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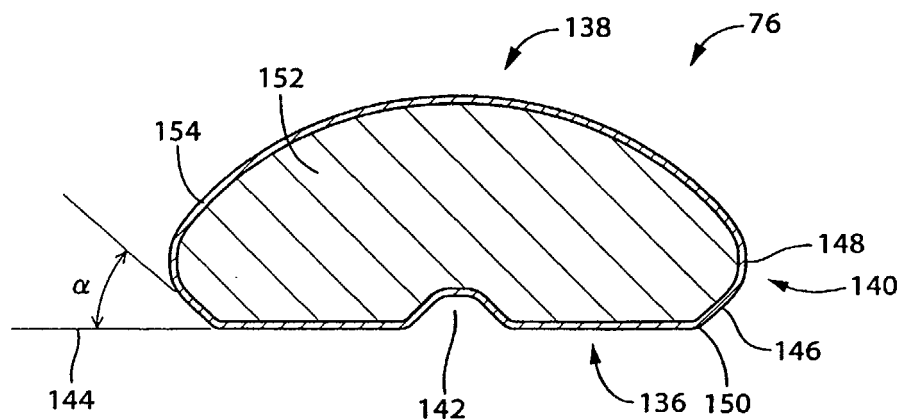
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(54) Shoe for swash plate type compressor

(57) A shoe for use in a swash plate type compressor, interposed between a swash plate and a piston, has a plane sliding surface, a spherical sliding surface and a side surface. The plane sliding surface, which is substantially a plane, slides with respect to the swash plate. The spherical sliding surface, which is substantially a

part of sphere surface, slides with respect to the piston. The side surface is provided between the plane sliding surface and the spherical sliding surface. The side surface includes a chamfered surface adjacent to the plane sliding surface. An angle between the chamfered surface and the extended plane sliding surface ranges from 20° to 80°.

FIG. 2



Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to a shoe for use in a swash plate type compressor and a swash plate type compressor with the pair of shoes interposed between a swash plate and a piston.

[0002] A swash plate type compressor compresses gas by converting rotation of a swash plate to reciprocation of a piston. A pair of shoes, or sliding members, is interposed between the swash plate, which rotates at a high speed, and the piston, which reciprocates at a high speed, to ensure smooth operations of the swash plate and the piston. Since the swash plate rotates at a high speed, sliding performance between the swash plate and the piston is required to be relatively high. The shoe is generally hemispherical crown-shaped. Namely, the shoe includes a substantially plane sliding surface sliding with respect to the swash plate, and a substantially hemispherical sliding surface sliding with respect to the piston. In the hemispherical crown shoe, it is desired that sliding performance between the plane sliding surface and a sliding surface of the swash plate is relatively high. Lubricant oil is supplied between the sliding surfaces, and a layer of the lubricant oil is formed between the sliding surfaces. Thereby, relatively high sliding performance is maintained. Accordingly, when the lubricant oil supplied between the sliding surfaces is not sufficient, sliding performance therebetween deteriorates.

[0003] A prior art for supplying sufficient lubricant oil between the sliding surface of the hemispherical crown shoe and the sliding surface of the swash plate is disclosed in Japanese Unexamined Patent Publication No.56-126686. In the prior art, a chamfered surface is provided in the vicinity of the plane sliding surface of the shoe with respect to the swash plate, and an angle between the chamfered surface and the extended plane sliding surface of the shoe with respect to the swash plate ranges from 0.5° to 10° . According to the prior art, sufficient lubricant oil is supplied between the sliding surfaces due to the chamfered surface provided at the outer periphery of the shoe.

[0004] There is another problem that causes sliding performance to deteriorate. For example, There are many foreign substances in a swash plate type compressor, such as refuse produced due to friction in various places, remaining microscopic burrs arisen upon manufacturing process of components, and dusts introduced from a refrigerant conduit connected to the compressor. These foreign substances should be sufficiently managed. However, completely removing these foreign substances is difficult. Therefore, these foreign substances can be involved in between the sliding surfaces, and then can remain. When the foreign substances remain between the sliding surfaces, the sliding surfaces are flawed, and sliding performance between the sliding surfaces deteriorates. When the angle between the chamfered surface and the extended plane sliding surface of the shoe with respect to the swash plate is as small as that in the prior art, not only lubricant oil but also foreign substances can be involved in between the sliding surfaces. Actually, sufficient sliding performance has not been obtained by such the hemispherical crown shoe yet.

SUMMARY OF THE INVENTION

[0005] The present invention addresses the above-mentioned problems by providing an improved shoe that ensures relatively high sliding performance.

[0006] According to the present invention, a shoe for use in a swash plate type compressor, interposed between a swash plate and a piston, has a plane sliding surface, a spherical sliding surface and a side surface. The plane sliding surface, which is substantially a plane, slides with respect to the swash plate. The spherical sliding surface, which is substantially a part of sphere surface, slides with respect to the piston. The side surface is provided between the plane sliding surface and the spherical sliding surface. The side surface includes a chamfered surface adjacent to the plane sliding surface. An angle between the chamfered surface and the extended plane sliding surface ranges from 20° to 80° .

[0007] The present invention also provides a swash plate type compressor having a housing, a drive shaft, a swash plate, a piston and a shoe. The drive shaft is rotatably supported by the housing. The swash plate is operatively connected to the drive shaft. The piston is accommodated in the housing, and is operatively connected to the swash plate. The shoe is interposed between the swash plate and the piston. The shoe includes a plane sliding surface, a spherical sliding surface and a side surface. The plane sliding surface, which is substantially a plane, slides with respect to the swash plate. The spherical sliding surface, which is substantially a part of sphere surface, slides with respect to the piston. The side surface is provided between the plane sliding surface and the spherical sliding surface. The side surface includes a chamfered surface adjacent to the plane sliding surface. An angle between the chamfered surface and the extended plane sliding surface ranges from 20° to 80° .

[0008] Other aspects and advantages of the invention will become apparent from the following description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The features of the present invention that are believed to be novel are set forth with particularity in the appended claims. The invention together with objects and advantages thereof, may best be understood by reference to the following description of the presently preferred embodiments together with the accompanying drawings in which:

FIG. 1 is a longitudinal cross-sectional view of a swash plate type compressor provided with a pair of shoes according to an embodiment of the present invention;

FIG. 2 is an enlarged cross-sectional view of one of the pair of shoes in FIG. 1;

FIG. 3 is an enlarged partially cross-sectional view of one of the pair of shoes sliding with respect to the swash plate according to the embodiment;

FIG. 4 is an enlarged partially cross-sectional view of one of the pair of shoes sliding with respect to the swash plate, and a foreign substance involved in between the shoe and the swash plate;

FIG. 5 is a table of the diameter q of a foreign substance, the radius r of curvature of a rounded corner and a tangent plane angle β during times when a foreign substance is in contact with the rounded corner;

FIG. 6A is a partial end view of a shoe according to another embodiment of the present invention;

FIG. 6B is a partial end view of a shoe according to another embodiment of the present invention;

FIG. 7 is a schematic view of a process for boring a recess;

FIG. 8 is a schematic view of a process for forging a shoe;

FIG. 9A is a partially cross-sectional view of a shoe #1 for durability test against cast iron particles;

FIG. 9B is a partially cross-sectional view of other shoes #2 to #4 for durability test against cast iron particles;

FIG. 9C is a partially cross-sectional view of the other shoe #5 for durability test against cast iron particles;

FIG. 10 is a schematic view of durability test against cast iron particles;

FIG. 11 is a graph of the number of flaws and the depth of the deepest flaw as a function of the diameter of cast iron particles, the diameter of which range from $38\text{ }\mu\text{m}$ to $75\text{ }\mu\text{m}$ according to the durability test; and

FIG. 12 is a graph of the number of flaws and the depth of the deepest flaw as a function of the diameter of cast iron particles, the diameter of which range from $38\mu\text{m}$ to $75\mu\text{m}$ according to the durability test.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0010] An embodiment of the present invention will now be described with reference to FIGs. 1 to 12. A pair of shoes constituting a swash plate type compressor for use in an air conditioner of a vehicle will be described, for example. The front side and the rear side correspond to the left side and the right side in FIG. 1, respectively.

[0011] As shown in FIG. 1, the reference numeral 10 denotes a cylinder block, and a plurality of cylinder bores 12 is defined in the cylinder block 10 on an identical circumference relative to the central axis of the cylinder block 10. The cylinder bores 12 extend in the direction of the central axis of the cylinder block 10. The cylinder bores 12 each accommodates a single-headed piston 14 so as to reciprocate. The front end surface of the cylinder block 10 connects with a front housing 16, and the rear end surface of the cylinder block 10 connects with a rear housing 18 through a valve plate assembly 20. The front housing 16, the rear housing 18 and the cylinder block 10 constitute a housing of the swash plate type compressor. A suction chamber 22 and a discharge chamber 24 are defined between the rear housing 18 and the valve plate assembly 20, and connect with an external refrigerant circuit, which is not shown, through an inlet 26 and an outlet 28, respectively. The valve plate assembly 20 forms a suction port 32, a suction valve 34, a discharge port 36 and a discharge valve 38.

[0012] A drive shaft 50 is supported by the housing so as to rotate with respect to the central axis of the cylinder

block 10. The front housing 16 and the cylinder block 10 respectively support the front end and the rear end of the drive shaft 50 through bearings. The cylinder block 10 forms a support hole 56 along its central axis, and the rear end of the drive shaft 50 is supported by the support hole 56. The front end of the drive shaft 50 connects with an engine of a vehicle, or a driving source, which is not shown, through a clutch mechanism such as an electromagnetic clutch. Therefore, as the drive shaft 50 connects with the engine by the clutch mechanism upon an operation of the engine, the drive shaft 50 rotates around the axis thereof.

[0013] A swash plate 60 is operatively connected to the drive shaft 50 such that the swash plate 60 tilts and relatively moves in a direction along the axis of the drive shaft 50. The swash plate 60 forms a through hole 61 along its central axis, and the drive shaft 50 extends through the through hole 61. The through hole 61 gradually increases in diameter toward both opening ends of the through hole 61, and the cross sections of the opening ends are oblong holes. A lug plate 62 is secured to the drive shaft 50, and is supported by the front housing 16 through a thrust bearing 64. The swash plate 60 integrally rotates with the drive shaft 50 and tilts with respect to the axis of the drive shaft 50 through a hinge mechanism 66. The hinge mechanism 66 is constituted of a pair of support arms 67 fixed to the lug plate 62, a pair of guide pins 69 slidably fitted into a pair of guide holes 68 of the support arms 67, the through hole 61 of the swash plate 60, and the outer circumferential surface of the drive shaft 50.

