

# INDUCTION MAGNETIC TRANSDUCER AND DRIVING CIRCUIT THEREFOR

## BACKGROUND OF THE INVENTION

The present invention relates to an induction magnetic transducer for use in magnetic disk units and a driving circuit for the induction magnetic transducer.

In a high speed data processing and a mass data processing, a magnetic disk units such as hard disk drive (HDD) has been widely used. Typically, as shown in Fig. 7, a magnetic head 1 comprises a magnetic core 5 which constitutes a magnetic circuit 6, a coil 3 wound on the magnetic core 5 and a slider assembly 4 supporting the magnetic core 5 and the coil 3. With this structure, the magnetic head 1 flies at a closer spacing above a rotating magnetic recording disk surface.

Magnetic heads conventionally used in the magnetic disk units usually has an induction magnetic transducer which writes data on a magnetic recording medium or reads recorded data from the magnetic recording medium by detecting the change in magnetic flux due to electromagnetic induction phenomena. As the induction magnetic transducer, a ferrite transducer, a metal-in-gap (MIG) magnetic transducer, a thin-film magnetic transducer, etc. are known in the art. Fig. 8 schematically shows a typical construction of the transducer for the ferrite head and the MIG magnetic head. In Fig. 8, the transducer comprises a pair of magnetic cores 5, 5 made of a magnetic oxide material such as ferrite, etc. The pair of magnetic cores 5, 5 faces each other so as to form a magnetic gap 8 between the magnetic cores 5, 5. On the surface of each magnetic core 5 facing the magnetic gap 8, a non-magnetic film is formed (not shown). The

space in the magnetic gap 8 is filled with glass 9, etc. to fix the magnetic cores 5, 5 to constitute a magnetic circuit 6. A transducer of an MIG magnetic head has, in place of the non-magnetic film in the ferrite head, a soft magnetic film 7 made of a material such as FeAlSi-based alloy which has a saturation magnetic flux density higher than ferrite. A thin-film magnetic head generally has a lower magnetic layer formed on a substrate, on which a spiral coil conductor is formed through an insulating layer. On the conductor, an upper magnetic layer is formed through an insulating layer to construct a closed magnetic circuit.

Fig. 9 is a diagrammatic circuit schematically showing a conventional induction transducer and a driving circuit therefor. As shown in Fig. 9, a transducer 1 has a coil 53, and a driving circuit 2 comprises a reproduction circuit 51 and a record circuit 52 both being connected to the coil 53. The reproduction circuit 51 reads induced current in the coil 53, and the record circuit 52 passes a recording (writing) current  $I_w$  through the coil 53 in both forward and reverse directions as indicated by arrows. Fig. 10 is a diagram illustrating the recording by the conventional induction transducer and the driving circuit shown in Fig. 9. After receiving control signals corresponding to the data being recorded, the record circuit 52 passes the recording current  $I_w$  through the coil 53. The control signal shown in Fig. 10 is NRZI (non-return-to-zero inversion) control signal which inverts the sign between plus and minus every time the recording data are input. When the writing current  $I_w$  is small and the magnetic recording medium is not magnetically saturated, the magnetization of the magnetic recording medium is insufficient (A in Fig. 10). When the recording current  $I_w$  reaches and exceeding the magnetization threshold value ( $I_+$  or  $I_-$ ), namely a current value sufficient for

magnetically saturating the magnetic medium (C in Fig. 10), the magnetic medium is sufficiently magnetized to allow the recording of the data (B in Fig. 10).

