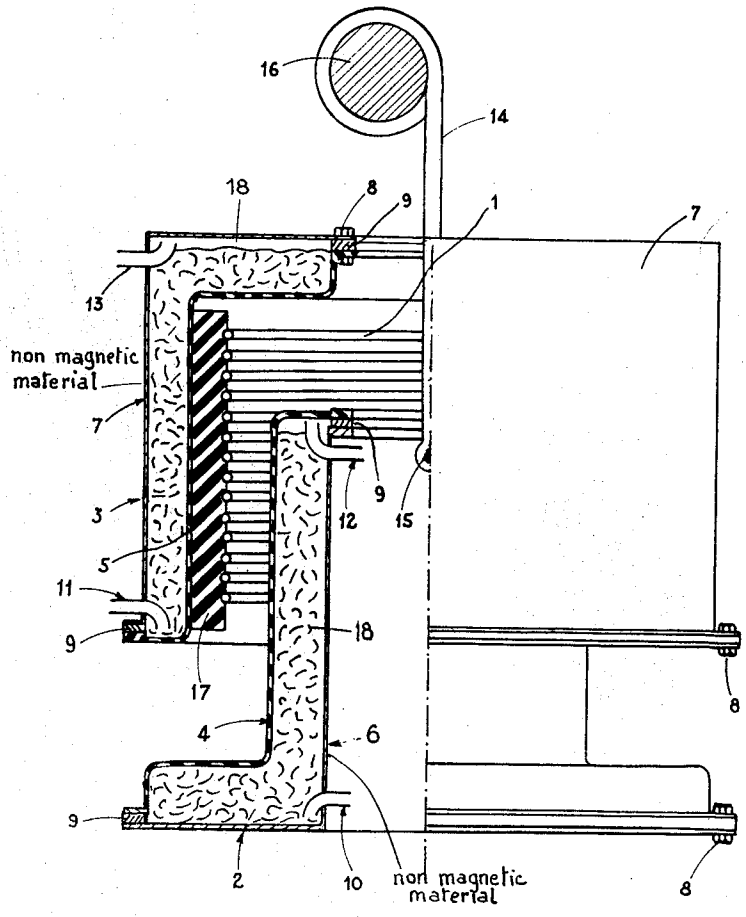
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MAGNETIC COIL AND CORE STRUCTURE

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MAGNETIC COIL AND CORE STRUCTURE

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This invention relates to magnetic circuit structures and is especially though not exclusively concerned with magnetic circuits for electromagnetic apparatus units of large power ratings, e.g. of the order of several thousand kilovoltamperes, operating at intermediate to high (and ultra-high) frequencies.

Magnetic circuits are utilized in a great variety of equipment in electrical engineering and related fields, and can assume widely differing forms depending on their particular use. Thus they may constitute closed circuits or may include airgaps; they may consist of essentially stationary components or may involve relatively displaceable parts such as adjustable cores; they may be associated with various kinds of electrical winding. However, regardless of the particular design of the circuit, the actual magnetic structure comprising it has generally been of one of two types, the type selected depending primarily on the frequency of the electromagnetic energy involved in the operation of the circuit. For low frequencies, the magnetic structure has usually consisted of stacks of thin, mutually insulated laminations of various magnetic alloys, while for higher frequencies it is now usual to use sintered blocks of so-called ferrimagnetic compounds.

The term "ferrimagnetic" has in recent years acquired a precise and well-defined meaning in physical science and electromagnetic engineering. A definition of ferrimagnetism may be found e.g. in "Solid-state Physics" by Charles Kittel, 2nd Edition, New York, 1960, page 445 and is based on a relationship between the constituent atoms of the molecules of the substances involved, such that the atomic spins are in part parallel and in part antiparallel in the saturated condition. While the significance of this definition depends on rather complex theory, it is for practical purposes sufficient to understand that all ferrimagnetic substances are characterized by a high magnetic permeability coupled with high electric resistivity, a combination of properties not to be found in the usual ferromagnetic materials such as ferrous alloys. Ferrimagnetic materials include the naturally occurring ferrites, which are complex oxides deriving from magnetite ($Fe^{++}O$, $Fe_2^{+++}O_3$) through replacement of the divalent iron atom therein with an atom of some other metal.

