April 5, 1966 H. EYBERGER 3,244,782

TOROIDAL CORE PRESSURE FORMING METHOD

Original Filed May 17, 1957 4 Sheets-Sheet 1

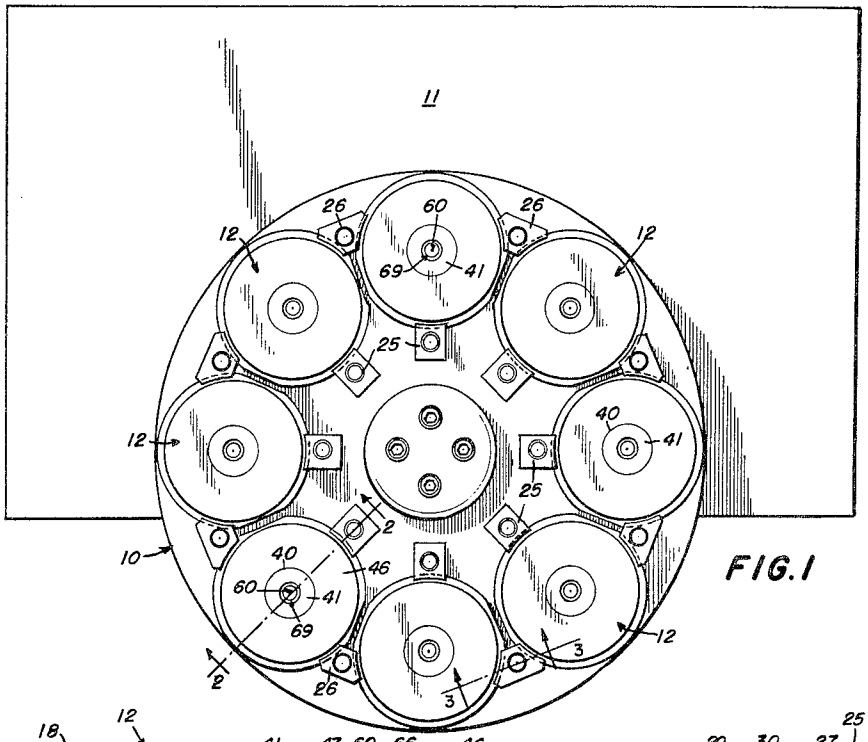



FIG. 1

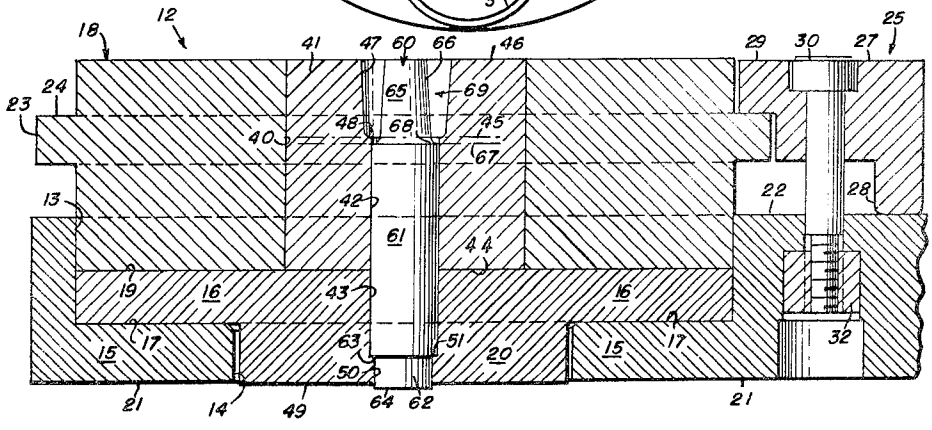



FIG. 2

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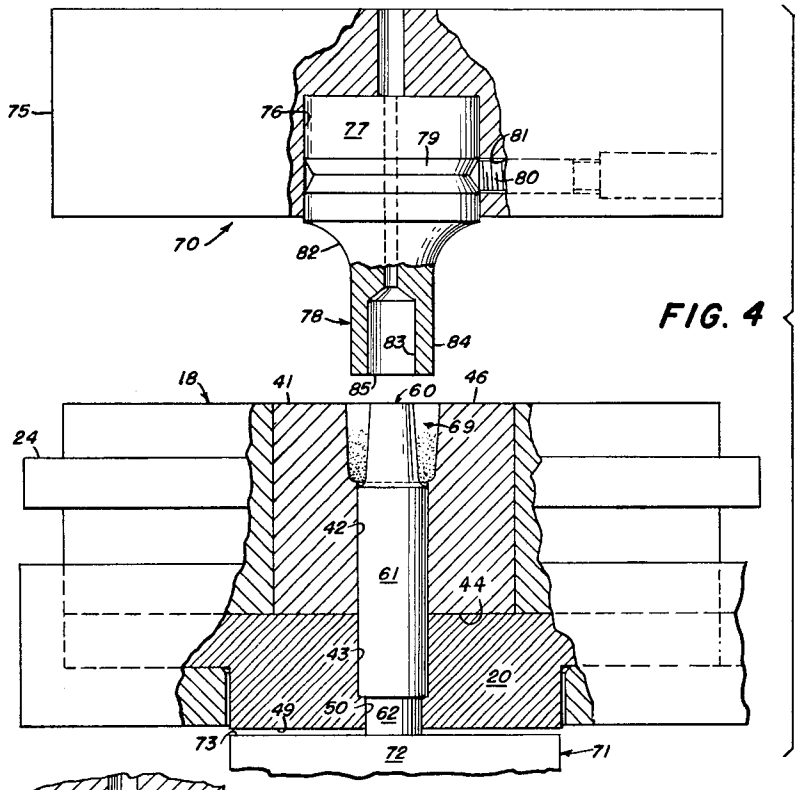



