

1 **TITLE: METHOD AND APPARATUS FOR TESTING MAGNETIC HEAD
 ELEMENTS**

TECHNICAL FIELD

6 The present invention relates to an apparatus for testing magnetic head elements in a head stack assembly ("HSA") or in a single head suspension. More particularly, the present invention relates to a method and apparatus for the measurement and the evaluation of a pseudo-asymmetry characterization of a magnetic head element.

BACKGROUND

11 Computer hard drives generally contain a magnetic head for reading from and writing to a magnetic recording element ("hard disk"). These heads are typically part of a head stack assembly ("HSA") and contain elements needed to write magnetic transitions on the hard disk and elements needed to read magnetic transitions previously written by a head. A typical write element contains thin film conductors looped inside soft magnetic pole pieces. A typical read
16 element is a magneto-resistive ("MR") or giant magneto-resistive ("GMR") strip that changes resistivity as it experiences changing magnetic fields.

 Manufacturers generally test their HSAs to insure that they only merge "good" HSAs into disk stacks and hard drives. One conventional testing method identifies "bad" heads using expensive "spin stand" testing machines, which require that the HSA be merged into a "disk test
21 stack" mounted on the tester. One of the key attributes measured by these spin stand testers is the track average asymmetry, ("TAA," also known as Track Average Amplitude Asymmetry, or "TAAA"). TAA is a measure of the asymmetric character of the positive and negative portions of the amplitude response of the head to a series of magnetic transitions written on a test track. That is, TAA measures the asymmetry of read back signals from a pre-written track of a test
26 disk stack. TAA is generally expressed as a percentage of the peak-to-peak amplitude of the track (V_{p-p}). A head is labeled "bad" when the absolute value of this TAA exceeds a specific

1 pre-established value, typically $\pm 15\%$. A TAA of greater than about $\pm 15\%$ is generally cause
for concern because the asymmetry could affect the drive performance by requiring excessive
use of error correction code algorithms and/or causing the product to fail a pre-set soft error rate
criteria.

6 One problem with conventional spin stand testing is that there is the risk of physical
damage to the HSA and/or the disk stack any time a merge is required. This problem results in
yield loss and raises the manufacturer's costs. Another problem with this solution is that the
merge process is time consuming. This problem either reduces the number of drives that can be
produced by an assembly line or requires that the manufacturer install the costly spin test
machines in parallel.

11 Clearly there is a need for an improved testing method that does not require a merge
operation or an expensive spin stand tester.

SUMMARY

16 The present invention includes hardware, a magnetic excitation methodology, and data
collection and manipulation process and software that will permit the identification of heads
with problems such as those described above. The invention uses these elements to create a
method of testing an HSA that does not require a merge operation or an expensive spin stand.

21 One aspect of this invention is an apparatus for testing a magnetic head element
comprising an electromagnetic structure having a core, a plurality of electrical windings, and an
air gap adapted to receive a magnetic head element. A power source may be operably
connected to the plurality of electrical coils and a series resonant driver may be operably
connected to the power source. Some embodiments of the present invention may further
comprise a controller operably connected to the series resonant driver and adapted to
compensate for a variation in a magnetic field strength across the air gap.

1 Another aspect of the present invention involves a method of testing a magnetic head
element. The method may comprise the steps of applying a magnetic field to a magnetic head
element, measuring an output signal from the magnetic head element, calculating a power level
for a fundamental signal and for a plurality of harmonic signals, and using the power levels to
calculate a value indicative of distortion. Some embodiments of the present invention may
6 further comprise the step of accepting or rejecting the magnetic head element based on the value
indicative of distortion. The step of applying a magnetic field may comprise the provision of an
electromagnetic structure having a core, a plurality of coils, and an air gap; and the generation
of a current in the plurality of coils using a power source connected to a series resonant driver.

