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GB 1071230
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(54) **Magnetoresistive transducers**

(57) A ferromagnetic metal film magnetoresistor (2) is subjected to a relatively movable magnetic field pattern comprising at least two areas (A1, A2) in which the magnetic fields (H1, H2) are in different directions. The fields magnetically saturate the respective portions of the magnetoresistor and since the resistivity of the material varies with the angle between the current flow (I) and the magnetic field (H1, H2) the total resistance of the element varies in accordance with the ratio of the areas exposed to the two fields. Numerous configurations of the magnetoresistor pattern, applied fields and associated circuitry are disclosed. The device may be used for detecting displacements, as a generator for controlling the commutation of an electric motor or as a contactless switch or variable resistor.

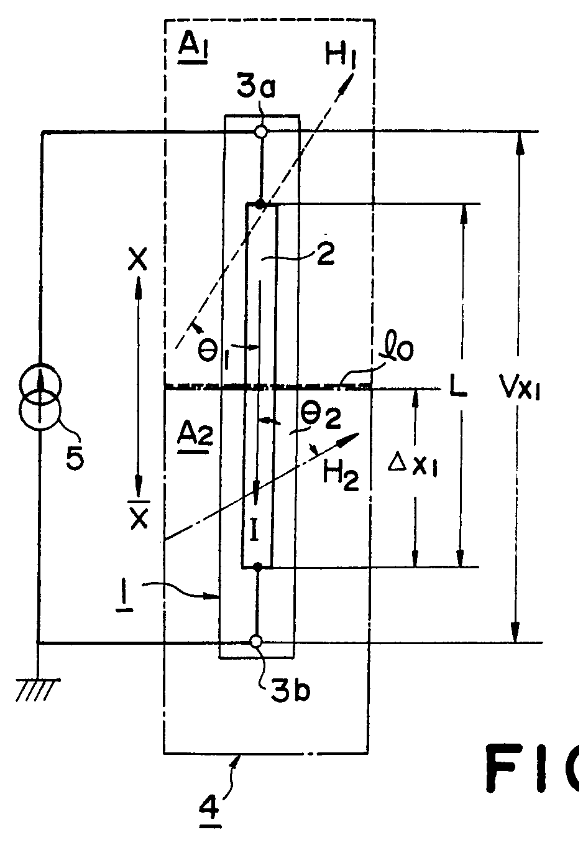

FIG.2

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FIG.1

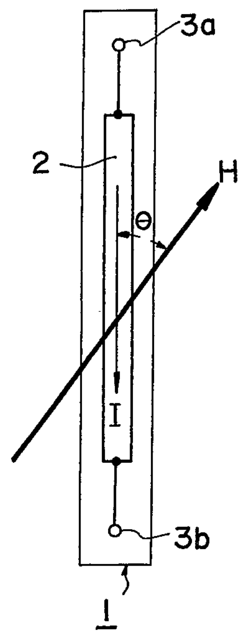

FIG.2

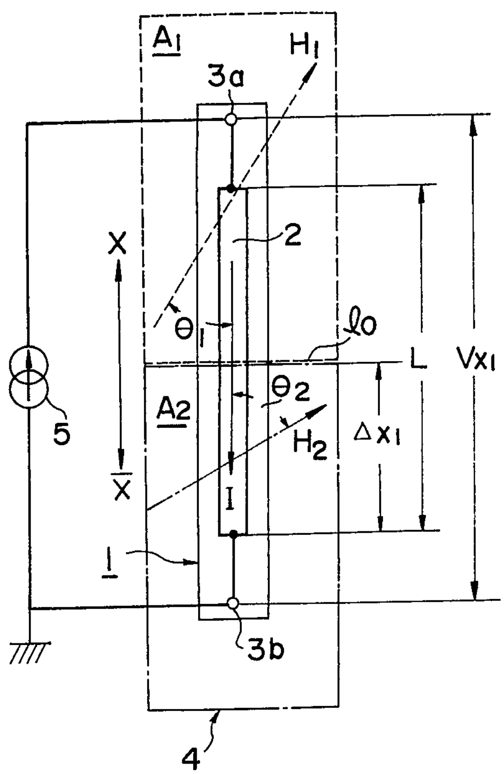

FIG.3

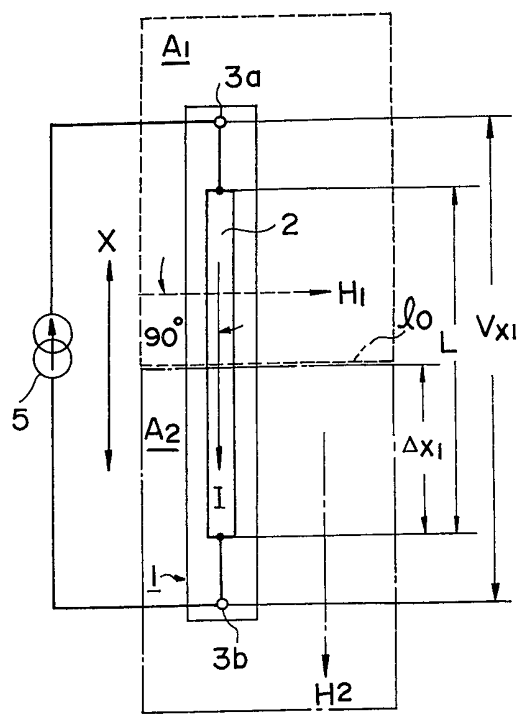

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FIG.4

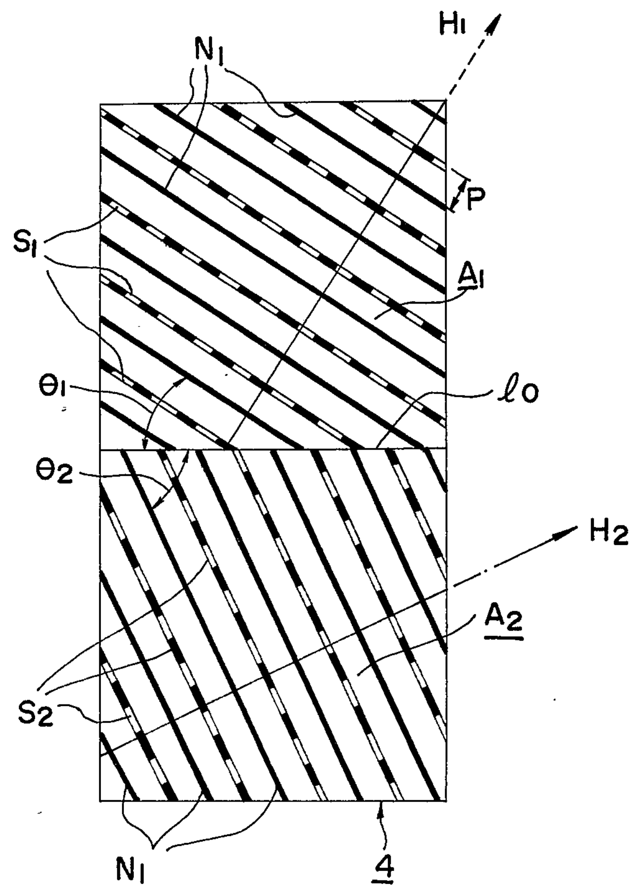


FIG.5

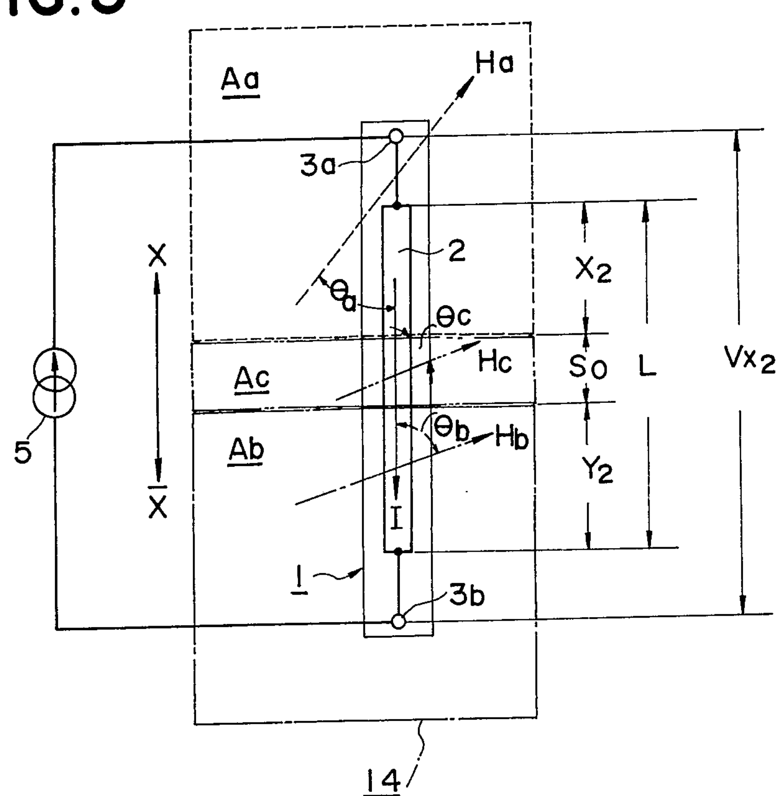


FIG.6

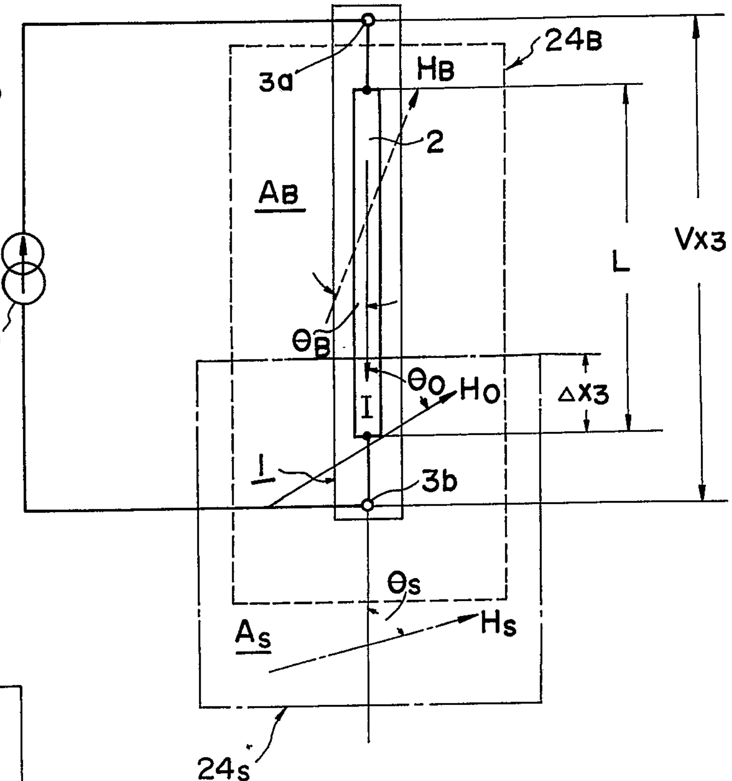


FIG.8

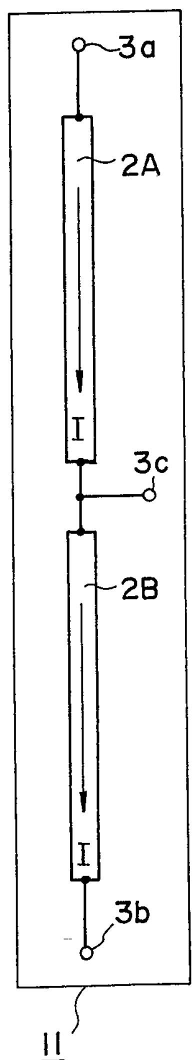


FIG.7

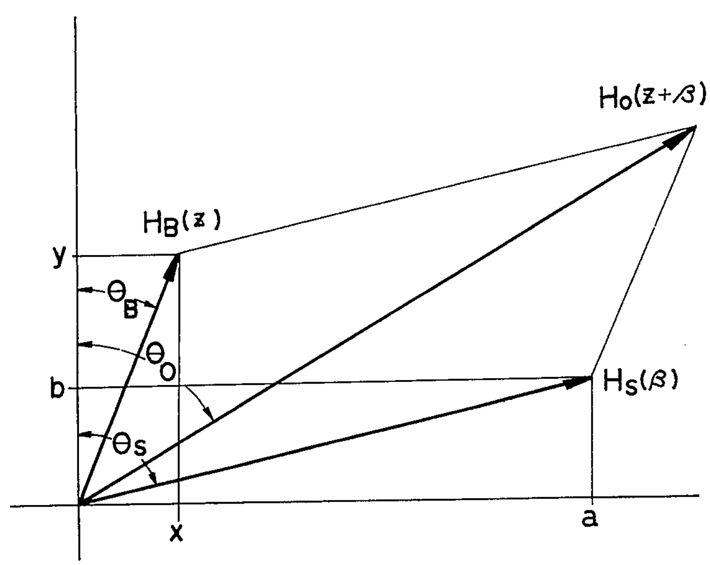
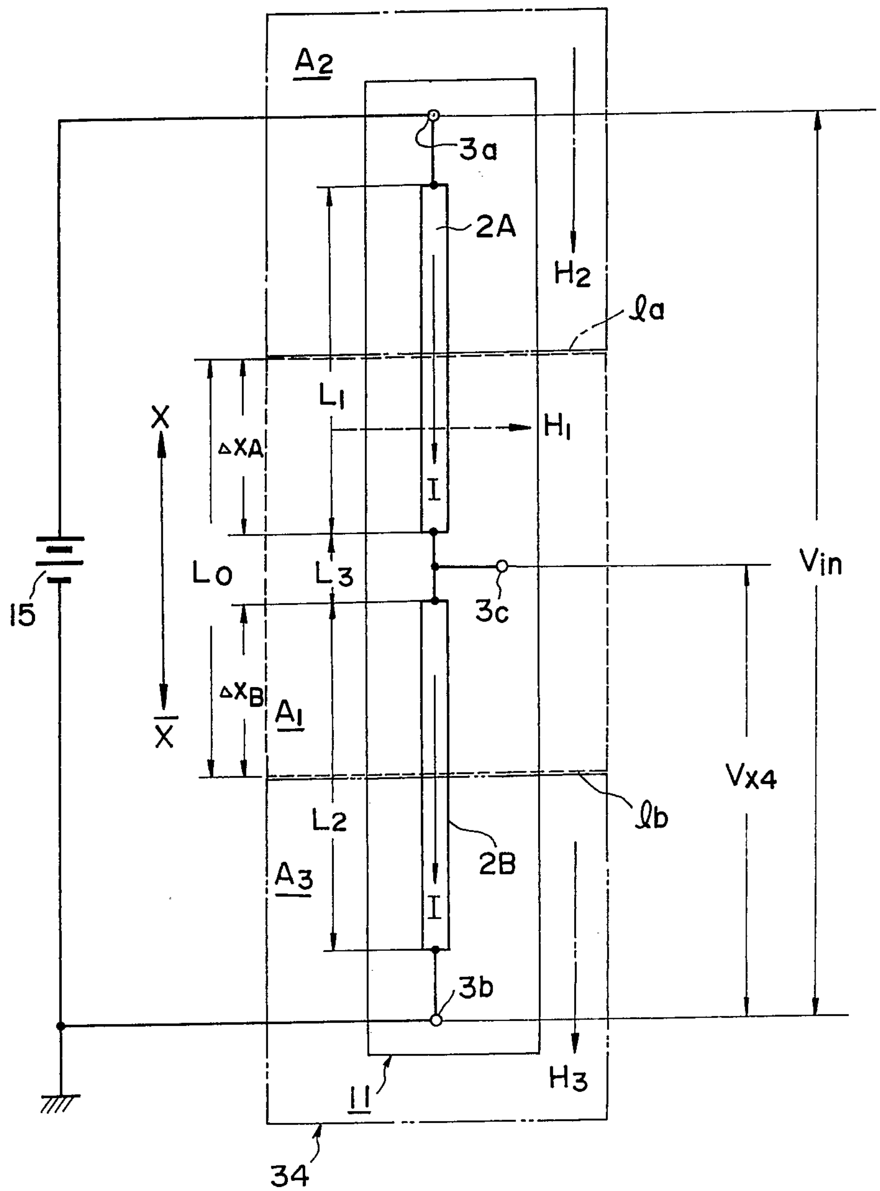


