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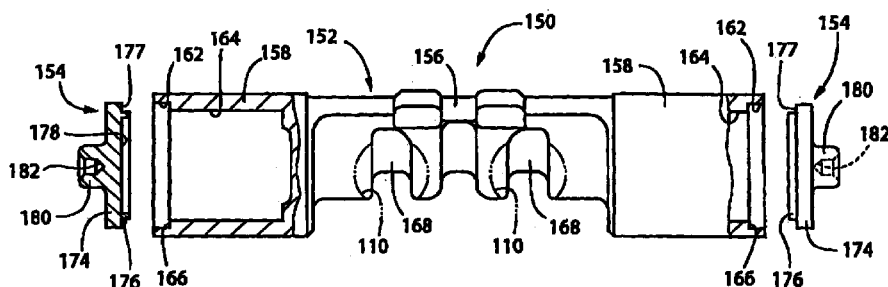
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(54) **Method of forming hollow head portion of piston for swash plate type compressor**

(57) A method of forming a hollow head portion (72) of a piston (14) for a swash plate type compressor, comprising the steps of fixing a closing member (154, 310) to a hollow cylindrical member (158, 200, 300) which is open at at least one of opposite ends thereof, so as to close an open end of the hollow cylindrical member, and applying a welding beam to welding surfaces of the closing member and the hollow cylindrical member,

which welding surfaces are adjacent to or in contact with each other, so that the closing member and the hollow cylindrical member are bonded to each other at the welding surfaces, wherein the welding beam is incident on the welding surfaces of the closing member and the hollow cylindrical member in a direction which intersects the welding surfaces.

FIG. 3



Description

[0001] This application is based on Japanese Patent Application No. 11-238547 filed August 25, 1999, the contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present invention relates to a method of forming a hollow head portion of a piston for a swash plate type compressor, by welding a closing member to a hollow cylindrical member which is open at at least one of opposite ends thereof, so as to close an open end of the hollow cylindrical member.

Discussion of Related Art

[0003] In a swash plate type compressor having a rotary drive shaft which is rotated about its axis, a swash plate which is rotatably supported by the drive shaft, and a plurality of pistons each of which includes a head portion slidably fitted in a cylinder bore formed in a cylinder block of the compressor and a neck portion which slidably engages the swash plate, the pistons are reciprocated by a rotary movement of the swash plate which is rotated together with the drive shaft. In this case, it is desirable that the pistons have a reduced weight especially when installed in a swash plate type compressor of variable capacity type wherein the angle of inclination of the swash plate with respect to the direction perpendicular to the axis of the drive shaft is variable, as well as when installed in a swash plate type compressor of fixed capacity type wherein the angle of inclination of the swash plate is fixed. In an attempt to reduce the weight of the piston, it has been proposed to form the piston with a hollow head portion. The hollow head portion of the piston is formed by welding a dosing member to a hollow cylindrical member which is open at at least one of opposite ends thereof, so as to close an open end of the hollow cylindrical member. The closing member is fixed to the hollow cylindrical member by a beam welding method such as electron beam welding or laser beam welding.

[0004] In welding the closing member to the hollow cylindrical member so as to close its open end for forming the hollow head portion of the piston, the welding beam is usually incident on the two members in a direction parallel to an interface between the inner and outer circumferential surfaces of the two members (welding surfaces), which circumferential surfaces are adjacent to or held in contact with each other, so that the two members are bonded to each other at the circumferential surfaces by the welding beam incident thereon. The circumferential surfaces of the two members, which are adjacent to or in close contact with each other, need to

be formed so as to extend in a specific direction depending upon the welding condition, such that the welding beam is incident on the circumferential surfaces in the direction parallel to the interface. In other words, it is rather difficult to form the circumferential surfaces so that the interface between these surfaces extends in a direction that is desirable or suitable for the purpose of improving the mechanical strength or durability of the piston and reducing its cost of manufacture. In addition, the above-described method may undesirably cause a variation of weld strength at the interface.

SUMMARY OF THE INVENTION

[0005] The present invention was made in the light of the background art described above. It is an object of the present invention to provide a method of forming a hollow head portion of a piston for a swash plate type compressor, which method assures a high degree of freedom in the direction of extension of the circumferential surfaces of the hollow cylindrical member and the dosing member, while avoiding a variation of the weld strength at the interface.

[0006] The object indicated above may be achieved according to any one of the following forms or modes of the present invention, each of which is numbered like the appended claims and depend from the other form or forms, where appropriate, to indicate and clarify possible combinations of 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 and their combinations described below. It is also to be understood that any technical feature described below in combination with other technical features may be a subject matter of the present invention, independently of those other technical features.

(1) A method of forming a hollow head portion of a piston for a swash plate type compressor, comprising the steps of fixing a closing member to a hollow cylindrical member which is open at at least one of opposite ends thereof, so as to close an open end of the hollow cylindrical member, and applying a welding beam to welding surfaces of the closing member and the hollow cylindrical member, which welding surfaces are adjacent to or in contact with each other, so that the closing member and the hollow cylindrical member are bonded to each other at the welding surfaces, wherein the welding beam is incident on the welding surfaces of the closing member and the hollow cylindrical member in a direction which intersects the welding surfaces.

In the method according to the above form (1) of the present invention, the hollow cylindrical member may be open at one or both of its opposite ends. In an attempt to minimize weld portions at which the hollow cylindrical member and the closing member

are bonded to each other by welding, it is preferable that the hollow cylindrical member be open at only one of its opposite ends. In this case, the hollow cylindrical member may be open on the side corresponding to the end face of the piston to be obtained, which end face partially defines a pressurizing chamber in the compressor. Alternatively, the end face may be open on the other side remote from the end face of the piston. When the piston includes a head portion which is fitted in the corresponding cylinder bore formed in the cylinder block of the compressor and a neck portion which engages a radially outer portion of the swash plate through a pair of shoes, the hollow cylindrical member may be formed integrally with the neck portion, and may be closed, by the closing member, at its open end which is remote from the neck portion and which corresponds to the end face of the piston which cooperates with the cylinder bore to define the pressurizing chamber. Alternatively, the hollow cylindrical member may be closed at its open end by the closing member which is formed integrally with the neck portion.

When the two members are fixed together by welding at their welding surfaces which are located adjacent to or in contact with each other, the laser beam is conventionally incident upon the two members in a direction parallel to the interface of the welding surfaces. As explained in the "DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS" provided below, it may be difficult to irradiate the two members with the laser beam in the above-indicated direction parallel to the interface of the welding surfaces, particularly because of a possible interference between a device used to generate the welding beam and any other device located near the beam generating device, such as a device for holding and rotating an assembly of the hollow cylindrical member and the closing member. Further, the bonding strength of the two members at the welding surfaces may undesirably vary if the position of the laser beam is offset in a radially inward or outward direction from the radial position of the interface of the welding surfaces. In contrast, the present method wherein the laser beam is incident upon the welding surfaces in a direction which intersects the welding surfaces eliminates the above-described conventionally experienced problems.

(2) A method according to the above form (1), the closing member is fitted in the open end of the hollow cylindrical member, so that an outer circumferential surface of the closing member and an inner circumferential surface of the hollow cylindrical member engage each other, as the welding surfaces.

