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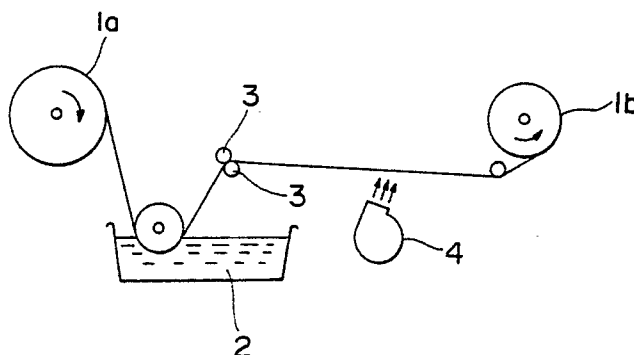
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(54) Magnetic ribbon and magnetic core.

(57) Disclosed are a magnetic ribbon on at least one surface of which fine particles formed of nonmagnetic inorganic substance having insulating properties are attached and a magnetic core around which this magnetic ribbon is wound or on which it is laminated. The fine particles serve as a spacer to form a layer of air between adjacent layers of the magnetic ribbon.

FIG.7



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## MAGNETIC RIBBON AND MAGNETIC CORE

The present invention relates to a magnetic ribbon and a magnetic core formed by using said magnetic ribbon.

If a magnetic core is formed by winding or laminating a magnetic ribbon, and if insulation between layers of the ribbon is poor, an eddy current flowing across the ribbon layers occurs and an increase in eddy current losses results in an increase in overall core losses (magnetic losses). This tendency is particularly noticeable in the case of high frequencies. In addition, the frequency characteristics of permeability is poor, and it is impossible to expect any advantageous use at 100 kHz or more.

Accordingly, in order to improve insulation between ribbon layers, an insulating layer formed of a nonmagnetic material is conventionally provided between the ribbon layers, and a uniform insulating film is formed on the ribbon surface as one means thereof, so as to solve the aforementioned problem.

In cases where an amorphous magnetic ribbon is processed as a magnetic ribbon, annealing is usually carried out at 400°C or thereabouts. However, if such annealing is carried out, because of a difference in the coefficient of linear expansion, i.e., since the coefficient of linear expansion of the insulating film is greater than that of the amorphous ribbon, compressive stress occurs in the ribbon, and magnetic characteristics deteriorate due to the adverse effect of magnetostriction.

In addition, there is another problem in that materials of such insulating films capable of withstanding annealing at 400°C or thereabouts are limited. Furthermore, if a magnetic core is formed by providing an insulating film, the filling factor (space factor) declines, which disadvantageously causes the magnetic core to become large in size.

Thus, as described above, when producing a magnetic core by using a magnetic ribbon, an insulating film is generally interposed between ribbon layers, and the greatest matter of concern to those skilled in the art lies in finding an insulating material having an excellent insulating performance.

In accordance with the present invention, there is provided a magnetic ribbon on at least one side of which particles, preferably fine particles, formed of a nonmagnetic, preferably inorganic, substance having insulating properties are attached.

The invention also provides a magnetic core having such a ribbon wound therearound or laminated thereon.

The particles may be attached so as to secure a layer of air so that in the absence of a conventional insulating film, the air present between the

layers can serve as an insulating layer and prevent an eddy current, and the space factor can be made as large as possible.

That is, particles formed of an inorganic substance are attached on at least one surface of the magnetic ribbon, so that if the magnetic ribbon is wound or laminated to form a magnetic core, the particles serve as a spacer, thereby forming a layer of air between adjacent layers of the ribbon.

However, the particles may be attached uniformly and densely on at least one surface of the ribbon. In this case, rather than particularly securing a layer of air, the particles themselves function as an insulating layer. Nevertheless, in this case as well, it is possible to obtain the same effect as that obtained by securing a layer of air by means of the particles. Accordingly, the present invention includes both the case where the particles are attached coarsely and the case where they are attached densely.

The particles may be applied by any suitable method for example by passing the magnetic ribbon through a suspension containing the particles. Where it is intended that the particles should act as a spacer trapping a layer of air between layers or windings of a core the proportion of particles in the suspension may be chosen to be suitably low. For example where the particles are antimony pentoxide suspended in toluene they may form 1% to 10%, preferably 2% to 5%, eg about 3%, by weight of the suspension.

Where it is intended that the particles should be attached more densely so as to act as the insulation then a higher proportion may be used in the suspension. For example, with the same materials as above, above 20% by weight, for example 20% to 50%, e.g. about 30% by weight.

Thus with the present invention a magnetic ribbon and a magnetic core can be provided having excellent magnetic characteristics while securing insulating properties between ribbon layers with the space factor reduced.

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

Figs. 1 to 3 are graphs illustrating magnetic characteristics in accordance with a first embodiment of the present invention, in which

Fig. 1 illustrates B-H characteristics;

Fig. 2 illustrates the frequency characteristics of core loss; and

Fig. 3 illustrates the frequency characteristics of permeability;

Figs. 4 to 6 are graphs illustrating the magnetic characteristics in accordance with a second embodiment of the present invention, in which

Fig. 4 illustrates B-H characteristics;

Fig. 5 illustrates the frequency characteristics of core loss; and

Fig. 6 illustrates the frequency characteristics of permeability; and

Fig. 7 illustrates the outline of apparatus for attaching fine articles; and

Fig. 8 is a diagram schematically illustrating means for producing a toroidal type magnetic core.

