

May 19, 1936.

F. PREISACH

2,041,147

SIGNALING SYSTEM

Filed Sept. 13, 1932

2 Sheets-Sheet 1

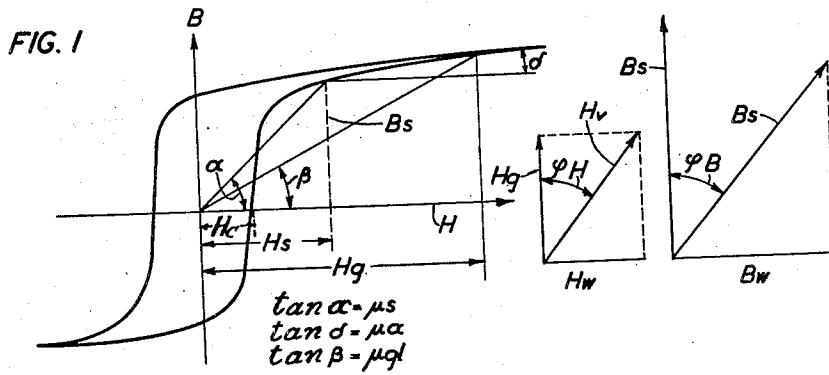


FIG. 3

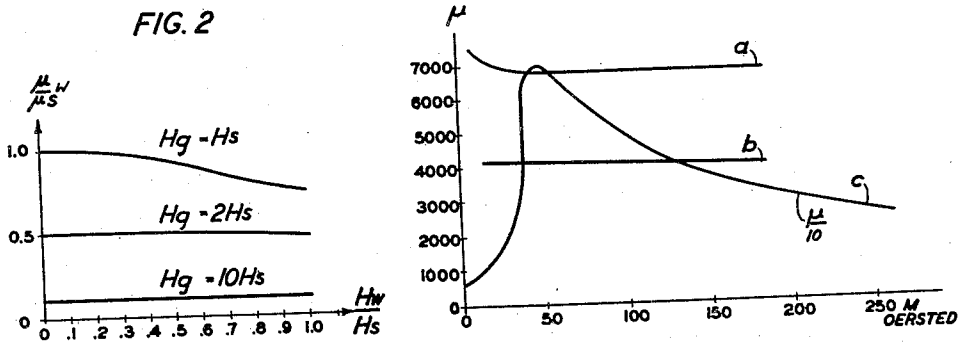
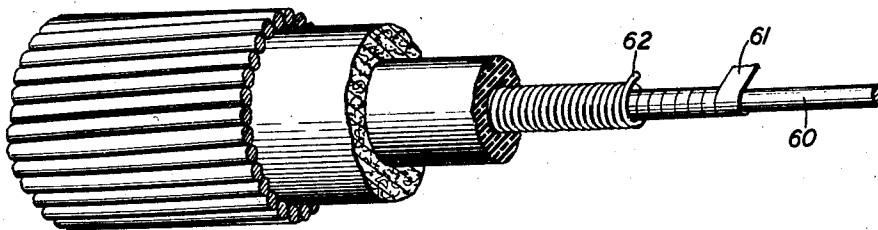


