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MAGNETIC REACTOR CORE AND METHOD OF FORMING

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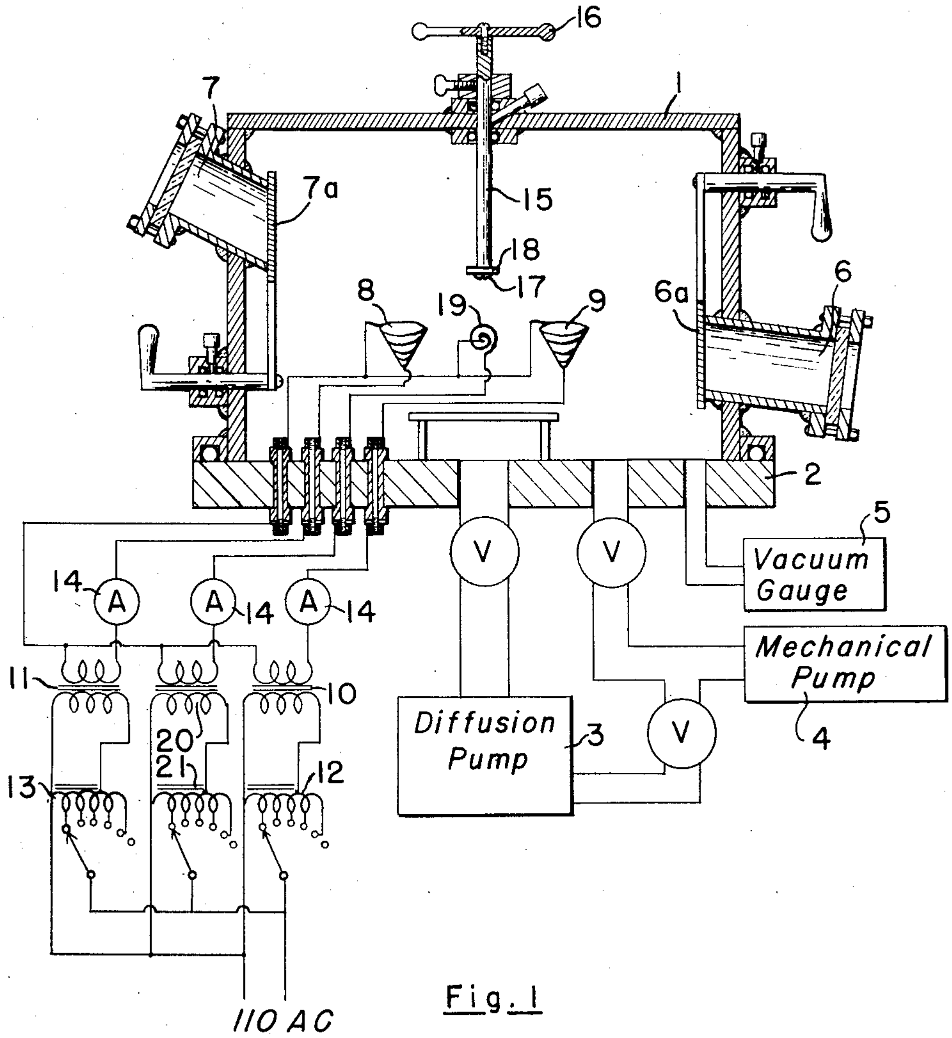

Fig. 1

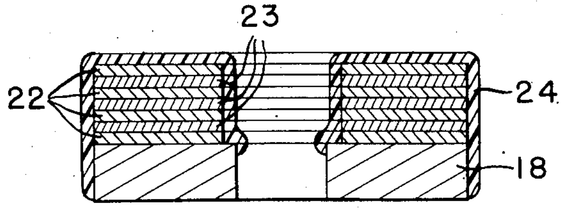

Fig. 2

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MAGNETIC REACTOR CORE AND METHOD OF FORMING

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1 Claim. (Cl. 336—200)

This invention relates to cores for magnetic reactors and to methods of forming such cores. Particular reference is made to such cores as are formed of laminates of magnetic material and insulating material.