FIG. 4

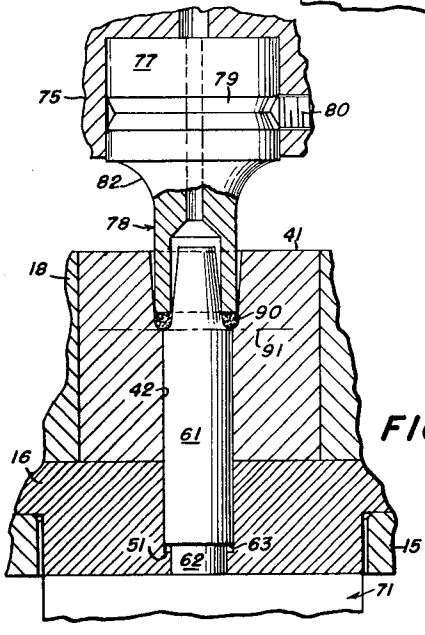



FIG. 5

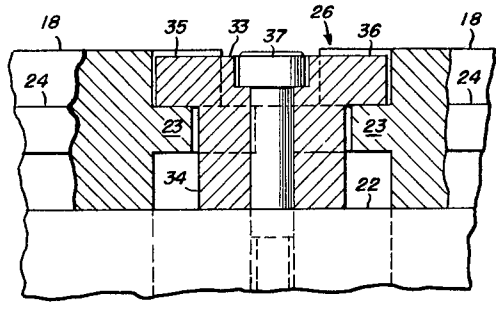



FIG. 3

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FIG. 6

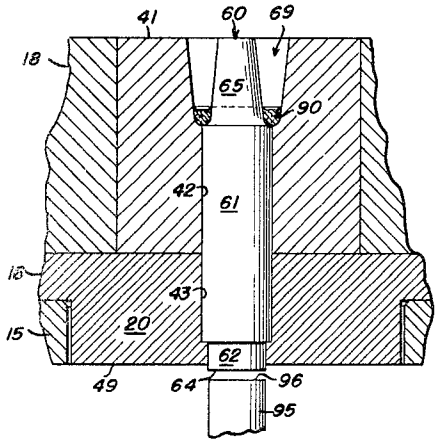
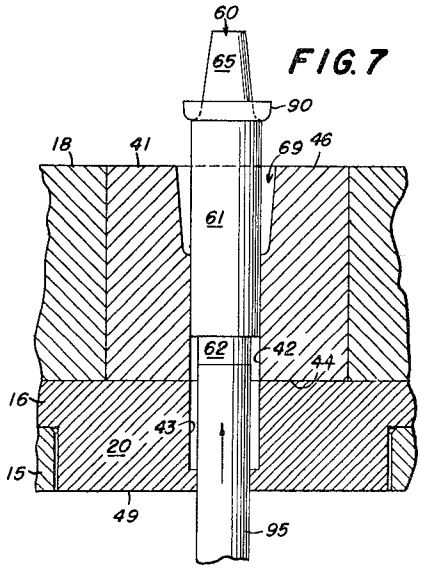



FIG. 7



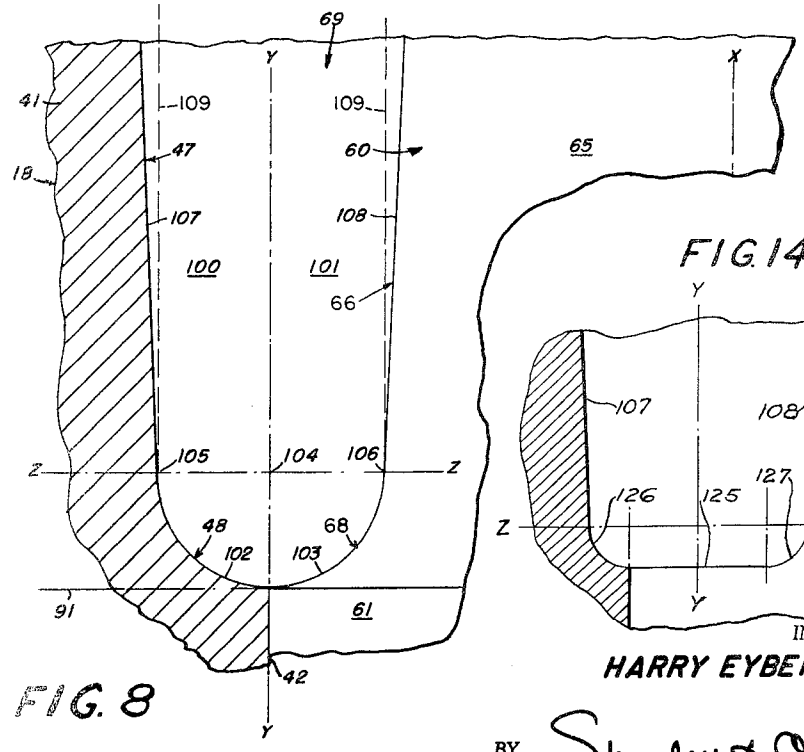




FIG. 8

FIG. 14




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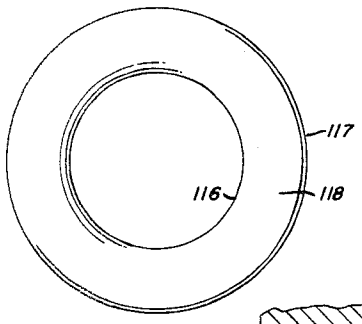



FIG. 12

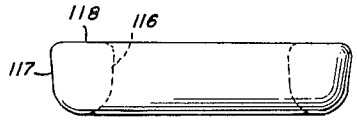



FIG. 13

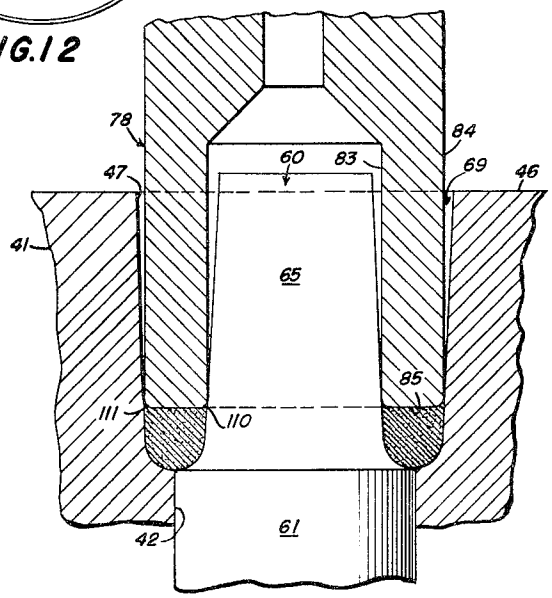



FIG. 9

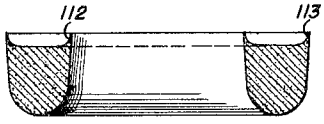



FIG. 10

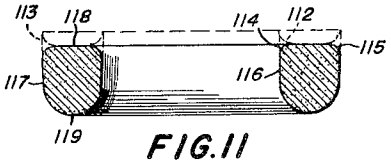



FIG. 11

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3,244,782

# TOROIDAL CORE PRESSURE FORMING METHOD

Harry Eyberger, Butler, Pa., assignor to Magnetics, Inc., a corporation of Pennsylvania

Original application May 17, 1957, Ser. No. 659,925, now Patent No. 3,063,098, dated Nov. 13, 1962. Divided and this application Aug. 23, 1962, Ser. No. 226,761

3 Claims. (Cl. 264—111)

This is a division of the applicant's copending application Serial No. 659,925, filed on May 17, 1957, and issued as Patent No. 3,063,098 on November 13, 1962, and subsequently reissued as Re. 25,441 on September 10, 1963.