(3) A method according to the above form (1), the hollow cylindrical member includes a large-diameter

portion having an inside diameter larger than that of the other portion thereof, the large-diameter portion being located on the side of the open end of the hollow cylindrical member, and the closing member includes a large-diameter plate portion and a small-diameter annular protruding portion, the closing member being fitted in the open end of the hollow cylindrical member such that an outer circumferential surface of the large-diameter plate portion of the closing member engages an inner circumferential surface of the large-diameter portion of the hollow cylindrical member, and such that an outer circumferential surface of the small-diameter annular protruding portion of the closing member engages an inner circumferential surface of the other portion of the hollow cylindrical member, the inner circumferential surface of the large-diameter portion of the hollow cylindrical member and the outer circumferential surface of the large-diameter plate portion of the closing member serving as the welding surfaces.

In the method according to the above form (3) of the present invention, the inner circumferential surface of the large-diameter portion of the hollow cylindrical member may be tapered, or may be cylindrical as explained below with respect to the following form (4). The outer circumferential surface of the large-diameter plate portion of the closing member is shaped to match the configuration of the inner circumferential surface of the large-diameter portion of the hollow cylindrical member. When the inner circumferential surface of the large-diameter portion of the hollow cylindrical member and the outer circumferential surface of the large-diameter plate portion of the closing member are tapered, the closing member is fitted in the open end of the hollow cylindrical member such that the tapered inner and outer circumferential surfaces are held in abutting contact with each other. When the hollow cylindrical member includes a shoulder formed between the large-diameter portion and the other portion thereof and the closing member includes a shoulder formed between the large-diameter plate portion and the small-diameter annular protruding portion, the closing member is fitted in the open end of the hollow cylindrical member such that the shoulders are held in abutting contact with each other. Alternatively, the closing member is fitted in the open end of the hollow cylindrical member such that the shoulder of the closing member is held in abutting contact with an annular end face of the hollow cylindrical member.

(4) A method according to the above form (3), the inner circumferential surface of the large-diameter portion of the hollow cylindrical member and the outer circumferential surface of the large-diameter plate portion of the closing member have constant diameters.

(5) A method according to the above form (4), the hollow cylindrical member includes a shoulder formed between the large-diameter portion and the other portion while the closing member includes a shoulder formed between the large-diameter plate portion and the small-diameter annular protruding portion, the inner circumferential surface of the large-diameter portion of the hollow cylindrical member and the outer circumferential surface of the large-diameter plate portion of the closing member are welded together by the welding beam while the closing member is fitted in the open end of the hollow cylindrical member such that the shoulder of the hollow cylindrical member and the shoulder of the closing member are held in abutting contact with each other.

In the above method, the closing member is fitted into the open end of the hollow cylindrical member with high accuracy by abutting contact between the shoulder of the hollow cylindrical member and the shoulder of the closing member, permitting easy axial positioning of the two members relative to each other, so that the two members can be welded together with high accuracy. When the closing member is fitted into the open end of the hollow cylindrical member and one of opposite end faces of the large-diameter plate portion of the closing member remote from the small-diameter annular protruding portion functions as the end face of the piston which partially defines the pressurizing chamber, the pressure of a compressed gas which acts on the end face of the piston during operation of the compressor is received by the shoulders which are held in abutting contact with each other, so as to improve the mechanical strength at the end wall of the hollow head portion of the obtained piston.

(6) A method according to any one of the above forms (4)-(5), the welding beam is incident on the welding surfaces in a direction perpendicular to a centerline of the hollow cylindrical member.

Though the welding beam may be incident on the welding surfaces in a direction which intersects the centerline of the hollow cylindrical member at an angle other than 90° , the welding beam is preferably incident on the welding surfaces in a direction which is perpendicular to the centerline of the hollow cylindrical member. In this case, the dimension of the weld nugget (the depth of fusion or the distance of penetration across the interface between the welding surfaces) as measured in the direction of the incidence of the electron beam, which is required to assure a high degree of weld strength between the two members, can be reduced. In this respect, it is noted that the dimension of the weld nugget in the radial direction is important from the standpoint of the weld strength.

(7) A method according to the above form (1), the

closing member includes a large-diameter plate portion, a small-diameter annular protruding portion, and a shoulder formed therebetween, and the closing member is fitted in the open end of the hollow cylindrical member such that the shoulder of the closing member is held in abutting contact with an end face of the hollow cylindrical member on the side of the open end, the shoulder of the closing member and the end face of the hollow cylindrical member serving as the welding surfaces.

When one of the opposite end faces of the large-diameter plate portion of the dosing member remote from the small-diameter annular protruding portion functions as the end face of the piston partially defining the pressurizing chamber, the pressure of the compressed gas which acts on the end face of the piston during operation of the compressor is received by the shoulder of the closing member and the annular end face of the hollow cylindrical member which are held in abutting contact with each other, resulting in an improved mechanical strength of the hollow head portion of the piston at its end wall partially defining the pressurizing chamber.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] 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 equipped with a piston having a hollow head portion produced by a method of the present invention;

Fig. 2 is a front elevational view in cross section of the piston shown in Fig. 1;

Fig. 3 is a front elevational view partly in cross section showing a blank used for manufacturing the piston of Fig. 2, before closing members are fixed to a body member of the blank;

Fig. 4 is a front elevational view in cross section showing engagement of a hollow head section of the body member with the closing member to provide the hollow head portion of the piston;

Fig. 5 is a fragmentary front elevational view in cross section showing a method of forming the hollow head portion of the piston by welding according to one embodiment of the present invention;

Fig. 6 is a fragmentary front elevational view in cross section showing a conventional method of forming the hollow head portion of the piston by welding;

Fig. 7 is a fragmentary front elevational view in

cross section showing a method of forming the hollow head portion of the piston by welding according to another embodiment of the invention;

Fig. 8 is a fragmentary front elevational view in cross section showing a method of forming the hollow head portion of the piston by welding according to still another embodiment of the invention;

Fig. 9 is a fragmentary front elevational view in cross section showing a method of forming the hollow head portion of the piston by welding according to yet another embodiment of the invention;

Fig. 10 is a fragmentary front elevational view in cross section showing a method of forming the hollow head portion of the piston by welding according to a further embodiment of the invention; and

Fig. 11 is a view showing a yet another embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0008] Referring first to Figs. 1 and 2, there will be described a piston for a swash plate type compressor, which is constructed according to one embodiment of the present invention. Fig. 1 shows the swash plate type compressor incorporating a plurality of single-headed pistons (hereinafter referred to simply as "pistons").

[0009] In Fig. 1, reference numeral 10 denotes a cylinder block having a plurality of cylinder bores 12 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 of the cylinder block 10. The piston generally indicated at 14 is reciprocally received in each of the 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 body 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.

[0010] 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 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, for

supporting the drive shaft 50 at its rear end portion. The front end portion of the drive shaft 50 extends through a central portion of the front housing 16, such that the front end of the drive shaft 50 is located outside the front housing 16, so that the drive shaft 50 is connected to a drive power source (not shown). 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 is mounted on the drive shaft 50 such that the drive shaft 50 passes through a central mounting hole 61 formed in the central portion of the swash plate 60. The diameter of the central mounting hole 61 of the swash plate 60 gradually increases in the axially opposite directions from its axially intermediate portion towards the axially opposite ends. To the drive shaft 50, there is fixed a rotary member 62 which is held in engagement with the front housing 16 through a thrust bearing 66. The swash plate 60 is rotated with the drive shaft 50 by a hinge mechanism 64 during rotation of the drive shaft 50. The hinge mechanism 64 guides the swash plate 60 for its axial and tilting motions. The hinge mechanism 64 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 mounting hole 61 of the swash plate 60, and the outer circumferential surface of the drive shaft 50.