Magnetic reactor cores for high frequency and other special applications are frequently made by one or another of the following processes:

1. Finely divided iron such as that prepared by the carbonyl process, or finely divided magnetic iron oxide, is mixed with a plastic binder-insulator and molded into the desired shape. Typical uses are for tuning slugs for radio frequency coil circuits.

2. Finely divided ferromagnetic spinels, commonly called ferrites, are molded as above with binders which are later fired out and give improved performance at higher frequencies as in certain television applications.

3. Laminates of thin magnetic foils coated with insulating layers such as oxides or lacquers are built up to the desired size and shape. Cores of this type are frequently used in magnetic amplifiers, pulse transformers, computer flip-flop circuits, and in static magnetic memory devices.

Magnetic foils of the type useful in the third application can only be produced on specially built rolling mills and often must be subjected to special anneal cycles and to orienting treatments in magnetic fields. By such techniques foils as thin as ⅛ mil, or approximately 2.86 microns, have been produced but only at great cost and by methods not inherently suitable for mass production. Such foils must then be laminated by difficult and tedious methods, often at a sacrifice of desirable magnetic properties as a result of the cold work associated with handling and lamination.

It is the object of this invention to produce magnetic reactor cores of the above types and to present a method for producing such cores by techniques which can be standardized and by which cores can be built up of particles or laminates much smaller than heretofore attainable. Theoretically, the diameter of the atom, which for iron is about .000252 micron, is the lower limit.

We contemplate the formation of magnetic reactor cores by vapor phase deposition, either alternately or simultaneously, of magnetic materials and insulating materials. Obviously, alternate deposition may be used to prepare a laminar structure and simultaneous deposition will produce a discontinuous structure in which adjacent particles of magnetic material are substantially separated by the simultaneously deposited insulating material.

At least for the purposes of this application, we wish to define vapor phase deposition as including the following specific processes or a combination of two or more of these processes:

Evaporation—the material to be deposited is heated in a vacuum to such a temperature as to pass from a liquid or solid state into a vapor phase and be deposited by condensation on the object to be coated.

Sputtering—the material to be deposited on an anode is emitted from a cathode in a glow discharge resulting from the application of a high electrical potential while a suitable low pressure is maintained.

Spraying—the material to be deposited is vaporized, or perhaps atomized, in extremely small molten droplets, in a high temperature flame and transported by the hot gases to the object on which the material is to be deposited, where it condenses or solidifies on the surface.

We have found that pure iron is a suitable magnetic material for such deposition and that magnesium fluoride is a suitable insulating material. Other magnetic elements and alloys can also be so deposited and simultaneous deposition and later diffusion may be used to form alloys in situ. We also contemplate that silica and certain oxides, other fluorides, silicates, or organic materials capable of vapor phase deposition may also be used as insulators.

In addition to the previously mentioned objective of very thin films or small particles, it is an important objective to produce cores, particularly laminar cores, which are solid coherent bodies which can be handled as units and without the mechanical complications attendant upon the assembly or winding of laminar cores from thin strip foils or punchings of coated magnetic material.

The exact nature of the invention as well as other objects and advantages thereof will be more clearly apparent from consideration of the following specification referring to the attached drawing in which:

Fig. 1 is a schematic cross-sectional view through equipment arranged for practicing the invention.

Fig. 2 is a cross-sectional view through a core for a toroidal magnetic reactor produced in accordance with our invention.

Referring to the drawing, it may be seen that we have shown a metal bell jar **1** supported upon a base **2** and arranged to be evacuated by a diffusion pump **3** backed up by the usual mechanical pump **4**. A suitable vacuum gage **5** is provided and should be capable of accurate readings at very high degrees of vacuum, for the operating pressures average between 0.1 and 0.05 micron of mercury. Sight ports **6** and **7** are provided in the bell jar **1** to permit observation of the process, and shutters **6*a*** and **7*a*** manipulatable from outside the bell jar are used to protect the glass of the sight ports from material deposited within the bell jar. Suitable valves V are provided to control the flow of gases to the pumps during the initial stages of pumping out the system by the mechanical pump and the final high vacuum stage.