Referring now to the accompanying drawings, a description will be given of the preferred embodiments of the present invention.

The magnetic ribbon referred to in the present invention is a thin magnetic strip, and, as magnetic materials, it is possible to cite the following: ferromagnetic elements such as Fe, Co, and Ni among transition metals, alloys of ferromagnetic elements, alloys of ferromagnetic elements and nonferromagnetic elements which are added to improve characteristics, ferrite, permalloy, amorphous alloys, etc. As amorphous alloys, it is possible to cite Fe-based alloys such as Fe-B, Fe-B-C, Fe-B-Si, Fe-B-Si-C, Fe-B-Si-Cr, Fe-Co-B-Si, and Fe-Ni-Mo-B, Co-based alloys such as Co-B, Co-Fe-Si-B, Co-Fe-Ni-Mo-B-Si, Co-Fe-Ni-B-Si, Co-Fe-Mn-B-Si, Co-Fe-Mn-Ni, Co-Mn-Ni-B-Si, and Co-Fe-Mn-Ni-B, and other similar alloys.

The conditions of inorganic fine particles that are attached to such a magnetic ribbon are that it is nonmagnetic, and that it has insulating properties. If the fine particles are magnetic and conductive, an adverse effect is exerted on magnetic characteristics, and an eddy current is liable to flow.

As inorganic substances used in the present invention, it is possible to cite the following: (1) inorganic substances which are stable in a natural condition, including glass (sodium silicate), mica (aluminosilicate alkali salt and phyllosilicate alkali salt), silicon carbide, calcium sulfate semi-water salt, potassium carbonate, magnesium carbonate, calcium carbonate, barium sulfate, and the like; (2) metal oxides such as aluminum oxide, boron oxide, magnesium oxide, silicon dioxide, tin dioxide, zinc oxide, zirconium dioxide, antimony pentoxide, and the like; and (3) ceramics formed of the materials cited in (2) above and double oxides such as perovskite, silicate glass, phosphate, titanate acid salt, niobium, tantalum, and tungstate; ceramics formed singly or in a combination by using such ceramic materials as nitrides, including aluminum nitride, a sintered body of aluminum oxide and

nitride, boron nitride, boron nitride magnesium, boron nitride complexes, silicon nitride, silicon nitride lanthanum, and SIALON, carbides, including boron carbide, silicon carbide, boron carbide aluminum, and titanium carbide, and borides, including titanium diboride, calcium hexaboride, and lanthanum hexaboride. Among these substances, antimony pentoxide is preferably used.

As for the size of the fine particles of the inorganic substance, if consideration is paid to the fact that the fine particles are attached to the ribbon uniformly so as to form an insulating layer, the size of the fine particles may be small. However, if the particle size is made too small, it constitutes a factor making manufacture difficult. Meanwhile, if the particle size is too large, when the magnetic core is formed by a ribbon, the gap between the adjacent layers of the ribbon becomes too large, so that the space factor of the magnetic material becomes small. For this reason, it is preferred that the size of the fine particles is set in the range of 10 nm to 2  $\mu$ m.

In addition, as for the amount of the fine particles attached, the fine particles may preferably be attached in such a manner that they are attached by  $10^{-7}$  cm<sup>3</sup> to  $2 \times 10^{-4}$  cm<sup>3</sup>, more preferably  $3 \times 10^{-6}$  cm<sup>3</sup> -  $10^{-5}$  cm<sup>3</sup>, per unit area (1 cm<sup>2</sup>). If this amount attached is calculated into the weight of fine particles per unit area, although its value changes depending on the specific weight of the material of the fine particles, in the case of antimony pentoxide, the weight is  $3.8 \times 10^{-7}$  g/cm<sup>2</sup> -  $7.6 \times 10^{-4}$  g/cm<sup>2</sup>, preferably  $1.1 \times 10^{-5}$  g/cm<sup>2</sup> -  $3.8 \times 10^{-5}$  g/cm<sup>2</sup>.

Means for attaching the fine particles is so arranged that these fine particles are dispersed in water or a volatile organic solvent such as toluene, and, after this solution is applied to the ribbon surface, force or natural drying is carried out, thereby allowing the fine particles to be attached to the ribbon. The concentration of this solution determines the amount of fine particles to be attached to the ribbon. In other words, in the case of antimony pentoxide, this inorganic substance may be dispersed in toluene in a colloidal state at a rate of from 0.1 to 30 wt% with respect to toluene. 3 wt% or thereabouts in this range is also effective, a decline in the space factor is practically nil, and the magnetic characteristics do not deteriorate. The thickness of the film of the solution applied is preferably 10  $\mu$ m or less in determining the aforementioned amount of fine particles to be attached. In addition, a drying furnace may be used for evaporation of the solvent depending on the solvent, and drying may be carried out at 100°C or above.

With respect to the magnetic ribbon, or an amorphous ribbon, in particular, annealing may be

carried out for 0.5 - 5 hours at the temperature of 300 - 500° C in an inert gas atmosphere such as nitrogen so as to eliminate strain, as required. This annealing may be effected after the ribbon is wound or laminated into a magnetic core, or may be effected in the state of the ribbon. In particular, when annealing is effected at a temperature 10 to 50° C higher than the Curie point, a magnetic core exhibiting excellent characteristics with respect to high frequencies can be obtained. Incidentally, annealing may be effected in a magnetic field or in a nonmagnetic field.