This invention relates to the formation of bodies of compressed metallic particles, such as magnetic bodies of compressed insulated particles of magnetic material. In particular, the invention relates to novel methods for forming integral bodies from powdered metallic material, including insulated particles of magnetic material, under high pressure, and to a novel magnetic body formed of compressed particles of magnetic material having improved magnetic, electrical and mechanical characteristics.

The formation of certain bodies of compressed metallic particles, such as the formation of toroidal magnetic cores of compressed insulated particles of magnetic material, requires application of extremely high pressures, such as 200,000 to 250,000 pounds per square inch. For this operation, a molding die is employed presenting a pressure or molding cavity of toroidal shape, for example, into which a measured quantity of powdered material, such as insulated particles of magnetic material, is deposited. A pressure ring is placed in the cavity over the charge of powdered material and the required pressure is applied through the pressure ring to form the powdered material into an integral body of a shape theoretically determined by the configuration of the pressure cavity. In view of the high pressures required, it has been necessary in the past to employ a molding die made up of a plurality of removable arcuate die sections in order to permit withdrawal of the formed body from the pressure cavity. Ordinarily, three arcuate die sections have been employed to form a sectional ring about a center plug with a pressure cavity therebetween, the outer and inner contour of the pressure cavity being defined by the innermost surfaces of the die sections and the center plug, respectively. The arcuate die sections are positively clamped on a suitable platform or table about the center plug in end-to-end relation to form the cavity, and after the required pressure is applied to the charge of powdered material through the pressure ring, the die sections are unclamped from the platform and moved away from the formed body to permit the body to be removed from the center plug. The necessity of unclamping the die sections to permit removal of a formed body and of reclamping the die sections in proper relation with the center plug before formation of another body of compressed powdered material, does not lend to formation of compressed bodies of magnetic material in an automatic operation. Thus the prior teachings requiring the use of a plurality of die sections has made it impracticable to form bodies of compressed powdered material in an automatic operation.

When the required forming pressure is applied to a charge of powdered material in a cavity of a molding die including a plurality of arcuate die sections, the outer contour of the pressure cavity becomes distorted, that is, the outer wall of the cavity defined by the die sections flexes outwardly away from the center plug. After the pressure is relieved the die sections return to their original shape causing distortion or flexure of the formed body. The flexure of the formed body impairs the desired properties of the body and establishes undesired stresses in the body which may even cause the body to crack when the die sections are removed. Although attempts have been made to design the arcuate die sections in such a manner as to permit distortion while under pressure and allow the sections to return to their normal shape when the pressure is released without appreciably distorting the outer contour of the pressure cavity, the permitted flexure results in the formation of a body having non-uniform density characteristics which impairs its magnetic and electrical properties and reduces its strength.

Furthermore, the use of a plurality of arcuate die sections to form the outer contour of the pressure cavity results in the formed body being subjected to substantially lower pressures along the dividing line between adjacent die sections. The application of substantially different pressures during formation of the body is believed to result in further impairment of the desired uniform density characteristics of the body and provides a body of non-uniform permeability in cases where magnetic material is employed. As a result of the relieved pressure along the dividing lines between the arcuate die sections, the core has an outside surface including a number of seams, equal to the number of die sections employed, which break the continuity of the skin of the core and provide regions of non-uniform density. The foregoing impairs the magnetic, electrical and mechanical properties of the core.

It is an object of the present invention to provide novel methods which overcome the disadvantages outlined above.

In general, the present invention provides novel methods of forming integral bodies of compressed powdered material by substantially uniformly subjecting powdered material in a pressure cavity to relatively high pressure without flexure or deformation of the body during the forming process or upon releasing the pressure following the forming process, and of removing bodies of compressed powdered metallic material from a pressure cavity. The present invention also provides a novel molding die, capable of forming cores in an automatic operation, having a pressure cavity including an outside continuous or closed surface formed on a body member comprising a single piece of material and an inside continuous or closed surface formed on a center plug or member relatively movable with respect to the body member. The inside and outside continuous surfaces are formed in predetermined relative relationship to permit withdrawal of a formed core from the pressure cavity upon relative movement between the body member and the center plug along the longitudinal axis of the formed core. Magnetic cores produced by the novel methods and apparatus of the present invention are of more uniform density and permeability and possess improved magnetic, electrical and strength characteristics. In the preferred form of the invention the inside and outside continuous surfaces present substantially circular and substantially concentric inner and outer pressure cavity walls which provide more equal distribution of the forming pressure throughout the body.

The foregoing and other objects and features of the present invention will appear more fully from the following detailed description considered in connection with the accompanying drawings which disclose several embodiments of the invention. It is to be expressly understood, however, that the drawings are designed for purposes of illustration only and not as a definition of the limits of the invention, reference for the latter purpose being had to the appended claims.

In the drawings, in which similar reference characters denote similar elements throughout the several views;

FIGURE 1 is a diagrammatic plan view of an automatic machine including a plurality of novel molding dies provided by the present invention;

FIGURE 2 is a view in section taken along the line 2—2 of FIGURE 1;

FIGURE 3 is a view in section taken along the line 3—3 of FIGURE 1;

FIGURE 4 is an elevational view, partly in section, illustrating the novel molding die and pressure ring provided by the present invention;

FIGURE 5 is an elevational view, in section, illustrating the relative position of the molding die and pressure ring during a core forming operation;

FIGURE 6 is an elevational view, in section illustrating the position of the molding die relative to core ejecting means;

FIGURE 7 is an elevation view, partly in section, illustrating the core ejecting operation provided by the present invention;

FIGURE 8 is an enlarged fragmentary view, in section, illustrating details of the pressure cavity provided by a molding die constructed in accordance with the principles of the present invention;

FIGURE 9 is an enlarged fragmentary view, in section, illustrating another embodiment of the present invention;

FIGURE 10 is a view, in section, of a magnetic core during a phase of its formation according to a core forming method provided by the present invention;

FIGURE 11 is an elevational view, in section, of a magnetic core provided by the present invention;

FIGURE 12 is a plan view of a magnetic core provided by the present invention;

FIGURE 13 is a view in side elevation of a magnetic core provided by the present invention, and

FIGURE 14 is a fragmentary view, in section, of another embodiment of the present invention.

