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(54) **METAL INJECTION MOLDING MULTIPLE DISSIMILAR MATERIALS TO FORM COMPOSITE ELECTRIC MACHINE ROTOR AND ROTOR SENSE PARTS**

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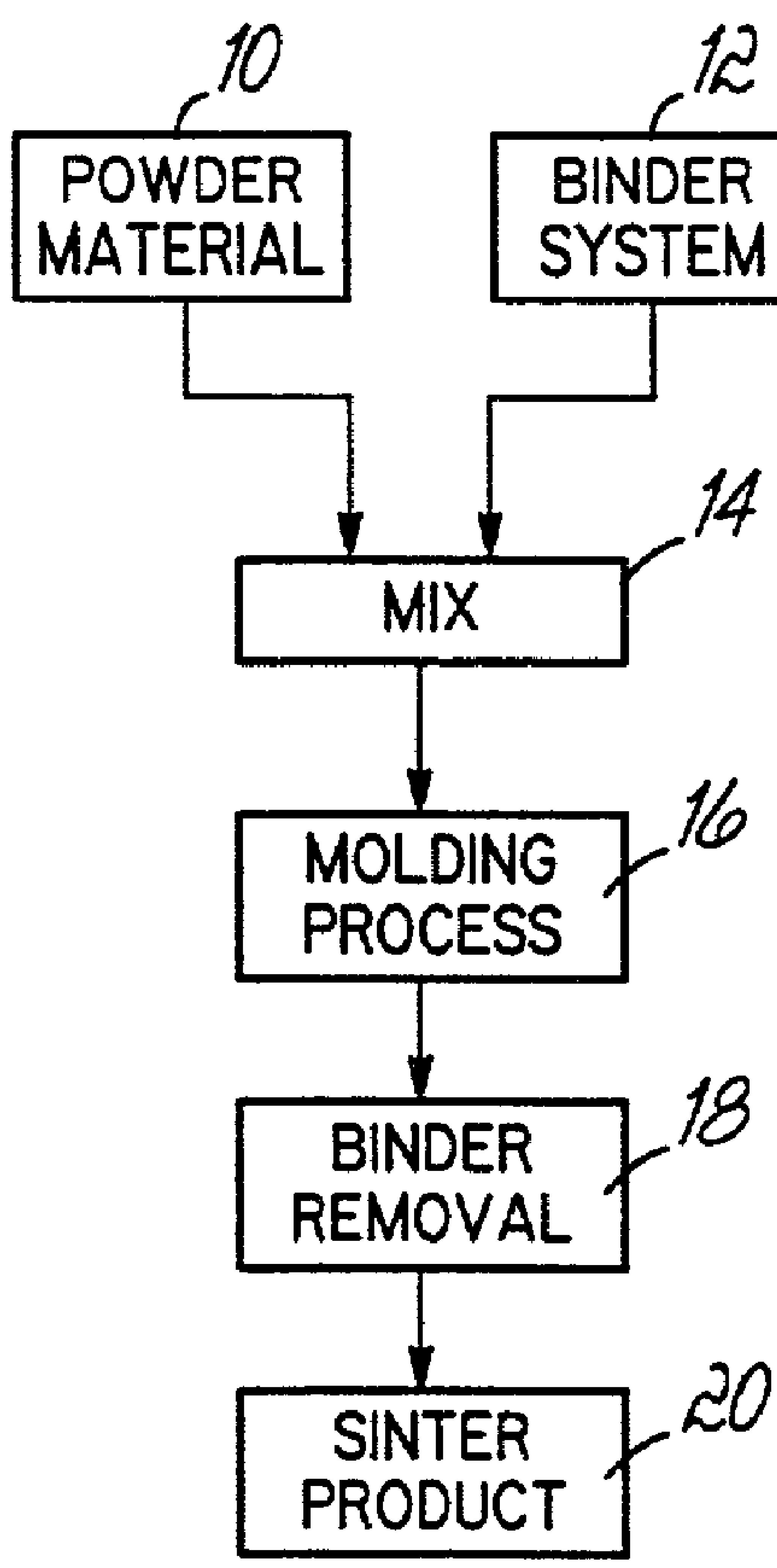
(57) **ABSTRACT**

A method for forming composite motor parts of two or more dissimilar materials by injection molding. Two or more different powder materials are injected under heat and pressure into cavities of a cylindrical-shaped mold and allowed to solidify to form a composite green compact. The final part may be used in machines of the type including permanent magnet, synchronous reluctance, switch reluctance and induction machines.