FIG. 8



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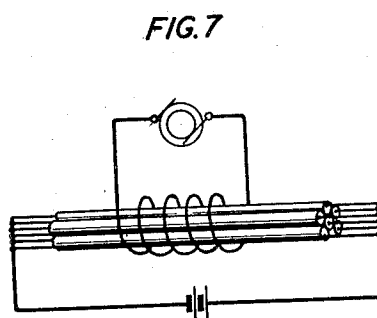
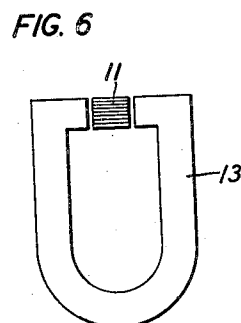
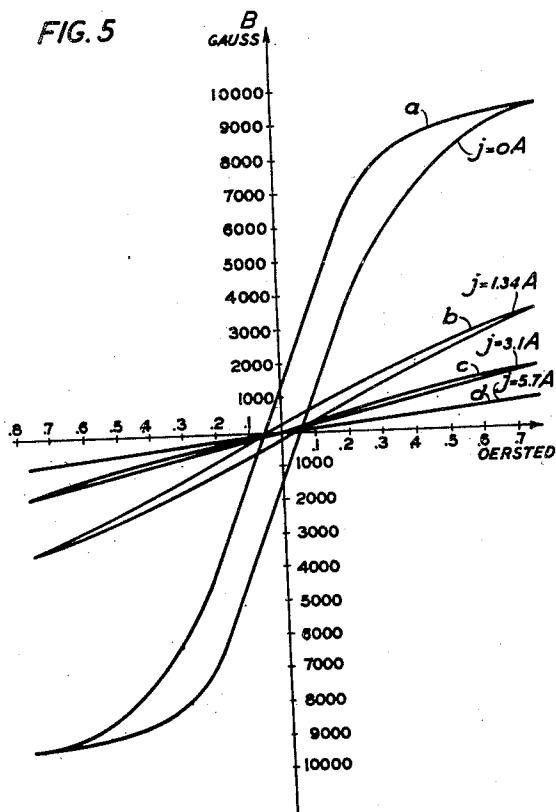
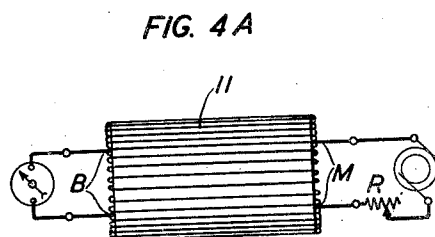
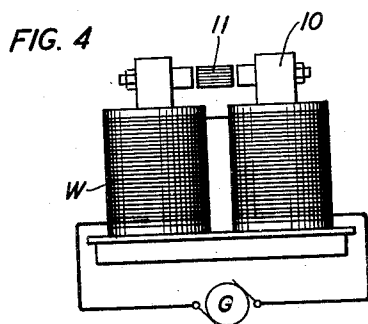
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2 Sheets-Sheet 2



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2,041,147

SIGNALING SYSTEM

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Application September 13, 1932, Serial No. 632,959
In Germany September 25, 1931

9 Claims. (Cl. 178—45)

The present invention relates to signaling systems and more particularly to magnetic materials and electromagnetic devices employed in such systems.

Among the more desirable properties of magnetic materials which are to be used in signaling systems are high permeability at low magnetizing forces, and for a wide range of field intensities, low hysteresis loss, low coercive force and a high flux density for a given magnetizing force. There is a great need and an important field of usefulness for materials combining these properties in electromagnetic devices such as transformers, loading coils, relays, electro-acoustic devices, continuously loaded conductors etc. The desirable characteristics mentioned presuppose a steep magnetization curve and at the same time the absence of irreversible phenomena. It has been found in practice that the very materials which have a steep magnetization curve have a strong tendency to irreversible phenomena such as the Barkhausen effect.

An object of this invention is to so condition electromagnetic devices comprising magnetic materials having high initial permeability to inhibit irreversible phenomena.

A further object of this invention is to reduce hysteresis losses and increase the constancy of permeability of magnetic materials.

Another object of this invention is to improve the desirable properties of magnetic materials forming a part of signaling systems.

Another object of this invention is to treat strain-sensitive magnetic materials to render their desirable properties immune to the effect of mechanical strains such as pressure.

Among the magnetic materials which are particularly suitable for treatments and applications in accordance with this invention are those which reach the saturation point when subjected to small magnetizing forces and to high values of flux density for a given magnetizing force, i. e., those having a hysteresis loop of an approximately rectangular shape. A material of this type, for example, is found in an iron nickel alloy of about 78% nickel and the balance iron possibly with small admixtures preferably of silicon. This composition exhibits in addition to a high initial permeability and a rectangular shape of its hysteresis loop, a low coercive force.

In pursuance of the above mentioned objects, this invention contemplates the reduction of hysteresis loss of magnetic materials while at the same time increasing their constancy of permeability by subjecting the materials either prior to,

or during their use in a signaling system where they are under the effect of an alternating or fluctuating magnetizing force, to an additional unidirectional magnetization, the latter magnetization being applied in a direction substantially perpendicular with respect to the alternating magnetization, and being furthermore of such an intensity as to at least completely saturate the material.

The present invention has its origin in the concept and discovery that the irreversible phenomena and consequently the hysteresis phenomena, which are caused by the abrupt change of the magnetic elementary domains, may be prevented if the magnetization changes are solely accomplished by circular or rotary magnetic effects, i. e., magnetization by spacial rotation of the H-vector. Scientific investigations have shown that with circular magnetization the hysteresis loss, as a function of the flux density B, exhibits a maximum but becomes vanishingly small if the induction is sufficiently increased. In a similar manner, the hysteresis angle ϕ , that is the angle between H and B as a function of B passes through a maximum and vanishes for the saturation value of induction.