A machine for automatically producing bodies of compressed metallic particles, such as insulated particles of magnetic material, according to the principles of the present invention is shown in FIGURE 1 of the drawings including a table **10** mounted for rotation about its center in a horizontal plane above a support **11**. A plurality of molding dies **12** are mounted on the upper surface of the table **10** at equally spaced angular positions and radial distances with respect to the center of rotation of the table. The machine includes a plurality of stations, not shown, located about the table **10** for successive cooperation with the molding dies **12** upon rotation of the table in a predetermined direction. Specific mechanisms are provided at the stations to perform particular functions, in cooperation with the molding dies, required in the formation of a core, such as introducing a measured quantity of powdered material into the die cavity, compressing the material to form an integral core and ejecting the formed core from the molding die. The molding dies are designed in a novel manner and cooperate with the station mechanisms to provide automatic operation and high speed formation of cores. It is to be expressly understood that a number of molding dies greater or less than the number shown in the drawing may be employed, as desired.

The table **10** is provided with a plurality of circular recesses **13** formed in its upper surface, the number of circular recesses being equal to the number of molding dies **12**. The table **10** is also provided with enlarged openings **14** extending through its lower wall **15**, an enlarged opening being formed in each of the circular recesses in concentric relation therewith. As shown in FIGURE 2, the molding dies include a cylindrical backing plate **16** positioned in a circular recess **13** and resting on its bottom surface **17**, and a circular body member **18** positioned in the circular recess in contact with the upper



surface **19** of the backing plate. The outside diameters of the backing plate **16** and the body member **18** are such as to provide a snug fit between their outer peripheral surfaces and the side walls of the circular recess. The backing plate **16** includes a downwardly depending cylindrical portion **20** of reduced diameter to freely enter the opening **14** in the bottom wall **15** of the table. The cylindrical depending portion **20** extends throughout the depth of the wall **15** and projects slightly downwardly beyond the lower surface **21** of the table **11**. The body member **18** extends upwardly above the upper surface **22** of the table **11**, and includes an outwardly extending circumferential flange **23** presenting an annular surface **24** parallel to and spaced from the upper surface **22**. The circumferential flange **23** cooperates with clamping devices **25** and **26** for positively retaining the backing plate and body member of the molding dies in respective circular cavities **13** of the table **10**.

As shown in FIGURE 1, each of the molding dies is provided with an inner clamping device **25** lying along a radial line of the table passing through the center of respective molding dies and a pair of opposed outer clamping devices **26**, **26** displaced approximately 120° from the respective inner clamp **25**, each of the outer clamping devices **26** being associated with a pair of adjacent molding dies. As illustrated in FIGURE 2, the inner clamping devices **25** include an L-shaped block **27** having a leg portion **28** adapted to contact the upper surface **22** of the table and an outwardly extending flange **29** adapted to contact a portion of the annular surface **24** of the body member, the outer edge of the flange **29** being curved to correspond to the curvature of the body member **18**. The block is secured in clamping position as shown by a bolt **30** passing through suitable openings in the block and the table and a co-operating nut **31** on the underside of the table. The outer clamping devices **26** may be of the type shown in FIGURE 3 of the drawings. These clamping devices comprise a T-shaped block **33** having a central leg **34** adapted to contact the table surface **22** and a pair of oppositely disposed flanges **34** and **35** adapted to contact the annular surfaces of adjacent body members, the outer edges of the flanges are oppositely curved in conformance with the curvature of the side walls of the body members. The block **33** is secured by a bolt **37** anchored to the table **10**. With this clamping arrangement, the molding dies are secured in respective circular recesses and onto the table. It is to be expressly understood that other types of clamping means may be employed.

The body member **18** of the molding die is preferably provided with a centrally disposed enlarged bore **40** receiving a cylindrical insert **41** comprising a single piece of carbide material. The circular bore **40** and the carbide insert **41** may extend throughout the depth of the body member **18**, and the carbide insert is maintained in the bore **40** under pressure to provide an integral structure. The carbide insert **41** and the backing plate **16** are provided with axially aligned bores **42** and **43**, respectively, concentrically positioned with respect to the circular recess **13**. The bore **42** is of constant diameter and extends upwardly, as viewed in the drawing, from the lower surface **44** of the body member to a plane **45** perpendicular to the longitudinal axis of the bore **42** and located below the upper surface **46** of the body member. At the plane **45**, the bore **42** merges with an enlarged opening in the insert **41** extending upwardly from the plane **45** to the upper surface **46** of the body member. The enlarged opening is defined by a continuous internal surface **47**, of circular cross-section, formed on the insert in concentric relation with the longitudinal axis of the bore **42**, and the internal surface **47** is uniformly inclined from the upper surface **46** of the body member inwardly toward the longitudinal axis of the bore **42**. In the region of the enlarged opening above the plane **45**, the inclined continuous internal surface **47** is merged with the bore

42 by a curved annular surface 48 formed on the insert. The bore 43, formed in the backing plate 16 in axial alignment with the bore 42, is of uniform diameter of the bore 42, and extends from the upper surface 19 of the backing plate downwardly, as viewed in the drawing, and terminates within the cylindrical depending portion 20 in spaced relation with its lower surface 49. At its terminating end, the bore 43 merges with a bore 50, of reduced diameter, extending throughout the portion 20 to the surface 49. The bore 50 is in axial alignment with the bores 42 and 43, and forms an upwardly facing annular shoulder 51 at the terminating end of the bore 43.

The molding die further includes a cylindrical center plug or member 60 which provides the inside surface and a portion of the bottom surface of the pressure or molding cavity of the die, and also functions as a means for removing formed cores from the cavity. As shown, the center plug 60 includes an intermediate cylindrical portion 61, of uniform diameter, adapted to be snugly received by the bores 42 and 43 for axial movement therein. The center plug 60 also includes a cylindrical bottom portion 62 extending downwardly from the lower end of the intermediate portion into the bore 50 of the projection 20, the bottom portion being in concentric relation with the longitudinal axis of the center plug. This construction presents a downwardly facing annular shoulder 63 at the end of the intermediate portion 61, the shoulder 63 being adapted to engage the annular flange 51 and limit downward movement of the center plug relative to the body member. The bottom portion 62 extends downwardly a distance greater than the depth of the bore 50 so that its end face 64 lies in a plane displaced a slight distance below the lower surface 49 of the cylindrical projection 20 when the center plug is in its lowermost position. The purpose of this arrangement will be described more fully below.

