METHOD OF PRODUCING MOLDED STATORS FROM STEEL PARTICLES

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ABSTRACT

A method is disclosed for forming a magnetic core. The core comprises a preformed coil about which a plurality of substantially rectangular microlaminations of a ferromagnetic material are disposed and the components are compressed into a unitary structure. The method includes the steps of preforming a coil assembling the coil in fluid-tight container together with a core bar positioned centrally of the coil. Microlaminations are added to the container which is thereafter pressurized to compress the microlaminations about the coil to form a unitary structure.

15 Claims, 6 Drawing Figures
METHOD OF PRODUCING MOLDED STATORS FROM STEEL PARTICLES

CROSS REFERENCE TO RELATED APPLICATIONS


BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to unitary structure which comprises a magnetic core having conductors embedded therein. Essentially the core is formed by performing a coil and disposing the same within a fluid tight container. Thereafter a core bar is positioned centrally of the coil and a quantity of microlaminations is added to the container to fill the space between the core bar, the coil and the container. Upon filling the container with the requisite amount of microlaminations, the container is sealed and subjected to pressure so as to mold the entire unit into a unitary structure which may be thereafter readily removed from the fluid tight container.

2. Description of the Prior Art

Cores and particularly motor stator cores are generally made from laminations. In conventional manufacturing techniques, these laminations are punched from electrical steel sheet which are thereafter annealed, insulated and stacked one upon the other in order to form the core. Conductors usually in the form of coils are then wound into the slots which have been machined within the core structure or which are formed when the laminations are punched. The material which is removed to produce this slot may comprise 25–40% of the total area of each lamination and this material is lost as scrap. Moreover the stamped core produces a slot geometry which is limited because of the die cost. Consequently the slot fill of the conductors is restricted since the conventional method of winding or inserting the conductors into the slot does not permit them to be compressed. Moreover thick liners are required to protect the conductors from abrasion by the rough edges of the laminations during the winding operation. Since the conductors cannot be compressed in the current method of manufacture some of the volume encompassed by the end turns of the windings is wasted due to the inherent limitation of the lamination construction. It therefore becomes apparent that it is desired to make a more efficient use of both the space and materials involved in such magnetic cores. As a result of the practice of the present invention both conductor and core configurations have been improved where the stator core is constructed by molding iron particles around the conductors and thereby completely eliminating the presently wasted space.

Past attempts for example those described in U.S. Pat. Nos. 1,850,181; 1,669,648 and 1,982,689 to produce simple ring cores by pressing the iron powder particles have produced very poor magnetic properties. One factor for the poor magnetic properties is believed to be due to the inability to achieve a sufficient density of iron. Part of the densification aspect was slightly improved were metallic iron in the form of flakes or wire employed in preference to iron powder. The metallic flakes simply consisted of atomizing molten iron into powder configuration and rolling the same to produce a flattened elongated powder metal particle.

In order to overcome these shortcomings in the prior art practice, the present invention teaches that small, substantially rectangular ferromagnetic particles in the form of microlaminations which may be formed for example from plain carbon steel sheet and processed to yield the required magnetic properties, can be molded around a preformed coil assembly. The resulting core formed from the microlaminations is scrapless, has a high precision bore due to the molding technique, utilizes more active magnetic materials since precut slots are eliminated and in addition the molding technique compacts the coil conductors during the molding pressurization and thereby eliminates the need for thick slot liners. As a result both better space factors and higher densities of both magnetic material and conductor can be obtained with the result that such molded cores exhibit outstanding magnetic characteristics.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a view of a preformed coil employed in making a molded motor stator with part of the insulation removed;

FIG. 2 is a view in vertical cross section of a loaded container which is utilized in practicing the method of the present invention;

FIG. 3 is a sectional view of the loaded container taken along the lines III–III of FIG. 2.

FIG. 4 is a plot of the applied voltage versus the no load amperes;

FIG. 5 is a plot of the applied voltage versus the no load watts; and

FIG. 6 is a macrograph of a cross-section of the conductors after pressurization and molding of the core into unitary structure.