Whereas it is old to subject magnetic materials to both alternating current and unidirectional cross magnetizations, whereby the hysteresis loss is reduced, the reduction of the hysteresis losses accomplished thereby is not sufficient to compensate for the resulting decrease in the alternating current permeability. In this invention, however, by having the unidirectional components of the magnetizing force of sufficient magnitude to at least saturate the magnetic material and by directing it at right angles to the alternating components of the magnetizing force, the hysteresis loss due to the alternating component is reduced to a very low value without a corresponding reduction in the alternating induction. In some cases it has been found that the mere combination of direct current and alternating current magnetizations and increase of the former to the saturation value of the materials renders the resulting circuits and devices inoperative; see, for example, page 188 of "Principles of Radio Communication" by J. H. Morecorft, second edition, 1927.

In these cases, it should be noted that the magnetizing forces are applied in the same direction instead of perpendicular to each other as in this invention.

The invention will now be described in more

detail with reference to the accompanying drawings in which:

Figs. 1 and 5 represent hysteresis loops and vector diagrams used for graphically depicting relations to be established between physical properties of materials treated in accordance with this invention;

Figs. 2 and 3 show permeability curves of materials treated in accordance with the invention; and

Figs. 4, 4-A, 6, 7 and 8 schematically illustrate various practical embodiments of the invention.

Hereinafter the alternating current magnetizing field will be designated by H_w and the unidirectional or direct current field will be designated H_g . H_s is that intensity of the field at which the material has a practically vanishing hysteresis angle ϕ for a rotating magnetization. This occurs for a field $H=H_s$ and an inductance $B=B_s$, where the material is practically in the saturation field for ordinary magnetization. In other words, with ordinary magnetization of $H>H_s$ no further perceptible irreversible processes take place which are apt to cause losses. The reversible rise $B-B_s=f(H)$ is disregarded in the following, since the differential permeability μ_d which determines this value is small with respect to

$$\mu_s = \frac{B_s}{H_s}$$

Neglecting μ_d does not affect the result to any considerable extent.

Fig. 1 represents a hysteresis loop and two vector diagrams of the magnetizing fields and flux densities. A relation shall now be established between (1) the alternating current permeability μ_w which corresponds to the combined application of a direct current magnetization equal to H_g and an alternating current magnetization H_w , and (2) the permeability μ_g which corresponds to the mere application of a direct current magnetization. Assuming ϕH to be equal to ϕB , that is, assuming the B-vector corresponding to rotary magnetization to coincide with the direction of the H-vector (see the diagrams of Fig. 1) then we obtain with a direct current cross magnetization exceeding the saturation point, a value for the alternating current permeability:

$$\mu_w = \frac{B_w}{H_w} = \frac{B_s}{H_g} \frac{1}{\sqrt{1 + \left(\frac{H_w}{H_g}\right)^2}} = \mu_g \frac{1}{\sqrt{1 + \left(\frac{H_w}{H_g}\right)^2}}$$

or if $H_g = kH_s$

$$\mu_w = \frac{B_s}{H_s} \frac{1}{k \sqrt{1 + \left(\frac{H_w}{H_s k}\right)^2}} \quad \text{or} \quad \mu_w = \frac{1}{k} \frac{1}{\sqrt{1 + \frac{1}{k^2} \left(\frac{H_w}{H_s}\right)^2}}$$

A valuable feature of this invention is found in the fact that for many materials such as high permeability alloys μ_s is very high, and theoretically may be higher than μ_g . Another feature of this invention which is of considerable practical importance is found in the fact that the direct current magnetization entails practically no serious reduction of the permeability. Thus for a magnetization $H_w=H_s$ at $H_g=H_s$ the permeability for small alternating fields is only 30% less than the value of the permeability in the absence of a direct current cross field.