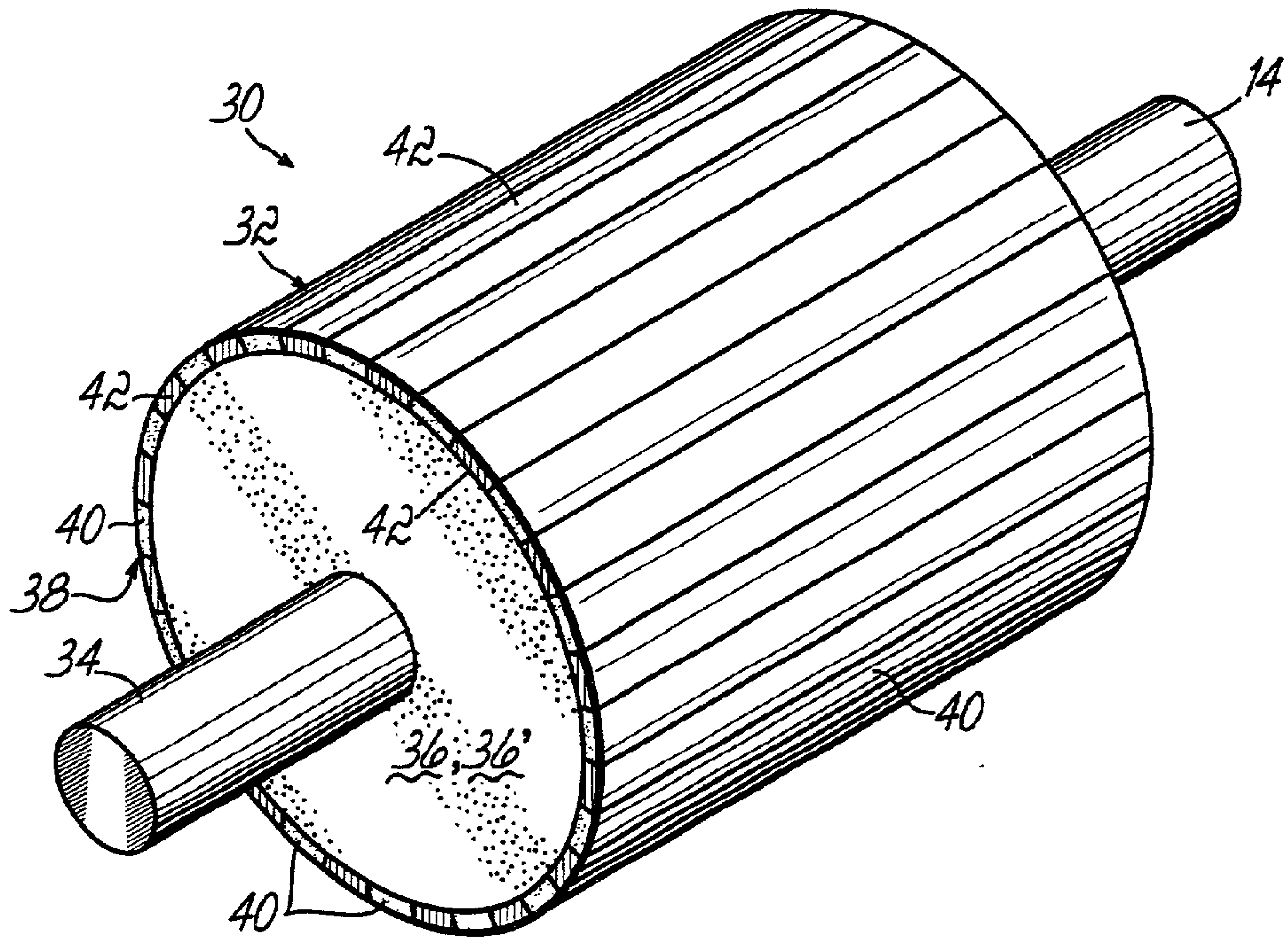


FIG. 2

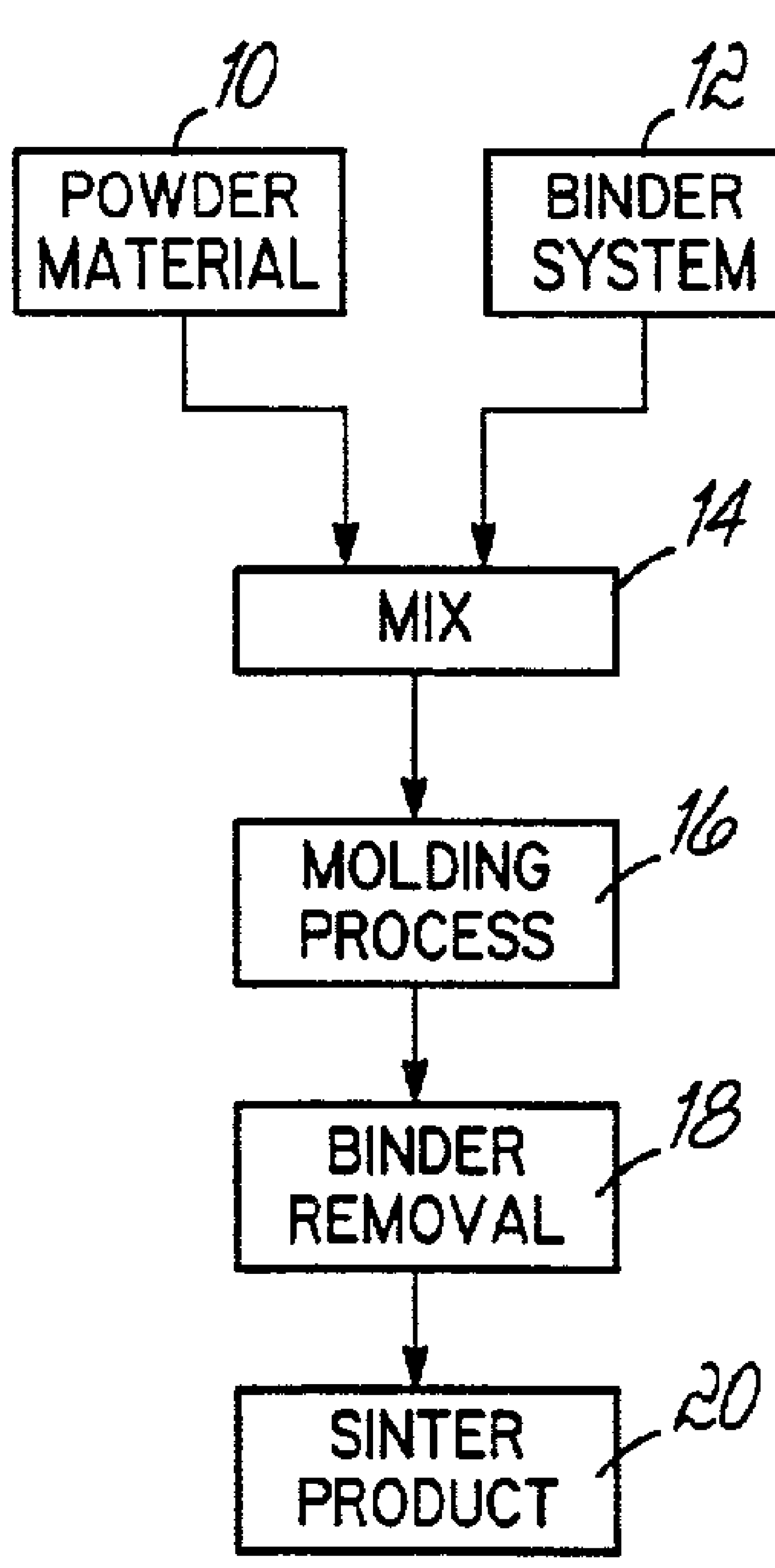


FIG. 1

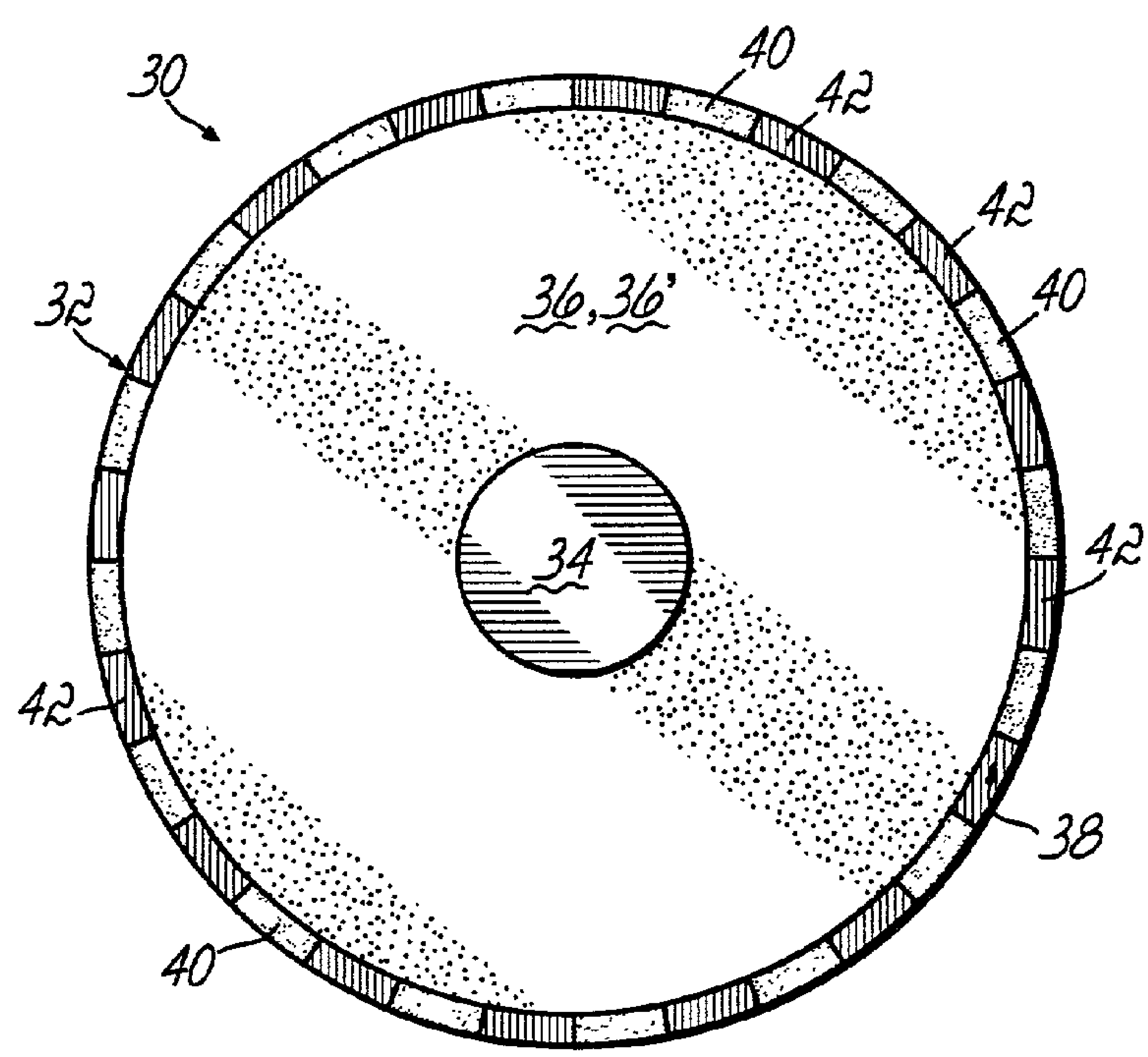


FIG. 3

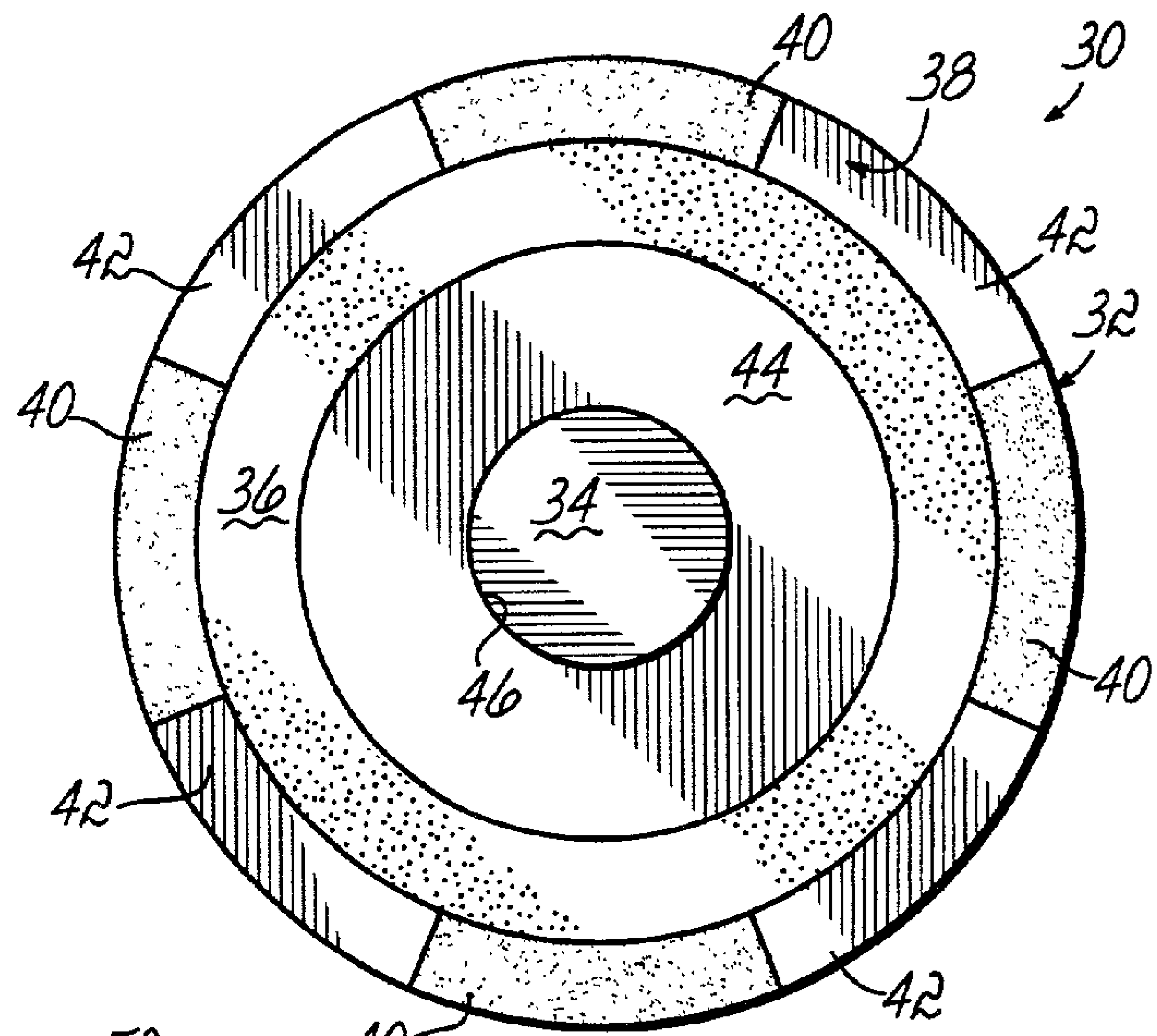


FIG. 4

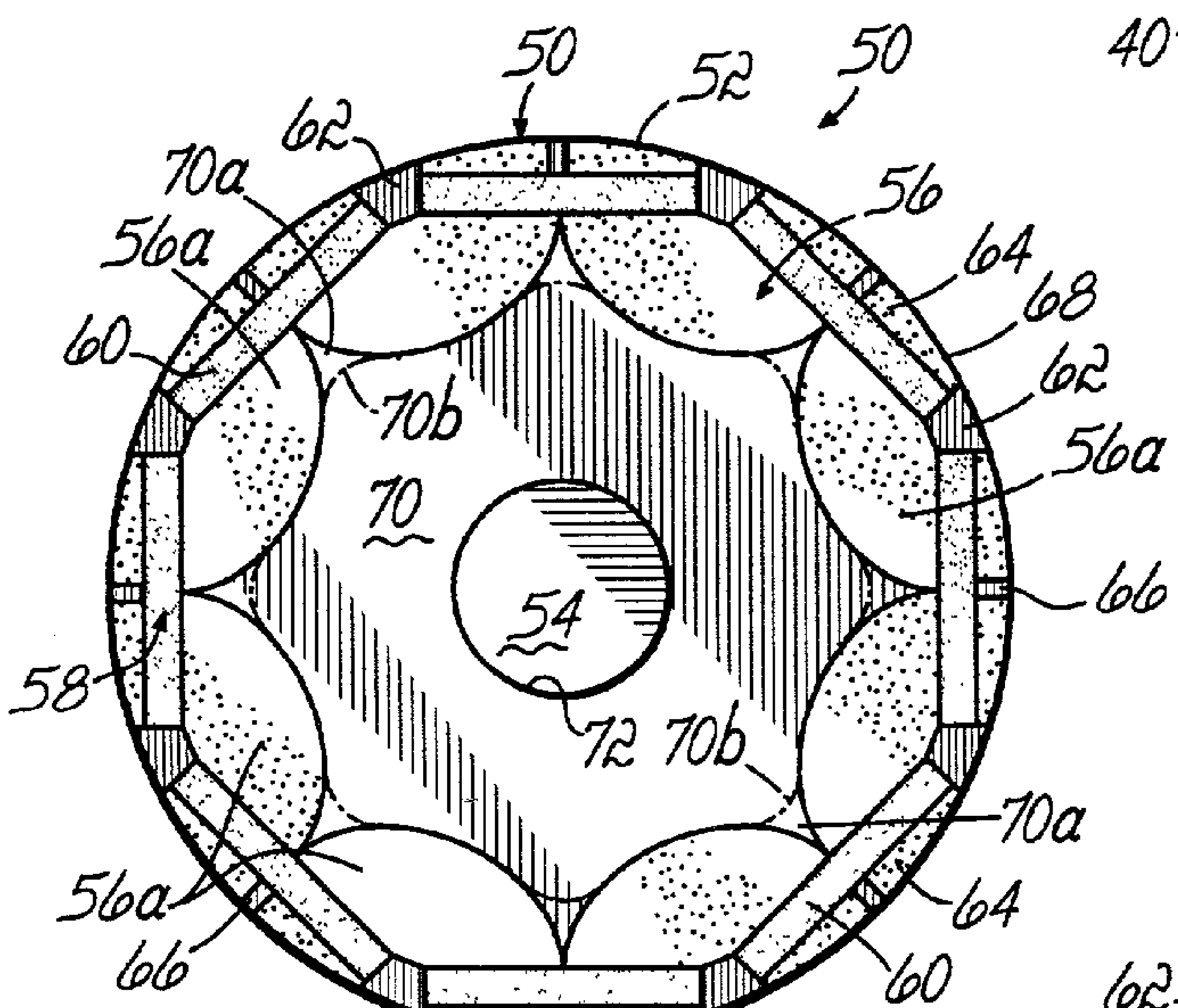


FIG. 5

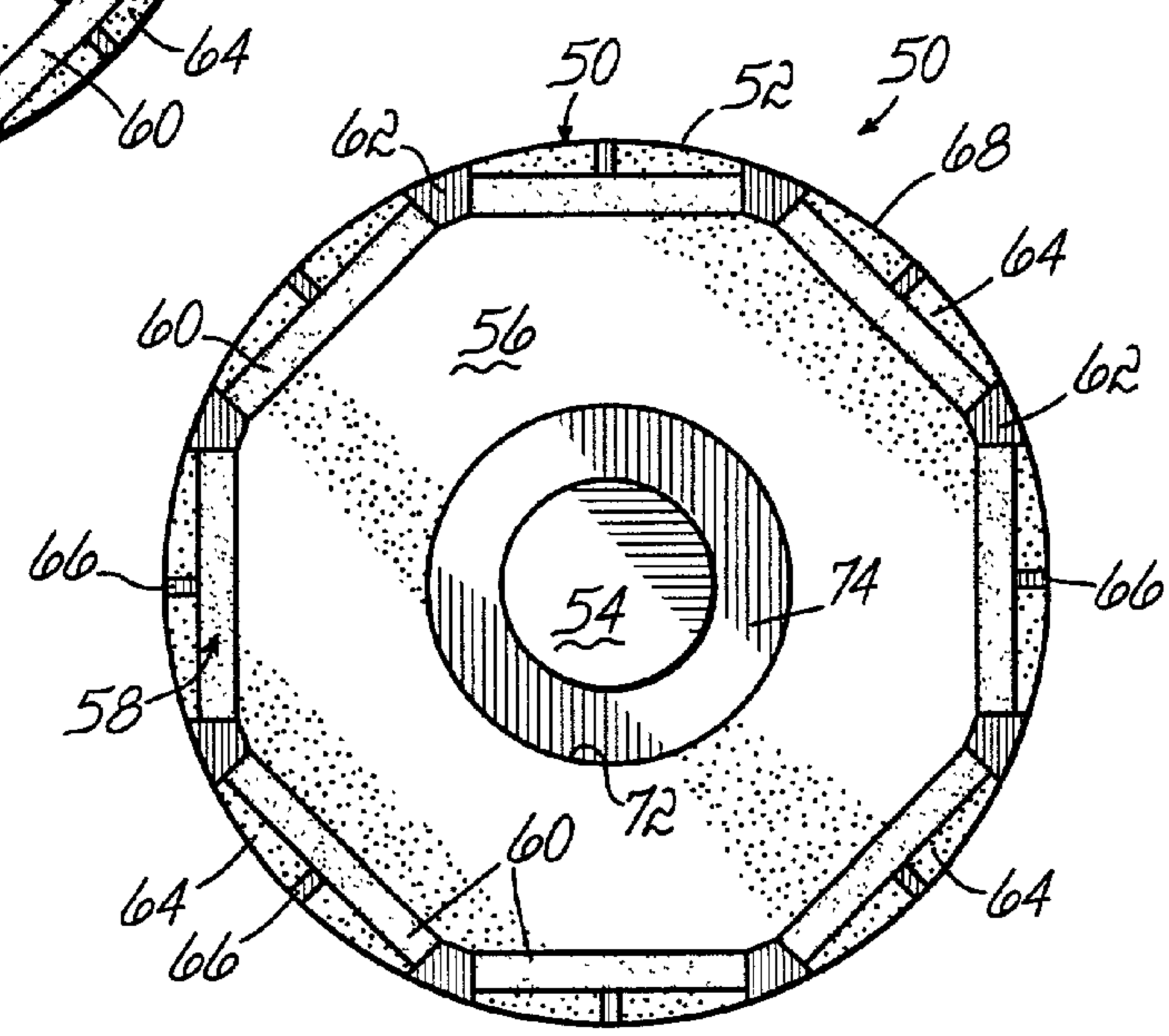


FIG. 6

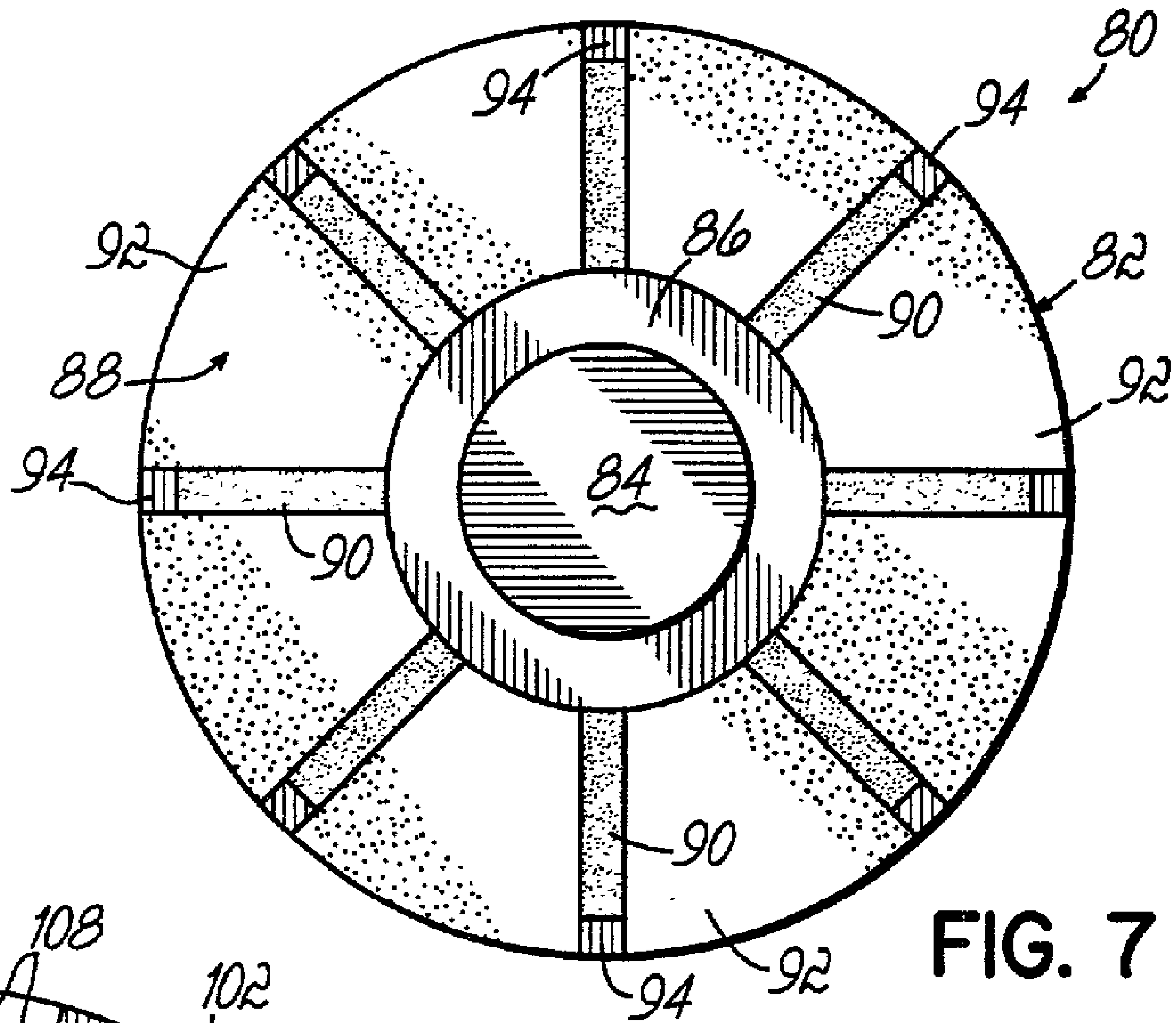


FIG. 7

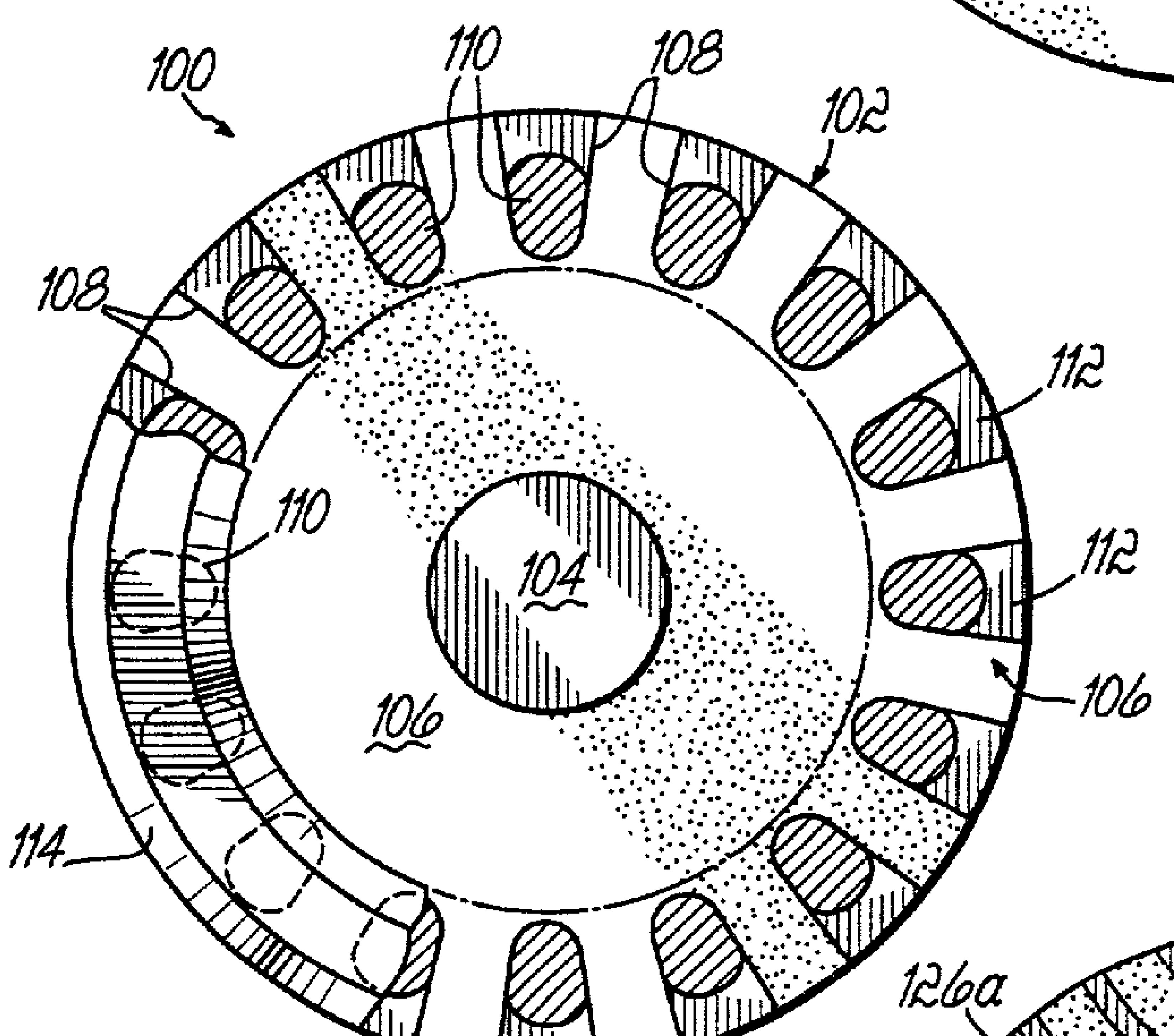


FIG. 8

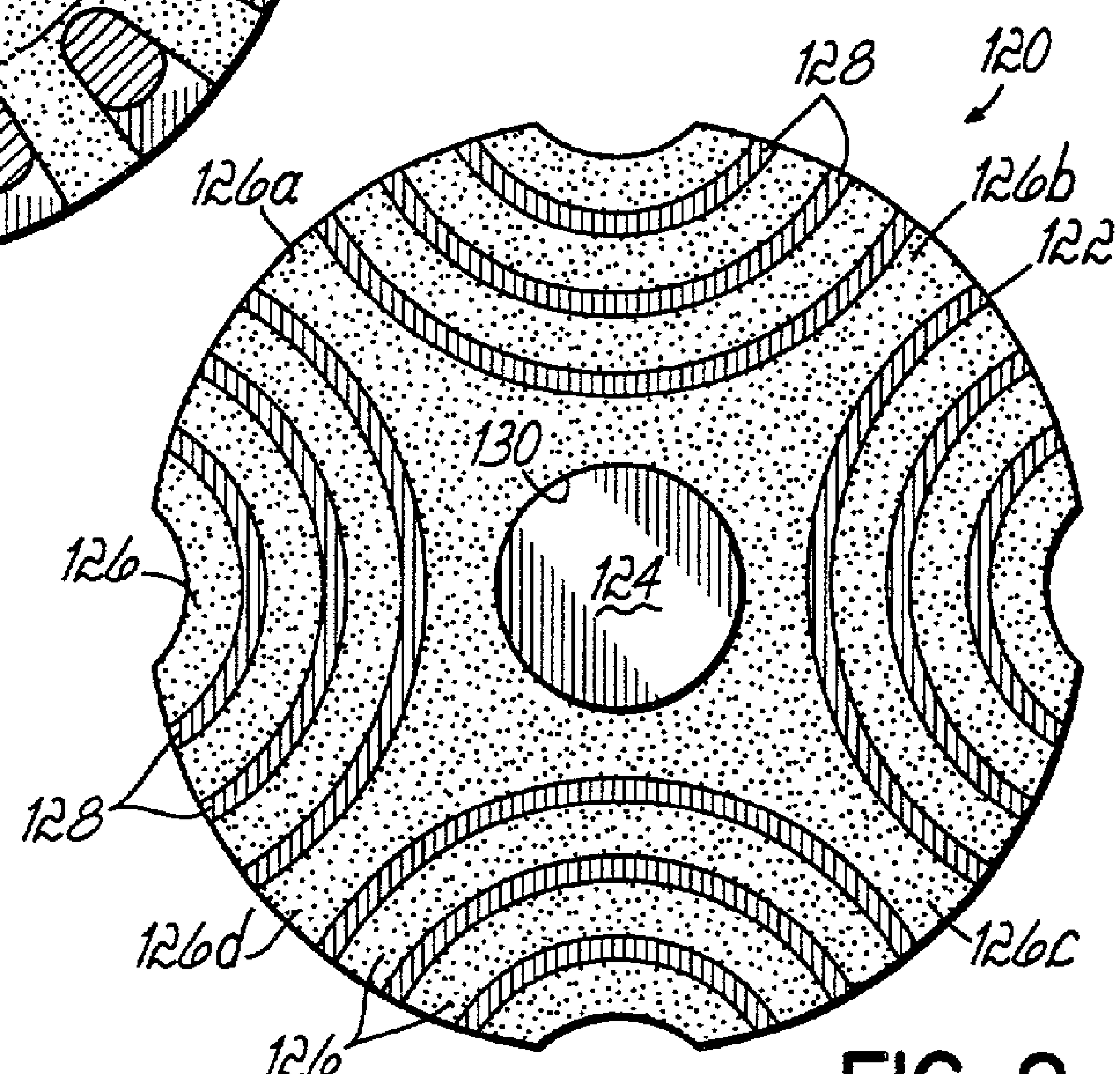