FIG. 9


A2
3a
2A
H2
ℓa
L1
H1
X
ΔXA
I
Vin
15
L0
L3
3c
ΔXB
A1
X̄
Vx4
ℓb
L2
2B
A3
I
3b
H3
11
34

2052855

FIG.10

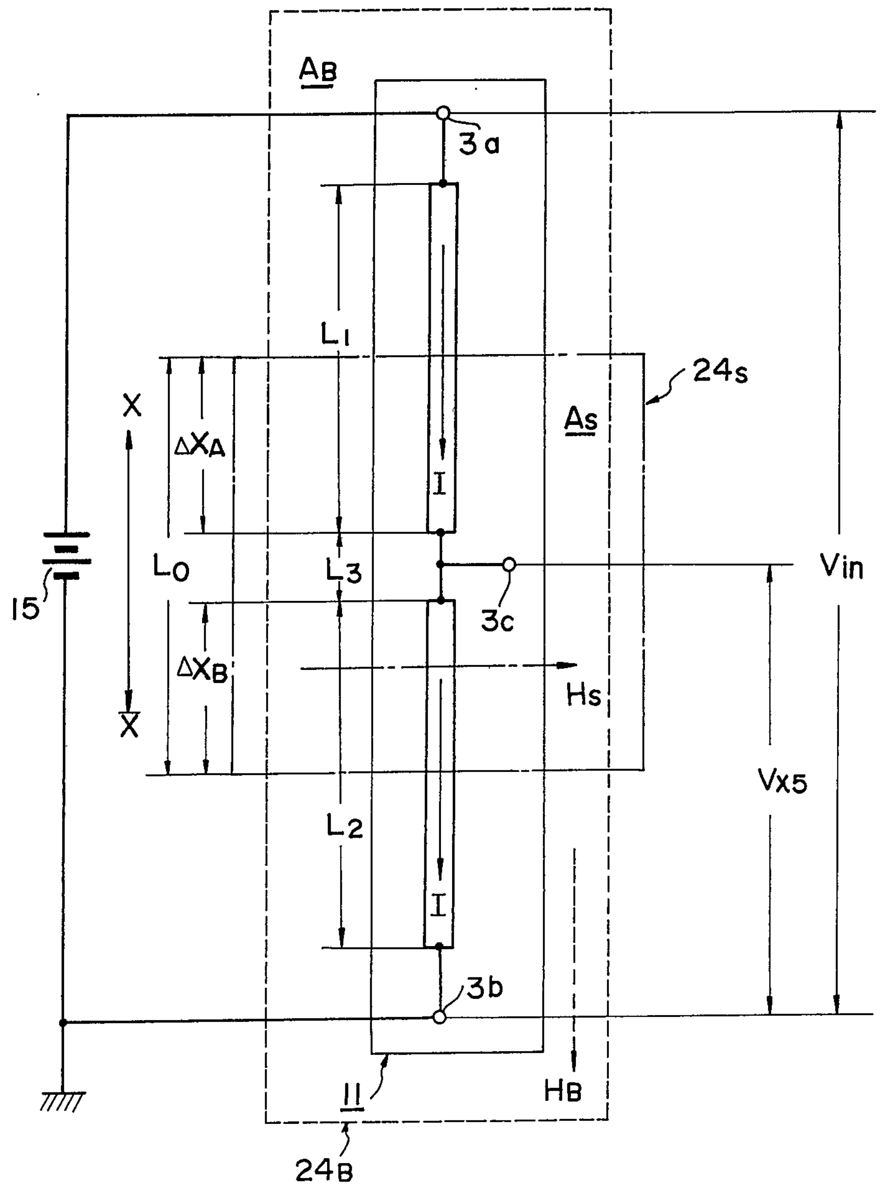


FIG.11

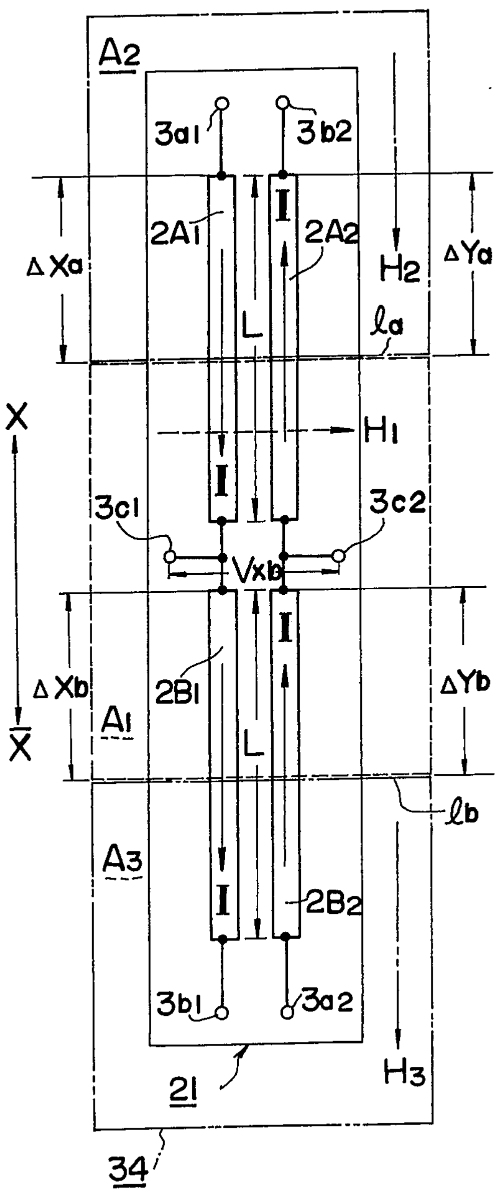

A2
3a1
3b2
2A1
2A2
ΔXa
ΔYa
H2
L
ℓa
X
H1
3c1
3c2
Vxb
ΔXb
ΔYb
2B1
A1
X̄
L
ℓb
A3
2B2
3b1
3a2
H3
21
34

FIG.12

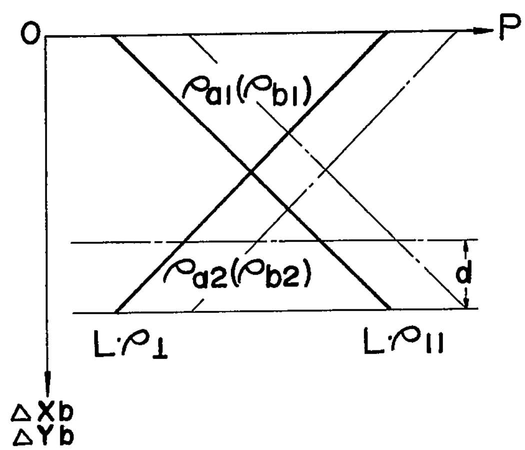
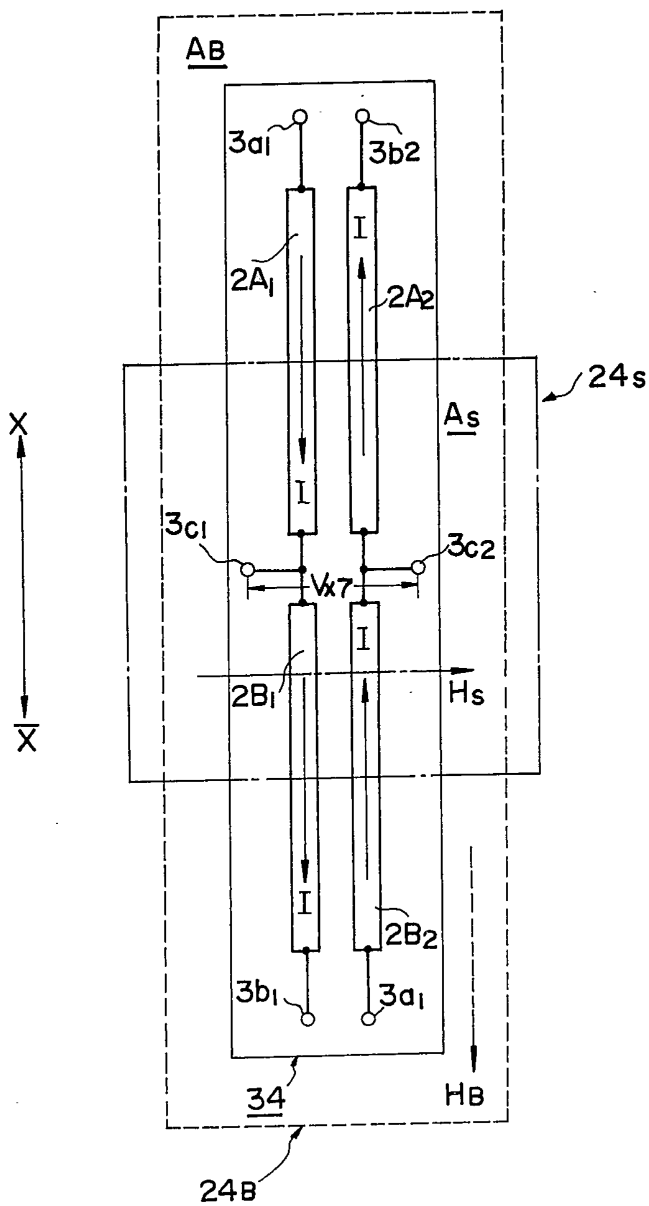

O
P
ρa1(ρb1)
ρa2(ρb2)
d
L·ρ⊥
L·ρ∥
ΔXb
ΔYb

FIG.13


AB
3a1
3b2
I
2A1
2A2
24s
As
X
I
3c1
3c2
Vx7
I
2B1
Hs
X̄
I
2B2
3b1
3a1
34
HB
24B

2052855

FIG.14

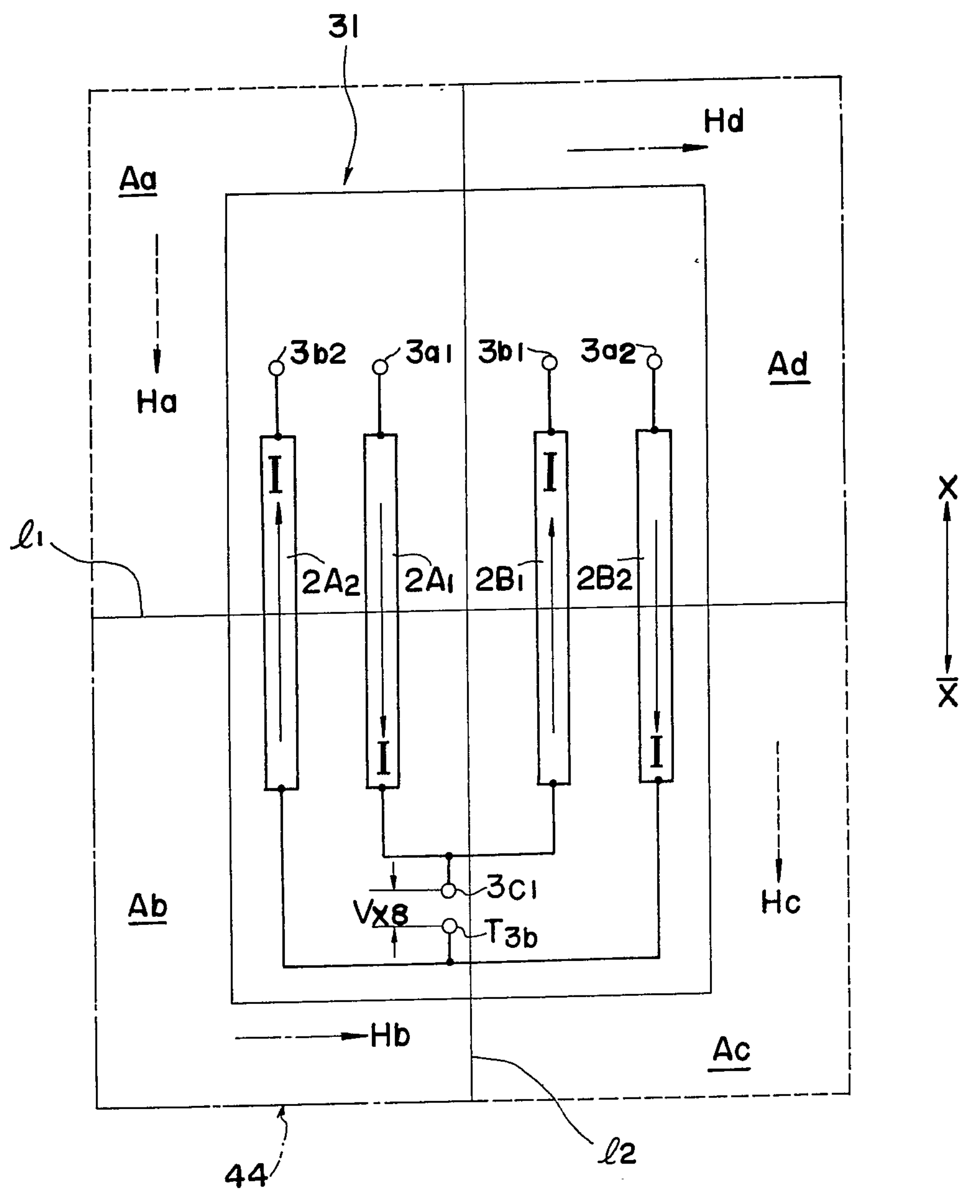


FIG.15

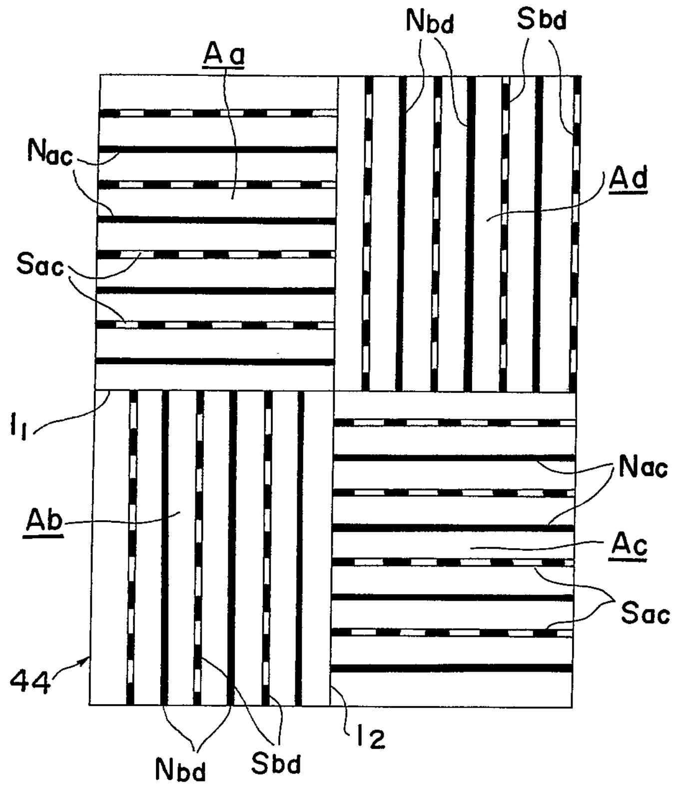
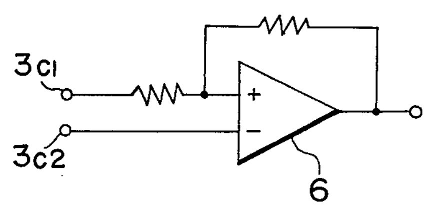


FIG.16



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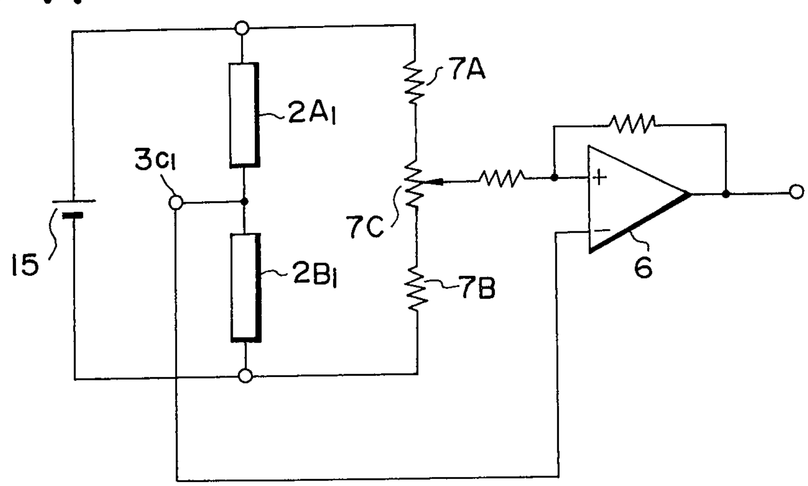
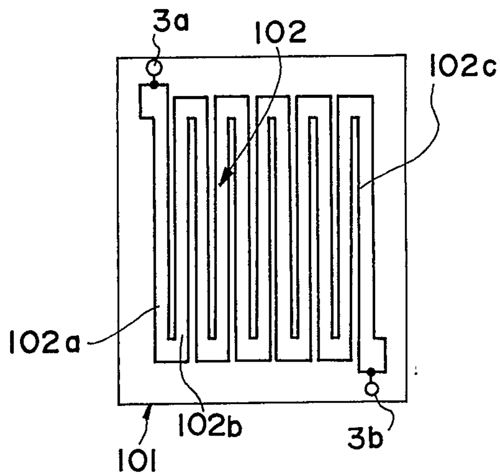