The writing current  $I_w$  being passed through the coil 53 for magnetically exciting the transducer 1 is usually controlled so as to make a reverse interval  $T$  constant, and a time delay (polarity reverse time  $T_r$ ) is generally found after the data are input and until the writing current exceeds the magnetization threshold value to complete the magnetization of the magnetic recording medium. The polarity reverse time  $T_r$  depends on the circuit properties of the record circuit 52 and inductance of the transducer 1. When the ratio ( $T_r/T$ ) of the polarity reverse time  $T_r$  to the reverse interval  $T$  becomes larger, for example, the unsaturatedly magnetized portion (A and A' in Fig. 10) is magnetized in the direction opposite to its own magnetization direction by the magnetic field from an adjacent saturatedly magnetized portion (B and B' in Fig. 10). As a result thereof, a magnetization transition point (C and C' in Fig. 10) is shifted as shown by the thick arrow D or D' to fail to create a good magnetization state in the magnetic recording medium. The shift of the magnetization transition point becomes considerable particularly in a high-frequency recording. Therefore, the polarity reverse time  $T_r$  is generally required to be  $1/2$  or less of the reverse interval  $T$ . In particular, a still shorter polarity reverse time  $T_r$  is required in a high frequency recording, because the reverse interval  $T$  is reduced.

Recent demand for the magnetic disk units is a high density and high frequency recording. For example, a high recording density of about 6000 TPI (tracks per inch) and about 134 kFCI (flux changes per inch), and a high recording frequency of 50 MHz or more are required. Since a recording current of 50 MHz or more has a reverse

interval  $T$  of 10 ns, the polarity reverse time  $T_r$  is required to be controlled to 5 ns or less. For example, in a transducer having a known record circuit and a coil of 42 turns, the inductance should be about 0.6  $\mu\text{H}$  for attaining a polarity reverse time  $T_r$  of 5 ns. However, since an MIG transducer of 42 turns has an inductance of about 1.8  $\mu\text{H}$ , it is difficult to reduce the polarity reverse time  $T_r$  to 5 ns or less. Therefore, the inductance should be reduced to attain a reduced polarity reverse time  $T_r$ . The inductance of the transducer depends on the number of turns of a coil and the cross-sectional area of the magnetic core in the coil. Since the MIG transducer is constructed by a machined ferrite as the magnetic core, the reduction of the cross-sectional area has its limit, and therefore, the number of turns of coil should be reduced in stead of reducing the cross-sectional area to attain a reduced inductance.

However, in the known transducer shown in Fig. 9, since the writing and reading operations use the same coil, a reduced number of turns results in the reduction of reproduction output level.

To reduce the inductance at writing operation without reducing the reproduction output level, proposed is an MIG transducer comprising, as shown in Fig. 11, a reading coil 54 having a larger number of turns and a writing coil 55 having a smaller number of turns which are wound on the magnetic circuit 6 separately from each other and are driven independently. However, the production of such a transducer having respective reading coil and writing coil of different number of turns requires additional process of winding coil, and in particular, the process of winding two separate coils on a small core is troublesome and time-consuming.

To avoid the time-consuming process of winding two separate coils and reduce the inductance at writing operation without

reducing the reproduction output level, a transducer having a three-terminal coil has been proposed, for example, in Japanese Patent Laid-Open No. 55-132514. Fig. 12 shows a schematic circuit diagram of the three-terminal transducer and a driving circuit therefor. As shown in Fig. 12, a three-terminal coil 63 consists of a first coil 64 and a second coil 65 which are connected to each other at a common terminal 60. Both ends of the coil 63 are respectively connected to a reproduction circuit 61 and a record circuit 62 through respective switching means 66, 66.

Figs. 13a to 13c illustrate the operation of the above three-terminal transducer and the driving circuit. Fig. 13a shows a reading operation, in which a reading current  $I_R$  is passed through the coil 63 consisting of the first coil 64 and the second coil 65 which are connected in series, thus obtaining a desired level of reproduction output due to a large inductance of the coil 63. Figs. 13b and 13c show a recording(writing) operation. In the recording operation, the first coil 64 and the second coil 65 are switched alternatively by a head selection signal from a supplier 67 for writing current, and a writing current  $I_{W1}$  is passed through the first coil 64 and a writing current  $I_{W2}$  is passed through the second coil 65. Since the length of the coil 64 and the coil 65 through which the writing current flows is one-half the length of the coil 63, the inductance of the first and second coils 64 and 65 is reduced to about  $1/4$  of that in the reading operation where the reading current flows the coil 63.