The center plug is provided with a top portion 65 having a continuous external surface 66, of circular cross-section, in concentric relation with the central longitudinal axis of the center plug and the bores 42 and 43. The surface 66 is inclined from the upper surface 46 of the body member outwardly away from the longitudinal axis of the center plug. The upper end of the intermediate portion 61 terminates in a plane 67 perpendicular to the longitudinal axis of the center plug, and the lower circular edge of the inclined surface 66 is merged with the upper circular edge of the intermediate portion by a curved annular surface 68. The plane 67 is spaced below the plane 45 a distance corresponding to the vertical displacement between the end face 64 and the lower surface 49 of the portion 20 so that upon movement of the end face 64 into the plane of the lower surface 49, the resulting upward movement of the center plug relative to the body member positions the upper circular ends of the bore 42 and the intermediate portion 61 in a common transverse plane. The inclined surface 47 of the insert 41 and the inclined surface 66 of the center plug 60 respectively define inside and outside concentric side walls of a toroidal pressure or molding cavity 69. The lower portions of the inner and outer side walls and the bottom of the pressure cavity 69 are defined by the annular curved surfaces 48 and 68.

In FIGURE 4 of the drawings, a molding die is shown at the pressing or core forming station. The mechanism for effecting the core forming operation includes a pressure device 70 located above the molding die and a load carrying member or anvil 71 positioned below the table beneath the molding die. The anvil 71 is mounted independently of the table on a foundation, not shown, suitable for carrying the high pressure applied during the core forming operation. The upper end of the anvil comprises a cylindrical metal block 72 presenting a flat, horizontally disposed upper surface 73. The diameter of the cylindrical block 72 may be approximately equal to the diameter of the projecting portion 20 of the backing plate 16 and is positioned with its central longitudinal axis aligned with the longitudinal axis of the center plug when the molding die is properly positioned at the core forming station. The vertical position of the upper surface 73 relative to the table may be such that the lower end face 64 of the center plug 60 is in contact therewith, while the lower face 49 of the cylindrical projecting portion 20 is spaced therefrom, upon movement of a molding die to the core forming station, as shown in FIGURE 4. With this arrangement core forming pressure is transmitted to the anvil independently of the table as will appear more fully below. The pressure device 70 includes a pressure plate or cylindrical block 75 having a centrally disposed cylindrical cavity 76 on its lower side adapted to receive a cylindrical plug 77 including an integrally formed downwardly depending pressure ring 78. The plug 77 includes a horizontally disposed circumferential groove 79, lying within the cylindrical cavity 76 and receiving one end of one or more pins, such as pin 80 carried in a horizontal bore 81 formed in the pressure plate, to retain plug in the cylindrical cavity. The pressure ring 78 is joined to the plug 77 through a tapered portion 82, and comprises an elongated annular member including concentric inner and outer cylindrical surfaces, 83 and 84, respectively, and a terminating annular end face 85 lying in a plane perpendicular to the central longitudinal axis of the pressure ring. The depth of the inner and outer cylindrical surfaces 83 and 84 and the spacing of the surfaces 83 and 84 from each other and from the central longitudinal axis of the pressure ring are determined in accordance with the dimensions of the pressure cavity.

The pressure plate 75 is mounted by guide means, not shown, for movement parallel to the longitudinal axis of the center plug 60, such as vertical movement, and is positioned relative to the table so that the central longitudinal axis of the pressure ring is in axial alignment with the central longitudinal axis of the center plug when the molding die is positioned at the core forming station. A suitable pressure applying means, such as a hydraulic system, not shown, is associated with the pressure plate 74 to move the pressure ring downwardly and into the pressure cavity 68 of the molding die and apply pressure required to form an integral core from powdered magnetic material.

In FIGURE 5 the molding die and the pressure ring are illustrated in their relative positions during a core forming operation. As shown, the pressure ring is moved to within the cavity of the molding die having a magnetic core 90 therein formed under extremely high pressure. The pressure applied to the molding die is transmitted through the center plug 60 and the body member and the projecting portion 20 of the backing plate to the anvil 71 independently of the table 15. During the core forming operation the end face 64 of the center plug and the lower surface 49 of the projecting portion 20 contact the upper horizontal surface 73 of the anvil, and the upper ends of the bore 42 and of the intermediate portion 61 of the center plug lie in a common plane 91 perpendicular to the longitudinal axis of the bore 42.

FIGURE 6 of the drawings shows a molding die at the ejector station, and FIGURE 7 illustrates the manner a formed core is ejected from the molding die. The ejector station mechanism includes an ejector rod or plunger 95 mounted by suitable guide means, not shown, for movement parallel to the longitudinal axis of the center plug 60, and positioned with respect to the center of rotation of the table so that its central longitudinal axis substantially coincides with the central longitudinal axis of the center plug when the molding die is moved to the ejector station. Power means, not shown, is provided for applying reciprocating movement to the plunger 95, to move the plunger between its non-ejecting position shown in FIGURE 6 and its ejecting position shown in FIGURE 7. When the plunger is in the non-ejecting position, its upper end face 96 lies in a plane displaced

below the plane of the end face 64 of the center plug when the center plug is normally positioned relative to the body member. Upon upward movement of the plunger 95, its end face 96 contacts the lower end of the center plug and moves the center plug upwardly relative to the body member 18. The formed core 90 moves upwardly with the center plug and is ejected from the pressure cavity. The stroke of the plunger is preferably such as to move the core 90 to a position above the upper surface 46 of the body member for removal from the center plug by any suitable device, such as by magnetic means. Upon removal of the core the plunger is moved downwardly to its non-ejecting position to permit movement of the molding die from the ejector station. In some cases it may be desirable to move a supporting member to beneath the core 90 when the center plug is positioned in the manner shown in FIGURE 7, and to thereafter positively move the center plug downwardly relative to the core, by any suitable downwardly movable means located above the center plug, not shown, in order to release the core from the center plug, the supporting means being operable, if desired, to deliver the core from the machine.