[0014] The piston 14 includes an engaging portion 70 and a head 72. The engaging portion 70 overpasses the periphery of the swash plate 60. The head 72 formed with the engaging portion 70 is fitted into the cylinder bore 12. The head 72 in the present embodiment is a hollow head to be light in weight. The head 72, the cylinder bore 12 and the valve plate assembly 20 cooperatively define a compression chamber. Also, the engaging portion 70 engages with the periphery of the swash plate 60 through a pair of shoes 76, which is substantially hemispherical. The shoes 76 will be described later.

[0015] Rotation of the swash plate 60 is converted to reciprocation of the piston 14. As the piston 14 moves from a top dead center toward a bottom dead center, refrigerant gas in the suction chamber 22 is sucked into the compression chamber in the cylinder bore 12 through the suction port 32 and the suction valve 34. As the piston 14 moves from the bottom dead center toward the top dead center, the refrigerant gas in the compression chamber in the cylinder bore 12 is compressed and discharged to the discharge chamber 24 through the discharge port 36 and the discharge valve 38. Compression reactive force acts on the piston 14 in a direction along the axis of the drive shaft 50 in accordance with compressing the refrigerant gas. The front housing 16 receives the compression reactive force through the piston 14, the swash plate 60, the lug plate 62 and the thrust bearing 64.

[0016] The cylinder block 10 forms a supply passage 80 so as to extend through the cylinder block 10. The supply passage 80 interconnects the discharge chamber 24 and a crank chamber 86, which is defined between the front housing 16 and the cylinder block 10. A control valve 90 is interposed in the supply passage 80. The value of an electric current supplied to a solenoid 92 of the control valve 90 is controlled by a controller mainly constituted of a computer, which is not shown, based on information such as cooling load.

[0017] The drive shaft 50 forms a bleed passage 100 inside. The bleed passage 100 opens its one end to the support hole 56, and opens its other end to the crank chamber 86. The support hole 56 interconnects with the suction chamber 22 through a bleed port 104.

[0018] The swash plate type compressor in the present embodiment is a variable displacement type. The pressure in the crank chamber 86 is controlled by utilizing pressure differential between the discharge chamber 24 as a relatively high pressure region and the suction chamber 22 as a relatively low pressure region. Thereby, pressure differential between the pressure in the compression chamber in the cylinder bore 12 applied to the pistons 14 and the pressure in the crank chamber 86 is adjusted, and strokes of the pistons 14 are varied by varying the inclination angle of the swash plate 60, thus adjusting the displacement of the compressor. Additionally, the crank chamber 86 disconnects from the discharge chamber 24 by energizing the control valve 90, and the crank chamber 86 interconnects with the discharge chamber 24 by de-energizing the control valve 90. Thereby, the pressure in the crank chamber 86 is controlled.

[0019] The cylinder block 10 and the pistons 14 are made of aluminum alloy. The outer circumferential surfaces of the pistons 14 are coated with fluororesin. Since the pistons 14 are coated with fluororesin, seizure is inhibited by avoiding directly contacting with a metal of the same kind, and clearances between the cylinder block 12 and the pistons 14 are drastically reduced. Besides, the material of the cylinder block 10, the pistons 14 and the coating layers are not limited as described above, but may be changed into other materials.

[0020] The engaging portions 70 of the pistons 14 are substantially U-shaped. The engaging portions 70 each provide a pair of arms 120, 122 and a connecting portion 124. The pair of arms 120, 122 extends in parallel with each other in a direction perpendicular to the central axis of the head 72. The connecting portion 124 interconnects the bases of the arms 120, 122. The facing surfaces of the arms 120, 122 form spherical concave surfaces 128 for supporting the shoes 76 and sliding with respect to the shoes 76, respectively. The spherical concave surfaces 128 cooperatively form a part of an identical hypothetical spherical sliding surface.

[0021] The swash plate 60, which slides with respect to the shoes 76, is made of ductile iron FCD700. Aluminum

layers are formed on the sliding surfaces 132, 134 of the base member by metal spraying, and lubricant layers are further formed on the aluminum layers. The lubricant layers are made of synthetic resin dispersedly containing molybdenum disulfide and graphite as a solid lubricant. The aluminum layers sufficiently reduce friction generated between the sliding surfaces, and ensure relatively high sliding performance between the shoes 76 and the swash plate 60. Even if the lubricant layers abrade or peel off due to some causes, the aluminum layers inhibit the base member from directly sliding, and maintain a smooth slide. In the swash plate 60, the thickness of the lubricant layers are respectively 15 μ m, and the thickness of the aluminum layers are respectively 60 μ m. Besides, The structure of the swash plate 60, such as the material of the base member of the swash plate 60, the material and thickness of the lubricant layer, with or without the lubricant layer, the thickness of the aluminum spraying layer, and with or without the aluminum spraying layer, may be varied. Since an iron series material is relatively low cost, a compressor with a swash plate made of iron series is also relatively low cost. In addition, when operating the compressor with constant displacement, the inclination angle of the swash plate is desired to be constant. Since the swash plate made of iron series is relatively large in weight, the inclination angle of the swash plate can be stable due to its inertial force. Since the shape of the swash plate made of iron series is complicated, the swash plate is preferably manufactured by molding. Therefore, the material of the swash plate is preferably cast iron, and is more preferably ductile cast iron having relatively high strength and high durability, and is much more preferably FCD700 having further high strength. Since the swash plate rotates at a high speed, the swash plate and the shoes slide under relatively hard conditions. Therefore, the lubricant layer is formed on the sliding surface of the swash plate for ensuring lubrication between the sliding surfaces. Thereby, friction generated between the sliding surfaces is reduced, and the compressor smoothly operates. For example, the lubricant layer may be formed by synthetic resin containing a solid lubricant. In such a state, the solid lubricant includes at least one of molybdenum disulfide, boron nitride, tungsten disulfide, graphite and polytetrafluoroethylene. Also, the synthetic resin includes at least one of polyamideimide, epoxy resin, polyether ketone and phenolic resin. For example, synthetic resin layer dispersedly containing the solid lubricant is formed on the surface of the swash plate by spraying, and after that the synthetic resin layer is solidified, thus forming the lubricant layer. Besides, the thickness of the lubricant layer preferably ranges from 3 μ m to 30 μ m. Also, the strength of the lubricant layer formed on the swash plate is less than that of the base member of the swash plate. When the lubricant layer is removed due to abrasion or peeling, the base member directly slides with respect to the shoe. Thereby, sliding performance of the swash plate deteriorates. When the base member of the swash plate abrades due to a direct slide, sliding performance of the swash plate further deteriorates. Therefore, even if the lubricant layers are removed off, the shoes including metal spraying layers between the base members and the lubricant layers sufficiently ensure high sliding performance due to high sliding performance of the metal spraying layers. Additionally, when the shoes made of iron series alloy slide with respect to the swash plate, the base member of which is made of iron series alloy, and when the lubricant layer of the swash plate is removed off, members made of materials of the same kind slide with respect to each other. Thereby, seizure may arise. Therefore, the metal spraying layer inhibits the seizure from arising. Also, an aluminum spraying layer is preferably employed as the metal spraying layer because of its relatively low cost. Also, the thickness of the metal spraying layer preferably ranges from 100 μ m to 200 μ m.

[0022] As shown in FIG. 2, the shoe 76 includes a plane sliding surface 136, a spherical sliding surface 138 and a side surface 140. The plane sliding surface 136, which is substantially a plane in shape, slides with respect to the swash plate 60. The spherical sliding surface 138, which is substantially a part of sphere surface in shape, slides with respect to the piston 14. The side surface 140 interconnects the plane sliding surface 136 and the spherical sliding surface 138. Strictly, the plane sliding surface 136 forms a convex surface, the radius of curvature of which is very large. Also, a recess 142 is formed at the center of the plane sliding surface 136 so as to stay lubricant oil. Thereby, high sliding performance is ensured. Consequently, the plane sliding surface 136 is annular in shape. Besides, the shoe 76 is generally called a hemispherical crown shoe. Practically, a spherical sliding surface and a plane sliding surface of the hemispherical crown shoe are modified from a strict spherical sliding surface and a strict plane sliding surface so as to improve sliding performance. Also, strictly, a shoe for use in a variable displacement compressor is smaller than a hemisphere, and a shoe for use in a fixed displacement compressor is larger than a hemisphere. In the variable displacement compressor, since both spherical sliding surfaces of the pair of shoes disposed on each side of the swash plate are required to cooperatively form a part of identical hypothetical spherical sliding surface, each of the shoes is substantially a part of sphere, and the thickness of each of the shoe is substantially a half of the thickness of the swash plate less than a hemisphere. On the other hand, in the fixed displacement compressor, since no such limitations as that of the variable displacement compressor is required, each of the shoes is substantially a part of sphere. However, the thickness of each of the shoes is more than a hemisphere to inhibit the area of the sliding surface of the shoe from reducing even if the plane sliding surface abrades.

[0023] The side surface 140 adjacent to the plane sliding surface 136 forms a chamfered surface 146, which is a side surface of a truncated cone. An angle between the chamfered surface 146 and an extended plane sliding surface 144 is a predetermined angle α , or a chamfered surface angle α in the following. In the present embodiment, the chamfered surface angle α of the shoe 76 is 45°. The side surface 140 other than the chamfered surface 146, or an

upper portion relative to the chamfered surface 146 in FIG. 2, forms a rounded surface 148, the radius of curvature of which is relatively large. The rounded surface 148 interconnects the chamfered surface 146 and the spherical sliding surface 138 without any definite border. Also, the chamfered surface 146 connects with the plane sliding surface 136 through a rounded corner 150. In other words, the chamfered surface 146 is adjacent to the plane sliding surface 136 by sandwiching the rounded corner 150. In the present embodiment, the radius of curvature of the rounded corner 150 of the shoe 76 is 0.2mm. Besides, a relatively small rounded corner is formed between a surface defining the recess 142 and the plane sliding surface 136.

[0024] As shown in FIGs. 1 and 2, the spherical sliding surface 138 of the pair of shoes 76 is slidably supported by a sliding surface 128 of the piston 14. The plane sliding surface 136 of the pair of shoes 76 contacts with sliding surfaces 132, 134 of the swash plate 60 at the outer peripheral portions, and the pair of shoes 76 sandwiches the swash plate 60 at the outer peripheral portions. In other words, the plane sliding surfaces 136 of the shoes 76 slide with respect to the swash plate 60, and the spherical sliding surfaces 138 of the shoes 76 slide with respect to the piston 14. Besides, the spherical sliding surfaces 138 of the pair of shoes 76 cooperatively form a part of identical hypothetical spherical sliding surface. Namely, the shoe 76 is substantially a part of sphere, the thickness of which is about a half of the thickness of the swash plate 60 less than a hemisphere.

