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(54) Title: METHOD FOR MAKING SOFT MAGNETIC PARTS FROM PARTICULATE FERROUS MATERIAL, AND PARTS MADE THEREFROM


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(57) Abstract

A method is provided for making soft magnetic parts from particulates of ferrous material. The methods includes the following steps. Providing a plurality of ferrous particles and coating at least one substantially uniform layer of from about 0 wt.% to about 15 wt.% of a metal onto each of the particles. The coated particles are consolidated to form a part, and the part is heated at a temperature and for a time period sufficient to promote the formation of intermetallic phases between the metal layer and the ferrous particle at the boundary therebetween. The intermetallic phases have an electrical resistivity of greater than about 100 ohm/mil-ft.
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METHOD FOR MAKING SOFT MAGNETIC PARTS FROM PARTICULATE 
FERROUS MATERIAL, AND PARTS MADE THEREFROM

This application is a continuation-in-part of provisional 
U.S. Patent Application No. 60/039410 filed on February 28, 
1997.

FIELD OF THE INVENTION

This invention relates to a method for making soft 
magnetic parts from particulate ferrous materials such as iron 
powders. More particularly, the invention relates to a method 
for making soft magnetic parts that have superior properties, 
such as increased density and improved magnetic properties due 
to decreased eddy current losses, etc. The invention further 
relates to materials and parts used in or produced by the 
aforementioned method.

BACKGROUND OF THE INVENTION

Magnetic core components are frequently used in 
electrical/magnetic conversion devices such as generators and 
transformers, particularly those found in automobile engines. 
The most important characteristics of these iron core 
components are their magnetic permeability and core loss 
characteristics. The magnetic permeability is an indication 
of the material’s ability to become magnetized or to carry a 
magnetic flux. Permeability is defined as the ratio of the 
induced magnetic flux to the magnetizing force or field 
intensity. When a magnetic material is exposed to a rapidly 
varying field, a resultant energy loss in the core occurs. 
These core losses are commonly divided into two types: 
hysteresis and eddy current losses. Hysteresis loss results 
from the expenditure of energy to overcome the retained 
magnetic forces within the iron core component. Eddy current 
losses are brought about by the production of electric 
currents in the iron core component due to the changing flux 
caus ed by alternating current (AC) conditions. This energy 
loss as a result of eddy currents can be seen in the graphs 
Figures 1a and 1b which chart magnetization as a function of 
applied field.
In U.S. Patent No. 4,602,957 to Pollock, et al. iron powders are coated with oxidizing agents such as potassium or sodium dichromate prior to compaction. The compact is then partially sintered at 600° C. These partially sintered compacts are reported to have increased resistivity and decreased hysteresis losses when compared to bulk iron compacts. This method has the disadvantage, however, of introducing oxides into the final structure of the part thereby having a negative effect on the overall mechanical properties of the soft magnetic part.

In other known processes to minimize eddy current losses in ferrous parts made by powder metallurgy, soft iron particles are coated with thermoplastic materials before pressing. U.S. Patent Nos. 4,947,065 to Ward et al. and 5,198,137 to Rutz et al. teach such a method whereby iron powders are coated with a thermoplastic material. This plastic, in principle, acts as a barrier between particles to reduce these induced eddy current losses. There is however a considerable disadvantage to coating the iron powders with plastic, specifically, plastic is not very strong when compared to the bulk alloy. Thus parts made using plastic coated iron typically have low strength. Moreover, plastic coating processes are also very expensive. Additionally, many of these plastic coated powders require a high level of binder when pressed. This results in decreased density of the pressed core part and, consequently, a decrease in magnetic permeability. Since these parts have plastic incorporated therein they cannot be used at higher temperatures wherein the plastic will begin to degrade. Lastly, the plastic coatings on the powders provide for soft magnetic compacts (parts) having relatively high hysteresis loss.

These soft magnetic parts, such as stator cores, have alternatively been made by stacking steel laminations which involves die stamping sheet steel to the required shape. After stamping, the laminations must be stacked in correct alignment and the stack of laminations must then be secured together, for example, by welding or riveting. In die stamping, there is however, a certain amount of scrap loss and
hence unnecessary expense. Moreover, the stacked cores are known to suffer from large core losses at higher frequencies and are noisy since the laminations tend to vibrate. This vibration also contributes to energy loss. U.S. Patent No. 3,670,407 to Mewhinney et al. describes such a stacked lamination stator and an attempt to reduce the eddy currents therein.