In addition, when the amorphous magnetic core with the ribbon wound therearound or laminated thereon is annealed since the fine particles disposed between adjacent ribbon layers are powders, the magnetic core is not subjected to linear expansion. The fine particles rather exhibit the action of absorbing the stress accompanying the shrinkage of the amorphous ribbon.

On the basis of the foregoing, a description will now be given of a method of producing a magnetic core in accordance with the present invention.

First, a magnetic ribbon and a solution containing fine particles are prepared. The solution containing the fine particles is applied to at least one surface of the magnetic ribbon by any of the various methods of application, and the solvent is allowed to dry. The resultant magnetic ribbon with the fine particles attached thereto is wound under tension, thereby obtaining a toroidal-type magnetic core. Finally, annealing for eliminating strain is carried out, as necessary. Incidentally, tension applied at the time of winding is preferably 0.05 to 2 kg.

Meanwhile, when a laminated type magnetic core is produced, the ribbon with fine particles attached thereto is cut into a predetermined configuration, and the cut pieces are laminated so as to form the magnetic core. Annealing which is carried out as necessary may be effected prior to the lamination or after the magnetic core has been formed subsequent to the lamination.

Examples of the present invention will be described hereafter.

By using the apparatus shown in Fig. 7, an amorphous ribbon 1a (2605S-2, Fe<sub>78</sub>-B<sub>13</sub>-Si<sub>9</sub>, 10 mm width) made by Allied Corp. is fed forward into a colloidal solution 2 of antimony pentoxide. When the amorphous ribbon 1a is lifted up, the amorphous ribbon 1a is clamped by a pair of bar coaters 3 so as to allow excess solution to drop. Then, while the ribbon 1a is being dried with hot air by means of a hot air drier 4, the ribbon 1a was taken up. As for the colloidal solution 2 of antimony pentoxide, toluene was used as the solvent, and 3 wt% of antimony was dispersed with respect to toluene 97 wt%.

Subsequently, as shown in Fig. 8, the ribbon

1b with the particles attached thereto was fed forward via a roller 5, and was wound under tension in a final stage, thereby forming an amorphous magnetic core 6. A plurality of magnetic cores having the same dimensions were then formed, and were subjected to annealing for two hours at 435° C in a nitrogen atmosphere.

With respect to the magnetic cores thus obtained, measurements were made of the B-H characteristics, frequency characteristics of core loss, and frequency characteristics of permeability. As for the B-H characteristics, measurements were made of two cases: one in which a magnetic field of 10 oersted (Oe), and the other in which a magnetic field of 1 oersted (Oe) was applied.

In addition, a colloidal solution in which 30 wt% of antimony pentoxide was dispersed with respect to 70 wt% of toluene was applied to the ribbon 1a, and measurements were similarly made. The detailed conditions in the respective examples were as follows:

#### (1) Example 1 (3 wt% solution)

##### (a) Magnetic core:

a toroidal core with the aforementioned ribbon wound therearound  
 Inside diameter: 23.00 mm  
 Outside diameter: 37.00 mm  
 Height: 10.00 mm  
 Mass: 42.00 g  
 Density of the material: 7.18 g/m<sup>3</sup>  
 Volume: 5.850 × 10<sup>-6</sup> (m<sup>3</sup>)  
 Effective sectional area: 6.207 × 10<sup>-5</sup> (m<sup>2</sup>)  
 Mean magnetic path length: 9.425 × 10<sup>-2</sup> (m)  
 Space factor: 88.67% (ratio of the volume of the ribbon to the total volume)  
 Tension during the magnetic ribbon winding: 0.8 kg

##### (b) Colloidal solution applied

Organic solvent: toluene, 100 wt%  
 Fine particles: antimony pentoxide, 3 wt%

##### (c) Results

\* B-H characteristics are shown in Fig. 1.  
 \* Frequency characteristics of core loss are shown in Fig. 2.  
 The number of turns of the primary winding around the core was 5, while the number of turns of the secondary winding was 10.  
 \* Frequency characteristics of permeability are shown in Fig. 3.  
 The number of turns of the primary winding around

the core was 10.

Measured magnetic field: 5 mOe

Measured current: 2.65173 mA

## (2) Example 2 (30wt% solution)

### (a) Magnetic core:

a toroidal core with the aforementioned ribbon wound therearound

Inside diameter: 23.00 mm

Outside diameter: 37.00 mm

Height: 10.00 mm

Mass: 25.57 g

Density of the material: 7.18 g/m<sup>3</sup>

Volume: 3.561 x 10<sup>-6</sup> (m<sup>3</sup>)

Effective sectional area: 3.779 x 10<sup>-5</sup> (m<sup>2</sup>)

Mean magnetic path length: 9.425 x 10<sup>-2</sup> (m)

Space factor: 53.98%

Tension during the magnetic ribbon winding: 0.8 kg

### (b) Colloidal solution applied

Organic solvent: toluene, 70 wt%

Fine particles: antimony pentoxide, 30 wt%

### (c) Results

\* B-H characteristics are shown in Fig. 4.

\* Frequency characteristics of core loss are shown in Fig. 5.

The number of turns of the primary winding around the core was 5, while the number of turns of the secondary winding was 10.

\* Frequency characteristics of permeability are shown in Fig. 6.

The number of turns of the primary winding around the core was 10.