However, in the above three-terminal transducer and driving circuit, a time delay  $T_d$  is inevitable at switching the writing current  $I_{W1}$  to the writing current  $I_{W2}$  and vice versa. This time delay extends the polarity reverse time  $T_r$  to make the transducer inapplicable to a high frequency recording. Fig. 14 illustrates a recording current  $I_W$

and the magnetization of a magnetic recording medium 20 in operating the above three-terminal transducer and driving circuit. As seen from Fig. 14, a time delay  $T_{d1}$  due to electrical characteristics of the switching means 66 and the record circuit 62 is found between the point where the recording current  $I_{w1}$  starts to decrease and the point where the recording current  $I_{w2}$  starts to negatively increase. Also, a time delay  $T_{d2}$  is found between the point where the recording current  $I_{w2}$  starts to negatively decrease and the point where the recording current  $I_{w1}$  starts to increase (the flow directions of  $I_{w1}$  and  $I_{w2}$  are expressed to be opposite to each other). The time delays  $T_{d1}$  and  $T_{d2}$  extend the polarity reverse time  $T_r$  in the recording current  $I_w$  synthesized from the recording currents  $I_{w1}$  and  $I_{w2}$  to result in a large ratio of the polarity reverse time to the reverse interval ( $T_{r1}/T_1$  and  $T_{r2}/T_2$ ).

In addition, the inductance  $L_1$  of the first coil 64 and inductance  $L_2$  of the second coil 65 in the conventional three-terminal transducer are likely different due to production variability. The difference in the inductances leads to different time delays  $T_{d1}$  and  $T_{d2}$ , thereby resulting in inconsistent magnetization of the recording medium 20. For this reason, the three-terminal transducer and driving circuit are conventionally not used in a magnetic disk unit employing a recording frequency of 30 MHz or more.

As described above, the conventional transducer and driving circuit cannot meet the requirements for the high density and high frequency magnetic recording, because the polarity reverse time  $T_r$  is difficult to be shortened due to the high inductance of the writing coil and the time delay at switching the writing coils.

#### OBJECT AND SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to solve the above problems involved in the conventional transducer and driving circuit, and provide an induction transducer and driving circuit applicable to the high density and high frequency magnetic recording while ensuring a sufficient level of reproduction output.

As a result of the intense research in view of the above objects, the inventors have found that the above problems in the art can be solved by suitably selecting a pair of terminals for a writing coil and another pair of terminals for a reading coil from a coil having at least three terminals so that the inductance of the writing coil may be smaller than that of the reading coil; and passing the recording current only through the same writing coil in both the forward and reverse directions. The present invention has been accomplished by this finding.

Thus, in a first aspect of the present invention, there is provided an induction magnetic transducer for magnetically writing and reading informational data by detecting a change of magnetic flux due to electromagnetic induction, comprising a coil having at least three terminals, wherein a pair of terminals selected from at least three terminals constitutes a reading terminal pair and another pair of terminals selected from at least three terminals constitutes a writing terminal pair so that an inductance of a writing coil defined between the pair of writing terminals is smaller than that of a reading coil defined between the pair of reading terminals, the inductance of the writing coil being  $0.3 \mu\text{H}$  or less, the inductance of the reading coil at reading operation being  $0.95 \mu\text{H}$  or less and a recording current in forward and reverse directions being passed only through the writing coil.

The reading terminal pair for obtaining output is a combination of two terminals selected from at least three terminals of the coil, and the writing terminal pair through which the recording current is passed is another combination of two terminals selected from at least three terminals of the same coil. The terminals of the coil are combined so that the inductance of the writing coil defined between the pair of the writing terminals is smaller than that of the reading coil defined between the pair of the reading terminals. In such a manner, the reading coil having a larger inductance and the writing coil having a smaller inductance are obtained from one coil, and therefore, the polarity reverse time  $T_r$  can be shortened to meet the requirements of high frequency recording having a short reverse interval  $T$ . In addition, since the recording current in the forward and reverse directions flows only the writing coil, no time delay due to switching a writing coil to another and no inductance difference between the writing coils, which cause inconsistent magnetization of the recording medium, occur. With such a construction, an induction magnetic transducer applicable to a high density and high frequency magnetic recording while ensuring a sufficient level of reproduction output can be attained.