[0011] The piston 14 indicated above includes a neck portion 70 engaging the swash plate 60, and a head portion 72 formed integrally with the neck portion 70 and fitted in the corresponding cylinder bore 12. The neck portion 70 has a groove 74 formed therein, and the swash plate 60 is held in engagement with the groove 74 through a pair of hemi-spherical shoes 76. The hemi-spherical shoes 76 are held in the groove 74 such that the shoes 76 slidably engage the neck portion 70 at their hemi-spherical surfaces and such that the shoes 76 slidably engage the radially outer portions of the opposite surfaces of the swash plate 60 at their flat surfaces. The configuration of the piston 14 will be described in detail.

[0012] 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 66.

[0013] The cylinder block 10 has an intake 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 intake passage 80 is connected to a solenoid-operated control valve 90 provided to control the pressure in the crank chamber 86. The solenoid-operated control valve 90 includes a solenoid coil 92, and a shut-off valve 94 which is selectively closed and opened by energization and de-energization of the solenoid coil 92. Namely, the shut-off valve 94 is placed in its closed state when the solenoid coil 92 is energized, and is placed in its open state when the coil 92 is de-energized.

[0014] 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.

[0015] By controlling the solenoid-operated control valve 90 as described above, the crank chamber 86 is selectively connected and disconnected to and from the discharge chamber 24, so as to control the pressure in the crank chamber 86 for adjusting the angle of inclination of the swash plate 60 with respect to the direction perpendicular to the axis of rotation of the rotary drive shaft 50, whereby the discharge capacity of the compressor is controlled. Thus, the swash plate type compressor of the present invention is a variable capacity type. Described more specifically, when the solenoid coil 92 of the solenoid-operated control valve 90 is energized, the intake passage 80 is closed, so that the pressurized refrigerant gas in the discharge chamber is not delivered into the crank chamber 86. In this condition, the refrigerant gas in the crank chamber 86 flows into the suction chamber 22 through the bleeding passage 100 and the communication port 104, so that the pressure in the crank chamber 86 is lowered, to thereby increase the angle of inclination of the swash plate 60. The reciprocating stroke of the piston 14 which is reciprocated by rotation of the swash plate 60 increases with an increase of the angle of inclination of the swash plate 60, so as to increase an amount of change of the volume of the pressurizing chamber 79, whereby the discharge capacity of the compressor is increased. When the solenoid coil 92 is de-energized, the intake passage 80 is opened, permitting the pressurized refrigerant gas to be delivered from the discharge chamber 24 into the crank chamber 86, resulting in an increase in the pressure in the crank chamber 86, and the angle of inclination of the swash plate 60 is reduced, so that the discharge capacity of the compressor is accordingly

reduced. The solenoid coil 92 of the solenoid-operated control valve 90 is controlled by a control device not shown depending upon a load acting on the air conditioning system including the present compressor. The control device is principally constituted by a computer.

[0016] 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. The cylinder block 10 and the piston 14 may also be formed of a hyper-eutectic aluminum silicon alloy. Other materials may be used for the cylinder block 10, the piston 14, and the coating film.

[0017] There will next be described the configuration of the piston 14.

[0018] The end portion of the neck portion 70 of the piston 14, which is remote from the head portion 72, has a U-shape in cross section, as shown in Fig. 2. The two opposed lateral walls of the U-shape of that end portion has respective recesses 110 which are opposed to each other. Each of these recesses 110 is defined by a part-spherical inner surface of the lateral wall. The pair of shoes 76 indicated above are held in contact with the opposite surfaces of the swash plate 60 at its radially outer portion and are received in the respective part-spherical recesses 110. Thus, the neck portion 70 slidably engages the swash plate 60 through the shoes 76. In the present embodiment, the neck portion 70 constitutes an engaging portion which engages the drive member in the form of the swash plate 60.

[0019] The head portion 72 of the piston 14 is formed integrally with the neck portion 70, and includes a cylindrical body portion 114 and a closure member 116 fixed to the body portion 114. The cylindrical body portion 114 is open at one of its opposite ends which is remote from the neck portion 70, and is closed at the other end. The closure member 116 closes the open end of the body portion 114. The hollow cylindrical section of the body portion 114 has an inner circumferential surface 120 which is divided into two portions, i.e., a large-diameter portion 122 on the side of the open end of the body portion 114 and a small-diameter portion 124 remote from the open end, which two portions cooperate with each other to define a shoulder 126 formed therebetween.

[0020] The closure member 116 is a generally disc-shaped member which consists of a circular plate portion 130, and an annular protruding portion 132 which extends from one of the opposite end faces of the plate portion 130 and which has a diameter smaller than that of the plate portion 130. The circular plate portion 130 may be referred to as a large-diameter portion while the annular protruding portion 132 may be referred to as a small-diameter portion. A shoulder 134 is formed

between the circular plate portion 130 and the annular protruding portion 132. The annular protruding portion 132 of the closure member 116 has a circular recess 136 open in the end face of the closure member 116 remote from the circular plate portion 130, as shown in Fig. 2, so that the weight of the closure member 116 is reduced. The closure member 116 is fitted into the inner circumferential surface 120 of the hollow cylindrical section of the body portion 114 such that the shoulder 134 of the closure member 116 is held in abutting contact with the shoulder 126 of the hollow cylindrical section of the body portion 114. In this state, the outer circumferential surface of the circular plate portion 130 of the closure member 116 engages the large-diameter portion 122 of the inner circumferential surface 120 of the body portion 114 while the outer circumferential surface of the annular protruding portion 132 of the closure member 116 engages the small-diameter portion 124 of the inner circumferential surface 120 of the body portion 114. The closure member 116 is fixed to the body portion 114 by welding. The compression reaction force which acts on the end face of the piston 14 as a result of compression of the refrigerant gas in the pressurizing chamber 79 during the compression stroke of the piston 14 is received by the shoulders 126 and 134 which are held in abutting contact with each other as well as the contacting circumferential surfaces of the body portion 114 and the closure member 116, which surfaces are bonded by welding.

[0021] Two pieces of the piston 14 constructed as described above are produced from a single blank 150 shown in Fig. 3. The blank 150 used for producing the two pistons 14 has a body member 152 and two closing members 154. The body member 152 consists of a twin neck section 156 and two cylindrical hollow head sections 158 formed integrally with the twin neck section 156 such that the two hollow head sections 158 extend from the opposite ends of the twin neck section 156 in the opposite directions. The twin-neck section 156 consists of mutually integrally formed two portions which correspond to the neck portions 70 of the two single-headed pistons 14. Each of the two hollow head sections 158 is closed at one of its opposite ends which is on the side of the twin neck section 156, and has a hollow cylindrical section which is open at the other end and which corresponds to the hollow cylindrical body portion 114 of the head portion 72.

[0022] As shown in Fig. 3, the hollow head section 158 has an inner circumferential surface which is divided into two sections, i.e., a large-diameter portion 162 located on the side of the open end of the hollow head section 158, and a small-diameter portion 164 located on the side of the twin neck section 156. A shoulder 166 is formed between the large-diameter portion 162 and the small-diameter portion 164. This shoulder 166 functions as the shoulder 126 of the piston 14. The body member 152 is formed by die-casting of a metallic material in the form of an aluminum alloy. This

formation of the body member 152 by die-casting is a step of preparing the body member 152. Reference numeral 168 in Fig. 3 denotes two bridge portions each provided for increasing the rigidity of the body member 152 and functions as a reinforcing portion by which the body portion 152 is protected from being deformed due to heat.

[0023] The two closing members 154 are identical in construction with each other. Like the closure member 116, each of these closing members 154 includes a circular plate portion 174 and an annular protruding portion 176 which extends from one of the opposite end faces of the circular plate portion 174. A shoulder 177 is formed between the circular plate portion 174 and the annular protruding portion 176. The circular plate portion 174 of the closing member 154 has a circular recess 178. The shoulder 177 and the recess 178 of the closing member 154 function as the shoulder 134 and the recess 136 of the closure member 116.