[0025] The shoe 76 includes a base member 152 and a metal plating layer 154, which coats the surface of the base member 152. In FIG. 2, the thickness of the metal plating layer 154 is exaggerated for easier understanding. The base member 152 is made of Al-Si series alloy such as A4032, the base of which is aluminum with containing silicon such that the composition ratio is closer to that of eutectic. The metal plating layer 154 is formed by electroless plating with nickel. The hardness and the strength of the metal plating layer 154 is relatively high. Thereby, the shoe 76 is inhibited from abrading and being flawed. The metal plating layer 154 includes an outer layer and an inner layer, which are not shown in figures. The outer layer forms the surface of the shoe 76. The inner layer is interposed between the outer layer and the base member 152. The outer layer is formed by electroless plating with nickel eutectic with phosphorus, boron and tungsten (Ni-P-B-W electroless plating). The inner layer is formed by electroless plating with nickel eutectic with phosphorus (Ni-P electroless plating). Additionally, the average thickness of the outer layer is 25 μ m, and the average thickness of the inner layer is 25 μ m. The total average thickness of the metal plating layer 154 is 50 μ m. Besides, the material of the base member 152 is not limited to that in the embodiment described above, but may be modified into various kinds of structures. The shoe, the base member of which is made of aluminum series alloy, is relatively light in weight. Therefore, the shoe is appropriate for use in a swash plate type compressor installed to an air conditioner of a vehicle. A kind of aluminum series alloy is not limited. Aluminum alloy, which is generally used, or which is well-known, may be applied. Concretely, for example, Al-Si having eutectic composition of approximately A4032, may be applied. Since Al-Si series alloy has relatively small coefficient of thermal expansion and relatively high abrasion resistance, the shoes slide smoothly. Also, for example, Al-Cu-Mg series alloy such as A2017 or A2024 may be applied. Since the strength of the Al-Cu-Mg series alloy is relatively high, the shoes perform relatively high strength and high durability. Since the strength and the hardness of the aluminum series alloy are relatively low, the aluminum series alloy is easily deformed, is flawed, and is relatively low in abrasion resistance. Since the shoes 76 in the present embodiment include the metal plating layer 154 on its surface. Thereby, the shoes 76 perform relatively high abrasion resistance. Also, the shoes 76 are inhibited from being flawed due to the metal plating layer, and have relatively high sliding performance. Besides, the metal plating layer may be formed on part of surface of the shoes, and, for example, may be formed on the plane sliding surface only. Also, a kind of the metal plating layer is not limited. As far as the metal plating layer is harder than aluminum series alloy forming the base member of the shoes, the metal plating layer inhibits the shoes from being flawed. The hardness of the metal plating layer is preferably Hv300 (Vickers hardness) or above. The shoes including the metal plating layer perform relatively high abrasion resistance, and are inhibited from being flawed. Concretely, the metal plating layer may be formed by electroless plating with nickel, a series of electroless plating with cobalt eutectic with phosphorus, and hard chrome plating. Particularly, the metal plating layer formed by Ni-P electroless plating, or by electroless plating with nickel eutectic with boron (Ni-B electroless plating), is uniform, and the metal plating layers when solidified has the hardness of Hv500 or above. Thereby, the metal plating layers perform relatively high abrasion resistance and high anti-corrosion. Therefore, the metal plating layer is preferably formed by electroless plating with nickel. Also, the metal plating layer may be formed with a single layer, and may be formed with a plurality of layers. For example, the metal plating layer includes an outer layer forming the surface of the shoe and an inner layer between the outer layer and the base member. When the two layers are formed by electroless plating with nickel, preferably, the inner layer is formed by Ni-P electroless plating, and the outer layer is formed by Ni-P electroless plating containing relatively small phosphorus in ratio and also containing another chemical element. A series of Ni-P metal plating layer firmly adheres to aluminum series alloy, solidifies relatively in a short time, materials for a plating bath are relatively low cost, and hardly corrodes. Therefore, the shoe having Ni-P metal plating layer also performs such characteristics. Additionally, the metal plating layer formed by Ni-P-B-W electroless plating performs much relatively high abrasion resistance. Therefore, the outer layer is preferably formed by Ni-P-B-W electroless plating. Also, the metal plating layer formed by Ni-P electroless plating is much relatively low cost among a series of

electroless plating with nickel, and firmly adheres to the base member. Therefore, the inner layer is preferably formed by Ni-P electroless plating. Besides, when the metal plating layer includes the inner layer formed by a series of Ni-P electroless plating and the outer layer formed by a series of Ni-B electroless plating, the thickness of the inner layer preferably ranges from 1μm to 25μm, the thickness of the outer layer preferably ranges from 19μm to 75μm, and the total thickness of the metal plating layer preferably ranges from 20μm to 100μm. Also, iron series alloy is relatively low cost and relatively high in strength and hardness. Therefore, the shoe, the base member of which is made of iron series alloy, is relatively low cost, and performs relatively high abrasion resistance and high durability. A kind of iron series alloy is not limited. Carbon chrome bearing steel SUJ2 is preferably employed. The shoe made of SUJ2 is manufactured by heat treatment such as quenching or tempering.

[0026] The metal plating layer 154 of the shoe 76 and the aluminum spraying layer and the lubricant layer of the swash plate 60 are omitted in FIG. 3 for easier understanding. Strictly, the plane sliding surface 136 of the shoe 76 is convex in shape as mentioned above. Therefore, a small clearance 160 is maintained between the plane sliding surface 136 of the shoe 76 adjacent to the outer periphery and the sliding surface 132 or 134 of the swash plate 60. A layer of lubricant oil is formed in between the sliding surfaces. Thereby, sliding performance improves. Besides, the clearance 160 is exaggerated in FIG. 3. In FIG. 3, the chamfered surface angle α between the chamfered surface 146 of the shoe 76 and the extended plane sliding surface 144 is different from an angle between the chamfered surface 146 and the sliding surface 132 of the swash plate 60, the angle called pseudo-chamfered surface angle α' . Actually, an angle differential between the chamfered surface angle α and the pseudo-chamfered surface angle α' is small enough, the angle differential being exaggerated in FIG. 3. Therefore, the pseudo-chamfered surface angle α' is regarded as approximately the same angle as the chamfered surface α .

[0027] When the shoe 76 slides with respect to the swash plate 60, that is, the shoe 76 relatively moves toward a direction indicated by an arrow in FIG. 3, lubricant oil on the surface of the swash plate 60 is led from a space 162 between the chamfered surface 146 of the shoe 76 and the sliding surface 132 of the swash plate 60 into the clearance 160. The cross section of the space 162 is wedge-shaped. Since the chamfered surface angle α and the radius of curvature of the rounded corner 150 are appropriately designed, that is, the chamfered surface angle α is 45° and the radius of curvature of the rounded corner 150 is 0.2mm in the present embodiment, relatively large foreign substances 164, which may affect sliding performance, is retarded from being involved in the clearance 160 when the foreign substances 164 are involved in the space 162. Namely, when the chamfered surface angle α is appropriately designed, the foreign substances 164 are excluded. Accordingly, the shoe 76 in the present embodiment efficiently excludes foreign substances, and hardly involves the foreign substances between the sliding surfaces. Thereby, high sliding performance is ensured.

[0028] The radius of curvature of the rounded corner 150 will be described. FIG. 3 shows a state that one of the relatively large foreign substances 164 is involved in the space 162. When the radius of curvature of the rounded corner 150 is relatively large, and when the foreign substance 164 is relatively small, the foreign substance 164 contacts with the rounded corner 150, as shown in FIG. 4. In such a state, the foreign substance 164 is excluded or involved based on an angle β or a tangent plane angle between a tangent plane 166 at a point of contact, where the foreign substance 164 abuts the rounded corner 150, and the extended plane sliding surface 144. Besides, the extended plane sliding surface 144 is regarded as the same surface as the sliding surface 132 of the swash plate 60. As the tangent plane angle β is relatively large, the foreign substances 164 are easily excluded. As the tangent plane angle β is relatively small, the foreign substances 164 are easily involved in between the sliding surfaces.

[0029] When the foreign substances 164 are assumed to be spheres, and when q denotes the diameter of the sphere, that is, the diameter of foreign substance 164, and when r denotes the radius of curvature of the rounded corner 150, relationship among the tangent plane angle β , the diameter q of foreign substances 164 and the radius r of curvature of rounded corner 150 is expressed as follows.

$$r - r \cdot \cos \beta = q/2 + (q/2) \cdot \cos \beta$$

[0030] According to the above-described expression, the tangent plane angles β are calculated based on each diameter q of the foreign substances and each radius r of curvature of rounded corner 150, respectively, and are shown in FIG. 5.

[0031] As shown in FIG. 5, when the diameter q of the foreign substance is the same, as the radius of curvature of the rounded corner 150 reduces, the tangent plane angle β increases. When the radius r of curvature of the rounded corner 150 is the same, as the diameter q of the foreign substance increases, the tangent plane angle β increases. Also, in the shoe 76 described in the present embodiment, the chamfered surface angle α is 45°, and the radius of curvature of the rounded corner 150 is 0.2mm. Therefore, the foreign substances 164, the diameter of which are approximately above 70μm, contact with the chamfered surface 146, and the foreign substances 164, the diameter of which are about 70μm or below, contact with the rounded corner 150. In the shoe 76 described in the present embod-

iment, even if the foreign substances 164 contact with the rounded corner 150, the tangent plane angles β at points of contacts of the foreign substances 164, the diameters of which are approximately $20\mu\text{m}$ or above, exceed 20° . Therefore, the shoe 76 in the present embodiment efficiently excludes the foreign substances 164, the diameters of which are relatively small.

[0032] For example, when the tangent plane angle β is 20° , and when the radius of curvature of the rounded corner 150 is 0.5mm , the shoe 76 efficiently excludes the foreign substances 164, the diameters of which are approximately $30\mu\text{m}$ or above. Also, when the tangent plane angle β is 20° , and when the radius of curvature of the rounded corner 150 is 0.3mm , the shoe 76 efficiently excludes the foreign substances 164, the diameters of which are approximately $20\mu\text{m}$ or above.

