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(54) **BORON ALUMINUM MAGNESIUM COATING FOR EARTH-BORING BIT**

Publication Classification

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(57) **ABSTRACT**

(21) Appl. No.: **12/986,656**

(22) Filed: **Jan. 7, 2011**

A rotatable cone earth boring bit has a bearing system with at least on the surfaces being AlMgB14 alloy material. The alloy material also contains an alloying agent, which may be titanium boride (TiB2); titanium carbide (TiC) plus iron, nickel and carbon; silicon nitride (Si3N4) powder; whiskered silicon nitride (Si3N4); boron carbide (B4C); titanium boride (TiB2); or tungsten boride (W2B4). The surface containing the AlMgB14 alloy material may be a journal surface or thrust face on the bearing pin. The surface containing the AlMgB14 alloy material may also be a seal surface, either on a metal face seal or a gland on the bearing pin engaged by an elastomeric ring. The AlMgB14 alloy material may a coating or it may be a free-standing structural member within the bearing system.

Related U.S. Application Data

(60) Provisional application No. 61/294,675, filed on Jan. 13, 2010.

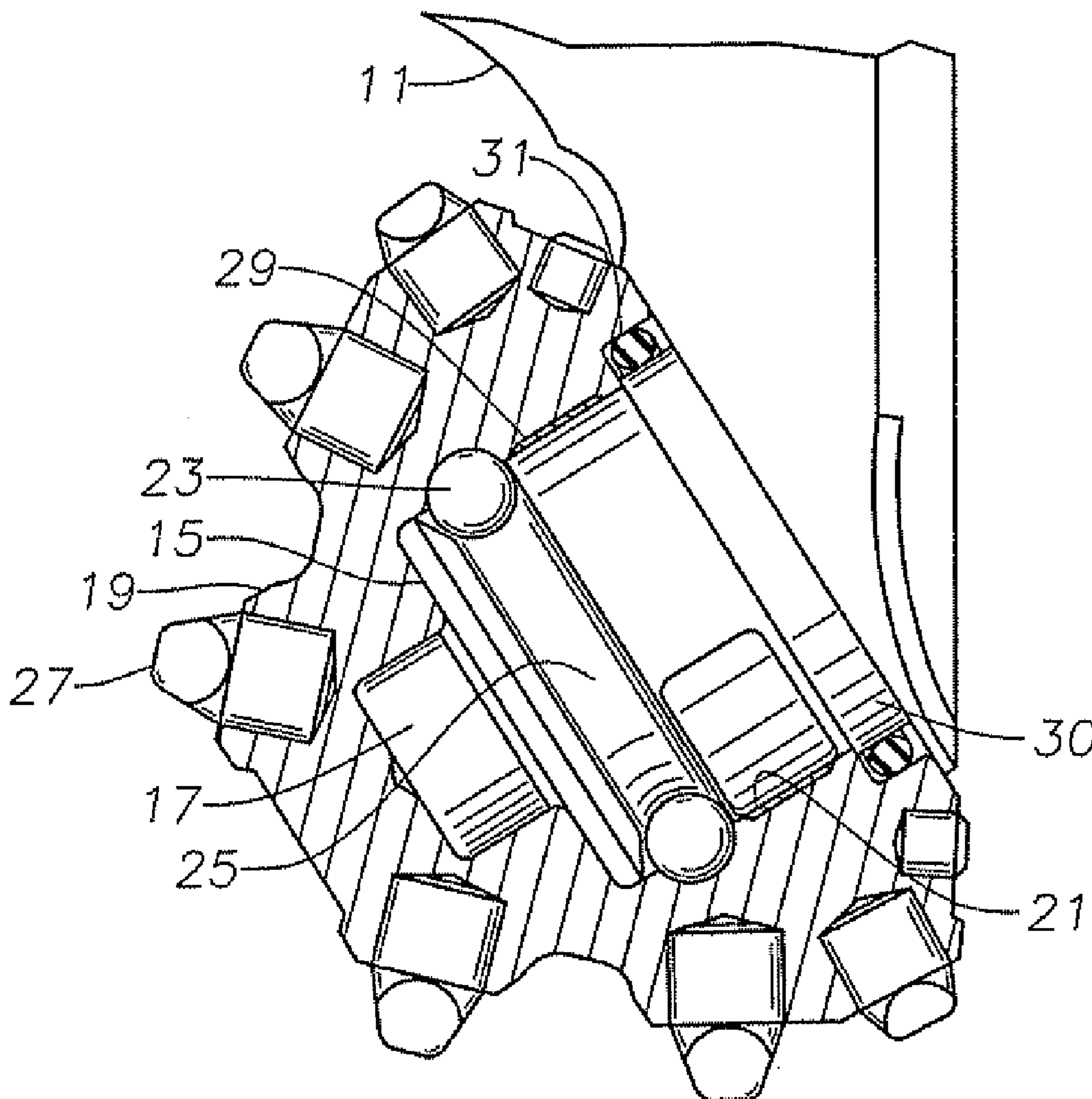


Fig. 1

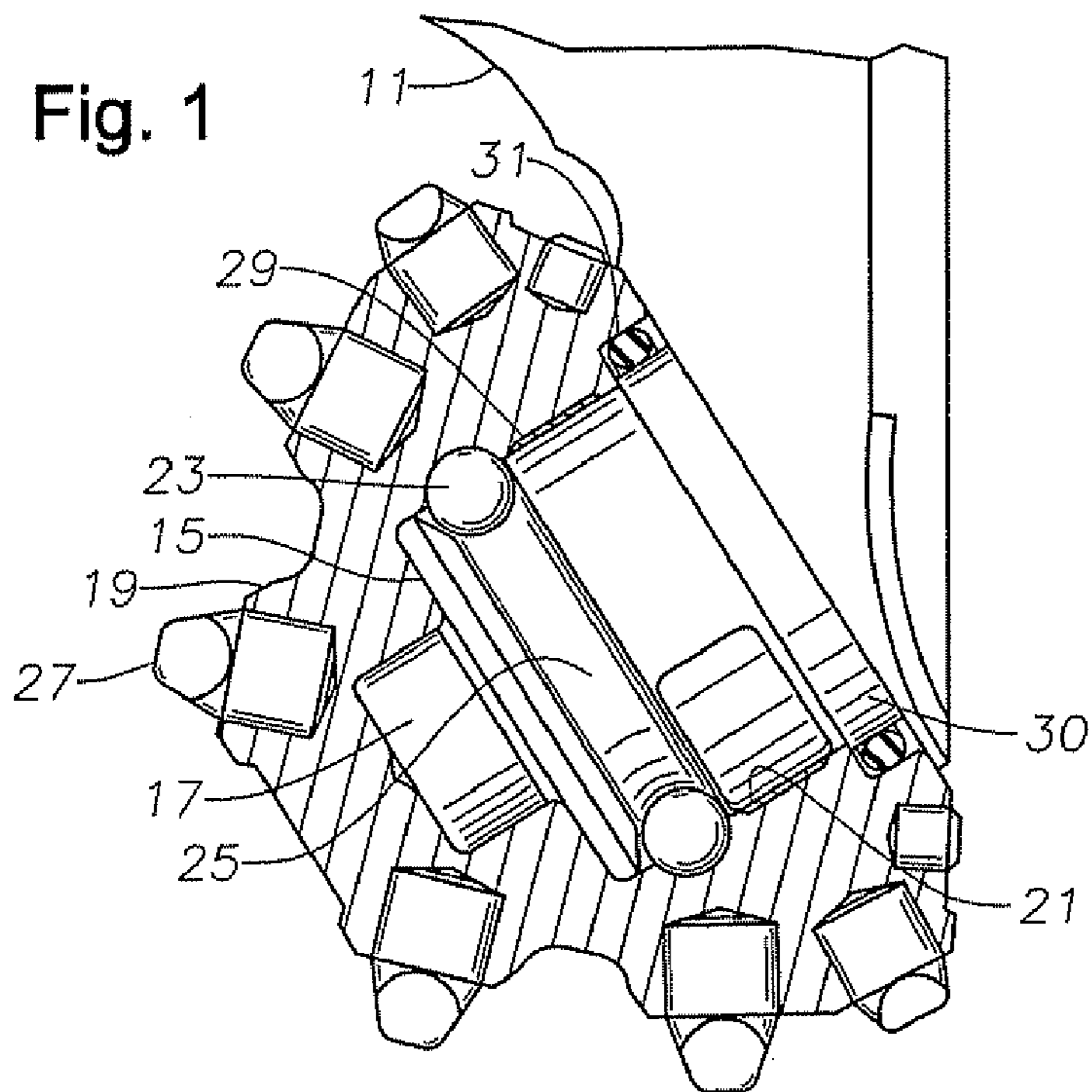


Fig. 2

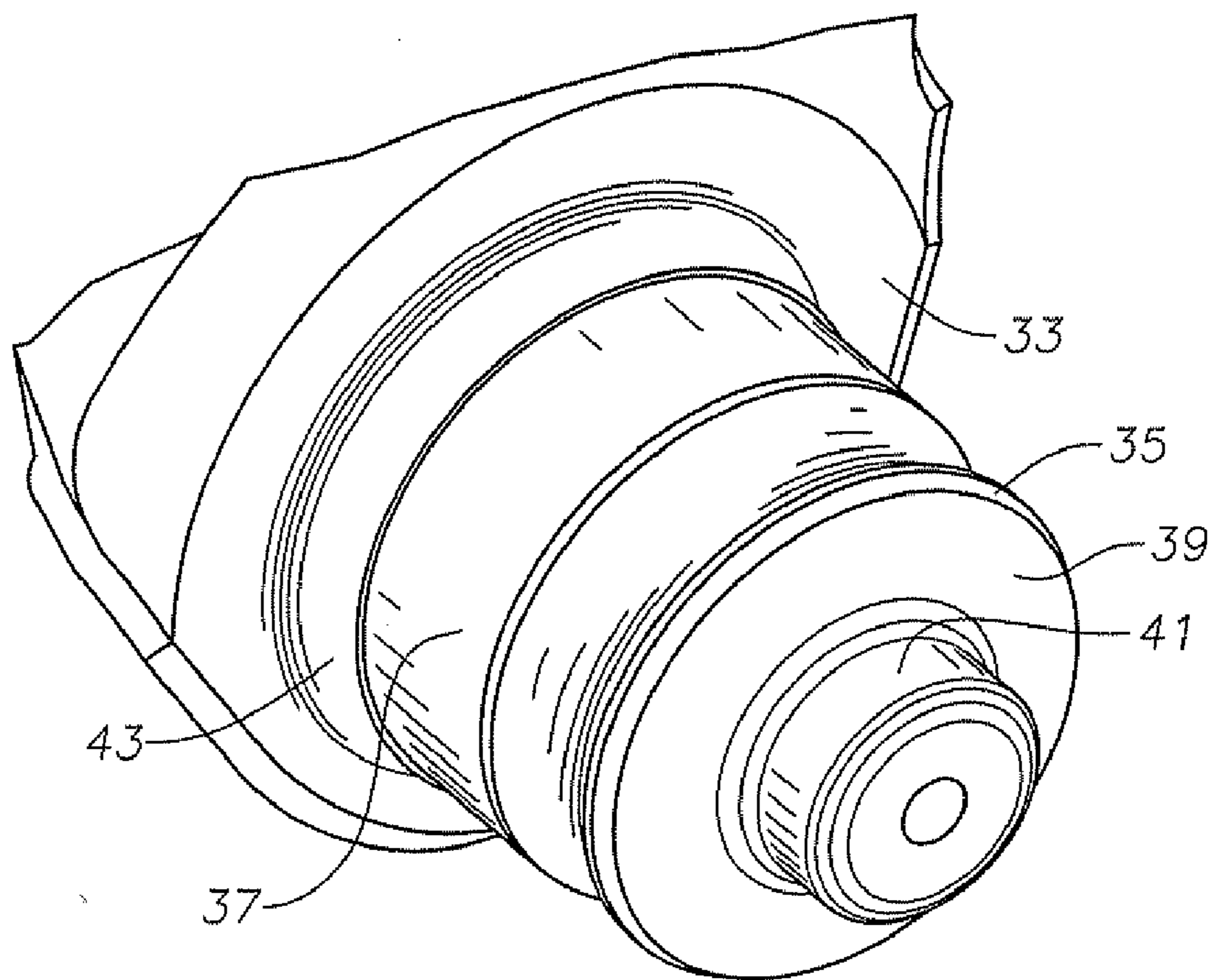


Fig. 3

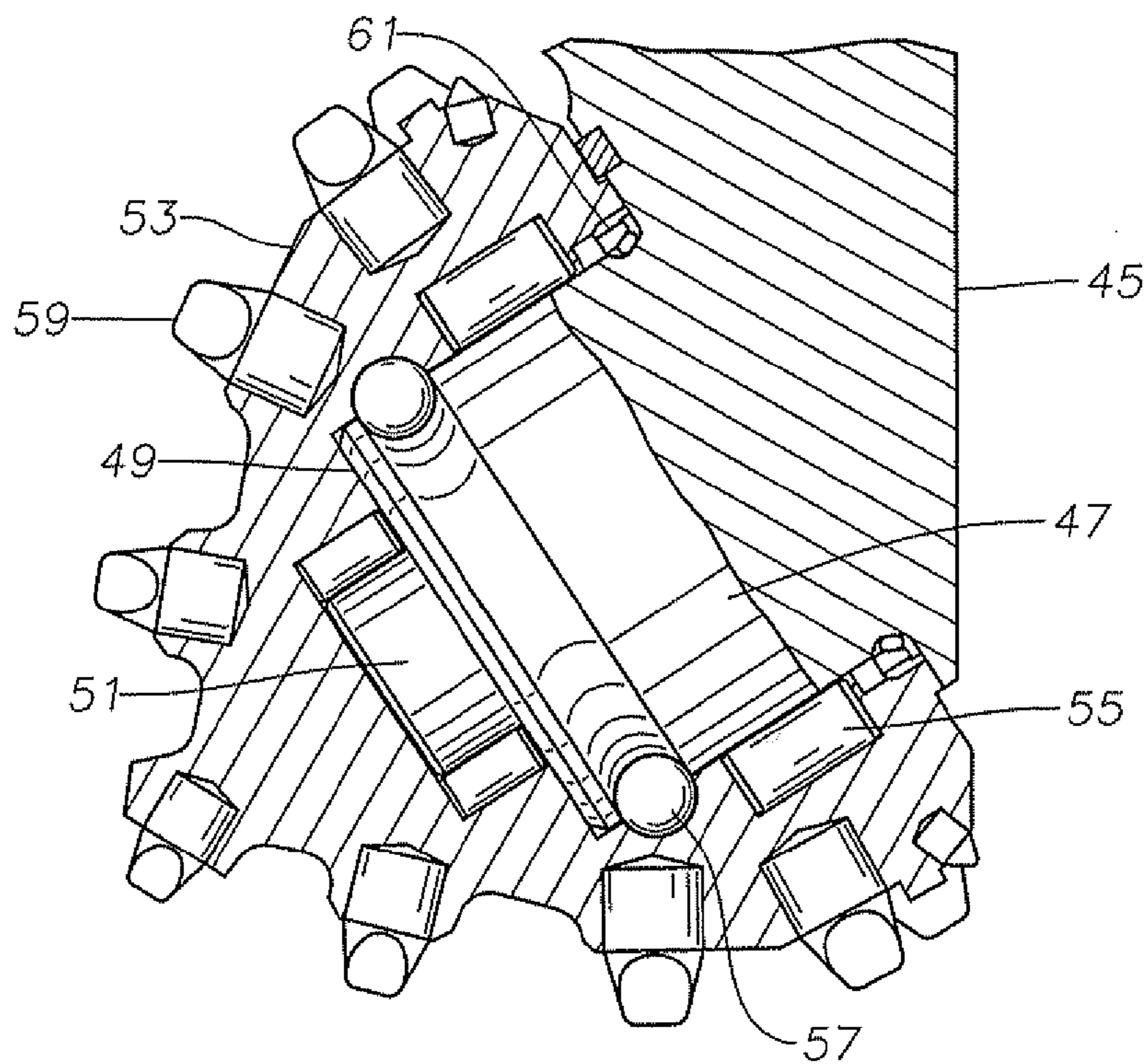
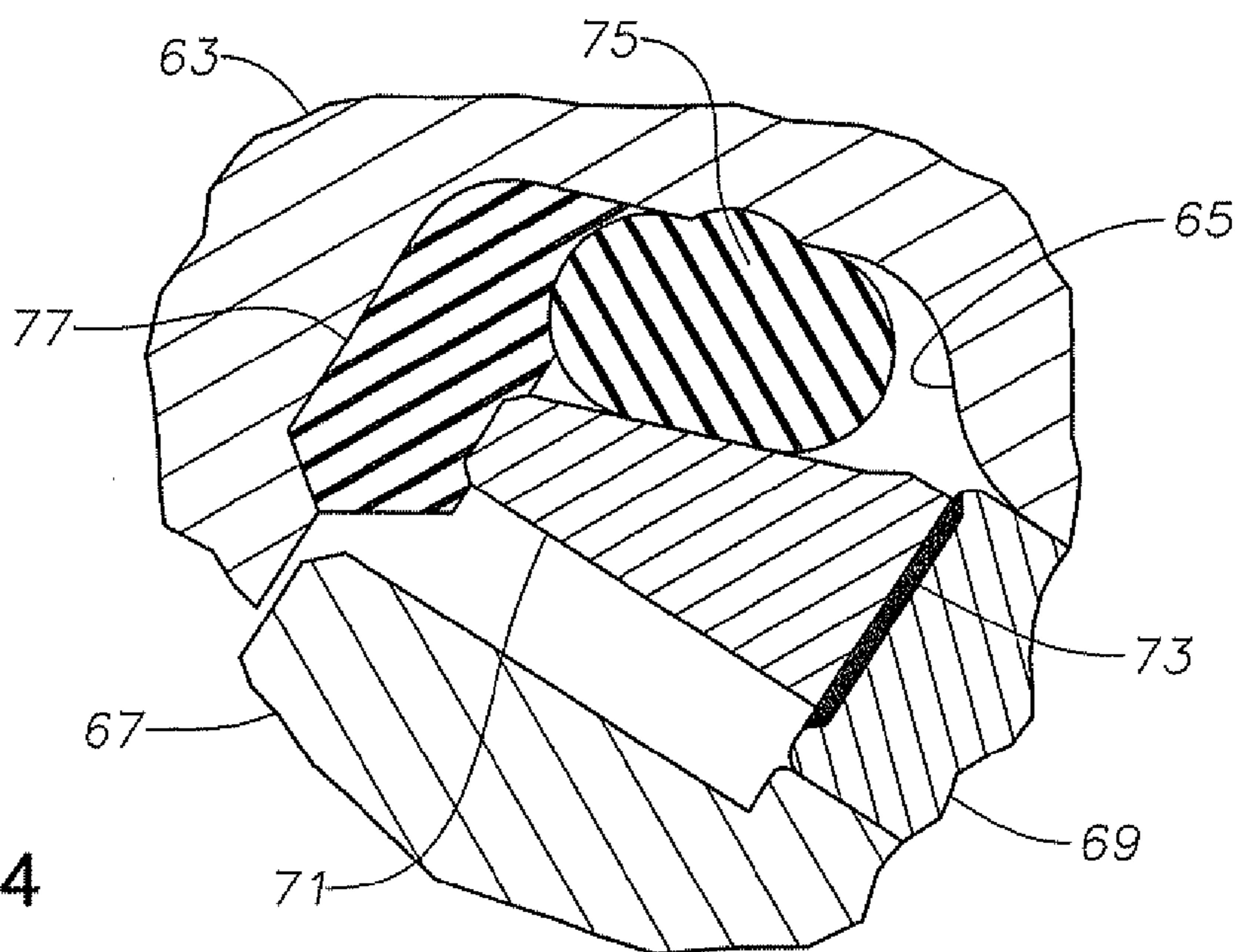