Measured magnetic field: 5 mOe

Measured current: 2.65173 mA

From the foregoing results, it can be appreciated that the magnetic cores of the Examples display a hysteresis which is closer to a linear configuration, and that the core loss is low as a whole, and a rise in the high-frequency component can be reduced to a low level. A substantially fixed permeability was obtained up to 200 kHz.

As described above, in accordance with the present invention, since the above-described arrangement is adopted, it is possible to improve the magnetic characteristics at a frequency higher than 10 kHz, and the space factor can be made as large as possible, thereby making contributions to making the magnetic core compact.

## Claims

1. A magnetic ribbon on at least one surface of which particles formed of a nonmagnetic substance having insulating properties are attached.

2. A magnetic ribbon according to claim 1, wherein said magnetic ribbon is formed of an amorphous metal.

3. A magnetic ribbon according to claim 1 or 2 wherein the particles are formed of an inorganic substance.

4. A magnetic ribbon according to claim 1, 2 or 3, wherein said non-magnetic substance is a metal oxide, and the size of said particles is 10nm to 2μm.

5. A magnetic ribbon according to any of claims 1, 2, 3 or 4, wherein said magnetic ribbon is subjected to annealing for 0.5 - 5 hours at a temperature of 300 - 500 °C in an inert gas atmosphere.

6. A magnetic ribbon according to any one of the preceding claims wherein the particles are attached so as to secure a layer of air.

7. A magnetic ribbon are to any one of the preceding claims wherein the particles are attached at such a surface density to act as spacers so that when the ribbon is wound or laminated with other ribbons, air and/or the particles electrically insulate the layers from each other.

8. A magnetic core around which said magnetic ribbon according to any of claims 1 to 7 is wound or on which said magnetic ribbon is laminated.

9. A magnetic core around which said magnetic ribbon according to any of claims 1 to 4 is wound or on which said magnetic ribbon is laminated, and which is subsequently subjected to annealing for 0.5 - 5 hours at a temperature of 300 - 500 °C in an inert gas atmosphere.