In a second aspect of the present invention, there is provided an induction magnetic transducer for magnetically writing and reading informational data by detecting a change of magnetic flux due to electromagnetic induction, comprising a coil having two end terminals at both the ends of the coil and an intermediate terminal, wherein two end terminals define a reading coil therebetween and one of two end terminals and the intermediate terminal define a writing coil therebetween so that the reading coil has an inductance of  $0.95 \mu\text{H}$  or less at reading operation, the writing coil has an inductance

of 0.3  $\mu\text{H}$  or less, and a recording current in forward and reverse directions is passed through only the writing coil.

In the above induction magnetic transducer, since the coil defined between two end terminals at both the ends of the continuous coil is used as the reading coil and the coil defined between one of the end terminals and the intermediate terminal is used as the writing coil, the inductance of the writing coil is always smaller than that of the reading coil and the same writing coil is passed through by the recording current in both the forward and reverse directions. Therefore, the polarity reverse time  $T_r$  can be shortened to make the magnetic transducer applicable to the high frequency recording having a short reverse interval  $T$ . In addition, since the same writing coil is passed through by the recording current in both the forward and reverse directions, no time delay due to switching a writing coil to another and no inductance difference between the writing coils, which cause inconsistent magnetization of the recording medium, occur. With such a construction, an induction magnetic transducer applicable to a high density and high frequency magnetic recording while ensuring a sufficient level of reproduction output can be attained.

By regulating the inductance of the reading coil at reading operation to 0.95  $\mu\text{H}$  or less and the inductance of the writing coil to 0.3  $\mu\text{H}$  or less, a high frequency recording utilizing a recording frequency of 50 MHz or more can be satisfactorily conducted.

The continuous coil is formed by winding a wire on a magnetic core. In this case, a parallel wire composed of at least two wires may be used. An end of a wire and an end of another wire, each constituting the parallel wire, serve as the end terminals. Thus, a single winding operation using the parallel wire simultaneously produces both the reading coil and the writing coil. The continuous

coil may be a thin film coil having two end terminals and an intermediate terminal. By forming these terminals in the thin-film forming process, both the reading coil and the writing coil are simultaneously produced by a single process.

In a third aspect of the present invention, there is provided a driving circuit for an induction magnetic transducer magnetically writing and reading informational data by detecting a change of magnetic flux due to electromagnetic induction, comprising a coil having at least three terminals, wherein the driving circuit comprises a reproduction circuit connected to a pair of reading terminals selected from at least three terminals, the reproduction circuit reproducing signals from a reading coil defined between the pair of reading terminals; and a record circuit connected to another pair of writing terminals selected from at least three terminals, the record circuit passing a recording current through only a writing coil defined between the pair of writing terminals in both the forward and reverse directions.

During the reading operation, the reproduction circuit receives the signals from the reading coil to read the informational data recorded on the recording medium. The record circuit passes a recording current in the forward and reverse directions through the same writing coil to write the informational data on the recording medium without switching a writing coil to another. Thus, the driving circuit of the present invention provides an induction magnetic transducer applicable to a high density and high frequency magnetic recording while ensuring a sufficient level of reproduction output.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic circuit diagram showing an induction magnetic transducer and driving circuit of the present invention;

Figs. 2a and 2b are schematic diagrams showing an operation of the induction magnetic transducer and driving circuit shown in Fig. 1;

Fig. 3 is a schematic diagram graphically showing a recording operation by the induction magnetic transducer and driving circuit shown in Fig. 1;

Figs. 4a to 4c are schematic diagrams illustrating an induction magnetic transducer and a bifilar coil embodying the present invention;

Fig. 5 is a schematic diagram illustrating an induction magnetic transducer having a thin film coil embodying the present invention;