[0033] As the radius of curvature of the rounded corner 150 reduces, the shoe 76 excludes the foreign substances 164 more efficiently, as mentioned above. On the other hand, when the radius of curvature of the rounded corner 150 is relatively large, lubricant oil is more efficiently involved in between the sliding surfaces, as compared with the radius of curvature of the rounded corner 150, which is relatively small. When the radius of curvature of the rounded corner 150 is extremely small, and when the rounded corner 150 of the shoe 76 contacts with the sliding surface 132 of the swash plate 60, the rounded corner 150 of the shoe 76 may peel off the lubricant layer containing a solid lubricant because of the relatively low strength and hardness of the lubricant layer. Also, when the radius of curvature of the rounded corner 150 is extremely small, the rounded corner 150 of the shoe 76 excludes not only the foreign substances 164 but also lubricant oil. Furthermore, the surfaces of the shoes 76 are usually smoothed by barrel polishing, and the shoes 76 may abut against each other upon barrel polishing. Therefore, when the radius of curvature of the rounded corner 150 is extremely small, the shoes 76 may be flawed due to the rounded corner 150. Accordingly, the radius of curvature of the rounded corner 150 of the shoe 76 is determined based on the purpose of the shoe 76 in view of characteristics for excluding foreign substances 164 and characteristics for involving lubricant oil. To smoothly involve the lubricant oil in between the sliding surfaces, to inhibit the shoe from being flawed upon barrel polishing, and to avoid the metal plating layer from abrading, the radius of curvature of the rounded corner is preferably 0.05mm or above, and is more preferably 0.1mm or above, and is much more preferably 0.15mm or above. When the radius of curvature of the rounded corner is relatively large, relatively small foreign substances abut not against the chamfered surface but against the rounded corner. In such a state, characteristics for excluding foreign substances depends on an angle between a tangent plane at a point of contact with a foreign substance and the extended plane sliding surface, that is, a tangent plane angle. When the shoe abuts against foreign substances at its chamfered surface, as the tangent plane angle increases, characteristics for excluding foreign substances improves. In addition, when a foreign substance of the same diameter abuts against the rounded corner, as the radius of curvature of the rounded corner increases, the tangent plane angle reduces. Namely, as the radius of curvature of the rounded corner reduces, characteristics for excluding foreign substances improves. When the shoe abuts against foreign substances at its chamfered surface, the chamfered surface angle exceeding 20° sufficiently excludes foreign substances. Likewise, when the shoe abuts against foreign substances at its rounded corner, the tangent plane angle exceeding 20° sufficiently excludes foreign substances. For example, when foreign substances are assumed to be sphere in shape, and when the rounded corner having the radius of curvature of 0.5mm abuts against a foreign substance having the diameter of approximately $30\mu\text{m}$, the tangent plane angle is approximately 20° . Also, when the rounded corner having the radius of curvature of 0.3mm abuts against a foreign substance having the diameter of approximately $20\mu\text{m}$, the tangent plane angle is approximately 20° . Accordingly, when focusing on characteristics for excluding foreign substances, the radius of curvature of the rounded corner is 0.5mm or below, preferably is 0.4mm or below, and is more preferably 0.3mm or below.

[0034] A conventional shoe (not shown in the drawings) will be described for comparing the conventional shoe with the shoe 76 in the present embodiment. A chamfered surface angle of the conventional shoe is a few degrees. Therefore, the conventional shoe hardly excludes foreign substances involved in between the sliding surfaces, and the chamfered surface climbs on the foreign substances. Thereby, the foreign substances are strongly caught in between the sliding surfaces in accordance with the movement of the conventional shoe. Namely, the foreign substances are easily involved in a space between the sliding surfaces due to the wedge-shaped cross section of the space. Accordingly, the conventional shoe not only easily involves the foreign substances in between the sliding surfaces, but also causes a plane sliding surface with respect to the swash plate to be severely flawed. Also, the conventional shoe may peel off the lubricant layer formed on the sliding surface of the swash plate, and may cause the sliding surface of the swash plate to be flawed. Consequently, the sliding performance of the conventional shoe is not sufficient.

[0035] In the above-described shoe 76 in the present embodiment, the chamfered surface angle α is 45° , and the radius of curvature of the rounded corner 150 is 0.2mm . According to the present invention, the chamfered surface angle α and the radius of curvature of the rounded corner 150 are determined based on the purpose of the shoe. When the chamfered surface angle α is a relatively small appropriate angle, the shoe 76 sufficiently involves lubricant oil in between the sliding surfaces. However, as the chamfered surface angle α reduces, the shoe 76 excludes foreign substance between the plane sliding surface 136 and the sliding surface of the swash plate 60 less efficiently. Namely, the chamfered surface 146 easily climbs on the foreign substances. When the shoe 76 moves in such a state, the

foreign substances are consequently involved in between the plane sliding surface 136 and the sliding surface of the swash plate 60. On the contrary, as the chamfered surface angle α increases, the chamfered surface 146 is operative to exclude the foreign substances. Namely, as the chamfered surface angle α increases, the chamfered surface 146 excludes foreign substance more efficiently.

[0036] When foreign substances are involved in between the sliding surfaces, the foreign substances cause not only friction of the sliding surfaces to increase but also each of the sliding surfaces to be flawed. The flaws on each of the sliding surfaces further flaw each of the facing sliding surfaces, and cause sliding performance to deteriorate. When the chamfered surface angle α is relatively small, the shoe 76 climbs on the foreign substances. Therefore, the foreign substances are forced in between the sliding surfaces, and flaws arisen between the shoe 76 and the sliding surface of the swash plate 60 is deepened. Since flaws arise easily, durability against foreign substances reduces. Consequently, sliding performance of the shoe 76 having a small chamfered surface angle α is relatively low.

[0037] Meanwhile, when the chamfered surface angle α is too large, that is, the chamfered surface angle α is closer to 90° , a problem on manufacturing a shoe rises. A hemispherical crown shoe is generally manufactured by flop forging. For example, a pair of dies for forging the shoe is constituted of a die for mainly molding the plane sliding surface 136 and a die for mainly molding the spherical sliding surface 138. A raw material in a predetermined shape plastically flows by forging the raw material in a cavity defined between the pair of dies. When forging by utilizing such the pair of dies, the accuracy of the height of the hemispherical crown shoe is especially important, that is, the accuracy of a distance between the plane sliding surface 136 and the spherical sliding surface 138 is important. Therefore, the cavity is preferably defined so as to permit quantity differentials among the raw materials at a side portion of the cavity. However, when the chamfered surface angle α is too large, it is difficult to define a cavity for sufficiently permitting quantity differentials among the raw materials at a side portion of the cavity. Thereby, the shoe having high accuracy is hardly forged. Therefore, a relatively small chamfered surface angle α of the shoe efficiently permits quantity differentials among the raw materials. When a shoe is inaccurately molded by forging, it takes many hours to adjust the accuracy by polishing after forging. Thereby, manufacturing cost of the shoe increases. Therefore, a relatively small chamfered surface α is desirable when a hemispherical crown shoe is manufactured with low cost with high accuracy. Besides, when the height of the shoe is inaccurate and a distance between the shoe and the piston is relatively large, foreign substances are easily involved in between the sliding surfaces, or when a distance between the shoe and the piston is relatively small, friction generated between the sliding surfaces is excessive. In either case, sliding performance deteriorates. Also, when the chamfered surface angle is 30° or above, characteristics for excluding foreign substance further improves. Additionally, when the chamfered surface angle is 40° or above, characteristics for excluding foreign substance much further improves.

[0038] One of the manufacturing processes of the shoe 76 in the present embodiment will be described. The shoe 76 is manufactured by the steps of: a partially molding process, a forging process, a heat treatment process, a grinding and polishing process, a plating process, and a finishing process. The base member 152 is formed by the steps of a semi-molding process, a forging process, a heat treatment process, and a grinding and polishing process. The metal plating layer 154 is formed by the step of a plating process. The raw material of the shoe 76 will be described first, and each of the manufacturing processes will be described later.

[0039] The raw material of the base member 152 is a cylindrical aluminum series alloy having a smaller diameter and a greater height than the base member 152 of the shoe 76. The raw material is made by the steps of molding a billet, which is made of aluminum alloy with predetermined composition, forming a cylindrical rod with a predetermined diameter by extruding and drawing the billet, annealing the cylindrical rod, cutting the cylindrical rod into pieces with predetermined length by a sawing machine, and smoothing a surface of the cut raw material by barrel polishing.

[0040] A part of the raw material is molded upon the partially molding process. Particularly, the recess 142 at the center of the plane sliding surface 136 of the shoe 76 is formed. The partially molding process is schematically shown in FIG. 7. A pressing apparatus with a pair of dies 178 is used for partially molding the raw material. The pair of dies 178 includes a drag 174 and a punch 176. The drag 174 forms a hole 172 with a bottom at one end, the hole 172 having approximately the same inner diameter as the outer diameter of the raw material 170. The punch 176 is operative to extend into the hole 172. The partially molding is performed by the steps of putting the raw material 170 in the hole 172, forcing the end of the punch 176 onto the raw material 170, pushing the end of the punch 176 into the raw material 170 by moving the punch 176 downward until the punch 176 reaches a predetermined position, A hole bored by the end of the punch 176 forms the shape of the recess 142 of the base member 152.

[0041] The partially molded raw material is forged upon the forging process. The forging process is schematically shown in FIG. 8. A forging apparatus with a pair of dies 184 including a cope 180 and a drag 182 is used for cold-forging the partially molded raw material. The pair of dies 184 defines a cavity, which has substantially the same shape as the base member 152 of the shoe 76, by fitting the cope 180 onto the drag 182. The drag 182 has a protrusion 186, the shape of which is substantially the same shape as the recess 142. The partially molded raw material 188 is positioned on the drag 182 by fitting the protrusion 186 into the recess 142. In this manner, since the recess 142 is previously formed before a forging process, the partially molded raw material 188 is positioned appropriately in the pair of dies

184 by means of the recess 142 and the protrusion 186. Thereby, the partially molded raw material 188 plastically flows isotropically. The forged base members 152 of the shoes 76 maintain substantially the same shape and approximately the same dimensions, and ensure high quality. After putting the partially molded raw material 188 on the drag 182, the base member 152 is forged by operating the cope 180 downward and fitting the cope 180 onto the drag 182.

[0042] More particularly, a plane portion 190 of a molding surface of the drag 182 molds a part of the base member 152 corresponding to the plane sliding surface 136 of the shoe 76, and an inclined portion 192 of the molding surface of the drag 182 molds a part of the base member 152 corresponding to the chamfered surface 146. Therefore, an angle between the plane portion 190 and the inclined portion 192 determines the foregoing chamfered surface angle α . A rounded corner 194 provided between the plane portion 190 and the inclined portion 192 determines the radius of curvature of the rounded corner 150 of the shoe 76. Likewise, a molding surface 196 of the cope 180 molds a part of the base member 152 corresponding to the spherical sliding surface 138 of the shoe 76. The height of the base member 152 is determined by a clearance between the plane portion 190 of the drag 182 and the molding surface 196 of the cope 180 upon fitting the cope 180 onto the drag 182.