DESCRIPTION OF THE PREFERRED EMBODIMENT

One of the basic materials which is employed in the method of the present invention includes small substantially rectangular parallelepipeds of magnetic material, each of which has been termed a "microlamination." Essentially this material preferably comprises a low carbon steel and that steel which is normally used for tin cans is an ideal source since it is abundantly available and is quite low in cost. Of course any other ferromagnetic material which can be obtained in essentially this shaped particle may function just as well. This material is preferably purchased in the so-called black plate condition, that is the condition prior to the application of the metal coating thereto for the tin can stock. Essentially this material is available in a wide range of thicknesses usually within the range between about 0.005 inch to about 0.014 inch. While a relatively wide range of steel particle sizes and thicknesses appears to be satisfactory it is preferred to have the microlamination formed with the length ranging between about 0.05 inch and about 0.06 inch, a width of between 0.01 inch and 0.02 inch and a thickness of between 0.005 and about 0.008 inch. The laminations are usually formed from the tin can stock to the above dimensions by cutting with a high speed rotary die cutter in free space or the material may be slit to the width desired and then cut with a rotary cutter against a station-
ary knife edge. In the latter case, the cutter and slitter are in line.

Other feedstock can also be employed with equally good results, for example steel wool, scrap and billet shavings, scrap cobalt iron can be processed into microlaminations for use in motors for special applications, as aircraft. It will be appreciated that the formation of the microlaminations entails a considerable amount of stressing of the material. Accordingly where the materials are to be used in a magnetic core the desired magnetic properties must be developed. This aspect includes the relieving of the stresses in the steel imparted during the formation of the microlamination plus a deoxidation and a decarburization treatment so that the core structure of a high density or packing factor can be obtained which will also exhibit excellent magnetic characteristics. Thus in developing the magnetic characteristics it is preferred to anneal the microlaminations at a temperature within the range between about 700°C and 800°C. It has been found that these temperatures are sufficient for relieving the stresses in microlaminates which have been induced during their processing.

In order to decarburize the microlaminations, during the initial stage of the heat treatment at the temperature range indicated, an atmosphere of wet hydrogen having a dew point in excess of about +60°F is utilized. The wet hydrogen atmosphere is effective for removing the carbon content to a value of less than about 0.01% by weight. This wet hydrogen atmosphere is maintained about the heated microlaminations for a period of up to about 2 hours in order to obtain the desired low carbon content therein, and thereafter the annealing within the stated temperature range is continued in a dry hydrogen atmosphere which is also effective for deoxidizing the microlamimations. It has been found that forming gas or other strongly oxidizing atmospheres that produce oxides on the steel cannot be used since the oxide thickness adversely affects the packing factor and thereby detracts from the overall magnetic characteristics of the finished magnetic core. The dry hydrogen atmosphere having a dew point of less than about −40°C is also maintained for a period of about 2 hours and thereafter the microlaminations are cooled to room temperature while being maintained within the protective atmosphere.

In order to develop the required core loss characteristics within the finished core, the microlaminations must be insulated from one another. It has been found that treatment with magnesium methylate is a preferred medium for providing an insulating coating on the laminations since the insulating coating is very thin and is flexible enough to withstand the molding pressures. While other insulating coatings may be employed, this coating provides sufficient interlaminar resistance that after the core is molded it will exhibit the required core loss as well as other magnetic characteristics.

The method of the present invention is applicable to produce any molded core having at least one conductor contained wherein and the method is amenable to other techniques such as the so-called "free mold" or the "fixed mold" techniques. However specific reference will be placed in the following description to a method of molding stators having embedded conductors therein and is applicable to the production of a stator core for a motor it being understood that the method is applicable to both static and dynamic electrical apparatus where conductors are to be molded in a magnetic core.

More specifically, the method of the applicants' present invention is directed to the utilization of a preformed coil which is used in the manufacture of a stator for a motor. Referring now to FIG. 1 there is shown a stator coil preform 10 which comprises a plurality of vertically extending slot conductors 12 which according to the prior art methods of manufacturing motors would be disposed within the slots of the stator laminations. The coil perform 10 having its slot conductors 12 disposed as shown in FIG. 1 is formed on a mandrel or form with the requisite number of end turns 14. The coil preform 10 is usually formed of a electrical conductor wire such as magnet wire to which an electrically insulative coating 16 has been applied. The coil perform 10 may be wound on a mandrel (not shown) and can be thereafter coated with any suitable resins or other insulating coating 16 of a thickness not exceeding about 3 mils which will maintain the dimensional integrity of the coil perform 10 after it has been removed from the forming mandrel.