Figs. 6a to 6c are schematic diagrams illustrating another coil produced from a parallel wire composed of three wires;

Fig. 7 is a schematic diagram illustrating a typical structure of a magnetic head;

Fig. 8 is a schematic diagram illustrating a magnetic circuit for a ferrite transducer or an MIG transducer;

Fig. 9 is a schematic diagram showing a conventional induction magnetic transducer and driving circuit;

Fig. 10 is a schematic diagram graphically showing a recording operation by the conventional induction magnetic transducer and driving circuit shown in Fig. 9;

Fig. 11 is a schematic diagram showing a conventional induction magnetic transducer having another structure;

Fig. 12 is a schematic circuit diagram showing a conventional three-terminal magnetic transducer and driving circuit;

Figs. 13a to 13c are schematic diagrams showing the read/write operation of the conventional three-terminal magnetic transducer and driving circuit shown in Fig. 12; and

Fig. 14 is a schematic diagram graphically showing a recording operation by the conventional three-terminal magnetic transducer and driving circuit shown in Fig. 12.

#### DETAILED DESCRIPTION OF THE INVENTION

Fig. 1 shows the construction of a transducer assembly comprising an induction magnetic transducer and a driving circuit of the present invention. In Fig. 1, a magnetic transducer 1 has a coil 3, and a driving circuit 2 comprises a reproduction circuit 21 and a record circuit 22, each being connected to the coil 3. The coil 3 has three terminals, namely, two end terminals 33 and 35 at both the ends of the coil 3 and an intermediate terminal 34. A coil defined between the end terminals 33 and 35, namely the whole part of the coil 3, constitutes a reading coil. A coil defined between the end terminal 33 and the intermediate terminal 34 is a first coil 31, and a coil defined between the end terminal 35 and the intermediate terminal 34 is a second coil 32. Either one of the first coil 31 and the second coil 32 is used as a writing coil to be connected to the record circuit 22. In Fig. 1, although the second coil 32 is used as the writing coil and connected to the record circuit 22, it should be noted that the first coil 31 may be also used as the writing coil and connected to the record circuit 21. The position of the intermediate terminal 34 on the coil 3 may be arbitrarily selected so long as the writing coil has an inductance which gives a polarity reverse time  $T_r$  sufficient small for a high frequency recording.

Fig. 2a shows a reading operation by the induction magnetic transducer and the driving circuit shown in Fig. 1. A whole part of the coil 3 is used as the reading coil, and the informational data on the recording medium is reproduced by the measurement of a reading current  $I_R$  by the reproduction circuit 21. For a high frequency recording of 50 MHz or more while ensuring a desired reproduction output level, the total inductance  $L_h$  of the coil 3 at reading operation is preferably about 0.95  $\mu\text{H}$  or less.

Fig. 2b shows a writing operation using the second coil 32 as the writing coil. At the writing operation, only the second coil is used and a recording current in both the forward and reverse directions, namely, a recording current  $I_{W1}$  and a recording current  $I_{W2}$  from the record circuit 22, is passed through only the second coil 32. In this manner, the inductance  $L_2$  (inductance of the second coil 32) at the writing operation can be made smaller than the inductance  $L_h$  at the reading operation. An inductance  $L$  of a coil is proportional to a square of the number of turns. When the intermediate terminal 34 is positioned at near the center of the coil 3, the inductance  $L_2$  at the writing operation is about 1/4 of the inductance  $L_h$  at the reading operation.

In the present invention, the flowing direction of each recording current  $I_{W1}$  or  $I_{W2}$  passing through the second coil 32 is fixed by the direction of the output current from the record circuit 22. Therefore, a means for switching the recording current from  $I_{W1}$  to  $I_{W2}$  and vice versa can be omitted. Also, since only one writing coil is used in the present invention, a means for switching a writing coil to another can be omitted.