FIG. 9

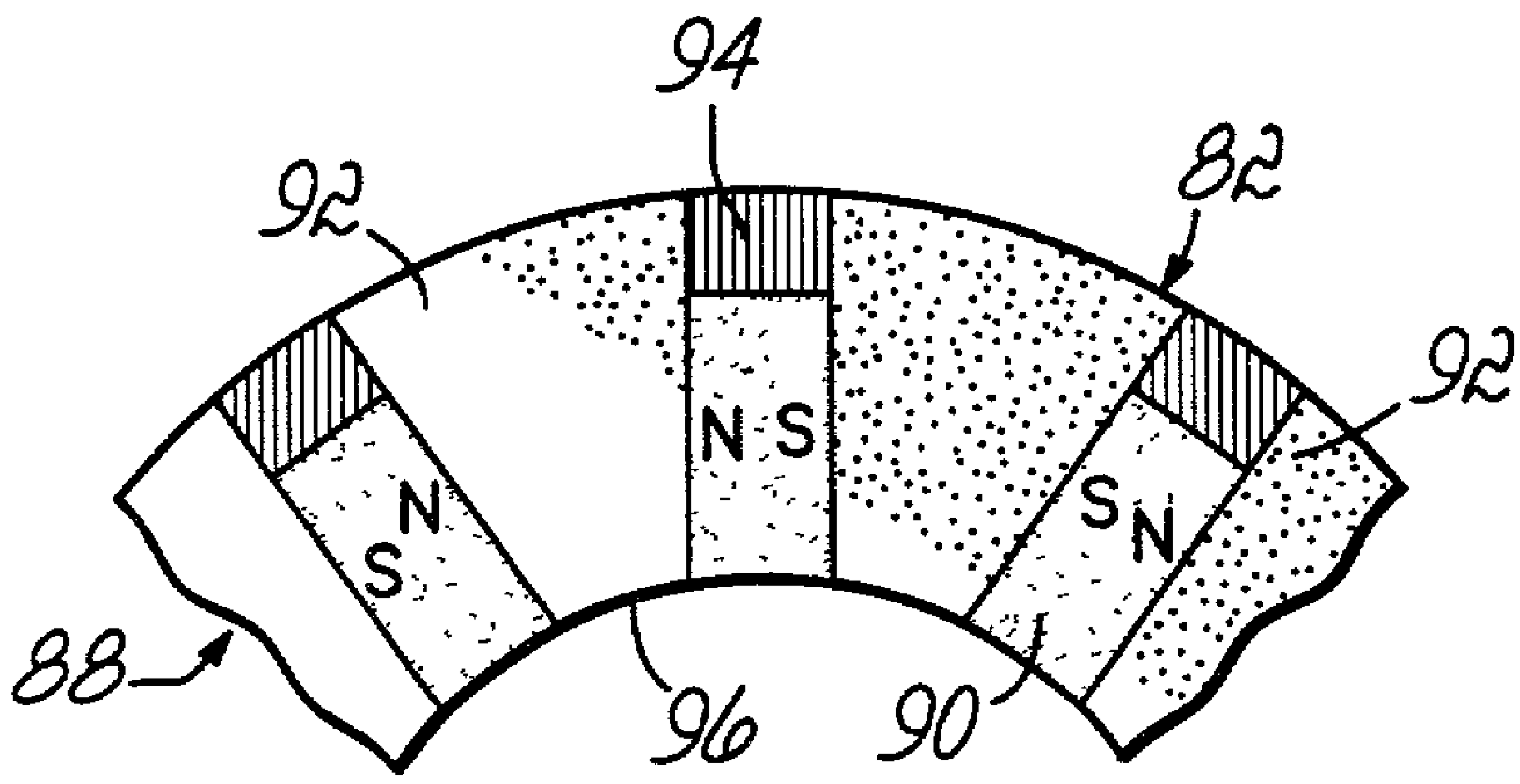


FIG. 7A

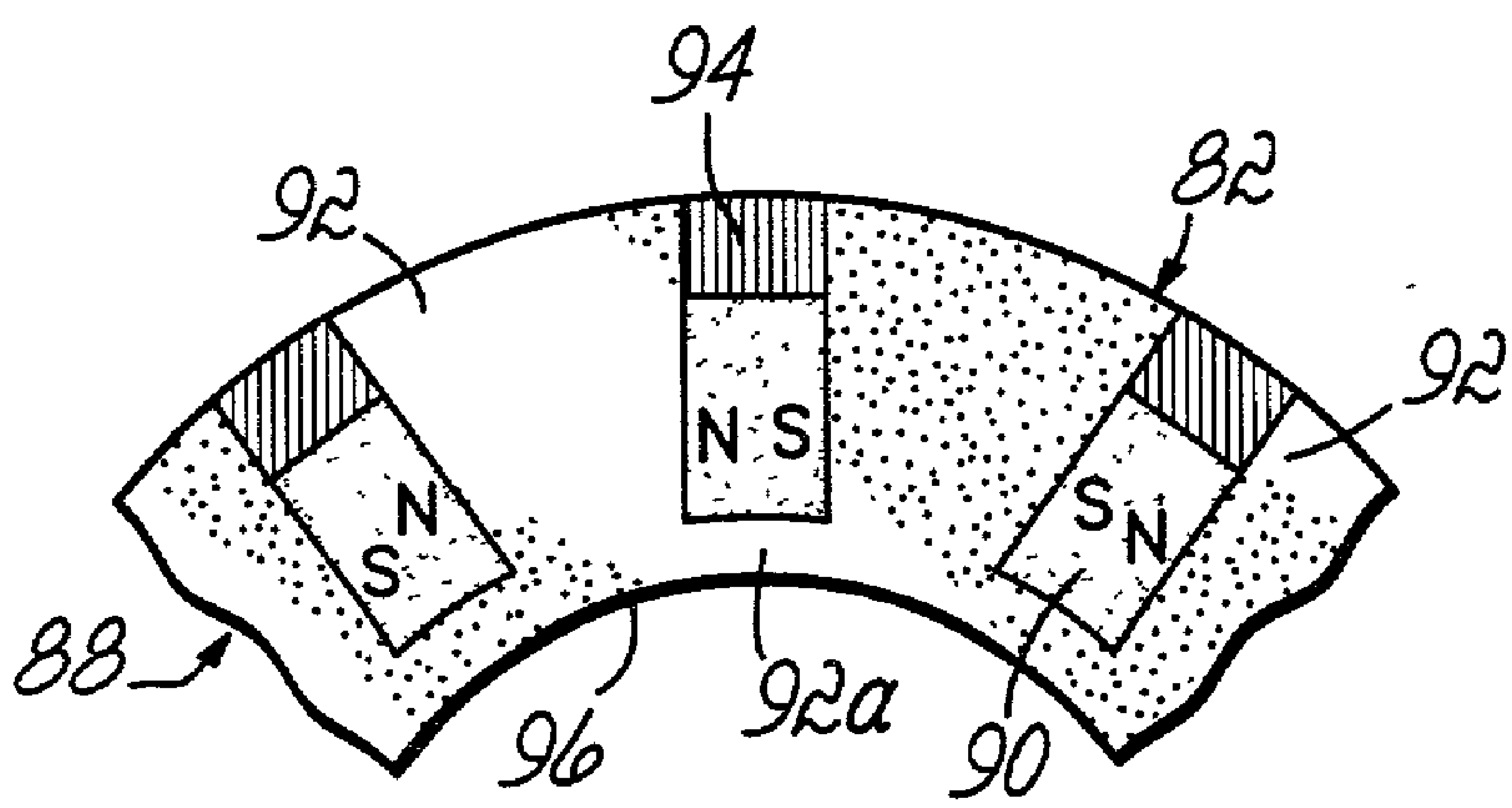


FIG. 7B

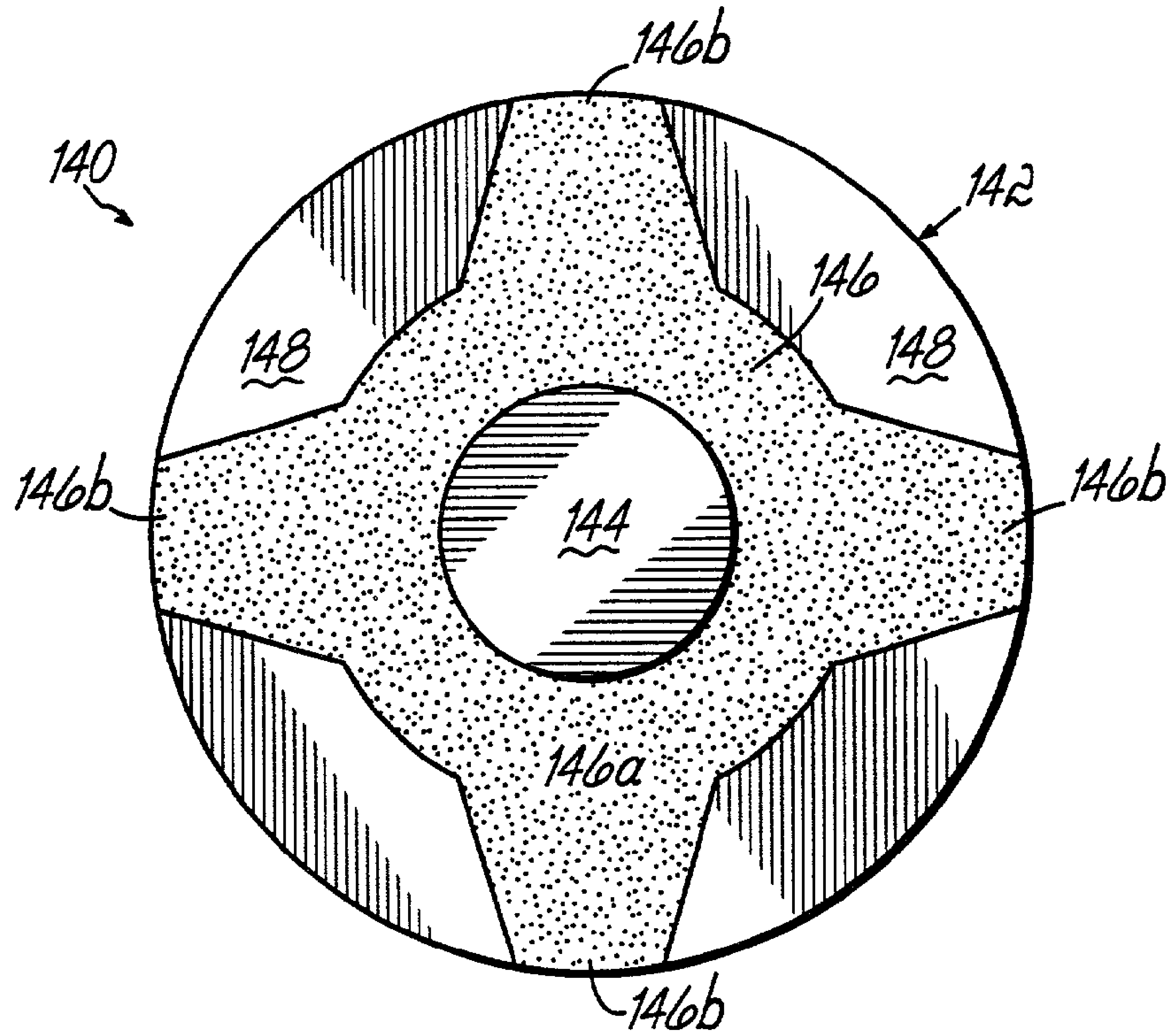

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FIG. 10

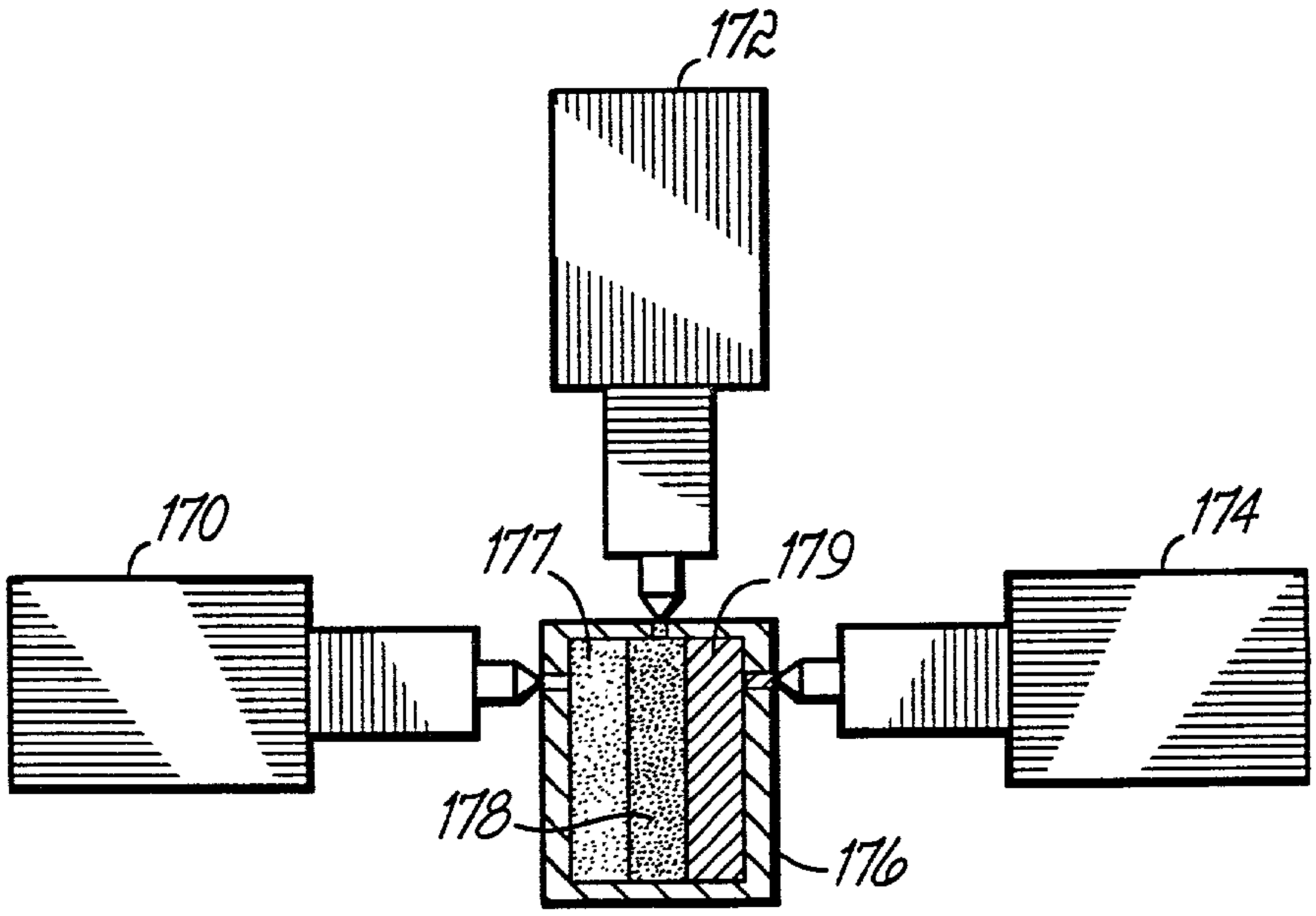
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FIG. 11

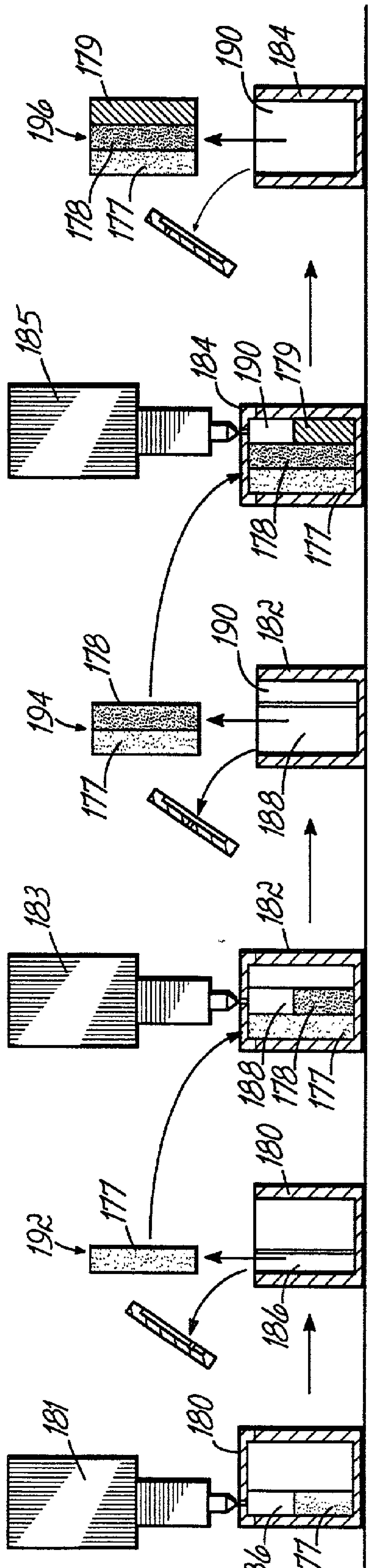
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FIG. 12