Referring now to FIG. 2 there is illustrated a container shown generally at 20 which comprises a unitary structure with a base 22 and upwardly extending sidewalls 24. In practice it has been found that such a container 20 may be formed of elastic or flexible polyurethane resin which is cast into the desired shape. Natural rubber, silicone rubbers and synthetic elastomers can be also employed. Situated on the base 22 of the container 20 and within the sidewalls 24 is a cast resin base 26 having a centrally disposed opening therein 28 for accommodating a core bar 30 which is centrally disposed within the container 20 and functions to accurately position the bore of the formed molded stator so as to accommodate the rotor of a motor. The base 26 is also provided with an annular opening or slot 32 which is disposed for accommodating the end turns 14 of the coil preform 10.

Reference to FIG. 3 will show in cross-section the assembled relationship of the sidewalls 24, lot conductors 12 and core bar 30. As thus assembled, a selected quantity of the annealed and insulated microlaminations 35 is deposited and positioned in the space 34 between the outer container sidewalls 24 the core bar 30 and the slot windings 12. During the addition of the quantity of microlamimations 35 in the spaces provided therefor, the entire container and its contents are subjected to vibratory energy so that the "green" packing factor will be maximized in order to obtain the highest possible packing factor in the completely molded stator after the same has been pressurized. Where desired, in order to obtain a preferred orientation the preformed coil may be energized with a suitable source of electrical current in order to align the microlamimations along the magnetic flux lines to form poles to provide maximum magnetic cooperation with the shape and pattern in which the coil is wound.

When a sufficient quantity of microlaminations has been added to occupy the predetermined space, a matching top filler and seal 36 which is essentially a mirror image of the cast base 26 is disposed in a seating arrangement on top of the microlamination 35, the coil end turns 14 and core bar 30. As thus assembled the loaded container is ready for pressurization to effect consolidation.
In order to compact the microlaminations 35 uniformly around the preformed coil 14 it is preferred to apply isostatic pressure to the assembly. Such isostatic pressurization will be effective for densifying both the conductors 12 and the microlaminations and since the container 20 which is preferably formed out of polyurethane is flexible it will permit dimensional changes to occur during the pressurization thereby enabling the attractive backing factor of 90% to be obtained.

To effect consolidation the loaded container is placed within a suitable isostatic pressurization chamber which is thereafter filled with a fluid and pressurized sufficiently to cause densification of the microlaminations and coils to occur such that the packing factor or density thereof will be in excess of 80% of the volume occupied by the microlaminations and the embedded conductors. While the degree of pressurization above a certain limit is not too critical, it has been found that with the application of about 50,000 psi a molded stator is produced exhibiting a density or packing factor in excess of 80% of theoretical.

In order to more clearly demonstrate the present invention reference may be had to the following which describes the construction of a two-pole dual voltage, three-quarter horsepower induction motor. A preformed coil similar to that illustrated in FIG. 1 was employed in which the conductors were wound on a mandrel to provide the slot conductors 12 and the end turns 14 in the manner illustrated in FIG. 1. After winding, and removal of the coil preform from the mandrel the coil was treated in a fluidized bed of dry powder of an epoxy resin of the polyglycidyl ester of a dihydric phenol type. This fluidized bed treatment with the epoxy resin was effective for providing a very hard out flexible electrical insulation coating to the slot conductors as well as the end turns.

A cast flexible polyurethane container 20 with a cast base 26 for accurately positioning the preformed stator coil 10 was thereafter employed in which the preformed stator coil 10 was positioned within the cast base and a steel core bar 30 was thereafter inserted within the interior of the coil to accurately dimension the bore thereof. The container 20 with the cast base 26, preformed coil 10 and core bar 30 were thereafter placed on a vibrator and previously prepared microlaminations 35 were poured into the space 34 between the core bar and the preformed coil 10, as well as between the coil 10 and the polyurethane container 20 until a predetermined amount of the space between the end turns of the coil was completely filled with a mass of microlaminations compacted by such vibration. Thereafter the top filler 36 and seal were placed over the compacted microlaminations 35, core bar 30 and preformed coil 10 and the entire assembly was loaded into the chamber of an isostatic press and subjected to hydrostatic pressure of 50,000 psi. Thereafter the pressure was released and the molded stator was then removed from the polyurethane container after removing top filler 36. This molded stator was assembled into a three-quarter horsepower two pole induction motor and tested with the results as graphically illustrated in FIGS. 4 and 5.