Fig. 3 shows a magnetic recording on a magnetic recording medium 20 by the induction magnetic transducer and driving circuit

of the present invention. In Fig. 3, when the record circuit 22 receives control signals corresponding to the data being recorded, the record circuit 22 passes the recording current  $I_w$  through the second coil 32. The control signal shown in Fig. 3 is NRZI control signal which inverts the sign between plus and minus every time the recording data are input. The recording current  $I_w$  in the forward direction and the recording current in the reverse direction is represented in Fig. 3, for convenience, by  $I_{w1}$  and  $I_{w2}$ , respectively. The magnetic recording medium 20 is magnetized by a magnetic field produced by the recording current  $I_w$ . When the flowing direction of the recording current  $I_w$  is reversed due to the signal change of the control signal, the recording current  $I_w$  varies at a time constant corresponding to the inductance  $L_2$ .  $I_+$  and  $I_-$  represented by broken lines are magnetization threshold values for sufficiently and magnetically saturating the magnetic recording medium 20. When the recording current  $I_w$  exceeds the magnetization threshold value  $I_+$  or  $I_-$ , the magnetic recording medium 20 is sufficiently magnetized to allow the data to be magnetically recorded. The recording current  $I_w$  for magnetically exciting the transducer is controlled so as to have a constant reverse interval  $T$ , and there is a time delay (polarity reverse time  $T_r$ ) between the input of the control signal and the beginning of the magnetization of the recording medium 20. The polarity reverse time  $T_r$  depends on the circuit properties of the record circuit 22 and the inductance of the writing coil. When the inductance  $L_2$  of the writing coil 32 is  $0.3 \mu\text{H}$  or less, a polarity reverse time  $T_r$  of desired level, i.e., a polarity reverse time  $T_r$  of  $1/2$  or less of the reverse interval  $T$  can be attained to provide a magnetic transducer applicable to magnetic disk units using a maximum recording frequency of 50 MHz or more. In a high frequency

recording, the reverse interval  $T$  becomes smaller to increase the ratio of the polarity reverse time  $T_r$  to the reverse interval  $T$ . The increase in the ratio results in the shift of the magnetization transition point because an unsaturatedly magnetized portion in the recording medium is magnetized in the direction opposite to its own direction by the magnetic field from an adjacent saturatedly magnetized portion. In the present invention, such a shift of the magnetization transition point can be minimized by a shortened polarity reverse time  $T_r$  resulted from reducing the inductance of the writing coil.

Fig. 4a shows a structure of the magnetic transducer embodying the present invention. In Fig. 4a, a coil is formed by winding a parallel wire 10 on a magnetic circuit 16 assembled by magnetic core pieces made of ferrite, etc. Each of the surface of the magnetic circuit 16 facing a magnetic gap 18 has a magnetic metal film (Fe-Ta-N) 17. The parallel wire 10 consists of a pair of conductor wires 10a and 10b. As shown in Fig. 4b, the wire 10a has an end A and an end B<sub>1</sub>, and the wire 10b has an end B<sub>2</sub> and an end C. An intermediate terminal 14 is formed by connecting one of the ends of the wire 10a (end B<sub>1</sub> in Fig. 4c) and one of the ends of the wire 10b (end B<sub>2</sub> in Fig. 4c). The end A and the end C as the end terminals 13 and 15 define a reading coil corresponds to a coil formed by winding a single wire having a total length of the wire 10a and the wire 10b. A writing coil 11 and a writing coil 12 are defined between the end terminal 13 (end A) and the intermediate terminal 14, and between the end terminal 15 (end C) and the intermediate terminal 14, respectively. Each of the writing coils 11 and 12 corresponds to a coil winding a single wire having a length of the wire 10a or 10b. Since the ratio of the number of turns between the writing coil 11 or 12 and the reading coil is about 1:2, the ratio of the inductance is about 1:4.