[0043] The height of the hemispherical crown shoe is required to be accurate, nevertheless. Quantity of the raw material 188 does not affect the height of the forged base member 152. The volume of the cavity in the pair of dies 184 is determined so as to exceed the volume of the partially molded raw material 188. Thereby, the plastically flowed raw material 188 does not fill the cavity, but flows toward the outer periphery of the cavity. Then, a space 198 is left between the plastically flowed raw material 188 and the pair of dies 184. In other words, the rounded surface 148 of the side surface 140 is molded substantially by open die forging, and the shape of the rounded surface 148 reflects the quantity of the raw material 188. The plane sliding surface 136, the spherical sliding surface 138 and the chamfered surface 146 of the side surface 140 are accurately molded. In the present embodiment, since the chamfered surface angle α of the shoe 76 is 45° , the volume of the space 198 become relatively large. Therefore, even if the quantity of each of the raw materials is different, the raw materials can accurately be forged. Accordingly, cost for adjusting the dimensions of the raw material reduces. As a result, manufacturing cost of the shoe 76 reduces. For example, as the chamfered surface angle α increases, the volume of the space 198 reduces. In such a state, a permissible range of the dimensions of the raw materials reduces. Therefore, the chamfered surface angle α may be preferably 60° or below, and more preferably be 50° or below.

[0044] In the present manufacturing process, the forging process is constituted by only one process. However, a multi-process, which includes a plurality of sub-forging processes, may constitute the forging process. In such a state, the sub-molded raw material may be treated by annealing at one of intervals between the sub-forging processes.

[0045] The base member 152 molded upon the forging process is treated by thermal refining upon the heat treatment process. In the present embodiment, thermal refining treated to the base member 152 is T6 treatment, in which the base member 152 is treated by solution heat treatment, and then treated by artificial age hardening. In the solution heat treatment, the base member 152 is kept in a heating furnace with a temperature of approximately 490°C for approximately an hour, and after that the base member 152 is rapidly cooled to a room temperature. In the artificial age hardening, the base member 152 is kept in the heating furnace with a temperature of approximately 180°C for approximately five hours. T7 treatment in place of T6 treatment may be applied. In T7 treatment, the base member 152 may be treated by solution heat treatment, and then treated by stabilizing treatment. In such a state, after treated by the solution heat treatment in the above-mentioned condition, the base member 152 may be kept in a heating furnace with a temperature of approximately 200°C for approximately five hours.

[0046] The base member 152 treated by thermal refining is ground and polished for adjusting its dimensions and smoothing its surface upon the grinding process. The grinding and polishing process is constituted of a surface grinding process and a barrel polishing process. The surface of the base member 152 corresponding to the plane sliding surface 136 is ground upon the surface grinding process. Several pieces of the base members 152 are aligned, and then ground by a surface grinding apparatus by means of free abrasive grains. The entire surface of the base member 152 is polished upon the barrel polishing process. The base member 152 together with free abrasive grains is put in a barrel polishing apparatus, and then is started. The surface grinding is mainly intended to adjust the height of the base member 152. On the other hand, the barrel polishing is mainly intended to smooth the surface of the base member 152. The surface grinding process or the barrel polishing process, whichever can be performed first.

[0047] The surface of the polished base member 152 is coated with a metal plating layer upon the plating process. The metal plating layer is formed by electroless plating with nickel. An inner layer is formed by Ni-P electroless plating, and then an outer layer is formed by Ni-P-B-W electroless plating. The inner and the outer layers are formed by a conventional procedure, that is, the base member 152 is pretreated and then immersed in a plating bath in accordance with the procedure.

[0048] The base member 152, the surface of which is coated with the metal plating layer 154, or the shoe 76, is polished upon the finishing process. The shoe 76 is ground by barrel polishing upon the finishing process. When necessary, the shoe 76 is treated by surface grinding. After that, the shoe 76 is polished by buffing. The barrel polishing and the surface grinding are performed in such a manner as described above upon the grinding and polishing process.

Since the shoes 76 abut against each other upon barrel polishing, when corners or substantially corners are formed on the surfaces of the shoes 76, the shoes 76 can be flawed due to the corners. Also, the metal plating layer 154 formed on the corners may abrade, and the base members 152 could expose themselves outside. However, In the shoe 76 in the present embodiment, since a portion between the chamfered surface 146 and the plane sliding surface 136 is the rounded corner 150, the radius of curvature of which is 0.2mm, the shoes 76 are inhibited from being flawed, and the metal plating layers 154 are also inhibited from abrading.

[0049] The hemispherical crown shoe 76 is completed through the above-described processes. Manufacturing processes are not limited to the above-described processes. The shoe may be manufactured by various kinds of processes in accordance with specifications of target shoes.

[0050] According to the present invention, the following advantageous effects are obtained.

[0051] Since the strength of the lubricant layer is relatively low, the lubricant layer may be easily peeled off due to foreign substances involved in between the shoes and the swash plate, and due to flaws of the shoes, however. In the present embodiment, the shoes 76 efficiently exclude the foreign substances. Thereby, the shoes 76 are inhibited from being flawed. Accordingly, the shoes 76 rarely flaw the lubricant layer of the swash plate 60, and relatively high sliding performance lasts relatively for a long time.

[0052] The present invention is not limited to the embodiment described above, but may be modified into the following examples.

[0053] For example, the present invention may be applied to a swash plate type compressor with a double-headed piston, having two heads on both sides of the engaging portion relative to the swash plate, or may be applied to a fixed displacement compressor.

[0054] In the shoe 76 in the present embodiment, the side surface 140 includes the chamfered surface 146 and the rounded surface 148 connecting with the chamfered surface 140. The side surface 140 in the present embodiment may be modified into structures shown in FIGs. 6A and 6B. The side surface 140 of the shoe 76 shown in FIG. 6A includes only a chamfered surface 146. Namely, the chamfered surface 146 connects with both the plane sliding surface 136 and the spherical sliding surface 138. The side surface 140 of the shoe 76 shown in FIG. 6B includes a chamfered surface 146 and a cylindrical surface 168. Namely, one end of the chamfered surface 146 connects with the outer periphery of the plane sliding surface 136, and the other end of the chamfered surface 146 connects with one end of the cylindrical surface 168. In addition, the other end of the cylindrical surface 168 connects with the outer periphery of the spherical sliding surface 138. Thus, the shape of the side surface 140 may be modified diversely. Besides, the shape of the surface other than the chamfered surface is not limited. Only when the side surface of the shoe has the chamfered surface adjacent to the plane sliding surface, the shoe may be applied. For example, the shoe having the chamfered surface connecting with the spherical sliding surface, that is, the entire of side surface is the chamfered surface, may be applied. Also, for example, the side surface other than the chamfered surface may form a cylindrical surface or a truncated cone-shaped surface, and an angle between the side surface other than the chamfered surface and the extended plane sliding surface may be optional, and then the side surface other than the chamfered surface may interconnect the chamfered surface and the spherical sliding surface. Also, the side surface other than the chamfered surface may include a plurality of rounded surfaces, and each of the rounded surfaces has the different radius of curvature.

[0055] An experiment is performed on the chamfered surface angle, the radius of curvature of the rounded corner and flaws of the shoes. Based on the above-described spherical shoe, several shoes were manufactured in such a manner that each of the chamfered surface angles was different from one another. Additionally, a shoe having a conventional shape is also manufactured. Each of the shoes was checked how the plane sliding surface worked relative to cast iron particles. The test comparatively checks characteristics for excluding cast iron particles and durability against cast iron particles. Manufactured shoes, conditions of the durability test against cast iron particles, and results of the durability test will now be described.

[0056] Five kinds of shoes in different shapes were manufactured. The shoes were, respectively, numbered from #1 to #5. The shapes of the manufactured shoes are schematically shown in FIG. 9. Each of the shoes #1 to #5 has the same material of the base member, the same material of the metal plating layer formed on the surface, and the same thickness of the layer as those of the shoe 76 described above.

[0057] The shoe #1 has a conventional shape. The shape of shoe #1 is partially shown in FIG. 9A. An angle between the plane sliding surface 136 and the extended surface 144 of the chamfered surface 146, or a chamfered surface angle α_1 , is 10° , relatively small. The radius of curvature R1 of the rounded corner between the plane sliding surface 136 and the chamfered surface 146 is 0.7mm. A space 162, the cross section of which is wedge-shaped, is defined between the chamfered surface 146 and the sliding surface of the swash plate, that is, between the chamfered surface 146 and the extended surface 144 in FIG. 9A. The height h1 of the outer periphery of the space 162 from the extended surface 144 is 0.16mm.

[0058] The shoes #2 to #4 are the shoes according to the present invention. The shapes of shoes are partially shown in FIG. 9B. The chamfered surface angles α_2 of the shoes #2 to #4 are, respectively, 45° , 60° and 70° . Namely, each

of the chamfered surface angles α 2 of the shoes #2 to #4 is greater than the chamfered surface angle α 1 of the shoe #1. The radiuses of curvature R2 of the corners R between the plane sliding surfaces 136 and the chamfered surfaces 146 of the shoes #2 to #4 are all 0.2mm. The similar spaces 162, the cross sections of which are wedge-shaped, are also defined between the chamfered surfaces 146 and the sliding surfaces of the swash plates, that is, between the chamfered surfaces 146 and the extended surfaces 144 in FIG. 9B. The heights h2 of the outer peripheries of the spaces 162 for the shoes #2 to #4 are, respectively, 0.67mm, 0.82mm and 0.89mm.

[0059] The shoe #5 has a characteristic shape for being compared with the other shoes #1 to #4. The shape of shoe #5 is partially shown in FIG. 9C. The shoe #5 has no chamfered surface, so that an angle α 3 between the side surface 140 and the extended surface 144 of the plane sliding surface 136 is 90° . Namely, an angle between the chamfered surface and the extended surface 144 of the plane sliding surface 136 is 90° , and the side surface 140, which is cylindrical in shape, is adjacent to the plane sliding surface 136. The radius of curvature R3 of the rounded corner between the side surface 140 and the plane sliding surface 136 is approximately 0mm. In other words, the rounded corner of the shoe #5 is edged.

