HIGH VOLTAGE SWIVEL

TECHNICAL FIELD

[0001] The presently disclosed subject matter relates generally to high voltage swivels, and more particularly to a high voltage swivel for transmitting power from a first element to a second element rotatable relative to the first element.

BACKGROUND

[0002] A high voltage swivel assembly generally provides power transfer across a rotating interface. The swivel or slip ring provides an electrical connection between one or more electrical conductors, commonly referred to as passes, through the rotary interface. Such swivels provide a sliding electrical contact interface, typically comprising a separate ring and brush for each pass.

[0003] Swivel assemblies are used, for example, in floating or marine production systems where floating vessels with power generating capacity are used as a power source for offshore and subsea equipment. The vessel may be moored to a buoy which is remote from the equipment and a cable may extend from the buoy to where the power is needed. Winds, tides, and current effects may cause the floating vessel to weathervane about the buoy which is attached to the sea bottom such that an electrical swivel is needed to transmit the power generated on the vessel to the nonrotating attachment.

[0004] Such production systems may include offshore oil and gas industry systems in which large floating vessels, such as a floating production storage and offloading (FPSO) vessel, are used to receive produced hydrocarbons from subsea wells or other subsea equipment. The floating vessel may be moored to a single point mooring (SPM) system, which permits the vessel to weathervane and rotate 360 degrees about a single mooring point. The vessels use swivel assemblies to allow for the transfer of power across the rotary interface when the vessel weathervanes or rotates around the mooring site.

[0005] U.S. Patent No. 4,252,388, entitled “High Power Slip Ring Assembly,” discloses a slip ring assembly used to transmit power from a floating generating vessel to an offshore installation. A subsea cable is used to connect the slip ring to the installation, and the slip ring acts as an electric swivel to allow the floating vessel to weathervane around the buoy as may be required. The slip ring conducts three phase high voltage power through an open stack of rings

to spaced brushes which are connected to the subsea cable. Insulating oil, which has a breakdown voltage more than four times that of air, fills a chamber in which the ring stack is located.

[0006] U.S. Patent No. 4,329,004, entitled "Gas Filled High Voltage Slip Ring Assembly," discloses a slip ring for use in high voltage systems that includes the use of an insulating gas to fill a sealed cavity between a rotor and a stator to maintain electrical integrity of the slip ring.

BRIEF SUMMARY

[0007] With parenthetical reference to corresponding parts, portions, or surfaces of the disclosed embodiment, merely for the purposes of illustration and not by way of limitation, the present disclosure provides a high voltage swivel (15) comprising: an outer component (61); an inner component (21); the outer component and the inner component being rotatable about a longitudinal axis (x-x) relative to each other at a rotary bearing interface (51, 52) between the outer component and the inner component; the rotary bearing interface comprising a first bearing interface (51) and a second bearing interface (52) offset axially from the first bearing interface; the outer component and the inner component forming an enclosure (16) comprising an inner sealed chamber (58); a gas contained in the inner sealed chamber; one of the outer and inner components comprising at least a first conductive ring assembly (30) and the other of the outer and inner components comprising at least a first conductive brush assembly (70); the first conductive ring assembly and the first conductive brush assembly being in electric contact with and rotatable about the longitudinal axis relative to each other at a first rotary electrical interface (55) between the outer component and the inner component; the first conductive ring assembly having at least one ring (31) and the first conductive brush assembly having at least one brush (71) in contact at the first electrical interface between the outer component and the inner component; the first electrical interface between the outer component and the inner component disposed in the inner sealed chamber of the enclosure; the first electrical interface between the outer component and the inner component offset from the longitudinal axis and disposed axially between the first bearing interface and the second bearing interface; a first ring shield (40) supported in the sealed chamber; the first ring shield having a first portion (41) radially overlapping the electric contact between the ring and the brush at the first electrical interface and disposed axially between the first bearing interface and the first electrical interface; and the first ring shield having a second portion (42) radially overlapping the electric contact between the ring and the brush at the first electrical

interface and disposed axially between the second bearing interface and the first electrical interface.

[0008] The first portion of the first ring shield may comprise an annular outer first lip (92) and a rotary axial first gap (97) between the annular outer first lip and the first brush assembly or the first ring assembly; and the second portion of the first ring shield may comprise an annular outer second lip (96) and a rotary axial second gap (98) between the annular outer second lip and the first brush assembly or the first ring assembly. The first gap may have a minimum first axial gap thickness (97a); the ring may have a maximum axial ring thickness (RT); and the minimum first axial gap thickness may be less than or equal to the maximum axial ring thickness. The second gap may have a minimum second axial gap thickness (98a) and the minimum second axial gap thickness may be less than or equal to the maximum axial ring thickness. The first portion of the first ring shield may comprise a generally semi-toroidal outer surface (91a) extending about the longitudinal axis from the outer first lip and the second portion of the first ring shield may comprise a generally semi-toroidal surface (91b) extending about the longitudinal axis from the outer second lip. The rotary axial first gap may be between the outer first lip and the brush assembly; the rotary axial second gap may be between the outer second lip and the brush assembly; the semi-toroidal surface of the first portion of the first ring shield may extend between the ring assembly and the outer first lip; and the semi-toroidal surface of the second portion of the first ring shield may extend between the ring assembly and the outer second lip.

[0009] One of the outer and inner components may comprise a second conductive ring assembly (30) and the other of the outer and inner components may comprise a second conductive brush assembly (70); the second conductive ring assembly and the second conductive brush assembly may be in electric contact with and rotatable about the longitudinal axis relative to each other at a second rotary electrical interface (55) between the outer component and the inner component; the second conductive ring assembly may have at least one ring (31) and the second conductive brush assembly may have at least one brush (71) in contact at the second electrical interface between the outer component and the inner component; the second electrical interface between the outer component and the inner component may be disposed in the inner sealed chamber of the enclosure; the second electrical interface between the outer component and the inner component may be offset from the longitudinal axis and disposed axially between the first bearing interface and the first electrical interface; a second ring shield (40) may be supported in

the sealed chamber; the second ring shield may have a first portion (41) radially overlapping the electric contact between the ring and the brush at the second electrical interface and disposed axially between the first bearing interface and the second electrical interface; and the second ring shield may have a second portion (42) radially overlapping the electric contact between the ring and the brush at the second electrical interface and disposed axially between the second electrical interface and the first electrical interface. The first portion of the first ring shield may comprise an annular outer first lip (92) and a rotary axial first gap between the annular outer first lip and the first brush assembly or the first ring assembly; the second portion of the first ring shield may comprise an annular outer second lip (96) and a rotary axial second gap between the annular outer second lip and the first brush assembly or the first ring assembly; the first portion of the first ring shield comprises a generally semi-toroidal outer surface extending about the longitudinal axis from the outer first lip; the second portion of the first ring shield may comprise a generally semi-toroidal surface extending about the longitudinal axis from the outer second lip; the first portion of the second ring shield may comprise an annular outer first lip and a rotary axial first gap between the annular outer first lip and the second brush assembly or the second ring assembly; the second portion of the second ring shield may comprise an annular outer second lip and a rotary axial second gap between the annular outer second lip and the second brush assembly or the second ring assembly; the first portion of the second ring shield may comprise a generally semi-toroidal outer surface extending about the longitudinal axis from the outer first lip; and the second portion of the second ring shield may comprise a generally semi-toroidal surface extending about the longitudinal axis from the outer second lip.