In the present specification and claims, the term ferrimagnetic is used in its accepted sense as just explained. These materials are generally moulded prior to firing. Their fabrication to requisite shapes presents difficult problems especially in the case of large and more or less intricately formed magnetic circuit components. Usually they are moulded to simple parallelopipedic bar shape and these basic elements are then assembled by means of adhesive to the shape of the final magnetic circuit. This procedure is long and tedious, and the brittleness of the materials concerned leads to considerable rejects due to breakage, distortion, and other causes, thereby further increasing manufacturing costs.

Moreover, because of the inherent property of ferrimagnetic materials being poor conductors of electricity—one of the main advantages of these substances in electromagnetic engineering—they are correspondingly poor conductors of heat. Because of this the considerable amounts of heat evolved in service due primarily to hysteresis losses are unable to be dissipated at a satisfactorily high rate out of the magnetic structure and objectionably high temperatures result.

It is an object of this invention to provide a novel form of manufacturing technique for magnetic circuit structures which will be especially useful in the construction of electromagnetic apparatus of various types of large power ratings and operating e.g. at high frequencies, and which will combine the well-known benefits of ferrimagnetic materials such as ferrites while being completely free from the manufacturing difficulties and other drawbacks of the same.

It is an object to provide a magnetic structure comprising ferrimagnetic material, which will be considerably easier and cheaper to produce than was heretofore possible, can readily be shaped to any required configuration, and will be easy to cool effectively in service.

In accordance with a basic aspect of the invention, a magnetic structure or component comprises wall means providing a casing conforming externally to the desired shape of the magnetic structure or component and internally defining an enclosure, and a body of loose particles of ferrimagnetic material substantially filling said enclosure.

The particles may vary widely in size and shape, and may include particles differing considerably from one another as to each of these characteristics. However, according to the invention it is preferred so to select the range of size and shapes of the particles used as to provide a packing coefficient within the enclosure of approximately from 70 to 90%, 80% being a preferred average value. In other words, it is preferred that the weight of the body of particles filling the enclosure shall be about from 70% to 90% of the weight of a body of the same dimensions made of compact material of similar composition to that of the particles used, and preferably about 80% of such weight.

It will be understood that the loose character of the filler mass of ferrimagnetic material used according to the invention and its non-compact condition is in complete contrast with the bound and compact state of the powder particles of ferrimagnetic material as heretofore produced by sintering and the like techniques. The method of the invention not only affords a very great simplification in manufacturing procedure and a corresponding reduction in cost, but it has been found to lead to considerably improved operation, owing primarily to the presence of the interstitial gaps between the individual particles, and to the possibility of providing effective cooling thereof by the presence of a body of cooling fluid filling said interstitial gaps. In accordance with a preferred aspect of the invention, fluid inlet and outlet means are provided in the walls defining the enclosure, and an electrically insulating cooling fluid is circulated therethrough so as to pervade the interstitial gaps in the ferrimagnetic filler body and remove the heat therefrom in operation. Air, water, or oil may be used as the cooling agent as may be dictated by circumstances.

According to an important feature of the invention, the walls of the casing defining the enclosure filled with loose ferrimagnetic particles comprise, at least in the parts thereof lying within the magnetic field in the operation of the circuit, a material which is inactive both electrically and magnetically, that is non-magnetic and has low electric conductivity, such as a suitable plastic-base composition.

An exemplary embodiment of the invention will now be described for purposes of illustration but not of limitation with reference to the accompanying drawing, which is a view in elevation, with one half in section, of a high-power, low-loss variable inductor constructed in accord-

ance with the invention, and especially well-suited for intermediate frequencies.

The over-all design of the inductor shown is broadly conventional, comprising a vertical solenoid **1** made of copper tubing supported as presently described and provided with means, not shown, for circulating cooling water through it in use. The magnetic circuit structure of the variable inductor is in two parts, and includes a fixed outer part **3** and a vertically displaceable inner part or core **2**. Each of the parts **2** and **3** is constructed in accordance with the invention in the form of a casing filled with loose particles or granules of ferrite.