Fig. 4



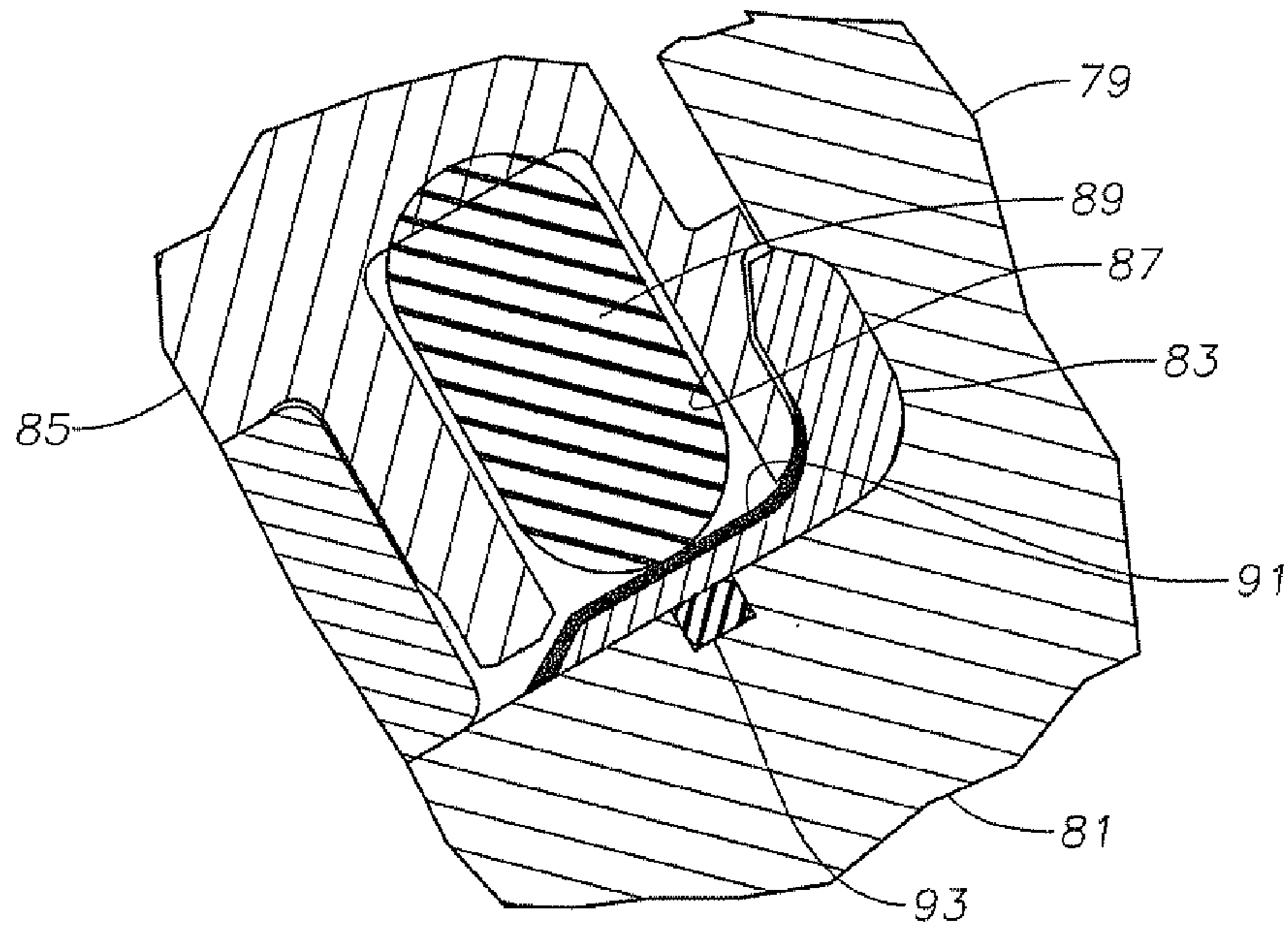


Fig. 5

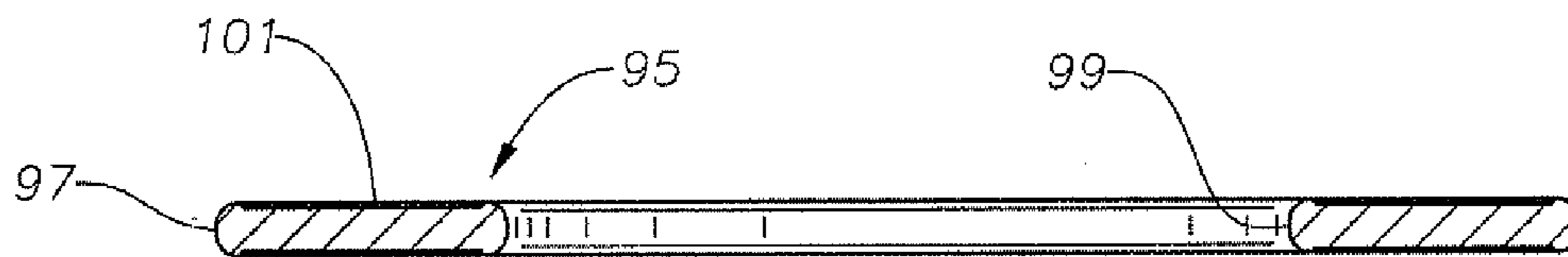


Fig. 6

BORON ALUMINUM MAGNESIUM COATING FOR EARTH-BORING BIT

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to provisional application 61/294,675 filed Jan. 13, 2010.

FIELD OF THE INVENTION

[0002] This application relates in general to hard coatings for improved abrasion resistance with reduced friction on downhole well tools such as rotary cone earth-boring bits, and in particular to coatings formed of boron, aluminum and magnesium.

BACKGROUND

[0003] One type of earth boring bit used in oil and gas well drilling has rotatable cones mounted to bearing pins of a bit body. The bearing system for the cones may be a journal bearing or a cylindrical roller bearing. The bearing system also includes thrust faces between the cone and bearing pin. A seal system seals lubricant within the bearing system. The seal system might be a metal-face-seal assembly, wherein an elastomeric member urges a metal-face seal into sliding engagement with a mating seal. Alternately, the seal system may comprise an elastomeric seal that is in sliding engagement with an annular gland journal on the bearing pin.

[0004] It is known that the journal bearing may be a bearing ring stationarily mounted around the bearing pin rather than the journal surface being the bearing pin itself. It is known that seal systems for earth boring bit bearings may employ a sleeve mounted around the bearing pin as the seal gland, rather than the seal gland being directly formed on the bearing pin.

[0005] Increasing the life of a bearing system is a continuing goal of earth boring bit manufacturers. It is known that various materials, such as diamond and diamond-like-carbon material, may be employed as the bearing and seal surfaces of the bearing system to enhance the life.

[0006] A recent type of lightweight, ultra-hard and wear resistant ceramics is in the area of complex ternary borides. These materials comprise aluminum magnesium boride alloyed with a few atomic percent group IV or group V elements as doping agents. The AlMgB14 intermetallic compound is based on four B12 icosahedral units positioned within an orthorhombic unit cell containing 64 atoms. The icosahedra are positioned at (0,0,0), (0,1/2,1/2), (1/2,0,0), and (1/2,1/2,1/2) while the Al atoms occupy a four-fold position at (1/4,3/4,1/4), and the Mg atoms occupy a four-fold position at (0.25,0.359,0). The hardness and wear resistance of this material are due to a complex interaction within each icosahedron (intrahedral bonding) combined with interaction between the icosahedra (intericosahedral bonding). The hexagonal icosahedra are arranged in distorted, close-packed layers.