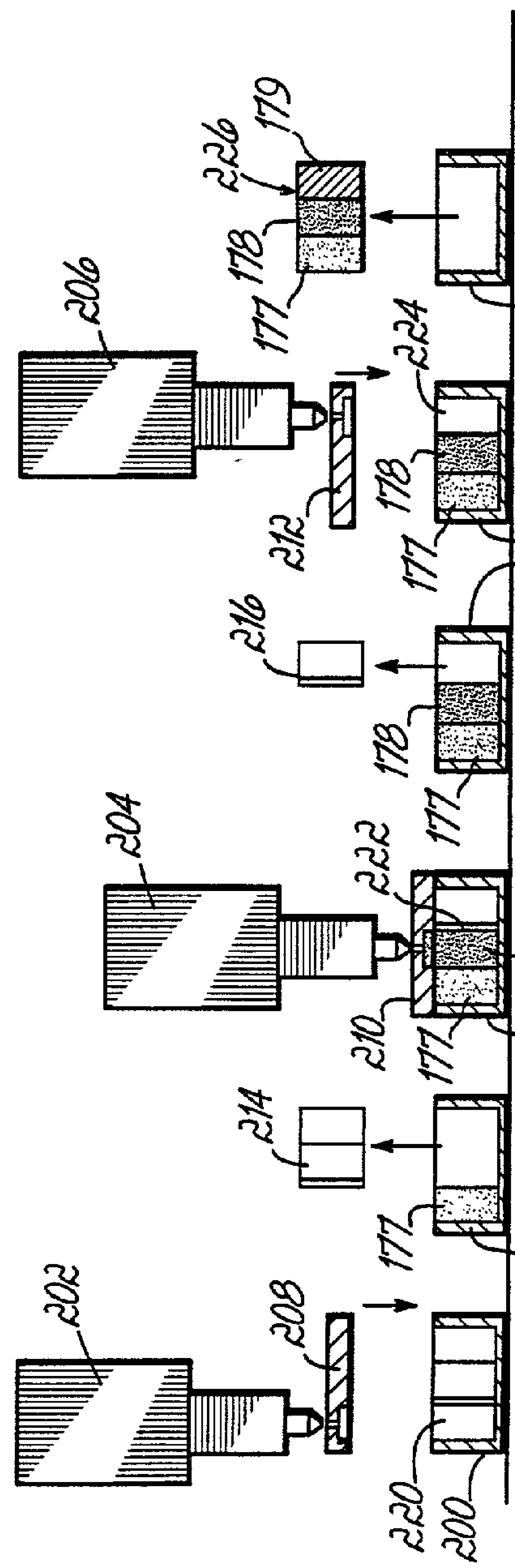
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FIG. 13

METAL INJECTION MOLDING MULTIPLE DISSIMILAR MATERIALS TO FORM COMPOSITE ELECTRIC MACHINE ROTOR AND ROTOR SENSE PARTS

FIELD OF THE INVENTION

[0001] This invention relates generally to composite electric machine rotors and rotor sense parts, and more particularly, to the manufacture of rotors and rotor sense parts by injection molding.

