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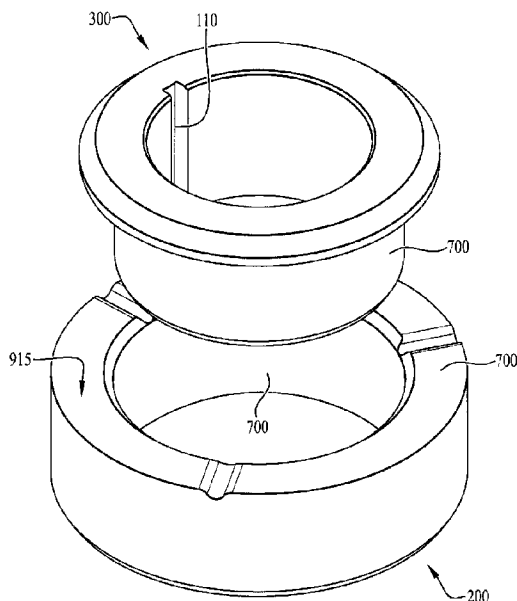
(72) Inventeurs/Inventors:
LUNK, DAVID J., US;
JOHNSON, KEITH LEON, US;
NOWITZKI, WESLEY JOHN, US;
GOTTSCHALK, THOMAS JOHN, US;
KENNER, JOHN VANDERSTAAY, US

(73) Propriétaire/Owner:
HALLIBURTON ENERGY SERVICES, INC., US

(74) Agent: PARLEE MCLAWS LLP

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(54) Title: ABRASION RESISTANCE IN WELL FLUID WETTED ASSEMBLIES



(57) **Abrégé/Abstract:**

Abrasion resistance in well fluid wetted assemblies is described. A method of enhancing an abrasion resistance of submersible assemblies includes polishing a first running surface of a sleeve and a second running surface of a bushing until the first running surface and the second running surface have a roughness average of four micro-inches roughness average (Ra) or less, coating the polished first running surface and the polished second running surface with one of titanium nitride, titanium aluminum nitride or a combination thereof, and placing the sleeve and the bushing in an electric submersible pump (ESP) assembly component such that the first running surface faces the second running surface and the first running surface rotates with respect to the second running surface, and pumping a fluid from an underground formation to a surface location using the ESP assembly.

ABSTRACT

Abrasion resistance in well fluid wetted assemblies is described. A method of enhancing an abrasion resistance of submersible assemblies includes polishing a first running surface of a sleeve and a second running surface of a bushing until the first running surface and the second running surface have a roughness average of four micro-inches roughness average (Ra) or less, coating the polished first running surface and the polished second running surface with one of titanium nitride, titanium aluminum nitride or a combination thereof, and placing the sleeve and the bushing in an electric submersible pump (ESP) assembly component such that the first running surface faces the second running surface and the first running surface rotates with respect to the second running surface, and pumping a fluid from an underground formation to a surface location using the ESP assembly.

[001] ABRASION RESISTANCE IN WELL FLUID WETTED ASSEMBLIES**[002] BACKGROUND OF THE INVENTION****[003] 1. FIELD OF THE INVENTION**

[004] Embodiments of the invention described herein pertain to the field of well fluid wetted assemblies.

[005] More particularly, but not by way of limitation, one or more embodiments of the invention enable abrasion resistance in well fluid wetted assemblies.

[006] 2. DESCRIPTION OF THE RELATED ART

[007] Fluid containing hydrocarbons, such as oil and natural gas, are often located in underground formations. In such situations, the oil or gas must be pumped to the surface so that it can be collected, separated, refined and sold. Many of these underground formations also contain well born solids, such as consolidated and unconsolidated sand. The hydrocarbon laden fluid must pass through the sand on their way to the pump intake, and ultimately to the surface. When this occurs, the hydrocarbon fluid carries some of that sand through pump components. Such well-born solids may have severe abrasive effects on the submersible pump components and increase the heat generated during use, since abrasive wear to the pump causes inefficiency in its operation. As a result, careful attention to fluid and pressure management in submersible pump systems is needed in order to improve the production of hydrocarbon laden fluids from subsurface formations.

[008] Currently available submersible pump systems are not appropriate for some well applications, such as high sand or engineered sand environments. For example, pump components used in oil or gas applications should be exceptionally resistant to erosive wear. When a pump is used in an oil or gas well, equipment failure is especially costly as this can impede well production and replacing parts is undesirable since the equipment is deep in the ground. Care must be taken in cooling the pump equipment and avoiding the damage caused by abrasive materials in the produced well fluid.

[009] In the case of an electric submersible pump (ESP), a failure of the pump or any support components in the pump assembly can be catastrophic as it means a delay in well production and having to remove the pump from the well for repairs. Downhole applications in particular require that ESP pumps be able to survive constant exposure to abrasive materials in the well fluid in addition to the heat generated when the pump is in operation. A submersible pump system with improved thrust handling and radial support capabilities, such as an improved ability to withstand abrasion and heat, would be an advantage in all types of submersible and non-submersible assemblies.

[0010] Currently available pump assemblies sometimes contain bearing surfaces. Conventional

bearing surfaces include a conventional sleeve and a conventional bushing. The conventional sleeve is keyed to the shaft of a submersible pump and rotates with the shaft as fluid is pumped to the surface of a well. The conventional bushing is pressed into the wall of the diffuser of the submersible pump, surrounding the outer diameter of the conventional sleeve, and does not rotate. As the shaft rotates along with the conventional sleeve, a thin layer of fluid forms in between the rotating conventional sleeve and conventional non-rotating bushing, providing hydrodynamic lift. The hydrodynamic benefits of the bearing set depend upon a tight clearance between the conventional bushing and conventional sleeve. A problem that arises is that when the pump is in operation, abrasive material passes between the outer diameter of the conventional sleeve and the inner diameter of the conventional bushing. Abrasive wear may cause loss of material between the rotating surfaces, enlarging the clearance, which leads to low performance. Thus, these conventional designs are not well suited to withstand excessive abrasion in pumping systems or to keep the bearing surfaces cool. These shortcomings decrease the longevity of the pump components.

[0011] Currently, in order to address abrasion and heat, grooves are sometimes added to the bearing surfaces. The grooves assist the flow of both fluids and solids through well fluid wetted assemblies by creating channels in the radial or thrust support surfaces. However, as wells include increased concentrations of sand, such as in fracing applications that employ engineered sand or other high sand conditions, the conventional grooves may not adequately combat abrasion and heat, reducing the lifespan of the pump.

[0012] In addition, conventional sleeves and conventional bushings are typically made of tungsten carbide. FIG. 1A illustrates a conventional tungsten carbide sleeve of the prior art. FIG. 1B illustrates an enlargement of the surface of a conventional sleeve of the prior art at one-hundred times magnification. FIG. 2 illustrates a conventional bushing of the prior art, which also includes a surface similar to that shown in FIG. 1B. The surface of FIG. 1B demonstrates the roughness of conventional bearing surfaces. The surface roughness is attributable to microscopic peaks and valleys on the surface of the material that form as the parts are ground during fabrication. The rough surfaces increase friction and heat production as abrasive materials flow across the bearing surfaces. As heat accumulates during operation of the pump and temperatures rise, the material of the conventional sleeve and conventional bushing tends to bind or weld together. Abrasive wear may also be a precursor to this type of welding. This binding between the bearing material increases friction and causes the pump to seize. Separately, when producing fluid containing slugs or high amounts of gas, pump stages can run dry further elevating temperatures.

[0013] Although tungsten carbide is a hard material, it is very brittle and prone to breaking. Forming

the bearings from materials harder than tungsten carbide is not considered practical, since the brittleness would only increase and the bearings would break during usage under the force of the pump. [0014] Therefore, there is a need for better abrasion resistance in well fluid wetted assemblies to more readily withstand the effects of well-born solids, improve cooling characteristics, reduce friction and surface defects and combat welding (seizing), thereby improving the lifespan of the pump and pump components in submersible pump applications.

BRIEF SUMMARY

[0015] Abrasion resistance in well fluid wetted assemblies is described. An illustrative embodiment of a submersible pump bearing set includes a rotatable sleeve comprising a first polished running surface, a bushing surrounding the rotatable sleeve, the bushing secured to a diffuser wall and including a second polished running surface, wherein the second polished running surface of the bushing faces the first running surface of the rotatable sleeve. In some embodiments, the rotatable sleeve is a flanged sleeve including a tubular portion and a flange extending radially from the tubular portion, and the flange includes the first polished running surface. In certain embodiments, the first polished running surface and the second polished running surface are made of a cemented carbide composite selected from the group consisting of titanium carbide, tungsten carbide and tantalum carbide. In some embodiments, the first polished running surface and the second polished running surface include a coating of one of titanium nitride or titanium aluminum nitride over each of the polished running surfaces. In some embodiments, the first polished running surface and the second polished running surface include a layer of infused diamond-like carbon over each of the polished running surfaces. In certain embodiments, the first polished running surface and the second polished running surface include a layer of one of polycrystalline diamond (PCD), thermally stable PCD (TSP) or amorphous diamond over each of the polished running surfaces. In some embodiments, the first polished running surface and the second polished running surface have a roughness average of four micro-inches roughness average (Ra) or less. In some embodiments, the rotatable sleeve is keyed to an electric submersible pump (ESP) shaft. In certain embodiments, the diffuser is in a stage of one of an ESP pump, ESP charge pump or ESP gas separator.