Reference to FIG. 4, which is a plot of the applied voltage versus the no-load amperes for both a conventionally wound motor a core made of punched laminations as well as the motor of the present invention, shows the improvement effected by the use of the microlaminations in conjunction with the preformed stator coil which are molded into a unitary stator core. For the same voltage over the range of 120 to 240 volts, the no-load amperes are lower for the molded stator motor of this invention.

The advantages of the present invention can be discussed quite clearly when the same stators are employed in the same motors and the plots of the respective applied voltage versus the no load watts is considered. As graphically illustrated in FIG. 5, employing a stator made in accordance with the teaching of the present invention results in a substantial improvement over a conventionally constructed motor. Thus at 220 volts the stator of this invention has 120 watts at no-load versus 170 watts, a 30% reduction. This improvement is believed to occur by reason of the higher overall density which can be obtained employing the present invention.

Reference is now directed to FIG. 6 which is a photomicrograph of the cross section of the slot conductors after hydrostatic pressing. It will be noted that by the mere application of a hydrostatic pressure of about 50,000 psi the slot conductors have been compressed so as to form substantially regular hexagons throughout the cross section. By the compression of the slot conductors, compression of the microlaminations and the elimination of the usual slot liners, more effective amounts of metal can be put to work in the same spare considerations. It is noted that while the space factor of the conductor approaches 100%, no damage was found to the wires or to the insulation. The wire to wire insulation withstand 800 volts and the wire microlaminations insulation withstand 2600 volts. Thus there is complete integrity to each of the individual slot conductors which is not disturbed through the subject of said conductors to the hydrostatic pressing.

Another advantage of the consolidation of the microlamination magnetic core and conductors into a solid unitary stator is that destructive vibration which takes place between insulated windings and laminations is greatly reduced because of the solid compaction of the windings and the core. Thus failure of the electrical insulator by abrasion or cut-through of the enamel on the conductors is avoided.

In order to finish the evaluation of a similar molded core a ring core was molded about a wire bundle under the same conditions and thereafter the conductors were machined out and the core alone was evaluated for magnetic performance. Density measurements indicate that the microlaminates had been compressed to a packing factor of about 89%. The core has a magnetic induction of 12.5 kilogausses where binder may applied field was 50 oersteds, and 14.2 kilogauss when the applied field was 100 oersteds. Moreover, the core exhibited a 15 kilogauss watt loss of 5.9 watts per pound. These are properties superior to laminated cores.

It will become apparent that while the specific example has been illustrated employing a fluid hydrostatic pressure technique, other methods such as a dry bag isostatic compaction technique can be employed equally as well. Moreover, while there were no specific binders for the microlaminates employed during pressing it will be appreciated that where large rotational forces may be involved or where low isostatic pressures are employed a binder may be advantageously used. An excellent binder comprises potassium silicate in an aqueous medium which has produced outstanding re-
It is imperative, however, that in the event that the binder is used that the same be capable of exerting its binding influence without entailing to excessive thicknesses, with lower packing density of the magnetic material per se. Thus binders generally used, for example, with iron powders such as carbowax and organic resins were not satisfactory because of excessive thicknesses which results in the decrease in packing density.

It will be further appreciated that if the use of the molded microlamination body in a completed stator assembly yields too high a reluctance it may be necessary to mold the core in the manner as previously described and then, for reducing the reluctance, a wound yoke can be applied as a tape of magnetic material wound on the core which comprises the molded microlamination, the applied tape being on the exterior portion of the stator.