It may be emphasized that the requirement of a high μ_s which is of importance from the standpoint of practical application is not necessarily identical with the requirement of a high initial permeability or a low coercive force. It is more a question of obtaining the reversible saturation

field with the smallest possible field intensity and the greatest possible inductance. It is also conceivable that a material with low initial permeability and great coercive force has a greater μ_s if the loop is sufficiently rectangular (in order to reach its saturation point soon after H becomes equal to H_c) and the saturation value of the flux density is high. For this reason, iron nickel alloys, particularly those of the permalloy type are suitable for the purposes of this invention. With permalloy, for example, it is possible, at least theoretically, to obtain a direct current permeability μ_g of 10,000 at a direct current magnetizing force of H_g of 0.5 gauss. From a practical standpoint the facts may be slightly different, which is partly due to unavoidable inhomogeneities of the fields, particularly of the cross field. This has the effect, that (1) H_s may not be reached; (2) H_s is not perpendicular to H_w , consequently hysteresis occurs in many fields; (3) the field H_g is partly greater than calculated and the resulting permeability is somewhat lower. The reduction of the hysteresis loss depends practically entirely upon the attainment of a homogeneous cross field. In practical embodiments any inhomogeneities will have the effect that a desired constancy of permeability or hysteresis factor is obtained with a greater direct current cross field and a lower permeability than calculated.

We shall now consider in what manner the alternating current permeability curves of Fig. 2 depend upon the direct current cross magnetization. The hysteresis loop shown in Fig. 1 may be taken as the basis of the curves. It is found that with a direct current cross magnetization H_g which is equal to the saturation magnetization H_s , there is still a certain dependency of the initial permeability upon the alternating field; in other words, the permeability is not entirely constant with increasing small magnetizing forces. If the direct current cross magnetization is increased to twice the value of the saturation magnetization, then this dependency becomes very low. With a cross magnetization field intensity of ten times the saturation magnetization no variation of the permeability as a function of the alternating field is perceptible. The curves of Fig. 2 show that with increasing cross magnetization the initial permeability decreases with respect to the value of the saturation permeability. In practical embodiments of the invention, the intensity of the direct current cross magnetization to be applied will thus be determined by the values of permeability and constancy of permeability which are desired.

Fig. 3 shows curves depicting the variations of the permeability as a function of increasing alternating magnetizing forces for a material comprising 78% nickel, a small amount of silicon and the rest iron. Curve *a* shows that when employing a direct current cross magnetization the permeability remains somewhat in the order of magnitude of the initial permeability (7500). Curve *b* shows that when the direct current cross magnetization is increased, the permeability decreases, but the constancy of permeability increases. For the experiments a laminated strip of 0.15 mm. thickness and 35 mm. width was rolled together into a tube, which, as shown in Fig. 4, was provided with a magnetizing winding for the useful field. The tube was subjected to a unidirectional field in the direction of the tube axis, which was applied by means of a yoke carrying a winding traversed by direct current in a manner shown in Figs. 4 and 4-A. Fig. 4 shows

a yoke 10 whose shanks are magnetized by the winding W which is traversed by direct current. In the yoke is placed a tube of magnetic material 11 shown in more detail in Fig. 4—A; it comprises the alternating current magnetization winding M and a winding B for connection to a ballistic galvanometer for testing purposes. By means of the direct current source G the unidirectional field generated by the direct current magnetization winding W may be set at a certain value and the alternating current field applied by the winding M may be varied by varying the resistance R; in this manner the curves of Fig. 3 were obtained. While the curve c was obtained without direct current cross magnetization, the cross magnetization corresponding to the curve a lay in the saturation field while that corresponding to curve b was increased considerably beyond the saturation field.

Fig. 5 shows a set of hysteresis loops which were obtained from an iron wire 1 millimeter in diameter and 40 centimeters long while it was subjected to different values of a circular direct current magnetic field. The wire was connected to a source of direct current so that direct current flowed through the wire from one end to the other and produced a circular magnetic field within the wire in a manner similar to that described in article 70 on page 199 and illustrated in Fig. 96 on page 201 of the first edition of "Principles of Electrical Engineering" by W. H. Timbie and V. Bush, published by John Wiley and Son, Inc. The wire was also surrounded by a coil which was employed to measure the magnetic characteristics of this wire in an alternating current magnetic field. The magnetic field due to the measuring alternating current in the coil is in an axial direction in the wire and thus at right angles to the circular direct current magnetic field. Fig. 7 shows a similar arrangement applied to a group of wires for subjecting them to a direct current magnetic field at right angles to the alternating current magnetic field. Curve a shows the hysteresis curve obtained without any current ($j=0$ A.) flowing in the wire. For curve b a direct current of 1.34 A. ($j=1.34$ A.) was flowing through the wire during the time at which measurements were made. This direct current caused a circular magnetic field within the wire which is at right angles to the alternating current magnetic field due to the coil surrounding the iron wire. For curves c and d the direct current flowing through the iron wire was 3.1 A. ($j=3.1$ A.) and 5.7 A. ($j=5.7$ A.) respectively. It is thus apparent that the hysteresis loop becomes narrower and straighter as the direct current through the wire increases and produces a stronger cross-magnetic field. This indicates that the hysteresis loss is materially decreased and the constancy of the permeability increased by the direct current magnetic field at right angles to the alternating current magnetic field.