[0016] An illustrative embodiment of a system for pumping a hydrocarbon from a downhole well includes a submersible pump that pumps a fluid hydrocarbon from a well, the submersible pump further including a bearing set comprising a bushing and a flanged sleeve, each of the bushing and the flanged sleeve comprising a polished running surface, and the polished running surface of each of the bushing and the flanged sleeve having a mirror finish. In some embodiments, an inner diameter of the

bushing includes the polished running surface of the bushing, and an outer diameter of the flanged sleeve includes the polished running surface of the flanged sleeve. In certain embodiments, a bottom of a flange of the flanged sleeve includes the polished running surface of the flanged sleeve, and a top of the bushing includes the polished running surface of the bushing. In some embodiments, the system includes a layer of diamond-like carbon on the polished running surface of each of the bushing and the flanged sleeve and the layer comprises a diamond-like carbon film. In certain embodiments the system further includes a coating of one of titanium nitride or titanium aluminum nitride over each of the polished running surfaces. In some embodiments, a load bearing surface of each of the polished running surfaces is at least 85% of a total surface area of each of the polished running surfaces. In certain embodiments, each of the polished running surfaces has a roughness average of four micro-inches roughness average (Ra) or less.

[0017] An illustrative embodiment of a method of enhancing an abrasion resistance of submersible assemblies includes polishing one of a first running surface of a sleeve, a second running surface of a bushing, or a combination thereof until the one of the first running surface, the second running surface or the combination thereof has a roughness average of four micro-inches roughness average (Ra) or less, coating the one of the first polished running surface, the second polished running surface or the combination thereof with one of titanium nitride or titanium aluminum nitride, placing the sleeve and the bushing in an electric submersible pump (ESP) assembly component such that the first running surface faces the second running surface and the first running surface rotates with respect to the second running surface, and pumping a fluid from an underground formation to a surface location using the ESP assembly. In some embodiments, the method further includes lapping the second running surface of the bushing and the second running surface is a top of the bushing. In some embodiments, the polishing includes wetting the one of the first running surface of the sleeve, the second running surface of the bushing or the combination thereof with a water slurry. In certain embodiments, the one of the first polished running surface, the second polished running surface or the combination thereof includes silicon carbide. In some embodiments, the one of the first polished running surface, the second polished running surface, or the combination thereof includes nickel-resist austenitic cast iron.

[0018] In further embodiments, features from specific embodiments may be combined with features from other embodiments. For example, features from one embodiment may be combined with features from any of the other embodiments. In further embodiments, additional features may be added to the specific embodiments described herein.

[0019] BRIEF DESCRIPTION OF THE DRAWINGS

[0020] Advantages of the present invention may become apparent to those skilled in the art with the benefit of the following detailed description and upon reference to the accompanying drawings in which:

[0021] FIG. 1A is a perspective view of a conventional sleeve of the prior art.

[0022] FIG. 1B is an enlarged view of the surface of the conventional sleeve of FIG. 1A of the prior art.

[0023] FIG. 2 is a perspective view of a conventional bushing of the prior art.

[0024] FIG. 3A is a perspective view of a downhole electric submersible pump (ESP) assembly of illustrative embodiments.

[0025] FIG. 3B is a perspective view of a downhole ESP assembly of illustrative embodiments.

[0026] FIG. 4 is a cross sectional view across line 4-4 of FIG. 3A of an electric submersible pump (ESP) of illustrative embodiments.

[0027] FIG. 5A is a perspective view of a polished sleeve of illustrative embodiments.

[0028] FIG. 5B is an enlarged view of a polished surface of the sleeve of FIG. 5A of illustrative embodiments.

[0029] FIG. 6 is a perspective view of a polished bushing of illustrative embodiments.

[0030] FIG. 7A is a perspective view of a polished and coated sleeve of illustrative embodiments.

[0031] FIG. 7B is an enlarged view of a surface of the polished and coated sleeve of FIG. 7A of illustrative embodiments.

[0032] FIG. 7C is a cross-sectional view across line 7C-7C of FIG. 7A of the polished and coated sleeve of illustrative embodiments.

[0033] FIG. 7D is an enlarged view of the polished and coated sleeve surface of FIG. 7C.

[0034] FIG. 8 is a perspective view of a polished and coated bushing of illustrating embodiments.

[0035] FIG 9. is a perspective view of a bearing set of an illustrative embodiment.

[0036] FIG. 10 is a perspective view of a bearing set of an illustrative embodiment.

[0037] While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings and may herein be described in detail. The drawings may not be to scale. It should be understood, however, that the embodiments described herein and shown in the drawings are not intended to limit the invention to the particular form disclosed, but on the contrary, the intention is to cover all modifications, equivalents and alternatives falling within the scope of the present invention as defined by the appended claims.

DETAILED DESCRIPTION

[0038] Abrasion resistance in well fluid wetted assemblies will now be described. In the following exemplary description, numerous specific details are set forth in order to provide a more thorough understanding of embodiments of the invention. It will be apparent, however, to an artisan of ordinary skill that the present invention may be practiced without incorporating all aspects of the specific details described herein. In other instances, specific features, quantities, or measurements well known to those of ordinary skill in the art have not been described in detail so as not to obscure the invention. Readers should note that although examples of the invention are set forth herein, the claims, and the full scope of any equivalents, are what define the metes and bounds of the invention.

[0039] As used in this specification and the appended claims, the singular forms “a”, “an” and “the” include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to a running surface includes one or more running surfaces.

[0040] “Coupled” refers to either a direct connection or an indirect connection (e.g., at least one intervening connection) between one or more objects or components. The phrase “directly attached” means a direct connection between objects or components.

[0041] “Downstream” refers to the direction substantially with the primary flow of pumped fluid when the centrifugal pump is in operation. Thus by way of example and without limitation, in a vertical downhole submersible pump assembly, the downstream direction may be towards the surface of the well.

[0042] “Upstream” refers to the direction substantially opposite the primary flow of pumped fluid when the centrifugal pump is in operation. Thus by way of example and without limitation, in a vertical downhole submersible pump assembly, the upstream direction may be towards the bottom of the assembly and/or deeper in the ground.

[0043] As used in this specification and the appended claims, the terms “inner” and “inwards” with respect to a bearing or other pump assembly component refer to the radial direction towards the center of the shaft of the pump assembly and/or the center of the aperture of the component through which the shaft would extend. In the art, “inner diameter” and “inner circumference” are sometimes used equivalently. As used herein, the inner diameter is used to describe what might otherwise be called the inner circumference of a pump assembly component, such as a bearing.

[0044] As used in this specification and the appended claims, the terms “outer” and “outwards” with respect to a bearing or other pump assembly component refer to the radial direction away from the center of the shaft of the pump assembly and/or the center of the aperture of the component through which the shaft would extend. In the art, “outer diameter” and “outer circumference” are sometimes

used equivalently. As used herein, the outer diameter is used to describe what might otherwise be called the outer circumference of a bearing.

[0045] As used in this specification and the appended claims, the term “axial” and “axially” refers to the longitudinal direction parallel to the length of the shaft of the pump.

[0046] Illustrative embodiments of the invention described herein provide abrasion resistance in well fluid wetted assemblies. A submersible pump of illustrative embodiments may include one or more thrust and/or radial support bearing sets. The bearing set of illustrative embodiments may include a polished surface, a thin coating (microns in thickness) of titanium nitride or titanium aluminum nitride, and/or a layer of diamond-like carbon. The polishing may provide one or more running surfaces of the bearings with a mirror finish. The coating or layer may be between one and five microns thick or may be thicker, depending on the type of layer employed. The polishing, coating and/or layer of illustrative embodiments may decrease friction between running surfaces and/or increase the surface hardness of the bearings, which may improve abrasion resistance, improve heat handling capabilities, reduce surface defects, improve lubrication and combat welding between the rotating member and the stationary member of the bearing set. One or more of these features may improve the lifespan of the pump. Although bearing sets in submersible pump applications are conventionally made of tungsten carbide, the polishing, diamond-like carbon layer and/or coating of illustrative embodiments may allow a softer, less expensive material such as steel, aluminum or plastic to be employed as a substrate for the coating while still maintaining or improving surface hardness, abrasion resistance and heat handling capabilities and reducing friction between the bearings. In addition, use of a softer substrate such as steel or aluminum may reduce the brittleness of the bearing as compared to bearings made of tungsten carbide or other materials of similar hardness. The polishing, coating and/or layering of illustrative embodiments, placed on the surface of a soft substrate, may increase the surface hardness of the bearing while avoiding the brittleness that may occur were the entire bearing made of a harder substance such as tungsten carbide.