[0007] The family of materials comprising AlMgB14 along with its alloys or doping agents is referred to herein as "BAM" materials. The alloy materials may include at least the following doping agents: titanium boride (TiB2); titanium carbide (TiC) plus iron, nickel and carbon; silicon nitride (Si3N4) as a powder or whiskered; boron carbide (B4C); titanium boride (TiB2); and tungsten boride (W2B4). The alloying may be by

mechanical alloying consolidated by vacuum hot pressing or it may be by laser ablation and/or magnetron sputtering.

[0008] The alloying agents can increase the hardness by as much as 10-20%, depending upon the particular doping agent used. The dopants create distinct phases within the material that have nanophase grain sizes down to 100 nm (nanometer). The term "nanophase" is used to describe materials with phases less than 100 nm. In addition, some of the whiskered materials have fibers with diameters in the nanometer realm. The "whiskered" material referred to above is a form of a fiber composite. In brittle materials, it generally entails including a small volume fraction of fibers of one compound or phase with or within another non-fibrous larger constitutive phase. The larger volume fraction phase is sometimes considered the "matrix" phase. The general purpose of the inclusions is to divert and deflect the propagation of cracks through the body and also subsequently to perform negative work through friction as two fractured surfaces attempt to pull apart and withdraw embedded and still intact fibers from the matrix. In ceramic composites, the whiskers (or fibers) can be between microns and hundreds of microns long and microns in diameter all the way down to nanometer dimensions in both length and diameter. There are many factors that determine the optimization of both size and volume fraction of fibers used in a composite.

[0009] A suggested use for BAM alloy materials is abrasive cutting tools for industrial purpose. Applicants are not aware of BAM alloy materials being used or suggested for use in bearing systems.