An enlarged sectional view of one side of the pressure cavity 69 shown in FIGURE 8 of the drawings illustrates in detail the shape of the surfaces 47, 48, 66 and 68 and their interrelationship in defining the pressure cavity according to one embodiment of the invention. As shown, the vertical axis X—X comprises the central longitudinal axis of the center plug 60 or the bore 43, and the axis Y—Y is coextensive with the line of contact between the intermediate portion 61 of the center plug and the bore 42. In view of the snug fit between the center plug and the bore 42, the external surfaces of the intermediate portion 61 of the center plug and the internal surface of the bore 42 may be considered as lying in a cylindrical plane concentric with the axis X—X, and any vertical section passing through the axis X—X would cut the cylindrical plane along a vertical line parallel to the axis X—X, such as the axis Y—Y. The axis Y—Y divides the pressure cavity 69 into zones 100 and 101 of equal cross sectional area which are symmetrical with respect to the axis Y—Y. The bottom of the pressure cavity 69 is defined by the curved annular surfaces 48 and 68 formed on the insert and the center plug, respectively, above the upper ends of the bore 42 and the intermediate portion 61, respectively, in concentric relation with the axis X—X. In cross-section, the curved annular surfaces 48 and 68 form 90° arcs of circles of equal radius, i.e., arcs 102 and 103, respectively, and when the upper ends of the bore 42 and the intermediate portion 61 lie in the common plane 91, the arcs 102 and 103 form a semi-circle having a center at point 104 lying on the axis Y—Y and in a plane Z—Z perpendicular thereto and passing through points 105 and 106 at the upper extremities of the arcs 102 and 103, respectively. The inclined surfaces 47 and 66 of circular cross-section define, in vertical section, straight lines 107 and 108, respectively, the line 107 being located on one side of the axis Y—Y and extending upwardly from the point 105 and being inclined outwardly from the axis Y—Y, and the line 108 being located on the other side of the axis Y—Y and extending upwardly from the point 106 and being inclined outwardly with respect to the axis Y—Y. Broken lines 109 and 110 passing through points 105 and 106, respectively, in parallel relation with the axis X—X, illustrate the equal taper of the inner and outer side walls of the pressure cavity with respect to the axis Y—Y.

As mentioned above one of the objects of the present invention is to provide a novel molding die including a single piece die body capable of forming cores of compressed metallic particles of powdered material in an automatic operation. This object is accomplished, in part, by the provision of a pressure cavity including inner and outer side walls defined by oppositely inclined or tapered surfaces. The feature of providing a pressure cavity including an outer wall surface inclined inwardly toward the central longitudinal axis of the core permits a formed core to be removed from the cavity upon movement of the core relative to the outside surface of the cavity in a direction corresponding to the direction the outer wall surface of the cavity tapers away from the longitudinal axis of the core without applying excessive pressures to the core which would impart injury to the core. Also, the feature of providing such a cavity with an oppositely tapered inside surface makes it possible to remove the core from the center plug upon movement of the core in the same direction relative to the center plug, i.e., in a direction corresponding to the direction the inner surface tapers toward the longitudinal axis of the core. It will therefore be appreciated that the feature of providing a pressure cavity defined by oppositely tapered inner and outer side walls, in combination with a pressure die including a single piece die body and a center plug movably mounted relative to the die body in which the inner surface of the cavity is formed on the center plug and the outer surface of the cavity is formed on the die body eliminates the prior necessity of employing a plurality of removal die sections and makes its possible to form cores of compressed powdered material in an automatic operation. In particular, after the core forming pressure is applied and the pressure ring moved to its retracted position, the center plug may be moved relative to the die body in a direction corresponding to the direction the outer surface of the cavity tapers away from the longitudinal axis of the core, upwardly as viewed in the drawings, to move the formed core relative to the die body and out of the cavity defined by the wall of the die body. Thereupon, the core may be moved relative to the center plug in a direction corresponding to the direction the inner surface of the pressure cavity tapers toward the longitudinal axis of the core, to move the core from the center plug. The latter operation may be accomplished in a number of ways such as by inserting a cradle beneath the core when positioned as shown in FIGURE 7 and then applying a downward force on the center plug of a magnitude necessary to terminate contact between the core and the center plug. By providing the surfaces defining the pressure cavity with a thin film of lubricating oil the cores may be easily removed from the pressure cavity upon application of pressures of a relatively low order of magnitude materially less than the magnitude of pressures that may impart damage to the core. The degree of taper of the inner and outer side walls is shown exaggerated in the drawings for the purpose of clarity. In actual practice it has been found that a taper of the order of one degree is adequate for the inner and outer side walls of a pressure cavity designed for forming magnetic cores. It is to be expressly understood that tapers in excess of one degree may be employed if desired. In addition, the feature of employing a pressure cavity defined by oppositely inclined concentric inner and outer surfaces permits the pressure cavity to be reformed to compensate for wear. The surfaces of pressure cavity which contact powdered metallic material, especially when under high pressure, that is, the surfaces of the cavity which define the formed core, are subject to wear due to abrasive action of the powdered particles, and eventually the cavity size will change and cores of the desired dimensions cannot be obtained. With a pressure cavity of the character provided by the present invention, it is possible to reform the lower portion of the pressure cavity by merely extending the depth of the pressure cavity in accordance with a predetermined shape. This features eliminates the disadvantage of prior molding dies in which the bottom face of the die body as well as the contacting surfaces of the die sections are required to be ground in order to compensate for wear of the surfaces defining the cavity.

The novel feature provided by the present invention of forming a pressure cavity composed of two zones 100 and 101 which are symmetrical about the axis Y—Y, re-

sults in equal distribution of the core forming pressure to the center plug and the body member and assures substantially uniform application of pressure to the core. This arrangement provides a core of maximum strength and improved uniform density characteristics. The further feature of defining the bottom portion of the pressure cavity by cooperating curved annular surfaces which are symmetrical with respect to the axis Y—Y, insures substantially equal distribution of forces throughout the core and minimizes development of localized stresses in the core structure.