[0047] While for illustration purposes, illustrative embodiments are described herein in terms of a thrust and/or radial support bearing set of a submersible pump, such as a mixed flow or radial flow centrifugal pump, nothing herein is intended to limit the invention to those embodiments. Other components of electric submersible pump (ESP) assemblies which may include stages and/or thrust bearings, such as a charge pump or gas separator may also make use of the improved bearing set of illustrative embodiments. In addition, any centrifugal pump encountering abrasive materials, such as horizontal surface pumps, may also make use of the improved bearing set of illustrative embodiments.

[0048] FIGs. 3A and 3B depict an exemplary ESP system arranged to pump natural gas and/or oil

from underground formation 420 and making use of the enhanced abrasion resistance of illustrative embodiments. As illustrated, the system of ESP assembly 400 may include well bore casing 445 with casing perforations 450 that allows well fluid to enter casing 445. ESP motor 440 may be a two pole, three phase squirrel cage induction motor that operates to turn ESP pump 410. Motor lead extension 435 and the electrical cable above it (not shown) may connect to a power source at the surface of the well and provide power to ESP motor 440. ESP seal 430 may supply oil to the motor and provide pressure equalization to allow for expansion of motor oil in the well bore. As shown in FIG. 3A, in some embodiments ESP intake 425 may serve as the intake for fluid into ESP pump 410. As shown in FIG. 3B, in certain embodiments gas separator 455 may serve as the intake in gassy wells. ESP charge pump 415, which maybe a lower tandem pump, may be employed in gassy wells. ESP pump 410 may be a multistage centrifugal pump including impeller and diffuser stages stacked around a shaft to lift fluid to the surface of the well. Production tubing 405 may carry pumped fluid to piping and/or storage tanks on the surface, for example. One or more of these system components may make use of the enhanced abrasion resistance of the invention. In some embodiments, the bearings of illustrative embodiments may be employed in ESP pump 410, ESP charge pump 415, gas separator 455 and/or ESP intake 425. For example, gas separator 455 may include impeller and diffuser stages to increase the pressure of the fluid during compression and separation of gases. Similarly, in gassy wells charge pump 415 may be used in tandem with a primary centrifugal pump, such as ESP pump 410, and may also employ stages.

[0049] FIG. 4 illustrates a cross section of one embodiment of a pump stage of ESP pump 410 of illustrative embodiments. The pump stage of FIG. 4 may also be a stage of ESP charge pump 415 or ESP gas separator 455. Diffuser 500 may be paired with impeller 505 and remain stationary while impeller 505 rotates with shaft 510. Bushing 200 may be pressed into and/or attached to the wall of diffuser 500 and may remain stationary during operation of ESP pump 410, for example by interference fit. Sleeve 300 may be keyed to shaft 510 and may rotate with shaft 510 when ESP pump 410 is in operation. When ESP pump 410 is in operation and shaft 510 rotates in a clockwise direction, pumped fluid and abrasive solids carried therein may be guided between the outer diameter of sleeve 300 and the inner diameter of bushing 200, as illustrated by axial arrow 530 and radial arrow 540. In grooved embodiments, axial groove (not shown) and radial groove 230 may assist in guiding pumped fluid between running surfaces 700 (shown in FIG. 9) of the bearings. As illustrated in FIG. 4, pumped fluid is moving upward to a successive stage of ESP pump 410 and/or production tubing 405. Abrasives may be carried along with the flow of well fluid as shown in FIG. 4 and/or may fall back to a previous stage in a direction opposite arrows 530 and 540.

[0050] The surfaces of sleeve 300 and/or bushing 200 of illustrative embodiments may be polished, infused with a layer of diamond-like carbon and/or coated with titanium nitride or titanium aluminum nitride, for example as illustrated by layer 100 shown in FIG. 7B and/or polished surface 600 as shown in FIG. 5B. The coating or layer of illustrative embodiments may permit softer, less expensive materials (as compared to tungsten carbide) to be used as the substrate material of the bearings of illustrative embodiments. For example, steel, aluminum, plastic such as nylon or polycarbonate, composites such as zirconia or Alumina, or nickel-resist (Ni-resist) austenitic cast iron may be used as the substrate underneath layer 100 of illustrative embodiments.

[0051] Running surfaces 700 may be sliding surfaces of bushing 200 and sleeve 300 that face each other and have different velocities relative to one another. As shown in FIG. 9 and FIG. 10, running surfaces 700 may include the inner diameter 910 of bushing 200, the top 915 of bushing 200, the outer diameter 905 of sleeve 300 and/or the bottom 900 of flange 105 of sleeve 300. In some embodiments, bearing surfaces that are not running surfaces, such as the inner diameter of sleeve 300 facing shaft 510 as well as the outer diameter of bushing 200 pressed into diffuser 500, need not be polished and/or need not include layer 100. However, in illustrative embodiments it may be less labor intensive and therefore more time and cost effective to polish, coat and/or infuse all surfaces of the bearings. In some embodiments, it may reduce fit-up issues to leave keyway 110 or inside diameter of sleeve 300 facing shaft 510 (shown in FIG. 4) uncoated and/or reserve coating or layering for running surfaces 700. FIGs. 9 and 10 illustrate running surfaces 700 of bushing 200 and sleeve 300 forming a bearing set and including layer 100 of illustrative embodiments only on running surfaces 700. In FIGs. 9 and 10, surfaces that are not running surfaces 700 do not include layer 100.

[0052] FIGs. 5A and 7A illustrate an exemplary sleeve 300 of illustrative embodiments. FIGs. 6 and 8 illustrate an exemplary bushing 200 of illustrative embodiments. Sleeve 300 may be tubular in shape and may include flange 105, for example for thrust support. The outer diameter 905 of sleeve 300 facing bushing 200 and/or the inner diameter 910 of bushing 200 facing sleeve 300, may include intersecting grooves that may assist and/or guide the flow of working fluid, and abrasive solids that may be contained therein, across the surfaces of the bearings, for example as described in U.S. Patent No. 8,684,679 that is assigned to the assignee of the present application, and/or as illustrated by radial groove 230 (shown in FIG. 6). In grooved embodiments, axial, radial and/or sector grooves may be applied to the running surfaces 700 of the bearings during the casting process and/or ground in place prior to polishing and prior to the application of layer 100.

[0053] The surface and/or running surfaces 700 of bushing 200 and/or sleeve 300 may be polished, as illustrated in FIGs. 5A-6. Bushing 200 may be annular and/or cylindrical in shape. Similarly, sleeve 300 may include a tubular portion and/or have a hollowed cylindrical shape. The inventors have determined that the cylindrical surfaces of bushing 200 and/or sleeve 300, including inner diameters, may be polished using the methods of illustrative embodiments described herein. The surface of bushing 200 and/or sleeve 300 may be first polished and then coated or layered, may be first coated or layered and then polished, may be polished without the need for any coating or layer, or may be coated or layered without the need for polishing. Polishing bearing surfaces may improve surface finish, remove surface defects, increase lubrication and/or provide a lower friction coefficient between the bearings. FIG. 5B illustrates a polished surface of illustrative embodiments at one-hundred times magnification. As shown in FIG. 5B, polished surface 600 may have peaks removed on the ground surface to produce plateaus that increase the bearing surface area that is load bearing. In one example, the load bearing surface area of running surfaces 700 may be increased to 85%, 92% or 95%, as compared to 50% or less in conventional bearings that are not polished, since polishing may reduce the valley area on the surface of the bearing. Although surface 600 of sleeve 300 is shown in FIG. 5B, the surface and/or running surfaces 700 of bushing 200 may be similarly polished and appear similarly to the surface shown in FIG. 5B.

[0054] In contrast to grinding, which produces a crude surface of about 32 micro-inches roughness average (Ra) on a tungsten carbide bearing, polishing may produce a much finer, smoother surface and/or mirror finish. For example, polished surface 600 of illustrative embodiments may have a roughness average of about 4.0 micro-inches Ra. In some embodiments, layer 100 applied to polished surfaces 600 may further reduce the roughness average to about 3.0 micro-inches Ra. Polished surface(s) 600 may lower the coefficient of friction between bushing 200 and sleeve 300, reducing the horsepower (hp) needed to operate ESP pump 410. In one example, a floater style pump may require 10 hp if no abrasion resistant (AR) trim is present in the pump. Adding conventional AR components, such as a conventional bushing and conventional sleeve, may increase the necessary horsepower to 12 hp as a result of friction between the convention bushing and conventional sleeve. Using the polishing and/or coating of illustrative embodiments, the floater style pump of this example may only require 10.5 hp making use of polished and/or coated sleeve 300 and/or bushing 200 of illustrative embodiments. Thus, polished surface 600 and/or layer 100 of illustrative embodiments may reduce the horsepower needed to operate a pump employing AR trim.