SUMMARY

[0010] A downhole well tool has at least one rotatable member, a bearing system including a bearing member having bearing surfaces on which the rotatable member rotates and a seal having a seal surface in sliding engagement with a mating seal surface to retain lubricant within the bearing system. At least one of the surfaces comprises an AlMgB14 alloy material to enhance the life of the bearing system.

[0011] The alloy material may include a dopant or alloy agent consisting of: titanium boride (TiB2); titanium carbide (TiC) plus iron, nickel and carbon; silicon nitride (Si3N4) powder; whiskered silicon nitride (Si3N4); boron carbide (B4C); titanium boride (TiB2); or tungsten boride (W2B4). The dopant creates a phase within the alloy material that has a grain size less than 100 nanometers. If whiskered silicon nitride is used, it may comprise fibers having diameters less than 100 nanometers.

[0012] The AlMgB14 alloy material may be a coating on at least one of the surfaces of the bearing system. Alternately, it may be a free-standing structure bonded to or forming one of the surfaces of the bearing system.

[0013] The AlMgB14 alloy material may be located on and form a cylindrical journal surface on the bearing member. It may be a flat circular thrust face on the bearing member. The AlMgB14 alloy material may be on cylindrical surfaces of roller bearings if the well tool employs roller bearings.

[0014] The AlMgB14 alloy material may be on at least one of the seal surfaces. For example it may be on a seal face of a rigid face seal assembly. If an elastomeric seal is employed rather than a rigid face seal assembly, the AlMgB14 alloy material may be on the seal gland that is slidingly engaged by the elastomeric seal.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] FIG. 1 is a partial sectional view of a cone and bit leg of an earth-boring bit having coatings applied in accordance with this invention.

[0016] FIG. 2 is a perspective view of a bearing pin of an earth-boring bit having a bearing sleeve with a surface treatment applied in accordance with this invention.

[0017] FIG. 3 is a partial sectional view of an earth-boring bit cone and bearing pin having roller bearings, the roller bearings and other surfaces having surface treatments in accordance with this invention.

[0018] FIG. 4 is an enlarged partial sectional view of a metal face seal employable with an earth-boring bit, the metal face seal having surface treatments applied in accordance with this invention.

[0019] FIG. 5 is a sectional view illustrating an elastomeric seal being employed with a floating insert ring, the insert ring being employable with any of the embodiments above and having surface treatments applied in accordance with this invention.

[0020] FIG. 6 is sectional view of a thrust washer that may be employed with any of the embodiments above, the thrust washer having surface treatments in accordance with this invention.

DETAILED DESCRIPTION OF THE INVENTION

[0021] Referring to FIG. 1, an example of a downhole well tool is illustrated. A bit leg 11 of an earth-boring bit is shown, the bit typically having three bit legs 11. A bearing member or pin 13 extends downward and inward from bit leg 11. Bearing pin 13 has a cylindrical journal surface that terminates in a downward and inward facing thrust shoulder or face 15. The lower portion of the journal surface is the portion of bearing pin 13 that is subject to the highest forces during drilling. A cylindrical nose 17 extends downward and inward from thrust face 15.

[0022] A rotatable member, which in this example comprises a cone 19, mounts rotatably on bearing pin 13. Cone 19 has a cavity 21 that conforms to the configuration of bearing pin 13. Cone 19 may be retained on bearing pin 13 by a plurality of locking elements or ball bearings 23. Ball bearings 23 are located within mating bearing races 25 formed on bearing pin 13 and in cavity 21. Cone 19 has a plurality of cutting elements 27 that protrude therefrom for disintegrating the earth formation. A seal 31 is in dynamic, sliding contact with a seal surface 30 on bearing pin 13 adjacent where bearing pin 13 joins bit leg 11. Seal 31 is illustrated as an elastomeric seal, but it could be a metal face seal assembly. Cavity 21 is filled with a lubricant, and seal 31 seals the lubricant within cavity 21 as well as preventing encroachment of drilling fluid from the well bore being drilled. Bearing pin 13 and the shell or body of cone 19 are typically formed of steel.

[0023] At least one of the surfaces of the bearing system is an ultra-hard and wear resistant ceramic material in the area of complex ternary borides and specifically comprising an AlMgB14 material. These materials comprise aluminum magnesium boride alloyed with a few atomic percent group IV or group V elements as doping agents. The AlMgB14 intermetallic compound is based on four B12 icosahedral units positioned within an orthorhombic unit cell containing 64 atoms. The icosahedra are positioned at (0,0,0), (0,1/2,1/2), (1/2,0,0), and (1/2,1/2,1/2) while the Al atoms occupy a four-fold position at (1/4,3/4,1/4), and the Mg atoms occupy a four-fold position at (0.25,0.359,0). The hardness and wear resistance of this material are due to a complex interaction within each icosahedron (intrahedral bonding) combined

with interaction between the icosahedra (intericosahedral bonding). The hexagonal icosahedra are arranged in distorted, close-packed layers.

[0024] The family of materials comprising AlMgB14 along with its alloys or doping agents is referred to herein as "BAM" materials. The alloy or doping agents may include at least one of the following: titanium boride (TiB2); titanium carbide (TiC) plus iron, nickel and carbon; silicon nitride (Si3N4) as a powder or whiskered; boron carbide (B4C); titanium boride (TiB2); and tungsten boride (W2B4). Some of the doping agents other than silicon nitride may be available in a whiskered form. The alloying may be by mechanical alloying consolidated by vacuum hot pressing or it may be by laser ablation and/or magnetron sputtering.