[0060] Upon the durability test, the above-described shoes #1 to #5 were actually slid with respect to a swash plate. The durability test was performed in a manner shown in FIG. 10. An apparatus 210 for the durability test includes a rotatable swash plate 60 and a shoe holder 212, by which the shoes 76 are positioned on a sliding surface 132 of the swash plate 60 so as to slide with respect to the sliding surface 132. The shoe holder 212 slidably holds the spherical sliding surface of the shoe 76, and slides the plane sliding surface of the shoe 76 with respect to the sliding surface 132 of the swash plate 60. The shoe holder 212 also pushes the shoe 76 onto the swash plate 60 with predetermined force. The swash plate 60 is the same as that in a practical use. The material of the base member, the thickness of the aluminum spraying layer formed on the sliding surface 132, a kind and the thickness of a lubricant layer are the same as those described-above.

[0061] The swash plate 60 was rotated once on condition that the sliding surface 132 of the swash plate 60 was lubricated by lubricant oil 50 μ l amount, each of the shoes #1 to #5 was held by the shoe holder 212 and was forced onto the swash plate 60 with force 784N, and cast iron particles 10mg in weight were scattered on all over the sliding surface 132. The cast iron particles are classified into two types by diameters of the particles. One type is the particles having the diameter of 38 μ m to 75 μ m, and the other type is the particles having the diameter of 75 μ m to 120 μ m. Each of the shoes #1 to #5 was tested with each type of the particles. Each of the shoes #1 to #5 was checked after the swash plate was rotated, and was scored by the number of flaws on the plane sliding surface of the shoes 76 and by the depth of the deepest flaw. Additionally, the number of the flaws was visually checked, and the depth of the flaw was checked by roughnessmeter.

[0062] The following TABLE 1 indicates the number of the flaws and the depth of the deepest flaw on each of the shoes #1 to #5 in associated with the chamfered surface angle α and the rounded corner of each of the shoes #1 to #5 based on a result of the durability test for cast iron particles of each type. Also, FIG. 11 is a graph showing the number of the flaws and the depth of the deepest flaw upon testing for cast iron particles having the diameter of 38 μ m to 75 μ m. FIG. 12 is a graph showing the number of the flaws and the depth of the deepest flaw upon testing for cast iron particles having the diameter of 75 μ m to 120 μ m.

TABLE 1

SHOE No.	CHAMFERED SURFACE ANGLE α ($^\circ$)	RADIUS OF CURVATURE OF ROUNDED CORNER (mm)	DIAMETER OF CAST IRON PARTICLES 38 to 75(μ m)		DIAMETER OF CAST IRON PARTICLES 75 to 120(μ m)	
			NUMBER OF FLAWS	DEEPEST FLAW(μ m)	NUMBER OF FLAWS	DEEPEST FLAW(μ m)
#1	10	0.7	25	1.9	20	4.0
#2	45	0.2	7	0.8	2	0.4
#3	60	0.2	4	0.7	4	0.9
#4	70	0.2	10	0.9	3	0.9
#5	90	0	1	0.8	2	1.5

[0063] As shown in TABLE 1, FIGs. 11 and 12, the shoe #1, the chamfered surface angle α of which is relatively

small 10° , has the greatest number of flaws and the deepest depth of flaw, irrespective of the diameter of the particles. Meanwhile, the shoes #2 to #4, the chamfered surface angles α of which are relatively large, have the fewer number of flaws and the shallower depth of flaws than those of the shoe #1. Particularly, particles having relatively large diameter cause the sliding surfaces of the shoe and the swash plate to be flawed, and deteriorate sliding performance between the sliding surfaces. Therefore, particles having relatively large diameter are simulated by scattering particles of diameter $75\mu\text{m}$ to $120\mu\text{m}$. The test result indicates that differentials of the number of flaws and the depth of the deepest flaw between the shoe #1 and the shoes #2 to #4 are relatively large. Accordingly, the shoes #2 to #4 having relatively large chamfered surface angle α efficiently exclude the cast iron particles, and ensure relatively high durability against the cast iron particles. Thereby, it was demonstrated that the shoe 76 in the present embodiment ensures relatively high sliding performance.

[0064] Besides, the shoe #5 having no chamfered surface but edged corner is manufactured for being compared with the other shoes #1 to #5. The shoe #5 as well as the shoes #2 to #4 efficiently excludes the cast iron particles and ensures relatively high durability against the cast iron particles. However, there is difficulty in accurately manufacturing a shoe with low cost. Additionally, the edged corner may cause the sliding surface of the swash plate to be flawed. Therefore, the shoe #5 is not practical.

[0065] Therefore, the present examples and embodiments are to be considered as illustrative and not restrictive and the invention is not to be limited to the details given herein but may be modified within the scope of the appended claims.

Claims

1. A shoe interposed between a swash plate and a piston in a swash plate type compressor, the shoe comprising:

a plane sliding surface, which is substantially a plane, sliding with respect to the swash plate;
a spherical sliding surface, which is substantially a part of sphere surface, sliding with respect to the piston; and
a side surface between the plane sliding surface and the spherical sliding surface, the side surface including a chamfered surface adjacent to the plane sliding surface;

wherein an angle between the chamfered surface and the extended plane sliding surface ranges from 20° to 80° .

2. The shoe according to claim 1, wherein the angle between the chamfered surface and the extended plane sliding surface is 30° or above.

3. The shoe according to claim 2, wherein the angle between the chamfered surface and the extended plane sliding surface is 40° or above.

4. The shoe according to claim 1, wherein the angle between the chamfered surface and the extended plane sliding surface is 60° or below.

5. The shoe according to claim 4, wherein the angle between the chamfered surface and the extended plane sliding surface is 50° or below.

6. The shoe according to claim 1 further comprising:

a rounded corner between the chamfered surface and the plane sliding surface.

7. The shoe according to claim 6, wherein the radius of the curvature of the rounded corner is 0.05mm or above.

8. The shoe according to claim 7, wherein the radius of the curvature of the rounded corner is 0.1 mm or above.

9. The shoe according to claim 8, wherein the radius of the curvature of the rounded corner is 0.15mm or above.

10. The shoe according to claim 6, wherein the radius of the curvature of the rounded corner is 0.5mm or below.

11. The shoe according to claim 10, wherein the radius of the curvature of the rounded corner is 0.4mm or below.

12. The shoe according to claim 11, wherein the radius of the curvature of the rounded corner is 0.3mm or below.

13. The shoe according to claim 1 further comprising:

a base member made of aluminum series alloy.

14. The shoe according to claim 13, wherein at least a part of the surface of the base member is coated with metal plating layer.

15. The shoe according to claim 1 further comprising:

a base member made of iron series alloy.

16. A swash plate type compressor comprising:

a housing;

a drive shaft rotatably supported by the housing;

a swash plate operatively connected to the drive shaft;

a piston accommodated in the housing, the piston operatively connected to the swash plate; and

a pair of shoes interposed between the swash plate and the piston, each of the shoes including:

a plane sliding surface, which is substantially a plane, sliding with respect to the swash plate;

a spherical sliding surface, which is substantially a part of sphere surface, sliding with respect to the piston;

and

a side surface between the plane sliding surface and the spherical sliding surface, the side surface including a chamfered surface adjacent to the plane sliding surface;

wherein an angle between the chamfered surface and the extended plane sliding surface ranges from 20° to 80°.

17. The swash plate type compressor according to claim 16, wherein the swash plate includes a base member made of iron series alloy.

18. The swash plate type compressor according to claim 16, wherein the swash plate includes lubricant layers on surfaces sliding with respect to the shoes.

19. The swash plate type compressor according to claim 18, wherein the swash plate includes a metal spraying layer made of one of aluminum, copper and alloys of them, the metal spraying layer is formed on the surfaces sliding with respect to the shoes, and the lubricant layer is formed on the surface of the metal spraying layer.