Thus, there exists a need for a method for making soft magnetic parts, such as stators, for AC applications from a ferromagnetic powder such as pure iron, where the parts have decreased eddy current losses, without any decrease in strength or density (and related magnetic permeability) and for parts made therefrom. There is also a need for a method for making soft magnetic parts and the parts made therefrom, that is less expensive than those using plastic coatings or die stamping.

Furthermore, present methods for making nickel phosphorus and cobalt phosphorus bulk alloys (and parts made therefrom) involve blending an iron phosphide, which is very abrasive, into pure iron and then pressing the part. There exists a need for a method by which non-abrasive nickel phosphorus and cobalt phosphorous materials can be made.

**SUMMARY OF THE INVENTION**

It is therefore an object of the present invention to provide materials and a method for making parts from particulates of ferromagnetic material and other materials that, inter alia, overcomes the aforementioned disadvantages. In doing so, the present invention provides a ferromagnetic powder such as pure iron that when compressed is useful to make magnetic materials having decreased eddy currents, a process for producing soft magnetic parts for magnetic/electrical components wherein eddy current losses are decreased, and parts, such as stators made from this process.

In another embodiment, the present invention provides a method for producing a part from a nickel phosphorus or cobalt phosphorus containing alloy wherein the part is made up of a non-abrasive material.
In the first embodiment, the ferromagnetic powder according to the present invention comprises water atomized iron core particles having from about .05 wt.% to about 5 wt.% of a substantially uniform coating of metallic material disposed thereon. The metallic material has the ability to form intermetallics with the iron core when the powder is compacted and heat treated at a temperature of from about 450 °C to about 650 °C for a time period of from about two minutes to about sixty minutes. Alternatively the metallic material is an electrically resistive alloy such as, constantin (57Cu, 45Ni), CuMn (87Cu, 13Mn), Invar (65Fe, 35Ni), chromax/chromel D (45Fe, 35Ni, 20Cr), nichrome (80Ni, 20 Cr) and Chromel AA (68Ni, 20Cr, 8Fe). The layer(s) of metallic material can also be precursors to the electrically resistive alloy that upon heat treatment react to form the alloy surrounding the iron core particle.

The present method for producing soft magnetic parts comprises as a first step, providing a quantity of a ferromagnetic powder. The powder is then substantially uniformly coated with a layer of at least one metallic material, as for example nickel, zinc or copper, with zinc being preferred. Alternatively, the powder is coated with an electrically resistive alloy of nickel-zinc or nickel-copper. This coated powder is then compressed into a desired shape or part by the application of pressure thereto. The shape or part is subsequently heat treated at a temperature of from about 400 °C to about 650 °C for a time period of from about two minutes to about sixty minutes.

In this embodiment, the temperature and length of time for low temperature sintering the compressed part is selected to promote formation of an intermetallic phase at the boundaries between the particles of powder and their respective coatings or in those embodiments where the powder has been coated with more than one metallic coating as for example, a coating of nickel and a second coating of copper and/or zinc, to form an alloy between the nickel and the copper or between the nickel and the zinc, respectively. These thus formed intermetallics and alloys have a higher
electrical resistivity than pure iron so eddy currents (energy losses) are reduced and the magnetic properties of the part are enhanced. The metallic coatings on the particles also serve to impart lubricity to the powders while they are being compacted. Thus, compacts having increased green densities over what would otherwise be the green density of a compact of the uncoated iron powders are obtained. The increased density of parts made in accordance with the present invention also contributes to increased magnetic permeabilities of the resultant parts.

This invention also includes parts or articles for AC (alternating current) applications, such as stators, that are made from ferrous powders that have been coated with metallurgical coatings, compressed into a part and heat treated at relatively low temperature to produce insulating boundaries between the compressed iron powders. These boundaries are preferably highly resistive alloys or intermetallic phases between the coating metal and the iron that are formed when the temperature and time period for heating the pressed part is selected to promote the formation of same.