[0025] The alloying agents can increase the hardness by as much as 10-20%, depending upon the particular doping agent used. The dopants create distinct phases within the material that have nanophase grain sizes down to 100 nm (nanometer). The term "nanophase" is used to describe materials with phases less than 100 nm. In addition, some of the whiskered materials have fibers with diameters in the nanometer realm. The "whiskered" material referred to above is a form of a fiber composite. In brittle materials, it generally entails including a small volume fraction of fibers of one compound or phase with or within another non-fibrous larger constitutive phase. The larger volume fraction phase is sometimes considered the "matrix" phase. The general purpose of the inclusions is to divert and deflect the propagation of cracks through the body and also subsequently to perform negative work through friction as two fractured surfaces attempt to pull apart and withdraw embedded and still intact fibers from the matrix. In ceramic composites, the whiskers (or fibers) can be between microns and hundreds of microns long and microns in diameter all the way down to nanometer dimensions in both length and diameter. There are many factors that determine the optimization of both size and volume fraction of fibers used in a composite.

[0026] The BAM materials may be formed into a free standing structural member that is attached to a downhole well tool. Alternately, the BAM materials may be applied as a thin film coating.

[0027] Bearing pin 13 and/or cavity 21 may have a number of BAM surface treatments 29 to prolong the life of the bearing surfaces between bearing pin 13 and cone 19. The term "BAM surface treatment" refers to either a solid, free standing member of BAM materials attached to various parts of bearing pin 13 and/or cone cavity 21, or to a coating applied to the steel surfaces of bearing pin 13 and/or cone cavity 21. BAM surface treatment 29 is illustrated on the cylindrical journal surface of bearing pin 13. BAM surface treatment 29 could optionally be located on only the lower or pressure side of bearing pin 13. A corresponding BAM treatment 29 could also be on the mating portion of cavity 21. Or, that portion of cavity 21 could contain a soft material, such as silver.

[0028] BAM surface treatments 29 may also be located on thrust face 15 and the cylindrical portion of nose 17. Normally, the flat end of nose 17 does not engage a surface in cone cavity 21, rather all of the thrust is handled by thrust face 15. BAM surface treatments 29 could also be applied as coatings to ball bearings 23 and race 25. Each BAM surface treatment 29 could be in dynamic contact with a steel surface, another surface containing a BAM surface treatment 29, a soft metal or other type of surface.

[0029] FIG. 2 illustrates another example of a BAM surface treatment. A bit leg 33 has a bearing pin 35 generally as described above. However in this instance, the journal bearing surface is not formed directly on the bearing pin 35. Instead, a bearing ring 37 is press-fitted over or otherwise fixed on bearing pin 35. Bearing ring 37 may be composed entirely of BAM material or it may be a steel member that has a BAM surface treatment on at least the lower side of its exterior cylindrical surface.

[0030] In addition, the drill bit in FIG. 2 may have a BAM surface treatment on seal engaging surface or seal gland 43. Seal surface 43 is located between bearing ring 37 and bit leg 33 and is an annular surface that will be engaged by an elastomeric seal, which is not shown in FIG. 2. Bearing pin 35 in FIG. 2 also has a thrust face 39 and a nose 41 as illustrated also in FIG. 1. Thrust face 39 and the cylindrical surface of nose 41 may have BAM surface treatments, as described in connection with FIG. 1.

[0031] Referring to FIG. 3, a somewhat different bit leg 45 and bearing pin 47 are illustrated. In this example, bearing pin 47 has a thrust face 49 and a nose 51 as described above. A cone 53 slidably engages and rotates relative to bearing pin 47; rather than a cylindrical journal bearing surface, roller bearings 55 are employed. Roller bearings 55 comprise individual cylindrical members that are located in the same area where the journal surface is located in FIGS. 1 and 2. Cone 53 has cutting elements 59 and may be retained by ball bearings 57 in the same manner as illustrated above. A metal face seal 61 seals lubricant within the cavity of cone 53. BAM surface treatments could be applied to a number of places on the bearing pin 47 and in cone 53. These areas could include thrust face 49, roller bearings 55, ball bearings 57 and the dynamic sealing surfaces engaged by seal 61.

[0032] Referring to FIG. 4, a different type of seal assembly is illustrated that could be used in place of elastomeric seal 31 shown in FIG. 1. The metal or rigid face seal assembly illustrated in FIG. 4 locates in a seal gland 65 between bit leg 63 and cone 67. Cone 67 may have a sleeve 69 within its cavity that rotates with cone 67. A metal or rigid seal ring 71 and a metal or rigid cone sleeve 69 have mating end faces 73 that slidably engage each other. One or both end rigid faces 73 has a BAM surface treatment, which may be a coating or a separate member attached to end face 73. As is conventional with this type of metal face seal, an elastomeric energizer ring 75 exerts a force on metal seal ring 71 against face 73 of cone sleeve 69. Energizer ring 75 is non-rotating and is deformed between seal gland 65 in bit leg 63 and metal seal ring 71. A backup ring 77 of elastomeric material may be deformed in seal gland 65 between one side of energizer ring 75 and also an end of metal seal ring 71.

[0033] FIG. 5 illustrates another embodiment of a seal assembly that could be used in place of elastomeric seal 31 of FIG. 1 and metal face seal 61 of FIG. 3. In FIG. 5, bit leg 79 has a bearing pin 81 extending downward and inward. A floating sleeve 83 slides over bearing pin 81 and is fixed against rotation relative to bearing pin 81. However, sleeve 83 is free to move slightly relative to the axis of bearing pin 81 because it has an inner diameter slightly larger than the outer diameter of bearing pin 81. Floating sleeve 83 is also able to cock slightly relative to the axis of bearing pin 81. Cone 85 has a seal groove or recess formed in it. An elastomeric dynamic seal 89 is located in recess 87 and deformed against floating sleeve 83. Dynamic seal 89 will normally rotate with cone 85 and slide against the exterior cylindrical surface of

floating sleeve 83. Preferably a BAM surface treatment 91 is located on the portion of floating sleeve 83 that is slidably engaged by dynamic seal 89. A static seal 93 is located in a groove on bearing pin 81 to engage the inner diameter of floating sleeve 83.

