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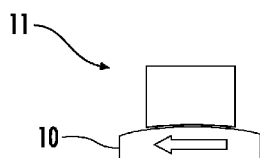


FIG. 1A

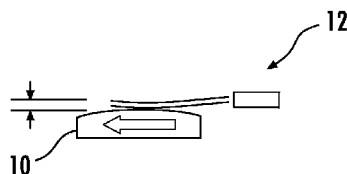


FIG. 1B

(57) **Abstract:** Improvements to slip rings and methods for the operation thereof include an improved slip ring assembly that has a stationary element, a rotating element rotatable with respect to the stationary element, a bearing assembly coupled between the stationary element and the rotating element, and one or more contact brushes on one of the stationary element or the rotating element. In some embodiments, the bearing assembly includes a primary bearing, a secondary bearing, a shear pin coupling the secondary bearing to the primary bearing, and an electrical monitoring circuit in communication with the shear pin. In some embodiments, the one or more contact brushes includes one or more metal fiber brushes constructed of a plurality of metal fibers that are configured to transmit one or more of electrical power or data between the stationary element and the rotating element.



## **DESCRIPTION**

### **IMPROVED SLIP RING DEVICES, SYSTEMS, AND METHODS**

#### **PRIORITY CLAIM**

[0001] The present application claims the benefit of and priority to U.S. Provisional Patent Application Serial No. 61/724,593, filed November 9, 2012, the disclosure of which is incorporated herein by reference in its entirety.

#### **TECHNICAL FIELD**

[0002] The subject matter disclosed herein relates generally to improvements to slip rings and deicing thereof.

#### **BACKGROUND**

[0003] Most helicopter types use electric resistance heating systems for preventing ice build-up on their rotors. These de-icing systems traditionally use a slip ring that incorporates monolithic brush systems to transmit the electrical power needed by the heating elements across the rotating interface between the stationary engine or gearbox and the rotating rotor. Although this arrangement can be considered generally sufficient for providing power to de-icing systems, future rotor systems will likely contain more electromechanical functionality, which will place additional demands on slip ring reliability and performance. Examples include rotorhead based active vibration control (AVC) and active rotors systems, both of which may have severe failure modes.

[0004] Besides being difficult to maintain, current slip ring technology has further proven to be universally unreliable and maintenance intensive. For example, current slip ring technology does not operate well in the cold, dry air encountered at typical operating altitudes. Another problem is that current slip ring technology is subject to deterioration and cracking resulting from minuscule amounts of oil often found leaking from rotor actuation systems. There is often wear on the mating slip ring, and a by-product of such wear is the creation of flammable, conductive carbon dust as the slip rings wear.

[0005] In view of these issues, it would be desirable for a slip ring design to provide increased service life, improved reliability, greater resistance to contaminants, less wear debris, increased power capability, higher and cleaner data

rates, higher durability, and/or reduced maintenance demands, with such improvements leading to increased aircraft availability relative to conventional slip ring designs.

### SUMMARY

[0006] In accordance with the disclosure provided herein, improvements to slip rings and deicing thereof are provided.

[0007] In many aspects, the subject matter disclosed herein provides for an improved slip ring assembly and method. In one aspect, the improved slip ring assembly includes a stationary element, a rotating element rotatable with respect to the stationary element, and one or more metal fiber brushes on one of the stationary element or the rotating element. Each of the one or more metal fiber brushes includes a plurality of metal fibers, and the one or more metal fiber brushes transmit one or more of electrical power or data between the stationary element and the rotating element.

[0008] In further aspects, an improved slip ring assembly includes a stationary element, a rotating element rotatable with respect to the stationary element, a bearing assembly coupled between the stationary element and the rotating element, and one or more contact brushes on one of the stationary element or the rotating element, the one or more contact brushes being configured to transmit one or more of electrical power or data between the stationary element and the rotating element. The bearing assembly includes a primary bearing, a secondary bearing, a shear pin coupling the secondary bearing to the primary bearing, and an electrical monitoring circuit in communication with the shear pin.

[0009] In further aspects, a method for transmitting one or more of electrical power or data between a stationary element and a rotating element includes coupling a bearing assembly between a stationary element and a rotating element rotatable with respect to the stationary element, where the bearing assembly includes a primary bearing, a secondary bearing, and a shear pin coupling the secondary bearing to the primary bearing. The method further includes measuring a resistance of the shear pin, comparing the resistance of the shear pin to a predetermined resistance corresponding to an intact state of the shear pin, and

indicating that the shear pin has broken if the resistance of the shear pin differs from the predetermined resistance.

[0010] These and other objects of the present disclosure as can become apparent from the disclosure herein are achieved, at least in whole or in part, by the subject matter disclosed herein.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

[0011] Figure 1A illustrates a partial side view of a monolithic carbon or metal-graphite brush contacting a slip ring.

[0012] Figure 1B illustrates a partial side view of a metal brush contacting a slip ring.

[0013] Figure 2A illustrates a partial side view of a metal fiber brush contacting a slip ring according to an embodiment of the subject matter disclosed herein.

[0014] Figure 2B illustrates an arrangement of metal fibers of a metal fiber brush according to an embodiment of the subject matter disclosed herein.

[0015] Figures 3A and 3B illustrate a main rotor slip ring assembly according to an embodiment of the subject matter disclosed herein.

[0016] Figure 4 illustrates a main rotor standpipe assembly according to an embodiment of the subject matter disclosed herein.

[0017] Figure 5 illustrates a block diagram of a main rotor slip ring assembly according to an embodiment of the subject matter disclosed herein.

[0018] Figure 6 illustrates a tail rotor slip ring assembly according to an embodiment of the subject matter disclosed herein.

[0019] Figures 7, 8 and 9 illustrate views of a brush block line replaceable unit for a tail rotor slip ring assembly according to an embodiment of the subject matter disclosed herein.

[0020] Figure 10 illustrates a cutaway side view of a tail rotor slip ring assembly according to an embodiment of the subject matter disclosed herein.

[0021] Figure 11 illustrates a block diagram of a tail rotor slip ring assembly according to an embodiment of the subject matter disclosed herein.

### **DETAILED DESCRIPTION**

[0022] In a helicopter, the main rotor and tail rotor slip rings provide circuit continuity between the stationary side and the rotational side of each rotor hub. The

circuit continuity provides for transmission of electrical power to components mounted on each rotor hub (e.g., de-icing systems) and permits transmission of data signals from the rotor hubs to components mounted in the aircraft fuselage. The subject matter described herein is directed to slip ring assemblies and methods providing increased service life, improved reliability, greater resistance to contaminants, less wear debris, increased power capability, higher and cleaner data rates, higher durability, and/or reduced maintenance demands relative to conventional slip ring designs.

