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(54) **Die-casting method and die-casting apparatus**

(57) A method of producing a die-cast article by die-casting, the die-cast article having at least one of an inner and an outer circumferential surface, the method comprising the steps of: preparing a mold assembly (224, 226; 400, 402; 500, 502) including a hollow portion (280, 410, 510) having a molding surface (300, 420, 530) for molding one of the inner and outer circumferential surfaces of the die-cast article; closing the mold assembly to define therein a mold cavity (236, 426, 540) having a configuration corresponding to that of the die-cast article; subjecting the hollow portion to an elastic deformation in a direction toward the one of the inner and outer circumferential surfaces of the die-cast article to be produced; introducing a molten metal into the mold cavity while the hollow portion is subjected to the elastic deformation; opening the mold assembly and permitting the elastic deformation to be removed from the hollow portion after the molten metal has solidified; and removing the die-cast article from the mold assembly. An apparatus for practicing the method is also disclosed.

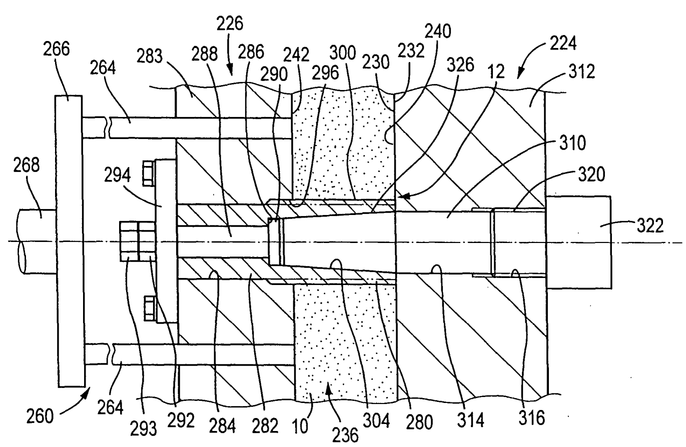

FIG. 4

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Description

[0001] This application is based on Japanese Patent Application No. 2001-083085 filed March 22, 2001, the contents of which are incorporated hereinto by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present invention relates in general to a method of producing a die-cast article having at least one of an inner and an outer circumferential surface which does not have an inclination corresponding to a draft provided on a casting mold, or which is provided with a relatively small angle of inclination. The present invention is also concerned with a die-casting apparatus suitable for practicing the method.

Discussion of the Related Art

[0003] One example of a method of producing a die-cast article having at least one of an inner and an outer circumferential surface comprises steps of positioning a slide core within a mold cavity formed in a casting mold, so that an outer circumferential surface of the slide core functions as a part of a molding surface partially defining the mold cavity; and introducing a molten metal into the mold cavity, so that the inner circumferential surface of the die-cast article is formed by the outer circumferential surface of the slide core. The slide core is retracted from the mold cavity after the molten metal has solidified to give the intended die-cast article, so that the slide core is removed from the die-cast article. Since the molten metal shrinks upon its solidification, the slide core is subjected to a holding force caused by shrinkage due to the solidification of the molten metal, so that the slide core cannot be easily removed from the die-cast article. For easy removal of the slide core from the die-cast article, the slide core is generally provided with a draft, so that the die-cast article produced by using the slide core has an inclined inner circumferential surface corresponding to the draft of the slide core. In general, the die-cast article which is produced by using the slide core desirably has a straight inner circumferential surface having a constant diameter. Accordingly, the inclined inner circumferential surface of the die-cast article is subjected, after the die-casting process, to a machining operation to provide the straight inner circumferential surface. For minimizing the required amount of the stock removal by the machining operation, it is desirable to minimize the angle of the draft of the slide core. To this end, EP 0642855 A (corresponding to JP-A-7-60399) discloses a casting mold having a slide core which is formed of a material whose thermal expansion coefficient is equal to or higher than that of a molten metal to be introduced into the mold cavity. According to this arrangement, the slide core has been heated to a temperature substantially equal to that of the molten metal before the metal molten solidifies into a die-cast article. Thereafter, the temperature of the slide core is lowered with a decrease of the temperature of the die-cast article. Since the thermal expansion coefficient of the slide core is equal to or higher than that of the molten metal, the slide core is subjected to shrinkage whose amount is equal to or larger than that of shrinkage of the molten metal. Therefore, the slide core is easily removed from the die-cast article. In the proposed method, however, the material of the slide core is inevitably limited to that which is suitable for a casting mold and which has a thermal expansion coefficient equal to or higher than the molten metal for forming the die-cast article. In addition, the proposed method is not available for eliminating or reducing an angle of inclination to be provided on an outer circumferential surface of the die-cast article.

SUMMARY OF THE INVENTION

[0004] It is therefore an object of the present invention to provide a method of die-casting which permits reduction in the angle of inclination provided on an inner or an outer circumferential surface of a die-cast article, and a die-casting apparatus suitably used for the method. This object may be achieved according to any one of the following modes of the present invention, each of which is numbered like the appended claims and depends from the other mode or modes, where appropriate, to indicate and clarify possible combinations of elements or technical features of the present invention, for easier understanding of the invention. It is to be understood that the present invention is not limited to the technical features or any combinations thereof which will be described for illustrative purpose only. It is to be further understood that a plurality of elements or features included in any one of the following modes of the invention are not necessarily provided all together, and that the invention may be embodied without some of the elements or features described with respect to the same mode.

[0005] (1) A method of producing a die-cast article by die-casting, the die-cast article having at least one of an inner circumferential surface and an outer circumferential surface, the method comprising the steps of: preparing a mold assembly including a hollow portion which has a molding surface for molding one of the inner and outer circumferential surfaces of the die-cast article; closing the mold assembly so as to define therein a mold cavity having a configuration which corresponds to that of the die-cast article; subjecting the hollow portion to an elastic deformation in a direction toward the one of the inner and outer circumferential surfaces of the die-cast article to be produced; introducing a molten metal into the mold cavity while the hollow portion is subjected to the elastic deformation; opening the mold assembly and permitting the elastic deformation to be removed from the hollow portion after the molten metal has solidified in the mold cavity; and removing the die-cast article formed in the mold cavity from the mold assembly.

[0006] If the molten metal is introduced into the mold cavity and solidified therein with the hollow portion of the mold assembly being elastically deformed in the direction toward one of the inner and outer circumferential surfaces of the die-cast article to be produced, the die-cast article and the hollow portion engage each other with an interference fit therebetween. Thereafter, the hollow portion is freed or released from the elastic deformation and is restored to its original state, that is, deformed in a direction opposite to the above-indicated direction. Described in detail, where the outer circumferential surface of the hollow portion of the mold assembly serves as the molding surface, the hollow portion which has been expanded by the elastic deformation contracts. Where the inner circumferential surface of the hollow portion serves as the molding surface, the hollow portion which has been contracted by the elastic deformation expands. Accordingly, the die-cast article and the hollow portion, which have been held in an interference fit with each other, are positioned relative to each other such that there is a clearance therebetween, so that the hollow portion and the die-cast article can be easily removed away from each other. According to the present method, it is possible to minimize or eliminate a draft provided on the molding surface of the hollow portion, so that the inner or outer circumferential surface of the die-cast article has a minimum inclination corresponding to the minimized draft of the molding surface, or no inclination.

[0007] (2) A method according to the above mode (1), wherein the hollow portion has a non-molding surface which is opposite to the molding surface, the non-molding surface being a tapered surface, a dimension of which in a direction perpendicular to a direction parallel to a centerline of the hollow portion gradually changes in the direction, the step of subjecting a hollow portion to an elastic deformation comprising steps of preparing a tapered member having a tapered surface which corresponds to the tapered surface of the hollow portion, and causing the elastic deformation of the hollow portion by an interference fit between the tapered surface of the hollow portion and the tapered surface of the tapered member.

[0008] According to the above mode (2), the hollow portion can be easily elastically deformed when the hollow portion and the tapered member engage each other with an interference fit between the respective tapered surfaces of the hollow portion and the tapered member.

[0009] (3) A method according to the above mode (1) or (2), wherein the hollow portion is a hollow cylindrical member having a circular shape in transverse cross section.

[0010] The transverse cross sectional shape of the hollow portion is not particularly limited. While the principle of the present invention is advantageously applicable to an arrangement wherein the hollow portion has an axsymmetric shape in transverse cross section such as a regular polygonal shape, the present invention provides a particularly desirable effect where the hollow portion has a circular shape in transverse cross section.

[0011] (4) A method according to any one of the above modes (1)-(3), wherein the die-cast article is a cylinder block which is used for a swash plate type compressor and which includes a plurality of cylinder bores, the at least one of the inner and outer circumferential surfaces of the die-cast article being an inner circumferential surface of each of the cylinder bores.

[0012] The present method is suitably used for producing a cylinder block for the swash plate type compressor. Where a plurality of cylinder bores are formed in the cylinder block such that the cylinder bores are adjacent to each other, the roundness of each cylinder bore may be deteriorated when the hollow portion has a complete circular shape in transverse cross section. In this case, the hollow portion is preferably arranged to have a transverse cross sectional shape which slightly deviates from a complete circular shape at least while the hollow portion is subjected to the elastic deformation, so that each cylinder bore to be formed in the cylinder block as the die-cast article has a complete circular shape in transverse cross section.

[0013] (5) A method according to any one of the above modes (1)-(3), wherein the die-cast article is a front housing which is used for a swash plate type compressor and which includes a hollow cylindrical recess, the at least one of the inner and outer circumferential surfaces of the die-cast article being an inner circumferential surface of the hollow cylindrical recess of the front housing.

[0014] The hollow cylindrical recess of the front housing for the swash plate type compressor has an inner circumferential surface which is slidable relative to a rotation preventing part of a piston of the compressor, for preventing a rotary motion of the piston about its centerline. Accordingly, it is required that the inner circumferential surface of the hollow cylindrical recess of the front housing has a high degree of dimensional accuracy. According to the present method, it is possible to reduce the required amount of stock removal from the inner circumferential surface of the hollow cylindrical recess of the front housing in the machining operation conducted thereon. Alternatively, the machining operation can be eliminated.

[0015] (6) A die-casting apparatus for producing a die-cast article having at least one of an inner circumferential surface and an outer circumferential surface, comprising: a mold assembly including a hollow portion which has a molding surface for molding one of the inner and outer circumferential surfaces of the die-cast article; and deforming device for elastically deforming the hollow portion such that the hollow portion is subjected to an elastic deformation in a direction toward the one of inner and outer circumferential surfaces of the die-cast article to be produced.

[0016] The method of producing a die-cast article according to the above mode (1) can be practiced by using the die-casting apparatus according to the above mode (6).

[0017] (7) An apparatus according to the above mode (6), wherein the mold assembly includes a first mold and a second mold which are moved toward and away from each other, so that the first mold and the second mold are opened and closed, the hollow portion extending in a direction parallel to a direction in which the first mold and the second mold are opened and closed.

[0018] The hollow portion may extend in a direction which intersects the direction in which the first mold and the second are opened and closed. (The direction in which the first and second molds are opened and closed is hereinafter referred to as a "parting direction" of the two molds.) The present arrangement wherein the hollow portion extends in the direction parallel to the parting direction of the two molds permits the hollow portion to be easily subjected to the elastic deformation, or permits the hollow portion to be easily removed from the die-cast article after the hollow portion has been freed from the elastic deformation.

[0019] (8) An apparatus according to the above mode (6) or (7), wherein the mold assembly has a main body in which an engaging portion is formed, the hollow portion being provided by a member separate from the main body, and wherein at least a part of the hollow portion, which part is adjacent to the molding surface, and the engaging portion are positioned relative to each other such that there is a clearance in a radial direction therebetween.

[0020] The engaging portion has an engaging hole and an engaging protrusion. Where the molding surface is an outer circumferential surface of the hollow portion, the engaging portion is provided by the engaging hole. Where the molding surface is an inner circumferential surface of the hollow portion, the engaging portion is provided by the engaging protrusion. In either case, if at least a part of the hollow portion, which part is adjacent to the molding surface of the hollow portion, is positioned relative to the engaging portion such that there is a clearance in a radial direction therebetween, the above-indicated part can be easily subjected to the elastic deformation, so that the hollow portion including the molding surface can be subjected to substantially uniform elastic deformation over an entire axial length thereof.

