June 17, 1952 F. BROCKMAN 2,600,473

MAGNETIC CORE

Filed Jan. 26, 1949 2 SHEETS—SHEET 1

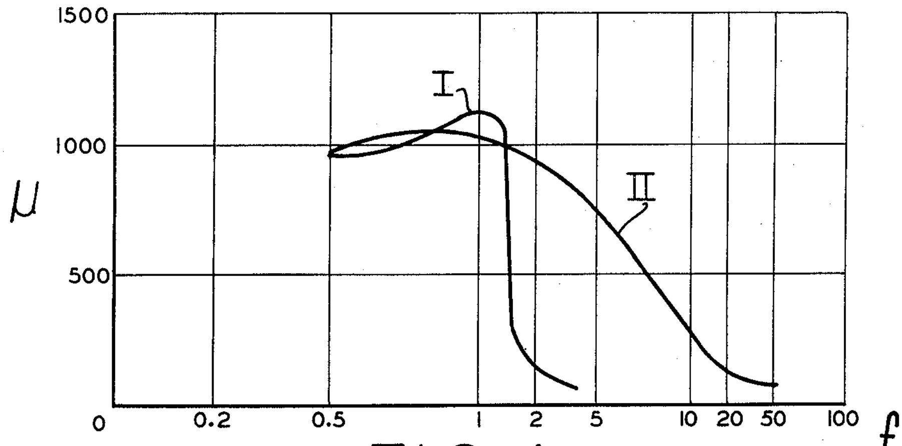

FIG. 1

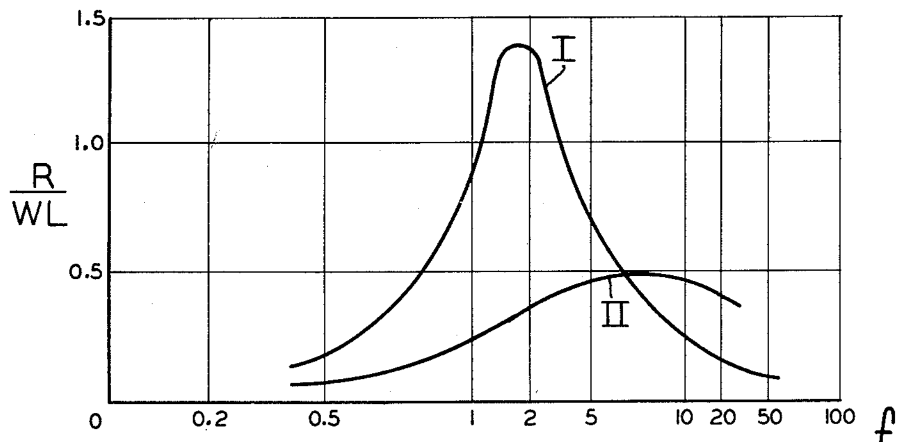

FIG. 2

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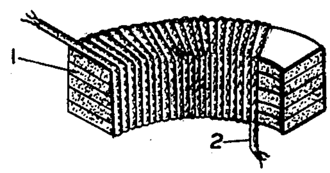
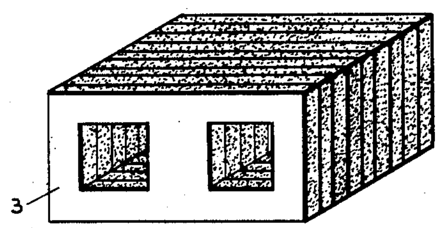
MAGNETIC CORE

Filed Jan. 26, 1949 2 SHEETS—SHEET 2



LAMINATED CORE
CONSTITUTED BY
A MIXED CRYSTAL
FERRITE

FIG. 3



LAMINATED CORE
CONSTITUTED BY
A MIXED CRYSTAL
FERRITE

FIG. 4

RODS CONSTITUTED
BY A MIXED
CRYSTAL FERRITE AND
IMPREGNATED WITH
A BINDER

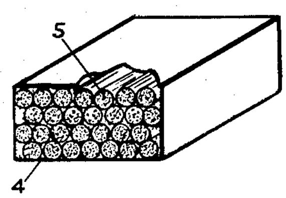


FIG. 5

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Patented June 17, 1952 **2,600,473**

UNITED STATES PATENT OFFICE

2,600,473

MAGNETIC CORE

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Application January 26, 1949, Serial No. 72,960

6 Claims. (Cl. 175—21)

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My invention relates to inductance assemblies having magnetic cores.