[0023] In this regard, in one aspect, the present subject matter provides an improved contact brush. In one conventional configuration shown in Figure 1A, a monolithic carbon or metal-graphite brush **11** can be positioned in sliding contact with a sliding surface **10** (e.g., a slip ring drum). In this arrangement, constriction heating can develop due to the few number of contact points between monolithic brush **11** and sliding surface **10**. In another conventional configuration shown in Figure 1B, a metal brush **12** can be used for contact with sliding surface **10**. In this configuration, however, there is very little available brush wear, which can result in a requirement for frequent replacement of metal brush **12**.

[0024] In contrast to these conventional configurations, the present subject matter provides a metal fiber brush **13** constructed of hair-fine metal fibers **15**. As shown in Figure 2A, for example, each of metal fibers **15** is physically compliant, and each metal fiber brush **13** contains thousands of electrically independent contact points. As a result, most of metal fibers **15** contact sliding surface **10** individually, and thus at any given time there are many more points of contact than with a carbon brush, thereby providing high data integrity in high vibration environments. Further in this regard, because metal fiber brush **13** maintains better electrical contact with sliding surface **10**, the potential for arcing and signal noise is significantly reduced. In addition, metal fibers **15** exhibit low brush wear and minimal debris generation. Accordingly, the design of metal fiber brush **13** creates very little wear on sliding surface **10**. As a result, running on the tips of metal fibers **15** gives metal fiber brush **13** an increased maintenance interval for replacing the elements and provides a longer service life compared to other metal brushes (e.g., at least an order of magnitude in every side-by-side comparison in actual field testing). Additionally, by running metal fiber brush **13** on the tips of metal fibers **15**, metal fibers **15** are better

able to conform to sliding surface **10** and thus require less force as do carbon brushes (e.g., one-fifth as much or less). As a result, the amount of heating from sliding friction is reduced, and metal fiber brush **13** can thus have an increased service life compared to carbon or metal-graphite brushes (e.g., at least twice the service life). Also, by using a material for metal fiber brush **13** that is softer than that of sliding surface **10**, the integrity of sliding surface **10** is better preserved.

[0025] In one embodiment, metal fiber brush **13** disclosed herein has a current density of 250 Amps/sq-in. In testing at 20A, 60Hz, 115VAC power, the voltage drop across the slip ring is about 26 millivolts or less. For comparison, the same test performed using silver graphite brushes yields a voltage drop of 400 millivolts. Regarding the electrical noise, when the slip rings are operating at rated speed of a helicopter rotor, and with 50 milliamperes applied, the variation in resistance of any circuit pair is configured to not exceed 50 milliohms peak-to-peak over a bandpass of about 1 Hz to about 100 kHz. In the embodiments discussed herein, the insulation resistance between adjacent current carrying parts or between any current carrying part and ground is about 100 megaohms at 500 V dc, and leakage current is less than 5 microamps. Further in this regard, the insulation between any two slip ring circuits and between any slip ring circuit and the assembly chassis is able to withstand a qualification dielectric test voltage of 1100 VRMS, 60 Hz, for 60±5 seconds, without failure or damage. The insulation is capable of withstanding 500 VRMS, 60 Hz, for 5 seconds and will have a maximum leakage current of 0.0001 ampere.

[0026] Alternatively or in addition to providing improved contact brushes, the present subject matter provides additional improvements to slip ring designs over conventional configurations. For instance, in another aspect, the present subject matter provides a configuration for a main rotor slip ring assembly, generally designated **100** in Figures 3a through 5. Main rotor slip ring assembly **100** provides circuit continuity between a stationary side and a rotational side of a main rotor hub to allow for electrical power and signals (e.g., power to de-ice systems) to pass to the components mounted on each rotor hub. Main rotor slip ring assembly **100** resides within an inner diameter of the rotor mast. An access port **106** is accessible through an access panel **108** providing an inspection window to enable visual inspection of the interface between the stationary elements and rotating elements of

main rotor slip ring assembly **100**. Accumulated brush debris is accessible and removable through this port without disassembly of the slip rings.

[0027] The lower end of main rotor slip ring assembly **100** is physically connected to a standpipe assembly, generally designated **102**, while the upper end of main rotor slip ring assembly **100** is configured to physically attach to the mast mount. Specifically, for example, main rotor slip ring assembly **100** is configured to connect directly to a main rotor upper distributor via a mounting flange **103** and a first electrical connector **104** (e.g., a MIL-STD-5015 style electrical connector) that is configured to connect to a complementary connector located on the underside of the distributor. First electrical connector **104** is designed with a flange that contains a clocking pin, and it utilizes a 32-68P insert arrangement. The clocking pin fixes the position of the connector on the distributor, allowing the distributor and slip ring assembly to be blind mated.

[0028] Main rotor standpipe assembly **102** is illustrated in detail in Figure 4. Main rotor standpipe assembly **102** provides a mechanical linkage between an alignment pin that is located on the lower gearbox and the lower portion of main rotor slip ring assembly **100**. Main rotor standpipe assembly **102** further provides a routing path for all wiring that exits from the lower portion of main rotor slip ring assembly **100**. In the embodiments disclosed herein, the weight of main rotor slip ring assembly **100** and main motor standpipe assembly **102** is lightweight. In one embodiment, for example, the combined weight is about 19 pounds or less.

[0029] Figure 5 illustrates a block diagram for one embodiment of main rotor slip ring assembly **100**. As shown in Figure 5, the wire bundle from the cabin is routed directly into a main rotor drum **110** of main rotor slip ring assembly **100**. One or more first brush assembly **113** is connected directly to first electrical connector **104** (e.g., a MIL-DTL-5015 connector) on top of main rotor slip ring assembly **100**. Although it is envisioned within the subject matter herein that each first brush assembly **113** is a metal fiber brush constructed of hair-fine metal fibers, as described above and shown in Figures 2A and 2B, any of a variety of contact brush configurations known in the art can be used for first brush assembly **113**. Regardless of the particular configuration, first brush assembly **113** is configured to provide high data integrity in high vibration environments, reduced potential for arcing and signal noise, low brush wear, and minimal debris generation.

[0030] Regardless of the particular configuration of main rotor slip ring assembly **100**, in the embodiments disclosed herein, the electrical power and signal information (e.g., ice protection system information) is transmitted across main rotor slip ring **100** via a Controller Area Network (CAN) bus in accordance with ISO-11898-2 with a data rate of at least up to 1Mbps. Other data buses such as ARINC-429, ARINC-825 or MIL-STD-1553 can also be used. Impedance is less than about 240 ohms through the slip ring assembly. Unless very short cable lengths are used, about a 500 kbps is recommended as the maximum transmission rate thru the slip ring channel. 500 kbps provides a more robust speed than 1Mbps for aerospace applications and can tolerate many more fault conditions.