Mounted within the bell jar are at least one pair of electrically heated crucibles **8** and **9**, which will later be described in detail. Preferably, the crucibles are each supplied with electrical power from separate transformers, respectively **11** and **10**, and the inputs to each transformer are respectively controlled by variable auto-transformers **13** and **12**. Suitable ammeters **14** are provided in each crucible circuit to permit reading the current supplied thereto.

A manipulator shaft **15** is carried through a vacuum-tight joint in the bell jar and provided with a handle **16** or other means permitting rotation and longitudinal displacement of the shaft. Within the bell jar a screw **17** on the shaft **15** provides means for mounting the objects **18** which are to be used as a base for the reactor core. In the example illustrated, the objects **18** are ceramic washers. Obviously, the object **18** might be mounted on an arm on the shaft **15** and by rotation of the shaft moved from a position directly over one crucible to a position directly over the other crucible.

In an illustrative laboratory apparatus the crucibles **8** and **9** referred to were made by winding a spiral of tungsten wire of .025 inch diameter on a metal form to define a conical shape. These conical elements were then heated electrically to near the boiling point of water and painted repeatedly with a water suspension of finely ground Alundum powder. After the application of a sufficient number of coats to build up a solid crucible in which the tungsten heating element is embedded, the assembly is baked under high vacuum by gradually increasing the current in the tungsten element to heat it to a temperature of around 2900° F. Almost inevitably, due to the relief of mechanical stresses and the like, cracks will develop on first baking but these cracks may readily be filled by reapplication of the Alundum suspension. Generally, one such filling followed by re-baking in vacuum will suffice to produce a leak-proof crucible, although obviously if cracks again develop on re-baking the repair technique may again be resorted to. A leakproof crucible is essential because the reaction of iron with the tungsten of the filament leads to destruction of the filament. For economical use of heat and for economical evaporation, we have found that it is desirable to use relatively deep crucibles of small diameter because of their lower radiation losses and because of the smaller solid angle seen by the molten material in the crucible, which angle is determined by the intercepts of the molten surface with the edges of the crucible and controls the area over which the vapor will spread.

In such crucibles, we have used sections cut from spectroscopically pure iron rods as a magnetic material and for an insulator we have used pellets of magnesium fluoride formed by compressing a laboratory grade of powdered magnesium fluoride in a steel die under high pressure.

As a base for the magnetic core we have used an unglazed ceramic toroidal washer composed, for example, of one of the materials known as steatitic porcelains. The base material does not appear to be critical, although it should be easy to clean, be corrosion resistant, and be capable of withstanding relatively high temperatures. For some applications it appears that non-ferromagnetic metals, to which the successive deposits will adhere, may be used as base materials.

In an illustrative run the ceramic washer was baked prior to deposition of any film by positioning it about ⅛″ above a tungsten wire heating coil **19** maintained, for a period of about ¾ of an hour, at a temperature between 2200° F. and 2400° F. This heating coil is also provided with an ammeter **14**, transformer **20**, and variable autotransformer **21**. In another example the ceramic washer was baked for the same period over a tungsten coil heated to about 2760° F.

After the baking operation, the washer was supported on the end of the manipulator shaft **15** midway between the two spaced crucibles **8** and **9** and about 6 inches above them. One of the crucibles contained pellets, cut from rods of spectroscopically pure iron, and the other contained compressed magnesium fluoride pellets. The pumps were operated to establish a pressure of .06 micron of mercury and current was turned on to the crucible containing iron.

The current supplied to the iron crucible was gradually increased until 12.0 amperes were flowing and optical pyrometer measurements through the sight port showed a temperature on the visible interior of the crucible of 2630° F., at which point the iron vapor commenced to condense on the ceramic washer. Presumably, the temperature within the invisible bottom portion of the crucible was above the melting point of iron. Evaporation under these conditions was allowed to continue for 10 minutes and then the current to the iron crucible was cut back and current started in the crucible containing magnesium fluoride.

A gradual increase of current to the magnesium fluoride crucible to a value of eleven and one-half amperes raised the temperature to 2050° F., again as measured by an optical pyrometer on the visible interior of the crucible. Observation of the surface of the ceramic washer showed that evaporation was in progress by the usual progression of interference colors from red through the spectrum to a distinct violet and back to red. Three complete sequences of interference colors through red were deposited in about 3½ minutes when the current was cut back and current again supplied to the iron crucible.