[0055] Polishing may be accomplished by chemical, mechanical, chemical-mechanical polishing or another polishing method known to those of skill in the art. In some embodiments, surfaces may be

polished to a mirror finish. In one example, the bearing surfaces may be wetted with a water slurry containing an abrasive material, such as a colloidal silicon dioxide dispersed in water, aluminum oxide and silicon carbide in an aqueous slurry, and/or pressure against a firm surface. In some embodiments, diamond polishing pads, a suspension of diamond paste and/or a spinning wheel may be used to polish bearing surfaces. In another example, fluid-pressure regulated wafer polishing may be employed. Lapping may be employed in addition to polishing on bearing surfaces. For example, the top of bushing 200 and/or bottom of sleeve 300 may be lapped to further improve surface finish. Lapping of the bearing surfaces may use progressively smaller diamond grit suspended in a glycol, glycerine or other suitable carrier liquid. Polishing the bearings may remove surface defects, improve surface finish and provide a lower friction coefficient for the bearing. Polishing, lapping, layering and/or coating the bearings may reduce the sliding coefficient of friction between the bearings.

[0056] Illustrative embodiments may provide for a titanium nitride coating, aluminum titanium nitride coating or infused diamond-like carbon (DLC) layer on the surface of bushing 200 and/or sleeve 300. Layer 100 may be applied to polished surfaces 600, unpolished surfaces and/or surfaces may be polished after layer 100 has been applied. In some embodiments, one of polishing or coating may not be necessary. The layer or coating of illustrative embodiments may increase the surface hardness of the bearings and/or allow the bearing substrate to be of a softer, less expensive and/or more ductile material as compared to tungsten carbide— without sacrificing surface hardness, and in some embodiments, increasing surface hardness. The hard layer or coating of illustrative embodiments may assist in reducing surface defects increasing lubrication and reducing welding between sleeve 300 and bushing 200. In diamond-like carbon film or infusion embodiments, the diamond-like coating may expand with the substrate material during temperature changes, thereby further increasing options for substrate materials. Although polishing may be conducted after layer 100 has been applied, the inventors currently prefer polishing without the need for layer 100, or alternatively polishing prior to application of layer 100 in order to obtain polished surface 600 without losing a portion of layer 100 in the polishing process.

[0057] Bushing 200 and/or sleeve 300 may be made of a cemented carbide composite, such as titanium carbide, tungsten carbide or tantalum carbide, another carbide such as silicon carbide, or another material having similar hardness and abrasion resistant properties. In some embodiments, bushing 200 and/or sleeve 300 may include layer 100 of illustrative embodiments and be made of a softer substrate 705 material such as plastic, steel, aluminum or Ni-resist austenitic cast iron that would otherwise be too soft to function as abrasion resistant trim in ESP applications.

[0058] FIGs. 7A-8 illustrate an exemplary coating or layer of illustrative embodiments. Layer 100 may be a thin infusion, coating and/or film of titanium nitride (TiN), aluminum titanium nitride (AlTiN) or diamond-like carbon (DLC) between about one and five microns in thickness. FIG. 7C and 7D illustrate a cross section view of an illustrative embodiment of layer 100. In FIG. 7D, layer 100 is shown on polished surface 600 of substrate 705. Layer 100 may provide a separation in surface hardness which may reduce binding between sleeve 300 and bushing 200. DLC coating may be a carbon compound having a combination of SP^2 (graphite) and SP^3 (diamond) carbon bonding and varying hydrogen content. Films with a higher SP^3 bonding content may be harder with a high level of abrasion resistance, but may be less ductile than films with higher SP^2 bonding content. DLC coating of illustrative embodiments should have similar or slightly higher hardness to titanium nitride at about 2500 on the Vickers scale, and a friction coefficient of DLC against DLC of about 0.15. Titanium nitride (TiN), on the other hand, may have a TiN on TiN friction coefficient of about 0.4-0.9. In some embodiments, DLC may be employed as layer 100 without modification to sleeve 300 and bushing 200, due to the thinness of a DLC layer.

[0059] In certain embodiments, poly crystalline diamond (PCD), thermally stable PCD (TSP) or amorphous diamond may be employed as layer 100. PCD, TSP or amorphous diamond may be a coating of between about 0.06 inches and 0.09 inches in thickness, and may be brazed to keep layer 100 in place. Due to the thickness of PCD, TSP and/or amorphous diamond coatings, sleeve 300 and bushing 200 may need to be modified such as by removing material, to accommodate the extra thickness added by layer 100.

[0060] Layer 100 may be applied using physical vapor deposition, plasma-assisted chemical vapor deposition, or a similar process. In one example, layer 100, whether DLC, AlTiN or TiN, may be applied to substrate 705 using physical vapor deposition in a vacuum at 350 °C. In another example, layer 100 may be applied to substrate 705 using plasma-assisted chemical vapor deposition at 180 °C with a plasma nitride surface layer that is then overlaid with physical vapor deposition of DLC.

[0061] In some embodiments layer 100 may be a PCD layer deposited onto substrate 705 with the use of binder-catalyzing materials, for example cobalt, nickel or iron. The catalyzing material may assist in the formation of carbon-carbon bonds within layer 100 and improve adherence of layer 100 to substrate 705. After deposition, residual particles of binder-catalyzing materials may remain in interstices and/or interstitial matrices interposed between PCD particles. Above temperatures of about 750°C, such as may occur if the ESP assembly runs dry, layer 100 that includes a PCD layer may suffer from differential thermal expansion between catalyst and diamond particles in layer 100. In such instances and/or in instances where the presence of binder-catalyzing materials is undesirable,

TSP may be utilized for layer 100. In layer 100 including TSP, the binder-catalyzing material may be removed from layer 100 by leaching.

[0062] PCD layer 100 having residual binder-catalyzing material contained in the diamond structure's interstitial spaces may undergo leaching to remove some, all, or about all, catalyst impurities. A strong acid (like hydrofluoric acid or nitric acid) or a combination of strong acids may be used as a leaching agent that may remove binder-catalyzing material from PCD layer 100. Once substantially free of such catalyst particles, layer 100 including PCD becomes instead TSP. Layer 100 including TSP may withstand operating temperatures of up to 1200°C. In other illustrative embodiments, the catalyst leaching process may be performed with varying temperature and pressure conditions to control the extent of catalyst removal and eventual physical properties of the layer. In some illustrative embodiments, catalyst particles may be leached from interstitial spaces and then replaced with a similar, diamond-like material. In other illustrative embodiments, the binder-catalyst may be removed by evaporation, or galvanic means instead of acid etch leaching, as described herein.

[0063] Leaching may also be applied to layer 100 including various nitrides in order to remove other impurities that may have accumulated during the deposition process. Removal of such impurities may improve the homogeneity of layer 100, which may prevent differential thermal expansion between different materials contained in the layer.

[0064] FIG. 7B illustrates an enlarged view of layer 100 of illustrative embodiments. In FIG. 7B, the enlarged surface of sleeve 300 is shown, but the surface of bushing 200 may appear similarly. Layer 100 of illustrative embodiments adhered to substrate 705 may increase the operating life of the bearings in a submersible pump in both benign and abrasive heavy environments. The increased hardness that may be afforded by layer 100 may lower the cost of the bearings since softer, cheaper materials such as aluminum or steel may then be used as the base material for the bearing, and then coated to increase surface hardness. The substrate material may then be less fragile than conventional bearing materials such as tungsten carbide, and as a result of the coating of illustrative embodiments, still achieve surface hardness to combat abrasion and increase the life of the pump.

[0065] The coating and/or polishing of illustrative embodiments may reduce friction between the bearings, provide a lubrication barrier that may prevent reduce friction and necessary horsepower, reduce binding/welding, reduce surface defects and improve lubrication and resistance to solids. The bonding shear strength of layer 100 may be high and thus may not rub off during operation. The improved features of illustrative embodiments may improve the lifespan of an ESP pump making use of the bearings of illustrative embodiments.

[0066] Thus, the invention described herein provides one or more embodiments of abrasion resistance in well fluid wetted assemblies. Further modifications and alternative embodiments of various aspects of the invention may be apparent to those skilled in the art in view of this description. Accordingly, this description is to be construed as illustrative only and is for the purpose of teaching those skilled in the art the general manner of carrying out the invention. It is to be understood that the forms of the invention shown and described herein are to be taken as the presently preferred embodiments. Elements and materials may be substituted for those illustrated and described herein, parts and processes may be reversed, and certain features of the invention may be utilized independently, all as would be apparent to one skilled in the art after having the benefit of this description of the invention. Changes may be made in the elements described herein without departing from the scope of the following claims. In addition, it is to be understood that features described herein independently may, in certain embodiments, be combined.