In the formation of magnetic cores pressed from insulated particles of magnetic material under extremely high pressure it has been found that the presence of air trapped in the powdered material may have a disadvantageous effect upon the properties of the formed core, depending upon the permeability of the core, which is determined, for the most part, by the size of the particles and the thickness of the insulation. In the formation of low permeability cores by compressing heavily insulated and finely divided particles of magnetic material, it is believed that trapped air collects in the powdered material adjacent the lower surface of the pressure ring and prevents the formation of the powdered material in this region into an integral mass with the remaining portion of the powdered material. It has been found that this phenomenon results in the formation of cores which are weak at its end which contacts the pressure ring during the forming operation, and frequently the outer surface of the core at this end will split from the main body of the core. The present invention provides a novel arrangement for overcoming this problem. As shown in FIGURE 9, the inner and outer annular edges of annular end face **85** and the lower edges of the cylindrical inner and outer side walls **83** and **84** are joined together by annular curved surfaces **110** and **111**, respectively. When a pressure ring shaped in this manner is moved downwardly into a pressure cavity and into pressure contact with a charge of powdered material, a portion of the powdered material including trapped air is forced outwardly toward the inner and outer surfaces of the cavity and collects in upstanding circumferential recesses located between the inner surface of the cavity and the inner curved annular surface **110** of the pressure ring, and between the outer surface of the cavity and the outer curved annular surface **111** of the pressure ring. As shown in FIGURE 10, a core formed with the type of pressure ring described above, includes inner and outer circumferential upstanding lips **112** and **113** which are of different density and are relatively weak with respect to the remaining portion of the core comprising an integral mass substantially free of trapped air. After the core is removed from the molding die, the circumferential lips **112** and **113** may be removed by a simple grinding operation at which time the inner and outer concentric edges of the core at its upper end may be rounded, such as at **114** and **115**, to provide a core as shown in FIGURE 11. It has been determined that in the formation of cores of high permeability, requiring lightly insulated, coarse particles of magnetic material, the strength of the core is not affected by the presence of air that may be trapped in the powdered material during the core forming operation, and that a pressure ring having the inner and outer annular edges of its end face **85** lying in the plane of the side walls **83** and **84**, respectively, may be employed, such as a pressure ring of the shape illustrated in FIGURE 4. In actual operations it has been determined that magnetic cores of a permeability of the order of **125** may be formed with a pressure ring having an end face shaped in the manner shown in FIGURE 4, while magnetic cores of a permeability of 60 or less should be formed with a pressure ring of the character illustrated in FIGURE 9.

As shown in FIGURES 11, 12 and 13, a core formed of pressed powdered magnetic material employing the principles of the present invention includes substantially perfectly circular, concentric inner and outer wall surfaces **116** and **117**, which are continuous and substantially smooth, and continuous top and bottom surfaces **118** and **119** which merge smoothly, without surface interruptions, such as grooves or raised portions, into the side wall surfaces. In addition, the core is of substantially uniform density transversely of the section, that is, in any section of the core lying in a plane perpendicular to the longitudinal axis of the core, the core structure is of substantially uniform density. With this construction the outer circumferential marginal portion of the core, including its outer circumferential surface, will be of uniform density. A magnetic core having the foregoing characteristics possesses improved magnetic, electrical and mechanical properties as compared to corresponding properties of cores produced according to prior art teachings.

According to the preferred embodiment of the invention, the body member **18** includes an insert **41** comprising a single piece of carbide material and the center plug **60** and pressure ring **78** may also be formed of carbide material. In order to obtain cores of compressed particles of metallic material having substantially uniform density characteristics as described above, it is necessary to provide a super finish on the core defining surfaces. It has been found that carbide material, such as tungsten carbide, is capable of receiving a super finish which is maintained throughout a large number of core forming operations in spite of the highly abrasive action of the particles of metallic material. Also, it is believed carbide material has a lower coefficient of friction, as compared to steel die surfaces employed heretofore, which aids in the removal of formed cores from the pressure cavity. In the prior molding dies including a plurality of arcuate die sections, it was not possible to employ a carbide insert to define the outer contour of the pressure cavity since the inherent flexure of the die sections would break the carbide material.

Another form of cavity construction is shown in FIGURE 14 of the drawings. As shown, the outer and inner walys of the cavity are formed by tapered surfaces **107** and **108**, respectively, and the bottom of the cavity includes a flat surface **125** having its edges merged with curved surfaces **126** and **127** which in turn merge with the lower edges of the outer and inner side walls, respectively. This type of cavity construction has particular utility in connection with the formation of cores having relatively large spacing between the inner and outer wall surfaces. In the cavity structure shown in FIGURE 14 and in FIGURE 8 the dividing line between the center plug and the body member lies along a line which intersects the bototm of the cavity at the point of tangency thereon with a plane perpendicular to the longitudinal axis of the cavity. In FIGURE 8 in which the bottom of the cavity is formed by a curved surface, which in section defines a semi-circle, there exists one point of tangency on the bottom surface with a plane perpendicular to the longitudinal axis of the cavity, and the dividing line between the center plug and the die body coincides with the axis Y—Y. In FIGURE 14, however, there exist two points of tangency and the dividing line between the center plug and the die body preferably passes through the point of tangency adjacent the outer wall of the cavity. Although in the form of pressure cavity of the character shown in FIGURE 14 the dividing line may be displaced from the position shown inwardly toward the longitudinal axis of the cavity, location of the dividing line as shown in this figure and also as shown in FIGURE 8 provides the maximum area of contact between the formed core and the center plug for the particular type of cavity without presenting difficult problems that would exist if the dividing line was displaced outwardly from the position shown in FIGURE 14 or inwardly or outwardly from the position shown in FIGURE 8. Inasmuch as a greater

area of the core contacts the outer surface of the cavity than the area of the core that contacts the inner surface of the cavity, more pressure will be required to move the core relative to the die body than will be required to move the core relative to the center plug. Consequently, the feature of forming the center plug to provide the flat surface 125 of the bottom of the cavity provides the maximum permissible area of contact between the core and the center plug and makes it possible to apply forces of the necessary magnitude to remove the core from the die body without imparting injury to the core.

In operation, the table 10 is rotated in a predetermined direction to successively move the molding dies 12 to a charging station, the pressing station and the ejector station, in the order named. At the charging station a mechanism is provided for introducing a predetermined quantiy of powdered material into the pressure cavity, the quantity of the charge depending upon the size of pressure cavity. When a molding die is located at the charging station the center plug 60 is positioned relative to the body member 18 as shown in FIGURE 2. Before the charge of powdered material is introduced into the pressure cavity, the surfaces defining the pressure cavity are coated with a suitable lubricating material. A separate station, preceding the filling station, may be provided for this operation. After the pressure cavity is charged, the table is rotated to position the molding die at the pressure or core forming station in proper relation with the anvil 71 and the pressure ring 78 as shown in FIGURE 4. Thereupon the pressure plate 75 is moved downwardly to move the pressure ring into the cavity in contact with the charge of powdered material and the required pressure is applied to form an integral core, such as a pressure of 200,000 to 250,000 pounds per square inch. FIGURE 5 shows the relative positions of the pressure ring and molding die during the core forming operation. The applied pressure is equally distributed between the center plug and the body member, due to the design of the pressure cavity, transmitted independently to the anvil, without loading the table. Following the core forming operation the pressure is relieved and the pressure ring removed from the cavity. Thereupon the table is rotated to move the molding die to the ejector station shown in FIGURE 6. After location at this station, the plunger 95 is moved upwardly into the bore 43 to move the center plug 60 upwardly relative to the body member, as shown in FIGURE 7. The formed core 90 moves upwardly with the center plug and is removed from the opening provided in the insert 41. When the center plug is in its ejecting position the core 90 may be removed therefrom by applying upward movement to the core relative to the center plug. The core 90 may also be removed by placing a support beneath the core and applying a downward force on the center plug. The support may thereafter function as a means for delivering the core from the machine. The center plug is then retracted to its normal position and the molding die in a condition to be moved to the charging station to receive another charge of powdered material and proceed through the sequence of operations described above.