A second layer of iron was deposited for a period of 12 minutes proceeding as before, and a second layer of magnesium fluoride deposited, again running through three sequences of interference colors. A third layer of iron was similarly deposited and the magnesium fluoride became exhausted shortly after the red interference color came up the second time. The core was completed by the deposition of a fourth layer of iron and the core removed from the bell jar and given a thin protective coating with a moistureproof lacquer.

This core illustrated at an exaggerated scale in Fig. 2 consisted of the ceramic washer **18** on one face of which there had been deposited four layers of iron **22** with a layer **23** of magnesium fluoride between each layer and an overall protective coating **24**. Under the microscope, the layers appeared to be of comparable thickness and the seven layers had a total thickness of about 3.3 microns or an average of slightly less than one-half micron per layer. In appearance, the successive deposits each appeared to be smooth continuous layers.

The toroidal core so formed exhibited magnetic properties as evidenced by the fact that it could be readily picked up by a permanent magnet and, when wound with a coil consisting of 50 turns of No. 38 wire, linked with the toroid, could be magnetized by connection across a 6-volt dry cell battery. A small permanent magnet suspended by a thread readily aligned itself with the magnetic field and remained so after the current was cut off. Reversal of the current in the coil reversed the direction of the magnetization, as evidenced by reorientation of the searching magnet, and again the magnetization remained after the current was disconnected.

Hysteretic memory action was also demonstrated by winding a second similar coil upon the toroidal core and examining oscillographically the pulses in the secondary coil as current pulses were applied to the primary by connection across a single conventional No. 6 dry cell battery. As would be expected, the first current pulse which was applied in a direction to reverse the direction of magnetization in the core produced a relatively large secondary pulse because of the large change in flux involved. Succeeding current pulses of the same polarity produced comparatively small pulses in the secondary. Upon reversal of the polarity of the pulses in the primary, the first pulse was again large and the succeeding pulses small. The output voltage on first pulses as read on a calibrated oscilloscope was about 1.2 volts and the output voltage for succeeding pulses was about 0.2 volt. Actual measurement at the high amplification levels employed on the oscilloscope is facilitated by passing the output signal from the coil through a crystal diode connected to pass a signal of the proper polarity with a small condenser shunted across the oscilloscope terminals to bypass the high frequency "hash" inductively picked up by the coils. The ability of the reactor so formed to serve as a magnetic memory device was demonstrated by tests in which a pulse was read in one evening and reversed the following morning to determine that the core had remained magnetized at the desired polarity, and by similar tests extending over a two-day week-end and over a ten-day period. In each test the voltage ratio between initial and succeeding pulses appeared to be substantially identical to the ratio previously determined and noted above.

Although the core so formed was made with the ceramic washer supported in view of both crucibles and control was maintained by alternate heating and cooling of the crucibles, we believe that for laminar cores the best results will be obtained by moving the washer to position it first over one crucible and then over the other crucible and by using an intermediate baffle which will prevent magnesium fluoride vapor from contacting the forming core while iron is being deposited, and vice versa. There are indications that the most coherent iron deposits are formed when the base is preheated as previously described and the deposition of iron started without delay which permits the base to cool. Similarly, the pressures should be low enough to prevent the diffusion of magnesium fluoride by collision with gas molecules since such diffusion during the period of depositing iron would serve to prevent the formation of a continuous smooth film. If the pressure is low enough that the mean free path between points of probable molecular collision is greater than the distance between crucible and receiving surface, there is little likelihood that diffusion will present any problem. Complete outgassing of the system is facilitated by the application of a gas torch to the exterior of the bell jar as the system is being pumped out.

To further protect the film from contamination, precautions should be taken in the layout and in the operation of equipment to prevent back-streaming from the diffusion pump. We believe that we have been able to trace nearly all examples of failures to produce smooth continuous layers of magnetic iron to contamination of the iron as it was being deposited either by failure to adequately outgas the base for the core or other elements of the system, by stray magnesium fluoride or by the products of back-streaming of the diffusion pump. The factors which make it comparatively easy to produce material having the insulated particulate structure characteristic of the known powdered magnetic material cores all work to make it more difficult to produce laminar structures in which there is complete continuity within each individual layer of magnetic material.