[0031] Regarding the particular electrical power and signals that are routed through main rotor slip ring assembly **100**, Table 1 provides a pinout for one embodiment of first electrical connector **104** of main rotor slip ring assembly **100** (e.g., for a MRSRA MIL-DTL-5015 interface):

| <b>MIL-DTL-5015<br/>32-68 Pin</b> | <b>Ring #</b> | <b>Function</b> | <b>Signal Type</b> | <b>Signal Frequency (Hertz)</b> | <b>Rated Current (Amps)</b> | <b>Rated Voltage (Volts)</b> |
|-----------------------------------|---------------|-----------------|--------------------|---------------------------------|-----------------------------|------------------------------|
| A                                 | 1             | Power A+        | Power              | DC <sup>1</sup>                 | 100                         | ±135 DC                      |
| B                                 | 2             | Power A-        | Power              | DC <sup>1</sup>                 | 100                         | ±135 DC                      |
| Q                                 | 3             | Power B+        | Power              | DC <sup>1</sup>                 | 100                         | ±135 DC                      |
| R                                 | 4             | Power B-        | Power              | DC <sup>1</sup>                 | 100                         | ±135 DC                      |
| C                                 | 5             | Low Power A+    | Power              | DC <sup>1</sup>                 | <5                          | 28 DC                        |
| F                                 | 6             | Low Power A-    | Power              | DC <sup>1</sup>                 | <5                          | 28 DC                        |
| G                                 | 7             | Low Power B+    | Power              | DC <sup>1</sup>                 | <5                          | 28 DC                        |
| H                                 | 8             | Low Power B-    | Power              | DC <sup>1</sup>                 | <5                          | 28 DC                        |
| K                                 | 9             | CAN Bus Ahigh   | Data               | 1Mbps                           | <1                          | 10V                          |
| L                                 | 10            | CAN Bus Alow    | Data               | 1Mbps                           | <1                          | 10V                          |
| W                                 | 11            | CAN Bus Bhigh   | Data               | 1Mbps                           | <1                          | 10V                          |
| P                                 | 12            | CAN Bus BLow    | Data               | 1Mbps                           | <1                          | 10V                          |

Table 1- Main Rotor Slip Ring Assembly Connector Interface

[0032] To ensure high integrity of the electrical power and signals routed through main rotor slip ring assembly **100**, the number of first brush assemblies **113** used to

transmit power is selected to provide redundant transmission paths. As shown in Table 1, for example, quadruple redundant power brushes are provided.

[0033] Similarly, Table 2 illustrates one exemplary embodiment defining the cable bundle exiting from main rotor slip ring assembly **100** and traveling thru main rotor standpipe assembly **102** into the cabin:

| From Item           | To Item           | Ring Number | Wire Type        |
|---------------------|-------------------|-------------|------------------|
| NVX-2178-1<br>MRSRA | Cabin Power A     | 1           | M22759/2-6       |
|                     |                   | 2           | M22759/2-6       |
|                     | Cabin Power B     | 3           | M22759/2-6       |
|                     |                   | 4           | M22759/2-6       |
|                     | Cabin 28 Power A  | 5           | MIL-W-22759/2-20 |
|                     |                   | 6           | MIL-W-22759/2-20 |
|                     | Cabin 28 Power B  | 7           | MIL-W-22759/2-20 |
|                     |                   | 8           | MIL-W-22759/2-20 |
|                     | Cabin CAN A       | 9,10        | M27500-24ML2T08  |
|                     | Cabin CAN B       | 11,12       | M27500-24ML2T08  |
|                     | Shear Pin Monitor | N/A         | M27500-24ML2T08  |

Table 2 - Main Rotor Slip Ring Assembly Cabin Cable Bundle Interface

[0034] In one embodiment, the main de-ice power cables use 6-gauge 260C wires. For lower temperature rated cable, 4-gauge wires would be required, but the weight of the lower temperature rated cable bundle is significant. As a result, using 6-gauge wiring provides advantages where such use is permitted.

[0035] In one embodiment, main rotor slip ring assembly **100** has the electrical current and voltage ratings illustrated in Table 3 below.

| Ring Number | Function               | Signal Type | Signal Frequency (Hertz) | Rated Current (Amps) | Rated Voltage (Volts) |
|-------------|------------------------|-------------|--------------------------|----------------------|-----------------------|
| 1, 2        | Blade De-Ice Power "A" | Power       | DC <sup>1</sup>          | 100                  | ±135 DC               |
| 3, 4        | Blade De-Ice Power "B" | Power       | DC <sup>1</sup>          | 100                  | ±135 DC               |
| 5, 6        | Low Power "A"          | Power       | DC <sup>1</sup>          | <5                   | 28 DC                 |
| 7, 8        | Low Power "B"          | Power       | DC <sup>1</sup>          | <5                   | 28 DC                 |
| 9, 10       | CAN Bus "A"            | Data        | 1Mbps                    | <1                   | 10V                   |
| 11, 12      | CAN Bus "B"            | Data        | 1Mbps                    | <1                   | 10V                   |

<sup>1</sup> Main rotor deice power is generated from a rectified 400 Hz input

Table 3 - Main Rotor Slip Ring Assembly Current and Voltage Rating

[0036] Table 4 provides the main rotor slip ring current overload capability. The current overload capabilities are for the circuits contained in the main rotor slip rings.

| Slip Ring Size<br>(100% Load) | Percent Load<br>and Required Duration |              |               |
|-------------------------------|---------------------------------------|--------------|---------------|
|                               | 100%<br>Load                          | 110%<br>Load | 1000%<br>Load |
| 100A                          | Continuous                            | Continuous   | 150 msec      |
| Less Than 10A                 | Continuous                            | Continuous   | 2 sec         |

Table 4 - Main Rotor Slip Ring Current Overload

[0037] In addition to providing electrical power and signals to the components mounted on each rotor hub, main rotor slip ring assembly **100** is further configured to monitor the integrity of the bearing assembly that permits the movement of the rotating portions of main rotor slip ring assembly **100** relative to main rotor drum **110**. For example, main rotor slip ring assembly **100** includes a main rotor bearing assembly **120** having a primary main rotor bearing **122** and a redundant secondary main rotor bearing **124** that is coupled to primary main rotor bearing **122** by a first

shear pin **126**. In this configuration, in the event of seizure between rotating and non-rotating parts of main rotor slip ring assembly **100** (bearing seizure, etc.), the torque developed in main rotor slip ring assembly **100** (i.e., between primary main rotor bearing **122** and main rotor drum **110**) can cause first shear pin **126** to shear. Secondary main rotor bearing **124** is then engaged to provide rotatable support for the rotating elements of main rotor slip ring assembly **100** with respect to main rotor drum **110** and to allow free rotation between the rotating elements of main rotor slip ring assembly **100** and main rotor drum **110**. For example, in one particular configuration, the design of first shear pin **126** is selected to shear at a torque between 50 and 100 times the normal torque of the primary bearing. In this way, seizure of the primary bearing will not cause seizure of the slip ring and thus will not damage aircraft wiring connected to the slip ring assembly, nor will it cause mechanical interference with other aircraft components.