FIG.18



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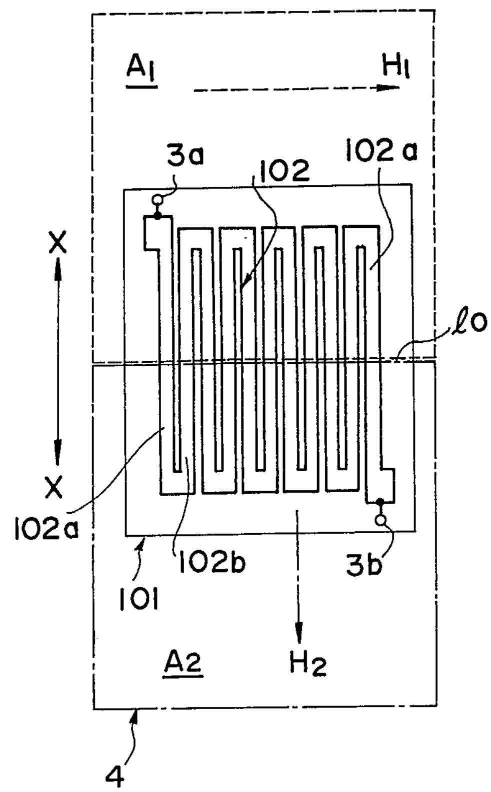

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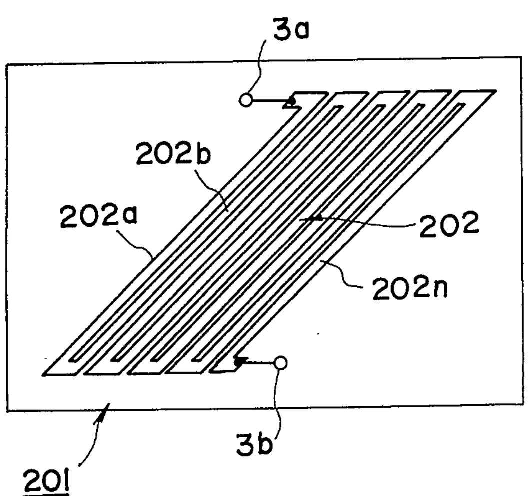

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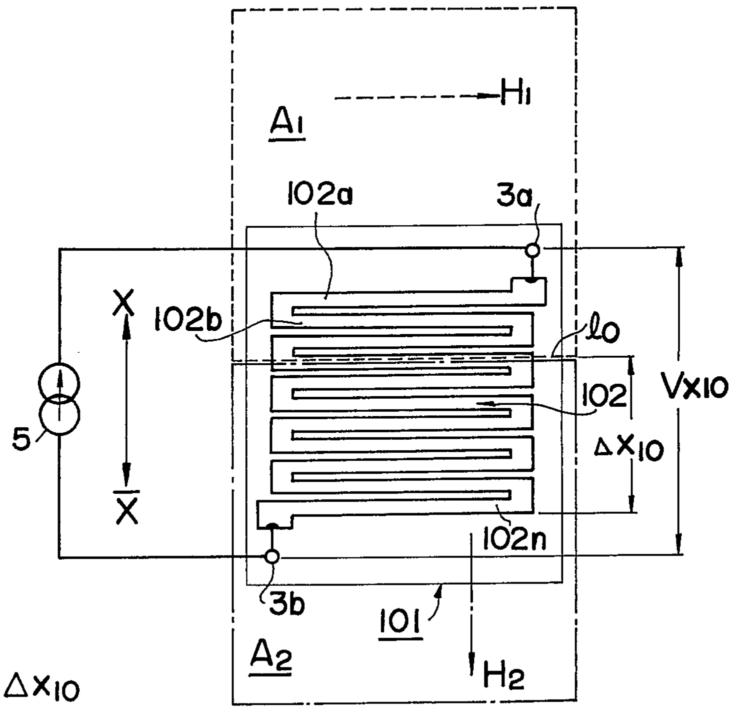

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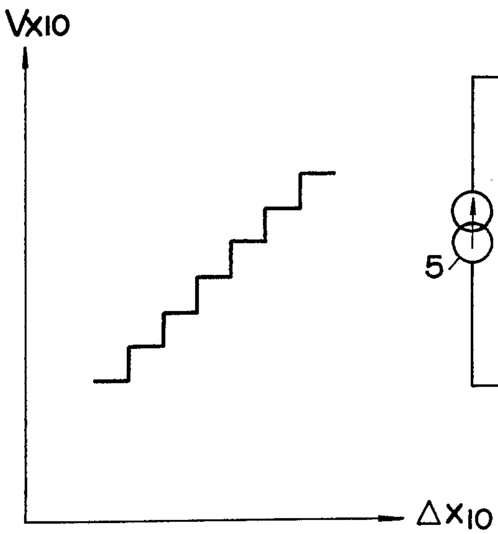

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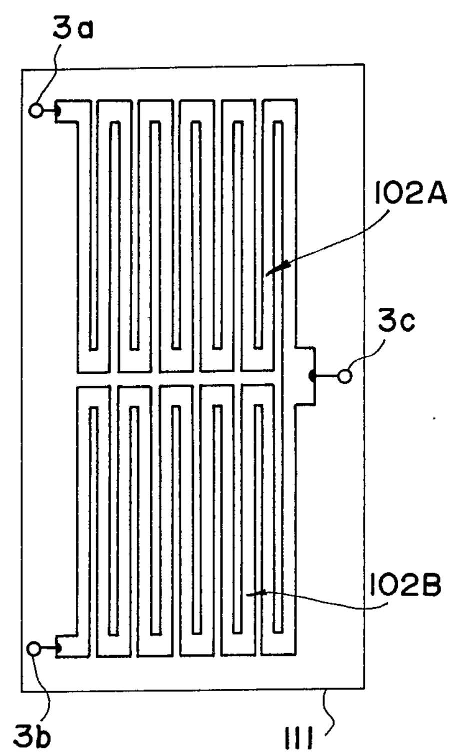

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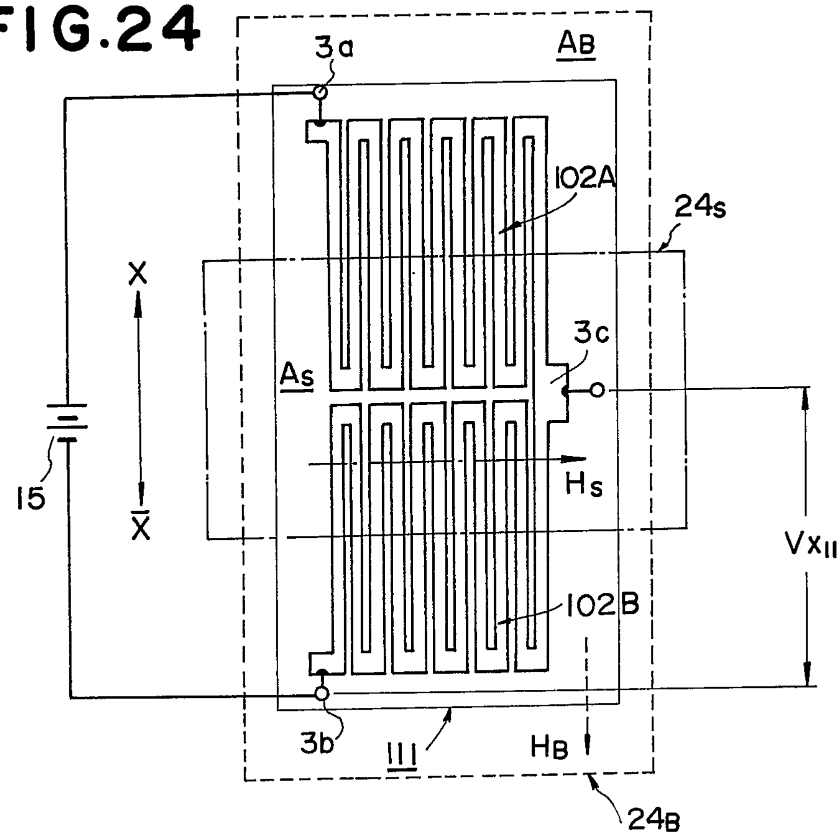
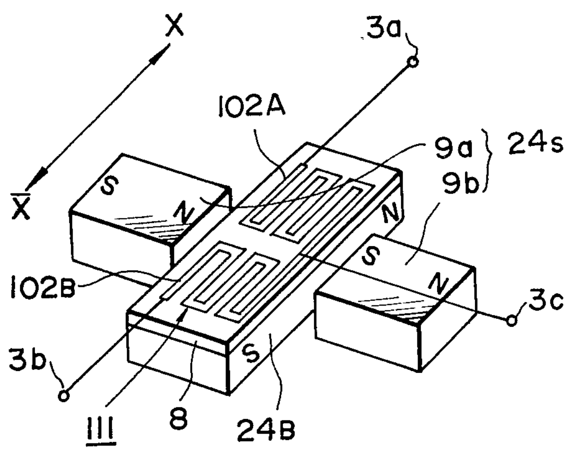


FIG.25



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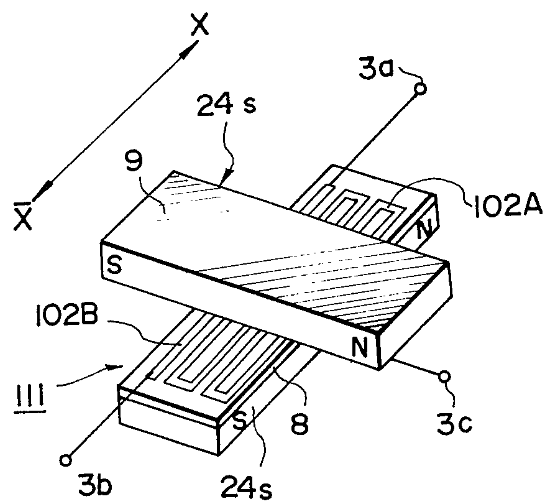


FIG. 27

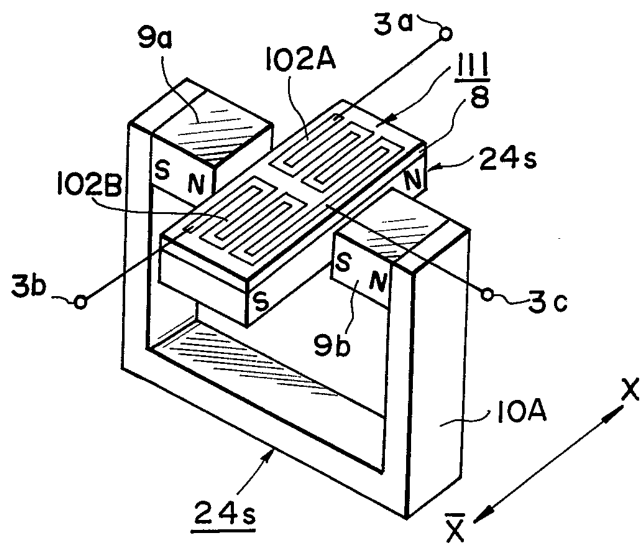


FIG. 28

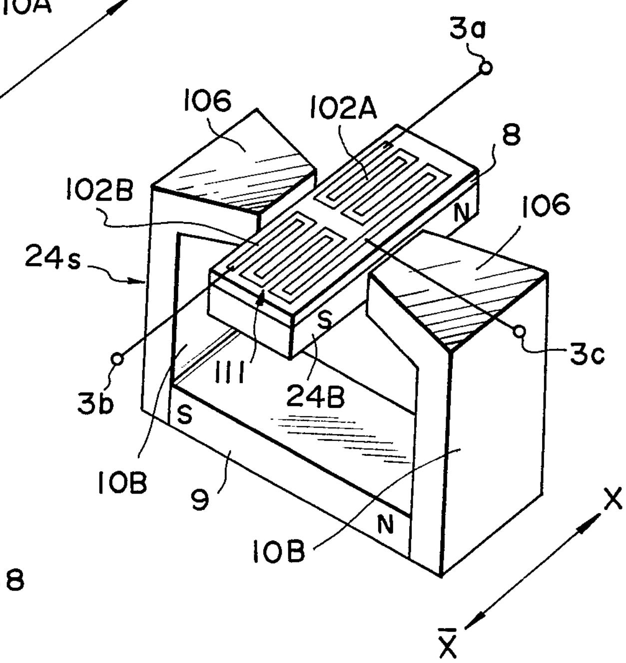
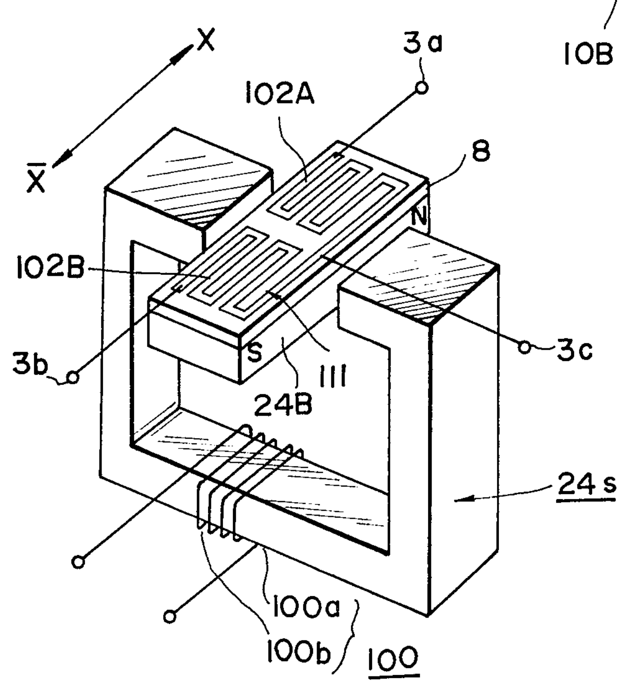


FIG. 29



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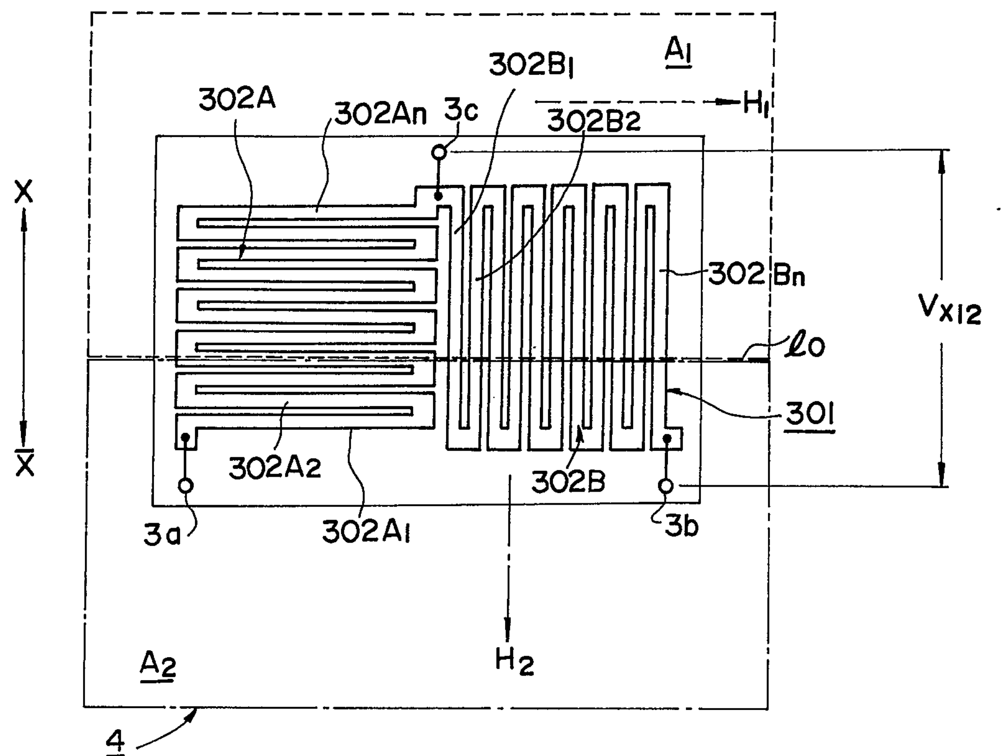