Although we have above described as a specific example a process which is capable of laboratory use, it should be obvious that better techniques must be devised for production operations. It appears probable that the greatest demand for units of the type described will be for those having a laminated structure of alternating continuous layers respectively of magnetic material and insulating material. It also appears that in order to reduce stray field effects and to provide low reluctance magnetic circuits, it will be desirable to produce these structures in toroidal form, and that the laminations should be arranged in such a manner as to minimize eddy currents within the laminations induced by the changes in the magnetic flux. With conventional magnetic cores such eddy current minima have been attained by building up the core in the form of a stack of insulated washers, by winding a flat helix, by using a series of coaxial insulated cylinders of progressively greater diameter, and by utilizing a spirally wound insulated ribbon. Any of these configurations can be formed by vapor deposition and the following discussion of a production technique will be directed to the production of such structures.

In the laboratory process specifically described above, the core in the form of a series of insulated disks was built up on a flat ceramic washer with the core form stationary and with alternately heated evaporation crucibles. A more convenient production method of achieving the same result would be to maintain both crucibles at evaporating temperature and move the ceramic core form from one crucible to the other in succession, using suitable stationary baffles such as to keep the two vapors from mixing. This process lends itself to automatic operation by mounting the core forms in circumferentially spaced positions about the axis of the manipulator shaft, and rotating that shaft intermittently or continuously to expose the cores for the right length of time to the vapor emitted from the crucible. A relatively large number of cores may be simultaneously treated by this method, permitting relatively high production without requiring evaporation at extremely high rates.

A flat or edge-wound helix may be produced by supporting the core form for rotation about an axis in the plane of a fairly close fitting vertical baffle so that substantially one-half of the core projects from each side of the baffle and is exposed to the vapor emitted from a different crucible. Continuous rotation with both crucibles at evaporating temperature would build up alternate layers of iron and insulator, each layer being in the form of a flat edge-wound helix.

To produce a structure of concentric cylinders the cylindrical core form or forms may be strung on a horizontal shaft rotatable about its own axis and supported above and midway between two alternately heated crucibles. Obviously, the shaft should make one or more complete revolutions during the cycle of evaporation from each of the alternately heated crucibles.

A structure analogous to the conventional cores wound from a ribbon of foil can be produced by the same equipment described in the preceding paragraph with the addition of a stationary baffle in a plane including the axis of the rotating shaft and fairly closely fitting the circumference of the cores. Continuous rotation with both crucibles at evaporating temperature will produce alternate but continuous spirals of insulating and magnetic material.

Although each of the production processes described above has been described by reference to the technique of evaporating from crucibles, it should be obvious that the same manipulative methods will be applicable to other vapor deposition processes previously noted herein or to the use of combination processes such as the evaporation process with a sufficiently high attracting potential applied to the cores to be coated to minimize the dispersion of the vapor.

For an exact definition of the limits upon the scope of what we regard as our invention, reference may be had to the appended claims.

We claim:

A magnetic reactor core comprising a non-ferromagnetic base supporting a succession of alternate films of spectroscopically pure iron having a thickness of less than 2½ microns and magnesium fluoride having a thickness of less than 2½ microns.

References Cited in the file of this patent

UNITED STATES PATENTS

1,784,611	Polanyi	Dec. 9, 1930
2,153,363	Bruche	Apr. 4, 1939
2,293,037	Atlee	Aug. 18, 1942
2,353,612	Gardner	July 11, 1944
2,427,592	Dimmick	Sept. 16, 1947
2,441,960	Eisler	May 25, 1948
2,633,427	Dimmick et al.	Mar. 31, 1953
2,671,034	Steinfeld	Mar. 2, 1954

OTHER REFERENCES

"Printed Circuit Techniques," National Bureau of Standards Circular 468, issued November 15, 1947, pp. 17, 18, 25, 26, 32 and 33.