[0038] Engagement of any of the slip ring back-up bearings is electrically indicated via a first shear pin monitoring circuit **128** embedded within main rotor drum **110** of main rotor slip ring assembly **100** (e.g., the leads are electrically connected in series in the non-rotating section of main rotor slip ring assembly **100**) and sent down main rotor standpipe assembly **102**. In one non-limiting configuration, first shear pin **126** provides a predetermined resistance of between about 0.25 ohms and 10 ohms when it is intact. If first shear pin monitoring circuit **128** exhibits a resistance that differs significantly from this predetermined normal resistance (e.g., greater than 10 ohms), failure of the shear pin and engagement of secondary main rotor bearing **124** is indicated. In the embodiments of the subject matter disclosed herein, first shear pin monitoring circuit **128** is monitored by the aircraft's Avionics System for indication of bearing seize as evidenced by shear pin shearing. In particular, the aircraft's Avionics System can determine that the first shear pin **126** has broken if a measured resistance differs significantly from the predetermined normal shear pin resistance.

[0039] In still another aspect, the present subject matter provides a configuration for a tail rotor slip ring assembly, generally designated **200** in Figures 6 through 11. Similarly to main rotor slip ring assembly **100** with respect to a main rotor, tail rotor slip ring assembly **200** provides circuit continuity between a stationary side **202** and a rotational side **210** of a tail rotor hub to allow for electrical power and data signals

(e.g., power to de-ice systems) to pass directly to the tail rotor blades. As shown in Figure 10, for example, tail rotor slip ring assembly **200** is configured to be positioned about a tail rotor hub **230** at or near a position from which one or more tail rotor blades **240** extend from tail rotor hub **230**.

[0040] One non-limiting configuration for tail rotor slip ring assembly **200** is illustrated in Figure 6. As illustrated, tail rotor slip ring assembly **200** includes a second electrical connector **204** (e.g., a MIL-DTL-38999 electrical connector) on an aft quadrant of stationary side **202** to accommodate aircraft wiring. Tail rotor slip ring assembly **200** provides one or more un-terminated pigtail harnesses **212** on rotational side **210** of the assembly to accommodate rotor hub wire routing to the tail rotor blade disconnects. Tail rotor slip ring assembly **200** provides mounting provisions for a rotating pickup **214** and a stationary monopole sensor **206** (e.g., Honeywell 3030AN VRS) operable to measure the speed of rotation rotational side **210** with respect to stationary side **202**.

[0041] In one embodiment, tail rotor slip ring assembly **200** has a replaceable brush block assembly, generally designated **203**, which is a separate line replaceable unit (LRU). In the configuration shown in Figures 7-9, for example, brush block assembly **203** is a single piece design, which also contains second electrical connector **204** (e.g. a MIL-DTL-38999 Shell Size G 21-99 connector). In this arrangement, brush block assembly **203** contains one or more second brush assembly **213**. Although it is envisioned within the subject matter herein that each of the one or more second brush assembly **213** is a metal fiber brush constructed of hair-fine metal fibers as described above and shown in Figures 2A and 2B, any of a variety of contact brush configurations known in the art can be used for second brush assembly **213**. Regardless of the particular configuration, each of the one or more second brush assembly **213** is configured to provide high data integrity in high vibration environments, reduced potential for arcing and signal noise, low brush wear, and minimal debris generation.

[0042] In addition to containing one or more second brush assembly **213**, the embodiment of tail rotor slip ring assembly **200** further has blind mate attachment for a bearing shear pin monitoring circuit and the once-per-revolution stationary monopole sensor **206**, which is routed to second electrical connector **204** to reduce cable bundles and connectors. As a result, each of the elements of tail rotor slip ring

assembly **200** that may require periodic maintenance are provided together on brush block assembly **203**. To conduct such maintenance, brush block assembly **203** is inspectable and replaceable, as necessary, at a defined periodic maintenance interval. For example, in the particular embodiment shown in Figure 6, an inspection port **208** can be removable to enable visual inspection of the interface between the stationary elements and rotating elements of tail rotor slip ring assembly **200**. Another example is that inspection port **208** is provided at approximately a 90-degree angle from brush block assembly **203**. Accumulated brush debris is accessible and removable through this port without disassembly of the slip rings.

[0043] Alternatively or in addition, in the embodiments shown in Figure 7 through 9, brush block assembly **203** is removable in its entirety from tail rotor slip ring assembly **200** for maintenance (e.g., repair and or replacement of one or more second brush assembly **213**) or replacement. As a result, brush block assembly **203** is designed to be maintained and/or replaced at defined intervals, but the remainder of tail rotor slip ring assembly **200** is designed to last the life of the helicopter without replacement (although it may be replaced if desired). As discussed above, when using a metal fiber brush design for second brush assembly **213**, even for those elements of brush block assembly **203** that are designed to be replaceable at specified maintenance intervals, very little wear is created on the slip ring drum. Therefore, second brush assembly **213** does not need to be replaced with great frequency. In addition, the metal fiber brush design also generates much less debris as compared to carbon based brush designs. As a result, inspection and maintenance of tail rotor slip ring assembly **200** to remove such debris can be conducted more infrequently compared to currently known conventional slip ring assemblies.

[0044] Figure 11 illustrates a block diagram for one embodiment of tail rotor slip ring assembly **200**. In the embodiment illustrated in Figure 11, second electrical connector **204** is mounted on stationary side **202** of tail rotor slip ring assembly **200**, which does not rotate, and one or more second brush assembly **213** is connected directly to second electrical connector **204**. The one or more second brush assembly create an electrical contact with elements contained on rotational side **210**, which carries cable bundles out to each blade (e.g., via pigtail harnesses **212**). Regarding the particular electrical power and signals that are routed through tail rotor

slip ring assembly **200**, Table 5 illustrates one embodiment with a pinout for second electrical connector **204** (e.g., Mil-DTL-38999 Interface with a de-ice connector):

| MIL-DTL-38999 Pin | Ring # | Function        | Signal Type | Signal Frequency (Hertz) | Rated Current (Amps) | Rated Voltage (Volts) |
|-------------------|--------|-----------------|-------------|--------------------------|----------------------|-----------------------|
| A                 | 1      | Power AA        | Power       | 400                      | 20                   | 115 AC                |
| B                 | 2      | Power AB        | Power       | 400                      | 20                   | 115 AC                |
| C                 | 3      | Power AC        | Power       | 400                      | 20                   | 115 AC                |
| D                 | 4      | Power BA        | Power       | 400                      | 20                   | 115 AC                |
| E                 | 5      | Power BB        | Power       | 400                      | 20                   | 115 AC                |
| F                 | 6      | Power BC        | Power       | 400                      | 20                   | 115 AC                |
| M                 | N/A    | Bearing Monitor | Signal      | DC                       | <1                   | <10V                  |
| K                 | N/A    | Bearing Monitor | Signal      | DC                       | <1                   | <10V                  |

Table 5 - Tail Rotor Slip Ring Assembly Connector Interface

[0045] To ensure high integrity of the electrical power and signals routed through tail rotor slip ring assembly **200**, the number of second brush assemblies **213** used to transmit power is selected to provide redundant transmission paths. As shown in Table 5, for example, quadruple redundant power brushes are provided.