More specifically, an MIG transducer shown in Fig. 4a was produced by winding a bifilar parallel wire 10, each of the wires 10a and 10b having a diameter of 20  $\mu\text{m}$ , on the core having a cross-sectional area of 2500  $\mu\text{m}^2$  (50  $\mu\text{m}$  x 50  $\mu\text{m}$ ) to form a coil of 13-turn. The end B<sub>1</sub> of the wire 10a was connected to the end B<sub>2</sub> of the wire 10b to form the intermediate terminal 14, thereby producing a three-terminal coil having the reading coil of 26-turn and the writing coils 11 and 12 of 13-turn. The measured inductance of each coil was 0.83  $\mu\text{H}$  for the reading coil defined between the terminals 13 and 15, 0.26  $\mu\text{H}$  for the writing coil 12 defined between the terminals 14 and 15, and 0.24  $\mu\text{H}$  for the writing coil defined between the terminals 13 and 14. For comparison, the same magnetic circuit as shown in Fig. 4a was wound by a single wire (monofilar) to form a two-terminal coil of 26-turn. The measured inductance of the coil was 0.80  $\mu\text{H}$ .

Generally, the number of turns of the coil is selected according to the inductance  $L_h$  of the coil at reading operation so that a desired resonance frequency  $f_0$  between the magnetic transducer and the reproduction system containing the reproduction circuit may be obtained. The resonance frequency  $f_0$  is represented by the following formula:

$$f_0 = 1/\{2\pi (L_h \cdot C)^{1/2}\}$$

wherein  $C$  is a sum of an input capacitance  $C_{in}$  of the reproduction circuit and a stray capacitance  $C_h$  between the coil wires. Assuming that the input capacitance  $C_{in}$  is 7 pF and the stray capacitance  $C_h$  between the coil wires is 4 pF, the resonance frequency  $f_0$  of the system containing the induction magnetic transducer of the present invention is calculated as 52.7 MHz because the inductance  $L_h$  of the coil at reading operation is 0.83  $\mu\text{H}$ . The resonance frequency  $f_0$  of the system containing the conventional two-terminal magnetic transducer

having a single wire (monofilar) coil is calculated as 53.7 MHz because the inductance  $L_h$  of the coil at reproduction operation is 0.80  $\mu\text{H}$ .

The polarity reverse time  $T_r$  of the recording current was measured on a system containing the induction magnetic transducer of the present invention and a system containing a conventional two-terminal magnetic transducer having a single wire (monofilar) coil. The magnetic recording was conducted by using a 3.5-inch disk having an coercive force  $H_c$  of 2000 Oe under the conditions that a rotating speed was 5200 rpm, a radial position ( $r$ ) of measurement was 37.3 mm at which a relative speed between the transducer and the disk was 20.32 m/s, a flying height of the head was 30 nm, and a recording frequency was 50 MHz (corresponding to a line recording density of 125 kFCI). As a result thereof, it was found that the polarity reverse time  $T_r$  was 5 ns in the present invention, and 7.7 in the conventional system. Thus, it was confirmed that the polarity reverse time  $T_r$  was reduced by the induction transducer and driving current of the present invention.

Also, a non-linear magnetization transition shift (NLTS), a measure for evaluating the magnetization state of the magnetic recording medium, was measured. The results showed that NLTS was 25% in the present invention and 50% in the conventional system. The NLTS is represented by the ratio ( $\delta/T$ ) of the shifted amount ( $\delta$ ) of the magnetization transition point to the reverse interval  $T$ , and the smaller the ratio is, the better the magnetization state of the recording medium is. The NLTS may be determined by several methods, and herein measured by a fifth harmonic wave extraction.

In the above measurements, a 50%-size composite MIG magnetic head in which the magnetic core was glass-bonded to a non-magnetic slider. The 50%-size in the present invention means a

dimension of 1.6 mm in length, 1.2 mm in width and 0.4 mm in thickness.

Fig. 5 shows another type of induction magnetic transducer of the present invention having a thin film coil. In Fig. 5, a thin film coil 40 was formed around a joint portion which connects an upper magnetic layer 41 and a lower magnetic layer 42, and is made by known thin film forming techniques. Between the end of the upper magnetic layer 41 and the end of the lower magnetic layer 42, a magnetic gap 48 is formed. The thin film coil 40 has end terminals 43 and 45 and an intermediate terminal 44, and as mentioned above referring to Fig. 4, the reading coil is defined between the end terminals 43 and 45 and the writing coil is defined between the end terminal 43 or 45 and the intermediate terminal 44. The end terminals 43 and 45 and the intermediate terminal 44 may be simultaneously formed in the pattern formation of the thin film coil.