Magnetic core materials consisting essentially of mixed crystal ferrites are described in U. S. Patents 2,452,529, 2,452,530, and 2,452,531 dated October 26, 1948, to J. L. Snoek. These magnetic materials have a high magnetic permeability and have excellent electrical insulating properties. Because of these properties these materials are particularly suitable as core materials for high-frequency inductances which have low eddy current losses. Due to these excellent electrical properties and resulting low eddy current losses it has been thought unnecessary and of no particular value to subdivide such cores, for instance by laminating the same.

I have found quite unexpectedly that at high frequencies above a given value determined by the particular core material involved a core of the above-mentioned magnetic materials exhibits a marked change in its magnetic properties, particularly the magnetic permeability and magnetic losses. I have further found that these materials are characterized by unexpectedly high dielectric constants and that the said change in permeability and losses are to a significant extent attributable to this high dielectric constant.

The exact reason that this higher dielectric constant affects the permeability and losses of the magnetic material is not completely known to me. However, I believe that in view of the large permeability and the large dielectric constant the wave length of the electromagnetic wave generated in the core becomes of the same order of magnitude as the dimensions of the core in its usual form and thereby standing waves are established in the core.

It is an object of my invention to produce an inductance assembly of improved characteristics and comprising a magnetic core of a mixed crystal ferrite.

It is a further object of my invention to improve the magnetic qualities of cores for inductance assemblies which consist essentially of mixed crystal ferrites.

It is another object of my invention to provide a core for inductance assemblies which consist of a mixed crystal ferrite having reduced core losses.

It is a further object of my invention to provide an inductance assembly comprising a core of a mixed crystal ferrite having small dielectric losses.

These and further objects of my invention will appear as the specification progresses.

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According to the invention the deleterious effects of the said dielectric constant on the effective magnetic permeability and losses of inductors having a core of a mixed crystal ferrite are reduced to a substantially small amount by establishing within the core structure certain discontinuities which provide core elements having a cross-sectional dimension smaller than the wave length of the wave generated therein. More particularly, I have found that by laminating the core so as to provide discontinuity boundaries between the sections I can reduce the effective dimensions of the core to values which are smaller than the wave length of the wave generated in normal operation of the inductance assembly, i. e. I can reduce the effective dimensions of the core to a value less than one-half the wave length of the highest frequency applied to the inductance assembly thereby preventing the setting up of standing waves in the core. The core is laminated in the direction of the magnetic flux so as to provide a continuous low reluctance path for the magnetic lines of force.

It is, of course, well known that an alternating current in a coil will generate electromagnetic waves, the frequency and wave-length of which, are related to the excitation frequency of the current flowing through the coil. It is also well known that the frequency f and wave-length λ of any electromagnetic wave are related by the velocity of propagation of the wave in the medium by the following equation:

$$\lambda = \frac{\text{Velocity of propagation}}{f}$$

For air or a vacuum having a magnetic permeability μ of 1 and a dielectric constant ϵ of 1, the velocity of propagation of electromagnetic waves is 3×10^{10} cm./sec. so that at a frequency of 50 megacycles, the wave-length will be approximately 6 meters.

The core material employed in the inductance assembly according to the invention has a magnetic permeability μ of the order of 1000 and a dielectric constant ϵ of the order of 10^4 to 10^5 and the velocity of propagation of an electromagnetic wave in this material has been calculated to be of the order of 4×10^6 cm./sec., so that the wave-length of the waves that are generated in the core becomes of the the order of 2 cm. The core element, which has a cross-sectional dimension less than one-half of this wave-length then becomes of the order of less than 1 cm. at 2 megacycles per second.

The laminations may be in the form of thin strips or sheets of the magnetic material or in the form or rods as hereinafter more particularly described.