Specifically, the stationary outer part **3** of the magnetic circuit comprises an inner wall **5** and an outer wall **7** in spaced relationship defining a generally bell-shaped casing having a vertical cylindrical portion and an inturned flange portion at its top. The inner and outer walls **5** and **7** are assembled together by bolts **8** with interposed sealing rings as at **9** so as to provide a tightly sealed enclosure within the casing. Similarly the displaceable core **2** comprises an inner wall **6** and an outer wall **4** assembled together with bolts **8** by way of seal rings **9** and defining between them a fluid-tight enclosure of a shape generally similar to the outer component **3** but inverted with respect thereto. Each of the fluid-tight enclosures thus defined by the parts **2** and **3** is filled with granulated ferrite material **18**. The casing **2** is provided with a bottom inlet **10** and a top outlet **12** for the circulation of coolant fluid, e.g. water, and similarly the casing **3** is provided with a bottom inlet **11** and a top outlet **13**.

As earlier stated, the wall portions of the casing that are exposed to be traversed by magnetic flux in the operation of the apparatus, herein the inner wall **5** of the outer magnetic part **3** and the outer wall **4** of the inner magnetic part **2**, are made of non-magnetic, electrically insulating material. Various materials may be used for this purpose having the requisite magnetic and electrical properties as well as mechanical strength, including various synthetic resin compositions such as polyvinyl chloride, fiber reinforced resin laminates, and the like. As concerns the remaining wall elements, herein the outer wall **7** of the outer magnetic component and the inner wall **6** of the inner component, which are not substantially exposed to the magnetic field in use, these may be made from similar materials as those mentioned above, but may preferably comprise metal of non-ferromagnetic character having good electrical conductivity, e.g. copper and/or aluminium alloys, thereby to serve as shielding for the magnetic structure while imparting improved mechanical strength to it.

A plurality of vertical racks such as **17** secured to the inner wall **5** of the outer magnetic member **3** serve to support the solenoid **1** as shown. The inner magnetic component **2** is shown as being suspended from a cable **14** attached to the top centre of said component as at **15** and wound around an overhead sheave **16** actuated by a winch not shown. Suitable guiding means, not shown, are provided for vertically guiding the displaceable magnetic core **2** in its vertical movements.

In use it will be understood that cooling fluid, e.g. liquid, is circulated through casing **2** from inlet **9** to outlet **12**, and through casing **3** from inlet **11** to outlet **13**. As shown the orifices of outlets **12** and **13** are positioned rather close to the top of the casings **2** and **3** respectively, so that the egress of the granular filling material **18** through said outlets is prevented. As will be evident, screens of suitable mesh size may if desired be provided across the fluid outlets to assist in preventing such outflow of the granular material with the fluid.

It will be noted that in the exemplary variable inductor shown, the two parts of the magnetic circuit structure are so shaped owing to the provision of the top and base flanges of the outer and inner parts **3** and **2** respectively, that in the uppermost end position of the movable inner part **2** the resulting magnetic circuit may be completely

or nearly completely closed. The circuit inductance can thus be varied over a total range corresponding to a factor of about 4:1. If such a wide range of variation is not needed, the parts **2** and **3** may be shaped as simple cylindrical members. With such an arrangement the inductance can still be varied by a factor of about 3:1 over the full range of displacement of the inner core.

In an exemplary test apparatus constructed in accordance with the illustration, the ferrimagnetic filling of the two parts of the magnetic circuit comprised ferrite particles obtained by coarse grinding of rejected sintered parts, mainly parts that had been distorted on firing and broken. The granulometry of the ferrite filling was substantially chosen for providing a packing coefficient of 80%.