Articles or parts according to the present invention exhibit superior as pressed strength, high permeability through an extended frequency range up to 2000Hz and decreased eddy currents. Additionally, the powders according to this invention can be pressed to a relatively high green density.

**BRIEF DESCRIPTION OF THE DRAWINGS**

Figure 1 is a graph showing the B vs H curves for parts made in accordance with the present invention and uncoated materials.

Figure 2 is a graph showing core loss vs. B for electrically resistive materials made in accordance with the present invention and materials made with uncoated iron powders.

**DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

In a first embodiment the present invention is directed to a method for making soft magnetic parts from particulates of any ferromagnetic material such as nickel-cobalt, cobalt,
iron, aluminum-iron, aluminum-nickel, with pure iron being preferred. The method comprises as a first step providing a plurality of ferrous core particles. The ferrous core particles for use in the present inventive method are preferably high compressibility powders of iron or ferromagnetic material, preferably having a average particle size of from about 1 to about 120 microns.

A layer of from about 0 wt.% to about 50 wt.%, and preferably less than 2 wt.% of metal or alloy is coated onto each of the particles. For purposes of this invention, “particles” should be interpreted to include powders, whiskers, fibers, continuous wires, sheets and foils.

The coating step can be done by any method for coating metals known in the art such as for example, ball milling, reduction from sol-gel and plating such as electroplating. Preferably, the coating step is done by electroplating to ensure as uniform a layer of the metal material on each of the particles of the particulate ferrous material as possible. The only requirement for the metal coating is that it be a true metallurgical coating. Hence, any known electroplating process can be used to coat the particles in this invention. A particularly preferred process for plating the layer of metal or alloy onto the particulates is one using the Fluidized bed apparatus taught in U.S. Patent No. 5,603,815 to Lashmore et al. hereby incorporated in its entirety by reference herein. This process comprises combining particles of a particulate substrate material and an electrolyte in an imperforate container; vibrating the container to generate a fluidized bed of the particles in the electrolyte and electrochemically depositing a coating on the particles from the reactants in the electrolyte. The container should preferably be an electrically conductive container and the process is preferably an electrolytic method which includes applying an electric current through the electrolyte concurrent with the existence of the fluidized bed of particles. As an example only, nickel can be deposited from a sulfamate, sulfate, citrate or acetate electrolyte in the fluidized bed onto commercially available pure iron powder.
(Hoeganaes 1000C Fe particles of sizes ranging from about 20μ to about 150μ). Zinc is preferably deposited from a cyanide or ammonia electrolyte, copper is preferably deposited from a pyrophosphate or cyanide electrolyte and nickel is preferably deposited from a sulfate or sulfamate electrolyte.

Preferred materials for use as the plating metal or alloy, can also include, but should not be limited to, cobalt, nickel, zinc, antimony, copper, hafnium, molybdenum, platinum, ruthenium, selenium, tin, gallium, gadolinium, manganese, niobium, osmium, palladium, rhenium, titanium, tantalum and zinc tin alloys. Another class of coatings that can be deposited are alloys that are themselves electrically resistive. The choice of material to be coated on the particles should be based on the ability of the plated metal to form a substantially electrically insulating material (intermetallic or alloy) at the interfaces of the particles and the coatings after the particles are compressed and heat treated at relatively low temperatures. Particularly preferred materials for use as coating materials in this embodiment are zinc, nickel, cobalt, copper, chromium, manganese and alloys of zinc and nickel and copper and nickel. The coating should preferably be from about 1 wt% to about 20 wt% of the total weight of the coated powder. As a general guideline, the thickness of the plating should be thick enough to avoid porosity in the metallic layer, but thin enough not to impede the magnetic permeability of the compressed material.

Secondarily, the appropriate coating material can optionally be chosen for its ability to "lubricate" the ferrous particulates during consolidation. For the purposes of this invention, "lubricate" is intended to mean to impart to the particles an ability to slip and slide by each other during consolidation, thereby minimizing or eliminating point to point welding of the powders during the process and maximizing the density of the pressed part and hence increase its magnetic permeability.