[0021] (9) An apparatus according to any one of the above modes (6)-(8), wherein the molding surface of the hollow portion for molding the one of the inner and outer circumferential surfaces of the die-cast article is an outer circumferential surface of the hollow portion, and wherein the deforming device for elastically deforming the hollow portion includes: an expanding member which engages an inner circumferential surface of the hollow portion; and a pushing device which forces the expanding member onto the inner circumferential surface of the hollow portion, so that the hollow portion is expanded.

[0022] The expanding member according to the above mode (9) may be provided by a tapered member or a collet described below, for instance. Where the expanding member is provided by the tapered member, the pushing device is a device for effecting an interference fit described below. Where the expanding member is provided by the collet, the pushing device is a collet-diameter changing device described below.

[0023] (10) An apparatus according to any one of the above modes (6)-(8), wherein the molding surface of the hollow portion for molding the one of the inner and outer circumferential surfaces of the die-cast article is an inner circumferential surface of the hollow portion, and wherein the deforming device for elastically deforming the hollow portion includes: a contracting member which engages an outer circumferential surface of the hollow portion; and a pushing device which forces the contracting member onto the outer circumferential surface of the hollow portion, so that the hollow portion is contracted.

[0024] The contracting member according to the above mode (10) may be provided by a tapered member or a collet described below, for instance. Where the contracting member is provided by the tapered member, the pushing device is a device for effecting an interference fit described below. Where the contracting member is provided by the collet, the pushing device is a collet-diameter changing device described below.

[0025] (11) An apparatus according to any one of the above modes (6)-(8), wherein the hollow portion has a non-molding surface which is opposite to the molding surface, the non-molding surface being a tapered surface, a dimension of which in a direction perpendicular to a direction parallel to a centerline of the hollow portion gradually changes in the direction, the deforming device for elastically deforming the hollow portion including: a tapered member having a tapered surface which corresponds to the tapered surface of the hollow portion; and a device for effecting an interference fit between the tapered surface of the hollow portion and the tapered surface of the tapered member.

[0026] The die-casting apparatus according to the above mode (11) is suitably used for practicing the method according to the above mode (2).

[0027] (12) An apparatus according to the above mode (11), wherein the tapered member is held by the main body of the mold assembly such that the tapered member and the hollow portion are axially movable relative to each other, the device for effecting an interference fit including an axial moving device for moving the tapered member and the hollow portion relative to each other in an axial direction of the tapered member.

[0028] The present arrangement is particularly advantageous when the hollow portion and the tapered member are located such that they extend in a direction which intersects the above-indicated parting direction of the two molds. The present arrangement is applicable to an arrangement wherein the hollow portion and the tapered member extend in a direction parallel to the parting direction of the two molds.

[0029] (13) An apparatus according to the above mode (12), wherein the axial moving device includes a hydraulic cylinder which is fixed to the mold assembly.

[0030] (14) An apparatus according to the above mode (11), wherein the tapered member is fixed to one of the first and second molds, which one mold is opposite to the other of the first and second molds which is equipped with the hollow portion, the first and second molds being opened and closed by an opening and closing device which also functions as the device for effecting an interference fit.

[0031] (15) An apparatus according to any one of the above modes (7)-(14), wherein the other of the first and second molds which is equipped with the hollow portion includes an ejecting device which pushes the die-cast article in a direction away from the other mold to remove the die-cast article from the hollow portion.

[0032] The ejecting device permits the die-cast article to be easily removed from the hollow potion. The die-cast article can be easily removed from the hollow portion especially when the ejecting device is actuated after the hollow portion has been freed from the elastic deformation. It is particularly advantageous to employ the feature of this mode (15) and the feature of the above mode (14) in combination. In this case, at the same time when the first and second molds are opened, the tapered member and the hollow portion are separated away from each other, so that the hollow portion is freed from the elastic deformation for permitting easy removal of the die-cast article from the hollow portion. In this state, the ejecting device is actuated, whereby the die-cast article can be easily removed from the hollow portion.

[0033] (16) An apparatus according to the above mode (6), wherein the hollow portion is a hollow cylindrical portion having an annular shape in transverse cross section, and wherein the deforming device for elastically deforming the hollow portion includes: a collet which engages, at one of inner and outer circumferential surfaces thereof, a non-molding surface of the hollow portion, which non-molding surface is opposite to the molding surface for molding the one of the inner and outer circumferential surfaces of the die-cast article; and a collet-diameter changing device for changing a diameter of the collet so as to force the collet onto the non-molding surface.

[0034] In the above mode (16), the collet is a hollow cylindrical member which consists of a plurality of segments that are arranged in a spaced-apart relation with each other in the circumferential direction. The thus constructed collet is easily expanded or contracted in its radial direction. If the spacing between the adjacent segments of the collet is relatively large, the amount of the elastic deformation of the hollow portion is undesirably small at portions thereof corresponding to the relatively large spacing of the segments of the collet. In this case, the roundness of the outer or inner circumferential surface of the hollow portion is deteriorated, leading to deterioration of the roundness of the inner or outer circumferential surface of the die-cast article provided by the corresponding outer or inner circumferential surface of the hollow portion. In view of this, the spacing between the adjacent segments of the collet is preferably minimized. While the segments of the collet may be completely separated from each other, it is desirable that the segments of the collet are partially connected to each other so as to constitute an integral unitary member.

[0035] (17) An apparatus according to the above mode (16), wherein the other of the inner and outer circumferential surfaces of the collet, which the other circumferential surface is opposite to the one circumferential surface which engages the non-molding surface of the hollow cylindrical portion, is tapered to give a first tapered surface whose diameter gradually changes in an axial direction of the hollow cylindrical portion, and wherein the collet-diameter changing device includes: a tapered member having a second tapered surface which corresponds to the first tapered surface; a multiplicity of balls interposed between the collet and the tapered member such that the balls maintain a constant position relative to each other, and such that the balls are rotatable independently of each other, at least while the first and second tapered surfaces engage each other; and an axial moving device which moves the tapered member and the hollow cylindrical portion relative to each other in an axial direction of the tapered member and the hollow cylindrical portion, so that the first and second tapered surfaces engage each other with an interference fit therebetween via the balls.

[0036] The multiplicity of the balls are accommodated and held in a recess formed in one of the first and second tapered surfaces, such that each ball is rotatable and such that a part of each ball projects outwardly from the recess. In this case, the ball is held in contact with the other of the first and second tapered surfaces at its projecting portion. Alternatively, the balls may be held by a retainer which is a separate member from the tapered member and the hollow cylindrical portion. The balls are held by the retainer such that the balls are rotatable and such that the balls project from the inner and outer surfaces of the retainer, respectively, so that the balls are held in rolling contact with and between the first and second tapered surfaces. Either of those arrangements are effective to reduce the friction caused between the tapered member and the hollow cylindrical portion when the tapered member and the hollow cylindrical portion engage each other with an interference fit therebetween. Accordingly, the present arrangement improves the durability of the die-casting device.

BRIEF DESCRIPTION OF THE DRAWINGS

[0037] The above and optional objects, features, advantages and technical and industrial significance of the present invention will be better understood and appreciated by reading the following detailed description of presently preferred embodiments of the invention, when considered in connection with the accompanying drawings, in which:

Fig. 1 is a front elevational view in cross section of a swash plate type compressor produced according to one embodiment of a die-casting method and apparatus of the present invention;
Fig. 2 is a perspective view showing a cylinder block of the swash plate type compressor of Fig. 1;
Fig. 3 is a front elevational view partly in cross section schematically showing a casting system including the die-casting apparatus;
Fig. 4 is a front elevational view in cross section showing a principal part of the die-casting apparatus;
Fig. 5 is a front elevational view in cross section showing a die-casting apparatus constructed according to another embodiment of the present invention;
Fig. 6 is a front elevational view in cross section showing a die-casting apparatus constructed according to still another embodiment of the present invention; and
Fig. 7 is a side elevational view showing a part of the die-casting apparatus of Fig. 6.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0038] Referring to the accompanying drawings, there will be described presently preferred embodiments of a die-casting method and apparatus according to the present invention as applied to the production of a swash plate type compressor.

[0039] Referring first to Fig. 1, there is shown a compressor of swash plate type used for an air conditioning system of an automotive vehicle. In Figs. 1 and 2, reference numeral 10 denotes a cylinder block having a plurality of cylinder bores 12 (seven cylinder bores in this embodiment) formed so as to extend in its axial direction such that the cylinder bores 12 are arranged along a circle whose center lies on a centerline L of the cylinder block 10 and such that the cylinder bores 12 are equiangularly spaced from each other in the circumferential direction of the cylinder block 10. Single-headed pistons generally indicated at 14 (hereinafter simply referred to as "piston 14") are reciprocably received in the respective cylinder bores 12. To one of the axially opposite end faces of the cylinder block 10, (the left end face as seen in Fig. 1, which will be referred to as "front end face"), there is attached a front housing 16. To the other end face (the right end face as seen in Fig. 1, which will be referred to as "rear end face"), there is attached a rear housing 18 through a valve plate 20. The front housing 16, rear housing 18 and cylinder block 10 cooperate to constitute a housing assembly of the swash plate type compressor. The rear housing 18 and the valve plate 20 cooperate to define a suction chamber 22 and a discharge chamber 24, which are connected to a refrigerating circuit (not shown) through an inlet 26 and an outlet 28, respectively. The valve plate 20 has suction ports 32, suction valves 34, discharge ports 36 and discharge valves 38.

[0040] A rotary drive shaft 50 is disposed in the cylinder block 10 and the front housing 16 such that the axis of rotation of the drive shaft 50 is aligned with the centerline L of the cylinder block 10. The drive shaft 50 is supported at its opposite end portions by the front housing 16 and the cylinder block 10, respectively, via respective bearings. The cylinder block 10 has a central bearing hole 56 formed in a central portion thereof, and the bearing is disposed in this central bearing hole 56, for supporting the drive shaft 50 at its rear end portion. The front end portion of the drive shaft 50 is connected, through a clutch mechanism such as an electromagnetic clutch, to an external drive source (not shown) in the form of an engine of an automotive vehicle. In operation of the compressor, the drive shaft 50 is connected through the clutch mechanism to the vehicle engine in operation so that the drive shaft 50 is rotated about its axis.

[0041] The rotary drive shaft 50 carries a swash plate 60 such that the swash plate 60 is axially movable and tiltable relative to the drive shaft 50. The swash plate 60 has a central hole 61 through which the drive shaft 50 extends. The diameter of the central hole 61 of the swash plate 60 gradually increases in the axially opposite directions from its axially intermediate portion towards the axially opposite ends. (In other words, the inner dimension of the central hole 61 as measured in a vertical direction of Fig. 1 is larger at the axially opposite ends than the axially intermediate portion.) To the drive shaft 50, there is fixed a rotary member 62 as a torque transmitting member, which is held in engagement with the front housing 16 through a thrust bearing 64. The swash plate 60 is rotated with the drive shaft 50 by a hinge mechanism 66 during rotation of the drive shaft 50. The hinge mechanism 66 guides the swash plate 60 for its axial and tilting motions. The hinge mechanism 66 includes a pair of support arms 67 fixed to the rotary member 62, guide pins 69 which are formed on the swash plate 60 and which slidably engage guide holes 68 formed in the support arms 67, the central hole 61 of the swash plate 60, and the outer circumferential surface of the drive shaft 50.

[0042] The piston 14 indicated above includes an engaging portion 70 engaging the radially outer portion of the opposite surfaces of the swash plate 60, and a head portion 72 formed integrally with the engaging portion 70 and fitted in the corresponding cylinder bore 12. The head portion 72, cylinder bore 12, and valve plate 20 cooperate with one another to define a pressurizing chamber 79. The engaging portion 70 engages the radially outer portion of the opposite surfaces of the swash plate 60 through a pair of hemi-spherical shoes 76.

[0043] A rotary motion of the swash plate 60 is converted into a reciprocating linear motion of the piston 14 through the shoes 76. A refrigerant gas in the suction chamber 22 is sucked into the pressurizing chamber 79 through the suction port 32 and the suction valve 34, when the piston 14 is moved from its upper dead point to its lower dead point, that is, when the piston 14 is in the suction stroke. The refrigerant gas in the pressurizing chamber 79 is pressurized by the piston 14 when the piston 14 is moved from its lower dead point to its upper dead point, that is, when the piston 14 is in the compression stroke. The pressurized refrigerant gas is discharged into the discharge chamber 24 through the discharge port 36 and the discharge valve 38. A reaction force acts on the piston 14 in the axial direction as a result of compression of the refrigerant gas in the pressurizing chamber 79. This compression reaction force is received by the front housing 16 through the piston 14, swash plate 60, rotary member 62 and thrust bearing 64. The engaging portion 70 of the piston 14 has an integrally formed rotation preventive part (not shown), which is arranged to contact the inner circumferential surface of the front housing 16, for thereby preventing a rotary motion of the piston 14 about its centerline to prevent an interference between the piston 14 and the swash plate 60.