[0010] One of the outer and inner components may comprise a plurality of conductive ring assemblies (30) and the other of the outer and inner components may comprise a plurality of conductive brush assemblies (70); each of the plurality of conductive ring assemblies and conductive brush assemblies may be in electric contact with and rotatable about the longitudinal axis relative to each other at one of a plurality of rotary electrical interfaces (55) between the outer component and the inner component; each of the plurality of conductive ring assemblies may have at least one ring (31) and each of the plurality of conductive brush assemblies may have at least one brush (71) in contact at one of the plurality of electrical interfaces between the outer component and the inner component; each of the plurality of electrical interfaces between the outer component and the inner component may be disposed in the inner sealed chamber of the enclosure;

each of the plurality of electrical interfaces between the outer component and the inner component may be offset from the longitudinal axis and disposed axially between the first bearing interface and the first electrical interface; a plurality of ring shields (40) may be supported in the sealed chamber; and each of the plurality of ring shields may have a first portion (41) extending radially over the electric contact between the ring and the brush at one of the plurality of electrical interfaces and disposed axially between the first bearing interface and such electrical interface and may have a second portion (42) extending radially over the electric contact between the ring and the brush at the second electrical interface and disposed axially between the second bearing surface and such electrical interface.

[0011] The first ring shield may form an annular shielded interior chamber (48) having an electrical field strength less than an electrical field strength of the inner sealed chamber outside the shielded interior chamber of the first ring shield. The second portion of the first ring shield may comprise a debris trap (95) configured to collect debris operatively formed by contact between the ring and the brush at the first electrical interface between the outer component and the inner component.

[0012] The rotary interface may comprise an annular debris trap (80) configured to collect debris operatively formed at the first bearing interface between the outer component and the inner component. The debris trap may comprise an annular portion having a generally semi-toroidal inner surface (81) extending about the longitudinal axis and axially facing the first bearing interface between the outer component and the inner component. The debris trap may be supported by the inner component and may comprise a rotary debris gap (85) between an annular surface (86) of the debris trap and an axially opposed surface (67) of the outer component. The first bearing interface may comprise: an annular first rotary gap (82) between the outer component and the inner component; an annular first seal (83, 84) disposed in the first rotary gap; and an annular first bearing (87) disposed in the first rotary gap axially between the annular first seal and the annular debris trap.

[0013] The outer component may comprise the first brush assembly (70); the first brush assembly may comprise a socket (74) mounted at a first end portion to the outer component and extending radially from the outer component into the inner sealed chamber; and the socket may comprise a second end portion (72) supporting the brush in contact with the ring of the first ring assembly. The brush may comprise an axially-facing first brush pad (71a) and an opposed axially-

facing second brush pad (71b); the ring may comprise an annular axial-facing first ring surface (38a) and an annular opposite axially-facing second ring surface (38b); and the ring may be disposed axially between the first brush pad and the second brush pad such that the first ring surface is in electric contact with the first brush pad and the second ring surface is in electric contact with the second brush pad.

[0014] The first bearing interface may comprise a cylindrical first inwardly-facing bearing surface (64a) of the outer component opposing a cylindrical first outwardly-facing bearing surface (24a) of the inner component; the first inwardly-facing bearing surface of the outer component may be orientated about the longitudinal axis and may have a first outer bearing diameter (BOD1); the first outwardly-facing bearing surface of the inner component may be orientated about the longitudinal axis and may have a first inner bearing diameter (BID1); the second bearing interface may comprise a cylindrical second inwardly-facing bearing surface (65a) of the outer component opposing a cylindrical second outwardly-facing bearing surface (25a) of the inner component; the second inwardly-facing bearing surface of the outer component may be orientated about the longitudinal axis and may have a second outer bearing diameter (BOD2); the second outwardly-facing bearing surface of the inner component may be orientated about the longitudinal axis and may have a second inner bearing diameter (BID2); the first inner bearing diameter (BID1) may be less than the second inner bearing diameter (BID2); and the first outer bearing diameter (BOD1) may be less than the second outer bearing diameter (BOD2). The ring may comprise an outer maximum radial surface (39) orientated about the longitudinal axis and having a ring outer diameter (ROD); and the first inner bearing diameter (BID1) may be less than the ring outer diameter (ROD). The second outer bearing diameter (BOD2) may be greater than or equal to the ring outer diameter (ROD).

[0015] The outer component may comprise a cylindrical outermost portion (62) having an inner sleeve surface (62a) orientated about the longitudinal axis between the first bearing interface and the second bearing interface and defining in part the sealed chamber; the inner sleeve surface may have a maximum inner sleeve diameter (MXID); the inner component may comprise a cylindrical innermost portion (22) having an outer shaft surface (22a) orientated about the longitudinal axis between the first bearing interface and the second bearing interface and defining in part the sealed chamber; the outer shaft surface may have a minimum outer shaft diameter (MIOD); the second bearing interface may be offset axially from the first bearing interface by an

axial interface offset height (BH1); and the axial interface offset height (BH1) may be greater than the difference between the maximum inner sleeve diameter and the minimum outer shaft diameter (MXID-MIOD). The maximum inner sleeve diameter (MXID) may be greater than the first outer bearing diameter (BOD1) of the first inwardly-facing bearing surface of the outer component; and the maximum inner sleeve diameter (MXID) may be greater than the second outer bearing diameter (BOD2) of the second inwardly-facing bearing surface of the outer component. The outer component may comprise a first narrowing sleeve surface (63a) orientated about the longitudinal axis between the first bearing interface and the cylindrical inner sleeve surface; and the outer component may comprise a second narrowing sleeve surface (66a) orientated about the longitudinal axis between the second bearing interface and the cylindrical inner sleeve surface. The minimum outer shaft diameter (MIOD) may be less than the first inner bearing diameter (BID1) of the first outwardly-facing bearing surface of the inner component; and the minimum outer shaft diameter (MIOD) may be less than the second inner bearing diameter (BID2) of the second outwardly-facing bearing surface of the inner component.

[0016] The inner component may comprise an annular first end plate (24) orientated about the longitudinal axis and comprising the cylindrical first outwardly-facing bearing surface of the inner component; the inner component may comprise an annular second end plate (25) orientated about the longitudinal axis and comprising the cylindrical second outwardly-facing bearing surface of the inner component; and the inner component may comprise a frustoconical outer shaft surface (23a) orientated about the longitudinal axis between the first end plate and the cylindrical outer shaft surface. The gas may consist essentially of nitrogen.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The accompanying drawings are incorporated herein as part of the specification. The drawings described herein illustrate embodiments of the presently disclosed subject matter and are illustrative of selected principles and teachings of the present disclosure. However, the drawings do not illustrate all possible implementations of the presently disclosed subject matter and are not intended to limit the scope of the present disclosure in any way.

[0018] FIG. 1 is a schematic view of an embodiment of an offshore system employing an embodiment of an improved high voltage swivel.

[0019] FIG. 2 is a top perspective view of the high voltage swivel assembly shown in FIG. 1.