[0024] The circular plate portion 174 of each closing member 154 has a holding portion 182 formed on one of its opposite end faces remote from the annular protruding portion 176. The holding portion 182 has a circular shape in cross section, and has a center hole 182. In the present embodiment, the closing member 154 is formed by die-casting of a metallic material in the form of an aluminum alloy. This formation of the closing members 154 by die-casting is a step of preparing the closing members 154. The circular plate portion 174 and the annular protruding portion 176 of the closing member 154 have the same dimensional relationship as the circular plate portion 130 and the annular protruding portion 132 of the closure member 116, and a detailed description of which is dispensed with.

[0025] As shown in Fig. 4, the closing member 154 is fitted into the open end of the hollow head section 158 such that the circular plate portion 174 of the closing member 154 engages the large-diameter portion 162 of the hollow head section 158 and such that the annular protruding portion 176 of the closing member 154 engages the small-diameter portion 164 of the hollow head section 158. The closing member 154 is inserted into the hollow head section 158 until the shoulder 177 is brought into abutting contact with the shoulder 166. With each closing member 154 fitted in the body member 152, the inner circumferential surface of the large-diameter portion 162 of the hollow head section 158 and the outer circumferential surface of the circular plate portion 174 of the closing member 154 are held close to or in abutting contact with each other, so that these inner and outer circumferential surfaces are bonded to each other by means of an electron beam welding. This welding process will be described in greater detail. In the present embodiment, since the body member 152 and each closing member 154 are both formed by die-casting and have a high dimensional accuracy, the closing member 154 is fitted in the body member 152 without mechanical working operations

such as machining and grinding operations, resulting in a reduced cost of manufacture of the blank 150 for the single-headed pistons 14.

[0026] After the two closing members 154 are fixedly fitted in the respective open end portions of the body member 152 as described above, a machining operation is performed on the outer circumferential surfaces of the hollow head sections 158 of the body member 152 and the exposed outer circumferential surfaces (Fig. 9) of the closing members 154. This machining operation is effected on a lathe or turning machine such that the blank 150 is held by chucks at the holding portions 180 of the closing members 154, with the blank 150 being centered with two centers engaging the center holes 182, and such that the blank 150 is rotated by a suitable drive device. Since the closing members 154 are fixed to the body member 152 by welding, the closing members 154 and the body member 152 are prevented from rotating relative to each other, so that the blank 150 can be turned as a whole for efficient machining on its outer circumferential surface.

[0027] Then, the outer circumferential surfaces of the hollow head sections 158 of the body member 152 and the closing members 154 are coated with a suitable material, such as a film of polytetrafluoroethylene. The blank 150 is then subjected to a machining operation to cut off the holding portions 180 from the closing members 154, and a centerless grinding operation on the coated outer circumferential surfaces of the hollow head sections 158 and the closing members 154, so that the two portions which provide the head portions 72 of the two pistons 14 are formed. In the next step, a cutting operation is performed near the two bridge portions 168 of the twin-neck portion 156, to form the recesses 110 in which the shoes 76 of the pistons 14 are received. Thus, the two portions which provide the neck portions 70 of the two pistons 14 are formed at the twin neck portion 156. Finally, the twin neck portion 156 is subjected at its axially central portion to a cutting operation to cut the blank 150 into two pieces which provide the respective two pistons 14.

[0028] The process of welding each closing member 154 to the body member 152 will be described.

[0029] The closing member 154 and the body member 152 which engage each other as described above are irradiated with an electron beam emitted from an electron beam emitting device of an electron beam welding apparatus, so that the large-diameter portion 162 of the inner circumferential surface of the hollow head section 158 and the outer circumferential surface of the circular plate portion 174 of the closing member 154 are bonded to each other by welding, so that these bonded surfaces provide an interface. The inner and outer circumferential surfaces of the hollow head section 158 and the circular plate portion 174 at which the two members 152, 154 are welded together will be hereinafter referred to as "welding surfaces". Described in detail referring to Fig. 4, the body member 152 and

the two closing members 154 fitted in the body member 152 are held and sandwiched by and between a pair of jigs 186 such that each closing member 154 is pressed onto the body member 152 by each jig with the holding portion 180 of the closing member 154 being fitted in a hole formed in the jig 186. In this state, a torque is applied to each closing member 154 through the jig 180 by a suitable drive device, so that the body member 152 and the closing members 154 are rotated together. In this state, the electron beam is incident upon the body member 152 and the closing members 154, so that these members are welded together at the welding surfaces described above. The closing members 154 are prevented from being moved away from the body member 152 by the jigs 180 which press the closing members 154 onto the body member 152, permitting an efficient welding of the these members. The welding in the present embodiment is effected under vacuum or at a reduced pressure, so as to avoid air expansion due to heat and to eliminate a need of breathing the interior of the body member 152 air-tightly dosed by the closing members 154, and a need of providing the piston with an air vent or breather.

[0030] The drive device for rotating the body member 152 and the closing members 154 and the electron beam emitting device are known in the art, and a detailed explanation of which is dispensed with. In the present embodiment, the rotation of the blank 150 in which the closing members 154 are fitted permits the spot of the electron beam to be moved in the circumferential direction of the blank 150. Alternatively, the electron beam emitting device or the spot of the electron beam may be rotated while the blank 150 is kept stationary.

[0031] As shown in Fig. 5, the electron beam emitted from the electron beam emitting device is incident upon the blank 150 along a straight line which is inclined with respect to a centerline of the body member 152 indicated by a one-dot chain line such that a distance between the above-indicated straight line and the centerline of the body member 152 in the radial direction of the hollow head section 158 decreases as the straight line approaches the shoulder surface 166 in the direction parallel to the centerline of the body member 152 and in the direction from the large-diameter portion 162 toward the small-diameter portion 164. That is, the line of incidence of the electron beam upon the interface of the welding surfaces intersects the welding surfaces such that the line of incidence approaches the interface in the radially inward direction of the hollow head section 158 as the line of incidence approaches the interface in the axial direction of the hollow head section 158 from the large-diameter portion 162 toward the small-diameter portion 164. In other words, the electron beam is incident upon the blank 150 along obliquely extending arrow-headed straight lines indicated in Fig. 5.

[0032] If the electron beam is incident upon the blank 150 in a direction parallel to the interface of the

contacting circumferential surfaces as in the prior art shown in Fig. 6, the amounts of fusion of the materials of the body member 152 and the closing members 154 can be made uniform for the two members 152, 154 as long as the electron beam is accurately aligned with the interface (162) in the radial direction of the hollow head section 158. However, if the spot of the electron beam is offset from the interface in a radially inward or outward direction of the hollow head section 158, the amounts of fusion of the materials of the body member 152 and the closing members 154 cannot be made uniform for these members 152, 154, reducing a weld area, namely, an area in which those members 152, 154 are welded together, resulting in a decrease of the weld strength between the body member 152 and the closing members 154. If the spot of the welding beam is slightly offset from the interface in the radially outward direction of the hollow head section 158 as indicated by an upper arrow-headed line in Fig. 6, for instance, the amount of fusion of the material of the body member 152 is larger than that of the closing members 154, so that the weld area in which these members are welded together is reduced. Thus, in the prior art welding method, the weld strength between the body member 152 and the closing members 154 undesirably varies depending upon individual blanks. In the present embodiment of Fig. 5, in contrast, the weld area does not largely varies even if the spot of the electron beam is offset from the interface in the radially outward direction of the hollow head section 158 as in Fig. 6, so that a variation of the weld strength in the individual blanks 150 can be prevented according to the method of Fig. 5.