Yet another aspect of the present invention is a system for testing a magnetic head
1 element. This system comprises a means for generating a magnetic field around a magnetic
head element, a computer processor means for processing data, a storage means for storing data
on a storage medium, a first means for collecting data from a magnetic head element, a second
means for processing data to produce a number representative of a distortion in an output from a
magnetic head element.

16 Still another aspect of the present invention is a method of detecting defective magnetic
head elements, one embodiment of which comprises inserting a magnetic head element inside
magnetic structure, the magnetic structure including a conductive element, inducing a current in
the conductive element, whereby the magnetic structure generates a magnetic field around the
magnetic head element, and whereby the generated magnetic field is related to the induced
21 current, and simultaneously controlling the induced current and measuring an output signal
from the magnetic head element.

One feature and advantage of the present invention is that it provides a "good/bad"
assessment analogous to the TAA without having to merge the HSA with a disk stack and
without requiring an expensive spin stand tester. This and other features, aspects, and

1 advantages of the present invention will become better understood with reference to the
following description, appended claims, and accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a perspective view of one embodiment of a head stack assembly tester
6 electromagnetic drive device.

Figure 2 is a block diagram showing one data collection and data analysis embodiment.

Figure 3 is a graph showing one cycle of a time varying magnetic field curve.

Figure 4 is a graph showing a first buffered head voltage output curve produced by a
magnetic head element in response to the magnetic field of Figure 3.

11 Figure 5 is a graph showing a second buffered head voltage output curve produced by a
magnetic head element in response to the magnetic field of Figure 3.

Figure 6 is a plot comparing the results of the "% distortion" test of the present
invention with the results from a spin stand TAA test.

DETAILED DESCRIPTION

16 The inventions disclosed in this detailed description allow many of the final head tests
usually run on a spin stand to be accomplished without the necessity of merging the HSA with a
disk stack. It was realized that if a magnetic field were used to simulate the data magnetic
transitions in a recording disk and applied perpendicularly to the HSA in an appropriate
(sinusoidal for example) manner, a measure of output signal asymmetry might be extracted by
21 mathematical analysis of the analog buffered head voltage ("BHV") output of the magnetic head
elements. Accordingly, the present invention can be used to provide a "good/bad" assessment
analogous to the TAA without the need to merge the HSA with a disk stack.

The present invention can be broken down into three principal parts: (1) an
electromagnetic drive structure that stimulates the MR device under test and the necessary

1 electronic drive circuitry to optimize the desired performance; (2) a method for optimizing the sample data collection, including the software necessary to accomplish the amassing of the MR device outputs affected by the applied field; and, (3) a method of processing the data to produce a meaningful output from the test that is related to some attribute of head performance.

6 I. Electromagnetic Drive Structure

Figure 1 is a perspective view of an electromagnetic device 10 designed to excite an HSAs under test. The electromagnetic device 10 includes a magnetic core 12 having an air gap 13 and a plurality of windings 14 connected to a power source 16. The electromagnetic device 10 in some embodiments may be a "squared C" type of structure. This structure is desirable due to its simple construction and well-known magnetic characteristics. However, other electromagnetic structures capable of generating a magnetic field in an air gap are within the scope of this invention.

In operation, the power source 16 generates an electrical current in the windings 14. This, in turn, generates magnetic flux through the magnetic core 12 and the air gap 13. A manufacturer may insert an HSA into the air gap 13 and use the magnetic field to simulate a magnetic recording element.

The electromagnetic device 10 embodiment depicted in Figure 1 has: (1) a dimension, "A," determined by the height of the HSA under test plus a small clearance allowance; (2) a pole face area, "B," designed to provide a large enough area of relatively undistorted flux lines between them to permit easy placement of the active portion of the HSA under test inside a straight flux line column; area "B" will also establish the maximum cross-sectional area of the HSA devices; (3) a dimension, "C," determined by a balance between: (i) maximizing the length to minimize the direct effect on the gap flux lines of the field generated by the coil, and (ii) minimizing the length to reduce the total reluctance, thus enhancing efficiency; and, (4) a

1 dimension, "D," determined by a balance between: (i) maximizing the length to provide for a
dimension, "E," sufficient length to avoid distortion of the flux lines between areas "B," and (ii)
minimizing the length to reduce the total reluctance of the structure.