[0020] FIG. 3 is a vertical cross-sectional view of the high voltage swivel shown in FIG. 2.

[0021] FIG. 4 is a partial cross-sectional view of the high voltage swivel shown in FIG. 3.

[0022] FIG. 5 is an enlarged cross-sectional view of an electric rotary interface shown in FIG. 3.

[0023] FIG. 6 is a further enlarged cross-sectional view of the electric rotary interface shown in FIG. 4.

[0024] FIG. 7 is a top perspective view of the bottom pass ring shield shown in FIG. 3.

[0025] FIG. 8 is a vertical radial cross-sectional view of the ring shield shown in FIG. 7.

[0026] FIG. 9 is an enlarged cross-sectional view of the upper bearing rotary interface shown in FIG. 3.

[0027] FIG. 10 is a perspective view of the brush assembly shown in FIG. 4.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0028] At the outset, it should be clearly understood that like reference numerals are intended to identify the same structural elements, portions or surfaces consistently throughout the several drawing figures, as such elements, portions or surfaces may be further described or explained by the entire written specification, of which this detailed description is an integral part. Unless otherwise indicated, the drawings are intended to be read (e.g., cross-hatching, arrangement of parts, proportion, degree, etc.) together with the specification, and are to be considered a portion of the entire written description of this invention. As used in the following description, the terms "horizontal", "vertical", "left", "right", "up" and "down", as well as adjectival and adverbial derivatives thereof (e.g., "horizontally", "rightwardly", "upwardly", etc.), simply refer to the orientation of the illustrated structure as the particular drawing figure faces the reader. Similarly, the terms "inwardly" and "outwardly" generally refer to the orientation of a surface relative to its axis of elongation, or axis of rotation, as appropriate.

[0029] It is to be understood that the specific assemblies and systems illustrated in the attached drawings and described in the following specification are simply exemplary embodiments of the inventive concepts defined herein. Hence, specific dimensions, directions, or other physical characteristics relating to the embodiments disclosed are not to be considered as limiting, unless expressly stated otherwise. Also, although they may not be, like elements in various embodiments described herein may be commonly referred to with like reference numerals within this section of the application.

[0030] It is to be appreciated that the present teaching is by way of example only, not by limitation. The concepts herein are not limited to use or application with a specific system or method. Thus, although the instrumentalities described herein are for the convenience of explanation, shown and described with respect to exemplary embodiments, it will be appreciated that the principles herein may be applied equally in other types of systems and methods involving high voltage swivels.

[0031] Where they are used herein, the terms "first," "second," and so forth, do not necessarily denote any ordinal, sequential or priority relation, but are simply used to distinguish one element or set of elements more clearly from another element or set of elements, unless specified otherwise.

[0032] An improved high voltage swivel is provided, a first embodiment of which is generally indicated at 15. As shown in FIG. 1, in an exemplary embodiment, high voltage swivel 15 may be employed in offshore system 10. In system 10, floating production storage and offloading (FPSO) vessel 11 is moored to the ocean floor via anchoring lines and mooring turret 12. Vessel 11 can weathervane around geostationary turret 12 having various swivels or rotary joints for providing fluid, power, and communications across the rotary joint when vessel 11 weathervanes or rotates around the mooring site and turret 12. Thus, for example, one or more risers (not shown) of a production system (not shown) moored to the ocean floor may extend up to process or fluid swivel 13 on turret 12 and power may be provided by vessel 11 to offshore equipment (not shown) of an offshore installation (not shown) at the ocean floor via high voltage swivel 15 on turret 12 and power lines 14 that extend down from swivel 15 to, as a first example, the subsea equipment. In this first example, swivel 15 thereby couples subsea cable 14 to a power cable from vessel 11 and power from vessel 11 may be transmitted to the outer rotary side of swivel 15, which is fixedly attached to or stationary relative to vessel 11, then transmitted across the electrical rotary interface of swivel 15, and then transmitted to power cables 14 from the inner stationary side of swivel 15, which is fixedly attached to or stationary relative to turret 12 moored to the ocean floor. As another example, high voltage power may be provided to vessel 11 by an onshore generating source (not shown) via high voltage swivel 15 on turret 12 and power lines 14 that extend from swivel 15 to, as a second example, the onshore generating source. In this second example, swivel 15 thereby couples a subsea export cable 14 to a power cable from vessel 11 and high voltage power from the onshore generating source via power cable 14 may be transmitted to the inner

stationary side of swivel 15, which is fixedly attached to or stationary relative to turret 12 moored to the ocean floor, then transmitted across the electrical rotary interface of swivel 15, and then transmitted to vessel 11 from the outer rotary side of swivel 15, which is fixedly attached to or stationary relative to vessel 11. Swivel 15 may thereby be operable as a high-voltage electrical swivel for voltages greater than 36 kV for alternating current, and for example may be used for high voltages between about 52 kV and about 245 kV for alternating current.

[0033] Swivel 15 may be used in various alternative types of floating production storage and offloading, in various types of floating systems such as floating offshore wind platforms, in various systems that require the transfer of high voltage electrical power through a rotary interface, such as offshore wind energy and tidal stream turbines, in various types of subsea production systems and installations, in various offshore interconnections such as power to shore and power from shore systems, and in various alternative applications to an offshore production or power system.

[0034] As shown in FIGS. 2-3, swivel 15 generally comprises inner geostationary stator assembly 20 and outer rotor assembly 60. Inner assembly 20 and outer assembly 60 are rotatable about longitudinal axis x-x relative to each other at sealed upper rotary bearing interface 51 and sealed lower rotary bearing interface 52, with upper bearing interface 51 being axially offset from lower bearing interface 52 by bearing axial offset distance or height BH1.

[0035] Inner assembly 20 comprises inner tubular or hollow shaft 21 orientated about axis x-x and extending axially between upper bearing interface 51 and lower bearing interface 52. Outer assembly 60 comprises outer sleeve 61 orientated about axis x-x and extending axially between upper bearing interface 51 and lower bearing interface 52. Inner shaft 21 and outer sleeve 61 form annular housing enclosure 16 orientated about axis x-x and having inner sealed chamber 58, which is filled with a gas or gas mixture as a dielectric medium. Such gas or gas medium may comprise a pure gas, such as for example and without limitation nitrogen, or a gas mixture, such as for example and without limitation perfluoronitrile (C4F7N) or sulfur hexafluoride (SF6). Other gas or gas mixture examples include without limitation C5-FK, N2, O2, CO2 C4F8, C3F8, NF3,CCl3F, C4F8O, CF4, C4F6, SOF2, C3F6, SO2, C2F6, CF3I, CF3NO2, C4F10, CCl4, and N2O.

[0036] Inner assembly 20 generally comprises hollow shaft 21 supporting five ring assemblies, severally indicated at 30, and outer assembly 60 generally comprises sleeve 61

supporting five corresponding brush assemblies, severally indicated at 70. In this embodiment, swivel 15 is configured to include passes for three electrical phases, indicated at 17a, 17b, and 17c. Swivel 15 is also configured to include optional spare pass 17d also capable of transmitting power, and to include ground pass 17e. For passes 17a-17d, four connector plugs, severally indicated at 35, and flameproof connector cover assemblies, severally indicated at 36, extend from shaft 21. Four corresponding connector plugs, severally indicated at 65, and connector cover assemblies, severally indicated at 76, extend from sleeve 61. However, the number of passes, connector plugs and connector covers may be varied and may be less than four or greater than four. In addition, spare pass 17d may include a modified or smaller exterior plug and/or cover to protect the respective sockets when not in use.