FIG.30

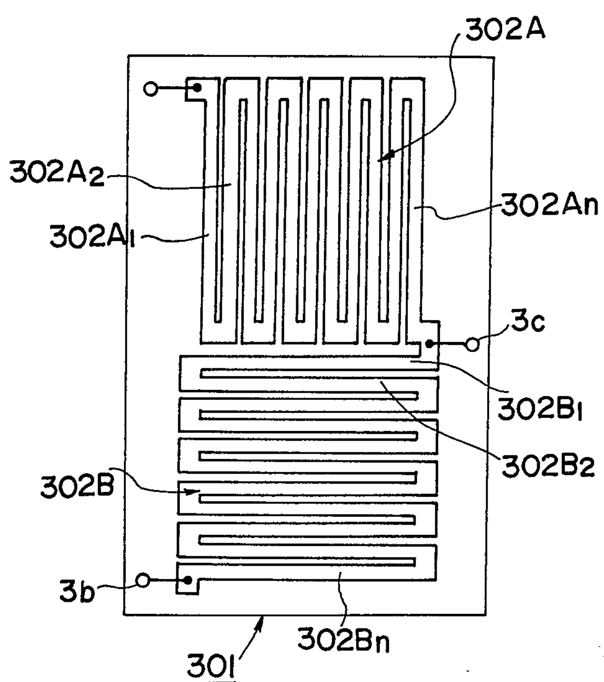


FIG.32

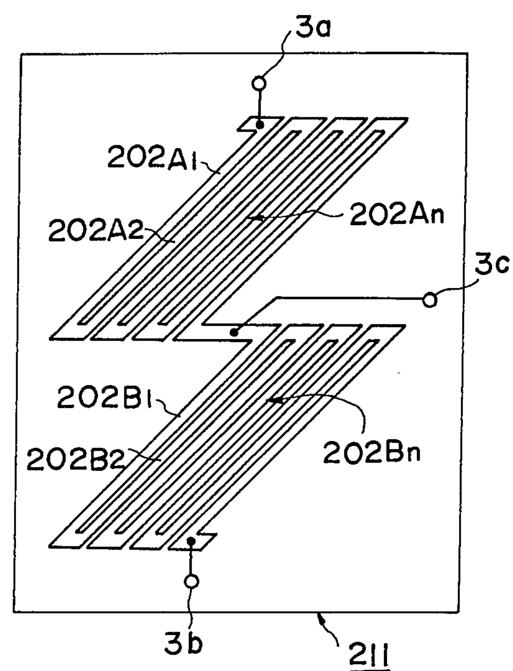


FIG. 33

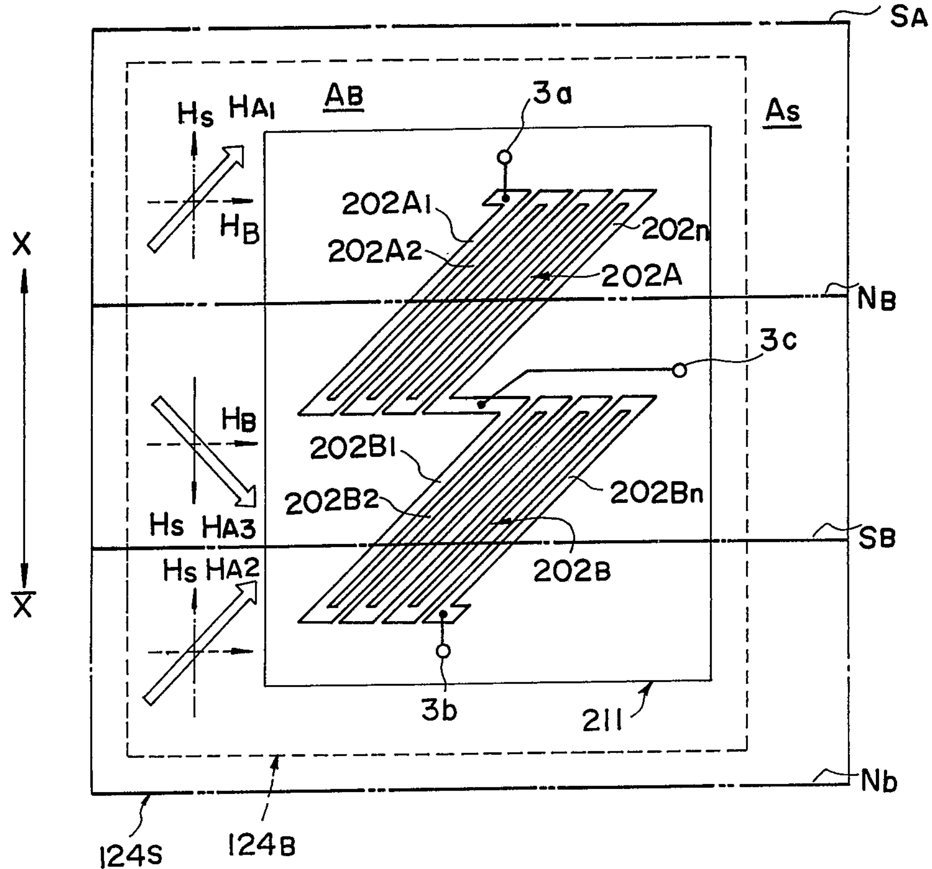


FIG. 34

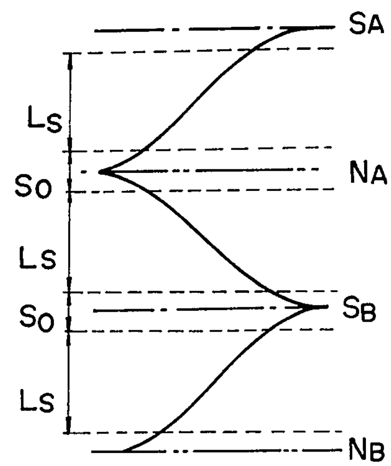


FIG. 35

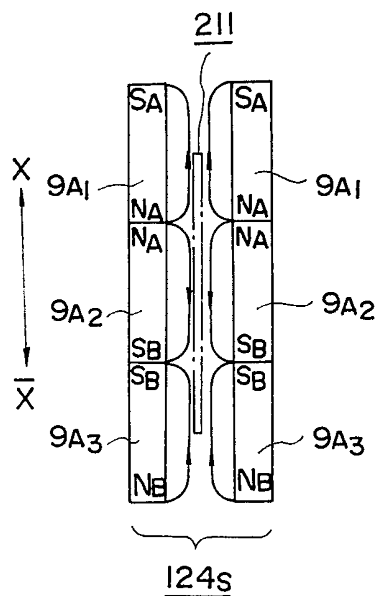


FIG.36

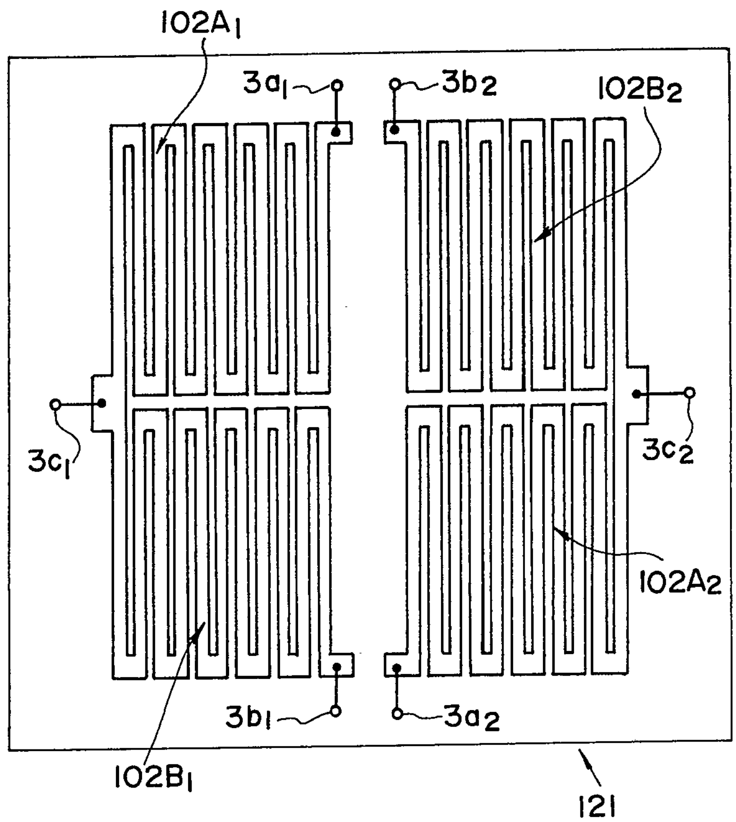


FIG.37

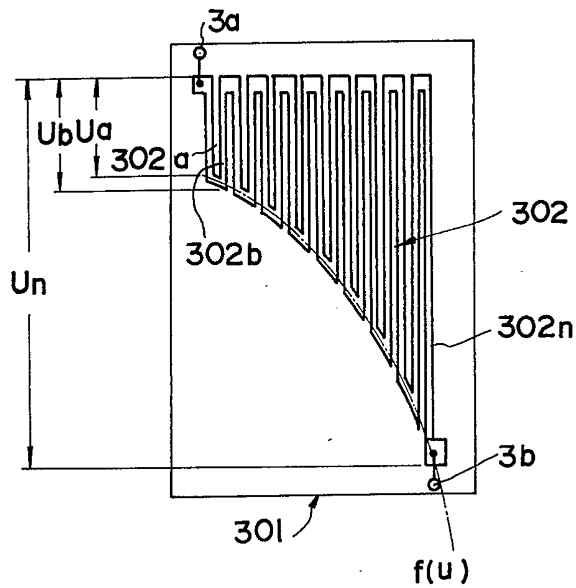
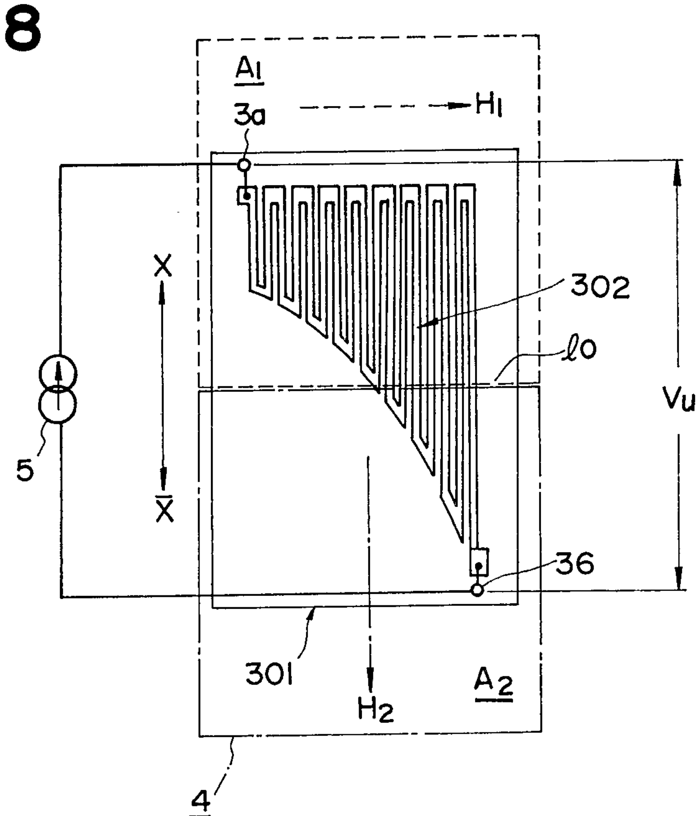

3a
Ub
Ua
302 a
302b
302
Un
302n
3b
301
f(u)

FIG.38


A1
3a
H1
X
302
ℓ0
Vu
5
X̄
36
301
H2
A2
4

SPECIFICATION

Magnetic sensor

This invention generally relates to a magnetic sensor device and more particularly to a magnetic sensor device suitable for detecting fine displacement by use of a magneto-resistive element showing resistance property according to the magneto-resistance effect of ferromagnetic material.

Magnetic sensor elements which produce changing output voltage in response to magnetic field are widely used in the fields of instruments and apparatus used at work, such as readers for magnetic position-indicating scales, frequency generators for controlling rotation of motors and the like and for controls such as contactless switches and continuously variable controls.

For the above-mentioned magnetic sensor element can be used a ferromagnetic resistive element based upon the magnetism-sensing principle utilizing the ferromagnetic magneto-resistance effect of ferromagnetic metal, a semiconductor resistive element or hole element based upon the magnetism sensing principle utilizing the magneto-resistance effect of semiconductors. The magneto-resistive elements and hole elements using semiconductors have been so far used mainly for the above-mentioned magnetic sensor element.

The magneto-resistance effect of ferromagnetic metal can be divided into two types of effects. The first effect is the change in resistance which is produced through the change in self-magnetization caused by the external magnetic field, which can be satisfactorily explained by Mott's theory. Generally, this effect is a negative one which linearly reduces the resistance as the magnetic field is increased and is isotropic with respect to the direction of the magnetic field. While this effect is magnified at the neighbourhood of the Curie temperature where the self-magnification is intensified, it can be neglected as long as it is not operated by a large magnetic field. Also, the second effect can be observed in a relatively small magnetic field and change anisotropically resistance according to the angle between the directions of magnetization and current. This effect is intensified in the region of temperature where the change in self-magnetization is small, and reduced towards the Curie temperature. Generally in ferromagnetic metal, the resistance is maximized when the directions of current and magnetization become parallel, and minimized when they intersect each other orthogonally. This is generally represented by the following equation:

$$\rho(\theta) = \rho_{\perp}.\sin^2\theta + \rho_{11}.\cos^2\theta \qquad (1)$$

In the above equation (1), known as Voigt-Thomson's equation, θ is an angle between the directions of current and saturated magnetization, $\rho_{\perp}$, the resistance when the directions of current and saturated magnetization intersect each other orthogonally and ρ_1 the resistance with the directions of current and saturated magnetization are parallel to each other. A ferromagnetic metallic magneto-resistive element utilizing this second effect has partially been put into practical use. As ferromagnetic metals having the abovementioned magneto-resistance effect are known NiCo alloy, NiFe alloy, NiAl alloy, NiMn alloy, NiZn, etc.

Semiconductor magnetic sensor elements heretofore widely used have transducer characteristics depending upon the nature of semiconductor material being used. For example, since the semiconductor magneto-resistive element is formed by semiconductor material such as GaAs, InSb, etc., the number of carriers and the ease of transition are highly dependent upon temperature. The elements have adverse temperature characteristics and large dispersion of resistance values for individual elements so that the external compensation circuit is required to compensate the temperature and dispersion of resistance values. Also, since the resistance of the semiconductor magneto-resistive element depends approximately upon the square of the intensity of the magnetic field when the magnetic field is small, at least 1KG of magnetic bias is usually required, and even in a large magnetic field there is insufficient linearity of resistance. Thus it is very difficult in a magnetic sensor device using such semiconductor magneto-resistive element to realize a displacement sensor for detecting fine displacement with satisfactory linearity.

SUMMARY OF THE INVENTION

Accordingly an object of the present invention is to provide a magnetic sensor device which detects magnetism by a magneto-resistive element provided as magnetism sensing region with current path portion formed by ferromagnetic material and produces transducer output related to the relative displacement between magnetizing material producing magnetic field and magneto-resistive element.

Another object of the present invention is to provide a magnetic sensor device which provides transducer output corresponding to the ratio of ferromagnetic material regions magnetized by magnetic fields given to magnetism sensing region of magneto-resistive element and having respectively different directions.

Still another object of the present invention is to provide a magnetic sensor device in which the regions of ferromagnetic material magnetized by magnetic field given to the magnetism sensing region of magneto-resistive element are clearly defined by boundary lines.

A further object of the present invention is to provide a magnetic sensor device in which magnetic fields having different directions are given to the magnetism sensing region of magneto-resistive element by magnetizing material with simple constitution.