**THE SUBJECT-MATTER OF THE INVENTION FOR WHICH AN EXCLUSIVE
PROPERTY OR PRIVILEGE IS CLAIMED IS DEFINED AS FOLLOWS:**

1. A submersible pump bearing set comprising:
 - a rotatable sleeve comprising a first polished running surface consisting of an uncoated and unlayered carbide selected from the group consisting of titanium carbide, tungsten carbide, tantalum carbide, and silicon carbide, wherein the first polished running surface has a roughness average of four micro-inches roughness average (Ra) or less;
 - a bushing surrounding the rotatable sleeve, the bushing secured to a diffuser wall and comprising a second polished running surface consisting of an uncoated and unlayered carbide selected from the group consisting of titanium carbide, tungsten carbide, tantalum carbide, and silicon carbide, wherein the second polished running surface has a roughness average of four micro-inches roughness average (Ra) or less;wherein the second polished running surface of the bushing faces the first running surface of the rotatable sleeve.
2. The submersible pump bearing set of claim 1, wherein the rotatable sleeve is a flanged sleeve comprising a tubular portion and a flange extending radially from the tubular portion, and wherein the flange comprises the first polished running surface.
3. The submersible pump bearing set of claim 1 or 2, wherein the rotatable sleeve is keyed to an electric submersible pump (ESP) shaft.
4. The submersible pump bearing set of claim 1 or 2, wherein the diffuser is in a stage of one of an ESP pump, ESP charge pump or ESP gas separator.
5. A system for pumping a hydrocarbon from a downhole well, the system comprising:
 - a submersible pump that pumps a fluid hydrocarbon from a well, the submersible pump further comprising:
 - a bearing set comprising a bushing and a flanged sleeve;

each of the bushing and the flanged sleeve comprising a polished running surface consisting of an uncoated and unlayered carbide selected from the group consisting of titanium carbide, tungsten carbide, tantalum carbide, and silicon carbide, wherein each of the polished running surfaces has a roughness average of four micro-inches roughness average (Ra) or less.

6. The system of claim 5, wherein an inner diameter of the bushing comprises the polished running surface of the bushing, and an outer diameter of the flanged sleeve comprises the polished running surface of the flanged sleeve.
7. The system of claim 5, wherein a bottom of a flange of the flanged sleeve comprises the polished running surface of the flanged sleeve, and a top of the bushing comprises the polished running surface of the bushing.
8. The system of any one of claims 5 to 7, wherein a load bearing surface of each of the polished running surfaces is at least 85% of a total surface area of each of the polished running surfaces.
9. A method of enhancing an abrasion resistance of submersible assemblies, the method comprising:
 - providing a sleeve comprising a first running surface consisting of an uncoated and unlayered carbide selected from the group consisting of titanium carbide, tungsten carbide, tantalum carbide, and silicon carbide;
 - polishing the first running surface so that the first running surface has a roughness average of four micro-inches roughness average (Ra) or less;
 - providing a bushing comprising a second running surface consisting of an uncoated and unlayered carbide selected from the group consisting of titanium carbide, tungsten carbide, tantalum carbide, and silicon carbide;
 - polishing the second running surface so that the second running surface has a roughness average of four micro-inches roughness average (Ra) or less;
 - placing the sleeve and the bushing in an electric submersible pump (ESP) assembly component such that the first running surface faces the second running surface

and the first running surface rotates with respect to the second running surface;
and
pumping a fluid from an underground formation to a surface location using the ESP
assembly.

10. The method of claim 9, further comprising lapping the second running surface of the bushing.
11. The method of claim 10, wherein the second running surface is a top of the bushing.
12. The method of claim 9, wherein the polishing comprises wetting the first running surface of the sleeve and the second running surface of the bushing with a water slurry.
13. The method of any one of claims 9 to 12, wherein at least one of the sleeve and the bushing further comprises Ni-resist austenitic cast iron.

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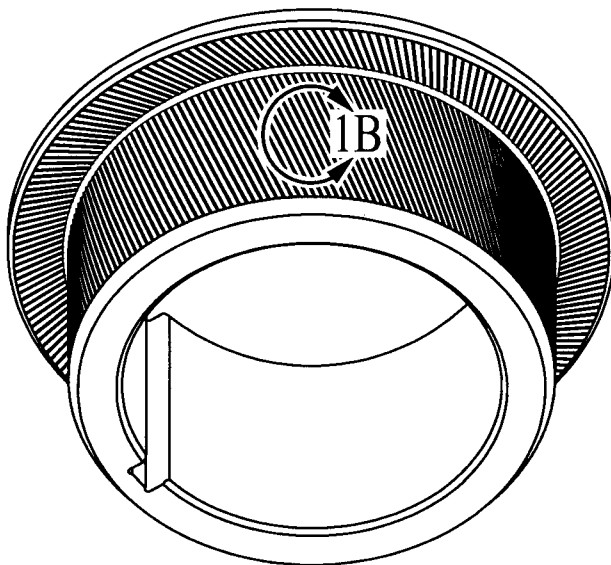