It is desirable that the material for the core 12 have the following characteristics: (1)
high permeability and high saturation magnetization for high efficiency and adequate flux
6 carrying capability; (2) high electrical resistance to minimize eddy current losses when driven in
an AC mode; and, (3) low magnetic remanence to minimize the exposure of the HSA
components to a magnetic field between the pole faces when being inserted or removed from
the test fixture. One suitable material is a polycrystalline ferrite material having high
permeability and low remanent magnetization. This material is desirable because it generally
11 satisfies the above criteria, is highly available, and is relatively inexpensive. However, other
electromagnetic materials are within the scope of this invention.

The electromagnet 10 in some embodiments may be driven by a 600 Hertz ("Hz")
sinusoidal signal produced by the power source 16. This sinusoidal signal is desirable because
it can emulate the flux density seen by a head as it passes over magnetic transitions on a media
16 and because it permits the extraction of dynamic responses from the heads under test. The 600
Hz frequency is desirable because it is compatible with both 60 and 50 Hz sources and because
it is high enough frequency to eliminate DC background noise/effects. However, other
waveforms, such as a square or triangular signal, and other frequencies are within the scope of
this embodiment.

21 The number of coil turns, "N," around the electromagnetic device 10 is arbitrary.
However, those skilled in the art will realize that Ampere's Law relates the chosen number of
turns with the desired gap field "A" and with the desired power supply 16. Thus, increasing the
number of turns "N" will increase the magnetic field produced by a particular power supply 16.

1 Similarly, decreasing the number of turns "N" will decrease the magnetic field produced by a particular power supply 16.

The peak magnetic field strength is controlled by the drive voltage ("V_{p-p}") produced by the power source 16 against the resistance of the coil wires 13. The necessary drive voltage may be minimized in some embodiments by applying a series resonant driver 22, as shown in
6 Figure 1. This driver 22 allows the electromagnet 10 to be driven in a manner yielding higher field strengths at a given voltage. Some key advantages of this drive method are: (1) minimized size and weight of driving power supplies; (2) the ability to use non-custom drive amplifiers; and (3) minimized radiated and conducted electromagnetic interference, which are frequently of concern when other sensitive electronic devices are nearby.

11 The series resonant driver 22 uses a capacitor 18 to compensate for the inductance of the coil 14 and the core 12. The capacitance, "C," should be chosen so that the circuit operates at resonance. That is, the power source 16, the capacitor 18, the coil 14, and the core 12 form an "RLC" circuit. The circuit will operate at resonance if: $C = \frac{1}{L\omega^2}$, where "L" is the inductance of the coil/core structure and "ω" is the frequency of the power source 20. At this capacitance
16 value, the impedance of the capacitor 18 will cancel the inductance of the coil/core structure, which minimizes the total impedance of the electromagnetic device 10.

Referring again to the embodiment shown in Figure 1, the magnetic field strength across the air gap 13 may vary with vertical position. This effect may occur due to increased flux line loss as the vertical center of the magnet is approached. To compensate for this effect, some
21 embodiments may incorporate a controller 20 that controls the voltage produced by the power source 16 depending on which head in the HSA is currently being tested. Some controller 20 embodiments may be a feedback device that implements a standard analog or digital control algorithm. However, other devices capable of adjusting and maintaining the peak to peak voltage of the power source 16 are within the scope of this invention.

1 Some embodiments of the present invention use a calibration technique to determine the
proper peak to peak voltage. These embodiments may use an independent device to measure
the magnetic field at various positions across the air gap 13 or to measure the output of a
reference HSA assembly. The data from this calibration process may be provided to the
controller 20 and used to adjust the voltage of the power source 16 depending on the head's
6 position. That is, an appropriate correction factor may be calculated using a computer or a
similar device and used to ensure that the vertical component of the magnetic field at the
horizontal center of the magnetic jaws is approximately constant regardless of a head's vertical
location in the HSA.