[0046] In one embodiment, Table 6 provides tail rotor slip ring assembly **200** current and voltage rating:

| Ring Number | Function               | Signal Type | Signal Frequency (Hertz) | Rated Current (Amps) | Rated Voltage (Volts) |
|-------------|------------------------|-------------|--------------------------|----------------------|-----------------------|
| 1,2,3       | Blade De-Ice Power "A" | Power       | 400                      | 20                   | 115 AC                |
| 4,5,6       | Blade De-Ice Power "B" | Power       | 400                      | 20                   | 115 AC                |

Table 6 - Tail Rotor Slip Ring Assembly Current and Voltage Rating

[0047] Table 7 provides the tail rotor slip ring current overload capability. The current overload capabilities are for the circuits contained in the tail rotor slip rings:

| Slip Ring Size<br>(100% Load) | Percent Load<br>and Required Duration |              |               |
|-------------------------------|---------------------------------------|--------------|---------------|
|                               | 100%<br>Load                          | 110%<br>Load | 1000%<br>Load |
| 20A                           | Continuous                            | Continuous   | 150 msec      |
| Less Than 10A                 | Continuous                            | Continuous   | 2 sec         |

Table 7 - Tail Rotor Slip Ring Current Overload

[0048] In addition to providing electrical power and signals to the components mounted on each rotor hub, rotational side **210** is connected to a shear pin. The slip ring also has a bearing monitor circuit, which loops through the intermediate stage of each of two nested redundant bearings.

[0049] In this configuration, tail rotor slip ring assembly **200** includes a tail rotor bearing assembly **220** having a primary tail rotor bearing **222** and a redundant tail rotor secondary bearing **224** that is coupled to primary tail rotor bearing **222** by a second shear pin **226**. In this configuration, in the event of seizure between rotating and non-rotating parts of tail rotor slip ring assembly **200** (bearing seizure, etc.), the torque developed in tail rotor slip ring assembly **200** (i.e., between primary tail rotor bearing **222** and rotational side **210**) can cause second shear pin **226** to shear. Secondary tail rotor bearing **224** is then engaged to allow free rotation between the rotational side **210** and stationary side **202**. For example, the design of second shear pin **226** is selected to shear at a torque between 50 and 100 times the normal torque of the primary bearing. In this way, seizure of the primary bearing will not cause seizure of the slip ring and thus will not damage aircraft wiring connected to the slip ring assembly, nor will it cause mechanical interference with other aircraft components.

[0050] Engagement of any of the slip ring back-up bearings is electrically indicated via a second shear pin monitoring circuit **228** embedded within stationary side **202** of tail rotor slip ring assembly **200** and connected to second electrical connector **204**. In one particular configuration, a resistance measured in second shear pin monitoring circuit **228** is compared to a normal resistance across second shear pin **226** (e.g., between about 0.25 ohms and 10 ohms). A measured resistance that differs significantly from the expected normal resistance (e.g., greater

than 10 ohms) indicates that second shear pin **226** has failed. In the embodiments of the subject matter disclosed herein, second shear pin monitoring circuit **228** is monitored by the aircraft's Integrated Avionics System for indication of bearing seize as evidenced by shear pin shearing.

[0051] Regardless of the particular configuration, the main and tail rotor slip ring assemblies are designed to operate continuously in the designed direction of rotation. For example, main rotor slip ring assembly **100** operates continuously at various combinations within the ranges of about 0 RPM to about 350 RPM, and main rotor slip ring assembly **100** operates at about 500 RPM for 30 minutes without degradation of performance. Tail rotor slip ring assembly **200** operates continuously at various combinations within the ranges of about 0 RPM to about 1500 RPM, and tail rotor slip ring assembly **200** operate at about 1750 RPM for 30 minutes without degradation of performance. The torque between the rotating and non-rotating parts of each slip ring assembly does not exceed about 0.6 foot-pounds at any RPM defined above for main rotor slip ring assembly **100** and tail rotor slip ring assembly **200**. When either unit is unpowered, the respective slip ring can tolerate rotation in either clockwise or counterclockwise directions. The slip ring assemblies, minus the external wire cabling, are configured to be balanced such that the center of mass is within about 0.25 inches of the centerline of rotation.

[0052] In some embodiments, main rotor slip ring assembly **100** and standpipe assembly, and tail rotor slip ring assembly **200** and brush block assembly **203** are all line replaceable units (LRUs). As LRUs, each LRU incorporates electrical grounding features such that ground loops and common ground returns are avoided for signal and power circuits, effective shielding is provided for signal circuits, electromagnetic interference (EMI) is minimized, and personnel are protected from electrical hazards. Within the LRUs, the primary power returns, secondary power returns, and signal returns are not connected to the chassis. Rather, the LRUs are designed with more than 100 kilo ohms of isolation between the primary power return, the secondary power return, and the chassis case.

[0053] Main and tail rotor slip ring assemblies **100** and **200** are configured to require no on-aircraft mechanical adjustment or shimming of any LRU due to removal or replacement of any LRU. Instead, main and tail rotor slip ring assemblies **100** and **200** are configured to allow maintenance to be performed without inducing

faults as a result of handling. As discussed above, main rotor slip ring assembly **100** and tail rotor slip ring assembly **200** have access panels (e.g., access port **106** and inspection port **208**, respectively) for inspecting the brushes and drum of each slip ring assembly. If the operator or maintenance personnel choose to, brush block assembly **203** of tail rotor slip ring assembly **200** is replaceable. Once removed, visual inspection of the brushes, brush block assembly, and the slip ring can be performed. In addition, the failure of any one LRU, such as the slip rings and standpipe, will not cause a failure to any other LRU.

[0054] Each slip ring assembly has a minimum operating service life of about 10,000 hours. This service life anticipates periodic maintenance intervals. As discussed above, seizure between rotating and non-rotating parts of either main rotor slip ring assembly **100** and tail rotor slip ring assembly **200** slip ring assembly (e.g., bearing seizure, etc.) will not damage aircraft wiring connected to the respective slip ring assembly, nor will it cause mechanical interference with other aircraft components. In addition, wear of the metal fiber brushes and other slip ring components are designed to prevent degradation the electrical or mechanical performance of the slip ring assembly between maintenance cycles.