BACKGROUND OF THE INVENTION

[0002] It is to be understood that the present invention relates to generators as well as to motors, however, to simplify the description that follows, a motor will be described with the understanding that the invention also relates to generators. Plastic injection molding technology is well known to the plastics industry for producing parts of simple and complex geometry. The plastic injection molding process involves heating a plastic feedstock until it reaches a state of fluidity, transferring the fluid plastic under pressure into a closed hollow space referred to as a mold cavity, and then cooling the plastic in the mold until it again reaches a solid state, conforming in shape to the mold cavity.

[0003] The metal injection molding (MIM) process combines the structural benefits of metallic materials with the shape complexity of plastic injection molding technology. In the MIM process, a uniform mixture of metallic powder and binders is prepared and injected into a single mold cavity. The binder material provides the proper rheological properties necessary for injection of the metallic material into the mold cavity. Once the part is ejected from the mold, the binder material is removed and the part is then sintered to complete the process. The MIM process is capable of producing single material parts having densities ranging from 93 to 99% of theoretical density. Conventional powder metallurgy compaction techniques can form high density single material parts, but compaction techniques are more limited with respect to the intricate geometries required by some parts. For example, while compaction has about a 2 mm tolerance limit, MIM can be used for any geometry having a dimension at least equal to the size of the particles comprising the metallic powder, i.e., less than 100 μm. While the MIM process has been widely used for formation of single material parts of both simple and complex geometry, fields employing composite materials and parts would benefit from the high density and complex geometry obtainable by the MIM process.

[0004] In the field of electric machine rotors and generators, the machines are typically constructed of stacked axial laminations or stamped radial laminations. These laminations are configured to provide a machine having magnetic, non-magnetic, plastic and/or permanent magnet regions to provide the flux paths and magnetic barriers necessary for operation of the machines. By way of example, synchronous reluctance rotors formed from stacked axial laminations are structurally weak due to problems associated both with the fastening and with shifting of the laminations during operation of their many circumferentially discontinuous components. This results in a drastically lower top speed. Similarly, stamped radial laminations for synchronous reluctance rotors require structural support material at the ends and in the middle of magnetic insulation slots. This results in both structural weakness due to the small slot supports and reduced output power due to magnetic flux leakage through the slot supports. There are various types of machines utilizing rotors that require non-magnetic structural support, including synchronous reluctance type machines, switched reluctance machines, induction type machines, surface type permanent magnet machines, circumferential type interior permanent magnet machines, and spoke type interior permanent magnet machines. Each of these machines comprising rotor components or rotor sense rings of composite magnetic, non-magnetic, plastic and/or permanent magnet laminations suffer from the aforementioned problems.

[0005] While the MIM process has been widely used for formation of single material parts, the field of electric machine rotors and generators would benefit from the high density and complex geometry obtainable by the MIM process. Thus, there is a need for the MIM process to be adapted to the production of electric machine rotor and generator composite parts.

SUMMARY OF THE INVENTION

[0006] The present invention provides a method for forming composite motor parts of two or more dissimilar materials by injection molding. To this end, and in accordance with the present invention, two or more different powder materials are injected under heat and pressure into mold cavities and allowed to solidify to form a composite green compact. At least two of the powder materials are metallic-based, and are different from each other. In an example of the present invention, two or more powder metal materials are each mixed with a binder system to form feedstocks, the feedstocks are melted and concurrently or sequentially injected into a mold and allowed to solidify, and the solidified composite green compact is then subjected to binder removal and sintering processes. The present invention provides composite injection molded parts for machines of the type including permanent magnet, synchronous reluctance, switched reluctance, and induction.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and, together with a general description of the invention given above, and the detailed description given below, serve to explain the principles of the invention.

[0008] **FIG. 1** is a schematic view of the general process steps for manufacturing components by metal injection molding;

[0009] **FIG. 2** is a perspective view of an injection molded powder metal permanent magnet rotor assembly of the present invention having a rotor positioned on a shaft, the rotor having surface permanent magnets spaced around a powder metal magnetically conducting segment and separated by powder metal magnetically non-conducting segments;

[0010] **FIG. 3** is a plan view of the rotor assembly of **FIG. 2**;

[0011] **FIG. 4** is a plan view of an alternative embodiment of an injection molded powder metal permanent magnet rotor assembly of the present invention having surface permanent magnets;

[0012] FIGS. **5-6** are plan views of alternative embodiments of injection molded powder metal permanent magnet rotor assemblies of the present invention having circumferential type interior permanent magnets;

[0013] **FIGS. 7, 7A** and **7B** are plan views of embodiments of an injection molded powder metal permanent magnet rotor assembly of the present invention having spoke type interior permanent magnets;

[0014] **FIG. 8** is a plan view of an embodiment of an injection molded powder metal induction rotor assembly of the present invention having a magnetically conducting segment and a plurality of slots containing conductors enclosed in the slots by magnetically non-conducting segments;

[0015] **FIG. 9** is a plan view of an embodiment of an injection molded powder metal synchronous reluctance rotor assembly of the present invention having a plurality of arcuate magnetically conducting and non-conducting segments;

[0016] **FIG. 10** is a plan view of an embodiment of an injection molded powder metal switched reluctance rotor assembly of the present invention having a magnetically conducting segment and a plurality of magnetically non-conducting segments; and

[0017] FIGS. **11-13** are schematic views of embodiments of a molding step in a metal injection molding process in accordance with the present invention.

DETAILED DESCRIPTION

[0018] The present invention provides a method for metal injection molding of composite rotor parts formed of multiple dissimilar materials. Metal injection molding (MIM) is generally used to refer to injection molding of metallic-based materials; ceramic injection molding (CIM) is generally used to refer to injection molding of ceramic-based materials; and powder injection molding (PIM) is generally used to refer to injection molding of either metal-based or ceramic-based materials. For purposes of the present application, MIM, PIM, CIM and injection molding are used as synonymous terms for the injection molding of powder materials in accordance with the present invention.

[0019] The general process for injection molding is depicted schematically in **FIG. 1**. A powder material **10** and a binder system **12** are selected for the particular part to be molded. In step **14**, the powder and binder are blended or mixed together and granulated or pelletized to provide the feedstock for the subsequent molding process. The powder material **10** is mixed with the binder system **12** to hold the powder material **10** together prior to injection molding. For the molding process **16**, the feedstock is melted and then injected into a mold under moderate pressure (i.e., less than about 10,000 psi) and allowed to solidify to form a green compact. The green compact is then ejected from the mold.

[0020] The compact is then subjected to a binder removal process **18**, also referred to as debinding or delubing. The debinding step **18** typically involves heating the compact to a temperature sufficient to bum off the binder system, leaving a part which is essentially free of binder. Thermal debinding typically uses temperatures in the range of 100° C.-850° C. The debinding atmosphere may be, for example, nitrogen or nitrogen-based, argon, hydrogen, dissociated ammonia, or mixtures thereof, and may be exothermic or endothermic. Thermal diffusion debinding may be used in which a reducing atmosphere is provided in vacuum. Thermal permeation debinding may be used in which a reducing atmosphere is provided without a vacuum. Thermal wicking debinding may be used in which the part is packed in a ceramic powder or sand. Thermal oxidation debinding may be used in which debinding is performed in air. Thermal catalytic debinding may be used in which nitric acid is used to depolymerize polyacetals from the binder into formaldehyde, which is burned off at the exhaust of the debinding oven. A first stage solvent debinding may also be used prior to a second stage thermal debinding by one of the above methods. The first stage solvent debinding removes a portion of the binder, usually a wax portion, by exposing the part to temperatures less than about 260° C. Solvent immersion debinding involves placing the part in a solvent bath. Solvent vapor debinding places the part above a solvent and further uses vapors to remove the binder. Solvent supercritical debinding is similar to the vapor method, but a pressure is applied to assist and speed up the debinding process. The second stage thermal debinding then removes the remaining portion, typically the backbone binders.

[0021] This binder-free part is then subjected to a sintering process **20**, which typically includes heating to a temperature sufficiently high to insure densification and homogenization of the molded material, typically in a reducing atmosphere. Pressure could be introduced at the sintering temperature to aid in the densification of the part.

[0022] While metal and ceramic injection molding of a single source material, including the steps depicted in **FIG. 1**, is known to those skilled in the art of powder metallurgy, the present invention modifies the known process to permit injection molding of rotor parts comprising more than one material, including soft, hard, and non-ferromagnetic materials, and filler materials in sense rings. To this end, and in accordance with the present invention, two or more different feedstocks are prepared, each from a powder material **10** and a binder or carrier **12**, such that the mixtures will turn to pastes upon heating. At least two of the powder materials **10** are metallic-based, specifically, soft or hard ferromagnetic metals and non-ferromagnetic metals, and another powder material **10** may be used that is a filler material, such as a plastic, generally used in rotor sense ring parts. The binder or carrier **12** may be, for example, a plastic, wax, water or any other suitable binder system used for metal injection molding. By way of further example, the binder system **12** may include a thermoplastic resin, including acrylic polyethylene, polypropylene, polystyrene, polyvinyl chloride, polyethylene carbonate, polyethylene glycol, and polybutyl methacrylate. Non-restrictive examples of waxes include bees, Japan, montan, synthetic, microcrystalline and paraffin waxes. The binder system may also contain, if necessary, plasticizers, such as dioctyl phthalate, diethyl phthalate, di-n-butyl phthalate and diheptyl phthalate. Generally, a feedstock for metal injection molding will contain a binder system **12** in an amount up to about 70% by volume, with about 30-50% being most common.

[0023] As with the general method described above, each powder/binder mixture is formed into pellets, small balls or granules to provide the feedstocks for the subsequent molding process. Each feedstock is heated to a temperature sufficient to allow the mixture's injection through an injection unit. While although some materials may be injected at temperatures as low as room temperature, the mixtures are typically heated to a temperature between about 85° F. (29° C.) to about 385° F. (196° C.). The melted feedstocks are then injected into a mold, either sequentially or concurrently. The melting and injection are typically conducted in an inert gas atmosphere, such as argon, nitrogen, hydrogen and helium. The rates of injection are not critical to the invention, and can be determined by one skilled in the art in accordance with the compositions of each feedstock. Different injection units are advantageously used for each feedstock to avoid cross-contamination where such contamination should be avoided.

[**0024**] The mold is designed according to the pattern desired for the composite rotor part. Molds for metal injection molding are advantageously comprised of a hard material, such as steel, so as to withstand abrasion from the powder materials. Sliding cores, ejectors, and other moving components can be incorporated in the mold when necessary to form the different material regions of the composite part. Thus, the mold is created to have two or more cavities into which the feedstocks are injected. The cavities correspond to the particular design needed for the desired machine type. The overall mold is generally cylindrical, which corresponds to the general shape of a rotor component for mounting on a shaft to form a rotor assembly of a rotor machine. Rotor components and sense rings have part geometries and material boundaries that are often intricate, such that the tight tolerances achievable in injection molding can enable manufacture of a superior, high density intricate rotor part.

[**0025**] Exemplary embodiments will now be described for various types of rotor components that may be manufactured in accordance with the present invention. These embodiments are by no means exhaustive. Numerous variations exist in rotor design, and such variations are within the ordinary skill of one in the art.

[**0026**] The present invention provides an injection molded composite powder metal rotor component for use in a surface permanent magnet machine, the assembly having an inner annular magnetically conducting segment of injection molded soft ferromagnetic powder metal and an outer annular permanent magnet segment of alternating polarity permanent magnets. The permanent magnet segment may be a continuous magnet ring with regions of alternating polarity around the circumference of the component or may be discrete permanent magnets separated from each other by spaces or by non-ferromagnetic injection molded powder metal segments. The permanent magnets may be prefabricated discrete magnets or a full magnet ring affixed onto the inner annular segment or may be injection molded hard ferromagnetic powder metal. The injection molded component is mounted on a shaft to form a powder metal rotor assembly. A permanent magnet machine incorporating the powder metal rotor assembly of the present invention is simpler to manufacture and at a lower cost than prior surface permanent magnet rotors and exhibits increased efficiency by reducing flux leakage.

[**0027**] The present invention also provides a rotor sense ring having a configuration similar to the rotor component, but having a plastic or other filler material in place of the inner annular magnetically conducting segment.

[**0028**] With reference to the Figures, **FIGS. 2 and 3** depict in perspective view and plan view, respectively, a powder metal surface permanent magnet rotor assembly **30** of the present invention having an injection molded powder metal composite component **32** mounted on a shaft **34**, the component **32** having an inner annular magnetically conducting segment **36** and an outer annular permanent magnet segment **38** comprising a plurality of alternating polarity permanent magnets **40**. The permanent magnets **40** and inner annular segment **36** are formed by injection molding hard ferromagnetic powder metal and soft ferromagnetic powder metal, respectively. In the particular embodiment of **FIGS. 2 and 3**, the permanent magnet segment **38** includes magnetically non-conducting segments **42** separating the permanent magnets **40**. The non-conducting segments **42**, which are formed by injection molding non-ferromagnetic powder metal, provide insulation that directs the magnetic flux from one permanent magnet **40** to the next alternating polarity permanent magnet **40**. Further in this embodiment, the hard, soft and non-ferromagnetic powder metals may be injection molded sequentially or concurrently to form the permanent magnets **40**, the inner annular magnetically conducting segment **36** and the non-conducting segments **42**, respectively. In another embodiment, a plastic powder or filler powder material is injection molded to form a non-conductive inner annular segment **36**N in place of the magnetically conducting segment **36** to thus form a rotor sense ring.

[**0029**] In **FIG. 4**, the composite injection molded powder metal component **32** is similar to that depicted in **FIGS. 2 and 3**, but the component **32** further includes an inner annular non-conducting insert **44** adjacent the interior surface **46** of the component **32** in addition to the inner annular magnetically conducting segment **36**. The insert **44** blocks magnetic flux from being channeled toward the shaft **34**. **FIG. 4** also depicts a lower number of larger permanent magnets **40** separated by thicker non-conducting segments **42** as compared to **FIGS. 2 and 3**. It should be understood, however, that permanent magnet segment **38** may comprise the permanent magnets **40** only, with no separating non-conducting segments **42**.