[0044] The cylinder block 10 has a supply passage 80 formed therethrough for communication between the discharge chamber 24 and a crank chamber 86 which is defined between the front housing 16 and the cylinder block 10. The supply passage 80 is connected to a solenoid-operated valve 90 having a solenoid coil 92. The solenoid-operated valve 90 is selectively energized and de-energized by a control device (not shown) constituted principally by a computer. During energization of the solenoid coil 92, the amount of electric current applied to the solenoid coil 92 is controlled depending upon the air conditioner load, so that the amount of opening of the solenoid-operated valve 90 is controlled according to the air conditioner load.

[0045] The rotary drive shaft 50 has a bleeding passage 100 formed therethrough. The bleeding passage 100 is open at one of its opposite ends to the central bearing hole 56, and is open to the crank chamber 86 at the other end. The central bearing hole 56 communicates at its bottom with the suction chamber 22 through a communication port 104.

[0046] The present swash plate type compressor is of variable capacity type. By controlling the pressure in the crank chamber 86 by utilizing a difference between the pressure in the discharge chamber 24 as a high-pressure source and the pressure in the suction chamber 22 as a low pressure source, a difference between the pressure in the crank chamber 86 and the pressure in the pressurizing chamber 79 is regulated to change the angle of inclination of the swash plate 60 with respect to a plane perpendicular to the axis of rotation of the drive shaft 50, for thereby changing the reciprocating stroke (suction and compression strokes) of the piston 14, whereby the displacement capacity of the compressor can be adjusted. Described in detail, the pressure in the crank chamber 86 is controlled by controlling the solenoid-operated valve 90 to selectively connect and disconnect the crank chamber 86 to and from the discharge chamber 24. The maximum angle of inclination of the swash plate 60 is limited by abutting contact of a stop 106 formed on the swash plate 60, with the rotary member 62, while the minimum angle of inclination of the swash plate 60 is limited by abutting contact of the swash plate 60 with a stop 107 in the form of a ring fixedly fitted on the drive shaft 50.

[0047] Between the rotary member 62 and one of the opposite major surfaces of the swash plate 60 which is remote from the rear housing 18, an elastic member in the form of a compression coil spring 108 is disposed to function as biasing means for biasing the swash plate 60 toward the stop 107 so that when the compressor is in its off state, the swash plate 60 is positioned substantially at right angles with respect to the centerline of the cylinder block 10, in abutting contact with the stop 107. When the compressor is turned off, the swash plate 60 is moved to its minimum inclination position by the biasing force of the compression coil spring 108 and is kept at the position until the compressor is re-started.

[0048] The cylinder block 10 and each piston 14 are formed of an aluminum alloy. The piston 14 is coated at its outer circumferential surface with a fluoro resin film which prevents a direct contact of the aluminum alloy of the piston 14 with the aluminum alloy of the cylinder block 10 so as to prevent seizure therebetween, and makes it possible to minimize the amount of clearance between the piston 14 and the cylinder bore 12. Other materials may be used for the cylinder block 10, the piston 14, and the coating film.

[0049] The cylindrical wall of each of the cylinder bores 12 of the cylinder block 10 is formed with an extension 150 (Fig. 2) at a first circumferential part thereof which corresponds to a radially outer portion of the cylinder block 10 and which is more distant from the centerline L of the cylinder block than a second circumferential part which corresponds to a radially inner portion of the cylinder block 10. The extension 150 extends from the above-indicated first circumferential part of each cylinder bore 12 in the axial direction toward the crank chamber 86. Front end faces 152 of the extensions 150 are connected to each other in the circumferential direction of the cylinder block 10 so as to be flush with each other. The front housing 16 is attached to the front end faces 152 of the extensions 150. The inner circumferential surface of each cylinder bore 12 has a complete cylindrical surface 154, and a part-cylindrical surface 156 on the side of the front housing 16. Owing to provision of the extensions 150, the cylindrical wall of each cylinder bore 12 has a larger axial length at the above-indicated first circumferential part of the cylinder bore 12 which corresponds to the radially outer portion of the cylinder block 10 and which is distant from the centerline L of the cylinder block 10, than the second circumferential part of the cylinder bore 12 which corresponds to the radially inner portion of the cylinder block 10 and which is near to the centerline L of the cylinder block 10. Accordingly, the piston 14 placed at its end of the compression stroke engages the inner circumferential surface of the cylinder bore 12 over a larger axial distance corresponding to the axial dimension of the extension 150, at the above-indicated first circumferential part of the cylinder bore 12 corresponding to the radially outer portion of the cylinder block 10. This arrangement is effective to prevent the engaging portion 70 of the piston 14 from being inclined toward the radially outer portion of the cylinder block 10. Therefore, the piston 14 can be smoothly retracted into the cylinder bore 12 without being adversely influenced by an excessively large resistance of friction which would be otherwise caused between the inner circumferential surface of the cylinder bore 12 and the outer circumferential surface of the piston 14. Accordingly, the swash plate 60 can be moved to its minimum inclination position without being adversely influenced by the piston 14. Since the extension 150 is not formed at the above-indicated second circumferential part of each cylinder bore 12 which corresponds to the radially inner portion of the cylinder block 10 and which is near to the centerline L of the cylinder block 10, the swash plate 60 is not inhibited from moving from its maximum inclination position to its minimum inclination position.

[0050] There will be next described a method of producing, by die-casting, the cylinder block 10 constructed as described above, according to a first embodiment of the present invention. Referring to Fig. 3, there is schematically shown a casting system 200 which includes a die-casting apparatus for producing the cylinder block 10. The casting system 200 includes a pair of stationary platens 204, 206 which are located on a main frame 202 of the system 200 in opposed relation to each other. Four guide rods 208 extend between the two stationary platens 204, 206, such that each guide rod 208 connects one of four corners of the stationary platen 204 to the corresponding one of four corners of the stationary platen 206. The four guide rods 208 are parallel to one another. A movable platen 210 is slidably supported by the four guide rods 208. The stationary platen 204 is provided with a hydraulic cylinder 214 which is adapted to open and close the mold assembly described below. The hydraulic cylinder 214 is a kind of a hydropneumatic cylinder, and includes a housing 216 which is fluid-tightly fixed to one of the opposite major surfaces of the stationary platen 204 which is remote from the movable platen 210. The hydraulic cylinder 214 further includes a piston 218 which is carried by a piston rod 220 and which is slidably and fluid-tightly received in the housing 216. The piston rod 220 of the hydraulic cylinder 214 extends through the stationary platen 204 toward the movable platen 210, and is connected at its distal end to the movable platen 210. The movable platen 210 is advanced toward and retracted from the stationary platen 206 by the hydraulic cylinder 214 while being guided by the guide rods 208. A maximum distance of retracting movement of the movable platen 210 away from the stationary platen 206 is determined by suitable limiting means not shown.

[0051] A stationary mold 224 is removably attached to one of the opposite major surfaces of the stationary platen 206 on the side of the movable platen 210, while a movable mold 226 is removably attached to the other major surface of the movable platen 210 on the side opposite to the hydraulic cylinder 214. As described above, the casting system 200 includes the mold assembly of the stationary and movable molds 224, 226. The stationary mold 224 consists of a plurality of plate members which are superposed on one another. The plate members comprise a mold plate, and a fixing plate at which the stationary mold 224 is fixed to the stationary platen 206. Similarly, the movable mold 226 consists of a plurality of plate members which are superposed on one another. The plate members comprise a mold plate, and a fixing plate at which the movable mold 226 is fixed to the movable platen 210. The stationary and movable molds 224, 226 are fixed, with a high degree of positional accuracy, to the stationary platen 206 and the movable platen 210, respectively, by engagement of engaging grooves formed in the respective stationary and movable platens 206, 210 with engaging protrusions provided on the respective stationary and movable molds 224, 226, for instance. Alternatively, the stationary and movable molds 224, 226 are fixed to the stationary and movable platens 206, 210, respectively, while the two molds 224, 226 are positioned relative to each other such that a positioning pin provided on one of the two molds 224, 226 is fitted in a pin hole formed in the other of the two molds 224, 226.

[0052] The two molds 224, 226 are butted together and are spaced apart from each other at their contact surfaces 230, 232, as shown in Fig. 4. The movable mold 226 is moved toward the stationary mold 224 by a drive force of the hydraulic cylinder 214, so that the two molds 224, 226 are closed together with the contact surfaces 230, 232 being held in close contact with each other. The two molds 224, 226 have respective molding surfaces 240, 242 which cooperate with each other to define therebetween a mold cavity 236 whose configuration follows a profile of the cylinder block 10 to be obtained. A molten metal (a molten aluminum alloy whose major component is aluminum, in the present embodiment) is injected into the mold cavity 236 for die-casting the cylinder block 10.

[0053] The lower end of the mold cavity 236 is held in communication with a sleeve 250 (Fig. 3) via a runner (not shown) which extends in a direction parallel to the contact surfaces 230, 232. The sleeve 250 is provided with a molten metal inlet. The runner has a gate provided at one of its opposite open ends on the side of the mold cavity 236. The gate has a cross sectional area smaller than that of the other portion of the runner. The sleeve 250 is a cylindrical member which extends through the stationary platen 206, so that one of opposite end portions of the sleeve 250 remote from the mold cavity 236 is located outside the two molds 224, 226. A plunger chip 254 formed at one end of a plunger 252 and having a diameter larger than that of the plunger 252 is slidably fitted in the above-indicated one end portion of the sleeve 250 located outside the two molds 224, 226. The plunger 252 is fixed to a piston rod 258 of a plunger drive cylinder 256 as a plunger drive device. The plunger drive cylinder 256 is a hydraulically operated cylinder, and is fixedly supported by the main frame 202. The sleeve 250, plunger 252, plunger chip 254, plunger drive cylinder 256, and piston rod 258 cooperate with one another to constitute an injecting device for injecting the molten aluminum alloy into the mold cavity 236 via the molten metal inlet of the sleeve 250.

[0054] Within the movable mold 226, there is provided an ejecting device 260 which includes a pushing cylinder 262 (Fig. 3) and a pushing member 266 (Fig. 4) having a plurality of eject pins 264. The pushing cylinder 262 is a hydraulically operated cylinder, and fixed to the movable mold 226 such that the pushing cylinder 262 does not interfere with other members. When the pushing cylinder 262 is actuated, the piston rod 268 of the pushing cylinder 262 is advanced, for thereby pushing the pushing member 266 toward the main body 283 of the movable mold 226. Accordingly, the distal end of each eject pin 264 is moved from its retracted position in which the distal end of the eject pin 264 cooperates with the molding surface 242 to partially define the mold cavity 236, to its advanced position in which the distal end of the eject pin 264 projects into the mold cavity 236 so as to eject the die-cast article therefrom. When the piston rod 268 of the pushing cylinder 262 is retracted, the pushing member 266 is also retracted. A maximum distance of advancing movement of the pushing member 266 is determined by abutting contact of its front surface with one of two stops provided on the movable mold 226 while a maximum distance of retracting movement of the pushing member 266 is determined by abutting contact of its rear surface opposite to the front surface, with the other stop.

[0055] The hydraulic cylinder 214, plunger drive cylinder 256, and pushing cylinder 262 are controlled by a control device not shown principally constituted by a computer. More specifically described, directional control valves provided in the fluid passages which are connected to those cylinders are controlled by the control device.

[0056] The movable mold 226 is provided with a hollow cylindrical portion 280. Described in detail, a hollow cylindrical member 282, which is provided by a separate member from a main body 283 of the movable mold 226, is fixed to the main body 283 by suitable fixing means, such that the axial direction of the hollow cylindrical member 282 is parallel to the parting direction of the stationary and movable molds 224, 226, and such that the hollow cylindrical member 282 is not movable relative to the main body 283 of the movable mold 226. The distal end portion of the hollow cylindrical member 282 which projects from the molding surface 242 into the mold cavity 236 by a predetermined axial length functions as the hollow cylindrical portion 280 that is subjected to an elastic deformation to change (to increase or decrease) its diameter. The distal end face of the hollow cylindrical member 282 is flush with the contacting surface 232 of the movable mold 226. The hollow cylindrical member 282 is suitably formed of alloy tool steels (e.g., SKD 61 of SKD tool steels specified according to the Japanese Industrial Standard), which are usually used for forming the casting mold. It is desirable that at least portions of the stationary and movable molds 224, 226, which portions define the mold cavity 236, are formed of the alloy tool steels.

