method according to claim 24, wherein a spring constant of the cantilever is larger than a Van der Waals force gradient acting on the probe.

27. The method according to claim 24, wherein at least one of the vibration frequency and vibration
10 amplitude of the cantilever is adjusted.