In practice, a thin tape of magnetic material can be wound onto a cylindrical bell, placed in the pressurizing container, and the electrical conductor disposed therein, to be followed by the core bar, and finally the microlaminations are poured in between the tape shell and the core bar. Upon consolidation with a pressurized fluid the entire assembly will be integrally united.

From the foregoing it will be appreciated that substantial savings can be effected in both the conductor as well as the cores since for all practical purposes air gaps are eliminated and there is a higher material density than could be obtained from employing stacked laminations as the core material and thereafter winding the core in a manner of a conventional motor. Thus in addition to the savings in materials as well as labor, improved performance is obtained, resulting in the same power output from substantially reduced inputs, or stated conversely, higher power outputs can be obtained from the same electrical inputs.

We claim:

1. The method of producing a molded core having at least one conductor embedded therein employing microlaminations in which the microlaminations are formed from a ferromagnetic material, are substantially of an elongated rectangular cross-section, have been annealed to decarbonize, deoxidize and improve the magnetic characteristics thereof, and in which each of the microlaminations is provided with an electrically insulative coating on the surface thereof, the steps comprising, preforming a conductor into a desired configuration, assembling the preformed conductor in a flexible container of predetermined configuration, adding microlaminations about the conductor within the container, sealing the container, compressing the microlaminates about the conductor to attain a packing factor in excess of 80%, removing the pressure and thereafter removing the molded core from the container.

2. The method of claim 1 in which the microlaminations are treated with a binder prior to pressurization.

3. The method of claim 1, in which a core bar of predetermined shape is disposed within the preformed conductor which is disposed in the flexible container prior to introducing the microlaminations.

4. The method of claim 1 in which the conductor is provided with a conductor-to-microlaminate insulation not in excess of 3 mils in thickness.

5. The method of claim 1 in which a yoke is applied to the molded core, said yoke being in the form of a tape wound ring core.

6. The method of claim 1 in which a yoke is applied to the molded core, said yoke being in the form of a plurality of punched or stamped laminations.

7. The method of claim 1 in which the container is subjected to vibratory energy while the microlaminations are added thereto.

8. The method of producing a molded stator employing microlaminations in which the microlaminations are formed from low carbon steel, are substantially rectangular in shape, have been annealed to decarbonize and deoxidize the same and improve the magnetic characteristics thereof and in which each of the microlaminations is provided with a magnetically insulative coating on the surface thereof, the steps comprising, preforming a stator coil, preforming a stator yoke, said yoke having an outside diameter of the desired dimension of the finished stator and an inside diameter sufficiently great to accommodate the coil therein, assembling the preformed yoke and the preformed coil in a flexible container of predetermined configuration, said coil being positioned centrally of the yoke and both within the container, positioning a core bar centrally within the coil, energizing the coil, adding the microlaminates about the coil within the container, sealing the container, pressurizing the container to effect a packing factor in excess of about 80%, removing the pressure and thereafter removing the molded stator from the container.

9. The method of claim 4 in which the microlaminates are coated with a binder prior to pressurization.

10. The method of claim 4 in which the coil is provided with a wire-to-microlaminations electrical insulating not in excess of about 3 mils.

11. The method of claim 4 in which the yoke is formed in the manner of a tape wound ring core.

12. The method of claim 4 in which the yoke is formed of a plurality of stamped or punched laminations.

13. The method of producing a molded core having at least one conductor embedded therein employing microlaminations in which the microlaminations are formed from a ferromagnetic material, are substantially of an elongated rectangle cross section, have been annealed to decarbonize, deoxidize and improve the magnetic characteristics thereof, and in which each of the microlaminations is provided with an electrically insulative coating on the surface thereof, the steps comprising, preforming the conductor into a desired configuration, assembling the preformed conductor in a coil configuration, assembling the preformed coil centrally within a flexible container of predetermined configuration, positioning the core bar in predetermined spaced relation within the coil, adding a predetermined amount of microlaminations to the space between the core bar and container walls and about the coil, sealing the container, pressurizing the microlaminations and coil to attain a packing factor in excess of 80% to form a unitary structure, removing the pressure and thereafter removing the molded core from the container.

14. The method of claim 9 in which the assembly is subjected to vibratory energy during the addition of the microlaminates to the container.

15. The method of claim 9 in which the microlaminates are treated with a binder prior to pressurization.