[0055] In this regard, main and tail rotor slip ring assemblies **100** and **200** are designed to minimize maintenance/support requirements including the need for special tools, support equipment, personnel skills, manpower, and elapsed maintenance time. In one embodiment, the preferred Maintenance Man Hour per Flight Hour (MMH/FH), including both scheduled and unscheduled maintenance actions for main rotor slip ring assembly **100** and standpipe assembly **102** is about a maximum of 0.00040. For the same conditions, the MMH/FH, including both scheduled and unscheduled maintenance actions for tail rotor slip ring assembly **200** is about a maximum of 0.00333.

[0056] In one embodiment, the Mean Time to Repair (MTTR) for the combination of main rotor slip ring assembly **100** and standpipe assembly **102** is about a maximum of 0.50 hours with an average maintenance crew size of 1.0 maintainer. For the same conditions, the MTTR for tail rotor slip ring assembly **200** is preferably about a maximum of 0.75 hours with an average maintenance crew size of 1.0 maintainer.

[0057] Similarly, the system is designed with a Mean Time Between Corrective Maintenance (MTBCM). In one embodiment, the inherent MTBCM of main rotor slip ring assembly **100** and standpipe assembly **102** is about a minimum of 10,000 flight hours. A failure is defined as any inherent deficiency that necessitates either immediate or deferred maintenance to correct. In some embodiments, scheduled maintenance for main rotor slip ring assembly **100** occurs in intervals of not less than 1,600 operating hours. Likewise, the inherent MTBCM of tail rotor slip ring assembly **200** is about a minimum of 3,000 flight hours, with a failure being defined as any inherent deficiency that necessitates either immediate or deferred maintenance to correct. In some embodiments, scheduled maintenance for tail rotor slip ring assembly **200** occurs in intervals of not less than 400 operating hours.

[0058] In the embodiments disclosed herein, main rotor slip ring assembly **100** (and standpipe assembly **102**) and tail rotor slip ring assembly **200** (and brush block assembly **203**) are capable of operating across a variety of extreme temperatures. In one embodiment, the slip rings maintain their performance in operating environments in ambient temperatures between about  $-49^{\circ}\text{F}$  ( $-45^{\circ}\text{C}$ ) to about  $+39^{\circ}\text{F}$  ( $4^{\circ}\text{C}$ ) for active heating conditions and about  $-49^{\circ}\text{F}$  ( $-45^{\circ}\text{C}$ ) to about  $158^{\circ}\text{F}$  ( $70^{\circ}\text{C}$ ) for monitoring mode conditions. In another embodiment, the slip rings maintain their performance in non-operating environments following long periods of exposure to temperature extremes between about  $-65^{\circ}\text{F}$  ( $-54^{\circ}\text{C}$ ) to about  $185^{\circ}\text{F}$  ( $85^{\circ}\text{C}$ ). The slip ring equipment will operate without functional degradation over the range of altitudes between about  $-2,000$  feet to about  $+20,000$  feet for active heating conditions and about  $-2,000$  feet to about  $25,000$  feet for monitoring mode conditions. The slip ring is capable of operating without any component or system degradation in performance, and will sustain no physical damage during exposure to operations in ice and freezing rain conditions.

[0059] In one embodiment, main rotor slip ring assembly **100** (and standpipe assembly **102**) and tail rotor slip ring assembly **200** (and brush block assembly **203**) are capable of operating without degradation in any specified performance, and will sustain no physical damage during and after prolonged exposure to extremely high humidity levels, as encountered in tropical areas.

[0060] In one embodiment, the slip ring equipment is capable of operating without degradation in performance, and will sustain no physical damage, after exposure to

the corrosive effects of a salt fog atmosphere. Similarly, the slip ring equipment is capable of operating without degradation in performance and will sustain no physical damage after exposure to blowing sand and dust particles that may be present within the aircraft.

**[0061]** In one embodiment, the slip ring equipment provides no nutrients in material, coating, or contaminant form to support fungal growth, and will operate as specified after exposure to the fungal growth that may be expected to be encountered in tropical areas.

**[0062]** Other embodiments of the current invention will be apparent to those skilled in the art from a consideration of this specification or practice of the invention disclosed herein. Thus, the foregoing specification is considered merely exemplary of the current invention with the true scope thereof being defined by the following claims.

## CLAIMS

What is claimed is:

1. A slip ring assembly, comprising:
  - a stationary element;
  - a rotating element rotatable with respect to the stationary element; and
  - one or more metal fiber brushes on one of the stationary element or the rotating element, each of the one or more metal fiber brushes comprising a plurality of metal fibers;wherein the one or more metal fiber brushes are configured to transmit one or more of electrical power or data between the stationary element and the rotating element.
2. The improved slip ring assembly of claim 1, wherein the stationary element is connected to a chassis of a helicopter; and
  - wherein the rotating element is connected to a rotor hub of the helicopter.
3. The slip ring assembly of claim 1, wherein the one or more metal fiber brushes have a current density of about 250 Amps/sq-in or greater.
4. The slip ring assembly of claim 1, wherein a voltage drop across the one or more metal fiber brushes between the stationary element and the rotating element is about 26 millivolts or less.
5. The slip ring assembly of claim 1, comprising a bearing assembly coupled between the stationary element and the rotating element, the bearing assembly comprising:
  - a primary bearing;
  - a secondary bearing;
  - a shear pin coupling the secondary bearing to the primary bearing; and
  - an electrical monitoring circuit in communication with the shear pin.

6. The slip ring assembly of claim 6, wherein the second bearing provides rotatable support for the rotating element with respect to the stationary element if the shear pin is broken.
7. The slip ring assembly of claim 5, wherein the shear pin provides a predetermined resistance when the shear pin is intact.
8. The slip ring assembly of claim 7, wherein the predetermined resistance is between about 0.25 ohms and 10 ohms.
9. The slip ring assembly of claim 7, wherein the electrical monitoring circuit is configured to monitor a measured resistance of the shear pin; and  
wherein the electrical monitoring circuit is configured to indicate that the shear pin has broken when the measured resistance of the shear pin differs from the predetermined resistance.
10. The slip ring assembly of claim 1, wherein the one or more metal fiber brushes comprise a replaceable brush block that is selectively connectible to the respective one of the stationary element or the rotating element.
11. The slip ring assembly of claim 10, comprising an electrical connector configured for electrically coupling the one or more metal fiber brushes to an electrical component connected to the slip ring assembly.
12. The slip ring assembly of claim 11, wherein the electrical component connected to the slip ring assembly comprises an ice protection system.
13. A slip ring assembly, comprising:
  - a stationary element;
  - a rotating element rotatable with respect to the stationary element;
  - a bearing assembly coupled between the stationary element and the rotating element, the bearing assembly comprising:
    - a primary bearing;

a secondary bearing;  
a shear pin coupling the secondary bearing to the primary bearing; and  
an electrical monitoring circuit in communication with the shear pin; and  
one or more contact brushes on one of the stationary element or the rotating element, the one or more contact brushes being configured to transmit one or more of electrical power or data between the stationary element and the rotating element.