[0037] Hollow shaft 21 generally comprises inner cylindrical tubular portion 22, upper frustoconical portion 23, upper annular bearing plate 24, and lower annular bearing plate 25. Stator connector sockets, severally indicated at 34, are mounted to and extend axially into chamber 58 from circumferentially spaced apertures in lower bearing plate 25 such that they are spaced around the circumference of bearing plate 25. Stator connector plugs 35 are received in sockets 34 and connector cover assemblies 36 are mounted to and protrude out axially from bearing plate 25 to cover the protruding ends of connector plugs 35. Lower bearing plate 25 includes outwardly-facing cylindrical bearing surface 25a. Upper bearing plate 24 includes outwardly-facing cylindrical bearing surface 24a.

[0038] Sleeve 61 is positioned radially outside of shaft 21 and generally comprises outer cylindrical middle portion 62, inwardly curved annular upper portion 63, upper annular bearing plate 64, inwardly curved annular lower portion 66, and lower annular bearing plate 65. Rotor connector sockets, severally indicated at 74, are mounted to and extend radially into chamber 58 from circumferentially and axially spaced apertures in sleeve 61 such that they are spaced around the circumference of sleeve 61. Rotor connector plugs 75 are received in sockets 74 and connector cover assemblies 76 are mounted to and protrude out axially from outer cylindrical middle portion 62 to cover the protruding ends of connector plugs 75. Lower bearing plate 65 includes inwardly-facing cylindrical bearing surface 65a, which is radially opposed to outwardly-facing cylindrical bearing surface 25a of lower bearing plate 25 of shaft 21. Upper bearing plate 64 includes inwardly-facing cylindrical bearing surface 64a, which is radially opposed to outwardly-facing cylindrical bearing surface 24a of upper bearing plate 24 of shaft 21.

[0039] Thus, outer sleeve 61 and inner shaft 21 are rotatable about longitudinal axis x-x relative to each other at upper rotary bearing interface 51 between opposed inwardly-facing cylindrical bearing surface 64a of upper bearing plate 64 of sleeve 61 and outwardly-facing cylindrical bearing surface 24a of upper bearing plate 24 of shaft 21 and at lower rotary bearing interface 52 between opposed inwardly-facing cylindrical bearing surface 65a of lower bearing plate 65 of sleeve 61 and outwardly-facing cylindrical bearing surface 25a of lower bearing plate 25 of shaft 21.

[0040] As shown in FIGS. 2-4, shaft 21 and sleeve 61 form a specially configured and shaped enclosure 16. For example, annular upper rotary bearing interface 51 is at a radial distance from longitudinal axis x-x that is less than the radial distance of annular lower rotary bearing surface 52 from longitudinal axis x-x. Interfaces 51 and 52 are concentric, and accordingly inwardly-facing cylindrical bearing surface 64a of upper bearing plate 64 of sleeve 61, outwardly-facing cylindrical bearing surface 24a of upper bearing plate 24 of shaft 21, inwardly-facing cylindrical bearing surface 65a of lower bearing plate 65 of sleeve 61, and outwardly-facing cylindrical bearing surface 25a of lower bearing plate 25 of shaft 21 are concentric about axis x-x. However, diameter BOD1 of inwardly-facing cylindrical bearing surface 64a of upper bearing plate 64 of sleeve 61 is less than diameter BOD2 of inwardly-facing cylindrical bearing surface 65a of lower bearing plate 65 of sleeve 61, and in turn diameter BID1 of outwardly-facing cylindrical bearing surface 24a of upper bearing plate 24 of shaft 21 is less than diameter BID2 of outwardly-facing cylindrical bearing surface 25a of lower bearing plate 25 of shaft 21. Also in this embodiment, diameter BID1 of outwardly-facing cylindrical bearing surface 24a of upper bearing plate 24 of shaft 21 is less than outer diameter ROD of annular ring 31. Also in this embodiment, diameter BID2 of outwardly-facing cylindrical bearing surface 25a of lower bearing plate 25 of shaft 21 is equal to or greater than outer diameter ROD of annular ring 31. Also in this embodiment, the axial interface offset height BH1 between upper bearing interface 51 and lower bearing interface 52 is greater than the difference between maximum inner diameter MXID of inner surface 62a of outermost middle cylindrical portion 62 of sleeve 61 and minimum outer diameter MIOD of outer surface 22a of innermost cylindrical portion 22 of shaft 21. Also in this embodiment, the maximum inner diameter MXID of middle cylindrical portion 62 of sleeve 61 is greater than diameter BOD1 of inwardly-facing cylindrical bearing surface 64a of upper bearing plate 64 of sleeve 61 and the maximum inner diameter MXID of middle cylindrical portion 62 of sleeve 61

is greater than diameter BOD2 of inwardly-facing cylindrical bearing surface 65a of lower bearing plate 65 of sleeve 61. In addition, minimum outer diameter MIOD of cylindrical portion 22 of shaft 21 is less than diameter BID1 of outwardly-facing cylindrical bearing surface 24a of upper bearing plate 24 of shaft 21 and minimum outer diameter MIOD of cylindrical portion 22 of shaft 21 is less than BID2 of outwardly-facing cylindrical bearing surface 25a of lower bearing plate 25 of shaft 21.

[0041] The chosen diameters of the bearing and sealing surfaces at rotary interfaces 51 and 52, with upper rotary interface 51 smaller in diameter than lower rotary interface 52, interact together to provide an upward axial load on the bearing and enclosure 16 components. This force, when applied to upper bearing and with the shape of shaft 21 and sleeve 61 when enclosure 16 is pressurized, results in a matching of the vertical deflection of the upper shaft and sleeve flanges or plates 24, 64 with changes in internal gas pressure. This minimizes the relative vertical movement of upper rotary interface 51 and the sealing surfaces of seals 83 and 84 which increases the sealing effectiveness and reliability. Additionally, the vertical axial load on the upper bearing when combined with the pressurized enclosure 16 prevents radial movement of the sleeve 61 center axis relative to the shaft 21 center axis.

[0042] In addition, the shape of enclosure 16 helps distribute the internal forces throughout the internal and external walls of shaft 21 and sleeve 61, minimizing locations of high mechanical stress and thus lowering the cost and volume of material. For example, the cone shape of portion 23 at the top of shaft 21 combined with the upper shaft flange 24 minimizes bending stresses in that area while also contributing to the deflection benefits described above. The curved shape of top head 61 and bottom head 66 of sleeve 61 also smoothly transition the pressure loads to the top flanges 64 and bottom flanges 65 and minimizes the internal volume 58 of enclosure 16 while providing adequate clearance for the high voltage electrical components contained therein.