[**0030**] The present invention further provides an injection molded composite powder metal rotor component for use in a circumferential type interior permanent magnet machine, the component having an optional inner magnetically conducting segment and an outer permanent magnet segment. This outer segment includes alternating polarity permanent magnets separated in between by magnetically non-conducting barrier segments. The permanent magnets are also circumferentially embedded by radially outer magnetically conducting segments optionally having magnetically non-conducting bridge segments extending from the permanent magnets to an outer surface of the component. The outer and optional inner magnetically conducting segments comprise injection molded soft ferromagnetic powder metal. The magnetically non-conducting barrier and optional bridge segments comprise injection molded non-ferromagnetic powder metal. The permanent magnets comprise injection molded hard ferromagnetic powder metal, or may be prefabricated magnets affixed to adjacent segments. The hard, soft and non-ferromagnetic powder metals may be injection molded concurrently or sequentially. The injection molded component is mounted on a shaft to form a powder metal rotor assembly. A circumferential type interior permanent magnet machine incorporating the powder metal rotor assembly of the present invention exhibits increased power and speed capabilities, lower flux leakage, and may be produced at a lower cost.

[0031] **FIGS. 5 and 6** depict in plan view alternative powder metal circumferential type interior permanent magnet rotor assemblies **50** of the present invention having an injection molded powder metal composite component **52** mounted on a shaft **54**, the component **52** having an inner annular magnetically conducting segment **56** and an outer annular permanent magnet segment **58** comprising a plurality of alternating polarity circumferentially extending permanent magnets **60**. The permanent magnet segment **58** includes magnetically non-conducting barrier segments **62** separating the permanent magnets **60**. The non-conducting barrier segments **62** provide insulation that directs the magnetic flux from one permanent magnet **60** to the next alternating polarity permanent magnet **60**. The permanent magnet segment **58** further includes a radially outer magnetically conducting segment **64** adjacent each permanent magnet **60** that embeds the permanent magnet **60** in the component **52**. Each radially outer magnetically conducting segment **64** further includes an intermediate magnetically non-conducting bridge segment **66** that extends radially from a respective permanent magnet **60** to an outer circumferential surface **68** of component **52**. Each bridge segment **66** essentially cuts its respective radially outer magnetically conducting segment **64** in two. It should be understood, however, that the intermediate bridge segments **66** may be omitted from the component. The non-conducting segments **62** provide insulation that directs the magnetic flux from one permanent magnet **60** to the next alternating polarity permanent magnet **60**. **FIG. 5** includes a magnetically non-conducting insert **70** in the inner annular segment **56**. Insert **70** has an essentially star-shaped configuration and extends from the interior surface **72** of the component **52** into tip portions **70***a* or **70***b* that terminate at (**70***a*) or near (**70***b*) a respective permanent magnet **60** in the outer annular permanent magnet segment **58**. As can be seen, the magnetically conducting portions **56***a* of the inner annular magnetically conducting segment **56** direct magnetic flux from one permanent magnet **60** to the next alternating polarity permanent magnet **60**. The insert **70** also blocks magnetic flux from being channeled into the shaft **54**. **FIG. 6** is similar to **FIG. 5**, but the component **52** includes an inner annular non-conducting insert **74** adjacent the interior surface **72** of the component **52**. The insert **74** likewise blocks magnetic flux from being channeled into the shaft **54**.

[0032] Alternatively, component **52** can be made without the inner annular magnetically conducting segment **56**. Thus, component **52** would comprise a ring **58** of alternating polarity circumferentially extending permanent magnets **60** separated by magnetically non-conducting barrier segments **62** and partially embedded by radially outer magnetically conducting segments **64**, with or without bridge segments **66**. Component **52** is then assembled onto a sleeve or cylinder, with or without a separate wrought or machined shaft.

[0033] The present invention provides a composite powder metal rotor assembly for a spoke type interior permanent magnet machine, the component having an optional inner annular non-ferromagnetic powder metal segment and an outer annular permanent magnet segment with a plurality of alternating polarity, radially extending permanent magnets separated by magnetically conducting segments and capped by magnetically non-conducting segments. The outer and optional inner magnetically non-conducting segments comprise injection molded non-ferromagnetic powder metal. Thus, both ends of the permanent magnets are bordered by a structurally robust non-ferromagnetic powder metal material to thereby minimize flux leakage around the magnet ends. The magnetically conducting segments comprise injection molded soft ferromagnetic powder metal. The permanent magnets comprise injection molded hard ferromagnetic powder metal, or may be prefabricated magnets affixed to adjacent segments. The hard, soft and non-ferromagnetic powder metals may be injection molded concurrently or sequentially. The injection molded component is mounted on a shaft to form a powder metal rotor assembly. A spoke type interior permanent magnet machine incorporating the powder metal rotor assembly of the present invention exhibits flux concentration, minimal flux leakage and permits the motor to produce more power than a circumferential interior permanent magnet motor or to produce the same power using less powerful and less expensive magnets, and may be produced at a lower overall cost.

[0034] **FIG. 7** depicts in plan view a powder metal spoke type interior permanent magnet rotor assembly **80** of the present invention having an injection molded powder metal composite component **82** mounted on a shaft **84**, the component **82** having an inner annular magnetically non-conducting segment **86** and an outer annular permanent magnet segment **88** comprising a plurality of alternating polarity permanent magnets **90** separated by magnetically conducting segments **92**. The conducting segments **92** direct the magnetic flux from one permanent magnet **90** to the next alternating polarity permanent magnet **90**. The permanent magnet segment **88** further includes a radially outer magnetically non-conducting segment **94** adjacent each permanent magnet **90** that embeds the permanent magnet **90** in the component **82**.

[0035] Alternatively, a spoke type rotor component **82** can be made without the inner annular magnetically non-conducting segment **86**, as depicted in FIGS. **7A-7B**. Thus, the component **82** comprises an outer annular permanent magnet segment **88** having a plurality of alternating polarity permanent magnets **90** separated by magnetically conducting segments **92** and radially embedded by magnetically non-conducting segments **94**. The magnetically conducting segments **92** can be made with a continuous inner ring **92***a* adjacent the interior surface **96** of the component **82**, as shown in **FIG. 7B**. The inner ring **92***a* can be minimized or eliminated by machining. Magnets **90** can be prefabricated and affixed into the component **82** or can be hard ferromagnetic powder metal injected concurrently or sequentially with the other powder metals. Component **82** can be assembled onto a sleeve or cylinder (not shown), with or without a separate wrought or machined shaft (not shown).

[0036] The present invention provides an injection molded composite powder metal rotor component for use in an induction machine, the component comprising a magnetically conducting segment with spaced axially extending slots around the exterior surface of the component for receiving a plurality of conductors. A magnetically non-conducting segment encloses each slot opening adjacent the exterior surface of the component. The conductors may be cast into the slots of the composite components or may be prefabricated bars inserted into the slots. The magnetically conducting segment comprises injection molded soft ferromagnetic powder metal. The magnetically non-conducting segments comprise injection molded non-ferromagnetic powder metal. The soft and non-ferromagnetic powder metals may be injection molded concurrently or sequentially. The injection molded component is mounted on a shaft to form a powder metal rotor assembly. An induction machine incorporating the powder metal rotor assembly of the present invention can obtain high speeds with low flux leakage, and yet may be produced at a lower cost.

[**0037**] **FIG. 8** depicts in plan view a powder metal induction rotor assembly **100** of the present invention having an injection molded powder metal composite component **102** mounted on a shaft **104**, the component **102** having a magnetically conducting segment **106** and a plurality of slots or slot openings **108** extending along the axial length of the component **102**. Within each slot **108** is a conductor **110** enclosed by a magnetically non-conducting segment **112**. Thus, each slot **108** receives a conductor **110** in a radially inner portion of the slot **108**, and a radially outer portion of the slot **108** comprises the non-conducting segment **112** such that the conductors **110** are embedded within the rotor assembly **100**. At each end of the rotor assembly **100** is an end ring **114**, which end rings **114** are integral with the conductors **110**. In one embodiment of the present invention, the end rings **114** are cast together with the conductors **110**. In an alternative embodiment of the present invention, the conductors **110** are first inserted into the slot openings **108**, and then the end rings **114** are placed at either end of the assembly **100** and the conductors **110** are affixed to the end rings **114** by any suitable means. As may be appreciated by one skilled in the art, the end rings **114** may include molded fan blades (not shown).

[**0038**] The present invention provides an injection molded composite powder metal rotor component for use in a synchronous reluctance machine, the component having alternating magnetically conducting and magnetically non-conducting segments. The magnetically conducting segments comprise injection molded soft ferromagnetic powder metal. The magnetically non-conducting segments comprise injection molded non-ferromagnetic powder metal. The soft and non-ferromagnetic powder metals may be injection molded concurrently or sequentially. The injection molded component is mounted on a shaft to form a powder metal rotor assembly. A synchronous reluctance machine incorporating the powder metal rotor assembly of the present invention exhibits power density and efficiency comparable to induction motors and improved high speed rotating capability, yet may be produced at a lower cost.

[**0039**] **FIG. 9** depicts in plan view a powder metal synchronous reluctance rotor assembly **120** of the present invention having an injection molded powder metal composite component **122** mounted on a shaft **124**, the component **122** having a plurality of alternating magnetically conducting segments **126** and non-conducting segments **128**. In the particular embodiment of **FIG. 9**, the segment **126***a* adjacent the interior surface **130** of the component **122** is a conducting segment **126**. This segment **126** essentially forms four equiangular spaced, radially extending arm portions **126***a-d* that define axially extending channels there between. Within those channels are alternating layers of magnetically non-conducting segments **128** and magnetically conducting segments **126**. It should be understood, however, that the segment adjacent the interior surface **130** may be non-conducting, with alternating layers of magnetically conducting segments **126** and magnetically non-conducting segments **128** in the channels. A variety of other magnetic configurations are known and well within the skill of one in the art.

[**0040**] The present invention provides an injection molded composite powder metal rotor component for use in a switched or variable reluctance machine, the component having a magnetically conducting segment and a plurality of magnetically non-conducting segments. The magnetically conducting segment comprises injection molded soft ferromagnetic powder metal. The magnetically non-conducting segments comprise injection molded non-ferromagnetic powder metal. The soft and non-ferromagnetic powder metals may be injection molded concurrently or sequentially. The injection molded component is mounted on a shaft to form a powder metal rotor assembly. A switched reluctance machine incorporating the powder metal rotor assembly of the present invention exhibits low windage losses as compared to assemblies comprising stamped laminations.

[**0041**] **FIG. 10** depicts in plan view a powder metal switched reluctance rotor assembly **140** of the present invention having an injection molded composite powder metal component **142** mounted on a shaft **144**, the component having a magnetically conducting segment **146** that has a yoke portion **146***a* and a plurality of equiangular spaced, radially extending teeth **146***b* defining channels there between, and magnetically non-conducting segments **148** in the channels between the teeth **146***b*. The non-conducting segments **148** function to cut down on windage losses.

[**0042**] In an embodiment of the present invention, the soft ferromagnetic powder metal used in the above-described components is nickel, iron, cobalt or an alloy thereof. In another embodiment of the present invention, this soft ferromagnetic metal is a low carbon steel or a high purity iron powder with a minor addition of phosphorus, such as covered by MPIF (Metal Powder Industry Federation) Standard 35 F-0000, which contains approximately 0.27% phosphorus. In general, AISI 400 series stainless steels are magnetically conducting, and may be used in the present invention.

[**0043**] In an embodiment of the present invention, the non-ferromagnetic powder metal used in the above-described components is austenitic stainless steel, such as SS316. In general, the AISI 300 series stainless steels are non-magnetic and may be used in the present invention. Also, the AISI 8000 series steels are non-magnetic and may be used.

[**0044**] In an embodiment of the present invention, the soft ferromagnetic metal and the non-ferromagnetic metal are chosen so as to have similar densities and sintering temperatures, and are approximately of the same strength, such that upon injection and sintering, the materials behave in a similar fashion. In an embodiment of the present invention, the soft ferromagnetic powder metal is Fe-0.27%P and the non-ferromagnetic powder metal is SS316.

[**0045**] In an embodiment of the present invention, the hard ferromagnetic powder metal used in the above-described components for the permanent magnets is ferrite or rare earth metals.

[0046] Referring further to the Figures to illustrate the method of the present invention, **FIG. 11** depicts one embodiment of the present invention utilizing a single molding machine (not shown) having three injection units **170, 172, 174** for filling a single mold **176** with three dissimilar materials **177, 178, 179**, specifically hard ferromagnetic, soft ferromagnetic and non-ferromagnetic powder metals. As stated above, the mold is generally cylindrically shaped, which corresponds to the general shape of a rotor assembly. Depending on the pattern of the part to be molded, the injection units **170, 172, 174** may be stationary during the injection process, or may be rotated or moved in any desired pattern to inject the three materials **177, 178, 179** concurrently or sequentially to form the composite part. Although three different materials are described, it should be understood that the present invention and the embodiment of **FIG. 11** have application for forming parts made of two or more dissimilar materials, in any composite rotor or rotor sense ring pattern. Once all of the materials have been injected and have been allowed to solidify, the mold **176** is opened and the part ejected therefrom. The part may then be subjected to known binder removal and sintering processes to form a final high density composite part.

[0047] **FIG. 12** depicts an alternative embodiment of the method of the present invention. In this embodiment, multiple molds **180, 182, 184** are used to inject each of the dissimilar materials **177, 178, 179** independently or sequentially. A first material or melted feedstock **177** is injected into one or more cavities **186** in the first mold **180** by an injection unit **181** to form the proper shape. For purposes of simplicity of depiction, each mold **180, 182, 184** shown in **FIG. 12** has three cavities **186, 188, 190**, each cavity receiving a different material, for forming a three-material composite part. It is to be understood, however, that a first feedstock **177** may be injected into one cavity **186** or multiple distinct cavities, and a second feedstock **178** different than the first feedstock **177** may be injected into one cavity **188** or multiple distinct cavities, and so on, to form a composite part of two or more materials in any desired rotor or rotor sense ring pattern. After the first material **177** is injected, and allowed to solidify, the partially formed part **192** is then ejected and placed into a second mold **182**. A second dissimilar material **178** is injected into another cavity **188** in mold **182**, either by a second injection unit **183** from the same single machine (not shown), or by an injection unit **183** of a second machine (not shown). After the second material **178** is allowed to solidify, the partially formed part **194** is removed and placed into a third mold **184** for injection of a third dissimilar material **179** by a third injection unit **185**. After the third material **179** is allowed to solidify, the complete molded part **196**, or green compact, is ejected from the third mold **184**, and the compact **196** is debound and sintered. The embodiment shown and described with reference to **FIG. 12** may be used to form composite components having two or more dissimilar materials, in any composite rotor or rotor sense ring pattern.