It will be appreciated that the exemplary apparatus described above is purely illustrative of the wide range of possibilities of the invention and was selected because of the particular difficulties that would be involved in the provision of such a high-power, low-loss electromagnetic apparatus involving variable airgaps and large size magnetic components, by the use of conventional techniques, such as sintered ferrites. By constructing the apparatus in accordance with the teachings of the invention as above described, on the other hand, the production of the large-size magnetic components **2** and **3** posed no special engineering problem, since it was simply required to press-mould, or otherwise form the plastic and metallic wall members by well-known techniques, fill the resulting casings with the loose ferrite material and finally assemble the casing parts. This relatively simple procedure contrasts extremely favourably with the difficulties that would be normally encountered in moulding and sintering large bodies of ferrite powder material as would be necessary in constructing the magnetic parts **2** and **3** by present-day techniques. Moreover, the inductor described hereabove may be operated at several thousand kilovolt-amperes, due to the fact that the liquid filling all the gaps between the particles of ferrite achieves a fully efficient cooling, and the loss coefficient is only 1%. It is clear that a comparable cooling effect cannot possibly be achieved in conventional apparatus where the magnetic parts are solid, compact bodies.

The invention as earlier stated is broadly applicable to all apparatus embodying the use of magnetic circuits, including fixed and variable inductors, transformers, fields, and the like, both in the fields of power and communications engineering.

I claim:

1. A magnetic structure which comprises wall means providing at least one casing internally defining a sealed enclosure, a body of loose particles of ferrimagnetic material substantially filling said enclosure and providing interstitial gaps between the particles, and inlet and outlet means connected to said wall means for circulating a cooling fluid through said enclosure to fill said interstitial gaps between the particles therein and remove the heat generated in said particles in the operation of apparatus of which said structure forms part.

2. A magnetic structure which comprises wall means providing at least one casing internally defining a sealed enclosure, a body of loose particles of ferrimagnetic material substantially filling said enclosure and providing interstitial gaps between the particles, and means for circulating cooling fluid through the enclosure.

3. A magnetic structure as defined in claim 2, wherein said wall means is made of a substance having substantially non-magnetic, electrically non-conductive properties at least in a part of said wall means exposed to magnetic flux in the operation of said structure.

4. Magnetic structure as claimed in claim 3, wherein said substance comprises a synthetic resin-base composition.

5. Magnetic structure as claimed in claim 3, wherein said wall means is made of a metallic material having non-ferromagnetic, electrically conductive properties in

a part thereof not exposed to magnetic flux in the operation of the structure.

6. Magnetic structure as claimed in claim 1, wherein said material fills the enclosure with a packing coefficient of approximately from 70 to 90%.

7. Electromagnetic apparatus comprising in combination electromagnetic means of creating a magnetic field, magnetic circuit structure comprising rigid wall members, means for interassembling the wall members, the outer surfaces of the wall members when assembled defining a structure so shaped and positioned relative to said electromagnetic means as to be substantially traversed by said field and the inner surfaces of the wall members when assembled defining an enclosure therebetween, and a body of loose ferrimagnetic particles substantially filling said enclosure with interstitial gaps between the particles.

8. The apparatus defined in claim 7, including fluid inlet and outlet means associated with at least one of said wall members and connectable to a source of cooling fluid and means for circulating said fluid through said enclosure and in the interstitial gaps between said loose particles.

9. Electromagnetic apparatus comprising in combination electromagnetic winding means for creating a magnetic field, magnetic circuit structure comprising rigid wall members, means for interassembling said members, the outer surfaces of said members when assembled defining at least one generally cylindrical structure coaxial with said winding means and the inner surfaces of said members when assembled defining an enclosure therebetween, and a body of loose ferrimagnetic particles filling the enclosure with interstitial gaps between the particles.

10. The apparatus defined in claim 9, including fluid inlet and outlet means associated with at least one of said members and connectable to a cooling fluid circuit and means for circulating cooling fluid through the enclosure and the interstitial gaps between said loose particles.

11. The apparatus defined in claim 7, including means for relatively displacing said magnetic circuit structure and said field creating means.

12. Electromagnetic apparatus comprising in combination electromagnetic winding means for creating a magnetic field, at least one pair of rigid wall members interconnectable to define therebetween a sealed enclosure of generally annular cylindrical shape coaxial with said winding means, a body of loose ferrimagnetic particles substantially filling said enclosure with interstitial gaps between the particles, and fluid inlet and outlet means associated with at least one of said members and connectable to a fluid circuit for circulating cooling fluid through the enclosure and in the gaps between the particles.

13. The apparatus defined in claim 12, including two pairs of said wall members respectively defining two sealed enclosures coaxial with said winding means radially inward and radially outward thereof.

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