Various embodiments and practical modes of application of the invention will now be briefly described.

The device shown in Fig. 4 may be adapted to satisfy the demands of practical installations simply by reducing the dimensions of the yoke and of the magnetization windings. In many cases a permanent magnet may be substituted for the windings W of Fig. 4. An arrangement showing a permanent magnet 13 is shown schematically in Fig. 6.

The cross magnetization may also be produced

by constructing the magnetic core in the form of wire bundles, each wire of the bundle being traversed by a direct current which generates a circular cross field in the wire; see Fig. 7.

In the construction of toroidal loading coils and transformer coils, an insulated iron wire may be coiled to form a toroidal core to which the winding is then applied. A direct current is applied to the two ends of the iron wire forming the core. Several iron wires of the same core or of different cores may be supplied in parallel with the direct current. Such arrangements are particularly suitable for telephone or audio-transformers, distortionless coils, coils for filters and other networks, loading coils etc. Loading coils thus constructed are particularly valuable in cases where high current intensities are involved, for example, at the terminals of submarine cables. In such cable systems the magnetizing direct current may be supplied over special conductors of the cable or over the signaling currents themselves. In the latter case the direct current may be prevented from affecting the loading coils by means of blocking transformers or condensers, or other means well known in superposed telephony and telegraphy. In the case of multi-conductor cables, for example, a conductor or twin-conductor may be employed for the direct current supply to the loading coils.

In the case of continuously loaded cables the direct current cross magnetization may be produced by providing a special spiralled conductor around the loaded conductor or conductors, the cable armor being used as the return conductor.

Fig. 8 schematically illustrates a submarine signaling cable comprising a central conductor 60 continuously loaded with magnetic material 61. The loading material is surrounded by a spiralled conductor 62 which is connected to a source of direct current (not shown). The cable is insulated and armored in the conventional manner. In this embodiment of the invention the direct current magnetization is produced by the current flowing in the helical conductor 62 whereas the alternating magnetization is produced by the signaling currents flowing in the central conductor 60. It is understood that the direct current magnetization could be produced by other means, for instance, by sending direct current through the loading tape 61, without departing from the spirit and scope of the invention.

An important advantage of this invention is found in the fact that magnetic materials treated as described above are rendered substantially immune to external influences such as pressure for example.

What is claimed is:

1. A signaling system including an electromagnetic device which comprises a magnetic material, and means including a source of direct current and a source of alternating current for subjecting said material to a unidirectional magnetizing force sufficient to saturate said material and to an alternating magnetizing force which has a direction perpendicular to the unidirectional magnetizing force.

2. A system as defined in claim 1, characterized in that the magnetic material has a hysteresis loop of substantially rectangular shape.

3. A system as defined in claim 1, characterized in that means is provided for producing the unidirectional magnetization which includes a yoke, a direct current winding thereon and further characterized in that the material has the form of

a magnetic core magnetized in its longitudinal direction by alternating load currents.

4. A system as defined in claim 1, characterized in that the magnetic material is constituted by wires which are traversed by a direct current.

5. A system as defined in claim 1 comprising a continuously loaded conductor, characterized in that the direct current magnetizing means includes a winding for generating a magnetic field preponderantly in the direction of the conductor.

6. The method of treating a magnetic material during use which comprises subjecting the material to the effects of unidirectional and alternating magnetizing forces applied at right angles to one another, the unidirectional magnetizing force being of such a magnitude as to saturate said material.

7. A communication cable comprising a core conductor for transmitting signal currents, a loading material surrounding said conductor and an auxiliary conductor surrounding said loaded core conductor for transmitting a non-signaling

continuous current which produces a steady magnetic field within said loading material which is substantially at right angles to the magnetic field due to signaling currents in said core conductor.

8. A signaling system including an electromagnetic device which comprises a magnetic material, a permanent magnet for producing a unidirectional steady magnetic field within said magnetic material which substantially saturates said material, and means for subjecting said material to an alternating current magnetizing force which has a direction substantially perpendicular to the direction of said unidirectional magnetic field.

9. In an electrical device, a magnetic body means for simultaneously subjecting said body to a constant unidirectional magnetic field of sufficient magnitude to substantially saturate said body and an alternating current magnetic field which is directed at an angle to said constant magnetic field.

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