[0034] FIG. 6 illustrates a thrust washer 95 that could be employed in FIG. 1 between the thrust face 15 and the mating surface in the cavity of cone 19. It could also be employed in FIG. 2 between thrust face 39 and a mating surface of the cone that fits on bearing pin 35. It could also be employed in FIG. 3 between thrust face 49 and the mating surface in cone 53. Thrust washer 95 is a flat washer having an outer diameter 97 and an inner diameter 99. The inner diameter 99 will slide over the nose of the bearing pin and could optionally be prevented from rotating relative to the bearing pin. Thrust washer 95 contains BAM surface treatments 101 on one or both sides.

[0035] As mentioned, the various BAM surface treatments described in connection with FIGS. 1-6 may be free standing members attached to the downhole well tool, or they may be coatings. If coatings, they can be applied in many different ways. They may be applied as ceramic powders, ceramic coatings, thin film coatings sputtered from targets, thick film laser formed or ablated powders, thick film plasma spray powders and other known and similar coating techniques in the art.

[0036] The BAM alloy material has very good abrasion resistance and a low coefficient of friction, making it particularly suited for use in bearing systems of rotating cone earth boring bits.

[0037] While the specification discloses only a few embodiments, it should be apparent to those skilled in the art that various changes and modifications may be made. For example, the BAM alloy material could be used in non-lubricated bearing systems, such as air drilling bits, as well as bits having lubricated bearing systems. In addition, the BAM alloy material could be used in bearing systems of earth boring bits other than conventional three-cone bits.

1. A downhole well tool having at least one rotatable member, a bearing system including a bearing member having bearing surfaces on which the rotatable member rotates and a seal having a seal surface in sliding engagement with a mating seal surface to retain lubricant within the bearing system, the improvement comprising:

at least one of the surfaces comprising an AlMgB14 alloy material.

2. The well tool according to claim 1, wherein the alloy material further comprises a dopant selected from a group consisting of: titanium boride (TiB₂); titanium carbide (TiC) plus iron, nickel and carbon; silicon nitride (Si₃N₄) powder; whiskered silicon nitride (Si₃N₄); boron carbide (B₄C); titanium boride (TiB₂); and tungsten boride (W₂B₄).

3. The well tool according to claim 2, wherein the dopant creates a phase within the alloy material that has a grain size less than 100 nanometers.

4. The well tool according to claim 2, wherein the whiskered silicon nitride comprise fibers having diameters less than 100 nanometers.

5. The well tool according to claim 1, wherein the AlMgB14 alloy material comprises a coating on said at least one of the surfaces.

6. The well tool according to claim 1, wherein the AlMgB14 alloy material comprises a free-standing structure bonded to said at least one of the surfaces.

7. The well tool according to claim 1, wherein said at least one of the surfaces is at least one of the bearing surfaces and which comprises:

a cylindrical journal surface on the bearing member.

8. The well tool according to claim 1, wherein said at least one of the surface is at least one of the bearing surfaces and which comprises:

a fiat circular thrust face on the bearing member.

9. The well tool according to claim 1, wherein said at least one of the surface is at least one of the bearing surfaces and which comprises:

cylindrical surfaces of roller bearings.

10. The well tool according to claim 1, wherein said at least one of the surfaces is at least one of the seal surfaces and which comprises a seal face of a rigid face seal assembly.

11. The well tool according to claim 1, wherein said at least one of the surface is the mating seal surface and which comprises an annular seal gland on the bearing member that is slidingly engaged by an elastomeric seal ring.

12. An earth boring bit, comprising:

at least one rotatable cone with external cutting elements;

a bearing system comprising:

a bearing pin having bearing surfaces on which the cone rotates;

a seal having a seal surface in sliding engagement with a mating seal surface to retain lubricant within the bearing system;

at least one of the surfaces comprising an AlMgB14 alloy material; and

the AlMgB14 bearing material having an alloying agent selected from a group consisting of: titanium boride (TiB₂); titanium carbide (TiC) plus iron, nickel and carbon; silicon nitride (Si₃N₄) powder; whiskered silicon nitride (Si₃N₄); boron carbide (B₄C); titanium boride (TiB₂); and tungsten boride (W₂B₄).

13. The bit according to claim 12, wherein said at least one of the surfaces is at least one of the bearing surfaces and which comprises:

an exterior surface of a bearing ring stationarily mounted on the bearing pin and defining a bearing journal.

14. The bit according to claim 12, wherein said at least one of the surface is at least one of the bearing surfaces and which comprises:

a flat circular disk stationarily mounted on a thrust face of the bearing pin.

15. The bit according to claim 12, wherein said at least one of the surface is at least one of the bearing surfaces and which comprises:

cylindrical surfaces of roller bearings.

16. The bit according to claim 12, wherein said at least one of the surfaces is at least one of the seal surfaces and which comprises a rigid seal face of a rigid face seal assembly.

17. The bit according to claim 12, wherein said at least one of the surface is the mating seal surface and which comprises a sleeve mounted around the bearing pin and slidingly engaged by an elastomeric seal ring.

18. The bit according to claim 12, wherein the AlMgB14 alloy material comprises a coating on said at least one of the surfaces.

19. The bit according to claim 12, wherein the AlMgB14 alloy material comprises a free-standing structure bonded to said at least one of the surfaces.

20. An earth boring bit, comprising:

at least one rotatable cone with external cutting elements, the cone having a cavity with a bearing surface;

a bearing pin having a bearing surfaces on which the bearing surface of the cone rotates;

at least one of the bearing surfaces comprising an AlMgB14 alloy coating; and

the AlMgB14 bearing coating having an alloying agent selected from a group consisting of: titanium boride (TiB₂); titanium carbide (TiC) plus iron, nickel and carbon; silicon nitride (Si₃N₄) powder; whiskered silicon nitride (Si₃N₄); boron carbide (B₄C); titanium boride (TiB₂); and tungsten boride (W₂B₄).

21. The bit according to claim 20, wherein:

the bearing surface of the bearing pin comprises an exterior surface of a bearing ring stationarily mounted on the bearing pin and defining a bearing journal; and

the coating is located on the exterior surface of the bearing ring.

* * * * *