[0057] The proximal end portion of the hollow cylindrical member 282, which is opposite to the hollow cylindrical portion 280, is fitted in an engaging hole 284 formed in the main body 283 of the movable mold 226. The engaging hole 284 extends in a direction parallel to the parting direction of the two molds 224, 226. An engaging pin 288 having a large-diameter engaging portion 290 at its distal end is fitted in the proximal end portion of the hollow cylindrical member 282, such that the large-diameter portion 290 is held in engagement with a shoulder 286 formed in the inner circumferential surface of the hollow cylindrical member 282. The proximal end portion of the engaging pin 288, which is opposite to the large-diameter engaging portion 290 and which extends through the main body 283 of the movable mold 226 toward the pushing member 266, is externally threaded, and two nuts 292, 293 are engaged therewith, whereby the hollow cylindrical member 282 is fixed to a fixing member 294, and the fixing member 294 is in turn fixed to the main body 283 of the movable mold 226.

[0058] The engaging hole 284 formed in the main body 283 of the movable mold 226 has, at one of its axially opposite ends which is nearer to the molding surface 242, a large-diameter portion 296 having a diameter slightly larger than the other portion of the engaging hole 284. While the hollow cylindrical member 282 is not elastically deformed, the outer circumferential surface of the hollow cylindrical member 282 has a constant diameter over an entire axial length thereof as indicated by a two-dot chain line in Fig. 4. A portion of the outer circumferential surface of the hollow cylindrical member 282, which portion is adjacent to a molding surface 300 of the hollow cylindrical portion 280 (which will be described), is fitted in the large-diameter portion 296 of the engaging hole 294, such that there is a small clearance in a radial direction therebetween. The outer circumferential surface of the hollow cylindrical portion 280 functions as the molding surface 300 for forming the inner circumferential surface of the cylinder bore 12 of the cylinder block 10 to be produced. Namely, the molding surface 240 of the stationary mold 224, the molding surface 242 of the movable mold 226, and the molding surface 300 of the hollow cylindrical portion 280 cooperate to define the mold cavity 236 having a configuration which follows that of the cylinder block 10. In Fig. 4, one of a plurality of the hollow cylindrical portions 280 (seven in the present embodiment) is shown for forming one of a plurality of the cylinder bores 12 (seven in the present embodiment). The inner circumferential surface of the hollow cylindrical portion 280 is a tapered surface 304 whose diameter linearly decreases in the axial dimension of the hollow cylindrical portion 280 from its open end on the side of the stationary mold 224 toward the movable mold 226.

[0059] The stationary mold 224 is provided with a tapered member 310 such that the tapered member 310 is coaxial with the hollow cylindrical portion 280 of the movable mold 226. The tapered member 310 is fixedly attached to a main body 312 of the stationary mold 224 by suitable fixing means. The main body 312 of the stationary mold 224 is formed with an engaging hole 314 which extends in the axial direction of the stationary mold 224. At one of opposite axial ends of the engaging hole 314 which is remote from the movable mold 226, there is formed an internally threaded portion 316. The tapered member 310 is formed, at one of its opposite ends which is remote from the movable mold 226, an externally threaded portion 320. The externally threaded portion 320 of the tapered member 310 is held in engagement with the internally threaded portion 316, whereby the tapered member 310 is fixed to the stationary mold 224. The tapered member 310 may be otherwise fixed to the stationary mold 224. For instance, the tapered member 310 may be fixed to the stationary mold 224 such that the tapered member 310 is press-fitted into an engaging hole formed in the stationary mold 224. The tapered member 310 has a head potion 322 formed at its proximal end adjacent to the externally threaded portion 320. The head portion 322 of the tapered member 310 has a diameter larger than the other portion. With the externally threaded portion 320 being engaged with the internally threaded portion 316 such that one of the opposite end faces of the head portion 322, which end face is adjacent to the externally threaded portion 320, is held in abutting contact with the end face of the stationary mold 224, as shown in Fig. 4, the distal end portion of the tapered member 310 (which is opposite to the externally threaded portion 320) projects a suitable axial distance from the contact surface 230 and the molding surface 240 of the stationary mold 224 in a direction toward the movable mold 226. The outer circumferential surface of the distal end portion of the tapered member 310 is a tapered surface 326 corresponding to the tapered inner circumferential surface 304 of the hollow cylindrical portion 280.

[0060] The movable mold 226 is moved toward the stationary mold 224, so that the two molds 224, 226 are closed together with the contact surfaces 230, 232 being held in close contact with each other. In this state, the tapered inner circumferential surface 304 of the hollow cylindrical portion 280 and the tapered outer circumferential surface 326 of the tapered member 310 engage each other with an interference fit therebetween, so that the hollow cylindrical portion 280 and an axial part of the hollow cylindrical member 282, which part is adjacent to the hollow cylindrical portion 280, are elastically deformed in a radially outward direction, whereby the diameter of the hollow cylindrical portion 280 and the above-indicated axial part of the hollow cylindrical member 282 is increased, as shown in Fig. 4. For easier understanding, the amount of the elastic deformation is exaggerated in Fig. 4. The above-indicated axial part adjacent to the hollow cylindrical portion 280 is radially outwardly expanded by the elastic deformation, so that the outer circumferential surface of the axial part adjacent to the hollow cylindrical portion 280 is held in sealing contact with the inner circumferential surface of the large-diameter portion 296 of the engaging hole 284. Accordingly, the engaging hole 284 is fluid-tightly closed at its open end on the side of the molding surface 242, for inhibiting fluid communication with the mold cavity 236. The axial dimensions of the hollow cylindrical portion 280 and the tapered member 310 are determined such that there is left an axial clearance between the front end faces of the tapered member 310 and the large-diameter engaging portion 290 of the engaging pin 288 when the tapered member 310 is entirely press-fitted into the hollow cylindrical portion 280. When the movable mold 226 is moved away from the stationary mold 224, the tapered member 310 is retracted from the hollow cylindrical portion 280, so that the hollow cylindrical portion 280 is freed from the elastic deformation and restored to its original state.

[0061] There will be next explained a method of die-casting the cylinder block 10 by using the die-casting apparatus constructed as described above. Initially, the hydraulic cylinder 214 is actuated so as to move the movable mold 226 toward the stationary mold 224, so that the two molds 224, 226 are closed together with the contact surfaces 230, 232 being held in close contact with each other. When the two molds 224, 226 are closed together so as to define therebetween the mold cavity 236, the tapered inner circumferential surface 304 of the hollow cylindrical portion 280 and the tapered outer circumferential surface 326 of the tapered member 310 engage each other with an interference fit therebetween, so that the hollow cylindrical portion 280 is elastically deformed in a direction toward the inner circumferential surface of the cylinder bore 12 of the cylinder block to be produced, namely in a radially outward direction. Since the engaging hole 284 formed in the movable mold 283 is fluid-tightly sealed as described above, the engaging hole 284 is inhibited from communicating with the mold cavity 236. While the two molds 224, 226 are closed together, the sleeve 250 is held in fluid communication with the mold cavity 236 via the runner, and the plunger chip 254 is placed in its retracted position at which the molten metal inlet of the sleeve 250 is held in communication with the mold cavity 236. In this state, the molten metal (e.g., the molten aluminum alloy) is introduced from the molten metal inlet into the sleeve 250. Subsequently, the plunger chip 254 is advanced toward the two molds 224, 226, so that the level of the molten metal in the sleeve 250 is raised, whereby the molten metal is introduced into the runner. Thereafter, the advancing speed of the plunger chip 254 is increased, so that the molten metal is jetted into the mold cavity 236 through the narrow gate provided at the end of the runner. The plunger chip 254 is kept actuated after the mold cavity 236 has been filled with the molten metal, and the molten metal in the mold cavity 236 solidifies under a sufficiently high pressure.

[0062] The molten metal in the mold cavity 236 solidifies into the cylinder block 10 a predetermined time after the mold cavity 236 has been filled with the molten metal. The inner circumferential surface of the cylinder bore 12 is formed by the molding surface 300, i.e., the outer circumferential surface of the hollow cylindrical portion 280 which is radially outwardly expanded by the elastic deformation. Thereafter, the movable mold 226 is moved away from the stationary mold 224. At the same time when the two molds 224, 226 are opened, the hollow cylindrical portion 280 is moved away from the tapered member 310, so that the tapered inner circumferential surface 304 of the hollow cylindrical portion 280 and the tapered outer circumferential surface 326 of the tapered member 310 which have been held in an interference fit with each other are disengaged from each other. Accordingly, the elastically deformed hollow cylindrical portion 280 is restored to its original state. That is, the hollow cylindrical portion 280 which has been radially outwardly expanded by the elastic deformation is radially inwardly contracted. Accordingly, the molding surface 300 of the hollow cylindrical portion 280 and the inner circumferential surface of the cylinder bore 12 of the cylinder block 10, which have been held in an interference fit with each other, are positioned relative to each other such that there is a radial clearance therebetween. Thereafter, the pushing cylinder 262 is actuated to advance the eject pins 264, whereby the die-cast cylinder block 10 held by the movable mold 226 is pushed in a direction away from the movable mold 226. Since there exists a radial clearance between the molding surface 300 of the hollow cylindrical portion 280 and the inner circumferential surface of the cylinder bore 12 as described above, the cylinder lock 10 can be easily removed from the movable mold 226.

[0063] In the present embodiment, the molding surface which forms the inner circumferential surface of the cylinder bore 12 of the cylinder block 10 is provided by the outer circumferential surface of the hollow cylindrical portion 280. The hollow cylindrical portion 280 corresponds to a hollow portion. The tapered inner circumferential surface 304 of the hollow cylindrical portion 280 is a tapered surface, a dimension of which in a direction perpendicular to a direction parallel to the centerline of the hollow portion gradually changes in the direction. The tapered outer circumferential surface 326 of the tapered member 310 is a tapered surface which corresponds to the above-indicated tapered surface of the hollow portion. The engaging hole 284 is an engaging portion. The stationary mold 224 and the movable mold 226 correspond to a pair of molds of the die-casting apparatus, which molds are moved toward and away from each other. The hydraulic cylinder 214 constitutes an axial moving device for moving the tapered member and the hollow portion relative to each other in the axial direction of the tapered member. The axial moving device is one example of a device for effecting an interference fit between the tapered surface of the hollow portion and the tapered surface of the tapered member. The hydraulic cylinder 214 corresponds to an opening and closing device for opening and closing the stationary and movable molds 224, 226. In the present embodiment, the hydraulic cylinder 214 also functions as the device for effecting an interference fit described above. The tapered member 310 is one example of an expanding member which engages the inner circumferential surface of the hollow cylindrical portion 280. The hydraulic cylinder 214 functioning as the above-described device for effecting an interference fit constitutes a pushing device which forces the expanding member onto the inner circumferential surface of the hollow cylindrical portion 280 for expanding the hollow cylindrical portion 280.

[0064] According to the present embodiment, the cylinder block 10 formed in the mold cavity 236 can be easily removed from the movable mold 226 without any problem even where the hollow cylindrical portion 280 which forms the inner circumferential surface of the cylinder bore 12 is provided with a relatively small angle of draft or no draft. Therefore, the present arrangement permits a reduction in the required amount of stock removal by the machining operation to be conducted on the inner circumferential surface of the cylinder bore 12, or eliminates the machining operation, resulting in a reduction in the cost of manufacture of the compressor. The outside diameter and the amount of the elastic deformation of the hollow cylindrical portion 280 are suitably determined depending upon the dimension of the intended inner circumferential surface of the cylinder bore 12.

[0065] The hollow cylindrical portion 280 may be provided on the stationary mold 224 while the tapered member 310 may be provided on the movable mold 226. The tapered member 310 may be arranged to be axially movable relative to the two molds 224, 226 by a suitable drive device such as a hydraulically operated cylinder which is provided independently of the hydraulic cylinder 214.