Fig. 1A
PRIOR ART

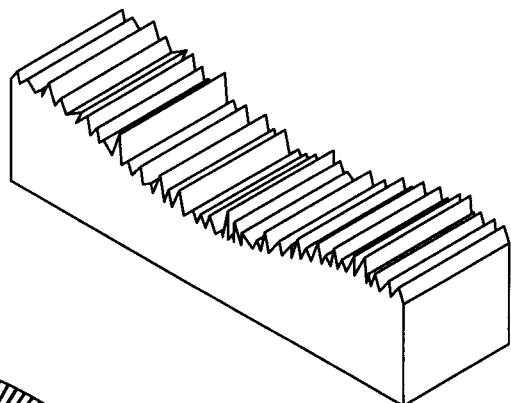


Fig. 1B
PRIOR ART

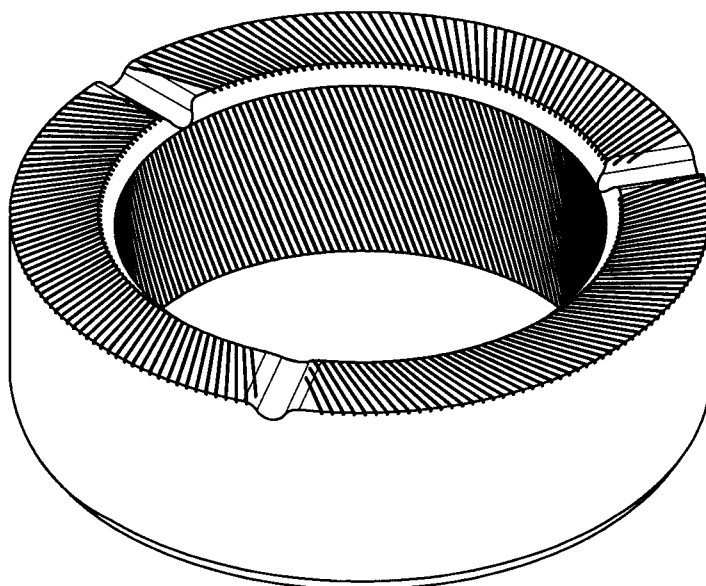
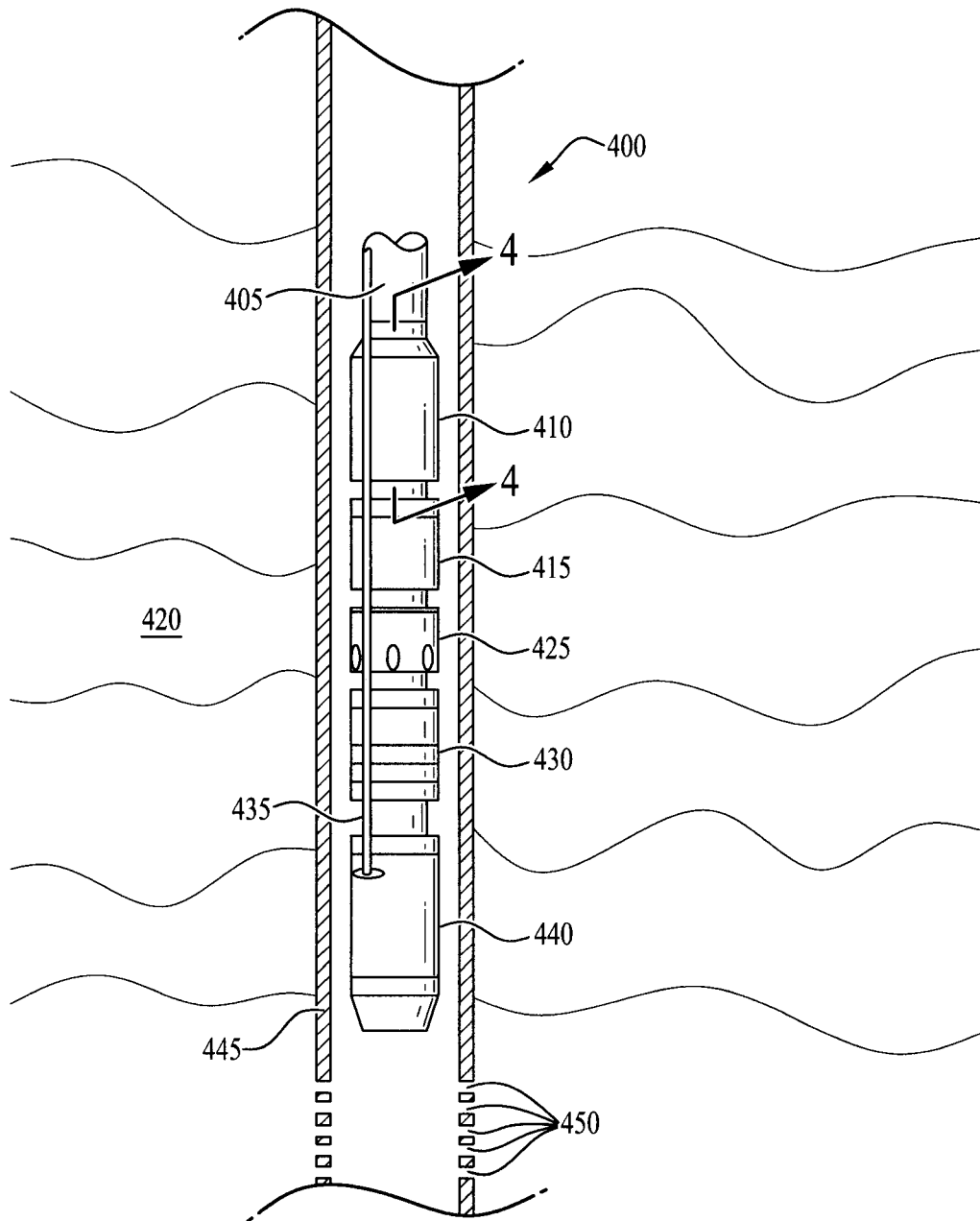
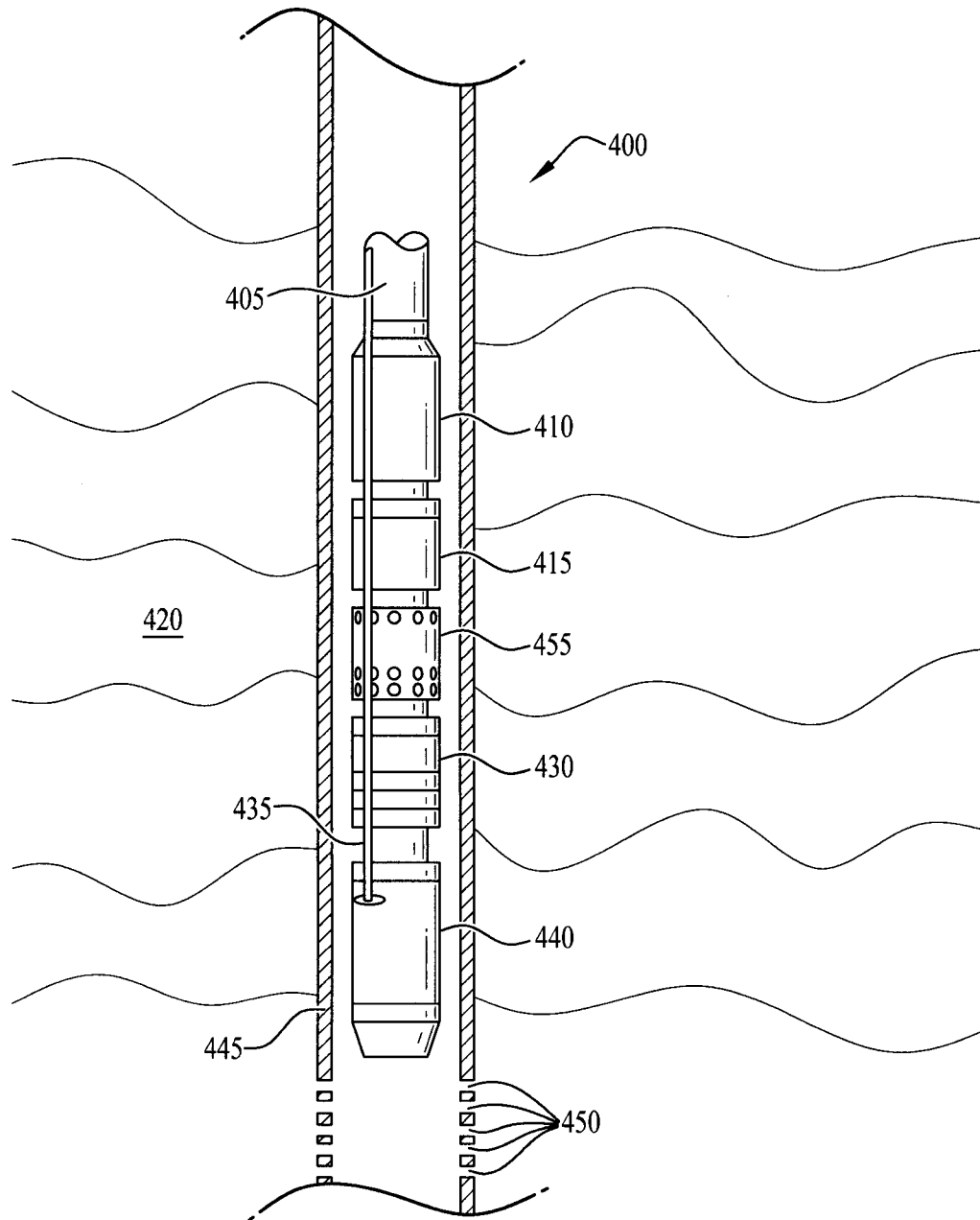


Fig. 2
PRIOR ART

*FIG. 3A*

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*FIG. 3B*

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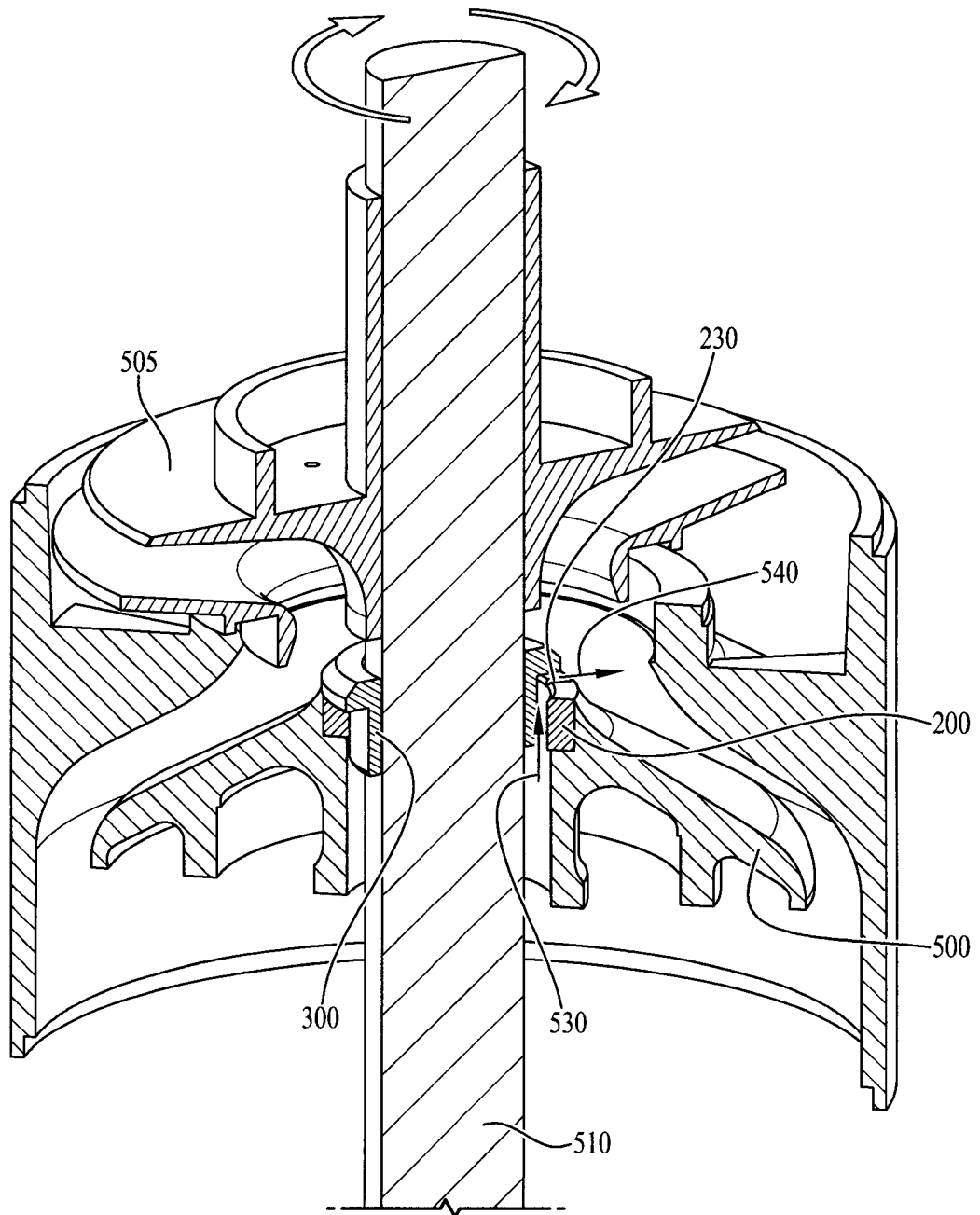