In order that the invention may be more clearly understood and readily carried into effect, it will now be described with reference to the accompanying drawing in which:

Figure 1 is a graph showing permeability-frequency curves of a prior art core and a core embodying my invention;

Fig. 2 shows the effect on the losses in the core with laminations;

Fig. 3 shows a toroidal shaped coil provided with a core according to the invention;

Fig. 4 shows a conventional closed core transformer provided with a core according to the invention; and

Fig. 5 shows a preferred construction of the core according to the invention.

In Fig. 1 of the drawing, I have shown curves indicating the effect on the permeability when the core is laminated. For illustrative purposes, I have shown the effect of laminations on a core consisting essentially of a mixed cryssal of manganese zinc ferrite. However, in the above-mentioned patents to J. L. Snoek, there are disclosed numerous other mixed crystal ferrites, for example, copper-zinc ferrite, magnesium-zinc ferrite, copper-cadmium ferrite and nickel-zinc ferrite, all of which are suitable as core materials and all of which are susceptible of improvement by laminating the core structure according to the invention. These mixed crystal ferrites may be prepared as disclosed in the patents to J. L. Snoek and have large permeabilities and large dielectric constants. For example, a mixed crystal of maganese-zinc ferrite has a magnetic permeability of about 1000 when measured on a ring core and a dielectric constant of the order of 10^4 to 10^5.

In the figure, the curves show the effect on the effective permeability as the frequency of an applied field to the core is increased. In the figure, abscissae represent values of frequency in megacycles and the ordinates represent the apparent permeability as measured on a toroidal core consisting essentially of manganese-zinc ferrite.

From curve I, showing the dependence of apparent permeability of a solid core of manganese zinc ferrite with increasing frequency, it will be seen that permeability of the core is in the order of 1000 at frequencies up to slightly above one megacycle, after which the permeability of the material falls sharply so that at about two megacycles, the core appears to become virtually non-magnetic.

If the core is laminated according to the invention, the permeability dependence upon frequency of a core for values of frequency up to about twenty megacycles is shown in curve II. The permeability of the material remains above about 500 up to frequencies above about 10 megacycles and continuing to even higher frequencies, the permeability slowly decreases as the frequency increases.

In Fig. 2, the losses of the same core are plotted against frequency. In the figure, the ordinates represent the losses as measured by the factor R/wL when a toroidal core of this material is wound with a coil. The abscissae represent the values of frequency at which losses are measured. Curve I shows the losses of the core as frequency increases, and it will be seen that the losses rise sharply in the neighborhood of two megacycles. At higher frequencies, at which the material is effectively no longer magnetic for practical purposes, the losses begin to decrease.

Curve II shows the effect on losses with increasing frequency when the core is laminated according to the invention. As will be seen from curve II, the losses are materially reduced in the lower range of frequencies, increasing somewhat in the range of higher frequencies which, however, is counter-balanced by the fact that the core has a higher permeability than the solid core shown for in curve I at those frequencies.

Fig. 3 illustrates the manner in which a toroidal core **1** is laminated. The laminae are parallel to the flux traversing the core and are dimensioned to reduce the cross-section of the lamination to less than about one-half a wave length of the electromagnetic wave propagated through the core in the normal operating range of frequencies to eliminate the formation of standing waves in the core. A coil **2** is wound about a portion of the core which generates a magnetic flux in the core when the coil is excited by alternating electric current.

Fig. 4 illustrates generally the laminated core construction for a transformer. The core **3** consists essentially of a homogeneous mixed crystal ferrite and is laminated parallel to the main path of the magnetic flux. The laminations are dimensioned to reduce the cross-section of the lamination to less than about one-half a wave length.

Fig. 5 shows a preferred laminated core construction according to the invention. In this construction, the core is composed of a plurality of rods **4** secured together by being impregnated with a suitable insulating binder **5**. The effect of this construction is to laminate the core in two directions parallel to the direction of magnetic flux traversing the core. In this construction, the coil (not shown) is axially wound around the rod assembly whereby the magnetic flux generated in the core by the coil traverses along the longitudinal axes of the rods. The individual rods are constructed with a diameter which is less than one-half a wave length of the electromagnetic wave propagated through the core in the normal operating range of frequencies. The effect of the rods having this diameter is to laminate the core in two directions eliminating the formation of standing waves in the core as a result of the high dielectric constant of the core material.