[0048] **FIG. 13** depicts yet another embodiment of the method of the present invention using a progressive or sequential molding process where the rotor part to be formed remains in a single mold. In this process, a bottom or ejector mold half **200** is shuttled from one injection unit **202** to another **204, 206** through a series of mating top mold halves **208, 210, 212** that contain the required runner system to inject the multiple dissimilar materials into the mold cavities **220, 222, 224** to form the desired composite rotor or rotor sense ring pattern. Removable cores **214, 216** may be used in conjunction with the top mold halves. Other runner system and core designs are within the ordinary skill of one in the art, and the invention should in no way be limited to the particular designs depicted herein. More specifically, the bottom mold half **200** is placed under a first injection unit **202** and first top mold half **208** for injection of a first material or melted feedstock **177** into one or more cavities **220** in the bottom mold half **200**. Again for simplicity of depiction, the mold **200** shown in **FIG. 13** has three cavities **220, 222, 224** formed by placement of the cores **214, 216**, each cavity receiving a different material, for forming a three-material composite part. The bottom mold half **200** is then moved to a second top mold half **210** and second injection unit **204**, which is either a second injection unit **204** in a single molding machine (not shown), or the injection unit **204** of a different machine (not shown). A second dissimilar material **178** is then injected into one or more cavities **222** in the bottom mold half **200**. The bottom mold half **200** is then moved to yet a third top mold half **212** and third injection unit **206** for injection of a third dissimilar material **179** into one or more cavities **224** of the bottom mold half **200**. After the materials have all solidified, the complete molded part **226**, or green compact, is ejected from the bottom mold half **200**, and the compact **226** is debound and sintered. The embodiment shown and described with reference to **FIG. 13** may be used to form composite components having two or more dissimilar materials, in any composite rotor or rotor sense ring pattern.

[0049] It should be understood that there is no limit to the number of cavities or geometry of the cavities in a mold for forming a composite rotor or rotor sense ring part, nor is there a limit to the number of dissimilar materials that may ultimately form the composite part. Sliding cores, removable cores, ejectors, and other moving components can be incorporated in one or more of the molds used in practicing the present invention whenever necessary to form the composite part. Although alternative embodiments for practicing the invention have been described, the invention should in no way be limited to the particular mold designs or methods described. The present invention provides a method for forming composite rotor parts of multiple dissimilar materials by metal injection molding, regardless of the part or mold geometry.

[0050] It should be further understood that dissimilar materials behave differently during injection and solidification, such that the dissimilar materials should be selected or manipulated to have similar shrinkage ratios, as well as compatible binder removal and sintering cycles to minimize defects in the final product, where such defects would render the part unacceptable for its purpose. By way of example only, particle size, particle size distribution, particle shape and purity of the powder material can be selected or manipulated to affect such properties or parameters as apparent density, green strength, compressibility, sintering time and sintering temperature. The amount and type of binder mixed with each powder material may also affect various properties of the feedstock, green compact and sintered component, and various process parameters. The method for forming the powder materials, including mechanical, chemical, electrochemical and atomizing processes, also can affect the performance of the powder material during the injection molding process.

[0051] Following ejection of the parts from the mold, the molded parts are debound to remove the binder material. Debinding processes are well known to those skilled in the art of powder metallurgy, and are described in detail above. By way of example, one general practice in the industry for thermal debinding includes heating to a temperature in the range of about 100° C. to about 850° C., typically about 760° C. (1400° F.), and holding at that temperature for less than about 6 hours, typically about 2 hours, to burn off the binder material.

[0052] The composite part is then subjected to a sintering process, which is also well known to those skilled in art of powder metallurgy. The sintering step typically comprises raising the temperature from the debinding step to a higher temperature in the range of about 1742° F. (950° C.) to about 3272° F. (1800° C.), typically about 2050° F. (1121° C.), and holding at that temperature for less than about 6 hours, typically about 2 hours. Sintering achieves densification chiefly by formation of particle-to-particle binding, thereby forming a high-density, coherent mass of two or more materials with clear, well-defined boundaries there between. Densities approaching full theoretical density are possible in the composite parts of the present invention, generally up to about 99% of theoretical.

[0053] The debinding and sintering processes may be conducted separately with intermediate cooling in between, or may be separate consecutive steps in a continuous process. It should be understood that the debinding and sintering times and temperatures may be adjusted as necessary, which adjustment is well within the skill of one in the art. For example, different binder systems may warrant differing debinding processes, temperatures, and time cycles, and different powder materials may warrant differing sintering temperature and time cycles. The debinding and sintering operations may be performed in a vacuum furnace, and the furnace may be filled with an argon or other reducing atmosphere. Alternatively, the processes may be performed in a continuous belt furnace, which is generally provided with a hydrogen/nitrogen atmosphere such as 75% H_2/25% N_2. Other types of furnaces and furnace atmospheres may be used within the scope of the present invention as determined by one skilled in the art.

[0054] While the present invention has been illustrated by the description of embodiments thereof, and while the embodiments have been described in considerable detail, they are not intended to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. The invention in its broader aspects is therefore not limited to the specific details, representative apparatus and methods and illustrative examples shown and described. Accordingly, departures may be made from such details without departing from the scope or spirit of applicant's general inventive concept.

What is claimed is:

1. A method for injection molding composite rotor components, the method comprising:

injecting a ferromagnetic powder material from a first injection unit under heat and pressure into a first mold cavity, and allowing the ferromagnetic material to solidify;

injecting a non-ferromagnetic powder material from a second injection unit under heat and pressure into a second mold cavity adjacent the ferromagnetic material, and allowing the non-ferromagnetic material to solidify to thereby produce a composite injection molded rotor component.

2. The method of claim 1, wherein the ferromagnetic powder material is soft ferromagnetic powder metal or hard ferromagnetic powder metal.

3. The method of claim 1, wherein the ferromagnetic powder material is a soft ferromagnetic powder metal selected from the group consisting of Ni, Fe, Co and alloys thereof.

4. The method of claim 1, wherein the ferromagnetic powder material is a soft ferromagnetic high purity iron powder with a minor addition of phosphorus.

5. The method of claim 1, wherein the non-ferromagnetic powder material is an austenitic stainless steel.

6. The method of claim 1, wherein the non-ferromagnetic powder material is an AISI 8000 series steel.

7. The method of claim 1, wherein the ferromagnetic and non-ferromagnetic powder materials are each combined with a binder prior to injecting.

8. The method of claim 7, further comprising the steps of:

ejecting the composite component from the mold;

subjecting the composite component to debinding to provide a composite part which is essentially free of binder; and

sintering the composite part.

9. The method of claim 1, wherein the first and second injection units are part of a single injection molding machine, with each unit positioned to inject the respective powder material into the respective first and second mold cavity of a single mold.

10. The method of claim 1, wherein the first and second injection units are part of separate injection molding machines, and a single mold having the first and second mold cavities is transferred sequentially to each machine for injecting the respective powder material into the respective first and second mold cavity.

11. The method of claim 1, wherein the first mold cavity is in a first mold and the second mold cavity is in a second mold, and wherein the ferromagnetic powder material is injected into and solidified in the first mold cavity, then removed and inserted into the second mold, and the non-ferromagnetic powder material is injected into and solidified in the second mold cavity.

12. The method of claim 1, further comprising injecting one or more additional powder materials into one or more additional mold cavities, each additional powder material having a different composition than the ferromagnetic and non-ferromagnetic powder materials, to form a composite injection molded component of at least three or more different materials.

13. The method of claim 12, wherein the ferromagnetic powder material is a soft ferromagnetic metal and one additional powder material is a hard ferromagnetic powder metal thereby forming a permanent magnet rotor component.

14. The method of claim 12, wherein the ferromagnetic powder material is a hard ferromagnetic metal and one additional powder material is a plastic filler material thereby forming a rotor sense ring component.

15. The method of claim 1, wherein the non-ferromagnetic powder material is injected concurrently with the ferromagnetic powder material.

16. The method of claim 1, wherein the non-ferromagnetic powder material is injected after the ferromagnetic powder material is allowed to solidify.

17. The method of claim 1 further comprising mounting the composite component on a shaft to form a powder metal rotor assembly.

18. A method for injection molding composite rotor components, comprising the steps of:

preparing at least two different feedstocks, each feedstock comprising a mixture of a powder material and a binder, the powder materials being selected from the group consisting of hard ferromagnetic, soft ferromagnetic and non-ferromagnetic;

feeding each feedstock to a respective injection unit;

melting the feedstocks; and

molding the feedstocks into a composite compact of desired shape comprising at least two different materials by injecting melted feedstock from each injection unit under heat and pressure into a respective portion of a mold, and allowing the feedstocks to solidify.

19. The method of claim 18, further comprising the steps of:

ejecting the compact from the mold;

subjecting the compact to debinding to provide a part which is essentially free of binder; and

sintering the part.

20. The method of claim 18, wherein each feedstock is injected into the respective portion of a single mold to form the composite compact.

21. The method of claim 20, wherein the injection units form a single injection molding machine, with each unit positioned to inject feedstock into the respective portion of the single mold.

22. The method of claim 21, wherein all feedstocks are injected concurrently.

23. The method of claim 21, wherein the feedstocks are injected sequentially.

24. The method of claim 20, wherein each injection unit is part of a separate injection molding machine, and the single mold is transferred sequentially to each machine for injecting the respective feedstock into the respective portion of the single mold.

25. The method of claim 18, comprising repeating the steps of injecting one melted feedstock into the respective portion of the mold and allowing the feedstock to solidify, followed by transferring the solidified feedstock to another mold, until each feedstock has been injected, to thereby form the composite compact.

26. The method of claim 18, wherein the soft ferromagnetic powder metal is Ni, Fe, Co or an alloy thereof.

27. The method of claim 18, wherein the soft ferromagnetic powder metal is high purity iron powder with a minor addition of phosphorus.

28. The method of claim 18, wherein the non-ferromagnetic powder metal is an austenitic stainless steel.

29. The method of claim 18, wherein the non-ferromagnetic powder metal is an AISI 8000 series steel.

30. The method of claim 18, further comprising mounting the composite component on a shaft to form a powder metal rotor assembly.

31. The method of claim 18, wherein a first feedstock is a soft ferromagnetic powder metal injected into an inner annular region of a cylinder-shaped mold, and a second feedstock is a non-ferromagnetic powder metal injected into discrete regions within an outer annular region of the mold so as to leave spaces between each discrete region, and a third feedstock is a hard ferromagnetic powder metal injected into the spaces between the discrete regions of the outer annular region of the mold, whereby upon solidifying a composite powder metal component for a surface permanent magnet machine is formed having an inner annular magnetically conducting segment and an outer annular segment of a plurality of alternating polarity permanent magnets separated by magnetically non-conducting segments.

32. The method of claim 18, wherein a first feedstock is a soft ferromagnetic powder metal injected into an inner annular region of a cylinder-shaped mold, and a second feedstock is a hard ferromagnetic powder metal injected into an outer annular region of the mold, whereby upon solidifying a composite powder metal component for a surface permanent magnet machine is formed having an inner annular magnetically conducting segment and an outer annular permanent magnet ring.

33. The method of claim 18, wherein a first feedstock is a soft ferromagnetic powder metal injected into an inner annular region of a cylinder-shaped mold, and a second feedstock is a non-ferromagnetic powder metal injected into discrete regions within an outer annular region of the mold so as to leave spaces between each discrete region, whereby upon solidifying a composite powder metal component for a surface permanent magnet machine is formed having an inner annular magnetically conducting segment and an outer annular segment of a plurality of spaces separated by magnetically non-conducting segments, the method further comprising affixing pre-fabricated magnets in the spaces in an arrangement of alternating polarity.

34. The method of claim 18, wherein a first feedstock is a non-ferromagnetic powder metal injected into discrete regions within an annular region of the mold so as to leave spaces between each discrete region, and a second feedstock is a hard ferromagnetic powder metal injected into the spaces between the discrete regions of the annular region of the mold, whereby upon solidifying a composite powder metal component for a surface permanent magnet machine is formed having an annular segment of a plurality of alternating polarity permanent magnets separated by magnetically non-conducting segments.

35. The method of claim 18, wherein a first feedstock is a soft ferromagnetic powder metal injected into an inner annular region of a cylinder-shaped mold, a second feedstock is a non-ferromagnetic powder metal injected into discrete first regions within an outer annular region of the mold so as to leave spaces between each discrete first region, and wherein the first feedstock is further injected into two discrete second regions between the first regions so as to leave a radially inner circumferentially extending space and a radially extending space between the two discrete regions, and wherein the second feedstock is further injected into the radially extending spaces, and a third feedstock is a hard ferromagnetic powder metal injected into the radially inner circumferentially extending spaces between the discrete first regions of the mold, whereby a composite powder metal component for a circumferential type interior permanent magnet machine is formed having an inner annular magnetically conducting segment and an outer permanent magnet segment of a plurality of alternating polarity permanent magnets separated by magnetically non-conducting barrier segments and radially embedded by magnetically conducting segments with intermediate magnetically non-conducting bridge segments.

36. The method of claim 18, wherein a first feedstock is a soft ferromagnetic powder metal injected into an inner annular region of a cylinder-shaped mold, a second feedstock is a non-ferromagnetic powder metal injected into discrete first regions within an outer annular region of the mold so as to leave spaces between each discrete first region, and wherein the first feedstock is further injected into two discrete second regions between the first regions so as to leave a radially inner circumferentially extending space and a radially extending space between the two discrete regions, and wherein the second feedstock is further injected into the radially extending spaces, whereby a composite powder metal component for a circumferential type interior permanent magnet machine is formed having an inner annular magnetically conducting segment and an outer permanent magnet segment of a plurality of circumferentially extending spaces separated by magnetically non-conducting barrier segments and radially embedded by magnetically conducting segments with intermediate magnetically non-conducting bridge segments, the method further comprising affixing pre-fabricated magnets in the circumferentially extending spaces in an arrangement of alternating polarity.

37. The method of claim 18, wherein a first feedstock is a non-ferromagnetic powder metal injected into discrete first regions within an annular region of the mold so as to leave spaces between each discrete first region, and wherein a second feedstock is a soft ferromagnetic powder metal injected into two discrete second regions between the first regions so as to leave a radially inner circumferentially extending space and a radially extending space between the two discrete regions, and wherein the first feedstock is further injected into the radially extending spaces, and a third feedstock is a hard ferromagnetic powder metal injected into the radially inner circumferentially extending spaces between the discrete first regions of the mold, whereby a composite powder metal component for a circumferential type interior permanent magnet machine is formed having an outer permanent magnet segment of a plurality of alternating polarity permanent magnets separated by magnetically non-conducting barrier segments and radially embedded by magnetically conducting segments with intermediate magnetically non-conducting bridge segments.