FIG. 1

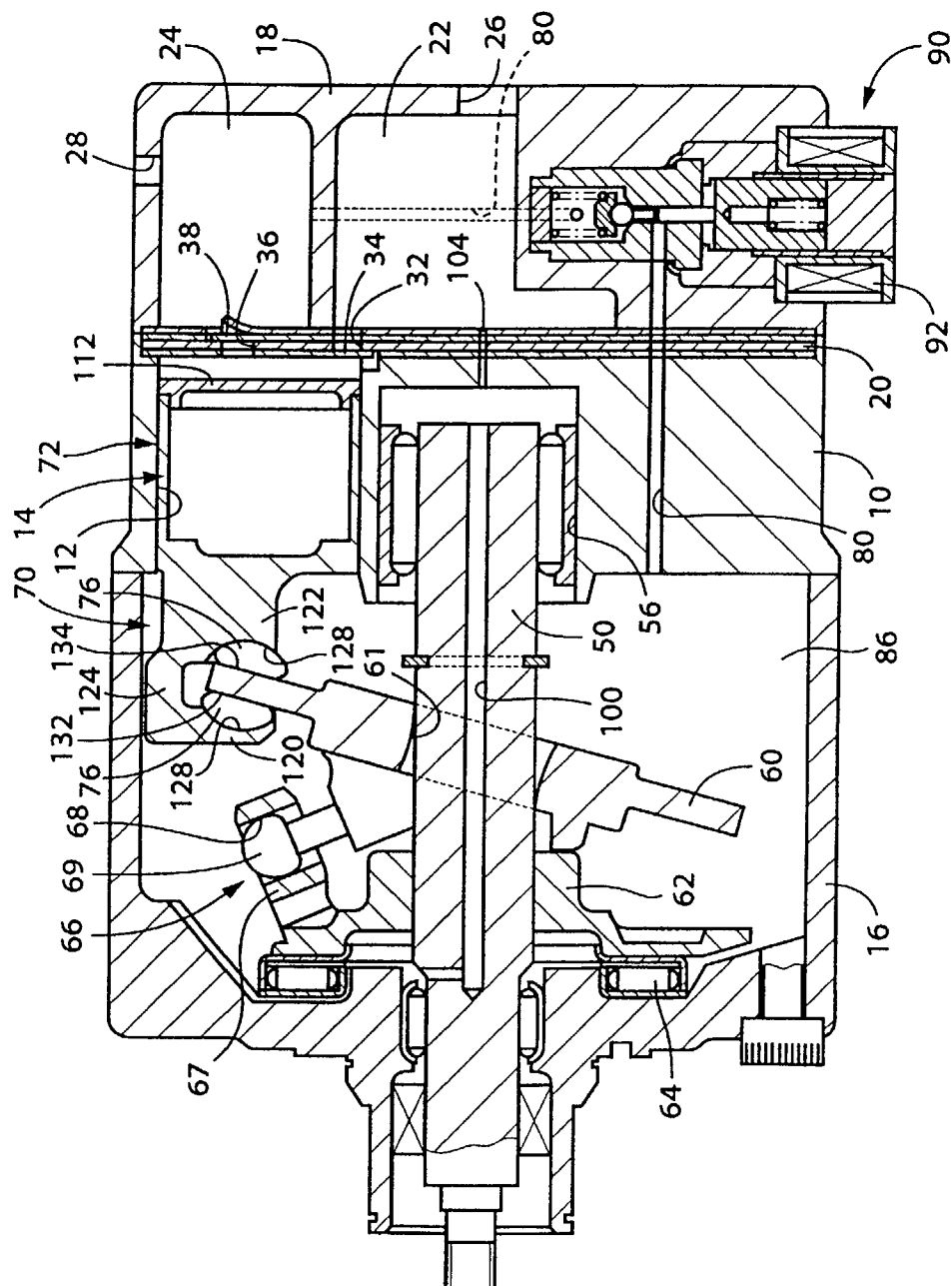


FIG. 2

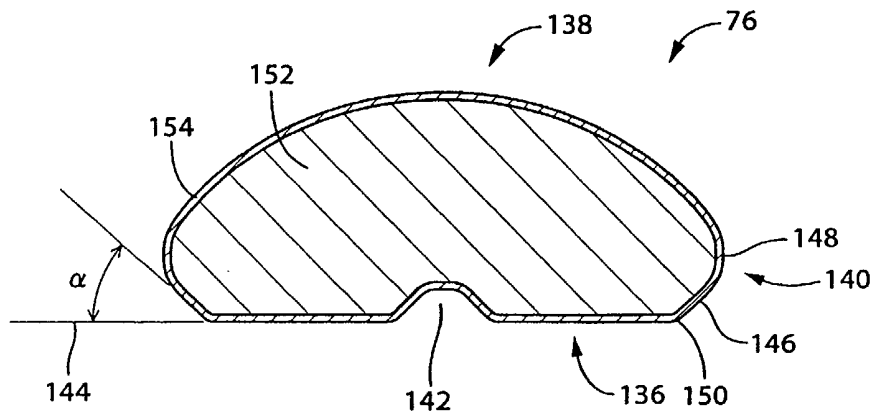


FIG. 3

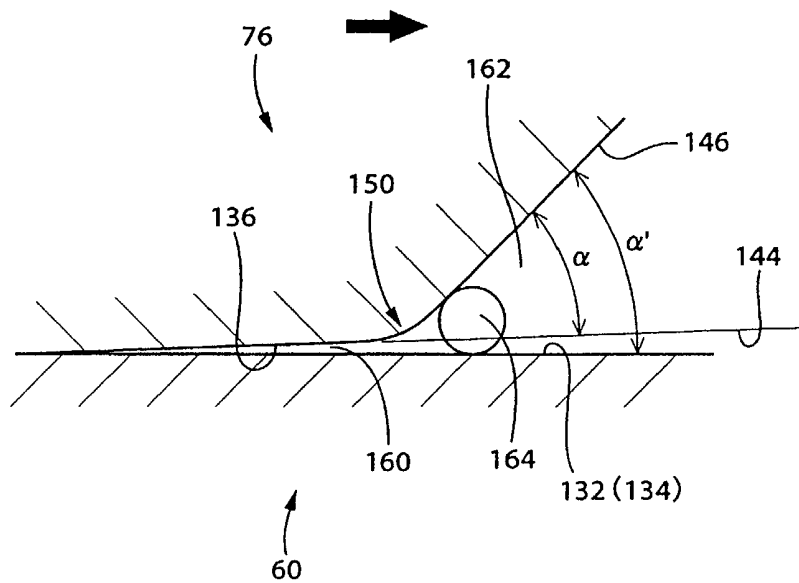


FIG. 4

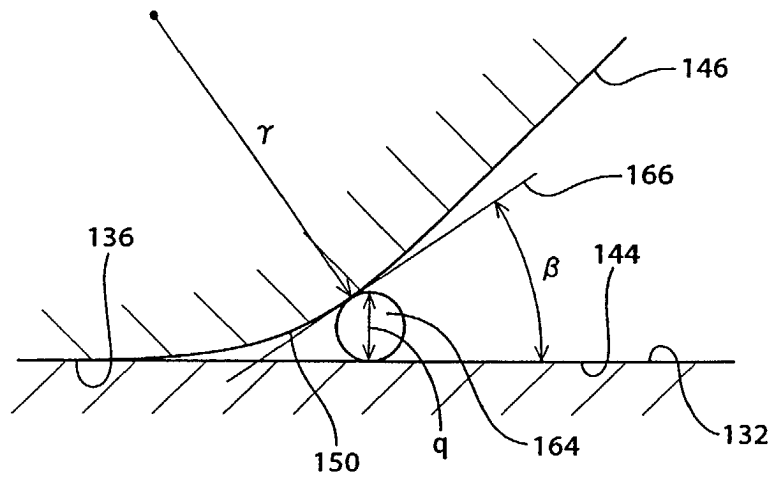


FIG. 5

DIAMETER OF FOREIGN SUBSTANCE (q) (μm)	TANGENT PLANE ANGLE (β) ($^\circ$)									
	10	20	30	40	50	60	70	80	90	100
CORNER R (r) (mm)										
0.05	35.10	48.19	57.42	64.62	70.53	75.52	79.84	83.62	86.98	90.00
0.10	25.21	35.10	42.34	48.19	53.13	57.42	61.22	64.62	67.71	70.53
0.15	20.69	28.96	35.10	40.12	44.42	48.19	51.57	54.62	57.42	60.00
0.20	17.97	25.21	30.63	35.10	38.94	42.34	45.40	48.19	50.75	53.13
0.25	16.10	22.62	27.53	31.59	35.10	38.21	41.03	43.60	45.98	48.19
0.30	14.71	20.69	25.21	28.96	32.20	35.10	37.72	40.12	42.34	44.42
0.35	13.63	19.19	23.39	26.89	29.93	32.64	35.10	37.36	39.45	41.41
0.40	12.76	17.97	21.92	25.21	28.07	30.63	32.96	35.10	37.08	38.94
0.45	12.03	16.96	20.69	23.81	26.53	28.96	31.17	33.20	35.10	36.87
0.50	11.42	16.10	19.65	22.62	25.21	27.53	29.64	31.59	33.40	35.10
0.55	10.89	15.36	18.75	21.59	24.07	26.29	28.32	30.18	31.93	33.56
0.60	10.43	14.71	17.97	20.69	23.07	25.21	27.16	28.96	30.63	32.20
0.65	10.02	14.14	17.28	19.90	22.19	24.25	26.13	27.86	29.48	31.00
0.70	9.66	13.63	16.66	19.19	21.40	23.39	25.21	26.89	28.45	29.93
0.75	9.34	13.17	16.10	18.55	20.69	22.62	24.38	26.01	27.53	28.96
0.80	9.04	12.76	15.59	17.97	20.05	21.92	23.63	25.21	26.68	28.07
0.85	8.77	12.38	15.13	17.44	19.46	21.28	22.94	24.48	25.92	27.27
0.90	8.53	12.03	14.71	16.96	18.92	20.69	22.31	23.81	25.21	26.53
0.95	8.30	11.72	14.32	16.51	18.43	20.15	21.73	23.19	24.56	25.84
1.00	8.09	11.42	13.96	16.10	17.97	19.65	21.19	22.62	23.95	25.21