Once plated, the particulates are consolidated to form a part, as for example a stator core and the part is heat
treated (annealed) or bonded at a temperature of from about 200° C to about 1000° C, for a period of from about 10 minutes to about 10 hours. Preferably, the temperature is from about 300 °C to about 550 °C and the time period is from about 20 minutes to about 60 minutes. In this embodiment, the appropriate temperatures and times for heat treatment step should in general be selected to be sufficient to cause the coating material to react with the core particulate material and form intermetallic phases and/or alloys that have increased resistivity over the iron core powders. Hence, eddy current losses are minimized in the final product.

The coated particles are compacted to a density approximating “full density” (the density at which the compacted coated particles have at least non-interconnected porosity and preferably no porosity). Hence, the green density of this coated particle compact would not be substantially increased if the compacted product were subjected to traditional high temperature sintering.

Although any source of pressure is suitable to consolidate or compact the powders, the consolidation step is preferably done in the die cavity of a powder press. Such powder pressing methods are known in the art of powder metallurgy. However, any method wherein adequate pressure to form a cohesive part (or cause the coated particulates to adhere to each other) can be applied, is or are suitable for use in the present invention. In general, the appropriate pressures to adequately consolidate these coated particles to a dense green part should preferably be from about 60,000 KSI to about 150,000 KSI when pressing is done on a traditional uni-axial powder press. Additionally, consolidation can be effected by high velocity projection (similar to thermal spraying), roll-bonding, hot isostatic pressing (hipping), cold isostatic pressing (cipping), forging, extruding, coining or rolling the coated powders.

In an alternative to the method set forth above, a substantially uniform layer of electroplating from about 0.1 wt.% to about 10 wt.% of an electrically resistive alloy or multiple layers of alloy precursor metals are coated onto the
surfaces of the particles and the plated particles are consolidated to bring particle surfaces in close contact with each other to form a part. In those instances when the coating step is used to plate multiple layers of alloy precursor metals, the method includes the optional step of heating the part at a temperature and for a time period sufficient to promote the formation of an electrically resistive alloy from the multiple layers of alloy precursor metals. The alloy forms from the interdiffusion of the precursor layers and is disposed in a substantially uniform layer around particle surfaces.

In this embodiment, the electrically resistive alloy should have an electrical resistance greater than about 100 ohms/mil-ft. Examples of such an electrically resistive alloy include constantin (57Cu,45Ni) having an electrical resistance of 294 ohms/mil-ft, CuMn (87Cu, 13Mn) having an electrical resistance of 290 ohms/mil-ft, Invar (65Fe, 35Ni) having an electrical resistance of 485 ohms/mil-ft, chromax/chromel D (45Fe, 35Ni, 20Cr) having an electrical resistance of 600 ohms/mil-ft, nichrome (80Ni, 20Cr) having an electrical resistance of 650 ohms/mil-ft, and Chromel AA (68Ni, 20Cr, 8Fe) having an electrical resistance of 700 ohms/mil-ft.

When layers of alloy precursors are plated onto the ferrous particles the metals are selected from the group consisting of copper, nickel, chromium, manganese and mixtures thereof. These metals and their appropriate percent by weight are of course, chosen to produce a layer of the aforementioned alloys. Hence, for example, if one were to produce an electrically insulating barrier of constantin between compressed ferrous powders, a layer of copper and then nickel would be plated on the ferrous particles prior to their compaction. The weight percent of the copper to nickel should be appropriate to produce the 57Cu, 43Ni composition of the final alloy. Additionally, the heating step should be done at a temperature of from about 400 °C to about 1000 °C for a time period of from about 5 minutes to about 60 minutes.

As an example of a part that can be made by the present process, this invention further includes a stator for an
alternating current generator. The stator comprises a one piece, die pressed stator core having an annular yoke and a plurality of integral inner circumferentially spaced projections radiating and extending inwardly and defining slots. The core is comprised of a plurality of die compressed metal coated particles of iron bound together by an electrically insulating material that surrounds each particle. The insulating material is a metalloid comprised of intermetallic phases between the iron and the metal. The metal should appropriately be selected from the group consisting of iron, zinc, nickel and cobalt.