10. An electrical or electronic device including a magnetic core according to claim 9.



FIG.1

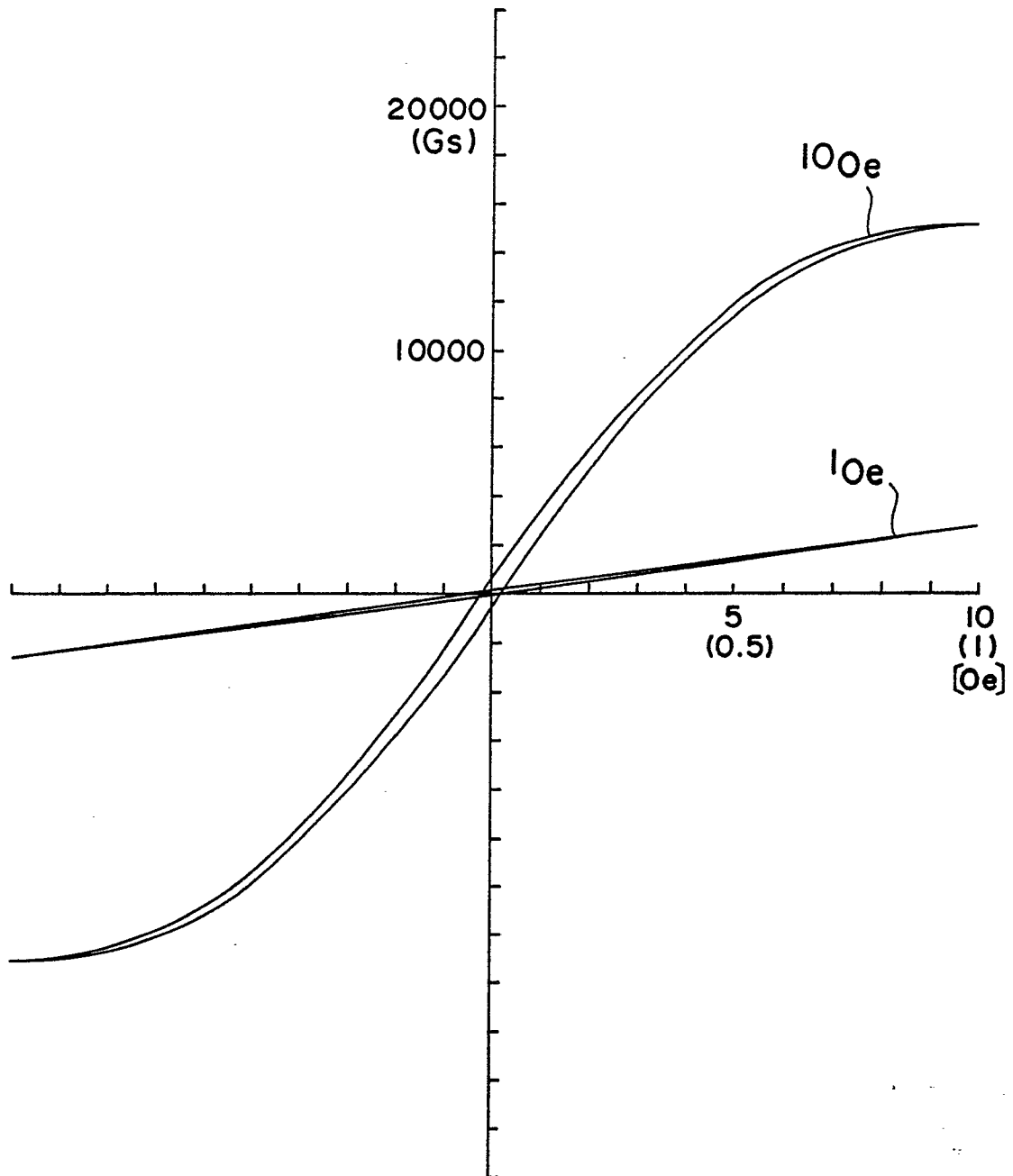


FIG.2

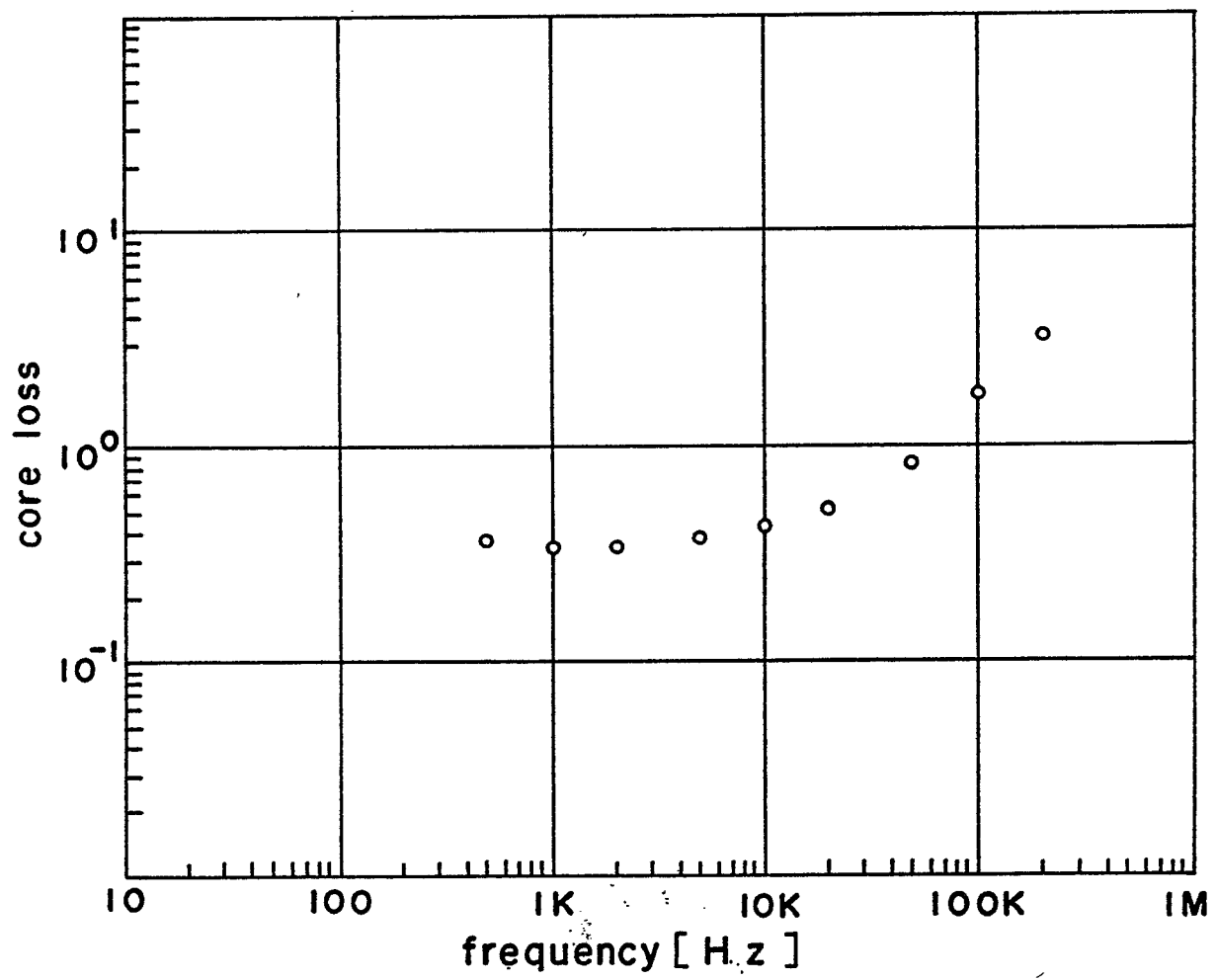