 Those skilled in the art will realize that the peak to peak strength of the magnetic field is
11 a function of the AC drive's peak to peak voltage. Thus, the magnetic field strength to which
the device under test is exposed in this embodiment will follow the sinusoidal voltage pattern
generated by the AC power source 16 and will be proportional to the voltage applied to the coil
14. Because each particular head design has a particular bias current at which it is most
sensitive, some embodiments of this invention may adjust the peak to peak voltage of the power
16 source for the particular device under test using the controller 20. The specific value of this
bias current is determined by the particular product head and/or manufacturers design of the
head structure.

II. Data Sampling and Collection

21 Figure 2 shows one suitable data sampling and collection algorithm. At block 50, an
operator may place the HSA under test between the faces "B" of the electromagnetic device 10.
At block 52, the operator may activate the power source 16. This generates a magnetic field in
the air gap between the faces. The induced magnetic field for one embodiment of the present
invention is shown graphically in Figure 3.

1 At block 56 in Figure 2, a manufacturer may sample the analog buffered head voltage
("BHV") output of each head in the HSA under test "n" times (the "time marks" along X axis of
Figure 2) during a cycle using a digital computer connected to an analog-to-digital converter
and a data storage device. Larger values for "n" will produce "smoother" the data curves, but
will require more time and computer resources to perform the analysis. Some embodiments
6 may also sample the BHV output for "m" cycles. At block 58, the sampled BHV output is
stored in a computer-accessible memory device as an "m" by "n" matrix. At block 60, the
values in this matrix may be averaged for each of the "n" columns in some embodiments,
resulting in a data array representing a single averaged cycle. The values in this averaged data
array for one embodiment of the present invention are graphically represented in Figures 4 and
11 5.

 Some embodiments of the present invention may include an optional time delay at block
54. In some instances, this time will allow the total system to settle down to the degree
necessary to provide acceptable accuracy and repeatability of the measurement. The time
required to settle the components is generally inversely proportional to the field strength
16 required to excite the MR device and to the accuracy required produce an acceptable,
analyzable, BHV analog output. Some embodiments of the present invention will also control
the frequency and the phase of the sampling to insure that "n" arrays in the data matrix each
represent an actual cycle. These embodiments may also use hardware to synchronize the start of
the data set with a particular point in the magnetic field's cycle or may use software to adjust
21 and sort the collected data. One suitable method is described in copending Provisional
Application Serial No. 09/120,995, filed February 19, 2000 (now Patent Application Serial No.
09/505,033, filed February 16, 2000), and entitled "Method and Apparatus for Analyzing Rotor
Imbalance," which is herein incorporated by reference. Other methods of ensuring that the data

1 matrix closely represents the actual HSA output are also possible and within the scope of this invention.

III. Distortion Measurement

Referring again to Figure 2, the average output data array may then be replicated at block 62 into a "t" second time record and subjected to a Fast Fourier Transform ("FFT") analysis by the computer's central processing unit. This analysis produces a power value (in decibels or "dB") for a fundamental and series of harmonics. At block 64, a "% Distortion" value can be computed by comparing all or selected portions of the FFT harmonic data with the FFT data for the fundamental signal. A wide variety of formulas may be used to perform this task. However, it is desirable that the formula used be relatively simple, such as an arithmetic, geometric, or gaussian weighing function that uses selected lower order harmonics. Examples of the interim averaged time domain waveforms are presented in Figures 4 and 5. These figures display two averaged data curves having a "% distortion" of 27.48 and 4.96. At block 66, this % distortion value may be used to accept or reject an HSA.

Some embodiments of the present invention utilize the FFTW subroutine library to perform a discrete Fourier transform using a computer. This subroutine library is produced for the "C" programming language by the Massachusetts Institute of Technology and is available, under the GNU General Public License, at <http://theory.lcs.mit.edu/~fftw/>. Those skilled in the art, however, will recognize that other discrete Fourier transform algorithms are widely available and potentially applicable.