[0033] In the conventional welding method shown in Fig. 6 wherein the electron beam is incident on the welding surfaces in the direction parallel to their interface, the welding surfaces need to be irradiated by the electron beam on the side of the end face of each closing member 154 on which the holding portion 180 is formed, such that the direction of incidence of the electron beam is parallel to the centerline of the body member 152 (indicated by the one-dot chain line in Fig. 6). In this arrangement, since the electron beam emitting device is inevitably positioned close to the jig 186, there may arise an interference between the electron beam emitting device and the jig 186. In contrast, according to the present arrangement wherein the electron beam is incident on the welding surfaces along the straight line which is inclined with respect to the rotation axis of the jig 186 shown in Fig. 5, the interference between the jig 186 and the electron beam emitting device can be advantageously avoided.

[0034] In the present embodiment, each of the hollow head sections 158 of the body member 152 corresponds to a hollow cylindrical member which cooperates with the closing member 154 to provide the head portion 72 of the piston 14, which is a hollow head portion. The large-diameter portion 162 serves as a large-diameter portion of each hollow head section 158.

The circular plate portion 174 serves as a large-diameter portion of each closing member 154, while the annular protruding portion 176 serves as a small-diameter portion of each closing member 154.

[0035] The electron beam is incident upon the welding surfaces in any directions which intersect the welding surfaces. For instance, the electron beam may be incident on the welding surfaces along a straight line which is inclined with respect to the centerline of the body member 152 (indicated by the one-dot chain line), as shown in Fig. 7, such that a distance between the above-indicated straight line and the centerline of the body member 152 in the radial direction of the hollow head section 158 decreases as the straight line approaches the end face of the circular plate portion 174 in the direction parallel to the centerline of the body member 152 and in the direction from the small-diameter portion 164 toward the large-diameter portion 162. That is, the line of incidence of the electron beam upon the interface of the welding surfaces intersects the welding surfaces such that the line of incidence approaches the interface in the radially inward direction of the hollow head section 158 as the line of incidence approaches the interface in the axial direction of the hollow head section 158 from the small-diameter portion 164 toward the large-diameter portion 162. In other words, the electron beam is incident upon the blank 150 along an obliquely extending arrow-headed straight line indicated in Fig. 7. This arrangement is also effective to prevent the interference between the electron beam emitting device and the jig 186.

[0036] Alternatively, the electron beam may be incident on the welding surfaces in a direction perpendicular to the welding surfaces, as shown in Fig. 8. This arrangement is particularly effective to avoid the interference between the electron beam emitting device and the jig 186. In this embodiment, the dimension of the weld nugget (the depth of fusion or the distance of penetration across the interface between the welding surfaces) as measured in the direction of the incidence of the electron beam, which is required for obtaining a desired weld strength between the body member 152 and the closing members 154, can be made smaller than that in the embodiments of Figs. 5 and 7 wherein the electron beam is incident on the welding surfaces in the directions inclined with respect to the centerline. In this respect, it is noted that the dimension of the weld nugget in the radial direction is important from the standpoint of the weld strength.

[0037] In the embodiments of Figs. 5 and 7-8, the welding surfaces are parallel to the centerline of the body member 152. The welding surfaces need not be parallel to the centerline of the body member 152, but may extend in the other directions, as shown in Figs. 9 and 10, wherein the same reference numbers as used in Figs 5 and 7-8 are used to identify the corresponding components, and a detailed explanation of which is dispensed with.

[0038] Referring to Fig. 9, a hollow head section 200 of the body member 152 is dosed at one of its opposite ends and open at the other end. The closing member 154 is fitted in a bore 202 of the body member 152 such that the shoulder 177 is held in abutting contact with an annular end face 204 of the body member 152, so that the annular protruding portion 176 of the closing member 154 is fitted at its outer circumferential surface in the corresponding portion of the inner circumferential surface of the hollow head section 200 of the body member 152. The head section 200 of the body member 152 of the present arrangement is simple in configuration with a constant small wall thickness. In the present embodiment, the annular end face 204 of the head section 200 and the shoulder 177 of the closing member 154 are bonded together by welding. Further, the axial end portion of the inner circumferential surface 202 of the head section 200 and the corresponding axial end portion of the outer circumferential surface of the annular protruding portion 176 of the closing member 154 are also bonded together by welding. As indicated by an arrow-headed line in Fig. 9, the electron beam is incident on the welding surfaces along a straight line which is inclined with respect to the centerline of the body member 152 such that a distance between the above-indicated straight line and the centerline of the body member 152 in the radial direction of the hollow head section 200 decreases as the straight line approaches the end face 204 or the shoulder surface 177 in the direction parallel to the centerline and in the direction from the hollow head section 200 toward the closing member 154. That is, the line of incidence of the electron beam upon the interface of the welding surfaces 177, 204 intersects the welding surfaces such that the line of incidence approaches the interface in the radially inward direction of the hollow head section 200 as the line of incidence approaches the interface in the axial direction from the hollow head section 200 toward the closing member 154. Alternatively, the electron beam may be incident on the welding surfaces along a straight line which extends in the lower left-hand direction as in the embodiment of Fig. 5. It is noted that only the end face 204 of the head section 200 and the shoulder 177 of the closing member 154 may be welded together. In this case, the welding surfaces are perpendicular to the centerline of the body member 152.

[0039] The embodiment shown in Fig. 9 is particularly effective to avoid the interference between the electron beam emitting device and the jig 186, and permits effective bonding between the end face 204 of the head section 200 and the shoulder 177 of the dosing member 154, which extend in the direction perpendicular to the centerline of the body member 152. In the present embodiment, the circular plate portion 174 serves as a large-diameter portion of the closing member 154 while the annular protruding portion 176 serves as a small-diameter portion of the closing member 154.

[0040] Referring to Fig. 10, the body member 152

has a hollow head section 300 whose annular end face 304 is tapered with its inside diameter continuously decreasing in the axially inward direction in which a closing member 310 is fitted into a bore 302 of the head section 300. The closing member 310 has the circular plate portion 174 whose outer circumferential surface 312 is tapered with its outside diameter continuously decreasing in the axially inward direction described above. The tapered surface 304 of the head section 300 and the tapered surface 312 of the plate portion 174 of the closing member 310 are bonded together by welding. In the present embodiment, the direction of incidence of the electron beam upon the welding surfaces 304, 312 is perpendicular to the centerline of the body member 152, and intersects these tapered welding surfaces 304 and 312. If the direction of incidence of the electron beam is parallel to the interface of the tapered welding surfaces as in the conventional method, the piston to be obtained is undesirably fused by the electron beam at the periphery of its end face which partially defines the pressurizing chamber 79. In this case, the minimum volume of the pressurizing chamber 79 when the piston is located at the end of the compression stroke undesirably is increased due to deformation by the fusion, resulting in a reduced operating efficiency of the compressor. The present embodiment shown in Fig. 10 wherein the direction of incidence of the electron beam intersects the tapered welding surfaces 304, 312 effectively avoids the above-indicated problem. In this arrangement, the welding surfaces are irradiated with the electron beam without suffering from the interference between the electron beam emitting device and the jig 186. As described above, the electron beam may be incident on the welding surfaces 304, 312 in any directions that intersect the welding surfaces. Accordingly, the welding can be easily effected even when the welding surfaces are inclined with respect to the centerline of the body member 152 as in the embodiment of Fig. 10. The tapered surface 304 of the head section 300 serves as an inner circumferential surface of the large-diameter portion of a hollow cylindrical member which cooperates with a closing member to provide the piston.