[0066] The present die-casting apparatus and the die-casting method may be employed in producing a die-cast article other than the cylinder block 10 described above. Referring next to Fig. 5, there will be described a die-casting apparatus constructed according to a second embodiment of the invention for producing the front housing 16 of the swash plate type compressor. The front housing 16 has a hollow cylindrical recess, as shown in Fig. 1. Since the structure of the casting system which includes the die-casting apparatus of this second embodiment (Fig. 5) is similar to that of the casting system 200 shown in Fig. 3, a detailed explanation of which is dispensed with. Like the die-casting apparatus of Fig. 4 of the above-described first embodiment, the die-casting apparatus of the second embodiment includes a stationary mold 400 and a movable mold 402, which are moved toward and away form each other. Each of the stationary and movable molds 400, 402 consists of a plurality of plate members which are superposed on one another. The movable mold 402 is moved toward and away from the stationary mold 400 by a suitable opening and closing device such as a hydraulic cylinder, and the two molds 400, 402 are closed together at their contacting surfaces 404, 406. The stationary mold 400 is provided with a hollow cylindrical member 408 such that the hollow cylindrical member 408 extends in a direction parallel to the axial direction of the two molds 400, 402, in other words, in a direction parallel to the parting direction of the two molds 400, 402. The hollow cylindrical member 408 includes a hollow cylindrical portion 410 which projects from the contact surface 404 in the axial direction of the hollow cylindrical member 408, and an engaging portion 414. The engaging portion 414 is adjacent to the hollow cylindrical portion 410 and fitted in an engaging hole 412 formed in a main body 411 of the stationary mold 400, such that the engaging portion 414 is axially unmovable with respect to the stationary mold 400. At one of the opposite axial ends of the engaging portion 414 which is remote from the hollow cylindrical portion 410, there is formed a flange 416 having a diameter larger than that of the hollow cylindrical portion 410 and the engaging portion 414. The engaging hole 412 includes a large-diameter section on the side which is remote from the contact surface 404, and a small-diameter section on the side which is nearer to the contact surface 404. The diameter of the inner circumferential surface of the small-diameter section of the engaging hole 412 is made smaller than that of the outer circumferential surface of the flange 416 of the engaging portion 414 of the hollow cylindrical member 408. The hollow cylindrical member 408 is inserted from its distal end into the large-diameter section of the engaging hole 412, until the flange 416 of the hollow cylindrical member 408 is brought into abutting contact with a shoulder surface formed between the large- and small- diameter sections of the engaging hole 412. Thus, an amount of protrusion of the hollow cylindrical portion 410 from the contact surface 404 is determined by the abutting contact of the flange 416 with the shoulder surface of the engaging hole 412. Further, a fixing member 417 is inserted into the large-diameter section of the engaging hole 412 until the end face of the fixing member 417 is brought into abutting contact with the end face of the flange 416. The fixing member 417 is fixed to the main body 411 of the stationary mold 400 by suitable fixing means in the form of bolts, so that the hollow cylindrical member 408 is inhibited from moving in the axial direction away from the main body 411 of the stationary mold 400. The thus fixed fixing member 417 serves as a part of the main body 411 of the stationary mold 400. While the hollow cylindrical member 408 is not subjected to the elastic deformation, the engaging portion 414 of the hollow cylindrical member 408 is fitted in the engaging hole 412 such that there is a clearance therebetween in the radial direction, as indicated by the two-dot chain line in Fig. 5. The outer circumferential surface of the hollow cylindrical portion 410 has a constant diameter over an entire axial length thereof, and function as a molding surface 420 for forming the inner circumferential surface of the front housing 16. The molding surface 420 cooperates with a molding surface 422 of the stationary mold 400 and a molding surface 424 of the movable mold 402 to define a mold cavity 426 whose configuration follows that of the front housing 16. The molding surface 424 of the movable mold 402 which forms the outer surface of the front housing is provided with a draft in its axial direction. The inner circumferential surface of the hollow cylindrical member 408 is a tapered surface 428 whose diameter gradually decreases in a direction parallel to the centerline of the hollow cylindrical member 408 from the stationary mold 400 toward the movable mold 402.

[0067] As shown in Fig. 5, the lower end of the mold cavity 426 is held in communication with a sleeve (not shown) having a molten metal inlet, via a runner 430. The runner 430 extends in a direction parallel to the contact surfaces 404, 406, and is provided, at one of its opposite open ends on the side of the mold cavity 426, with a gate having a cross sectional area smaller than the other portion of the runner 430. In this second embodiment, too, the injecting device which includes the sleeve, plunger, plunger chip, and plunger drive device is employed. The structure of the injecting device is similar to that of the injecting device used in the first embodiment described above, and a detailed explanation of which is dispensed with. The movable mold 402 is provided therein with an ejecting device (not shown) whose structure is similar to that of the ejecting device 260 used in the above-described first embodiment.

[0068] The stationary mold 400 is provided with a tapered member 440. The tapered member 440 is supported by the stationary mold 400 such that the tapered member 440 is axially movable within the inner space of the hollow cylindrical member 408. The tapered member 440 extends in the axial direction of the hollow cylindrical member 408 such that the axes of the tapered member 440 and the hollow cylindrical member 408 are aligned with each other. The outer circumferential surface of the tapered member 440 at its distal end which is on the side of the hollow cylindrical portion 410 is a tapered surface 444 corresponding to the tapered inner circumferential surface 428 of the hollow cylindrical member 408. The tapered member 440 is connected to a piston rod 446 of a tapered-member-moving cylinder (not shown) which is fixed to the stationary mold 400. The tapered-member-moving cylinder is a hydraulically operated actuator.

[0069] The movable mold 402 is moved toward the stationary mold 400, so that the two molds 400, 402 are closed together at the contact surfaces 404, 406. After the two molds 400, 402 have been closed together, the tapered-member-moving cylinder is actuated so as to move the tapered member 440 in the axial direction toward he hollow cylindrical member 408, so that the tapered inner circumferential surface 428 of the hollow cylindrical portion 410 and the tapered outer circumferential surface 444 of the tapered member 440 engage each other with an interference fit therebetween. Accordingly, the hollow cylindrical portion 410 and an axial part of the hollow cylindrical member 408 adjacent to the hollow cylindrical portion 410 (in other words, the entirety of the hollow cylindrical member 408) are elastically deformed in a radially outward direction, whereby the outside diameter of the hollow cylindrical member 408 is increased. The above-indicated axial part adjacent to the hollow cylindrical portion 410 is radially outwardly expanded within the engaging hole 412, so that the outer circumferential surface of the axial part is held in close contact with the inner circumferential surface of the engaging hole 412. Accordingly, the open end of the engaging hole 412 on the side of the molding surface 422 is fluid-tightly sealed for inhibiting the fluid communication with the mold cavity 426. At the same time, the advancing movement of the tapered member 440 is stopped, and the end faces of the tapered member 440 and the hollow cylindrical portion 410 are flush with each other. With the hollow cylindrical portion 410 being elastically deformed, the molten metal such as a molten aluminum alloy is introduced into the mold cavity 426. After the molten metal in the mold cavity 426 has solidified and before the stationary mold 400 and the movable mold 402 are opened, the tapered member 440 is retracted in the axial direction away from the hollow cylindrical portion 410 toward the stationary mold 400. Accordingly, the tapered outer circumferential surface 444 of the tapered member 440 and the tapered inner circumferential surface 428 of the hollow cylindrical portion 410 are disengaged from each other, whereby the elastically deformed hollow cylindrical member 408 including the hollow cylindrical portion 410 is restored to its original shape. In this state, there is a radial clearance between the molding surface 420 and the inner circumferential surface of the hollow cylindrical recess of the front housing 16 to be obtained. Thereafter, the movable mold 402 is moved away from the stationary mold 400 with the front housing 16 being held by the movable mold 402. After the two molds 400, 402 have been fully opened, the front housing 16 is pushed by the ejecting device in a direction away from the movable mold 402.

[0070] The front housing 16 produced as described above is formed with a through-hole through which the rotary drive shaft 50 extends. This through-hole may be formed by a machining operation after the die-casting process. Alternatively, the through-hole may be formed in the die-casting process. In this case, the through-hole may be formed by an axial member provided with a draft having a suitable taper angle. The through-hole may be formed by using a mold assembly which is equipped with a hollow cylindrical portion and a device for elastically deforming the hollow cylindrical portion, which are similar to those described in the present embodiment. In this case, the hollow cylindrical portion is provided with a relatively small angle of draft, or the hollow cylindrical portion does not have a draft.

[0071] The hollow cylindrical portion 410 may be fixed to the main body 411 of the stationary mold 400 by the fixing means similar to that as described above with respect to the first embodiment of Figs. 1-4. On the contrary, in the above-described first embodiment, the hollow cylindrical portion 280 may be fixed to the movable mold 226 by the fixing means as described with respect to the second embodiment of Fig. 5. The hollow cylindrical portion 410 and the tapered member 440 may be provided on the movable mold 402. The ejecting device may be provided on either the stationary mold 400 or the movable mold 402.

[0072] The present die-casting method and the die-casting apparatus permit formation of the inner circumferential surface of the axial through-hole such as the inner circumferential surface of the cylinder bore 12, as described with respect to the first embodiment of Figs. 1-4, and the inner circumferential surface of the recess having a closed end such as the inner circumferential surface of the front housing 16, as described with respect to the second embodiment of Fig. 5.

[0073] Referring next to Fig. 6, there is explained a die-casting apparatus constructed according to a third embodiment of the present invention, which die-casting apparatus is arranged to form an outer circumferential surface of a die-cast article by an inner circumferential surface of a hollow cylindrical portion. Like the die-casting apparatuses of the above-described first and second embodiments, the die-casting apparatus of this third embodiment includes a stationary mold 500 and a movable mold 502 which are moved toward and away from each other, so that the two molds 500, 502 are opened and closed. The structure of the casting system including the die-casting apparatus in this embodiment is similar to that of the casting system 200 shown in Fig. 3, a detailed description of which is dispensed with. Each of the stationary and movable molds 500, 502 consists of a plurality of plate members which are superposed on one another. The movable mold 502 is moved toward and away from the stationary mold 500 by an opening and closing device for opening and closing the two molds 500, 502 (not shown) in the form of a hydraulically operated cylinder, for instance. The two molds 500, 502 are closed together at their contact surfaces 504, 506.

[0074] The movable mold 502 is provided with a hollow cylindrical member 512 which extends in a direction parallel to the parting direction of the two molds 500, 502, in other words, in the axial direction of the two molds 500, 502. The hollow cylindrical member 512 is fixed at its flat fixing plate portion 514 to a main body 511 of the movable mold 502 by suitable fixing means such as bolts, such that the hollow cylindrical member 512 is not movable relative to the main body 511 of the movable mold 502. The hollow cylindrical member 512 includes a hollow cylindrical portion 510 which axially extends from an inner peripheral portion of the fixing plate portion 514 toward the stationary mold 500. The hollow cylindrical portion 510 has an annular shape in transverse cross section. An engaging member 520 is fitted in the hollow cylindrical member 512. The engaging member 520 includes, at its proximal end which is opposite to the hollow cylindrical portion 510, a fixing portion 522 having a diameter larger than the other portion of the engaging member 520. Like the hollow cylindrical member 512, the engaging member 520 is fixed to the main body 511 of the movable mold 502 at the fixing portion 522.

[0075] The engaging member 520 has a tapered outer circumferential surface 524 at its distal end portion which is opposite to the fixing portion 522. The hollow cylindrical potion 510 is subjected to an elastic deformation such that the hollow cylindrical portion 510 is radially outwardly expanded or radially inwardly contracted. While the hollow cylindrical portion 510 is not subjected to the elastic deformation, there is a radial clearance between the inner circumferential surface of the hollow cylindrical portion 510 and the tapered outer circumferential surface 524 of the engaging member 520. The inner circumferential surface of the hollow cylindrical portion 510 serves as a molding surface 530 while the front end face of the engaging member 520 serves as a molding surface 532. The stationary mold 500 has a protrusion 536 which protrudes in the axial direction of the stationary mold 500 from the contact surface 504 toward the movable mold 502. The protrusion 536 is located within a space defined by the molding surfaces 530, 532 when the stationary and movable molds 500, 502 are closed together at the contact surfaces 504, 506. The outer circumferential surface, and the front end face of the protrusion 536 which is remote from the stationary mold 500, serve as molding surfaces 538, 539, respectively. The molding surfaces 530, 532, 538, 539 cooperate to define a mold cavity 540 having a configuration which follows that of an intended die-cast article. The protrusion 536 is provided with a draft such that the diameter of the protrusion 536 gradually decreases in the axial direction from its proximal end toward its distal end.