21 Figure 6 shows the relationship between the "% distortion" calculated using one embodiment of this invention and the absolute value of the TAA measured by conventional spin stands. The general trend is noticeable, and quite good when the vastly different measurement systems are taken into account. Of significance, if one assumes an absolute TAA measurement of $< \sim 15\%$ is a "good" head and also a "% distortion" of $< \sim 10$ is a "good" head, is that most

1 heads tested good by the spin stand TAA method also tested good by the "% distortion" method. Similarly, every head tested bad by the spin stand TAA method also tested bad by the "% distortion" method. This "pass/fail" equivalency is accomplished without the need to merge the HSA into a disk stack, which results in the testing cycle time ("TAK") time that is about 60-70% less than required for the spin stand method.

6 The present invention is also desirable because it detects marginal heads, which a spin stand does not detect. This feature is desirable because manufacturers may use the data for statistical quality control purposes. This feature is also desirable because manufacturers can bin-sort the drives. That is, manufacturers use the better-performing heads in its high capacity drives and the poorer-performing heads in its lower capacity drives. This feature is
11 desirable because it can help manufacturers reduce waste.

Some embodiments may also measure the phase difference between the excitation signal and the resultant electrical signal from the magnetic heads. These embodiments are desirable because heads that have been damaged by electrostatic discharge ("ESD"), or by improper process control, may exhibit a significantly different phase than the desired population of heads.
16 This is especially true of GMR Heads. No know test on a spin stand clearly diagnoses this important problem. Still other embodiments may analyze the relative strengths of various resultant signal harmonics to detect ESD damage.

The present invention offers many advantages over known HSA testing methods and apparatuses. For example, the present invention includes a method of assessing MR or GMR
21 head element performance, comparable in results to a TAA measurement on a spin stand, without the necessity of a spin stand tester or the necessity of a merge operation at the HSA level. Another advantage is that the present invention may use a sinusoidal magnetic strength curve, unlike conventional non-merged testing of HSAs where the drive field is applied using stepped DC drive source (commonly referred to a "quasi static" testing). The resulting "quasi-

1 dynamic” test that is closer to the HSA’s actual operating conditions than the “quasi-static”
testing used by the prior art.

 Although the present invention has been described in detail with reference to certain
embodiments thereof, it may be also embodied in other specific forms without departing from
the essential spirit or attributes thereof. For example, although this disclosure focused on the
6 application of the invention to examining MR or GMR head elements at the HSA level of
fabrication, it is clear that minor modifications to the fixtures, control electronics, connections,
and analysis software will allow the described methodology to be equally applicable at the
slider, head gimbal assembly (“HGA”), and other such lower levels of device assembly. The
data collected for analysis in these embodiments would be sampled from the output of an
11 appropriate electronic connection to the contact pads, lead wires, flex lines. In addition,
although the embodiments in this disclosure generally utilize a programmable, general purpose
computer connected to an analog to digital converter and a data storage device, the present
invention may be implemented other using other hardware. Some high volume manufacturers,
in particular, may wish to replace the computer with a dedicated apparatus.

16 The accompanying figures and this description depict and describe embodiments of the
present invention, and features and components thereof. With regard to means for fastening,
mounting, attaching or connecting the components of the present invention to form the
mechanism as a whole, unless specifically described otherwise, such means were intended to
encompass conventional fasteners such as machine screws, nut and bolt connectors, machine
21 threaded connectors, snap rings, screw clamps, rivets, nuts and bolts, toggles, pins and the like.
Components may also be connected by welding, friction fitting, adhesives, or deformation, if
appropriate. Electrical connections or position sensing components may be made using
appropriate electrical components and connection methods, including conventional components
and connectors. Unless specifically otherwise disclosed or taught, materials for making

1 components of the present invention are selected from appropriate materials such as metal,
metallic alloys, fibers, plastics and the like, and appropriate manufacturing or production
methods including casting, extruding, molding and machining may be used. In addition, any
references to front and back, right and left, top and bottom and upper and lower are intended for
convenience of description, not to limit the present invention or its components to any one
6 positional or spacial orientation. Therefore, it is desired that the embodiments described herein
be considered in all respects as illustrative, not restrictive, and that reference be made to the
appended claims for determining the scope of the invention.