14. The slip ring assembly of claim 13, wherein the second bearing provides rotatable support for the rotating element with respect to the stationary element if the shear pin is broken.

15. The slip ring assembly of claim 13, wherein the shear pin provides a predetermined resistance when the shear pin is intact.

16. The slip ring assembly of claim 15, wherein the electrical monitoring circuit is configured to monitor a measured resistance of the shear pin; and  
wherein the electrical monitoring circuit is configured to indicate that the shear pin has broken when the measured resistance of the shear pin differs from the predetermined resistance.

17. A method for transmitting one or more of electrical power or data between a stationary element and a rotating element, the method comprising:

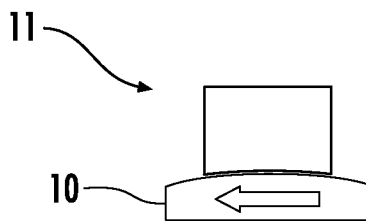
coupling a bearing assembly between a stationary element and a rotating element rotatable with respect to the stationary element, the bearing assembly comprising:

a primary bearing;  
a secondary bearing; and  
a shear pin coupling the secondary bearing to the primary bearing;  
measuring a resistance of the shear pin;  
comparing the resistance of the shear pin to a predetermined resistance corresponding to an intact state of the shear pin; and  
indicating that the shear pin has broken if the resistance of the shear pin differs from the predetermined resistance.

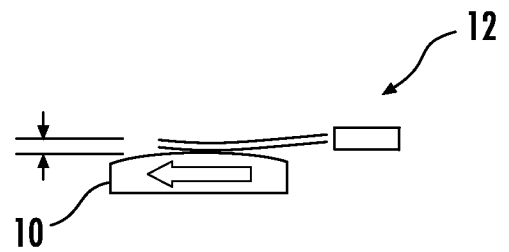
18. The method of claim 17, wherein measuring the resistance of the shear pin comprises measuring the resistance through an electrical monitoring circuit in communication with the shear pin.

19. The method of claim 17, wherein the predetermined resistance is between about 0.25 ohms and 10 ohms.

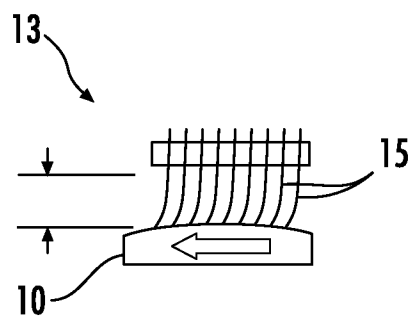
20. The method of claim 19, wherein indicating that the shear pin has broken comprises indicating that the resistance of the shear pin exceeds about 10 ohms.



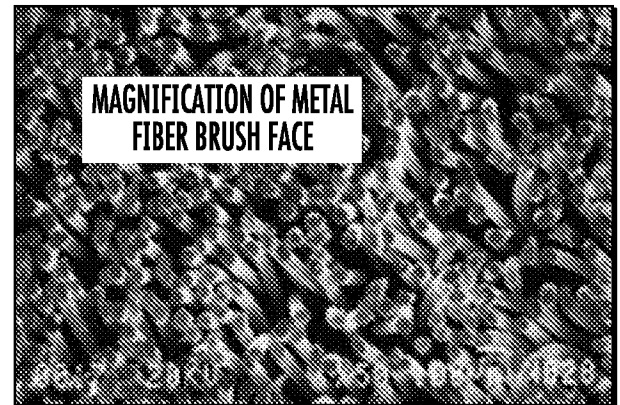
**FIG. 1A**



**FIG. 1B**

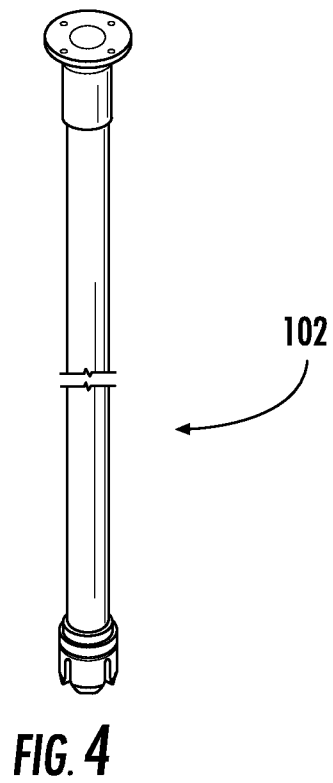
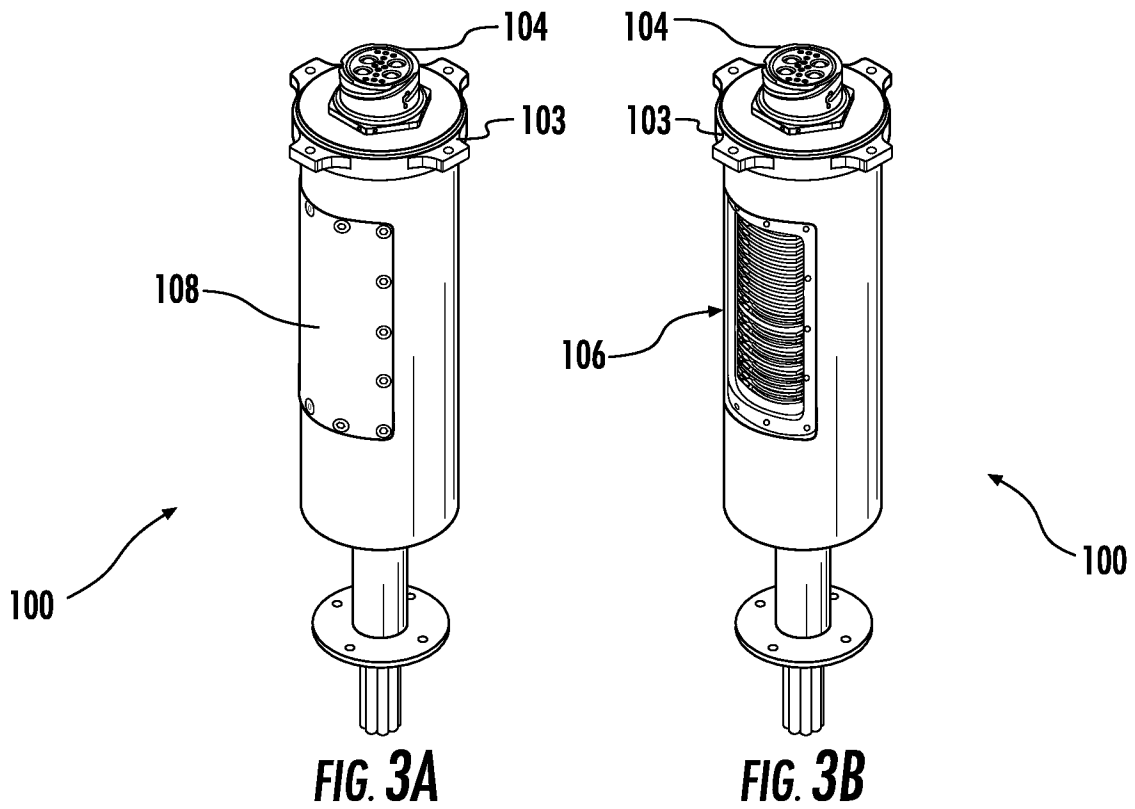