In the stator according to this invention the intermetallic phases are the reaction product obtained by exposing the die compressed metal coated particles to a temperature of from about 400 °C to about 1000 °C for a time period of from about 10 minutes to about 60 minutes when a layer of the metal is substantially uniformly disposed on each of the iron particles prior to die pressing.

The stator according to the present invention can further comprising a stator coil winding having conducting portions located in the slots of the annular core.

This invention further includes ferrous powder for use in making parts by powder metallurgy. The powder comprises water-atomized non-heat treated ferrous core particles having from about 0.1 wt.% to about 10 wt.% of at least one layer of a substantially uniform coating of metallic material disposed thereon. The layer defines a boundary between the ferrous core and the metallic material. The metallic material has the ability to form an electrically resistive barrier at the boundary upon compaction and heat treatment of the coated core particles at a temperature of from about 400 °C to about 1000 °C for a time period of from about 10 minutes to about 60 minutes.

In this ferrous powder the metallic material is selected from the group consisting of nickel containing boron, phosphorus or sulfur, zinc and cobalt and the electrically resistive barrier is the metalloid product of the reaction of the ferrous core with the metallic material when compaction
and heat treatment is applied thereto. Additives such as for example succinate ions can be added to the electrolyte and can be incorporated into the coating to increase its resistivity. Alternatively, when the metallic material is selected from the group consisting of copper, nickel, manganese, and chromium, the electrically resistive barrier is the alloy product of interdiffusion between a first and a second layer of the layers of metallic material when compaction and heat treatment is applied thereto.

In another embodiment, the present invention comprises a method for producing a part from a nickel phosphorus or cobalt phosphorus containing alloy. The method comprises providing a plurality of iron particles and disposing a layer of from about 2% to about 20% by weight of a member of the group consisting of nickel phosphorus alloys, cobalt phosphorus alloys and iron phosphorus alloys thereon. The alloy preferably has up to about 20 atomic percent phosphorus and is substantially uniformly coated onto each of said particles. The particles having a layer of the phosphorus containing alloy disposed thereon are pressed at a pressure of up to about 60 tons/si into the shape of a part. The pressed part is heated at a temperature of from about 400 ° to about 850°C for a time period of from about 15 to about 60 minutes to interdiffuse the coating material into the iron particle thereby forming a part from a nickel phosphorus alloy or from a cobalt phosphorus alloy. In a preferred embodiment the alloy thus formed has an electrical resistivity of at least about 100 ohms/mil-ft.

In all of the aforementioned embodiments. The heat treating step (annealing) should preferably be done in a reducing atmosphere. Such an atmosphere can be provided by argon gas, or by nitrogen gas containing hydrogen. By annealing the consolidated part in a reducing atmosphere, the production of internal oxides is prevented.

Examples

Example 1
Coating:

Two hundred (200) grams of 99.9+% iron powder (Haeganaes 1000C) is coated with a layer of zinc by plating the powders with 10wt.% zinc by electrochemically depositing zinc from a cyanide solution in a vibratory fluidized bed. This serves to coat each particle with a uniform thin film of zinc.

Pressing:

A small sample, enough to create a pressed disk of about .125" thick, (approximately 3 grams) of the coated powders are charged into a 0.5 inch cylindrical die and into a 1 inch die, respectively of a uni-axial 50 ton hydraulic press (Dake 50H) and pressed at a pressure of 30 Tsi. The pressed disk is removed from the die and its center is bored out creating an annular shaped structure with a hole measuring about 0.8 times the diameter centered on the diameter.

Magnetic Instrumentation:

Two coils are wound on the disk using 24 gauge insulated copper transformer wire. Each coil has 50 turns of wire, tightly wound through the center of the annular disk. A current of 0.8 amps is applied through the first coil. The second coil is connected to a 16 bit A/D converter and then to a computer to record data. The current is applied by a galvanostat whose frequency response is not dependent on frequency at frequencies up to about 18 KHz. The current waveform is determined by a voltage waveform across a resistor connected to a galvanostat controlled by a function generator. Waveforms are either a sine wave or a saw tooth wave at frequencies that vary from about 50 Hz to 200 Hz. The results of this is shown at 60Hz below:

Results:

Saturation induction: 4855 Gauss
Core loss at 60Hz (watts/pound): 2.68

Example 2

Coating:

Two hundred (200) grams of 99.9+% iron powder (Haeganaes 1000C) are coated with a layer of nickel and then with a layer of copper to atomic ratio (57Cu, 43Ni) by plating the powders by electrochemically depositing nickel and then copper from an electrolyte solution in a vibratory fluidized bed. This serves to coat each particle with a uniform thin film of first nickel, then copper.