[0041] For enjoying the advantages of the present invention, it is desired that the angle of inclination of the welding beam with respect to the welding surfaces be larger than 10 degrees, preferably larger than 20 degrees, and more preferably larger than 30 degrees.

[0042] In the illustrated embodiments of Figs. 4, 5, 7, 8, 9, 10, the closing member 154, 310 is fixed to the hollow cylindrical section 158, 200, 300 such that the closing member is fitted in the open end of the hollow head section. The closing member may be fitted on the hollow cylindrical section, as shown in Fig. 11. In the embodiment of Fig. 11, a hollow head section 400 has an annular protruding end portion 402 which is formed at its open end. The annular protruding end portion 402 has an outside diameter which is smaller than that of the

other portion thereof, so that a shoulder 404 is formed between the annular protruding end portion 402 and the other portion. The closing member 154 is fitted on the outer circumferential surface of the annular protruding end portion 402 of the hollow head section 400 such that an annular end face 352 of an annular protruding portion 350 is held in abutting contact with the shoulder 404 of the hollow head section 400. In this embodiment, the annular end face 852 of the annular protruding portion 350 of the closing member 154 and the shoulder 404 of the hollow head section 400 are bonded together by welding.

[0043] In the blank 150 shown in Fig. 3, each of the two cylindrical hollow head sections 158 is formed integrally with the twin neck section 156, and is open at one of its opposite ends remote from the twin neck section 156 while the opening of each hollow head section 158 is closed by the separately formed closing member 154. The blank 150 may be otherwise constructed. For instance, two closing members are formed integrally with a twin neck member by die-casting, and each closing member is bonded by welding to a corresponding one of two separately die-cast hollow cylindrical members, so as to close an open end of the hollow cylindrical member.

[0044] The closing members and the hollow cylindrical members may be formed by forging.

[0045] The pistons in the illustrated embodiments may be used in a swash plate type compressor of fixed capacity type as well as a swash plate type compressor of variable capacity type. Further, the pistons may be double-headed.

[0046] While some 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.

Claims

1. A method of forming a hollow head portion (72) of a piston (14) for a swash plate type compressor, comprising the steps of fixing a closing member (154, 310) to a hollow cylindrical member (158, 200, 300) which is open at at least one of opposite ends thereof, so as to close an open end of said hollow cylindrical member, and applying a welding beam to welding surfaces of said closing member and said hollow cylindrical member, which welding surfaces are adjacent to or in contact with each other, so that said closing member and said hollow cylindrical member are bonded to each other at said welding surfaces, characterized in that:

said welding beam is incident on said welding surfaces of said closing member and said hol-

low cylindrical member in a direction which intersects said welding surfaces.

2. A method according to claim 1, wherein said closing member (154) is fitted in said open end of said hollow cylindrical member (158, 300), so that an outer circumferential surface of said dosing member and an inner circumferential surface of said hollow cylindrical member engage each other, as said welding surfaces.
3. A method according to claim 1, wherein said hollow cylindrical member (158, 300) includes a large-diameter portion (162, 304) having an inside diameter larger than that of the other portion (164, 302) thereof, said large-diameter portion being located on the side of said open end of said hollow cylindrical member, and said closing member (154) includes a large-diameter plate portion (174) and a small-diameter annular protruding portion (176), said closing member being fitted in said open end of said hollow cylindrical member such that an outer circumferential surface of said large-diameter plate portion of said closing member engages an inner circumferential surface of said large-diameter portion of said hollow cylindrical member, and such that an outer circumferential surface of said small-diameter annular protruding portion of said dosing member engages an inner circumferential surface of said other portion of said hollow cylindrical member, said inner circumferential surface of said large-diameter portion of said hollow cylindrical member and said outer circumferential surface of said large-diameter plate portion of said closing member serving as said welding surfaces.
4. A method according to claim 3, wherein said inner circumferential surface of said large-diameter portion (162) of said hollow cylindrical member (158) and said outer circumferential surface of said large-diameter plate portion (174) of said closing member (154) have constant diameters.
5. A method according to claim 4, wherein said hollow cylindrical member (158) includes a shoulder (166) formed between said large-diameter portion (162) and said other portion (164) while said closing member (154) includes a shoulder (177) formed between said large-diameter plate portion (174) and said small-diameter annular protruding portion (176), said inner circumferential surface of said large-diameter portion of said hollow cylindrical member and said outer circumferential surface of said large-diameter plate portion of said dosing member are welded together by said welding beam while said closing member is fitted in said open end of said hollow cylindrical member such that said shoulder (166) of said hollow cylindrical member

and said shoulder (177) of said closing member are held in abutting contact with each other.

6. A method according to any one of claims 4-5, wherein said welding beam is incident on said welding surfaces in a direction perpendicular to a centerline of said hollow cylindrical member. 5
7. A method according to claim 1, wherein said closing member (154) includes a large-diameter plate portion (174), a small-diameter annular protruding portion (176), and a shoulder (177) formed therebetween, and said closing member is fitted in said open end (202) of said hollow cylindrical member (200) such that said shoulder of said closing member is held in abutting contact with an end face (204) of said hollow cylindrical member on the side of said open end, said shoulder of said closing member and said end face of said hollow cylindrical member serving as said welding surfaces. 10 15 20