Figs. 6a to 6c show a coil having an increased number of terminals. The coil is produced, as in Fig. 4, by winding a conductor wire 46 on the magnetic circuit constituted by a magnetic core made of ferrite, etc. The conductor wire 46 is composed of three wires 46a, 46b and 46c as shown in Fig. 6a. The wire 46a has ends A and B, the wire 46b has ends C and D, and the wire 46c has ends E and F. The conductor wire 46 is wound on the core and the terminal B and the terminal C, and the terminal D and the terminal E are respectively connected to each other as shown in Fig. 6b. As seen from Fig. 6c, a reading coil winding a wire having a total length of the three wires is defined between the end terminals A and F. Also, as shown in Fig. 6c, a writing coil shown by the solid line is defined between the terminal A and the terminal B+C, a writing coil shown by the broken line is defined between the terminal B+C and the terminal D+E, and a writing

coil shown by the dot-dash line is defined between the terminal D+E and the terminal F. Further, a writing coil shown by the solid line and the broken line is defined between the terminal A and the terminal D+E, and a writing coil shown by the broken line and the dot-dash line is defined between the terminal B+C and the terminal F. In this manner, coils having different inductance may be obtained by suitably combining the end terminals and the intermediate terminals.

As described above, an induction magnetic transducer and driving circuit applicable to a high density and high frequency recording while ensuring a sufficient reproduction output can be provided by the present invention.

## WHAT IS CLAIMED IS:

1. An induction magnetic transducer for magnetically writing and reading informational data by detecting a change of magnetic flux due to electromagnetic induction, comprising a coil having at least three terminals, wherein a pair of terminals selected from said at least three terminals constitutes a reading terminal pair and another pair of terminals selected from said at least three terminals constitutes a writing terminal pair so that an inductance of a writing coil defined between said pair of writing terminals is smaller than an inductance of a reading coil defined between said pair of reading terminals, said inductance of said writing coil being  $0.3 \mu\text{H}$  or less, said inductance of said reading coil at reading operation being  $0.95 \mu\text{H}$  or less and a recording current in forward and reverse directions being passed through only said writing coil.
2. An induction magnetic transducer for magnetically writing and reading informational data by detecting a change of magnetic flux due to electromagnetic induction, comprising a coil having two end terminals and an intermediate terminal, wherein said two end terminals define a reading coil therebetween and one of said two end terminals and said intermediate terminal define a writing coil therebetween so that said reading coil has an inductance of  $0.95 \mu\text{H}$  or less at reading operation, said writing coil has an inductance of  $0.3 \mu\text{H}$  or less, and a recording current in forward and reverse directions is passed through only said writing coil.
3. The induction magnetic transducer according to claim 1 or 2, wherein said coil is wound on a magnetic circuit.



4. The induction magnetic transducer according to claim 3, wherein said magnetic circuit comprises a magnetic core or a magnetic thin film.

5. The induction magnetic transducer according to claim 3 or 4, wherein said coil comprises a parallel wire composed of at least two wires, each end of said at least two wires constituting said terminals.

6. The induction magnetic head according to claim 1 or 2, wherein said coil is a thin film coil.

7. A driving circuit for an induction magnetic transducer magnetically writing and reading informational data by detecting a change of magnetic flux due to electromagnetic induction, comprising a coil having at least three terminals, wherein said driving circuit comprises:

a reproduction circuit connected to a pair of terminals constituting a reading terminal pair and selected from said at least three terminals, said reproduction circuit reproducing signals from a reading coil defined between said pair of reading terminals; and

a record circuit connected to another pair of terminals constituting writing terminal pair and selected from said at least three terminals, said record circuit passing a recording current through only a writing coil defined between said pair of writing terminals in both forward and reverse directions.