Pressing:

A small sample, enough to create a pressed disk of about .125" thick, (approximately 3 grams) of the coated powders are charged into a 0.5 inch cylindrical die and into a 1 inch die, respectively of a uni-axial 50 ton hydraulic press (Dake 50H) and pressed at a pressure of 30 Tsi (tons/square inch). The pressed disk is removed from the die and its center is bored out creating an annular shaped structure with a hole measuring about 0.8 times the diameter centered on the diameter. The disk is heated at 450°C for 30 minutes to form a constant boundary between compressed iron particles.

Magnetic Instrumentation:

Two coils are wound on the disk using 24 gauge insulated copper transformer wire. Each coil has 50 turns of wire, tightly wound through the center of the annular disk. A current of 0.8 amps is applied through the first coil. The second coil is connected to a 16 bit A/D converter and then to a computer to record data. The current is applied by a galvanostat whose frequency response is not dependent on frequency at frequencies up to about 18 KHz. The current waveform is determined by a voltage waveform across a resistor connected to a galvanostat controlled by a function generator.
Waveforms are either a sine wave or a saw tooth wave at frequencies that vary from about 50 Hz to 200 Hz. The results at 60 Hz of this is shown below:

5 Results:

Saturation induction: 5300 Gauss
Core loss at 60 Hz (watts/pound): 5.08

10 Example 3
Coating:

Two hundred (200) grams of 99.9+% iron powder (Haeganaes 1000C) are coated with an alloy of 45Fe, 35Ni and 20Cr (atomic percent) so that the coating is 2 wt% of total weight of particle. The particles are further coated with zinc by plating the powders with 2wt.% zinc by electrochemically depositing zinc from a cyanide solution in a vibratory fluidized bed. This serves to coat each particle with a uniform thin film of zinc for lubricating purposes.

Pressing:

A small sample, enough to create a pressed disk of about .125" thick, (approximately 3 grams) of the coated powders are charged into a 0.5 inch cylindrical die and into a 1 inch die, respectively of a uni-axial 50 ton hydraulic press (Dake 50H) and pressed at a pressure of 30 Tsi. The pressed disk is removed from the die and its center is bored out creating an annular shaped structure with a hole measuring about 0.8 times the diameter centered on the diameter. The disk is heated at 400 °C for 1 hour to bond the structure together.

Magnetic Instrumentation:

Two coils are wound on the disk using 24 gauge insulated copper transformer wire. Each coil has 50 turns of wire, tightly wound through the center of the annular disk.
current of 0.8 amps is applied through the first coil. The second coil is connected to a 16 bit A/D converter and then to a computer to record data. The current is applied by a galvanostat whose frequency response is not dependent on frequency at frequencies up to about 18 KHz. The current waveform is determined by a voltage waveform across a resistor connected to a galvanostat controlled by a function generator. Waveforms are either a sine wave or a saw tooth wave at frequencies that vary from about 50 Hz to 200 Hz. The results of the analysis of magnetic properties are shown below:

Results:

Saturation induction : 6000 Gauss
Core loss at 60 Hz (watts/pound): 3

Example 4
Coating:

Two hundred (200) grams of 99.9+% iron powder (Haeganaes 1000C) are coated with layer of NiPCu so that the coating is 3 wt% of total weight of particle by electrochemically depositing NiPCu from a cyanide solution in a vibratory fluidized bed. This serves to coat each particle with a uniform thin film of nickel phosphorus for insulation.

Pressing:

A small sample, enough to create a pressed disk of about .125" thick, (approximately 3 grams) of the coated powders are charged into a 0.5 inch cylindrical die and into a 1 inch die, respectively, of a uni-axial 50 ton hydraulic press (Dake 50H) and pressed at a pressure of 30 Tsi (tons/square inch). The pressed disk is removed from the die and its center is bored out creating an annular shaped structure with a hole measuring about 0.8 times the diameter centered on the diameter. The
disk is heated at 180 °C for 15 minutes create a high resistivity intermetallic.