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Fig. 1

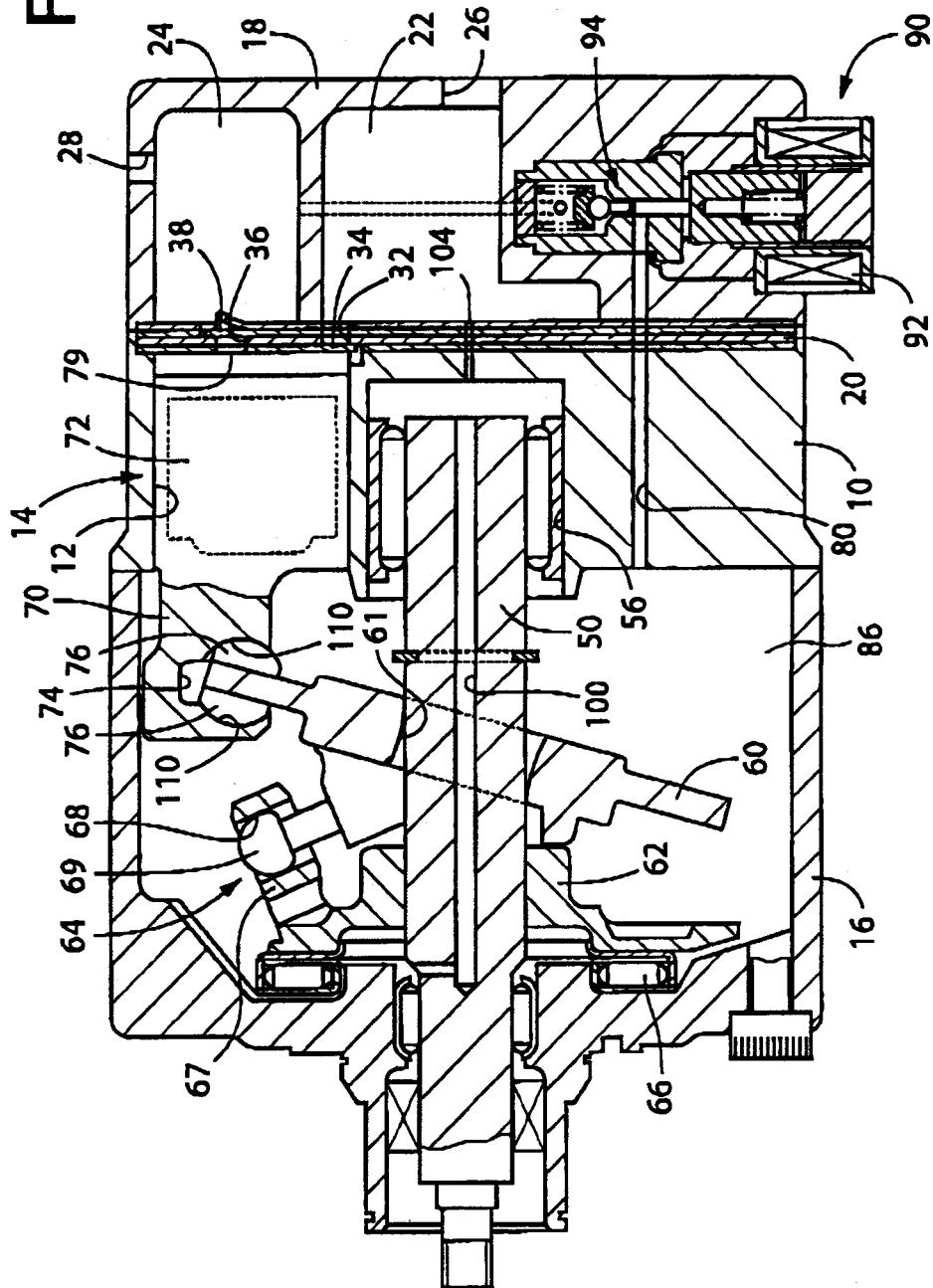


FIG. 2

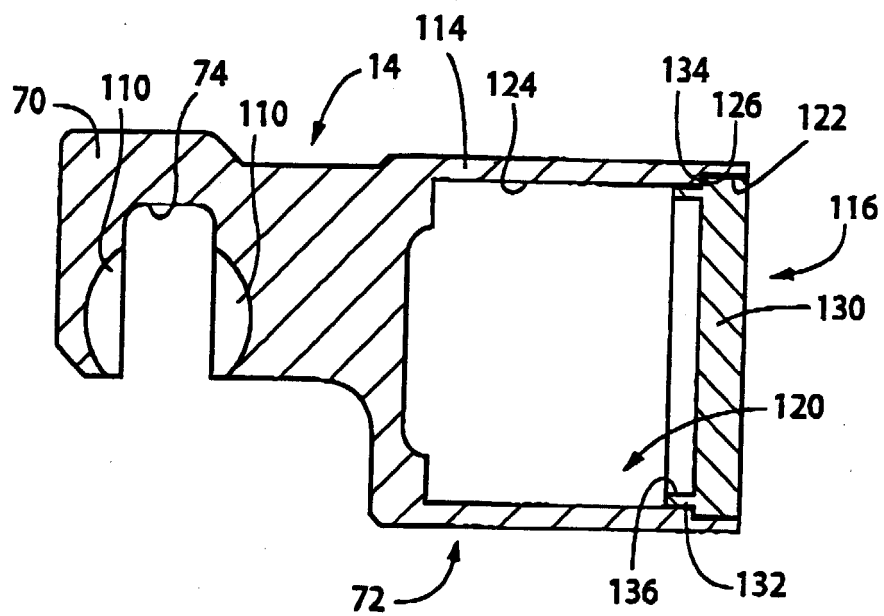


FIG. 3

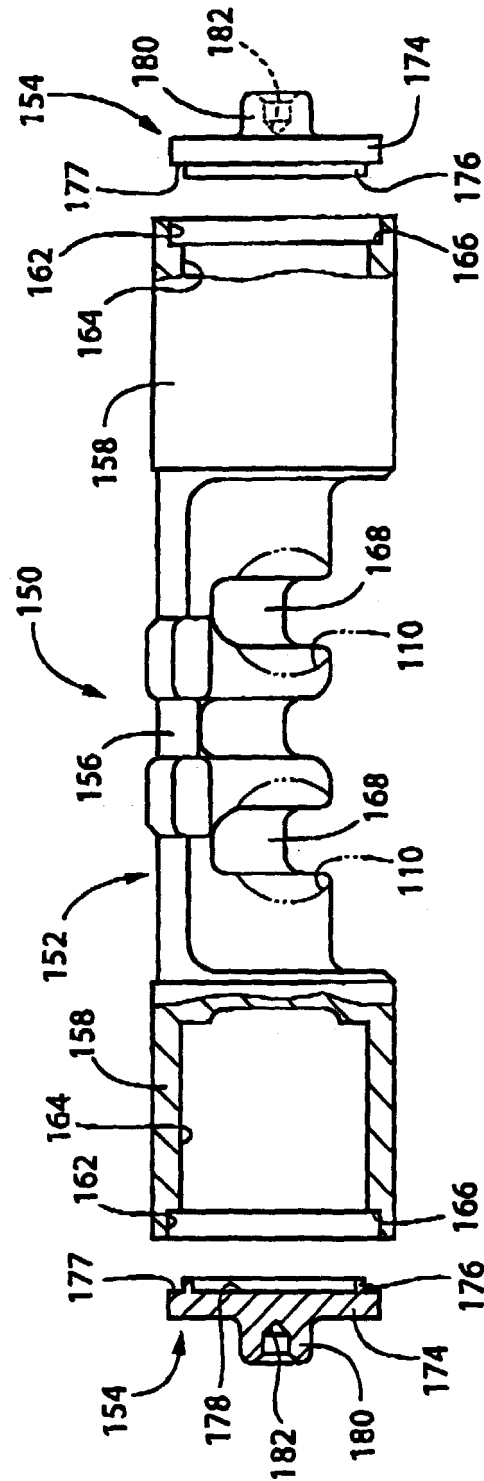


FIG. 4

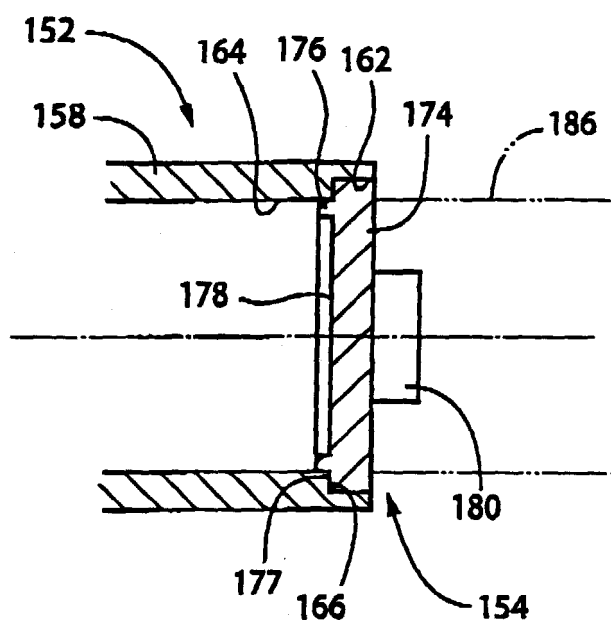


FIG. 5