[0076] A collet 550 is fitted on the outer circumferential surface 544 of the hollow cylindrical portion 510, which outer circumferential surface 544 is opposite to the molding surface 530. As shown in Fig. 7, the collet 550 consists of a plurality of segments 551 (preferably, six or more segments) which are equiangularly spaced from each other in the circumferential direction of the collet 550. The diameter of the colet 550 is mechanically changed (i.e., decreased) by a collet-diameter changing device 552, so that the inner circumferential surface 554 of the collet 550 is forced onto the outer circumferential surface 544 of the hollow cylindrical portion 510, for thereby elastically deforming or contracting the hollow cylindrical portion 510 in a radially inward direction. The collet 550 has a tapered outer circumferential surface 556 whose diameter gradually decreases in the axial direction of the collet 550 from the stationary mold 500 toward the movable mold 502.

[0077] The collet-diameter changing device 552 includes as major components a tapered member 560, and an axial moving device for axially moving the tapered member 560. The tapered member 560 is a generally cylindrical member, and has a tapered inner circumferential surface 568 which corresponds to the tapered outer circumferential surface 556 of the collet 550. A multiplicity of balls 570 are interposed between those tapered inner and outer circumferential surfaces 568, 556. The balls 570 are held by a retainer 572, such that the balls 572 maintain a constant position relative to each other, and such that the balls are rotatable independently of each other. The retainer 572 is a member separate from the collet 550 and the tapered member 560. Each of the balls 572 projects from the retainer 572 in both of the radially inward and outward directions of the retainer 572, and cooperates with the retainer 572 to constitute a rolling bearing. Namely, the rolling movement of the balls 570 between the tapered outer circumferential surface 556 of the collet 550 and the tapered inner circumferential surface 568 of the tapered member 560 of the collet-diameter changing device 552 effectively reduces friction caused when the tapered member 560 and the collet 550 engage each other with an interference fit therebetween by the axial moving device 564. The rolling bearing constituted by the balls 570 and the retainer 572 is prevented from moving apart from the collet 550 and the tapered member 560, by abutting contact with stops 576, 578 which are formed at two axial portions of the tapered member 560. The axial moving device 564 for axially moving the tapered member 560 includes a hydraulic actuator in the form of a hydraulically operated cylinder (not shown) as a drive source, a piston rod 580 of the hydraulically operated cylinder, and a connecting member 582 for connecting the piston rod 580 and the tapered member 560.

[0078] An ejecting device 590 is provided within the movable mold 502 such that the ejecting device 590 does not interfere with other components of the movable mold 502. Like the ejecting device 260 in the above-indicated first embodiment, the ejecting device 590 includes a pushing cylinder 592 fixed to the movable mold 502 and a pushing member 596 equipped with a plurality of eject pins 594. When the pushing cylinder 592 is actuated, a piston rod of the pushing cylinder 592 is advanced so as to move the pushing member 596 toward the stationary mold 500, so that the front end face of each eject pin 594 is moved from its retracted position in which the front end face of each eject pin 594 is flush with the molding surface 532 so as to partially define the mold cavity 540, into its advanced position in which the front end face of each eject pin 594 projects into the mold cavity 540 so as to push the die-cast article in a direction away from the movable mold 502.

[0079] The mold cavity 540 is held in fluid communication with a sleeve 602 having a molten metal inlet, via a runner 600. The runner 600 is provided, at one of its opposite open ends on the side of the mold cavity 540, with a gate having a cross sectional area smaller than the other portion of the runner 600. In this third embodiment, too, the injecting device which includes the sleeve 602, a plunger 608, a plunger chip 610, and plunger drive device is employed. The structure of the injecting device is similar to that of the injecting device used in the first embodiment described above, and a detailed explanation of which is dispensed with. The movable mold 402 is provided therein with an ejecting device (not shown) whose structure is similar to that of the ejecting device 260 used in the above-described first embodiment.

[0080] The movable mold 502 is moved toward the stationary mold 500, so that the two molds 500, 502 are closed together with their contact surfaces 504, 506 being held in close contact with each other. After the two molds 504, 506 have been closed together, the axial moving device 564 is actuated to move the tapered member 560 toward the stationary mold 500, whereby the tapered inner circumferential surface 568 of the tapered member 560 and the tapered outer circumferential surface 556 of the collet 550 engage each other with an interference fit therebetween. Accordingly, the hollow cylindrical portion 510 and an axial part of the hollow cylindrical member 512 adjacent to the hollow cylindrical portion 510 are elastically deformed in a radially inward direction, so that the diameter of the inner circumferential surface of the hollow cylindrical portion 510 (the molding surface 530) is decreased, as shown in Fig. 6. The above-indicated axial part of the hollow cylindrical member 512 adjacent to the hollow cylindrical portion 510 is radially inwardly deformed such that its inner circumferential surface is held in close contact with the tapered outer circumferential surface 524 of the engaging member 520, for thereby inhibiting a fluid communication between the mold cavity 540 and the inside of the movable mold 500 in which the axial moving device 564 and other components are disposed. With the hollow cylindrical portion 510 being elastically deformed, a molten metal such as a molten aluminum alloy is introduced into the mold cavity 540. After the molten metal has solidified in the mold cavity 540, the stationary mold 500 and the movable mold 502 are separated away from each other with the die-cast article being held by the movable mold 502. Thereafter, the tapered member 560 is retracted in a direction away from the stationary mold 500, and the tapered inner circumferential surface 568 of the tapered member 560 is disengaged from the tapered outer circumferential surface 556 of the collet 550, so that the elastically deformed hollow cylindrical portion 510 is restored to its original state, namely, the diameter of the hollow cylindrical portion 510 which has been reduced is increased to the original value. In this state, there is a radial clearance between the molding surface 530 of the hollow cylindrical portion 510 and the outer circumferential surface of the die-cast article. Accordingly, the die-cast article held by the movable mold 502 is easily pushed by the ejecting device 590 in a direction away from the movable mold 502. The die-casting apparatus according to this embodiment is suitably used in die-casting a blank for a head portion of a compressor piston, for instance.

[0081] In the present embodiment wherein the tapered surfaces are formed on the tapered member 560 and the collet 550, the thickness of the hollow cylindrical portion 510 can be made constant over an entire axial length thereof, so that the hollow cylindrical portion 510 can be uniformly subjected to the elastic deformation in the radially inward direction. Since the tapered member 560 and the collet 550 engage each other with an interference fit via the rolling bearing constituted by the retainer 572 and the balls 570, the tapered member 560 and the collet 550 have a relatively small degree of mutually frictional resistance. Accordingly, the tapered member 560 can be axially moved by the axial moving device 564 with high efficiency for the interference fit with the collet 550, resulting in a reduced size of the axial moving device 564. Further, the present arrangement wherein the tapered member 560 and the collet 550 engage each other via the rolling bearing assures a reduction of the wear and an improved durability of the two members.

[0082] For elastically deforming the hollow cylindrical portion 510 while keeping its roundness, the number of the segments 551 of the collet 550 is desirably maximized. It is desirable that the circumferential clearance between the adjacent ones of the plurality of segments 551 is minimized while the collet 550 is radially inwardly contracted for reduction of its diameter. On the other hand, it is desirable that the circumferential clearance between the adjacent ones of the plurality of segments 551 is constant while the collet 550 is in its original state. To this end, as in an ordinary collet, the segments of the collet 550 are connected to each other by an elastically deformable connecting member, rather than completely separated from each other. This elastically deformable connecting member is provided at one of opposite axial ends of the collet 550, e.g., at an axial end portion of the collet 550 which is remote from the hollow cylindrical portion 510 and which is nearer to the movable mold 511.

[0083] As is apparent from the foregoing description, in the present embodiment, the molding surface which forms the outer circumferential surface of the die-cast article is provided by the inner circumferential surface of the hollow cylindrical portion 510. The hollow cylindrical portion 510 corresponds to the hollow portion. The tapered outer circumferential surface 556 of the collet 550 is a first tapered surface whose diameter gradually changes in the axial direction of the hollow portion, while the tapered inner circumferential surface 568 of the tapered member 560 is a second tapered surface which corresponds to the first tapered surface. The collet 550 and the collet-diameter changing device 552 cooperate to constitute a deforming device for elastically deforming the hollow portion. The collet 550 is a contracting member which engages the outer circumferential surface of the hollow cylindrical portion 510. The collet-diameter changing device 552 is a pushing device which forces the contracting member onto the outer circumferential surface 544 of the hollow cylindrical portion 510 for contracting the hollow cylindrical portion 510. The collet and the collet-diameter changing device for mechanically changing the diameter of the collet used in the present third embodiment may be employed in the above-described first and second embodiments of Figs. 1-4 and Fig. 5, respectively, wherein the molding surface which forms the inner circumferential surface of the die-cast article is provided by the outer circumferential surface of the hollow portion.

[0084] The present die-casting apparatus and the die-casting method using the apparatus are suitably employed in producing articles such as the cylinder block 10 having the cylinder bores 12 and the front housing 16 having the hollow cylindrical recess, which articles are formed of a material whose major component is aluminum. The present die-casting apparatus and the die-cast method can be employed in producing articles other than the described above.

[0085] While the presently preferred embodiments of this invention have been described above, for illustrative purpose only, it is to be understood that the present invention may be embodied with various changes and improvements such as those described in the SUMMARY OF THE INVENTION, which may occur to those skilled in the art.

[0086] A method of producing a die-cast article by die-casting, the die-cast article having at least one of an inner and an outer circumferential surface, the method comprising the steps of: preparing a mold assembly (224, 226; 400, 402; 500, 502) including a hollow portion (280, 410, 510) having a molding surface (300, 420, 530) for molding one of the inner and outer circumferential surfaces of the die-cast article; closing the mold assembly to define therein a mold cavity (236, 426, 540) having a configuration corresponding to that of the die-cast article; subjecting the hollow portion to an elastic deformation in a direction toward the one of the inner and outer circumferential surfaces of the die-cast article to be produced; introducing a molten metal into the mold cavity while the hollow portion is subjected to the elastic deformation; opening the mold assembly and permitting the elastic deformation to be removed from the hollow portion after the molten metal has solidified; and removing the die-cast article from the mold assembly. An apparatus for practicing the method is also disclosed.

Claims

1. A method of producing a die-cast article by die-casting, said die-cast article having at least one of an inner circumferential surface and an outer circumferential surface, the method comprising the steps of:

    preparing a mold assembly (224, 226; 400, 402; 500, 502) including a hollow portion (280, 410, 510) which has a molding surface (300, 420, 530) for molding one of said inner and outer circumferential surfaces of said die-cast article;
    closing said mold assembly so as to define therein a mold cavity (236, 426, 540) having a configuration which corresponds to that of said die-cast article;
    subjecting said hollow portion to an elastic deformation in a direction toward said one of said inner and outer circumferential surfaces of said die-cast article to be produced;
    introducing a molten metal into said mold cavity while said hollow portion is subjected to said elastic deformation;
    opening said mold assembly and permitting said elastic deformation to be removed from said hollow portion after said molten metal has solidified in said mold cavity; and
    removing said die-cast article formed in said mold cavity from said mold assembly.

2. A method according to claim 1, wherein said hollow portion has a non-molding surface which is opposite to said molding surface, said non-molding surface being a tapered surface (304, 428, 556), a dimension of which in a direction perpendicular to a direction parallel to a centerline of said hollow portion gradually changes in said direction, said step of subjecting a hollow portion to an elastic deformation comprising steps of preparing a tapered member (310, 440, 560) having a tapered surface (326, 444, 568) which corresponds to said tapered surface of said hollow portion, and causing said elastic defor-

mation of said hollow portion by an interference fit between said tapered surface of said hollow portion and said tapered surface of said tapered member.

3. A method according to claim 1 or 2, wherein said hollow portion is a hollow cylindrical member having a circular shape in transverse cross section.

4. A method according to any one of claims 1-3, wherein said die-cast article is a cylinder block (10) which is used for a swash plate type compressor and which includes a plurality of cylinder bores (12), said at least one of said inner and outer circumferential surfaces of said die-cast article being an inner circumferential surface of each of said cylinder bores.

5. A method according to any one of claims 1-3, wherein said die-cast article is a front housing (16) which is used for a swash plate type compressor and which includes a hollow cylindrical recess, said at least one of said inner and outer circumferential surfaces of said die-cast article being an inner circumferential surface of said hollow cylindrical recess of said front housing.

6. A die-casting apparatus for producing a die-cast article having at least one of an inner circumferential surface and an outer circumferential surface, comprising:

a mold assembly (224,226; 400,402; 500, 502) including a hollow portion (280, 410,510) which has a molding surface (300, 420, 530) for molding one of said inner and outer circumferential surfaces of said die-cast article; and

deforming device (210, 310, 440, 550, 552) for elastically deforming said hollow portion such that said hollow portion is subjected to an elastic deformation in a direction toward said one of inner and outer circumferential surfaces of said die-cast article to be produced.