A still further object of the present invention is to provide a magnetic sensor device in which magnetic field is detected with high sensibility by magneto-resistive element to provide transducer output.

Moreover, another object of the present invention is to provide a magnetic sensor device which can be driven with constant voltage.

Yet another object of the present invention is to provide a magnetic sensor device having transducer characteristics which depend scarcely upon temperature.

Still further object of the present invention is to provide a magnetic sensor device having transducer characteristics which is excellent in the linearity.

Yet another object of the present invention is to provide a magnetic sensor device which is the most suitable for detecting fine displacement.

Moreover, another object of the present invention is to provide a magnetic sensor device having stepwise transducer characteristic curve.

Still further object of the present invention is to provide a magnetic sensor device which can have any transducer characteristic curves.

The above and other objects and novel features of the invention will more fully appear from the following detailed description when the same is read in connection with the accompanying drawings. It is to be expressly understood, however, that the drawings are for purpose of illustration only and are not intended as a definition of the limits of the invention.

According to the present invention, there is provided a magnetic sensor device comprising:

a magneto-resistive element having at least one current path portion formed of a ferromagnetic material to serve as a magnetism-sensing region;

a power source for supplying a bias current to the or each current path portion; and

a magnetizing means for providing magnetic fields of different direction to respective regions obtained by dividing said magnetism-sensing region into at least two regions the arrangement such that the ratio of the extent of one region to that of another region to which said respective magnetic fields are to be imparted is variable according to the relative displacement between said magneto-resistive element and said magnetizing means.

The invention will be further described by way of example with reference to the accompanying drawings, in which:—

Figure 1 is a schematic illustration showing a basic constitution of magneto-resistive element applied to a magnetic sensor device according to the present invention.

Figure 2 is a schematic illustration showing the principle of a first embodiment of the magnetic sensor device according to the present invention to which the magneto-resistive element shown in Fig. 1 is applied.

Figure 3 is a schematic illustration for describing the most suitable condition for magnetic field for the magneto-resistive element in the first embodiment.

Figure 4 is a schematic plan view showing a magnetizing pattern of magnetizing material applied to the above first embodiment.

Figure 5 is a schematic illustration showing the principle of a second embodiment of the magnetic sensor device according to the present invention to which the magneto-resistive element shown in Fig. 1 is applied.

Figure 6 is a schematic illustration showing the principle of a third embodiment of the magnetic sensor device according to the present invention to which the magneto-resistive element shown in Fig. 1 is applied.

Figure 7 is a vector diagram for describing composite magnetic field given to the magneto-resistive element in the third embodiment.

Figure 8 is a schematic illustration showing the constitution of a magneto-resistive element having two current path portions which are applied to the magnetic sensor device according to the present invention.

Figure 9 is a schematic illustration showing the principle of a fourth embodiment of the magnetic sensor device according to the present invention to which the magneto-resistive element shown in Fig. 8 is applied.

Figure 10 is a schematic illustration showing the principle of a fifth embodiment of the magnetic sensor device according to the present invention to which the magneto-resistive element shown in Fig. 8 is applied.

Figure 11 is a schematic illustration showing the principle of a sixth embodiment of the magnetic sensor device according to the present invention.

Figure 12 is a characteristic curve diagram showing the resistance characteristic of the magneto-resistive element in the sixth embodiment.

Figure 13 is a schematic illustration showing the principle of a seventh embodiment of the magnetic sensor device according to the present invention.

Figure 14 is a schematic illustration showing the principle of an eighth embodiment of the magnetic sensor device according to the present invention.

Figure 15 is a schematic plan view showing a magnetizing pattern of magnetizing material applied to the eighth embodiment.

Figure 16 is a circuit diagram showing a difference amplifier connected between output terminals in the sixth, seventh or eighth embodiment.

Figure 17 is a circuit diagram showing the constitution of modification of the sixth or seventh embodiment.

Figure 18 is a schematic illustration showing the constitution of magneto-resistive element having current path portions which are formed with a meandering pattern and applied to the magnetic sensor device according to the present invention.

Figure 19 is a schematic illustration showing the principle of a ninth embodiment of the magnetic sensor device according to the present invention to which the magneto-resistive element shown in Fig. 18 is applied.

Figure 20 is a schematic illustration showing a modification of the magneto-resistive element having current path portions which can be applied to the magnetic sensor device according to the present invention and formed with a meandering pattern.

Figure 21 is a schematic illustration showing a tenth embodiment of the magnetic sensor device according to the present invention to which the magneto-resistive element shown in Fig. 19 is applied.

Figure 22 is a characteristic curve diagram showing the relationship between output voltage and displacement obtained from the tenth embodiment.

Figure 23 is a schematic illustration showing the constitution of a magneto-resistive element which is applied to the magnetic sensor device according to the present invention and formed with two current path portions having a meandering pattern.

Figure 24 is a schematic illustration showing an eleventh embodiment of the magnetic sensor device according to the present invention to which the magneto-resistive element shown in Fig. 23 is applied.

Figures 25 to 29 are perspective pictorial views showing respectively particular examples of the eleventh embodiment.

Figure 30 is a schematic illustration showing modification of a magneto-resistive element applied to the magnetic sensor device according to the present invention and formed with two current path portions having a meandering pattern.

Figure 31 is a schematic illustration showing a twelfth embodiment of the magnetic sensor device according to the present invention to which the magneto-resistive element shown in Fig. 30 is applied.

Figure 32 is a schematic illustration showing another modification of a magneto-resistive element which is applied to the magnetic sensor device according to the present invention and formed with two current path portions having a meandering pattern.

Figure 33 is a schematic illustration showing a thirteenth embodiment of the magnetic sensor device according to the present invention to which the magneto-resistive element shown in Fig. 32 is applied.

Figure 34 is a characteristic curve diagram showing schematically the characteristics of signal magnetic field in said thirteenth embodiment.

Figure 35 is a front view showing a particular example of magnetizing material for signal applied to said thirteenth embodiment.

Figure 36 is a schematic illustration showing the constitution of magneto-resistive element which can be applied to the magnetic sensor device according to the present invention and formed with four current path portions having a meandering pattern.

Figure 37 is a schematic illustration showing the constitution of another modification of magneto-resistive element applied to the magnetic sensor device according to the present invention and formed with current path portions having a meandering pattern.

Figure 38 is a schematic illustration showing the constitution of a fourteenth embodiment of the magnetic sensor device according to the present invention to which the magneto-resistive element shown in Fig. 37 is applied.

The illustrated embodiments of magnetic sensors according to the present invention comprise a magneto-resistive element having as the magnetism-sensing region one or more current path portions formed in principle by ferromagnetic material, a power source for supplying bias current to said current path portions and a magnetizing material for applying magnetic fields in different directions respectively to at least two regions produced by dividing said magnetism sensing region, the ratio of these fields being changed corresponding to the relative displacement between said magneto-resistive element and magnetizing material.

Referring to Fig. 1, a magneto-resistive element is provided as the magnetism-sensing region and has a current path portion 2 formed by a long flat strip of ferromagnetic material. The ferromagnetic material forming said current path portion 2 is a ferromagnetic metal film having the ferromagnetic magneto-resistance effect, such as NiCo alloy, NiFe alloy, NiAl alloy, NiMn alloy or NiZn alloy. The magneto-resistive element 1 has applied to it a magnetic field H having a direction which makes an angle θ with the bias current I supplied to the current path portion 2 through power supplying terminals 3a, 3b. The current path portion 2 shows the resistance characteristics represented by the above set out Voigt-Thomson equation according to the second of the two ferromagnetic magneto-resistance effects.

In the various embodiments which will be hereinafter described, like reference numerals will be used for like parts.

Fig. 2 shows the principle of a first embodiment of the magnetic sensor device according to the present invention, in which the power supply terminals 3a, 3b of the magneto-resistive element 1 are provided respectively at both longitudinal ends of flat strip-shaped current path portion 2 which is made of a anisotropic ferromagnetic material having ferromagnetic magneto-resistance effect of NiCo alloy, NiFe alloy, NiAl alloy, NiMn alloy or NiZn alloy. Between the power supply terminals 3a, 3b is connected a constant current source 5 from which a constant bias current I is supplied to the current path portion 2. Further, one, 3b, of the power supply terminals is earthed.

The magneto-resistive element 1 has sufficient intensity to saturate the magnetically ferromagnetic material forming the current path portion 2 and is opposed to a magnetizing material 4 divided into a first magnetic field H_1 and a second one H_2 having different directions and separated by a boundary line l_0 transversing the longitudinal direction of said current path portion 2. The region A_1 of said first magnetic field H_1 is shown by the broken line and the region A_2 of said second magnetic field H_2 by the dot-and-dash line in Fig. 2. The magneto-resistive element 1 and magnetizing material 4 are displaceable relative to one another in the longitudinal direction (the direction of arrow X, $\bar{X}$ in the drawing) of current path portion 2, and the location of the boundary line l_0 traversing said current path portion 2 is moved by this relative movement.

Generally ferromagnetic metals have a ferromagnetic magneto-resistance characteristic in which the maximum resistance value $\rho_\perp$ is exhibited when as above-mentioned the direction of current and magnetization are parallel to each other and the minimum resistance value $\rho_{\perp 1}$ when said directions intersect each other orthogonally. The resistance value $\rho(\theta)$ per unit length is represented by a function of angle θ between the directions of current and magnetization in the Voigt-Thomson equation.

In the embodiment having this constitution, the ferromagnetic material forming on the magneto-resistive element 1 with the current path portion 2 has a resistance value $\rho_\perp$ per unit length represented by the following equation:–

$$\rho_1 = \rho_\perp . \sin^2\theta_1 + \rho_{11} . \cos^2\theta_1 \qquad (2)$$

due to the first magnetic field H_1 having a direction which makes an angle θ_1 with the direction of bias current I supplied to said current path portion 2, and similarly a resistance value ρ_2 per unit length represented by the following equation:–

$$\rho_2 = \rho_\perp . \sin^2\theta_2 + \rho_{11} . \cos^2\theta_2 \qquad (3)$$

for the second magnetic field H_2 making angle θ_2.

Since a constant bias current I is supplied from a constant current source 5 to the current path portion 2 on the magneto-resistive element 1, an output voltage V_{x1} represented by the following equation is obtained across terminals 3a, 3b provided at the ends of said current path portion 2:–

$$\begin{aligned} V_{x1} &= i.\{\Delta x_1 . \rho_1 + (L - \Delta x_1) . \rho_1\} \\ &= i.(\alpha - 1) . \rho_1 . \Delta x_1 + i.L.\rho_1 \qquad (4) \end{aligned}$$

where i represents the value of the bias current I, L the total longitudinal length of said current path portion 2, Δx_1 the length of said current path portion 2 located in the second magnetic field H_2 and α a constant represented by the following equation:–

$$\alpha = \frac{\rho 2}{\rho 1} \qquad (5)$$

This constant α can take value other than 1 according to the variation of the direction of each magnetic field H_1 or H_2 with reference to the direction of current I and take its maximum value when one of the magnetic fields H_1, H_2 intersects the direction of current I orthogonally and other is parallel to same. Thus in this embodiment for example as shown in Fig. 3, when the current path portion 2 is magnetically saturated by the first magnetic field H_1 having a direction orthogonal to that of current I supplied to the current path portion 2 and the second one H_2 parallel to the direction of the current I, the sensitivity of detecting the relative displacement between the magnetizing material 4 and magneto-resistive element 1 is maximized.

As is apparent from equation (4), the output voltage V_{x1} obtained across terminals 3a, 3b in this embodiment has a value proportional to the length Δx_1 and can be obtained from the corresponding location of boundary line l_o traversing the current path portion 2 on the magneto-resistive element 1 between the first and second magnetic fields H_1 and H_2.

A form of magnetizing material 4 as shown in Fig. 4 is used for producing the respective magnetic fields H_1, H_2 in the first embodiment. Namely, in Fig. 4, N_1 designates a zone magnetized on pole N for producing said first magnetic field H_1, S_1 similar zone magnetized on pole S, N_2 a zone magnetized on pole N for producing said second magnetic field H_2 and S_2 a zone similarly magnetized on pole S. Said magnetized zones N_1, S_1 are arranged in alternation and in parallel to each other and alternatively at intervals P. Also, similarly said respective magnetized zones N_2, S_2 are arranged in alternation and in parallel to each other. Said magnetized zones N_1, S_1 and said magnetized zones N_2, S_2 abut against the boundary line l_o on the respective longitudinal ends at different angles θ_1 and θ_2 respectively. Such a magnetizing material 4 produces the first magnetic field H_1 having direction orthogonal to said magnetized zones N_1, S_1, while producing the second magnetic field H_2 having direction orthogonal to said magnetized zones N_2, S_2. Further, since the extent of interaction of each magnetic field in the neighbourhood of the boundary line l_o is narrowed by reducing the interval P between the magnetizing zones N_1, S_1 and N_2, S_2, the boundary can be clearly given between the first and second magnetic fields H_1 and H_2.

Instead of dividing the region A_1 of the first magnetic field H_1 and the region A_2 of the second magnetic field H_2 in said first embodiment by the clear boundary line l_o, a region of magnetic field having a direction different from those of said respective magnetic fields H_1, H_2 and a predetermined width may be provided.

Thus in the second embodiment shown in Fig. 5, the magnetizing material 14 is divided into the first region A_a and the second region A_b by a third region A_c having a predetermined width S_o crossing the magnetism-sensing region on said magneto-resistive element 1 in the direction intersecting the direction (direction of arrow X–X in the drawing) of the relative displacement to the magneto-resistive element 1, and produces magnetic fields H_a, H_b, H_c having respectively different directions. The magneto-resistive element 1 on which the current path portion 2 of total length L is formed by ferromagnetic material as the magnetism-sensing region has a length x_2 in the region Ma of the first magnetic field Ha making angle θa with current I supplied to the current path portion 2, a length Y2 in the region M_b of the second magnetic field Hb making an angle θ_b and a length S_o in the region M_c of the third magnetic field H_c making angle θc, where $\theta a < \theta_c < \theta b$. In such a constitution of the second embodiment, the total resistance value ρ_t between both terminals 3a, 3b of the current path portion 2 on the magneto-resistive element 1 is obtained from the following equation:–

$$\begin{aligned}\rho_t &= x_2.(\rho_{\perp}.\sin^2\theta a + \rho_{11}.\cos^2\theta_a) \\ &+ y_2.(\rho\perp.\sin^2\theta_b + \rho_{11}.\cos^2\theta_b) \\ &+ \int_o^{S_o}\int_{\theta_a}^{\theta_b} (\rho_{\perp}.\sin^2\theta_c + \rho_{\perp 1}.\cos^2\theta_c)d\theta_c.ds \end{aligned} \qquad (6)$$

where $x_2 = L - S_o - y_2$ (7)

Assuming $\theta_2 = o°$ in the first region

$$Ma, \theta b = \frac{\pi}{2}$$

in the second region

$$Mb \text{ and } 0° \leq \theta_c \leq \frac{\pi}{2}$$

in the third region Mc for ideal requirements, the above equation (6) can be rewritten as follows:–

$$\rho_t = x_2.\rho_{11} + y_2.\rho_\perp + \int_0^{S_o}\int_0^{\frac{\pi}{2}} (\rho_\perp.\sin^2\theta c + \rho_{11}.\cos^2\theta c)\, d\theta_c.d_s$$

$$= x_2.\rho_{11} + (L - x_2 - S_o).\rho_\perp +$$

$$S_o.\rho_\perp.\left[\frac{\theta c}{2} - \frac{\sin^2\theta c}{4}\right]_0^{\frac{\pi}{2}} + S_o.\rho_{11}.\left[\frac{\theta c}{2} + \frac{\sin^2\theta c}{4}\right]_0^{\frac{\pi}{2}}$$

$$= x_2.(\rho_{11} - \rho_\perp) + (L - S_o).\rho_\perp + \frac{\pi.So}{4}.(\rho\perp + \rho_{11}) \qquad (8)$$

As is apparent from the equation (8) even if the region Ac with a predetermined width S_o of the third magnetic field H_c is located on the boundary portion between the respective regions A_a, A_b of the magnetic fields H_a, H_b locating the current path portion 2 of magneto-resistive element 1 and having different directions, the total resistance value ρ_t varies linearly with the change in the length x_2, i.e. the relative displacement between the magnetizing material 14 and current path portion 2 if the width S_o is constant. However both end portions of the current path portion 2 have to be located in the regions A_a, A_b of the respective magnetic fields H_a, H_b.