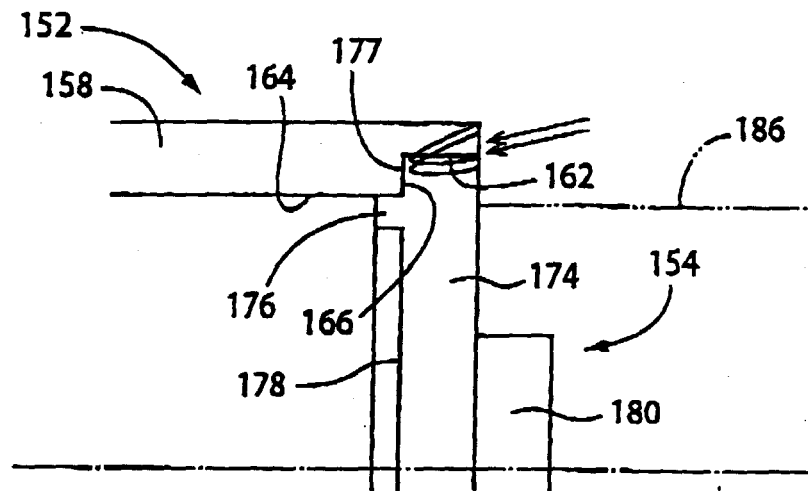


FIG. 6

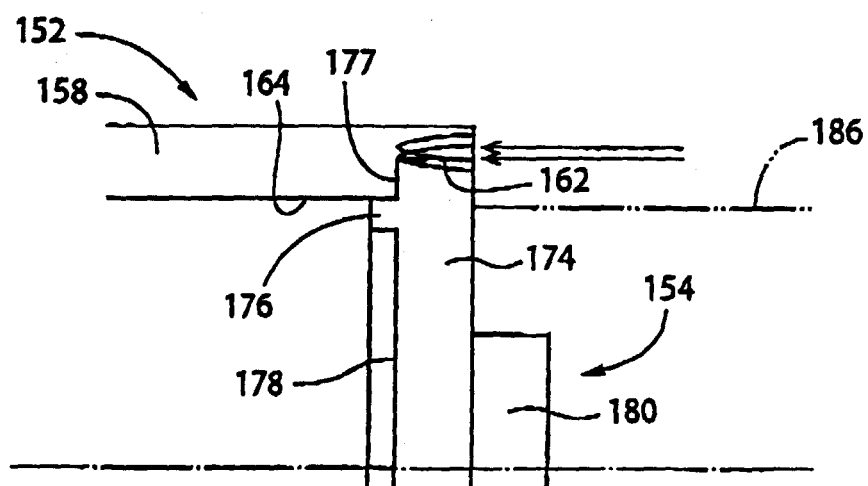


FIG. 7

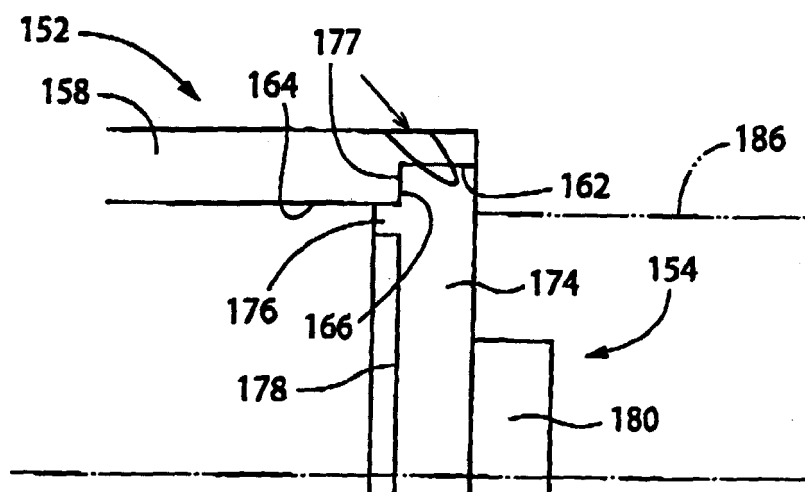


FIG. 8

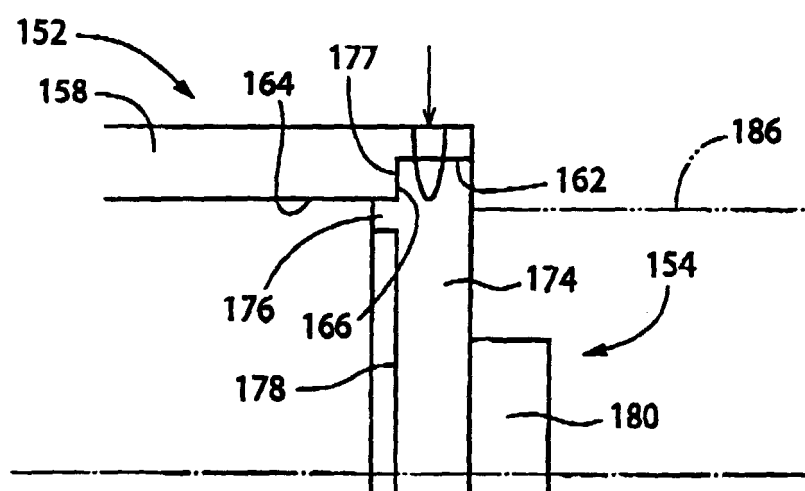


FIG. 9

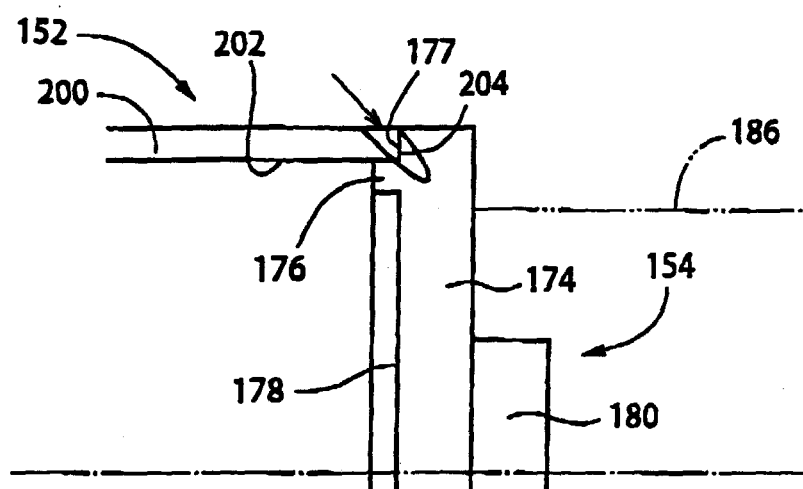


FIG. 10

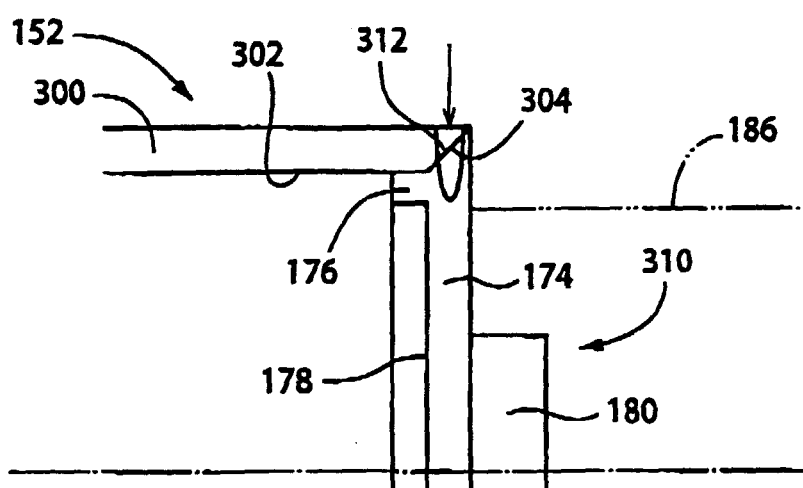


FIG. 11