7. An apparatus according to claim 6, wherein said mold assembly includes a first mold (224, 400, 500) and a second mold (226, 402, 502) which are moved toward and away from each other, so that said first mold and said second mold are opened and closed, said hollow portion extending in a direction parallel to a direction in which said first mold and said second mold are opened and closed.

8. An apparatus according to claim 6 or 7, wherein said mold assembly has a main body (283, 421, 511) in which an engaging portion (296, 412, 520) is formed, said hollow portion being provided by a member separate from said main body, and wherein at least a part of said hollow portion, which part is adjacent to said molding surface, and said engaging portion are positioned relative to each other such that there is a clearance in a radial direction therebetween.

9. An apparatus according to any one of claims 6-8, wherein said molding surface of said hollow portion for molding said one of said inner and outer circumferential surfaces of said die-cast article is an outer circumferential surface of said hollow portion, and wherein said deforming device for elastically deforming said hollow portion includes: an expanding member (310, 440) which engages an inner circumferential surface (304, 428) of said hollow portion; and a pushing device (214, 446) which forces said expanding member onto said inner circumferential surface of said hollow portion, so that said hollow portion is expanded.

10. An apparatus according to any one of claims 6-8, wherein said molding surface of said hollow portion for molding said one of said inner and outer circumferential surfaces of said die-cast article is an inner circumferential surface of said hollow portion, and wherein said deforming device for elastically deforming said hollow portion includes: a contracting member (550) which engages an outer circumferential surface (544) of said hollow portion; and a pushing device (552) which forces said contracting member onto said outer circumferential surface of said hollow portion, so that said hollow portion is contracted.

11. An apparatus according to any one of claims 6-8, wherein said hollow portion has a non-molding surface which is opposite to said molding surface, said non-molding surface being a tapered surface (304, 428, 556), a dimension of which in a direction perpendicular to a direction parallel to a centerline of said hollow portion gradually changes in said direction, said deforming device for elastically deforming said hollow portion including: a tapered member (310, 440, 560) having a tapered surface (326, 444, 568) which corresponds to said tapered surface of said hollow portion; and a device (214, 552) for effecting an interference fit between said tapered surface of said hollow portion and said tapered surface of said tapered member.

12. An apparatus according to claim 11, wherein said tapered member is held by said main body of said mold assembly such that said tapered member and said hollow portion are axially movable relative to each other, said device for effecting an interference fit including an axial moving device (214, 564) for moving said tapered member and said hollow portion relative to each other in an axial direction of said tapered member.

13. An apparatus according to claim 12, wherein said axial moving device includes a hydraulic cylinder (214, 446, 580) which is fixed to said mold assembly.

14. An apparatus according to claim 11, wherein said tapered member is fixed to one (224) of said first and second molds, which one mold is opposite to the other (226) of said first and second molds which is equipped with said hollow portion, said first and second molds being opened and closed by an opening and closing device which also functions as said device for effecting an interference fit.

15. An apparatus according to any one of claims 7-14, wherein the other of said first and second molds which is equipped with said hollow portion includes an ejecting device (260, 590) which pushes said die-cast article in a direction away from the other mold to remove said die-cast article from said hollow portion.

16. An apparatus according to claim 6, wherein said hollow portion is a hollow cylindrical portion having an annular shape in transverse cross section, and wherein said deforming device for elastically deforming said hollow portion includes: a collet (550) which engages, at one of inner and outer circumferential surfaces thereof, a non-molding surface (544) of said hollow portion, which non-molding surface is opposite to said molding surface for molding said one of said inner and outer circumferential surfaces of said die-cast article; and a collet-diameter changing device (552) for changing a diameter of said collet so as to force said collet onto said non-molding surface.

17. An apparatus according to claim 16, wherein the other of said inner and outer circumferential surfaces of said collet, which the other circumferential surface is opposite to said one circumferential surface which engages said non-molding surface of said hollow cylindrical portion, is tapered to give a first tapered surface (556) whose diameter gradually changes in an axial direction of said hollow cylindrical portion, and wherein said collet-diameter changing device includes: a tapered member (560) having a second tapered surface (568) which corresponds to said first tapered surface; a multiplicity of balls (570) interposed between said collet and said tapered member such that said balls maintain a constant position relative to each other, and such that said balls are rotatable independently of each other, at least while said first and second tapered surfaces engage each other; and an axial moving device (564) which moves said tapered member and said hollow cylindrical portion relative to each other in an axial direction of said tapered member and said hollow cylindrical portion, so that said first and second tapered surfaces engage each other with an interference fit therebetween via said balls.

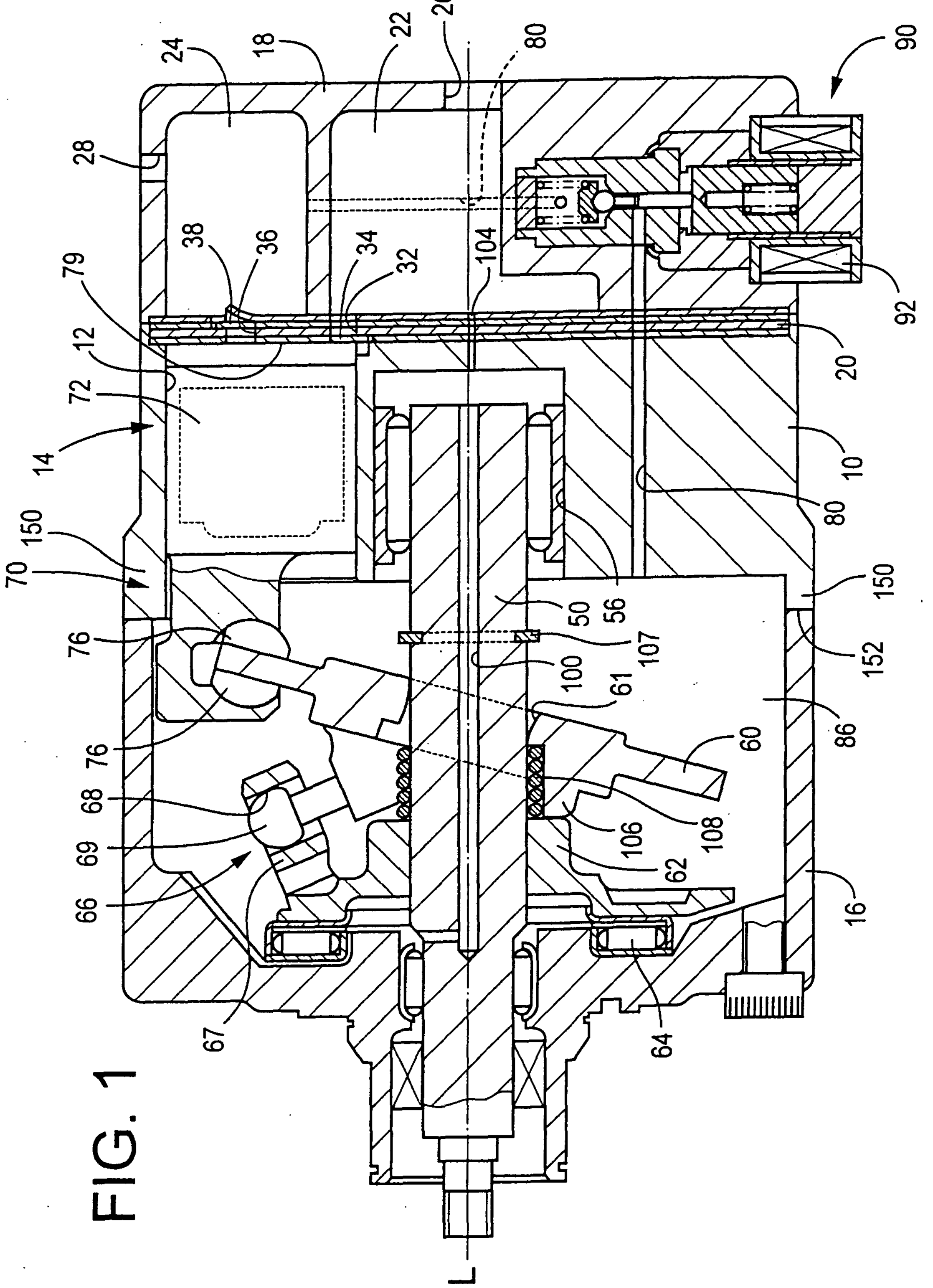

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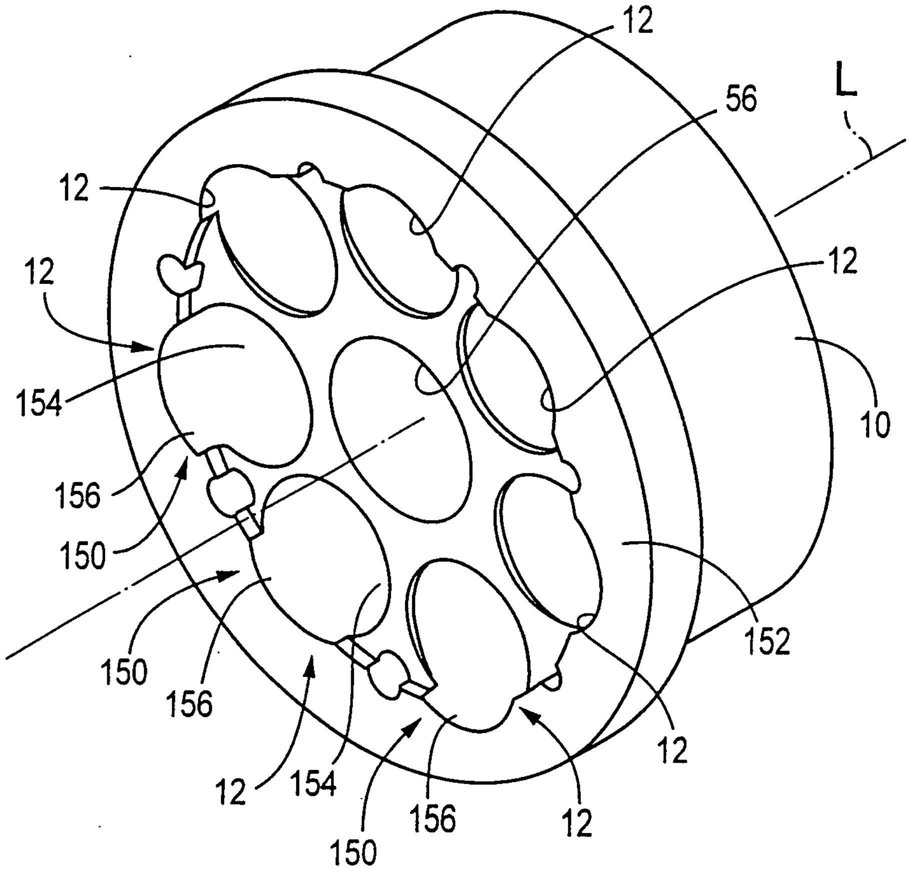
FIG. 1