Also, in such constitution of the second embodiment, an output voltage V_{x2} which varies linearly with the relative displacement between the magnetizing material 14 and magneto-resistive element 1 can be obtained across terminals 3a, 3b.

Next, Fig. 6 shows the principle of the third embodiment of the magnetic-sensor device according to the present invention, in which is used a magneto-resistive element 1 provided with power supply terminals 3a, 3b on both longitudinal ends of a flat strip-like current path portion 2 made of anisotropic ferromagnetic material exhibiting the ferromagnetic magneto-resistive effect, such as NiCo alloy, NiFe alloy, NiAl alloy, NiMn alloy or NiZn alloy. A constant current source 5 is connected between said power supply terminals 3a, 3b and a constant current I for bias is supplied from the constant current source 5 to the current path portion 2. Further, one of said power supply terminals 3a, 3b (power supply terminal 3b) is earthed.

The magneto-resistive element 1 is opposed to biasing magnetizing material 24_B producing in the first region A_B a bias magnetic field H_B having sufficient intensity to magnetically saturate the ferromagnetic material forming the current path portion 2 and signally magnetizing material 24s producing a signal magnetic field H_s in the second region A_s. Further, said signal magnetizing material 24_s and magneto-resistive element 1 are disposed to be displaced relative to each other. The resistance value ρ_B per unit length of said current path portion 2 caused by said bias magnetic field H_B having angle θ_B is given by the following equation;

$$\rho_B = \rho_\perp.\sin^2\theta_B + \rho_{11}.\cos^2\theta_B \qquad (9)$$

and the resistance value ρ_s per unit length of said current path portion 2 caused by the signal magnetic field H_s having angle θ_s is given by:–

$$\rho_s = \rho_\perp.\sin^2\theta_s + \rho_{11}.\cos^2\theta_s \qquad (10)$$

Assuming the total longitudinal length of current path portion 2 on said magneto-resistive element 1 is L and the length of said current path portion 2 located in the signal magnetic field H_s is Δx_3, the resistance value $r(\theta)$ is represented by the following equation (11), which depends upon the resultant magnetic field vector $H_B + H_s$ of the signal magnetic field H_s and the bias magnetic field H_B in the length Δx_3;

$$\rho(\theta_o) = \Delta x_3.(\rho_\perp.\sin^2\theta_o + \rho_{11}.\cos^2\theta_o) \qquad (11)$$

Further, angle θ_o in the above equation (11) is defined by angles θ_B, θ_s made between the respective directions of said bias magnetic field H_B and signal magnetic field H_s and the direction of bias current I supplied to said current path portion 2 as shown in Fig. 7. Namely, considering the bias magnetic field H_B and signal magnetic field Hs in a Gaussian plane, the size of the resultant magnetic field Ho of said bias magnetic field H_B and signal magnetic field Hs is represented by the following equation:–

$$|z+\beta| = \sqrt{(x+a)^2+(y+b)^2} \qquad (12)$$

Also, the declination θ_o is represented by the following equation:–

$$\theta_o = \text{Arg}\,(z+\beta) = \tan^{-1}\frac{y+b}{x+a} \qquad (13)$$

where

$$z = x + iy \qquad \because\ x = H_B.\sin\theta_B,\ y = H_B.\cos\theta_B$$
$$\beta = a + ib \qquad \because\ a = H_s.\sin\theta_s,\ b = H_s.\cos\theta_s$$

Accordingly, assuming that the current value of bias current I supplied from the constant current source 5 to between terminals 3a, 3b of said magneto-resistive element 1 is i, output voltage V_{x3} is obtained from the following equation:–

$$\begin{aligned} V_{x3} &= i.(L-\Delta x_3).(\rho_\perp.\sin^2\theta_B+\rho_{11}.\cos^2\theta_B) \\ &\quad + i.\Delta x_3.(\rho_\perp.\sin^2\theta_o+\rho_{11}.\cos^2\theta_o) \\ &= i.L.(\rho_\perp\sin^2\theta_B+\rho_{11}.\cos^2\theta_B) \\ &\quad + i.\Delta x_3.\{\rho_\perp.(\sin^2\theta_o-\sin^2\theta_B)+\rho_{11}.(\cos^2\theta_o-\cos^2\theta_B)\} \end{aligned} \qquad (14)$$

As is apparent from equation (13), the output voltage Vx3 obtained is in proportion to the length Δx_3 of current path portion 2 located in the signal magnetic field H_s if the directions of the bias magnetic field H_B and signal magnetic field H_s are constant.

Further in the above-mentioned embodiment, while the direction of the bias magnetic field H_B is parallel to and the direction of the signal magnetic field H_s is perpendicular to the direction of current I supplied to the current path portion 2, the sensitivity of detecting the relative change in magnetizing material 24_s for signal and magneto-resistive element 1 is maximized under an ideal condition of H_s, H_B. Under such ideal condition, the output voltage V_{x3} represented by the following equation is obtained by converting

$\theta_B = 0$, $\theta_o \doteqdot \frac{\pi}{2}$ in said equation (13):–

$$\begin{aligned} V_{x3} &\doteqdot i.\ (L-\Delta x_3).\rho_{11} + I.\Delta x_3.\rho_\perp \\ &= i.L.\rho_{11} + i.\Delta x_3.(\rho_{11}-\rho_\perp) \end{aligned} \qquad (15)$$

The magnetic sensor device having in principle the constitution of said first, second or third embodiment, as shown in Fig. 8, interconnects in series two current path portions 2A, 2B, and can constitute a potentiometer of magneto-resistive element 11, provided at the common junction with output terminal 3_c.

In Fig. 9 which shows a fourth embodiment constituting a potentiometer on the basis of the first and second embodiments, the magneto-resistive element 11 has first and second current path portions 2A, 2B made of flat strip-like ferromagnetic material interconnected in series, and is provided on the middle point of the connections with output terminal 3c and on its ends with power supply terminals 3a, 3b. In the magneto-resistive element 11, a constant voltage source 15 is connected across the respective power supply terminals 3a, 3b, and the first magnetic field H_1 having a direction (i.e. $\theta_1 = 90°$) orthogonal to the longitudinal direction of the respective current path portions 2A, 2B is produced in the first region A_1 between the first boundary line l_a crossing the first current path portion 2A and the second boundary line l_b crossing the second current path portion 2B, and magnetizing material 34 for producing the second and third magnetic fields H_2, H_3 having directions (i.e. $\theta = \theta_3 = 0°$) parallel to the respective current paths 2A, 2B in the second and third regions A2, A3 adjacent each other through said respective boundary lines l_a, l_b is disposed opposite element 11 to be relatively displaced in the direction of arrow X–$\bar{X}$ in the Figure.

In this form of the fourth embodiment, the first and second current path portions 2A, 2B disposed in the magnetic fields H_1, H_2, H_3 produced by said magnetizing material 34 show differential change characteristics such that one resistance value ρ_a increases while the other ρ_b decreases as the boundary lines l_a, l_b of said respective magnetic fields H_1, H_2, H_3 move longitudinally, and the total resistance value $(\rho_a + \rho_b)$ across terminals 3a, 3b does not vary so that a constant current I having current value i represented by the following equation is supplied from constant voltage source 15:–

$$i = \frac{Vin}{\rho_a + \rho_b} \qquad (16)$$

where Vin is the voltage applied across both terminals 3a, 3b of magneto-resistive element 11 by constant voltage source 15, ρ_a is the resistance value of the first current path portion 2A and ρ_b is the resistance value of the second current path portion 2B. The respective values ρ_a, ρ_b can be obtained from the Voigt-Thomson equation.

Thus, assuming the total longitudinal length of the first current path portion 2A is L_1, the total longitudinal length of the second current path portion 2B is L_2, the interval between the first and second current path portions 2A, 2B is L_3, the total longitudinal length of region A_1 of the first magnetic field H_1 is L_o, the longitudinal length of the first current path portion 2A located in said first magnetic field H_1 is Δx_A and the longitudinal length of the second current path portion 2B located in said first magnetic field H_1 is Δx_B, said respective resistance ρ_a, ρ_b can be obtained from the following equations:–

$$\rho_a = (L_1 - \Delta x_A).(\rho_\perp.\sin^2\theta_2 + \rho_{11}.\cos^2\theta_2) + \Delta x_A.(\rho_\perp.\sin^2\theta_1 + \rho_{11}.\cos^2\theta_1) \qquad (17)$$

$$\rho_b = (L_2 - \Delta x_B).(\rho_\perp.\sin^2\theta_3 + \rho_{11}.\cos^2\theta_3) + \Delta x_B.(\rho_\perp.\sin^2\theta_1 + \rho_{11}.\cos^2\theta_1) \qquad (18)$$

The total resistance value $(\rho_a + \rho_b)$ across terminals 3a, 3b of said magneto-resistive element 11 is represented by the following equation:–

$$\begin{aligned}\rho_a + \rho_b = {} & (L_1 - \Delta x_A).(\rho_\perp.\sin^2\theta_2 + \rho_{11}.\cos^2\theta_2) \\ & + \Delta x_A.(\rho_\perp.\sin^2\theta_1 + \rho_{11}.\cos^2\theta_1) \\ & + (L_2 - \Delta x_B).(\rho_\perp.\sin^2\theta_3 + \rho_{11}.\cos^2\theta_3) \\ & + \Delta x_B.(\rho_\perp.\sin^2\theta_1 + \rho_{11}.\cos^2\theta_1) \\ & = L_1.(\rho_\perp \sin^2\theta_2 + \rho_{11}.\cos^2\theta_2) + L_2. \\ & (\rho_\perp.\sin^2\theta_3 + \rho_{11}.\cos^2\theta_3) \\ & -\Delta x_A.(\rho_\perp.\sin^2\theta_2 + \rho_{11}.\cos^2\theta_2) + \Delta x_B. \\ & (\rho_\perp.\sin^2\theta_3 + \rho_{11}.\cos^2\theta_3) \\ & + (\Delta x_A + \Delta x_B).(\rho_\perp.\sin^2\theta_1 = \rho_{11}.\cos^2\theta_1) \qquad (19)\end{aligned}$$

Since $\theta_1 = 90°$, $\theta_2 = 0°$ and $L_o - L_3 = \Delta x_A + \Delta x_B$ in this embodiment, the total resistance value $(\rho_a + \rho_b)$ in equation (19) has a constant value, irrespective of the relative displacement between magnetizing material 34 and magneto-resistive element 11 as shown in the following equation:–

$$\begin{aligned}\rho_a + \rho_b = {} & (L_1 + L_2).(\rho_\perp.\sin^2\theta_2 + \rho_{11}.\cos^2\theta_2) \\ & - (L_o - L_3).(\rho_\perp.\sin^2\theta_2 + \rho_{11}.\cos^2\theta_2) \\ & + (L_o - L_3).(\rho_\perp.\sin^2\theta_1 + \rho_{11}.\cos^2\theta_2) \\ & = (L_1 + L_2).(\rho_{11} - (L_o - L_3).(\rho_{11} - \rho\perp) \\ & = (L_1 + L_2 + L_3 - L_0).\rho_{\perp 1} + (L_0 - L_3).\rho_\perp \qquad (20)\end{aligned}$$

Then, assuming each length $L_1 = L_2 = L_0$ and $\Delta x_A + \Delta x_B = L_0 - L_3 = L_4$, the output voltage Vx4 is represented by the following equation:–

$$Vx4 = \frac{\rho_b}{\rho_a + \rho_b}.Vin$$

$$= \frac{L_2.\rho_{11}}{(2.L_0 - L_4).\rho_{11} + L_4.\rho_\perp}.Vin$$

$$- \frac{(\rho_{11} - \rho_\perp)}{(2L_0 - L_4).\rho_{11} + L_4.\rho_\perp}.\Delta x_B.Vin \qquad (21)$$

The first term in the right side of the equation (21) represents a constant voltage, the second term being a voltage varying with the relative displacement between the magnetizing material 34 and magneto-resistive element 11. Also, in Fig. 10 showing the fifth embodiment in which a potentiometer is constituted on the basis of said third embodiment, the magneto-resistive element 11 is provided with a first current path portion 2A and the second current path portion 2B respectively made of flat strip-like ferromagnetic material and interconnected in series, while being provided at the middle of the current paths with output terminal 3c and on both ends with power supply terminals 3a, 3b. A constant voltage source 15 is connected to the respective power supply terminals 3a, 3b. Disposed opposite element 11 are a signal magnetizing material 24_s producing a signal magnetic field H_s in the longitudinal direction (i.e. $\theta_s = 90°$) orthogonal to the respective current path portions 2A, 2B in region A_s spanning the first and second current path portion 2A, 2B and bias magnetizing material 24_B producing a bias magnetic field H_B having direction (i.e. $\theta_B = 0°$) parallel to the respective current path portions 2A, 2B in region A_B covering the whole current path portions 2A, 2B.

The signal magnetizing material 24_s and magneto-resistive element 11 are disposed to be displaced relatively to each other.

In this embodiment, the first and second current path portions 2A, 2B in a manner similar to said fourth embodiment, show a differential change characteristic such that one resistance value ρ_a increases while other resistance value ρ_b decreases as the signal magnetizing material 24_s and element 11 move relatively longitudinally of element 11. Hence the total resistance value $(\rho_a + \rho_b)$ does not change between terminals 3a, 3b so a constant current I having constant current value i shown by said equation (16) is supplied by the constant voltage source 15 similarly to the fourth embodiment.

Assuming that L_1 is the total longitudinal length of the first current path portion 2A, L_2 is the total longitudinal length of the second current path portion 2B, L_3 is the interval between said first and second current path portions 2A, 2B, L_o is the total longitudinal length of region A_s of signal magnetic field H_s, Δx_A is the longitudinal length of the first current path portion 2A located in the region A_s of said signal magnetic field H_s and Δx_B is the longitudinal length of the second current path portion 2B, located in the region A_s the resistance values ρ_a, ρ_b are obtained from the following equations:–

$$\rho_a = (L_1 - \Delta x_A).(\rho_\perp.\sin^2\theta_B + \rho_{11}.\cos^2\theta_B) + \Delta x_A.(\rho_\perp.\sin^2\theta_o + \rho_{11}.\cos^2\theta_o) \qquad (22)$$

$$\rho_b = (L_2 - \Delta x_B).(\rho_\perp.\sin^2\theta_B + \rho_{11}.\cos^2\theta_B) + \Delta x_B.(\rho_\perp.\sin^2\theta_o + \rho_{11}.\cos^2\theta_o) \qquad (23)$$

The angle θ_o in said equations (22) and (23) is the one made between the resultant magnetic field of signal and bias magnetic fields H_s, H_B and the direction of current I and obtained from said equation (13). Equation (22) showing the resistance value ρ_a of said first current path portion 2A is equivalent to said equation (17) with $\theta_2 = \theta_B$ and $\theta_1 = \theta_o$ and equation (23) showing the resistance value ρ_b of the second current path portion 2_B is equivalent to said equation (18) with $\theta_3 = \theta_B$ and $\theta_1 = \theta_o$. Hence, in the fifth embodiment also, the total resistance value (ρ_a, ρ_b) between power supply terminals 3a, 3b of magneto-resistive element 11 holds a constant value, irrespective of the relative displacement to the signal magnetizing material 24_s if the respective directions of bias magnetic field H_s is constant. In a manner similar to the fourth embodiment, to the output terminal 3_c can be obtained an output voltage V_{xs} which is in proportion to the relative displacement between the magneto-resistive element 11 and the signal magnetizing material 24_s.

As is shown in said fourth and fifth embodiments, the magnetic sensor device can be driven by a constant voltage source while the sensitivity of detection is improved by forming a potentiometer of the magneto-resistive material.

Also, a pair of potentiometers according to said fourth or fifth embodiment can be used to form a bridge circuit with one potentiometer in each arm of the bridge.

Thus in Fig. 11 showing the sixth embodiment, a bridge circuit is formed on the basis of said fourth embodiment. Magneto-resistive element 21 is constituted by the series connected first and second current path portions $2A_1$, $2B_1$ of four current path portions $2A_1$, $2B_1$, $2A_2$, $2B_2$ arranged parallel to each other, to form a first potentiometer and the third and fourth current path portions $2A_2$, $2B_2$ are connected in series to form a second potentiometer. At one end of said first current path portion $2A_1$ is provided a positive side power supply terminal 3a1, and at one end of the second current path portions $2B_1$ is provided negative side power supply terminal 3b1. Further at the middle point of the connections between the respective other ends of current path portions $2A_1$, $2B_1$ is provided a first output terminal $3C_1$. Also, at one end of said third current path portion $2A_2$ is provided negative side power supply terminal $3b_2$, and at one end of the fourth current path portion $2B_2$ positive side power supply terminal $3a_2$. Further at the middle point of the connection between the respective other ends of current path portions $2A_2$, $2B_2$ is provided a second output terminal $3C_2$. Magnetizing material 34 producing the first to third magnetic fields H_1, H_2, H_3 having boundary lines l_a, l_b crossing respectively said current path portions $2A_1$, $2A_2$ and the first and second current path portions $2B_1$, $2B_2$ and directions different from each other is disposed to opposite the magneto-resistive element 21, the two being relatively movable in the direction of arrow X–$\bar{X}$ in the Figure.