Magnetic Instrumentation:

Two coils are wound on the disk using 24 gauge insulated copper transformer wire. Each coil has 50 turns of wire, tightly wound through the center of the annular disk. A current of 0.8 amps is applied through the first coil. The second coil is connected to a 16 bit A/D converter and then to a computer to record data. The current is applied by a galvanostat whose frequency response is not dependent on frequency at frequencies up to about 10 KHz. The current waveform is determined by a voltage waveform across a resistor connected to a galvanostat controlled by a function generator. Waveforms are either a sine wave or a saw tooth wave at frequencies that vary from about 1 Hz to 200 Hz. The results of this measurement are shown below and in Fig. 1 showing very low (1Hz) or DC curves wherein B vs. H is plotted for uncoated and coated material respectively and Fig. 2 showing the core loss vs. B for coated and uncoated material:

Results:

Saturation induction (Teslass): 1.5
Core loss (watts/pound): 1
What is claimed is:

1. A method for making soft magnetic parts from particulates of ferrous material comprising the steps of:
   providing a plurality of ferrous particles;
   coating at least one substantially uniform layer of from about 0 wt% to about 15 wt% of a metal onto each of said particles,
   consolidating said coated particles to form a part, and
   heating said part at a temperature and for a time period sufficient to promote the formation of intermetallic phases between the metal layer and the ferrous particle at the boundary there between, said intermetallic phases having an electrical resistivity of greater than about 100 ohms/mil-ft.

2. The method according to claim 1, wherein the coating step is done by electroplating.

3. The method according to claim 1, wherein the heating step is performed at a temperature from about 400 °C to about 1000 °C for a time period from about 10 minutes to about 60 minutes.

4. The method according to claim 1, wherein the ferrous material is selected from the group consisting of iron, steel, cobalt, nickel, cobalt alloys, nickel alloys and mixtures thereof.

5. The method according to claim 4, wherein the metal is selected from the group consisting of cobalt, nickel, zinc, antimony and chromium.

6. The method according to claim 5, wherein the wt.% of the coating is less than 5 wt.%.

7. The method according to claim 5, wherein the metal is nickel.

8. The method according to claim 5, wherein the metal is zinc.

9. The method according to claim 5, wherein the metal is cobalt.

10. The method according to claim 1, wherein the consolidation step is done in the die of a powder press.

11. A method for producing soft magnetic parts comprising the steps of:
providing a plurality of ferrous particles having particle surfaces,
coating from about 0.1 wt.% to about 10 wt.% of a substantially uniform layer of a member selected from the group consisting of electrically resistive alloys, metals that are precursors to electrically resistive alloys and combinations thereof onto said particle surface, said electrically resistive alloy having an electrical resistivity of greater than about 100 ohms/mil-ft.;
consolidating said coated particles to bring particle surfaces in close contact with each other to form a part, and optionally, heating said part at a temperature and for a time period sufficient to promote the formation of an electrically resistive alloy from the layers of alloy precursor metals in a substantially uniform layer around particle surfaces.

12. The method according to claim 11, wherein said coating is done by electroplating.

13. The method according to claim 11, wherein the electrically resistive alloy has an electrical resistance greater than 200 ohms/mil-ft.

14. The method according to claim 12, wherein the electrically resistive alloy is selected from the group consisting of constantin (57Cu, 45Ni), CuMn (87Cu, 13Mn), Invar (65Fe, 35Ni), chromax/chromel D (45Fe, 35Ni, 20Cr), nichrome (80Ni, 20Cr) and Chromel AA (68Ni, 20Cr, 8Fe).

15. The method according to claim 11 wherein the alloy precursor metals are selected from the group consisting of copper, nickel, chromium, manganese and mixtures thereof.

16. The method according to claim 11, wherein the heating step is done at a temperature of from about 400 °C to about 1000°C for a time period of from about 10 minutes to about 60 minutes.