FIG. 2



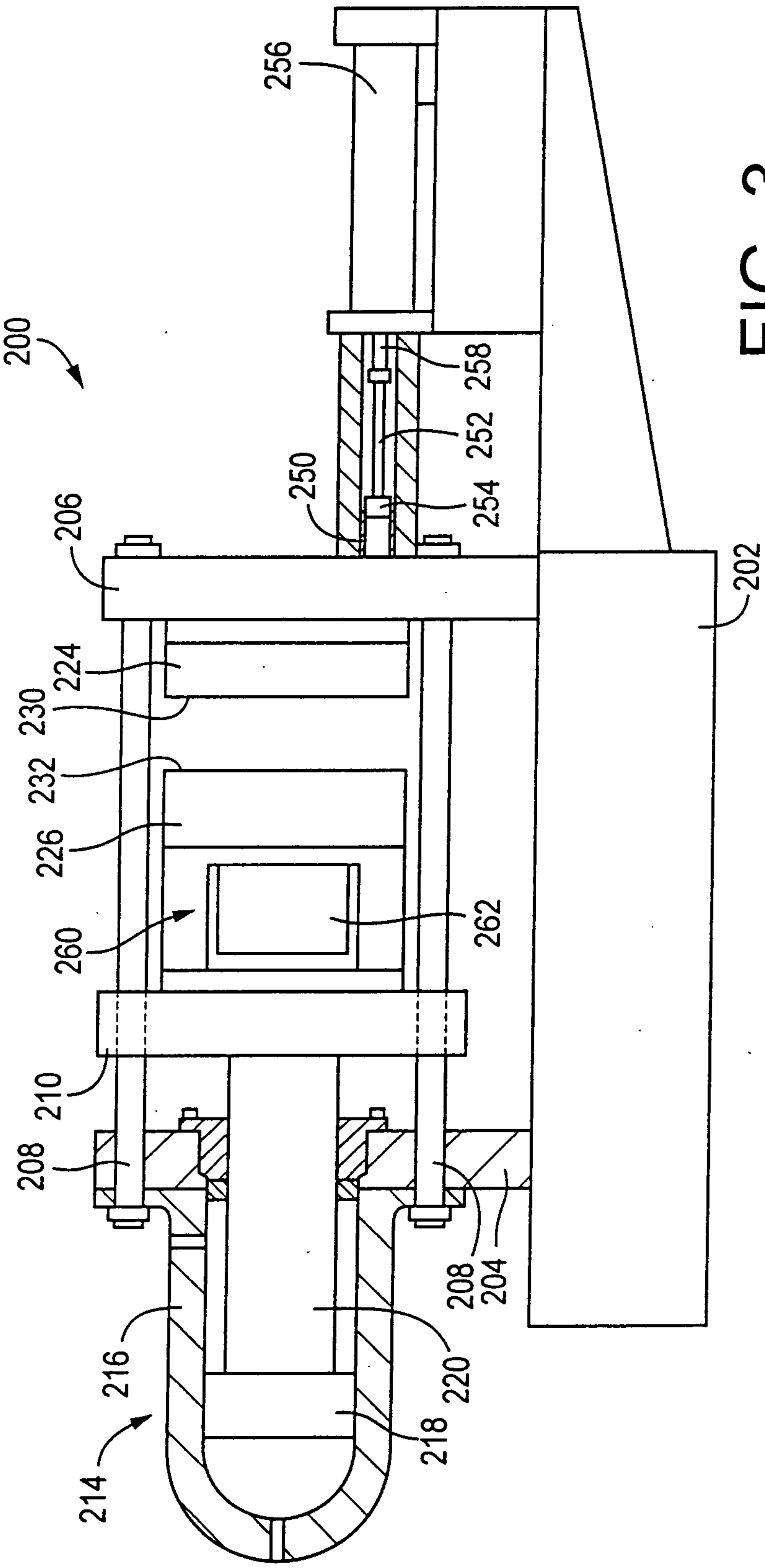

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FIG. 3

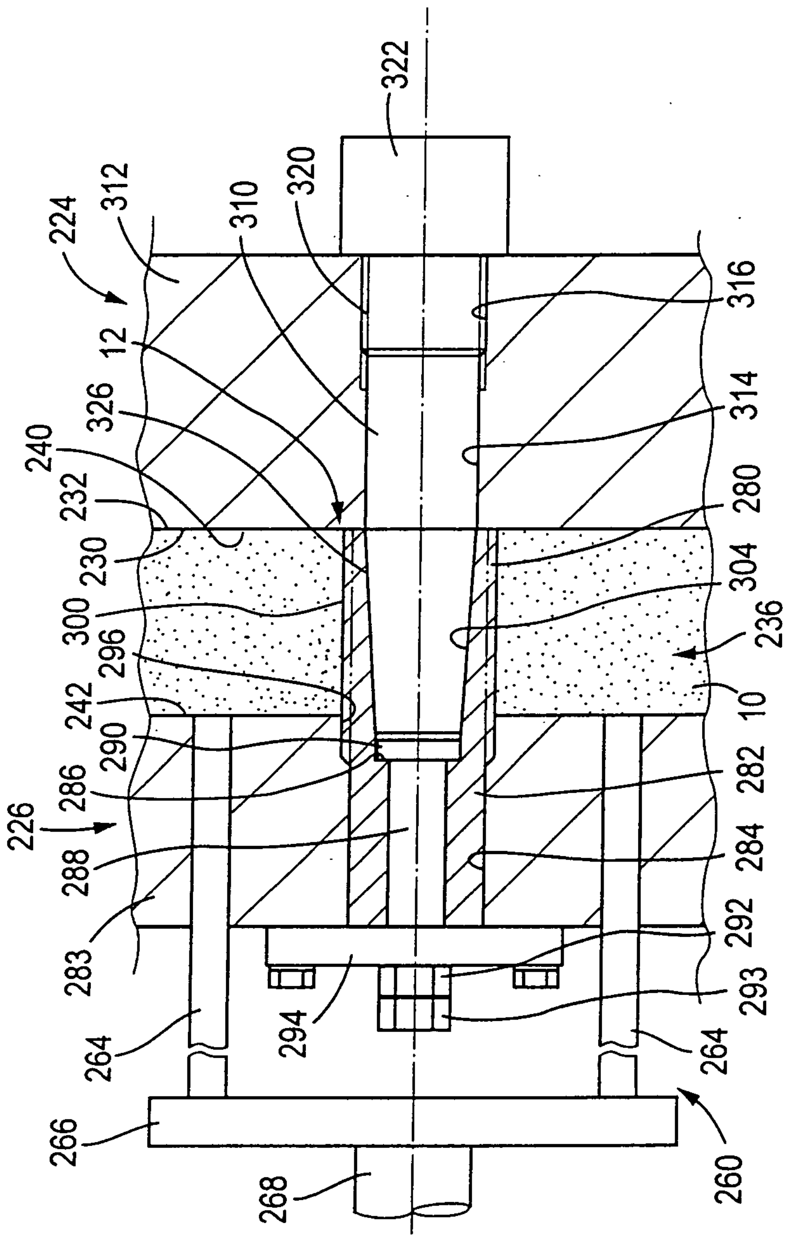
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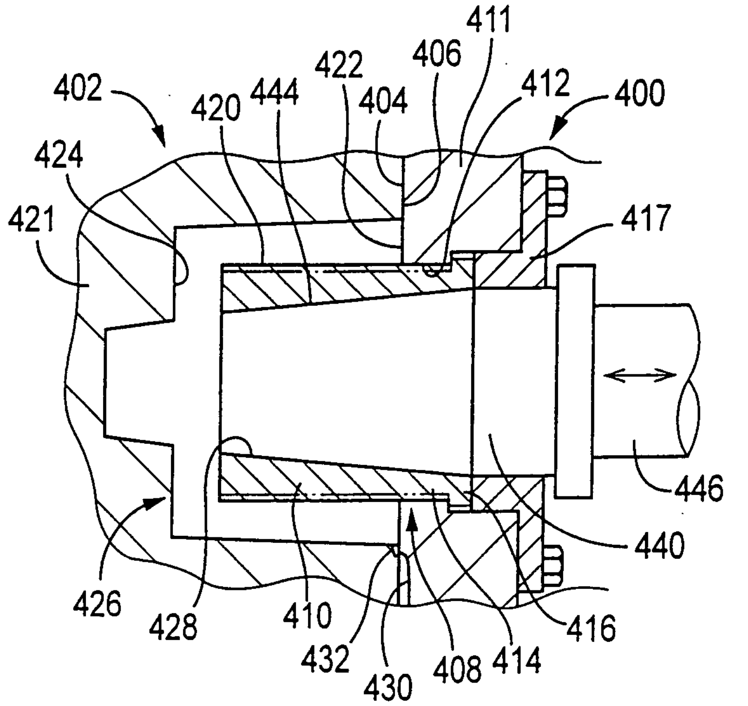
FIG. 4

FIG. 5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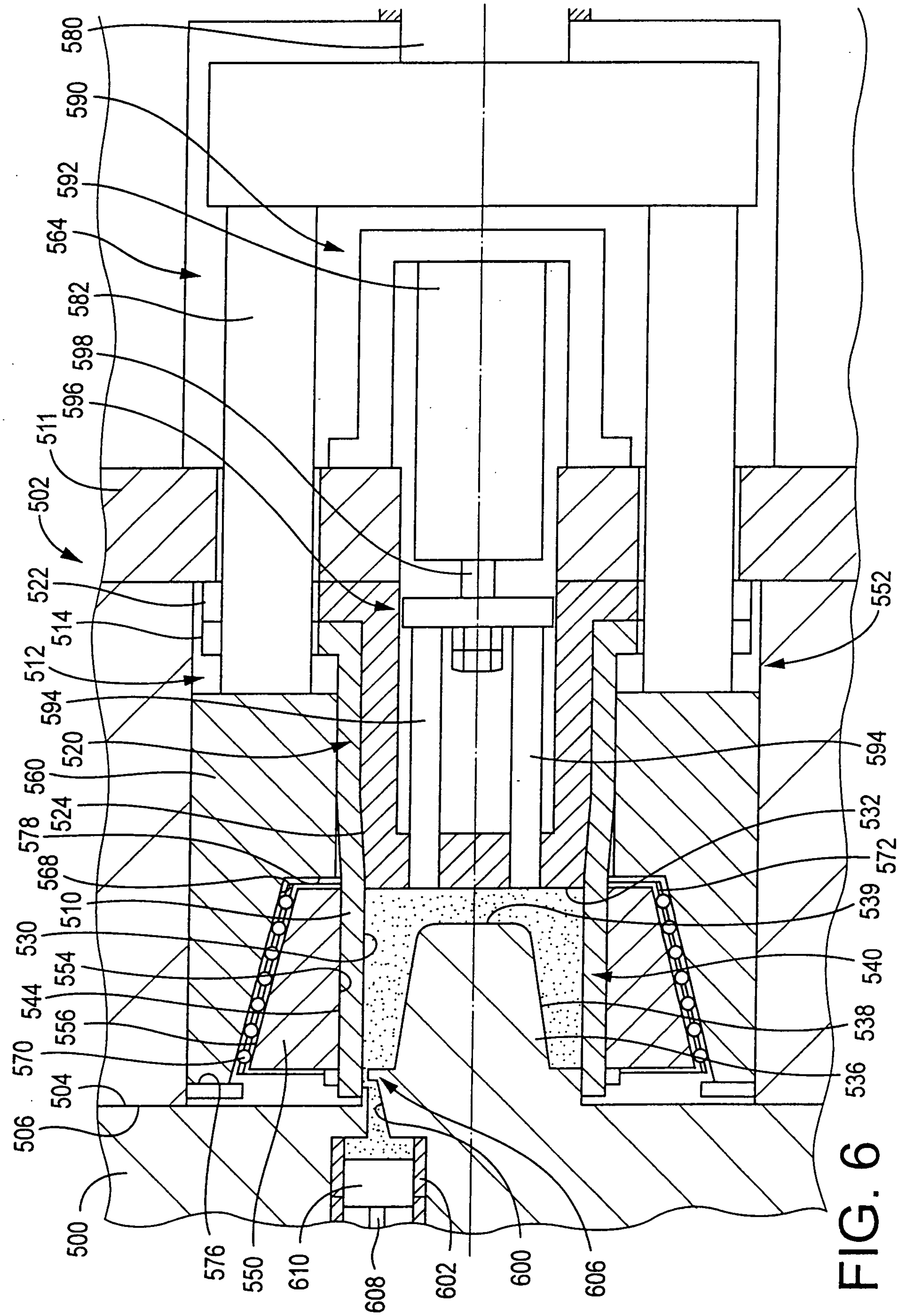
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FIG. 6

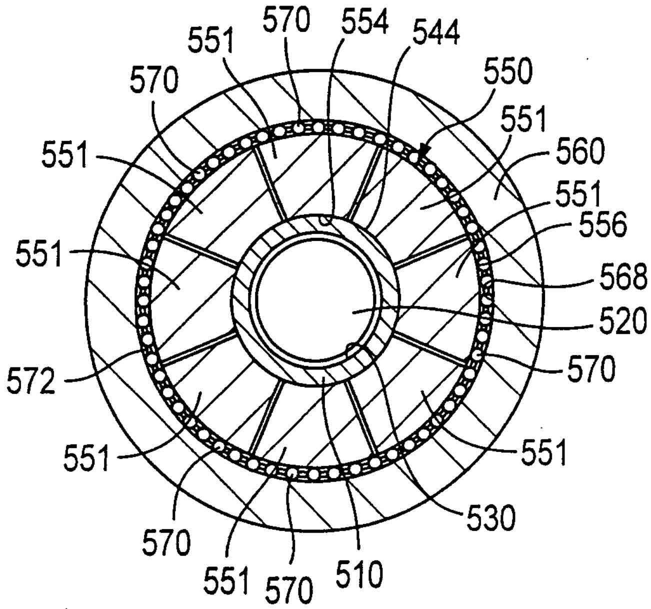
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FIG. 7