In the sixth embodiment, when the locations of the boundary lines l_a, l_b crossing respective current path portions $2A_1$, $2A_2$, $2B_1$, $2B_2$ of magneto-resistive element 21 in respective magnetic fields H_1, H_2, H_3 produced by magnetizing material 34, and said current path portions $2A_2$, $2B_1$, $2B_2$ of magneto-resistive element 21 is displaced by the relative movement of said magnetizing material 34 and magneto-resistive element 21, the first potentiometer formed by the first current path portion $2A_1$ and the second one $2B_1$ and the second potentiometer formed by the third current path portion $2A_2$ and the fourth one $2B_2$ are differentially affected in response to the displacement of said locations to provide a differential output voltage V_{x6} corresponding to said displacement between the first output terminal $3C_1$ and the second output terminal $3C_2$. Further in this embodiment, assuming L is the total length of current path portions $2A_1$, $2A_2$, $2B_1$, $2B_2$ of reluctance element 21 and $\rho a1$, $\rho a2$, $\rho b1$, $\rho b2$ the respective resistance values of the portions, the said first and second potentiometers change their outputs such that they show linear resistance characteristics corresponding to the displacement relative to the magnetizing material 34 as shown in Fig. 12. Also, assuming Δx_a, Δy_a are respectively the lengths of the first and third current path portions $2A_1$, $2A_2$ of said magneto-resistive element 21 located in the region A_2 of the second magnetic field H_2, and Δx_b, Δy_b are respectively the lengths of the second and fourth current path portions $2B_1$, $2B_2$ located in the region A_1 of the first magnetic field H_1, the total resistance value ρx, ρy of each potentiometer is obtained from the following equations:–

$$\rho_x = \rho_{a1} + \rho_{b1} = (\rho_{11} - \rho_\perp).(\Delta x_b - \Delta x_a) + L.(\rho_{11} + \rho_\perp) \qquad (24)$$

$$\rho_y = \rho_{a2} + \rho_{b2} = (\rho_{11} - \rho_\perp).(\Delta y_b - \Delta y_a) + L.(\rho_{11} + \rho_\perp) \qquad (25)$$

Assuming $\Delta x_b - \Delta x_a = \Delta y_b - \Delta y_a = d$

$$\rho_x = \rho_y = (\rho_{11} - \rho\perp).d + (\rho_{11} + \rho_\perp).L$$

is obtained to permit constant voltage drive.

In the seventh embodiment shown in Fig. 13, the magneto-resistive element 21 is used such that the first and second current path portions $2A_1$, $2B_1$ of the first to fourth ones $2A_1$, $2B_1$, $2A_2$, $2B_2$ arranged parallel to each other are connected in series to form the first potentiometer, and the third and fourth current path portions $2A_2$, $2B_2$ are connected in series to form the second potentiometer. At one end of said first current portion $2A_1$ is provided positive side power supply terminal $3a_1$ and at one end of the second current path portions $2B_1$ negative side power supply terminal $3b_1$. Further at the middle point of the connection between the respective other ends of current path portions $2A_1$, $2B_1$ is provided the first output terminal $3c_1$. Also at one end of said third current path portion $2A_2$ is provided negative side power supply terminal $3b_2$ and at one end of the fourth current path portion $2B_2$ positive side power supply terminal $3a_2$. Further at the middle point of the connection between the respective other ends of current path portions $2A_2$, $2B_2$ is provided the second output terminal $3c_2$. Signal magnetizing material 24_s giving a signal magnetic field H_s to partial region A_s spanning said current path portions $2A_1$, $2A_2$, $2B_1$, $2B_2$ is opposed to said magneto-resistive element 21 to be displaced relative thereto in the direction of arrow X–$\bar{X}$ in the drawing. Further, region A_B covering all said respective current path portions $2A_1$, $2A_2$, $2B_1$, $2B_2$ is given bias magnetic field H_B from bias magnetizing material 24_B.

In this, when the locations of signal magnetic field H_s produced by the signal magnetizing material 24_s and crossing the respective current path portions $2A_1$, $2A_2$, $2B_1$, $2B_2$ of magneto-resistive element 21 is displaced by the relative movement between said signal magnetizing material 24_s and magneto-resistive element 21, the first potentiometer formed by the first current path portion $2A_1$ and the second one $2B_1$ and the second potentiometer formed by the third and fourth current path portions $2A_2$, $2B_2$ are differentially affected in response to said displacement of the locations to provide output voltage V_{x7} corresponding to said displacement across the first output terminals $3c_1$ and the second one $3c_2$.

Further, as a case of constituting a bridge circuit from the potentiometers on the basis of the embodiment, there is provided the eighth embodiment constituted as shown in Fig. 14.

In this eighth embodiment, a magneto-resistive element 31 is used in which the first and second current path portions $2A_1$, $2B_1$ of the first to fourth ones $2A_1$, $2B_1$, $2A_2$, $2B_2$ which arranged parallel to each other are connected in series to form the first potentiometer and the third and fourth ones $2A_2$, $2B_2$ are connected in series to form the second potentiometer as shown in Fig. 14. At one end of said first current path portion $2A_1$ is provided positive side power supply terminal $3a_1$ and at one end of the second current path portion $2B_1$ negative side power supply terminal $3b_1$. Further, at the middle point of the connection between the respective other ends of current path portions $2A_1$, $2B_1$ is provided the first output terminal $3c_1$. Also, at one end of said third current path portion $2A_2$ is provided negative side power supply terminal $3b_2$ and on one end of the fourth current path portion $2B_2$ positive side power supply terminal $2a_2$. Further, at the middle point of the connection between the respective other ends of current path portions $2A_2$, $2B_2$ is provided the second output terminal $3c_2$. The magnetizing material 44 producing the first to fourth magnetic fields Ha, Hb, Hc and Hd divided by boundary line l_1 crossing said respective current path portions $2A_1$, $2A_2$, $2B_1$, $2B_2$ and boundary line l_2 separating the first one $2A_1$ from second one $2B_1$ to have directions different from each other is opposed to said magneto-resistive element 21 to be displaced relative thereto in the direction of arrow $X-\bar{X}$ in the drawing.

To produce said first to fourth magnetic fields Ha, Hb, Hc and Hd, a magnetizing material 44 constructed shown in Fig. 15 is used. That is, the magnetizing material 44 is constituted such that it is divided by the orthogonal boundary lines l_1, l_2 into four regions, the first to fourth ones Aa, Ab, Ac, Ad. Magnetized zone Nac on the pole N and magnetized zone Sac on the pole S are alternately arranged parallel to the boundary line in the first and third regions Aa, Ac and magnetized zone Nbd on the pole N and magnetized zone S_{bd} on the pole S are alternately arranged orthogonally to the boundary line l_1 in the second and fourth regions A_b, A_d. The magnetizing material 44 constructed in this way can produce the first to fourth magnetic fields H_a, H_b, H_c and H_d having directions orthogonal to each other in the respective regions A_a, A_b, A_c and A_d which are adjacent each other through said boundary lines l_1, l_2. Further the directions of the first magnetic field H_a and the third magnetic field H_c are parallel to each other and the second and fourth magnetic fields H_b, H_d are parallel to each other. Also, the direction of said first and third magnetic fields H_a, H_c and that of the second and fourth ones H_b, H_d are orthogonal to each other.

In the eighth embodiment, when the location of the boundary line l_1 crossing the respective current path portions $2A_2$, $2A_1$, $2B_1$, $2B_2$ of magneto-resistive element 31 in the respective magnetic fields Ha, Hb, Hc, Hd produced by the magnetizing material 44 is displaced by movement relative to said magnetizing material 44 and magneto-resistive element 31, the first potentiometer formed by the first current path portion $2A_1$ and the second one $2B_1$ and the second potentiometer formed by the third and fourth current path portions $2A_2$, $2B_2$ are differentially affected in response to said displacement to provide output voltage V_{x8} corresponding to said displacement across the first and second output terminal $3c_1$, $3c_2$.

Further, in the sixth, seventh, or eighth embodiment, a differential amplifier 6 as shown in Fig. 16 can be used for outputing a signal from the bridge circuit. Also, as shown in Fig. 17, one potentiometer may be substituted by one constituted from conventional resistances 7A, 7B, 7C connected in series.

According to the principle of each of said embodiments, magneto-resistive elements having current path portions with various shapes are applicable in place of one having flat strip-like current path portions. The current path portion 102 of magneto-resistive element 101 shown in Fig. 18 is formed by a meander-shaped ferromagnetic material consisting of a plurality of strips 102a, 102b, ... 102n connected in electrical series and arranged geometrically in parallel. The meander-shape of current path portion 102 increases its impedance so that the sensitivity responsive to magnetism is improved.

The ninth embodiment shown in Fig. 19 is one which applies the magneto-resistive element 101 shown in Fig. 18 to the first embodiment. In the ninth embodiment, the magneto-resistive element 101 having meander-shaped current path portion 102 is disposed such that the respective strips 102a, 102b ... 102n of said current path portion 102 intersect perpendicularly the boundary line l_0 between the region A_1 of the first magnetic field H_1 and the region A_2 of second one H_2 of the magnetizing material 4. In such ninth embodiment, since the impedance of said current path portion 102 is increased by forming the meander-shaped current path portion 102 of magneto-resistive element 101, the sensitivity of response of magnetizing material 4 to the respective magnetic fields H_1, H_2 can be improved higher than that of the first described version of the first embodiment. The magneto-resistive element 101 shown in Fig. 18 contributes to the improvement of the sensitivity of response to magnetic field also when it is applied to the second or third embodiment.

In the ninth embodiment, while the boundary line l_0 dividing the magnetizing material 4 into the respective regions A_1, A_2 is adapted to intersect perpendicularly each strip 102a, 102b . . . 102n of current path portion 102 of magneto-resistive element 101, it may intersect the strips at any angle. Thus, instead of said magneto-resistive element 101, a magneto-resistive element 201 may be used which consists of plurality of strips 202a, 202b . . . 202n of current path portion 202 formed by meander-shaped ferromagnetic material as shown in Fig. 20 and arranged parallel to each other with any angle of inclination. This magneto-resistive element 201 can be of course applied to said second and third embodiments.

In Fig. 21, showing the tenth embodiment, the magneto-resistive element 101 employs one shown in Fig. 18 and having meander-shaped current path portion 102 and a constant current I for biasing is supplied from constant current source 5 through power supply terminals 3a, 3b to said current path portion 102. In the magneto-resistive element 101, the respective strips 102a, 102b . . . 102n of the current path portion 102 are arranged parallel to the boundary line l_0 between the region A_1 of the first magnetic field H_1 and the region A_2 of the second magnetic field H_2 in the magnetizing material 4. The magneto-resistive element 101 and magnetizing material 4 are opposed to one another and relatively displaceable in the direction perpendicularly to said boundary line l_0 (the direction of arrow $X-\bar{X}$ in the drawing). In this form of the tenth embodiment, an output voltage V_{x10} as shown in Fig. 22 and the changing stepwise in response to the relative displacement of said magneto-resistive element 101 and magnetizing material 4 can be obtained across terminals 3a, 3b. Further, in place of said magneto-resistive element 101 magneto-resistive element 201 shown in Fig. 20 may be used. Also, in the ninth embodiment constituted on the basis of the first embodiment said magneto-resistive elements 101, 201 can constitute the magnetic sensor device which provides stepped output voltage even on the basis of the principle of said second and third embodiments.

Also, the magneto-resistive element 111 shown in Fig. 23 has the first and second current path portions 102A, 102B formed by meander-shaped ferromagnetic material and arranged longitudinally, and is applied to the fourth and fifth embodiments constituting the potentiometer.

The eleventh embodiment shown in Fig. 24 is one which applies the magneto-resistive element 111 to the fifth embodiment to constitute the potentiometer. In this eleventh embodiment, as shown in Fig. 24, while the first and second current path portions 102A, while the first and second current path portions 102A, 102B formed respectively by meander-shaped ferromagnetic material are connected in series, similar to said fifth embodiment, the output terminal 3c is provided on the middle point of the connection between said portions, and the magneto-resistive element 111 provided on both ends with power supply terminals 3a, 3b is used. In said magneto-resistive element 111, constant voltage source 15 is connected between the respective power supply terminals 3a, 3b, while the signal magnetizing material 24_s producing the signal magnetic field Hs having a direction perpendicular to each strip of respective current path portion 102A, 102B in the region As spanning the first and second current path portions 102A, 102B and the bias magnetizing material 24B producing bias magnetic field H_B having a direction parallel to each strip of respective current path portions 102A, 102B in the region A_B covering the whole current path portions 102A, 102B are provided opposite to each other.

The signal magnetizing material 24_s and magneto-resistive element 111 are disposed to be relatively displaced in the longitudinal direction of each strip of said current path portions 102A, 102B.

In this form of the eleventh embodiment, the respective current path portions 102A, 102B affected differentially for detection are formed in meandering configurations to have high impedance so that the sensitivity of magneto-resistive element 111 for detecting signal magnetic field H_s can be improved as compared with the fifth embodiment. Thus, an output voltage Vx11 can be obtained across the output terminal 3c of said magneto-resistive element 111 in proportion to the relative displacement to the signal magnetizing material 24s with high sensitivity.

Figs. 25 to 29 show respective ways of applying to the magneto-resistive element 111, the bias magnetic field H_B and signal magnetic field H_s in the eleventh embodiment adapted to constitute said potentiometer.

The bias magnetizing material 24B for producing the bias magnetic field H_B is formed by a permanent magnet and fixedly secured by adhesive to a substrate 8 formed with the respective current path portions 102A, 102B of magneto-resistive element 111. The bias magnetic field H_B can normally be such as to magnetically saturate the respective current path portions 102A, 102B of magneto-resistive element 111 in one direction with this bias magnetizing material 24B.

The signal magnetizing material 24_s disposed to be displaced relative to the magneto-resistive element 111 and bias magnetizing material 24B integrated with each other as above-mentioned, for example, consists of two opposed permanent magnets 9a, 9b between which said magneto-resistive element 111 is located as shown in Fig. 25. On the opposed surfaces of said permanent magnets 9a, 9b in which the magneto-resistance element 111 is sandwiched are formed poles having opposite polarity. Also, as shown in Fig. 26, as said signal magnetizing material 24_s may be used a permanent magnet 9 located opposedly to the respective current path portions 102A, 102B of magneto-resistive element 111. Further, as shown in Fig. 27 or 28, the signal magnetic field H_s can be intensified by mounting magnetic yokes 10A, 10B of ferromagnetic material on permanent magnets 9a, 9b, 9c for producing signal magnetic field H_s. Further in the embodiment shown in Fig. 28, opposed portions 10_b of magnetic yoke 10B in which the magneto-resistive element 111 is sandwiched are converged towards said magneto-resistive element 111 to focus signal magnetic flux for further intensifying the signal magnetic field H_s. Also, as the signal magnetizing material 24s for producing said signal magnetic field H_s may be used an electromagnet 100 comprising coil 100b wound around an iron core 100a as shown in Fig. 29. In the signal magnetizing material 24s using such electromagnet 100, the intensity of the signal magnetic field H_s can be set at will or sufficiently improved by drive current supplied to the electromagnet 100. Further in this case the permanent magnet used for the bias magnetizing material 24B should have a high resistance to having its magnetization changed.

Also, in the magneto-resistive element 111 shown in Fig. 23, when a potentiometer for detecting the relative displacement in the direction intersecting perpendicularly the respective strips of current path portions 102A, 102B is constituted, the output voltage changes stepwise similarly to the case in said tenth embodiment.