[0043] As shown in FIG. 9, in this embodiment upper bearing plate 24 of shaft 21 includes annular debris trap 80 configured to collect debris operatively formed at bearing interface 51. Debris trap 80 has a generally semi-toroidal shape and extends from the bottom circumferential surface of upper bearing plate 24 and extends radially across gap 82 between opposed inwardly-facing cylindrical bearing surface 64a of upper bearing plate 64 of sleeve 61 and outwardly-facing cylindrical bearing surface 24a of upper bearing plate 24 of shaft 21. The outer annular edge 86 of debris trap 80 is separated from the opposed bottom annular surface 67 of bearing plate 64 of

sleeve 61 by a narrow annular gap 85. Inner annular semi-toroidal surface 81 of debris trap 80 axially faces the bottom annular edge of gap 81 and bearing interface 51 to catch any debris formed by the contact between shaft 21 and sleeve 61 at rotary bearing interface 51. The outer annular edge 86 of debris trap 80 is separated from the opposed bottom annular surface 67 of bearing plate 64 of sleeve 61 by a narrow annular gap 85 so as to allow relative rotation without contact but to also retain any debris collected in debris trap 81. Alternatively, debris trap may be supported by bearing plate 64 of sleeve 61, rather than bearing plate 24 of shaft 21, with a rotary debris gap between an annular surface of the debris trap and an axially opposed surface of bearing plate 24 of shaft 21. Thus, debris trap 80 is provided below rotary interface 51 to allow debris created at the rotary interface to fall and settle into trap 80. Debris in trap 80, which forms a zone of low or zero electric field strength, will be less likely to migrate to zones of high electrical field strength where charged particulate may adversely influence the breakdown characteristics of swivel 15.

[0044] As shown in FIG. 9, in this embodiment inner-facing surface 64a of bearing plate 64 includes two outer axially-spaced annular grooves or seal glands that receive and support annular seals 83 and 84 in rotary gap 82 between outer-facing surface 24a of bearing plate 24 and inner-facing surface 64a of bearing plate 64. Inner-facing surface 64a of bearing plate 64 also includes an annular groove spaced axially below seal 84 that receives and supports annular bearing 87 in rotary gap 82 between outer-facing surface 24a of bearing plate 24 and inner-facing surface 64a of bearing plate 64. Bearing 87 is positioned between bearing plate 64 to the outside and bearing plate 24 to the inside and facilitates rotation of sleeve 61 about shaft 21. In this embodiment, bearing 87 is a not a roller bearing and is a non-metallic bumper type bearing that prevents metal-to-metal contact at upper rotary interface 51 between outer-facing surface 24a of bearing plate 24 and inner-facing surface 64a of bearing plate 64. The design eliminates the need for a roller bearing on upper rotary interface 51 to support axial and radial loads.

[0045] In this embodiment, shaft 21 includes a segmented annular top V-ring plate 26 connected to bearing plate 24 and extending radially over the upper edge of gap 82 between outer-facing surface 24a of bearing plate 24 and inner-facing surface 64a of bearing plate 64. Annular V-ring 88 is disposed axially above gap 82 and bearing plate 64 to direct fluids and fluid contaminates, such as abrasive particles, away from the top annular edge of rotary gap 82.

[0046] As shown in FIG. 3, lower rotary bearing interface 52 also includes seals and a rotary bearing assembly. In this embodiment, inner-facing surface 65a of bearing plate 65 includes two outer axially-spaced annular grooves or seal glands that receive and support annular seals 88 in the rotary gap between outer-facing surface 25a of bearing plate 25 and inner-facing surface 65a of bearing plate 65. In addition, in this embodiment rotary interface 52 includes slewing bearing 89 operating between shaft 21 and sleeve 61 at lower interface 52. However, varies alternative rolling-element bearings may be used.

[0047] As shown in FIG. 3, each of the ring assemblies 30 for passes 17a-17d generally comprises conductive annular ring 31 that is orientated about longitudinal axis x-x and is conductively supported from ring junction 37 by radially extending bus bar 32, an axially extending bus bar, severally indicated at 33 and being of different axial lengths, and conductor socket 34. The plurality of rings 31 for passes 17a-17e are congruent and axially spaced apart from each other to form a five pass ring stack in chamber 58. Three phase power may be coupled to the ring stack via rings 31, insulated bus bars 32 coupled to rings 31 at ring junction 37, insulated bus bars 33 coupled to bus bars 32, and sockets 34 coupled to bus bars 33, of passes 17a, 17b, and 17c, respectively. The top pass 17d ring may be used as a spare ring and optional power may be coupled to the ring stack via the top ring 31, the top insulated bus bar 32 coupled to the top ring 31 at the top ring junction 37, the longest insulated bus bar 33 coupled to the top bus bar 32, and socket 34 coupled to the longest bus bar 33. In this embodiment, ring 31e of pass 17e acts as a bonding ring for coupling stator assembly 22 to rotor assembly 60 via ring ground conductor 33e connected to lower plate 25 of shaft 21 and through a corresponding brush assembly and brush ground conductor (not shown) connected to sleeve 61.

[0048] Each of rings 31 is contacted by a corresponding brush 71 mounted in brush holder 72 of a corresponding brush assembly 70. Each of brush assemblies 70 generally comprises a conductive brush 71 that is supported by a brush holder 72, a radially extending bus bar 73 coupled to brush holder 72 at brush mount 77, a brush cover 78, a brush collar 79, and a conductor socket 74 coupled to brush bar 73. The several brush assemblies 70 are individual mounted to sleeve 61 around the circumference of sleeve 61 and extend radially inward from sleeve 61 such that they are spaced around the circumference of the ring stack of stator assembly 20. Three phase power may be coupled to the ring stack of the stator assembly 20 via the middle three brushes 71, brush holders 72 coupled to the middle three brushes 71, bus bars 73 coupled to the middle three brush

holders 72 by brush mounts 77, and sockets 74 coupled to bus bars 73, respectively. The top brush assembly 70 may be coupled to the spare top ring 31 of stator assembly 20 and optional power may be coupled to the top spare ring 31 via the top brush 71, brush holder 72 coupled to the top brush 71, the top bus bar 73 coupled to the top brush holder 72 by the top brush mount 77, and top socket 74 coupled to the top bus bar 73. Each of connector sockets 74 are mounted directly to sleeve 61 and are in turn connected directly to brush 71 such that brush 71 is entirely socket driven. In this arrangement, socket 74 provides the entire tangential force required to slide brush 71 along surfaces 38a and 38b of ring 31.

[0049] In this embodiment, the electric contact between brush 71 and ring 31 is axially orientated. As shown, ring 31 has an annular upwardly-facing contact surface 38a and an annular downwardly-facing contact surface 38b and brush 71 comprises a plurality of upper brush pads 71a and a plurality of lower brush pads 71b. Brush holder 72 comprises downwardly-biasing upper radial holding arm 72a supporting upper brush pads 71a in contact with top surface 38a of ring 31 and upwardly-biasing lower radial holding arm 72b supporting lower brush pads 71b in contact with bottom surface 38b of ring 31 such that ring 31 is sandwiched axially between upper brushes 71a and lower brushes 71b of brush 71. However, alternatively the electric contact between brush 71 and ring 31 may be radially orientated and a variety of alternative configurations and holding arrangements may be used to provide electrical rotary contact between the ring and brush assemblies at a rotary electrical interface.