FIG.3

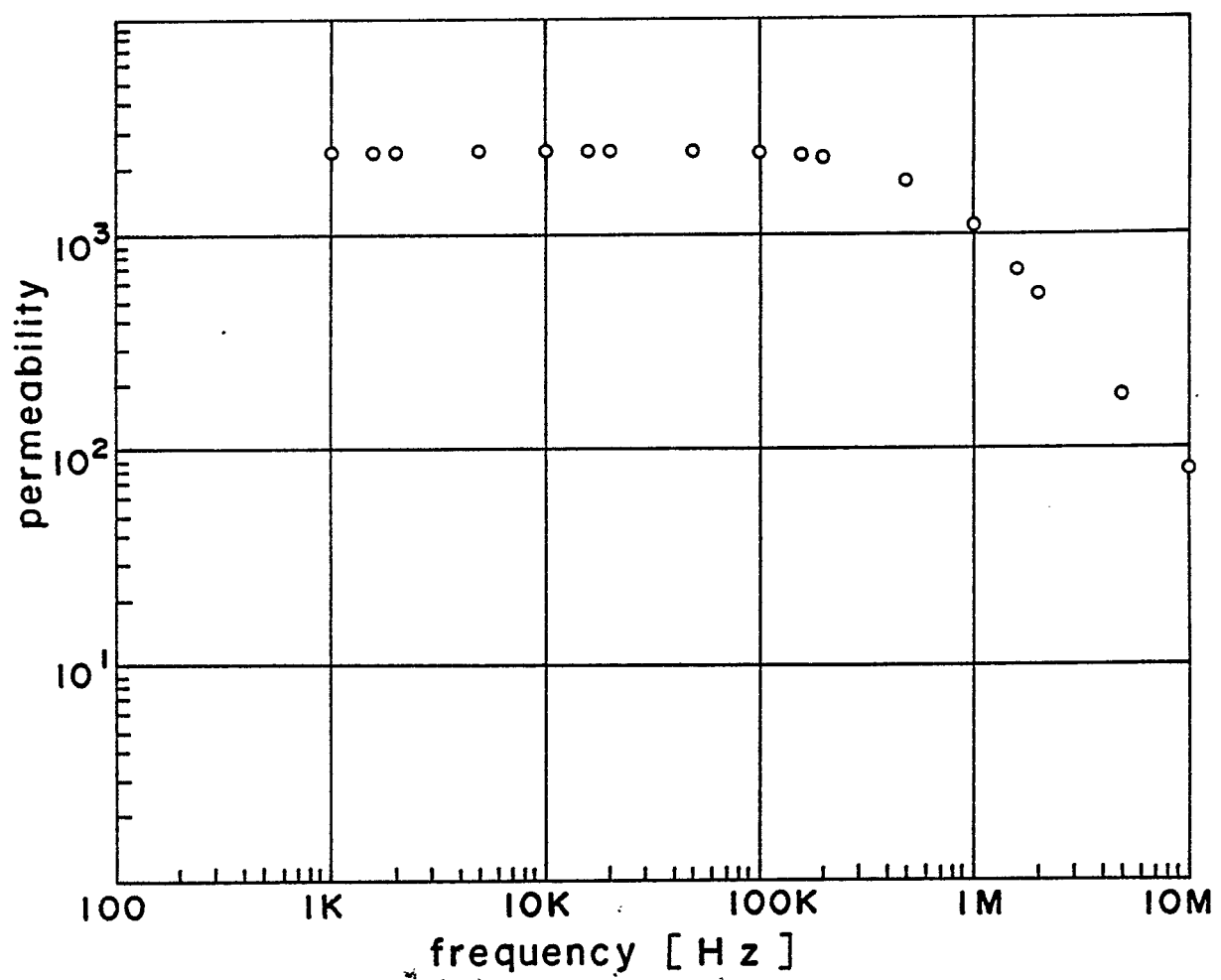
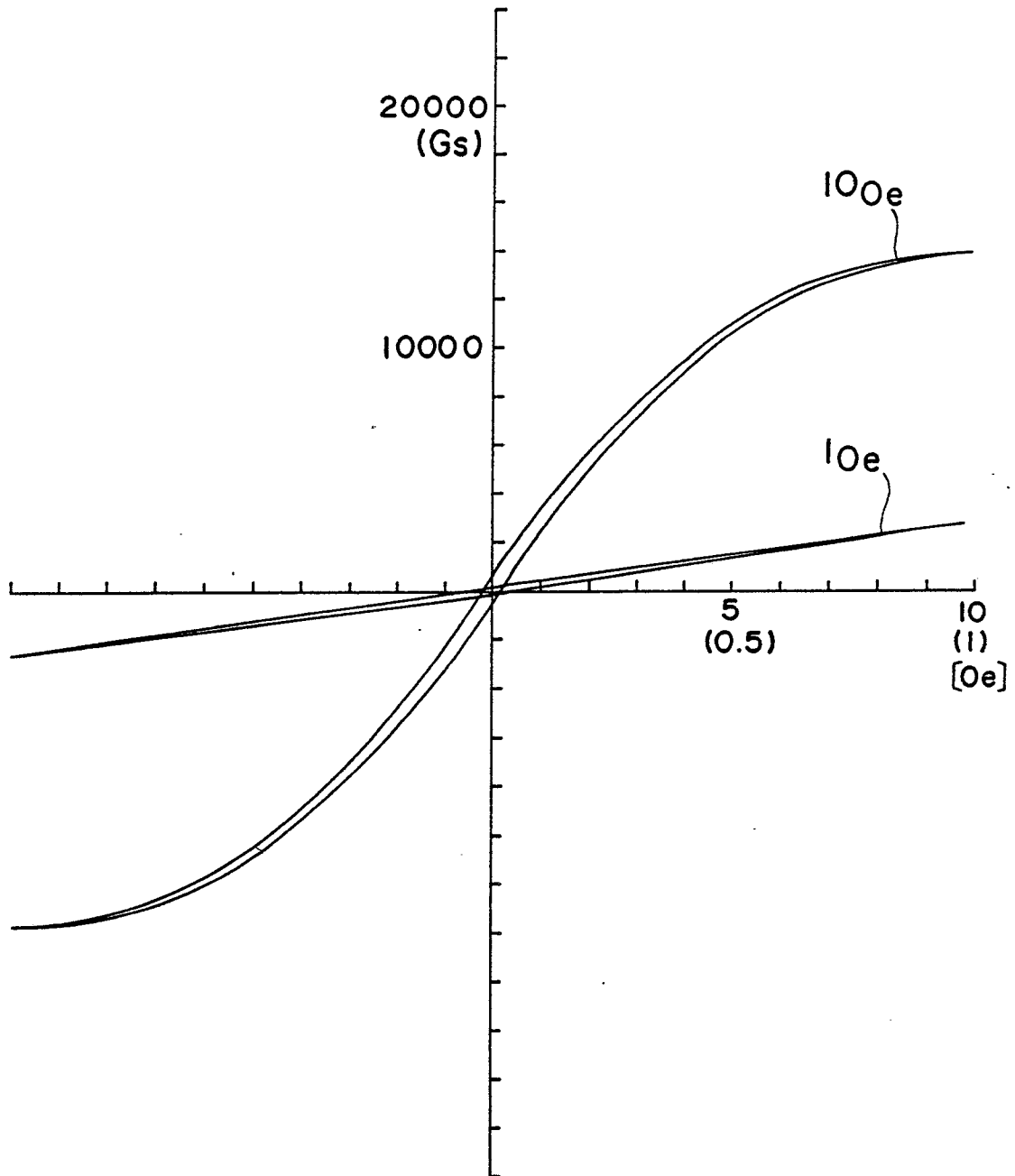