FIG. 4

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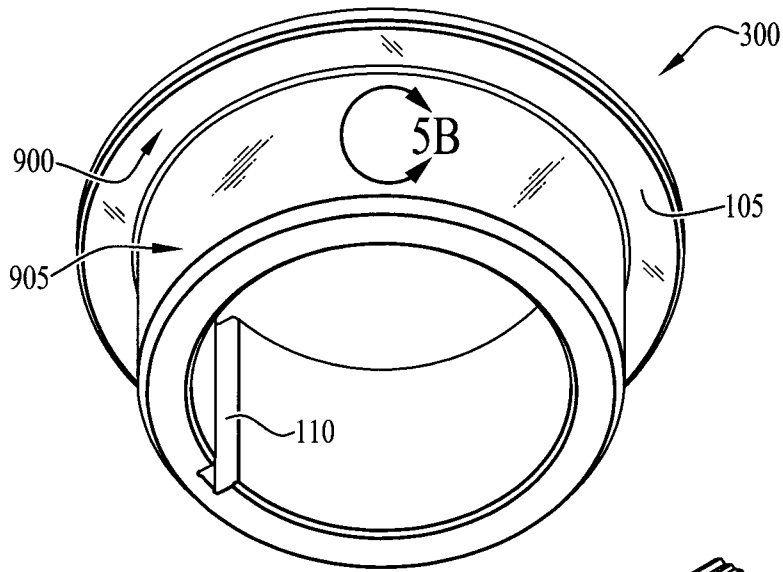


FIG. 5A

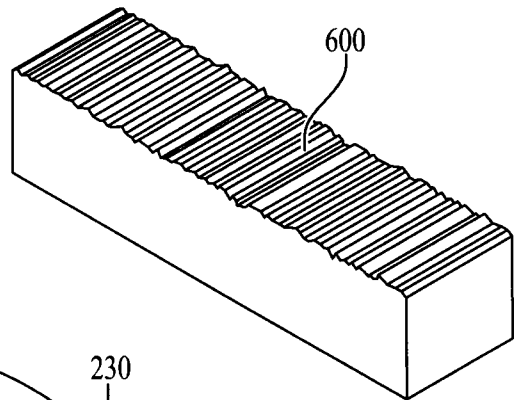


FIG. 5B

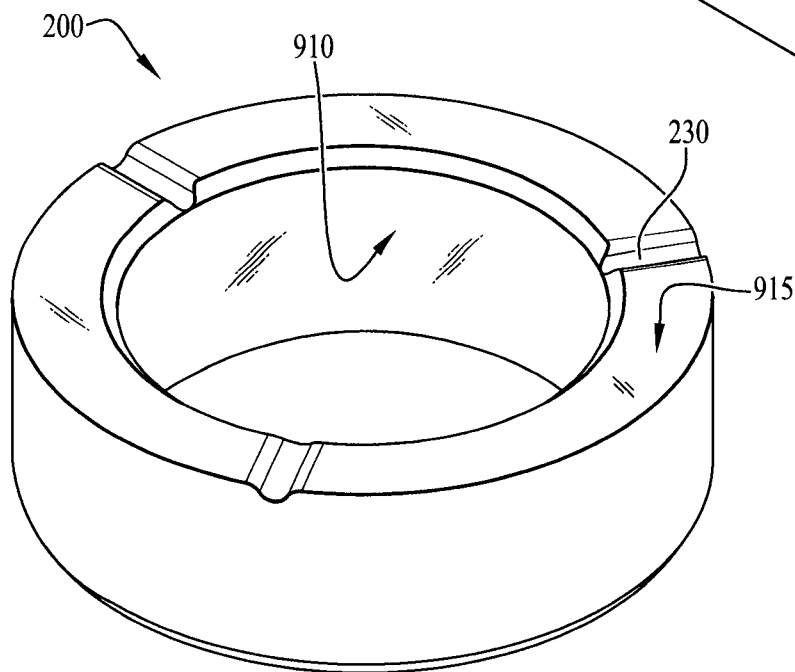


FIG. 6

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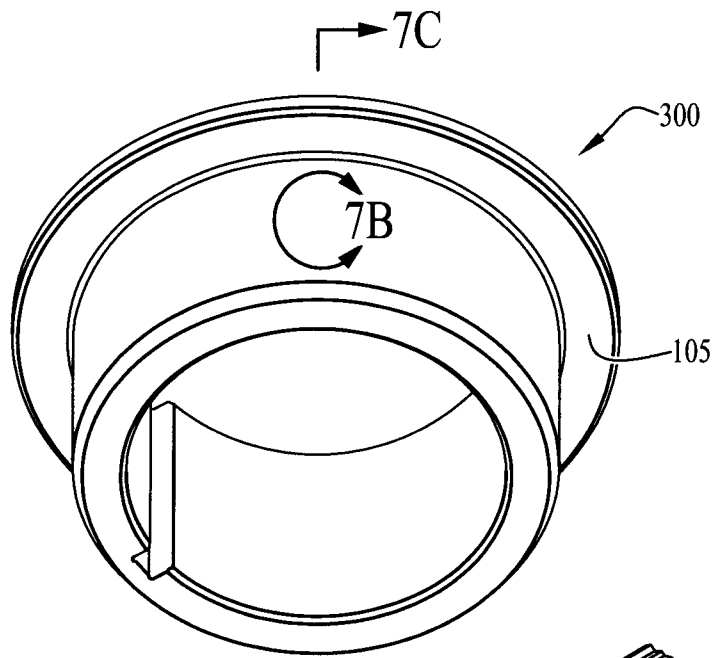


Fig. 7A

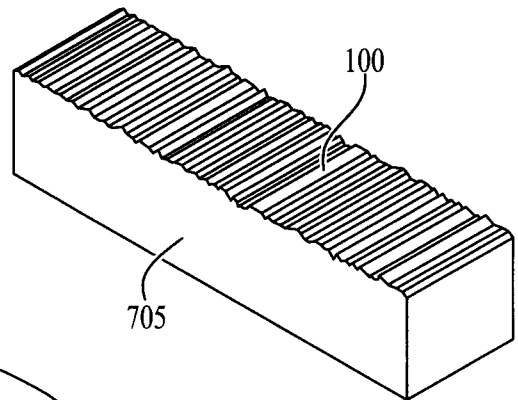


Fig. 7B

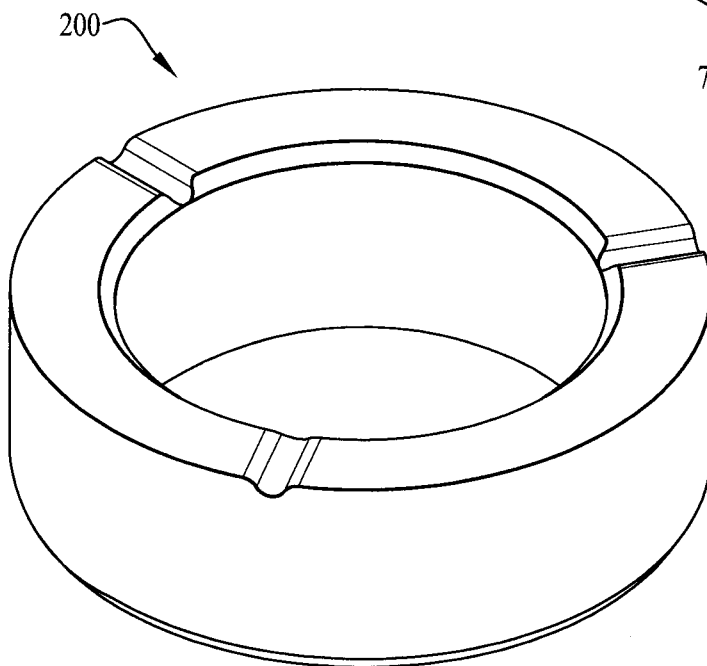


Fig. 8

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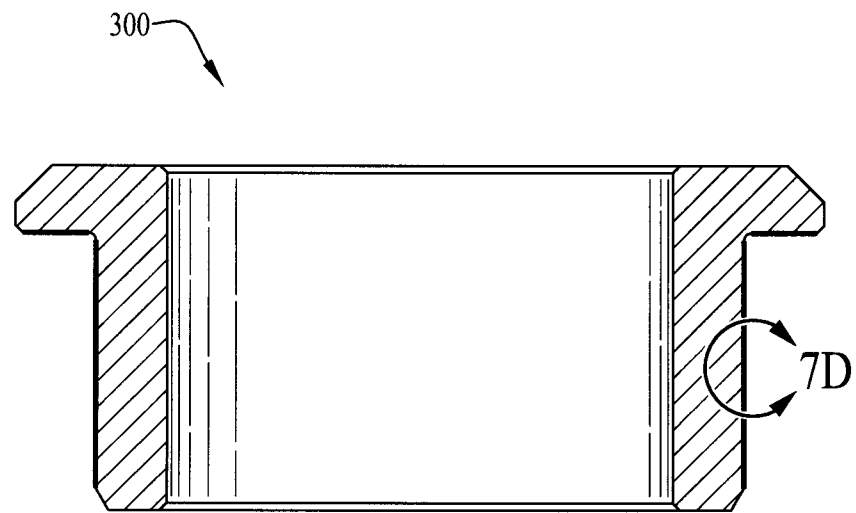