[0050] Thus, when shaft 21 rotates relative to sleeve 61 about longitudinal axis x-x, each conductive ring 31 for each pass 17a-17e is in electrical contact with a corresponding conductive brush 71 for each pass 17a-17e at a rotary electrical interface 55 for each pass 17a-17e within chamber 58 between outer sleeve 61 and inner shaft 21.

[0051] In this embodiment, the ring stack in chamber 58 includes specially configured and contoured ring shields, severally indicated at 40, protecting each of rings 31 for each pass 17a-17e and also supporting each of rings 31 for each pass 17a-17e via shield ring mount 99 at ring junction 37. As shown in FIGS. 3-8, each of the four ring shields 40 for passes 17a-17d is a specially formed hollow toroidal member that is orientated about longitudinal axis x-x with annular outer opening 43 to annular internal shield chamber or cavity 48 configured to receive and shield electric rotary interfaces 55 and the contacting surfaces and opposed ends of ring assemblies 30 and brush assemblies 70 at passes 17a-17d.

[0052] As shown in FIG. 3, ring shields 40 for passes 17a-17d are supported at circumferentially spaced upper and lower exterior pockets, severally indicated at 44, by axially extending and circumferentially spaced insulated posts, severally indicated at 45, stacked on lower annular half bond ring shield 40e mounted to lower bearing plate 25 of shaft 21. The plurality of ring shields 40 for passes 17a-17d are congruent and axially spaced apart from each other to form a shield stack in chamber 58. In this embodiment, bottom ring shield 40e comprises only an upper semi-toroidal outer surface that acts as a shield to bonding ring 40e and the corresponding brush 71 at the electric grounding interface of bottom grounding pass 17e.

[0053] As shown, stacked ring shields 40 extending around rings 31 are disposed radially outside of sockets 34 and axial bus bars 33 of the ring stack of ring assemblies 30. Accordingly, each ring shield 40 in the stack includes radially extending bore 46 configured to receive radial bus bar 32 extending therethrough to electrically connect ring 31 to axial bus 33 and socket 34. As shown, ring shields 40 are stacked on and axially supported around rings 31 by insulator posts 45, which are mounted at their ends in pockets 44 in the outer surfaces of ring shields 40. Thus, with reference to ring shield 40 for pass 17a shown in FIG. 3, a first set of circumferentially spaced posts 45 extend axially between pockets in the top annular surface of bond ring shield 40e, in which the bottom ends of the posts are mounted, and pockets 44 in the bottom annular surface of first level ring shield 40, in which the top end of the posts are mounted, to thereby support ring shield 40 for pass 17a, and in turn support ring 31 via shield ring mount 99 of ring junction 37 for pass 17a. A second set of circumferentially spaced posts 45 extend axially between pockets 44 in the top annular surface of the ring shield 40 for pass 17a, in which the bottom ends of the second set of posts are mounted, and pockets 44 in the bottom annular surface of the ring shield 40 for pass 17b, in which the top end of the second set of posts are mounted, to thereby support the ring shield 40 for pass 17b, and in turn support ring 31 via shield ring mount 99 ring at junction 37 for pass 17b. Thus, the rings shield 40 for each pass is supported by posts 45 from the ring shield 40 for the pass immediately below, up to the ring shield 40 for top pass 17d.

[0054] As shown in FIGS. 7 and 8, ring shield 40 has a generally C-shaped radial vertical cross-section and is generally bounded by partial toroidal outer surface 91, annular upper lip 92, downwardly-facing horizontal annular surface 93, vertical cylindrical back surface 94, upwardly-facing horizontal annular surface 95, and lower lip 96. Upper lip 92 and lower lip 96 define annular opening 43 to inner shield chamber 48 having axial height SGH1. Inner surfaces 93, 94

and 95 form shield chamber 48. Inner surface 94 of ring shield 40 includes a plurality of circumferentially spaced attachment points, severally indicated at 99a, to which a plurality of circumferentially spaced shield ring mounts 99 are attached around the inner circumference of surface 94 of ring shield 40 for connecting to ring 31. Outer surface 91 is a generally continuous smooth surface and has upper domed surface 91a to shield from above and lower domed surface 91b to shield from below. Opposed annular lips 92 and 96 define outer diameter SOD1 of ring shield 40. Ring shield 40 may be formed in arcuate sections, severally indicated at 47, to form a full protective ring orientated about longitudinal axis x-x.

[0055] As shown in FIGS. 3-6, ring 31 and brush 71 are disposed in protective cavity 48 of ring shield 40, with upper portion 41 of ring shield 40 radially overlapping the electric contact between ring 31 and brushes 71a at electrical interface 51 on the upper side 38a of ring 31 and with lower portion 42 of ring shield 40 radially overlapping the electric contact between ring 31 and brushes 71b at electrical interface 51 on the bottom side 38b of ring 31. Thus, upper portion 41 and lower portion 42 extend radially to encircle electrical interface 55. As shown, outer opposed lips 92 and 96 of shield 40 extend to radially overlap at least a portion of narrowed end 78a of brush cover 78. As shown, axial height SGH1 to opening 43 between outer opposed lips 92 and 96 of shield 40 is slightly greater than outer diameter BCD of end 78a of brush cover 78. Accordingly, the entire exposed conductive end of brush assembly 70 is within protective cavity 48 of ring shield 40. The entire exposed conductive ring 31 of ring assembly 30 is within protective cavity 48 of ring shield 40. And entire ring junction 37 connecting bus 32, ring 31 and shield ring mount 99 is within protective cavity 48 of ring shield 40. With opening 43 of ring shield 40 almost entirely filled by end 78a of brush cover 78 at the circumferential position of rotary electric interface 55, only narrow axial gap 97 is provided between upper lip 92 and the outer cylindrical surface of brush cover end 78a and only narrow axial gap 98 is provided between lower lip 96 and the outer cylindrical surface of brush cover end 78a. In this embodiment, thickness 97a of axial gap 97 is less than or equal to axial thickness RT of ring 31 between top surface 38a and bottom surface 38b of ring 31 and thickness 98a of axial gap 98 is less than or equal to axial thickness RT of ring 31. Thus, shielded interior chamber 48 will have an operative electrical field strength less than the electrical field strength of inner sealed chamber 58 outside shielded interior chamber 48 of ring shield 40. In addition, surface 95 of ring shield 40 is configured to collect debris operatively formed at electric rotary interface 55 with the operative

contact between brush 71 and ring 31. Thus, lower portion 42 of ring shield 40 is provided with a hollow below electric rotary interface 55 to allow debris created at the interface to fall and settle into electric debris trap 95. Debris in trap 95, which is in a zone of low or zero electric field strength by the effects of ring shield 40, will be less likely to migrate to zones of high electrical field strength where charged particulate may adversely influence breakdown characteristics of swivel 15. This zero-field debris trap is created around the high potential electrode of the ring-brush interface 55, as opposed to a more typical ground potential.