CLAIMS

What is claimed is:

1. An apparatus for testing a magnetic head element, comprising:
an electromagnetic structure having a core, a plurality of electrical windings, and an air gap adapted to receive a magnetic head element;
a power source operably connected to the plurality of electrical coils; and
a series resonant driver operably connected to the power source.
2. The apparatus of claim 1, further comprising:
a controller operably connected to the series resonant driver and adapted to compensate for a variation in a magnetic field strength across the air gap.
3. The apparatus of claim 2, wherein the controller is adapted to optimize a sensitivity of a response from a magnetic head element.
4. The apparatus of claim 2, wherein the controller comprises a feedback loop adapted to apply a preselected magnetic field to each magnetic head element in a head stack assembly.
5. The apparatus of claim 1, wherein the electromagnetic structure is adapted to maximize efficiency, minimize eddy current losses, and minimize remanent magnetization.
6. The apparatus of claim 1, wherein the core is made from a polycrystalline ferrite material having high permeability and low remanent magnetization.
7. The apparatus of claim 1, wherein a number of windings in the plurality of windings is determined by the air gap, the power supply, and a desired magnetic field.
8. The apparatus of claim 1, wherein electromagnetic structure has an inductance and the series resonant driver comprises a capacitor adapted to balance the inductance.
9. The apparatus of claim 1, wherein the power supply is adapted to deliver a sinusoidal voltage.



- 1 10. A method of testing a magnetic head element, comprising:
- applying a magnetic field to a magnetic head element;
- measuring an output signal from the magnetic head element;
- calculating a power level for a fundamental signal and for a plurality of harmonic signals; and
- 6 using the power levels to calculate a value indicative of distortion.
11. The method of claim 10, further comprising:
- rejecting the magnetic head element based on the value indicative of distortion.
12. The method of claim 10, wherein the step of applying a magnetic field comprises:
- providing an electromagnetic structure having a core, a plurality of coils, and an air gap;
- 11 and
- generating a current in the plurality of coils using power source connected to a series resonant driver.
13. The method of claim 12, wherein the step of applying a magnetic field further comprises:
- 16 adjusting the current to compensate for a position of the magnetic head element.
14. The method of claim 12, further comprising:
- placing a head stack assembly in the air gap.
15. The method of claim 10, wherein the step of applying a magnetic field further comprises:
- 21 optimizing the magnetic field for a particular magnetic head element.
16. The method of claim 10, wherein the step of applying a magnetic field further comprises:
- compensating for magnetic field variations using a controller.
17. The method of claim 10, wherein the step of measuring an output signal comprises:

- 1 sampling a plurality of data points during a plurality of cycles; and
storing the plurality of samples in a data storage device.
18. The method of claim 16, wherein the step of measuring an output signal further
comprises:
synchronizing a frequency and a phase of the plurality of data points.
- 6 19. A system for testing a magnetic head element, comprising:
a means for generating a magnetic field around a magnetic head element;
a computer processor means for processing data;
a storage means for storing data on a storage medium;
first means for collecting data from a magnetic head element; and
11 second means for processing data to produce a value indicative of an output distortion of
the magnetic head element.
20. A method of detecting defective magnetic head elements, comprising:
inserting a magnetic head element inside magnetic structure, the magnetic structure
including a conductive element;
16 inducing a current in the conductive element, whereby the magnetic structure generates a
magnetic field around the magnetic head element, and whereby the generated magnetic field is
related to the induced current; and
simultaneously controlling the induced current and measuring an output signal from the
magnetic head element.