FIG. 7C

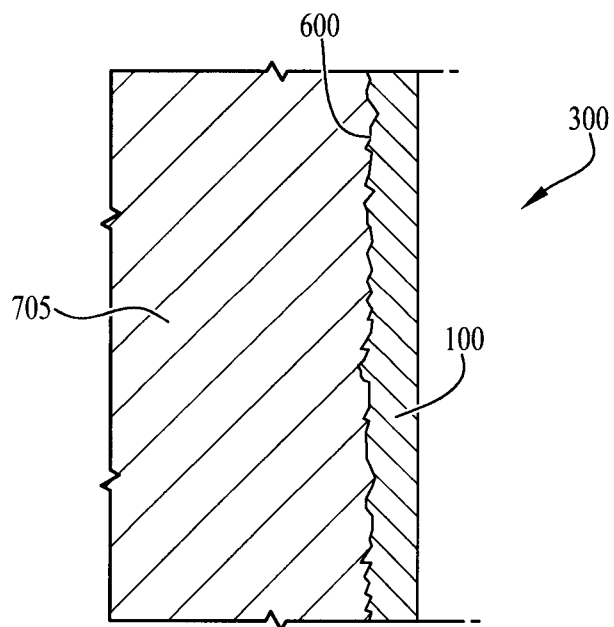
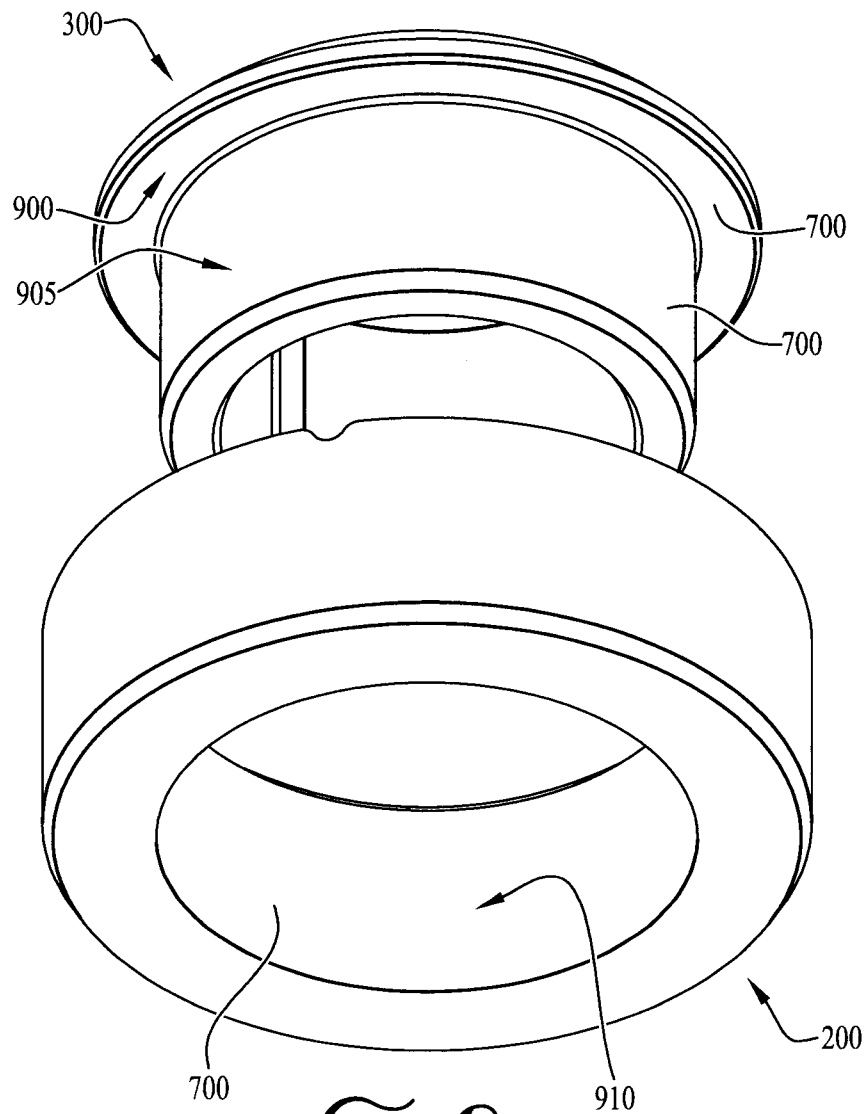


FIG. 7D

*FIG. 9*

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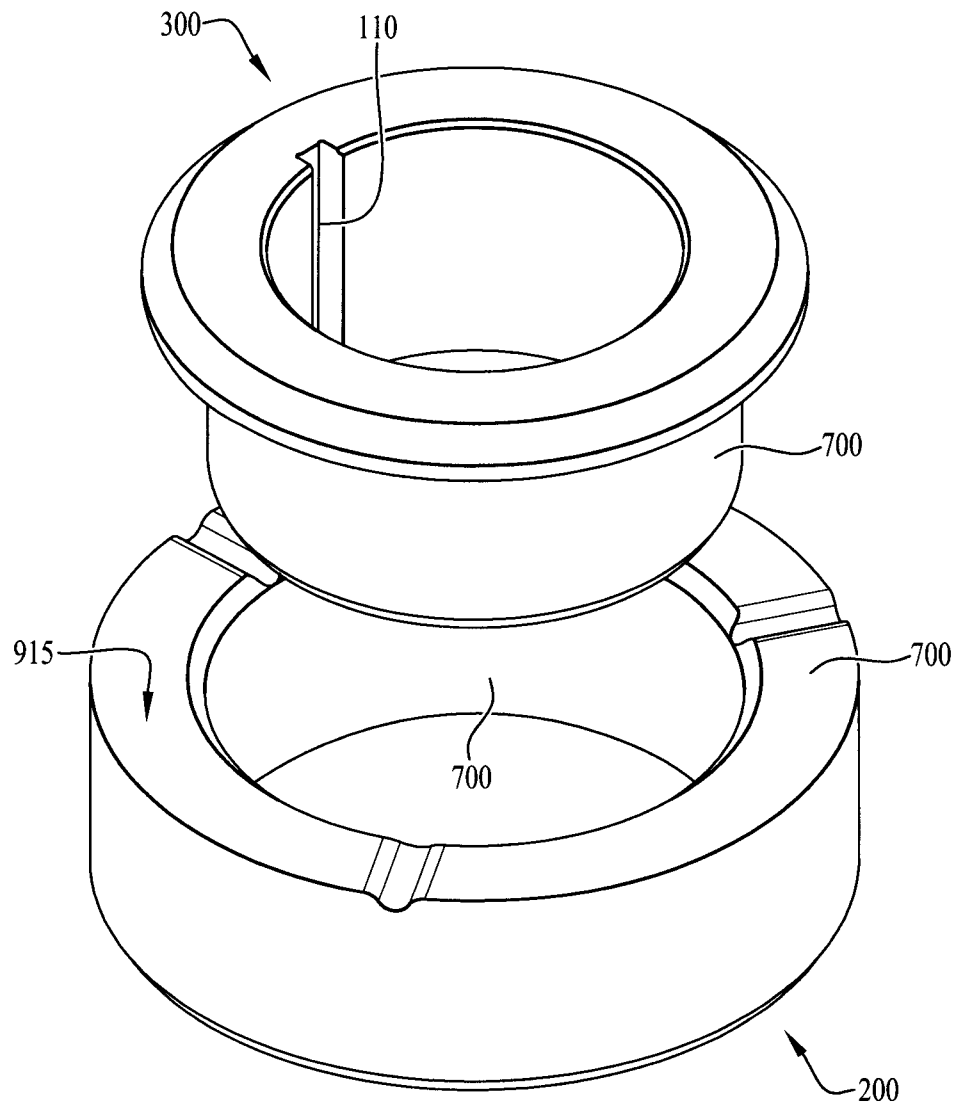


FIG. 10