[0056] Ring shields 40 provides an almost complete toroid outer shape to ring and brush interface 55, guarding against locations of extremely non-uniform electric field distributions that surround ring and brush interface 55. The locations of extremely non-uniform electric field distribution either increases the required distance between electrodes or passes, or decreases the critical voltage of the electrical breakdown of the dielectric medium. Ring shields 40 result in weaker non-uniform electric fields in the space between passes, thereby decreasing the spacing requirements of the swivel and thus reducing size and cost. Ring shields 40 incorporate pockets 44 for insulators that hide or shield the triple points where the dielectric gaseous medium, solid insulator posts 45, and solid conducting ring shield 40 meet and would otherwise exhibit high electrical field strength. The pocket hides this interface and results in lower maximum electrical field strengths. Despite creating a nearly uniform toroidal cover, ring shields 40 still allow continuous sliding of brush 71 along ring 31, thus allowing for 360 degree rotation of the swivel. The interior 48 of ring shield 40 is a zone of low or zero electrical field strength, significantly reducing or eliminating the possibility of brush-ring particulate being charged and pulled to zones of high electrical field strength that could potentially lead to dielectric breakdown.

[0057] While in this embodiment the ring shields are supported by and extend from the ring side of rotary electric interface 55, alternatively the ring shields could extend from the brush side of rotary electric interface 55 or may be incorporated into other elements of the ring-brush interface. The enclosure envelope may be of an alternative geometry. Alternative cable entry systems may be employed and alternative conductors, insulators, bus bars, rings, sliding contacts and brush assemblies and forms may be employed.

[0058] Swivel 15 provides a number of benefits. For example, the enclosure shape minimizes the mechanical stress on the enclosure due to pressure, thus minimizing the thickness and amount of material required. The location of the rotary interfaces provide a certain axial load on the

bearing. Combined with the shape of the enclosure, this balances the displacement of the upper rotary interface when the enclosure is subjected to changes in internal pressure and removes the need for a roller bearing at the upper rotary interface. The socket of the connector is used as the supporting feature for the brush, applying the tangential torque required to slide the brush along the ring surface. The ring shields at the ring-brush interface reduce or eliminate zones of high electrical field strength and are used to create a volume of low electrical field strength to trap brush and ring debris, reducing the likelihood of electrical breakdown caused by particulates. A second rotary bearing interface debris trap creates a volume of low electrical field strength to trap rotary bearing debris, reducing the likelihood of electrical breakdown caused by particulates.

[0059] It should be appreciated that certain features of the system, which are, for clarity, described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features, which are, for brevity, described in the context of a single embodiment, may also be provided separately or in any suitable combination. While various embodiments have been described in detail above, it should be understood that they have been presented by way of example, and not limitation. It will be apparent to persons skilled in the relevant arts that the disclosed subject matter may be embodied in other specific forms, variations, and modifications without departing from the scope, spirit, or essential characteristics thereof. The embodiments described above are therefore to be considered in all respects as illustrative, and not restrictive. The scope of the invention is indicated by the appended claims, and all changes that come within the meaning and range of equivalents thereof are intended to be embraced therein.

CLAIMS

What is claimed is:

1. A high voltage swivel comprising:

an outer component;

an inner component;

the outer component and the inner component being rotatable about a longitudinal axis relative to each other at a rotary bearing interface between the outer component and the inner component;

the rotary bearing interface comprising a first bearing interface and a second bearing interface offset axially from the first bearing interface;

the outer component and the inner component forming an enclosure comprising an inner sealed chamber;

a gas contained in the inner sealed chamber;

one of the outer and inner components comprising at least a first conductive ring assembly and the other of the outer and inner components comprising at least a first conductive brush assembly;

the first conductive ring assembly and the first conductive brush assembly being in electric contact with and rotatable about the longitudinal axis relative to each other at a first rotary electrical interface between the outer component and the inner component;

the first conductive ring assembly having at least one ring and the first conductive brush assembly having at least one brush in contact at the first electrical interface between the outer component and the inner component;

the first electrical interface between the outer component and the inner component disposed in the inner sealed chamber of the enclosure;

the first electrical interface between the outer component and the inner component offset from the longitudinal axis and disposed axially between the first bearing interface and the second bearing interface;

a first ring shield supported in the sealed chamber;

the first ring shield having a first portion radially overlapping the electric contact between the ring and the brush at the first electrical interface and disposed axially between the first bearing interface and the first electrical interface; and

the first ring shield having a second portion radially overlapping the electric contact between the ring and the brush at the first electrical interface and disposed axially between the second bearing interface and the first electrical interface.

2. The rotary interface set forth in claim 1, wherein:

the first portion of the first ring shield comprises an annular outer first lip and a rotary axial first gap between the annular outer first lip and the first brush assembly or the first ring assembly; and

the second portion of the first ring shield comprises an annular outer second lip and a rotary axial second gap between the annular outer second lip and the first brush assembly or the first ring assembly.

3. The rotary interface set forth in claim 2, wherein:

the first gap has a minimum first axial gap thickness;

the ring has a maximum axial ring thickness; and

the minimum first axial gap thickness is less than or equal to the maximum axial ring thickness.

4. The rotary interface set forth in claim 3, wherein the second gap has a minimum second axial gap thickness and the minimum second axial gap thickness is less than or equal to the maximum axial ring thickness.

5. The rotary interface set forth in claim 2, wherein:

the first portion of the first ring shield comprises a generally semi-toroidal outer surface extending about the longitudinal axis from the outer first lip; and

the second portion of the first ring shield comprises a generally semi-toroidal surface extending about the longitudinal axis from the outer second lip.

6. The rotary interface set forth in claim 5, wherein:

the rotary axial first gap is between the outer first lip and the brush assembly;

the rotary axial second gap is between the outer second lip and the brush assembly;

the semi-toroidal surface of the first portion of the first ring shield extends between the ring assembly and the outer first lip; and

the semi-toroidal surface of the second portion of the first ring shield extends between the ring assembly and the outer second lip.

7. The rotary interface set forth in claim 1, wherein:

one of the outer and inner components comprises a second conductive ring assembly and the other of the outer and inner components comprises a second conductive brush assembly;

the second conductive ring assembly and the second conductive brush assembly being in electric contact with and rotatable about the longitudinal axis relative to each other at a second rotary electrical interface between the outer component and the inner component;

the second conductive ring assembly has at least one ring and the second conductive brush assembly has at least one brush in contact at the second electrical interface between the outer component and the inner component;

the second electrical interface between the outer component and the inner component is disposed in the inner sealed chamber of the enclosure;

the second electrical interface between the outer component and the inner component is offset from the longitudinal axis and disposed axially between the first bearing interface and the first electrical interface;

a second ring shield is supported in the sealed chamber;

the second ring shield has a first portion radially overlapping the electric contact between the ring and the brush at the second electrical interface and disposed axially between the first bearing interface and the second electrical interface; and

the second ring shield having a second portion radially overlapping the electric contact between the ring and the brush at the second electrical interface and disposed axially between the second electrical interface and the first electrical interface.