While I have thus described my invention with specific examples and applications, I do not wish to be limited thereto since other modifications of the invention will be readily apparent to those skilled in the art without departing from the spirit and scope of the invention.

What I claim is:

1. An electrical inductance assembly for operation at frequencies above about one megacycle comprising a core consisting of a mixed crystal ferrite having a magnetic permeability of the order of 1000 and a dielectric constant of the order of 10^4 to 10^5 and means to produce a flux in a given direction in said core, said core having a cross-sectional area one dimension of which is greater than about one-half the effective wavelength of the wave generated in said core at the highest operating frequency of said inductance assembly, said core comprising a plurality of laminations arranged parallel to the given direction

of flux, each lamination having a cross-sectional area one dimension of which substantially at right angles to the direction of flux is smaller than one-half the said wave-length of the wave produced in said core.

2. An electrical assembly for operation at frequencies above about one megacycle comprising a core consisting of a mixed crystal ferrite having a magnetic permeability of the order of 1000 and a dielectric constant of the order of 10^4 to 10^5 and means to produce a flux in a given direction in said core, said core having a cross-sectional area one dimension of which is greater than about one-half the effective wave-length of the wave generated in said core at the highest operating frequency of said inductance assembly, said core comprising a plurality of flat laminations arranged in a direction parallel to the given direction of flux providing discontinuities in the core, each lamination having a cross-sectional area one dimension of which substantially at right angles to the direction of flux is smaller than one-half the said wave-length of the wave produced in said core.

3. An electrical inductance assembly for operation at frequencies above about one megacycle comprising a core having a magnetic permeability of the order of 1000 and a dielectric constant of the order of 10^4 to 10^5 and means to produce a flux in a given direction in said core, said core having a cross-sectional area one dimension of which is greater than about one-half the effective wave-length of the wave generated in said core at the highest operating frequency of said inductance assembly, said core comprising a plurality of laminations arranged in planes parallel to said given direction providing discontinuities in said core, each lamination having a cross-sectional area one dimension of which substantially at right angles to the direction of flux is smaller than one-half the said wave-length of the wave produced in said core.

4. An electrical inductance assembly for operation at frequencies above about one megacycle comprising a core having a magnetic permeability of the order of 1000 and a dielectric constant of the order of 10^4 to 10^5 and means to produce a flux in a given direction in said core, said core having a cross-sectional area one dimension of which is greater than about one-half the effective wave-length of the wave generated in said core at the highest operating frequency of said inductance assembly, said core comprising a plurality of rods each extending in said given direction and each having a cross-sectional area one dimension of which substantially at right angles to the direction of flux is smaller than one-half the said wave-length of the wave produced in said core.

5. An inductance assembly for operation at frequencies above about one megacycle comprising a core having a magnetic permeability of the order of 1000 and a dielectric constant of the order of 10^4 to 10^5 and means to produce a flux in a given direction in said core, said core having a cross-sectional area one dimension of which is greater than about one-half the effective wave-length of the wave generated in said core at the highest operating frequency of said inductance assembly, said core comprising a plurality of stacked annular laminations arranged in planes parallel to the given direction of flux and defining a toroidal-shaped core, each core element having a cross-sectional area one dimension of which substantially at right angles to the direction of flux is smaller than one-half the said wave-length of the wave produced in said core.

6. An electrical inductance assembly for operation at frequencies above about one megacycle comprising a core having a magnetic permeability of the order of 1000 and a dielectric constant of the order of 10^4 to 10^5 and means to produce a flux in a given direction in said core, said core having a cross-sectional area one dimension of which is greater than about one-half the effective wave-length of the wave generated in said core at the highest operating frequency of said inductance assembly, said core comprising a plurality of rod-like elements extending substantially parallel to said given direction, and an insulating binder between said rod-like elements, each of said rod-like elements having a cross-sectional area one dimension of which substantially at right angles to the direction of flux is smaller than one-half the said wave-length of the wave produced in said core.

FRANK BROCKMAN.

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