FIG.4



30 20 10 0 10 20 30

FIG.5

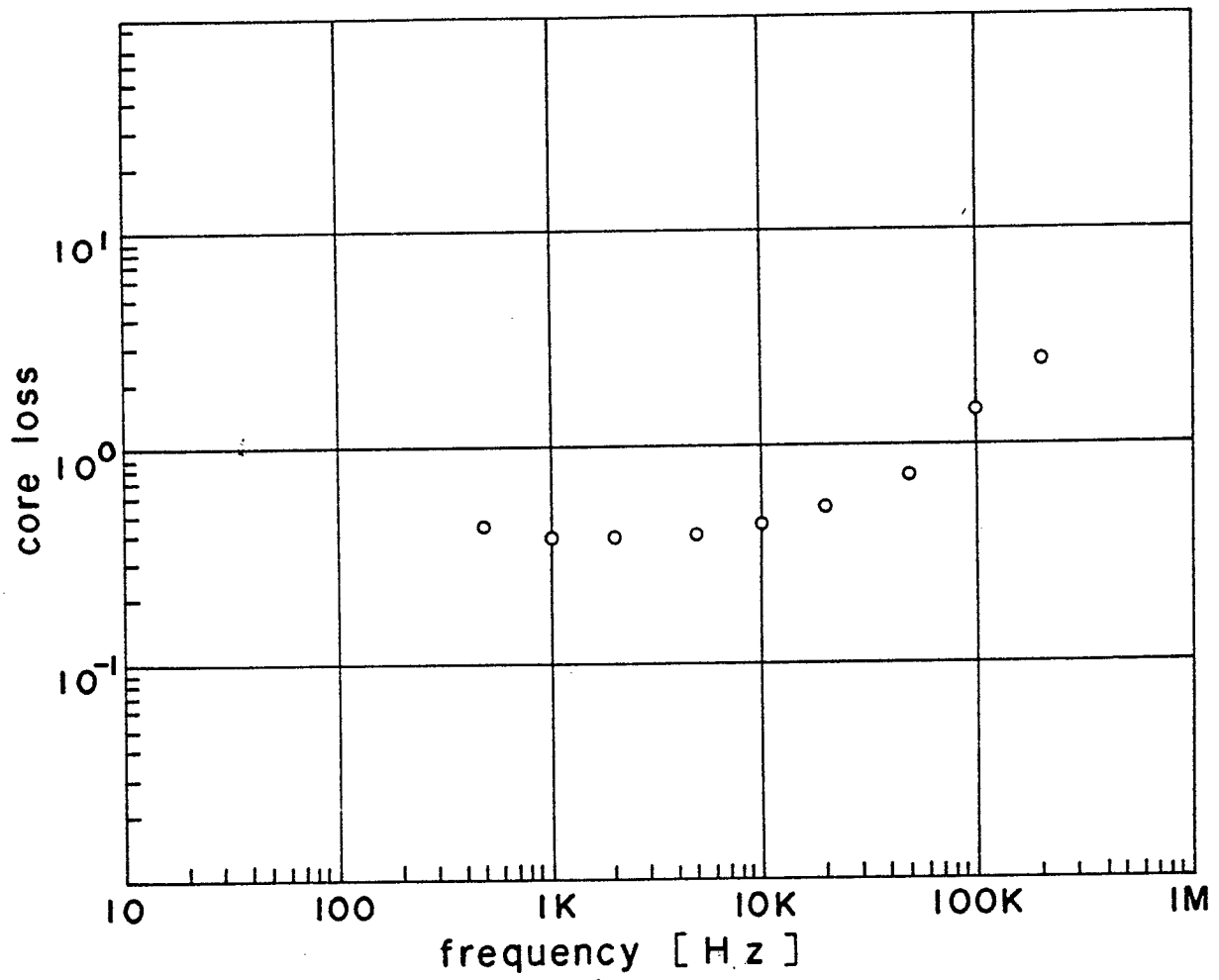




FIG.6

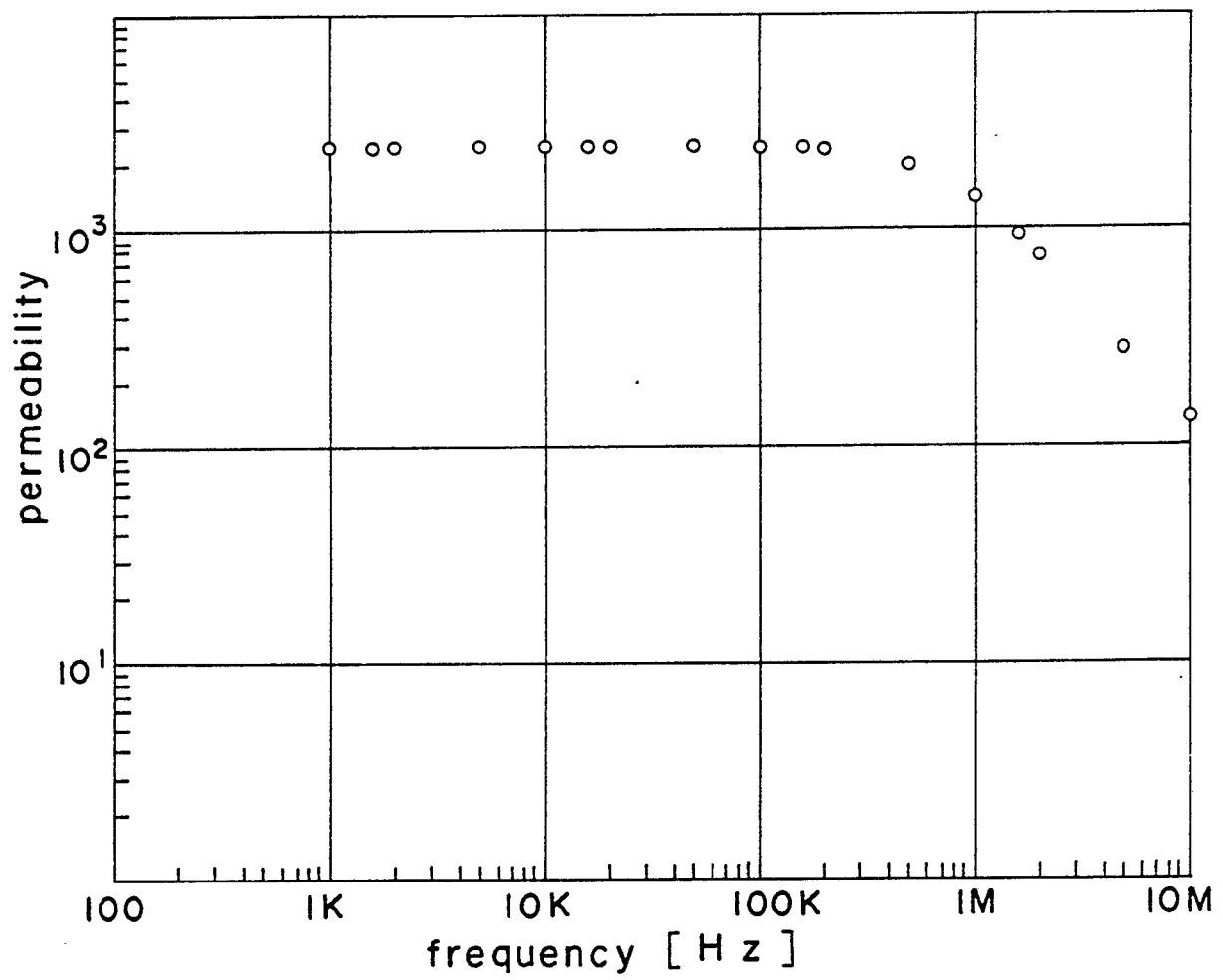


FIG.7

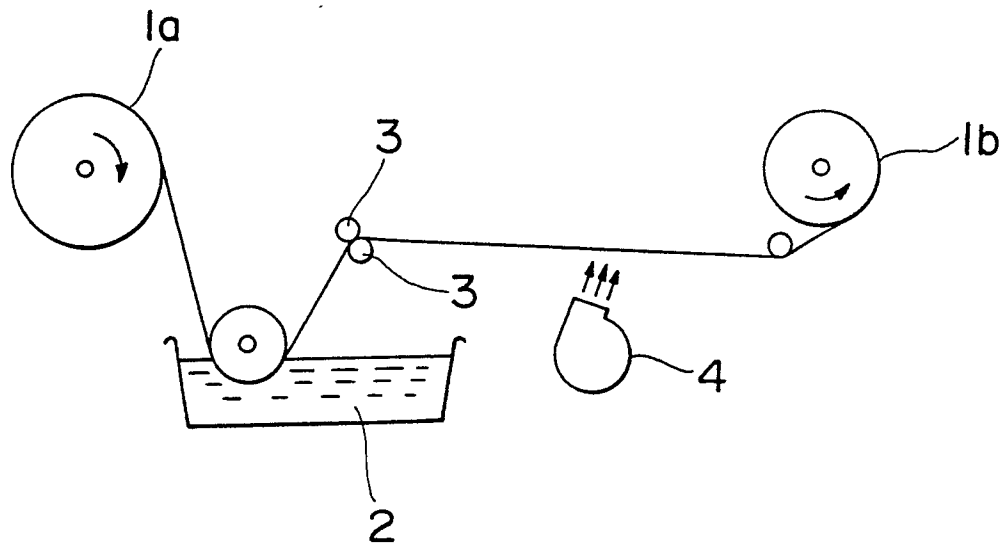


FIG.8