8. The rotary interface set forth in claim 7, wherein:

the first portion of the first ring shield comprises an annular outer first lip and a rotary axial first gap between the annular outer first lip and the first brush assembly or the first ring assembly;

the second portion of the first ring shield comprises an annular outer second lip and a rotary axial second gap between the annular outer second lip and the first brush assembly or the first ring assembly;

the first portion of the first ring shield comprises a generally semi-toroidal outer surface extending about the longitudinal axis from the outer first lip;

the second portion of the first ring shield comprises a generally semi-toroidal surface extending about the longitudinal axis from the outer second lip;

the first portion of the second ring shield comprises an annular outer first lip and a rotary axial first gap between the annular outer first lip and the second brush assembly or the second ring assembly;

the second portion of the second ring shield comprises an annular outer second lip and a rotary axial second gap between the annular outer second lip and the second brush assembly or the second ring assembly;

the first portion of the second ring shield comprises a generally semi-toroidal outer surface extending about the longitudinal axis from the outer first lip; and

the second portion of the second ring shield comprises a generally semi-toroidal surface extending about the longitudinal axis from the outer second lip.

9. The rotary interface set forth in claim 1, wherein:

one of the outer and inner components comprises a plurality of conductive ring assemblies and the other of the outer and inner components comprises a plurality of conductive brush assemblies;

each of the plurality of conductive ring assemblies and conductive brush assemblies are in electric contact with and rotatable about the longitudinal axis relative to each other at one of a plurality of rotary electrical interfaces between the outer component and the inner component;

each of the plurality of conductive ring assemblies has at least one ring and each of the plurality of conductive brush assemblies has at least one brush in contact at one of the plurality of electrical interfaces between the outer component and the inner component;

each of the plurality of electrical interfaces between the outer component and the inner component disposed in the inner sealed chamber of the enclosure;

each of the plurality of electrical interfaces between the outer component and the inner component offset from the longitudinal axis and disposed axially between the first bearing interface and the first electrical interface;

a plurality of ring shields are supported in the sealed chamber; and

each of the plurality of ring shields has a first portion extending radially over the electric contact between the ring and the brush at one of the plurality of electrical interfaces and disposed axially between the first bearing interface and such electrical interface and has a second portion extending radially over the electric contact between the ring and the brush at the second electrical interface and disposed axially between the second bearing surface and such electrical interface.

10. The rotary interface set forth in claim 1, wherein the first ring shield forms an annular shielded interior chamber having an electrical field strength less than an electrical field strength of the inner sealed chamber outside the shielded interior chamber of the first ring shield.

11. The rotary interface set forth in claim 1, wherein the second portion of the first ring shield comprises a debris trap configured to collect debris operatively formed by contact between the ring and the brush at the first electrical interface between the outer component and the inner component.

12. The rotary interface set forth in claim 1, comprising an annular debris trap configured to collect debris operatively formed at the first bearing interface between the outer component and the inner component.

13. The rotary interface set forth in claim 12, wherein the debris trap comprises an annular portion having a generally semi-toroidal inner surface extending about the longitudinal axis and axially facing the first bearing interface between the outer component and the inner component.

14. The rotary interface set forth in claim 13, wherein the debris trap is supported by the inner component and comprising a rotary debris gap between an annular surface of the debris trap and an axially opposed surface of the outer component.

15. The rotary interface set forth in claim 12, wherein the first bearing interface comprises:

an annular first rotary gap between the outer component and the inner component;

an annular first seal disposed in the first rotary gap; and

an annular first bearing disposed in the first rotary gap axially between the annular first seal and the annular debris trap.

16. The rotary interface set forth in claim 1, wherein:

the outer component comprises the first brush assembly;

the first brush assembly comprises a socket mounted at a first end portion to the outer component and extending radially from the outer component into the inner sealed chamber; and

the socket comprises a second end portion supporting the brush in contact with the ring of the first ring assembly.

17. The rotary interface set forth in claim 16, wherein:

the brush comprises an axially-facing first brush pad and an opposed axially-facing second brush pad;

the ring comprises an annular axial-facing first ring surface and an annular opposite axially-facing second ring surface; and

the ring is disposed axially between the first brush pad and the second brush pad such that the first ring surface is in electric contact with the first brush pad and the second ring surface is in electric contact with the second brush pad.

18. The rotary interface set forth in claim 1, wherein:

the first bearing interface comprises a cylindrical first inwardly-facing bearing surface of the outer component opposing a cylindrical first outwardly-facing bearing surface of the inner component;

the first inwardly-facing bearing surface of the outer component is orientated about the longitudinal axis and has a first outer bearing diameter;

the first outwardly-facing bearing surface of the inner component is orientated about the longitudinal axis and has a first inner bearing diameter;

the second bearing interface comprises a cylindrical second inwardly-facing bearing surface of the outer component opposing a cylindrical second outwardly-facing bearing surface of the inner component;

the second inwardly-facing bearing surface of the outer component is orientated about the longitudinal axis and has a second outer bearing diameter;

the second outwardly-facing bearing surface of the inner component is orientated about the longitudinal axis and has a second inner bearing diameter;

the first inner bearing diameter is less than the second inner bearing diameter; and

the first outer bearing diameter is less than the second outer bearing diameter.

19. The rotary interface set forth in claim 18, wherein:

the ring comprises an outer maximum radial surface orientated about the longitudinal axis and having a ring outer diameter; and

the first inner bearing diameter is less than the ring outer diameter.

20. The rotary interface set forth in claim 19, wherein the second outer bearing diameter is greater than or equal to the ring outer diameter.

21. The rotary interface set forth in claim 18, wherein:

the outer component comprises a cylindrical outermost portion having an inner sleeve surface orientated about the longitudinal axis between the first bearing interface and the second bearing interface and defining in part the sealed chamber;

the inner sleeve surface has a maximum inner sleeve diameter;

the inner component comprises a cylindrical innermost portion having an outer shaft surface orientated about the longitudinal axis between the first bearing interface and the second bearing interface and defining in part the sealed chamber;

the outer shaft surface has a minimum outer shaft diameter;

the second bearing interface is offset axially from the first bearing interface by an axial interface offset height; and

the axial interface offset height is greater than the difference between the maximum inner sleeve diameter and the minimum outer shaft diameter.

22. The rotary interface set forth in claim 21, wherein:

the maximum inner sleeve diameter is greater than the first outer bearing diameter of the first inwardly-facing bearing surface of the outer component; and

the maximum inner sleeve diameter is greater than the second outer bearing diameter of the second inwardly-facing bearing surface of the outer component.

23. The rotary interface set forth in claim 22, wherein:

the outer component comprises a first narrowing sleeve surface orientated about the longitudinal axis between the first bearing interface and the cylindrical inner sleeve surface; and

the outer component comprises a second narrowing sleeve surface orientated about the longitudinal axis between the second bearing interface and the cylindrical inner sleeve surface.

24. The rotary interface set forth in claim 21, wherein:

the minimum outer shaft diameter is less than the first inner bearing diameter of the first outwardly-facing bearing surface of the inner component; and

the minimum outer shaft diameter is less than the second inner bearing diameter of the second outwardly-facing bearing surface of the inner component.

25. The rotary interface set forth in claim 24, wherein:

the inner component comprises an annular first end plate orientated about the longitudinal axis and comprising the cylindrical first outwardly-facing bearing surface of the inner component;

the inner component comprises an annular second end plate orientated about the longitudinal axis and comprising the cylindrical second outwardly-facing bearing surface of the inner component; and

the inner component comprises a frustoconical outer shaft surface orientated about the longitudinal axis between the first end plate and the cylindrical outer shaft surface.

26. The rotary interface set forth in claim 1, wherein the gas consists essentially of nitrogen.