Further, the magneto-resistive element 311 shown in Fig. 30 has first and second current path portions 302A, 302B arranged longitudinally in the direction that the respective strips $302A_1$, $302A_2$ . . . $302A_n$ of meander-shaped first current path portion 302A intersect orthogonally the respective strips $302B_1$, $302B_2$, . . . $302B_n$ of the meander-shaped second current path portion 302B. This magneto-resistive element 301, when applied to said fourth or fifth embodiment, constitutes a potentiometer which changes stepwise the output voltage. Also, in Fig. 31 showing the twelfth embodiment to which said magneto-resistive element 301 is applied, the reluctance element 301 is disposed opposed to magnetizing material 4 having the respective regions A_1, A_2 of the first and second magnetic fields H_1, H_2 which have different directions and are defined by the boundary line l_o perpendicular to the respective strips $302A_1$, $302A_2$ . . . $302A_n$ of the first current path portion 302A and parallel to the respective strips $302B_1$, $302B_2$ . . . $302B_n$ of the second current path portion 302B. Said magneto-resistive element 301 and magnetizing material 4 are disposed to be relatively displaced in the direction perpendicular to the boundary line l_o. In such form of the twelfth embodiment, the magnetizing material 4 having the respective regions A_1, A_2 of the magnetic fields H_1, H_2 divided by one boundary line l_o crossing the respective current path portion 302A, 302B of the magneto-resistive element 301 is used for operating the potentiometer and providing an output voltage V_{x12} across output terminal 3c to simplify the constitution of magnetizing material 4. Also, in the constitution of potentiometer of said fourth and fifth embodiments, as shown in Fig. 32, may be used a magneto-resistive element 211 in which the respective strips $202A_1$, $202A_2$ . . . $202A_n$ of the first current path portion 202A and the respective strips $202B_1$, $202B_2$ . . . $202B_n$ of the second current path portion 202B are arranged parallel to each other with any angle of inclination.

The thirteenth embodiment shown in Fig. 33 constitutes the potentiometer employing magneto-resistive element 211 shown in Fig. 32. In this thirteenth embodiment, the signal magnetizing material124_s having parallel regions A_s of signal magnetic field H_s varying the direction by π sequentially in the order S–N–S–N . . . according to the parallel poles N_A, S_A, N_B, S_B and the bias magnetizing material 124_B having regions A_B of bias magnetic field H_B directed in the direction perpendicular to that of said signal magnetic field H_s produce magnetic fields HA_1, HA_2, HA_3 in the respective magnetic fields H_s, H_B, and such composite magnetic fields are applied to the first and second current path portions 202A, 202B of the reluctance element 211. Said magneto-resistive element 211 is disposed parallel to the isomagnetic surface of signal magnetic field H_s produced by signal magnetizing material 124s, and is displaceable relative to said signal magnetizing material 124s in the direction of the signal magnetic field H_s. Also, the bias magnetizing material 124B is fixedly secured to the magneto-resistive element 211 to sufficiently magnetically saturate the ferromagnetic material forming the first and second current path portions 202A and 202B in that direction. The magnetic field formed by the signal magnetic field H_s and bias magnetic field H_B applied to the respective current path portions 202A, 202B of said magneto-resistive element 211 provides composite magnetic fields H_{A1}, H_{A2} which have the same direction between said poles S_A, N_A and between poles S_B, N_B, and a magnetic field HA_3 which has the direction different from that of said composite one HA_1, HA_2 between poles N_A, S_B as shown in the Figure. In this embodiment, the respective strips $202A_1$, $202A_2 \ldots 202A_n$ of the first current path portion 202A and the respective strips $202B_1$, $202B_2 \ldots 202B_n$ of the second one 202B in the reluctance element 211 are formed at 45° inclination to make said strips $202A_1$, $202A_2 \ldots 202A_n$ and $202B_1$, $202B_2 \ldots 202B_n$ parallel to the direction of said composite magnetic fields HA_1 and HA_2 respectively.

In such form of the thirteenth embodiment as shown in Fig. 34, a region A_o in which the direction of signal magnetic field H_s varies gradually is produced in the neighbourhood of the respective poles S_A, N_A, S_B, N_B of signal magnetizing material 124s so that the signal magnetizing material 124s and reluctance element 211 should be relatively displaced by an amount L having a linear portion in the direction of magnetic field shown in the Figure. Further, the region A_s in which the direction of signal magnetic field H_s varies gradually does not affect the detection of said displacement described in the second embodiment if the width S_o is constant. Further, to obtain perfect linearity of output detected by said magneto-resistive element 211, the isomagnetic surface of signal magnetic fields H_s should be plane and the magneto-resistive element 211 should be disposed in the position of this isomagnetic surface. For example, such planar isomagnetic surface can be realized by the use of signal magnetizing material 124s constructed as shown in Fig. 35. That is, the magnetizing material 124s shown in Fig. 34 has two sets of three magnets opposedly in parallel to provide planar isomagnetic surfaces between the respective magnets $9A_1$, $9A_2$, $9A_3$, $9B_1$, $9B_2$, $9B_3$.

Furthermore, the magneto-resistive element 121 shown in Fig. 36, is formed with the first, second, third and fourth current path portions, $102A_1$, $102B_1$, $102A_2$ and $102B_2$ of meander-shaped ferromagnetic material constituting a pair of potentiometers. Since a pair of potentiometers constituted from the respective current path portions $102A_1$, $102B_1$. $102A_2$, $102B_2$ of said reluctance element 121 have high impedance, they can be applied to said sixth or seventh embodiment to realize a high sensitivity magnetic sensor device which can be most suitable for a fine displacement sensor and the like.

The meander-shaped current path portions $102A_1$, $102B_1$, $102A_2$, $102B_2$ can be produced simply and with very accurate shape by the evaporation of ferromagnetic material film and a hot etching process. Further, the magneto-resistive element 121 having the respective current path portions 102A, $102B_1$, $102A_2$, $102B_2$ formed by ferromagnetic material provides a characteristic with a small temperature coefficient and excellent linearity of resistance value compared with a semiconductor magneto-resistive element. Accordingly the magneto-resistive element 121, when applied to said sixth or seventh embodiment, can constitute a magnetic sensor device which is most suitable for fine displacement sensors with high sensitivity, linearity of output, excellent temperature characteristic, few unbalanced voltages and no necessity of compensatory circuits.

The magneto-resistive element 301 shown in Fig. 37 has a meander-shaped current path portion 302 constituted from a plurality of strips 302_a, $302_b \ldots 302_n$ having respective lengths U_a, $U_b \ldots U_n$ set according to a function f(u) shown by alternate long and two short dashed lines in the Figure, and may be applied to said first, second or third embodiment.

In Fig. 37 showing the first embodiment to which said magneto-resistive element 301 is applied, the current path portion 302 of magneto-resistive element 301 is meander-shaped and formed by the respective strips 302_a, $302_b \ldots 302_n$ whose lengths increase gradually. The current path portion 302 made of ferromagnetic material having a magneto-resistive characteristic is provided on both ends with respective power supply terminals 3a, 3b and supplied with bias current I from a constant current source 5 connected to said power supply terminals.

The magneto-resistive element 301 has sufficient intensity to magnetically saturate ferromagnetic material forming the current path portion 302 and is disposed opposed to the magnetizing material 4 for producing the first and second magnetic fields H_1, H_2 having different directions and the boundary line l_o crossing the longitudinal direction of respective strips, 302a, 302b . . . 302n of said current path portion 302. The region A_1 of said first magnetic field H_1 is shown by the broken line and the region A_2 of said second magnetic field H_2 shown by the dot-and-dash line in the Figure. Also, said magneto-resistive element 301 and magnetizing material 4 are provided to be relatively displaceable in the direction orthogonal to said boundary line l_o (direction of arrow $X-\bar{X}$ in the drawing, and the location of the boundary line l_o crossing said current path portion 302 is moved by the movement of said magnetizing material 4.

In such embodiment, magnetism-electricity conversion corresponding to the displacement of the boundary line l_o crossing said current path portion 302 is carried out according to the characteristic of function f(u) (shown by the function curve made up of alternative long and two short dashed lines in the drawing) given by the change in the longitudinal length of said strips 302a, 302b, . . . 302n to provide output voltage Vu across terminals 3a, 3b. When said function f(u) is set linearly, a linear characteristic of magnetism-electricity conversion is obtained, and when set curvedly, a curved one is obtained to permit any magnetism-electricity conversion characteristic corresponding to the function f(u) to be realized.

CLAIMS

1. A magnetic sensor device comprising:–

a magneto-resistive element having at least one current path portion formed of a ferromagnetic material to serve as a magnetism sensing region;

a power source for supplying a bias current to the or each current path portion; and

a magnetizing means for providing magnetic fields of different directions to respective regions obtained by dividing said magnetism sensing region into at least two regions, the arrangement such that the ratio of the extent of one region to that of another region to which said respective magnetic fields are to be imparted is variable according to the relative displacement between said magneto-resistive element and said magnetizing means.

2. A magnetic sensor device as defined in claim 1, wherein the magnetizing means is arranged to produce magnetic fields in different directions in a first region and a second region, respectively, partitioned by a boundary line across the magnetism sensing region in said magneto-resistive element across a direction of relative displacement between said magneto-resistive element and said magnetizing means.

3. A magnetic sensor device as defined in claim 2, wherein the magnetizing means has at least two magnetized regions respectively consisting of magnetized strips arranged in parallel and adjacent to each other and magnetized with opposite polarities, the direction of arrangement of parallel magnetized strips in one magnetized region being different from that of the parallel magnetized strips in the other magnetized region, and respective magnetized regions being arranged in side-by-side relation to each other with the boundary line interposed therebetween.

4. A magnetic sensor device as defined in claim 1, wherein the magnetism sensing region is divided into a first region and a second region in a direction orthogonal to the direction of relative displacement between said magneto-resistive element and said magnetizing means by a third region of a given width which crosses the magnetism sensing region in said magneto-resistive element; and said magnetizing means is arranged to produce a magnetic field of different direction in respective regions.

5. A magnetic sensor device as defined in claim 1, wherein said magnetizing means comprises; a biasing magnetizing means for producing a bias magnetic field for magnetically saturating the ferromagnetic material entirely in one direction alone, said ferromaggnetic material forming the current path portion serving as the magnetism sensing region in said magneto-resistive element; and

a signal magnetizing means for imparting a signal magnetizing field locally to the magnetism sensing region in said magneto-resistive element, said signal magnetizing field being different in direction from said bias magnetic field; said signal magnetizing means being free to displace relative to said magneto-resistive element.

6. A magnetic sensor device as defined in claim 1, wherein said magneto-resistive element comprises; a first current path portion; a second current path portion, which is connected in series relation with the first current path portion across current supply terminals; and an output terminal provided at the mid-point of the connection between current path portions.

7. A magnetic sensor device as defined in claim 4, wherein there is provided a magneto-resistive element having a first current path portion and a second current path portion, both of which are connected in series relation across current supply terminals, and an output terminal provided at the mid-point of the connection between respective current path portions; and

the magnetizing means is disposed in opposed relation to said magneto-resistive element in a manner such that a boundary line existing in respective regions in the magnetic fields of different directions extends across said first current path portion, and another boundary line extends across said second current path portion.

8. A magnetic sensor device as defined in claim 5, wherein there is provided a magneto-resistive element which comprises; first and second current path portions, which are connected in series across current supply terminals; and an output terminal provided at the mid-point of the connection between respective current path portions; and,

the signal magnetizing means is disposed in opposed relation to said magneto-resistive element, so as to provide a signal magnetic field to a region of a given width extends between said first current path portion and said second current path portion.

9. A magnetic sensor device as defined in claim 1, wherein the magneto-resistive element comprises; first and second current path portions, which are connected in series to each other between the current supply terminals; third and fourth path portions which are connected in series to each other across the current supply terminals; and first and second output terminals, which are provided at the mid-points of the connections between said current path portions, respectively.

10. A magnetic sensor device as defined in claim 2, wherein the magneto-resistive element comprises;

first and second current path portions, which are connected in series relation to each other across the current supply terminals; and,

third and fourth current path portions which are connected in series to each other across the current supply terminals; said respective current path portions being arranged in parallel to each other; and,

first and second output terminals provided at the mid points of the connection between respective current path portions.

11. A magnetic sensor device as defined in claim 4, wherein there is provided a magneto-resistive element which comprises; first and second current path portions, which are connected in series between the current supply terminals; third and fourth current path portions which are connected in series between the current supply terminals; and first and second output terminals which are provided at the mid points of the connection between respective current path portions; and

the magnetizing means is disposed in opposed relation to said magneto-resistive element in a manner that one boundary line existing in respective regions of the magnetic fields of different directions extends across said first current path portion and said third current path portion, and another boundary line extends across said second current path portion and said fourth current path portion.

12. A magnetic sensor device as defined in claim 5, wherein there is provided a magneto-resistive element which comprises; first and second current path portions which are connected in series across the current supply terminals; third and fourth current path portions which are connected in series between the current supply terminals; and first and second output terminals which are provided at the mid points of the connection across respective current path portions; and

the signal magnetizing means is disposed in opposed relation to said magneto-resistive element so as to provide a signal magnetic field to a region of a given width which extends between respective current path portions.

13. A magnetic sensor device as defined in any one of claims 2, 3, 4 and 5, wherein there is provided a constant current source for supplying a bias current to the current path portions in the magneto-resistive element.

14. A magnetic sensor device as defined in any one of claims 6, 7, 8, 9, 10, 11 and 12, wherein there is provided a constant voltage source for supplying a bias current to respective current path portions in the magneto-resistive element.

15. A magnetic sensor device as defined in any one of claims 2, 3 and 10, wherein a direction of a first magnetic field and a direction of a second magnetic field are such that one is in parallel to the direction of relative displacement between the magnetizing means and the magneto-resistive element, and the other crosses said direction of relative displacement.

16. A magnetic sensor device as defined in any one of claims 5, 8 and 12, wherein the direction of the signal field and that of the bias magnetic field are such that one is in parallel to the direction of relative displacement between the magneto-resistive element and the signal magnetizing material, and the other crosses the direction of relative displacement between the element and the material.

17. A magnetic sensor device as defined in any one of claims 1 through 12, the or each respective current path portion in the magneto-resistive element is formed of a ferromagnetic material and consists of plural strips disposed in parallel to and connected in series to each other, forming a meandering pattern.

18. A magnetic sensor device as defined in claim 17, wherein the relative displacement of the magnetizing means material to the magneto-resistive element, in use, takes place in a direction parallel to the length of the plural strips in the or each current path portion.

19. A magnetic sensor device as defined in claim 17, wherein, in use, the relative displacement between the magneto-resistive element and the magnetizing means takes place in a direction to cross the length of the plural strips of respective current path portion.

20. A magnetic sensor device as defined in claim 2, wherein there is provided a magneto-resistive element which comprises; first and second current path portions which are made of a ferromagnetic material and each of which consists of plural strips, the plural strips of the first current path portion being arranged in directions which cross the directions of the plural strips of the second current path portion.

21. A magnetic sensor device as defined in any one of claims 6, 7 and 8, wherein there is provided a magneto-resistive element having a first current path portion made of a ferromagnetic material and having plural strips arranged in a direction to cross plural strips of a second current path portion, to form meandering pattern.

22. A magnetic sensor device as defined in claim 17, wherein respective strips in respective current path portion are arranged in parallel to each other and at a given angle with respect to

the direction of relative displacement between the magneto-resistive element and the magnetizing means.

23. A magnetic sensor device as defined in any one of claims 6 and 9, wherein there are provided:

a magneto-resistive element made of a ferromagnetic material and having plural strips arranged in parallel to and connected in series to each other in respective current path portions, thereby forming a meandering pattern, said magneto-resistive element having a first region and a second region partitioned by a third region of a given width which crosses the magnetism sensing region of said magneto-resistive element in a direction to cross the direction of relative displacement between the magneto-resistive element and the signal magnetizing means;

the signal magnetizing means producing signal magnetic fields mutually inverted in direction in said first region, said second region and said third region respectively; and

a bias magnetizing means for producing bias magnetic fields different in direction from that of said signal magnetic field.

24. A magnetic sensor device as defined in claim 23, wherein respective strips constituting respective current path portions are arranged at an inclination of 45° with respect to the direction of relative displacement between the magneto-resistive element and the signal magnetizing means; and the direction of the signal magnetic field and that of the bias magnetic field are such that one crosses at a right angle the direction of relative displacement between the magneto-resistive element and the signal magnetizing means, and the other is in parallel to said direction of relative displacement.

25. A magnetic sensor device as defined in claim 17, wherein the lengths of respective strips constituting respective current path portion in the magneto-resistive element are determined in accordance with a desired function of their positions.

26. A magnetic sensor constructed and arranged substantially as hereinbefore described with reference to and and as illustrated in the accompanying drawings.

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