The principles of the present invention may be employed to form bodies from powdered material, especially in cases where extremely high pressures are required, such as bodies of powdered carbonyl or reduced iron or magnetic cores of insulated particles of magnetic material of high permeability such as permalloy, flakenol or alfenol, for example. In the formation of magnetic cores of compressed insulated particles of magnetic material according to the present invention, the novel features described above which result in application of uniform pressure to the core during its formation and the production of a core of substantially uniform density, also insures that the effectiveness of the insulation of the magnetic particles is not impaired and that the core possesses substantially



uniform insulation effectiveness. Thus cores of compressed insulated particles of magnetic material formed according to the principles of the present invention exhibit relatively low eddy current losses when incorporated in a coil.

There is thus provided by the present invention a novel magnetic core of compressed insulated particles of magnetic material which possesses improved magnetic, electrical and mechanical characteristics as compared to magnetic cores produced by following prior methods and apparatus. The core may be of toroidal shape, of substantially perfect circular cross-section having concentric inner and outer side walls and includes substantially smooth, continuous surfaces. The present invention also provides a novel method for forming a magnetic core having the foregoing characteristics as well as a novel molding die structure for use in performing such methods or for use in forming cores of other powdered material requiring application of relatively high pressure. The novel molding die structure is characterized by a single block of material presenting a continuous surface defining the outer contour of a pressure cavity. This feature makes it possible to form cores of a shape substantially corresponding to the shape of the pressure cavity, such as cores of substantially circular cross section having concentric inner and outer side walls. The pressure cavity of the novel molding die is formed in part by a center plug and is designed in such a manner as to permit removal of a formed core from the cavity upon movement of the center plug and overcomes prior core removal difficulties which required the use of a plurality of arcuate die sections and makes it practicable to form cores by an automatic operation.

Although several embodiments of the invention have been disclosed and described herein, it is to be expressly understood that various changes and substitutions may be made therein without departing from the spirit of the invention as well understood by those skilled in the art. Reference therefore will be had to the appended claims for a definition of the limits of the invention.

What is claimed is:

1. Method for producing a toroidal core from magnetic particles comprising the steps of

confining a measured quantity of magnetic particles in a toroidal shape having a central axis, inner and outer sidewalls, rounded edge bottom configuration, and top surface, the inner and outer sidewalls of the toroidal shape being in concentric relationship and tapering slightly toward each other in approaching the bottom configuration with a curved annular surface at each sidewall forming at least part of the bottom configuration of the toroidal shape,

applying pressure uniformly to the top surface of the toroidal shape with the pressure being applied in a direction parallel to the central axis of the toroidal shape to reduce the size of the toroidal shape and form an integral magnetic core,

maintaining the inner and outer sidewalls and the rounded edge bottom configuration of the toroidal shape in fixed positional relationship while applying the pressure to the magnetic particles to reduce the size of the toroidal shape,

relieving the pressure from the top surface of the toroidal shape while maintaining the inner and outer sidewalls and rounded edge configuration in fixed positional relationship, and

applying force to the inner sidewall of the toroidal shape and its associated curved annular surface at the bottom configuration of the toroidal shape in a direction opposite to the pressure applied to reduce the size of the toroidal shape causing the inner sidewall and its associated annular curved surface to move along the central axis of the toroidal shape with respect to the outer sidewall and release the integral magnetic core.

2. Method for producing a toroidal core from magnetic particles comprising the steps of

confining a measured quantity of magnetic metal particles in a toroidal shape having a central axis, inner and outer sidewalls, rounded edge bottom configuration, and top surface, the inner and outer sidewalls being in concentric relationship and tapering slightly toward each other in approaching the bottom configuration with a curved annular surface at each sidewall forming at least part of the bottom configuration of the toroidal shape,

applying pressure in the range of about 200,000 to about 250,000 p.s.i. to the top surface of the toroidal shape with the pressure being applied in a direction parallel to the central axis of the toroidal shape and toward the rounded edge bottom configuration to reduce the size of the toroidal shape and form an integral magnetic core,

maintaining the inner and outer sidewalls and the rounded edge bottom configuration of the toroidal shape in fixed relationship while applying the pressure to the magnetic metal particles,

relieving the pressure from the top surface of the toroidal shape while maintaining the inner and outer sidewalls and rounded edge bottom configuration in fixed positional relationship and

applying force to the inner sidewall of the toroidal shape and its associated annular curved surface at the bottom configuration of the toroidal shape, the force being applied in a direction opposite to the direction of the pressure applied to reduce the size of the toroidal shape to cause the inner sidewall and its associated annular curved surface to move along the central axis of the toroidal shape with respect to the outer sidewall and release the integral magnetic core.

3. Method for producing a toroidal core from magnetic particles comprising the steps of

confining a measured quantity of magnetic particles in a toroidal shaped pressure cavity having a central axis and defined by concentric circumferentially continuous inner and outer sidewalls which taper slightly toward each other with increasing cavity depth along the central axis of the cavity and terminate in curved annular surfaces forming at least part of a rounded edge bottom configuration for the cavity with the inner sidewall surface and its associated curved annular surface being defined by a center plug member which is movable along the central axis of the cavity,

applying pressure to the magnetic particles in the cavity in a direction parallel to the central axis of the cavity and toward the bottom configuration of the cavity to form an integral core,

maintaining the inner and outer sidewall surfaces and curved annular surfaces of the cavity in fixed positional relationship while applying the pressure,

relieving the applied pressure on the magnetic particles in the cavity while maintaining the inner and outer sidewall surfaces and curved annular surfaces of the cavity in fixed positional relationship, and

removing the integral core from the cavity by moving the center plug member along the central axis of the cavity in a direction opposite to the direction pressure was applied to form the core.




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