FIG. 6A

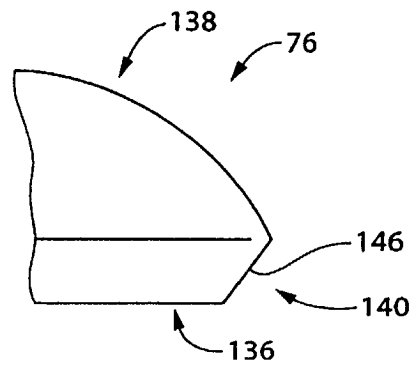


FIG. 6B

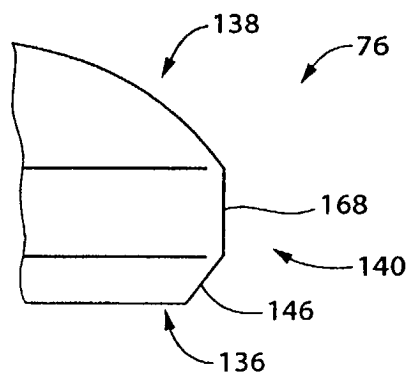


FIG. 7

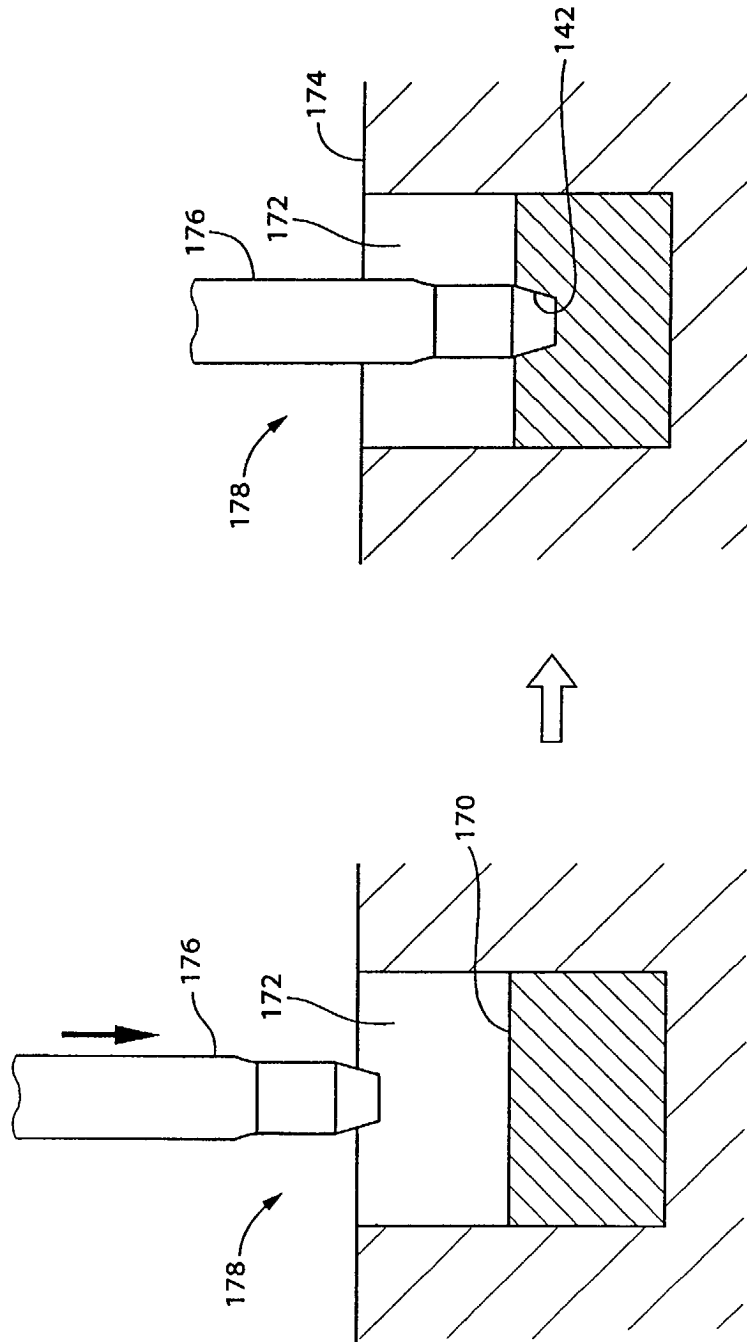


FIG. 8

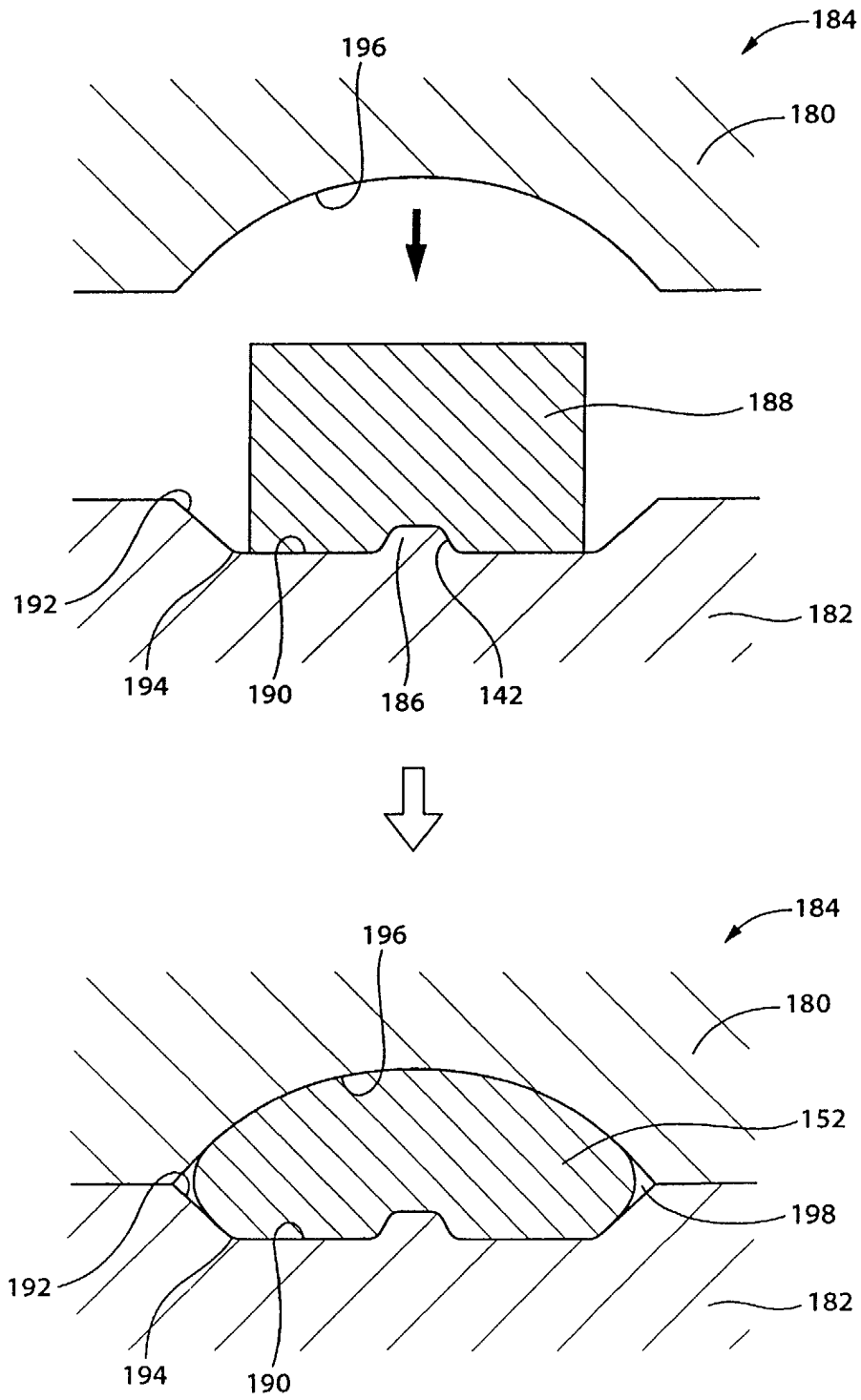


FIG. 9A

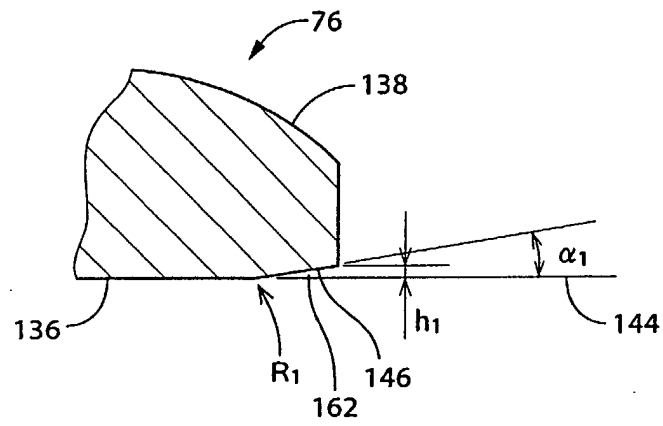


FIG. 9B

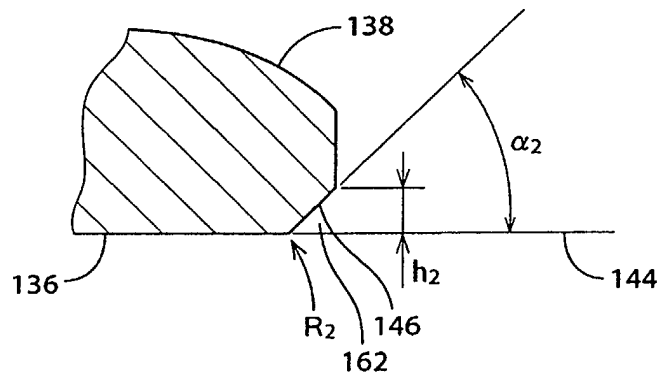


FIG. 9C

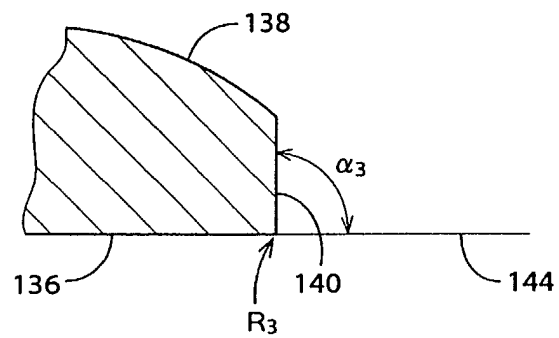


FIG. 10

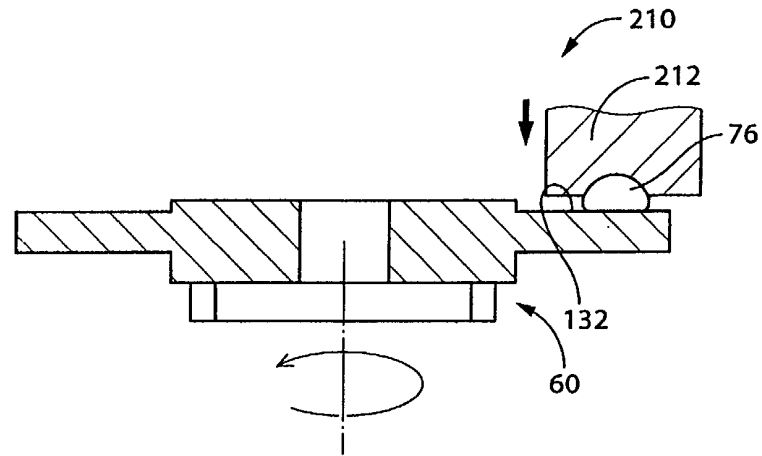


FIG. 11

DIAMETER OF CAST IRON PARTICLES

38 to 75 (μm)

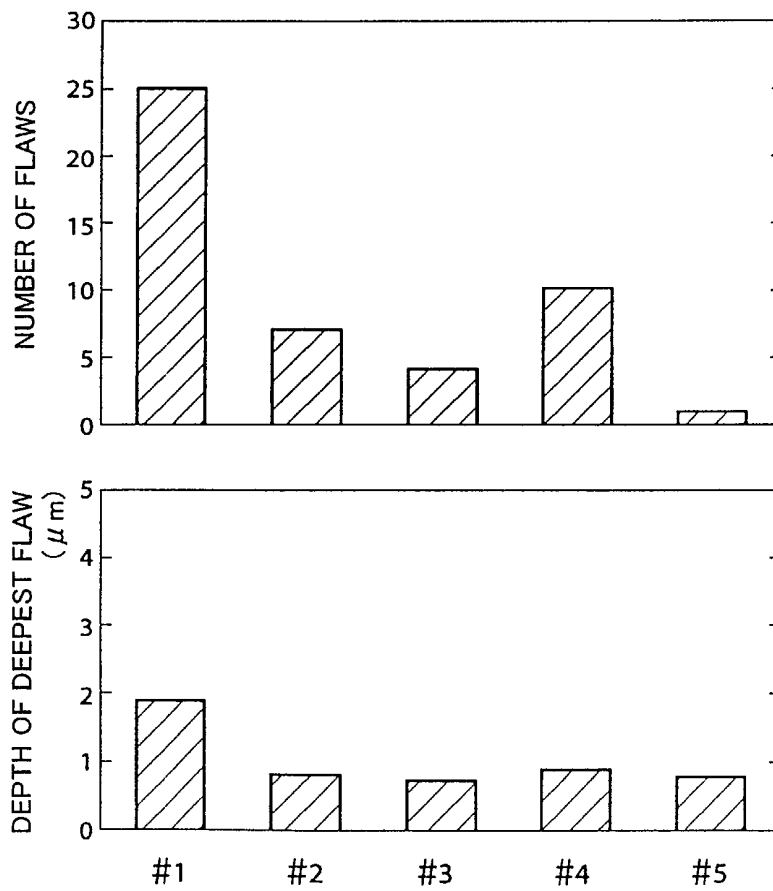


FIG. 12