17. A stator for an alternating current generator comprising:
a one piece, die pressed stator core having an annular yoke and a plurality of integral inner circumferentially spaced projections radiating and extending inwardly and
defining slots, said core being comprised of a plurality of die compressed metal coated particles of iron bound together by an electrically insulating material that surrounds each particle, said insulating material being a metalloid comprised of intermetallic phases between the iron and the metal, said metal being selected from the group consisting of zinc, nickel and cobalt.

18. The stator according to claim 16, wherein said intermetallic phases are the reaction product obtained by exposing said die compressed metal coated particles to a temperature of from about 400 °C to about 1000 °C for a time period of from about 10 minutes to about 60 minutes when a layer of said metal is substantially uniformly disposed on each of said particles prior to die pressing.

19. The stator according to claim 16, further comprising a stator coil winding having conducting portions located in the slots.

20. Ferromagnetic powder for use in making parts by powder metallurgy, comprising:

water-atomized non-heat treated ferrous core particles having from about 0.1 wt. % to about 10 wt. % of at least one layer of a substantially uniform coating of metallic material disposed thereon defining a boundary between the ferrous core and the metallic material, said metallic material having the ability to form an electrically resistive barrier at said boundary upon compaction and heat treatment of the coated core particles at a temperature of from about 400 °C to about 1000 °C for a time period of from about 10 minutes to about 60 minutes.

21. The ferromagnetic powder according to claim 20, wherein the metallic material is selected from the group consisting of nickel, zinc and cobalt and the electrically resistive barrier is the metalloid product of the reaction of the ferrous core with the metallic material when compaction and heat treatment is applied thereto.

22. The ferromagnetic powder according to claim 20, wherein the metallic material is selected from the group consisting of copper, nickel, manganese, and chromium and the
electrically resistive barrier is the alloy product of interdiffusion between a first and a second layer of said at least one layer of metallic material when compaction and heat treatment is applied thereto.

23. The ferromagnetic powder according to claim 22, wherein the alloy product is selected from the group consisting of constantin (57Cu, 45Ni), CuMn (87Cu, 13Mn), Invar (65Fe, 35Ni), chromax/chromel D (45Fe, 35Ni, 20Cr), nichrome (80Ni, 20 Cr) and Chromel AA (68Ni, 20Cr, 8Fe).

24. A method for producing a part from a nickel phosphorus or cobalt phosphorus containing alloy comprising the steps of:

- providing a plurality of iron particles;
- disposing a layer of from about 2% to about 20% by weight of a member of the group consisting of nickel phosphorus alloys, cobalt phosphorus alloys and iron phosphorus alloys, said member having up to about 20 atomic percent phosphorus substantially uniformly onto each of said particles;
- compressing the particles having a layer of the phosphorus containing alloy disposed thereon at a pressure of up to about 60 tons psi into the shape of the part;
- heating the pressed part at a temperature of from about 400 ° to about 850°C for a time period of from about 15 to about 60 minutes to interdiffuse the coating material into the iron particle thereby forming a part from a nickel phosphorus alloy or from a cobalt phosphorus alloy.

25. The method according to claim 24, wherein the alloy formed has an electrical resistivity of at least about 100 ohms/mil-ft.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC(6) : H01F 1/22; B22F 1/02; 3/02; C22C 33/02; B32B 15/02; H02K 15/12
US CL : 148/104, 306, 310, 311; 75/246; 428/570, 403; 310/44; 419/35
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
U.S. : 148/104, 306, 310, 311; 75/246; 428/570, 403; 310/44; 419/35

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS
search terms: powder or particle?, coat?, magnet?, ferromagnet?, electric?, resist? or insulat?.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
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<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<tr>
<td>A</td>
<td>US 5,352,522 A (KUGIMIYA et al.) 04 October 1994, col. 4, lines 23-49.</td>
<td>1-23</td>
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<tr>
<td>X</td>
<td>US 4,833,040 A (FISHMAN et al.) 23 May 1989, col. 4, lines 29-34.</td>
<td>20-23</td>
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<tr>
<td>A</td>
<td>US 4,309,457 A (KAWASUMI et al.) 05 January 1982, col. 2, lines 52-64.</td>
<td>20-23</td>
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Further documents are listed in the continuation of Box C. See patent family annex.

Date of the actual completion of the international search
14 MAY 1998

Date of mailing of the international search report
04 JUN 1998

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