38. The method of claim 18, wherein a first feedstock is a non-ferromagnetic powder metal injected into an inner annular region of a cylinder-shaped mold, a second feedstock is a soft ferromagnetic powder metal injected into discrete first regions within an outer annular region of the mold so as to leave spaces between each discrete first region, and wherein the first feedstock is further injected into discrete radially outer second regions between the first regions so as to leave a radially inner radially extending space between each of the adjacent first regions, and a third feedstock is a hard ferromagnetic powder metal injected into the radially extending spaces between the discrete first regions of the mold, whereby a composite powder metal component for a spoke type interior permanent magnet machine is formed having an inner annular magnetically non-conducting segment and an outer annular segment of a plurality of alternating polarity permanent magnets separated by magnetically conducting segments and embedded by magnetically non-conducting segments.

39. The method of claim 18, wherein a first feedstock is a non-ferromagnetic powder metal injected into an inner annular region of a cylinder-shaped mold, a second feedstock is a soft ferromagnetic powder metal injected into discrete first regions within an outer annular region of the mold so as to leave spaces between each discrete first region, and wherein the first feedstock is further injected into discrete radially outer second regions between the first regions so as to leave a radially inner radially extending space between each of the adjacent first regions, whereby a composite powder metal component for a spoke type interior permanent magnet machine is formed having an inner annular magnetically non-conducting segment and an outer annular segment of a plurality of radially extending spaces separated by magnetically conducting segments and embedded by magnetically non-conducting segments, the method further comprising affixing pre-fabricated magnets in the radially extending spaces in an arrangement of alternating polarity.

40. The method of claim 18, wherein a first feedstock is a soft ferromagnetic powder metal injected into discrete first regions within an annular region of the mold so as to leave spaces between each discrete first region, and wherein a second feedstock is a non-ferromagnetic powder metal injected into discrete radially outer second regions between the first regions so as to leave a radially inner radially extending space between each of the adjacent first regions, and a third feedstock is a hard ferromagnetic powder metal injected into the radially extending spaces between the discrete first regions of the mold, whereby a composite powder metal component for a spoke type interior permanent magnet machine is formed having an annular segment of a plurality of alternating polarity permanent magnets separated by magnetically conducting segments and embedded by magnetically non-conducting segments.

41. The method of claim 18, wherein a first feedstock is a soft ferromagnetic powder metal injected into a first region of a cylinder-shaped mold to form a pattern of a plurality of equally spaced axially extending slots adjacent an exterior circumferential surface of the mold, and a second feedstock is a non-ferromagnetic powder metal injected into a plurality of discrete second regions of the mold in a radially outer portion of each slot adjacent the exterior circumferential surface of the mold, whereby a composite powder metal component for an induction machine is formed having a magnetically conducting segment and a plurality of magnetically non-conducting segments enclosing slot openings.

42. The method of claim 18, wherein a first feedstock is a soft ferromagnetic powder metal injected into one or more discrete first regions in a cylinder-shaped mold, and a second feedstock is a non-ferromagnetic powder metal injected into one or more discrete second regions in the mold, the discrete second regions in alternating relation with the first discrete regions, whereby a composite powder metal component for a synchronous reluctance machine is formed having one or more magnetically conducting segments alternating with one or more magnetically non-conducting segments.

43. The method of claim 18, wherein a first feedstock is a soft ferromagnetic powder metal injected into a first region in a cylinder-shaped mold, the first region having a yoke and teeth configuration, and a second feedstock is a non-ferromagnetic powder metal injected into discrete second regions in the mold, the discrete second regions positioned between the teeth of the first region, whereby a composite powder metal component for a switched reluctance machine is formed having a magnetically conducting segment and a plurality of magnetically non-conducting segments.

44. A method of making a powder metal rotor component for a surface permanent magnet machine, the method comprising:

injecting a soft ferromagnetic powder metal from a first injection unit under heat and pressure into an inner annular region of a cylinder-shaped mold;

injecting a non-ferromagnetic powder metal from a second injection unit under heat and pressure into discrete regions within an outer annular region of the mold so as to leave spaces between each discrete region;

injecting a hard ferromagnetic powder metal from a third injection unit under heat and pressure into the spaces between the discrete regions of the outer annular region of the mold to provide an arrangement of alternating polarity permanent magnets; and

allowing the powder metals to solidify to thereby form a composite powder metal component having an inner annular magnetically conducting segment and an outer annular segment of a plurality of alternating polarity permanent magnets separated by magnetically non-conducting segments.

45. The method of claim 44, wherein the soft ferromagnetic powder metal is Ni, Fe, Co or an alloy thereof.

46. The method of claim 44, wherein the soft ferromagnetic powder metal is high purity iron powder with a minor addition of phosphorus.

47. The method of claim 44, wherein the non-ferromagnetic powder metal is an austenitic stainless steel.

48. The method of claim 44, wherein the non-ferromagnetic powder metal is an AISI 8000 series steel.

49. The method of claim 44, further comprising mounting the composite component on a shaft to form a powder metal rotor assembly.

50. The method of claim 44, wherein the powder metals are each combined with a binder prior to injecting.

51. The method of claim 50, further comprising the steps of:

ejecting the composite component from the mold;

subjecting the composite component to debinding to provide a composite part which is essentially free of binder; and

sintering the composite part.

52. A method of making a powder metal rotor component for a circumferential type interior permanent magnet machine, the method comprising:

injecting a soft ferromagnetic powder metal from a first injection unit under heat and pressure into an inner annular region of a cylinder-shaped mold;

injecting a non-ferromagnetic powder metal from a second injection unit under heat and pressure into discrete first regions within an outer annular region of the mold so as to leave spaces between each discrete first region;

injecting the soft ferromagnetic powder metal from the first injection unit under heat and pressure into discrete second regions between the first regions so as to leave a radially inner circumferentially extending space and optionally leaving a radially extending space through each discrete second region;

optionally injecting the non-ferromagnetic powder metal from the second injection unit under heat and pressure into the radially extending spaces;

injecting a hard ferromagnetic powder metal from a third injection unit under heat and pressure into the radially inner circumferentially extending spaces between the discrete first regions of the outer annular region of the mold to provide an arrangement of alternating polarity permanent magnets; and

allowing the powder metals to solidify to thereby form a composite powder metal component having an inner magnetically conducting segment and an outer permanent magnet segment of a plurality of alternating polarity permanent magnets separated by magnetically non-conducting barrier segments and radially embedded by magnetically conducting segments with optional intermediate magnetically non-conducting bridge segments.

53. The method of claim 52, wherein the soft ferromagnetic powder metal is Ni, Fe, Co or an alloy thereof.

54. The method of claim 52, wherein the soft ferromagnetic powder metal is high purity iron powder with a minor addition of phosphorus.

55. The method of claim 52, wherein the non-ferromagnetic powder metal is an austenitic stainless steel.

56. The method of claim 52, wherein the non-ferromagnetic powder metal is an AISI 8000 series steel.

57. The method of claim 52, further comprising mounting the composite component on a shaft to form a powder metal rotor assembly.

58. The method of claim 52, wherein the powder metals are each combined with a binder prior to injecting.

59. The method of claim 58, further comprising the steps of:

ejecting the composite component from the mold;

subjecting the composite component to debinding to provide a composite part which is essentially free of binder; and

sintering the composite part.

60. A method of making a powder metal rotor component for a spoke type interior permanent magnet machine, the method comprising:

injecting a non-ferromagnetic powder metal from a first injection unit under heat and pressure into an inner annular region of a cylinder-shaped mold;

injecting a soft ferromagnetic powder metal from a second injection unit under heat and pressure into discrete first regions within an outer annular region of the mold so as to leave spaces between each discrete first region;

injecting the non-ferromagnetic powder metal from the first injection unit under heat and pressure into discrete radially outer second regions between the first regions so as to leave a radially inner radially extending space between each of the adjacent first regions;

injecting a hard ferromagnetic powder metal from a third injection unit under heat and pressure into the radially extending spaces between the discrete first regions of the outer annular region of the mold to provide an arrangement of alternating polarity permanent magnets; and

allowing the powder metals to solidify to thereby form a composite powder metal component having an inner annular magnetically non-conducting segment and an outer annular segment of a plurality of alternating polarity permanent magnets separated by magnetically conducting segments and embedded by magnetically non-conducting segments.

61. The method of claim 60, wherein the soft ferromagnetic powder metal is Ni, Fe, Co or an alloy thereof.

62. The method of claim 60, wherein the soft ferromagnetic powder metal is high purity iron powder with a minor addition of phosphorus.

63. The method of claim 60, wherein the non-ferromagnetic powder metal is an austenitic stainless steel.

64. The method of claim 60, wherein the non-ferromagnetic powder metal is an AMSI 8000 series steel.

65. The method of claim 60, further comprising mounting the composite component on a shaft to form a powder metal rotor assembly.

66. The method of claim 60, wherein the powder metals are each combined with a binder prior to injecting.

67. The method of claim 66, further comprising the steps of:

ejecting the composite component from the mold;

subjecting the composite component to debinding to provide a composite part which is essentially free of binder; and

sintering the composite part.

68. A method of making a powder metal rotor component for an induction machine, the method comprising:

injecting a soft ferromagnetic powder metal from a first injection unit under heat and pressure into a first region of a cylinder-shaped mold to form a pattern of a plurality of equally spaced axially extending slots adjacent an exterior circumferential surface of the cylinder-shaped mold;

injecting a non-ferromagnetic powder metal from a second injection unit under heat and pressure into a plurality of discrete second regions of the mold in a radially outer portion of each slot adjacent the exterior circumferential surface, thereby forming closed slot openings; and

allowing the powder metals to solidify to thereby form a composite powder metal component having a magnetically conducting segment and a plurality of magnetically non-conducting segments enclosing slot openings.

69. The method of claim 68, wherein the soft ferromagnetic powder metal is Ni, Fe, Co or an alloy thereof.

70. The method of claim 68, wherein the soft ferromagnetic powder metal is high purity iron powder with a minor addition of phosphorus.

71. The method of claim 68, wherein the non-ferromagnetic powder metal is an austenitic stainless steel.

72. The method of claim 68, wherein the non-ferromagnetic powder metal is an MISI 8000 series steel.

73. The method of claim 68, further comprising mounting the composite component on a shaft to form a powder metal rotor assembly.

74. The method of claim 68, wherein the powder metals are each combined with a binder prior to injecting.

75. The method of claim 74, further comprising the steps of:

ejecting the composite component from the mold;

subjecting the composite component to debinding to provide a composite part which is essentially free of binder; and

sintering the composite part.

76. A method of making a powder metal rotor component for a synchronous reluctance machine, the method comprising:

injecting a soft ferromagnetic powder metal from a first injection unit under heat and pressure into one or more discrete first regions in a cylinder-shaped mold;

injecting a non-ferromagnetic powder metal from a second injection unit under heat and pressure into one or more discrete second regions in the mold, the discrete second regions in alternating relation with the discrete first regions; and

allowing the powder metals to solidify to thereby form a composite powder metal component having one or more magnetically conducting segments and one or more magnetically non-conducting segments.

77. The method of claim 76, wherein the soft ferromagnetic powder metal is Ni, Fe, Co or an alloy thereof.

78. The method of claim 76, wherein the soft ferromagnetic powder metal is high purity iron powder with a minor addition of phosphorus.

79. The method of claim 76, wherein the non-ferromagnetic powder metal is an austenitic stainless steel.

80. The method of claim 76, wherein the non-ferromagnetic powder metal is an AISI 8000 series steel.

81. The method of claim 76, further comprising mounting the composite component on a shaft to form a powder metal rotor assembly.

82. The method of claim 76, wherein the powder metals are each combined with a binder prior to injecting.

83. The method of claim 82, further comprising the steps of:

ejecting the composite component from the mold;

subjecting the composite component to debinding to provide a composite part which is essentially free of binder; and

sintering the composite part.

84. A method of making a powder metal rotor component for a switched reluctance machine, the method comprising:

injecting a soft ferromagnetic powder metal from a first injection unit under heat and pressure into a first region in a cylinder-shaped mold, the first region having a yoke and teeth configuration;

injecting a non-ferromagnetic powder metal from a second injection unit under heat and pressure into discrete second regions in the mold, the discrete second regions positioned between the teeth of the first region; and

allowing the powder metals to solidify to thereby form a composite powder metal component having a magnetically conducting segment and a plurality of magnetically non-conducting segments.

85. The method of claim 84, wherein the soft ferromagnetic powder metal is Ni, Fe, Co or an alloy thereof.

86. The method of claim 84, wherein the soft ferromagnetic powder metal is high purity iron powder with a minor addition of phosphorus.

87. The method of claim 84, wherein the non-ferromagnetic powder metal is an austenitic stainless steel.

88. The method of claim 84, wherein the non-ferromagnetic powder metal is an AISI 8000 series steel.

89. The method of claim 84, further comprising mounting the composite component on a shaft to form a powder metal rotor assembly.

90. The method of claim 84, wherein the powder metals are each combined with a binder prior to injecting.

91. The method of claim **90**, further comprising the steps of:

ejecting the composite component from the mold;

subjecting the composite component to debinding to provide a composite part which is essentially free of binder; and

sintering the composite part.

92. A method of making a powder metal rotor sense ring, the method comprising:

injecting a powder filler material from a first injection unit under heat and pressure into an inner annular region of a cylinder-shaped mold;

injecting a non-ferromagnetic powder metal from a second injection unit under heat and pressure into discrete regions within an outer annular region of the mold so as to leave spaces between each discrete region;

injecting a hard ferromagnetic powder metal from a third injection unit under heat and pressure into the spaces between the discrete regions of the outer annular region of the mold to provide an arrangement of alternating polarity permanent magnets; and

allowing the powders to solidify to thereby form a composite powder metal component having an inner annular filler segment and an outer annular segment of a plurality of alternating polarity permanent magnets separated by magnetically non-conducting segments.

93. The method of claim **92**, wherein the non-ferromagnetic powder metal is an austenitic stainless steel.

94. The method of claim **92**, wherein the non-ferromagnetic powder metal is an AISI 8000 series steel.

95. The method of claim **92**, further comprising mounting the composite component on a shaft to form a powder metal rotor assembly.

96. The method of claim **92**, wherein the powder metals are each combined with a binder prior to injecting.

97. The method of claim **96**, further comprising the steps of:

ejecting the composite component from the mold;

subjecting the composite component to debinding to provide a composite part which is essentially free of binder; and

sintering the composite part.

98. A composite injection molded rotor component for a rotor assembly comprising a first region of an injection molded soft ferromagnetic powder metal, a second region of an injection molded non-ferromagnetic powder metal, and optionally a third region of an injection molded hard ferromagnetic powder metal.

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