**FIG. 2A**



**FIG. 2B**

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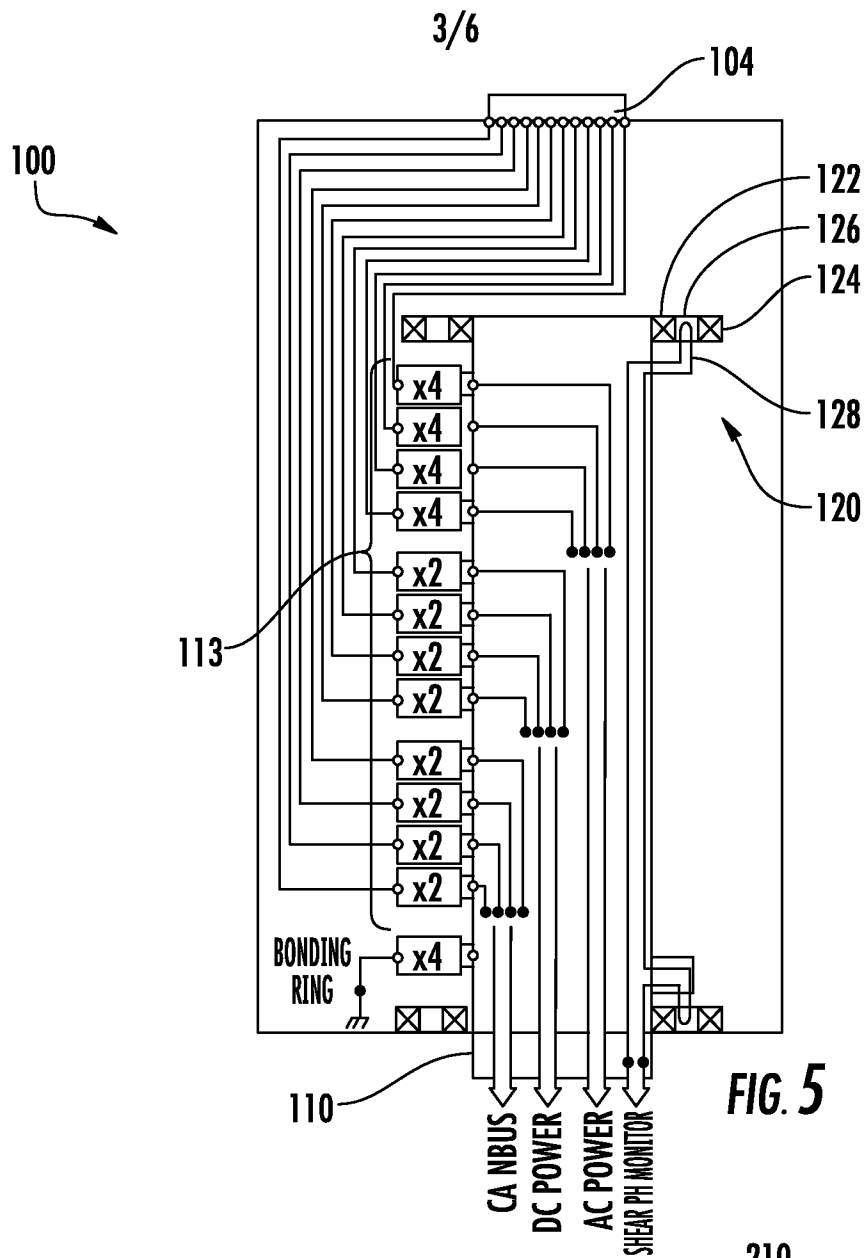


FIG. 5

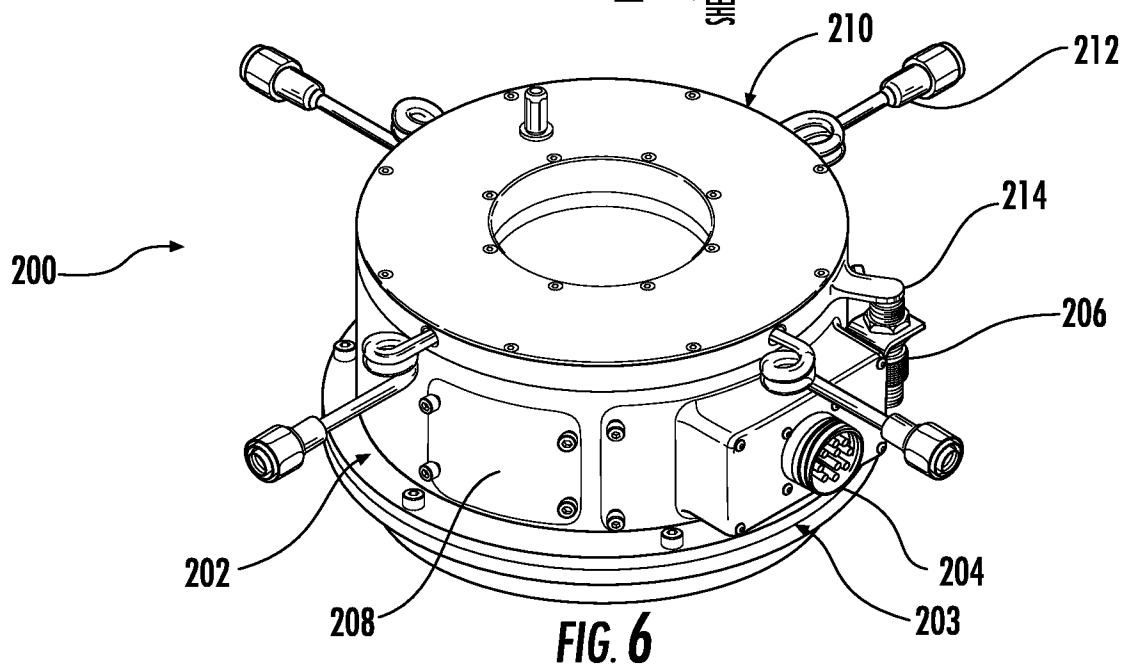
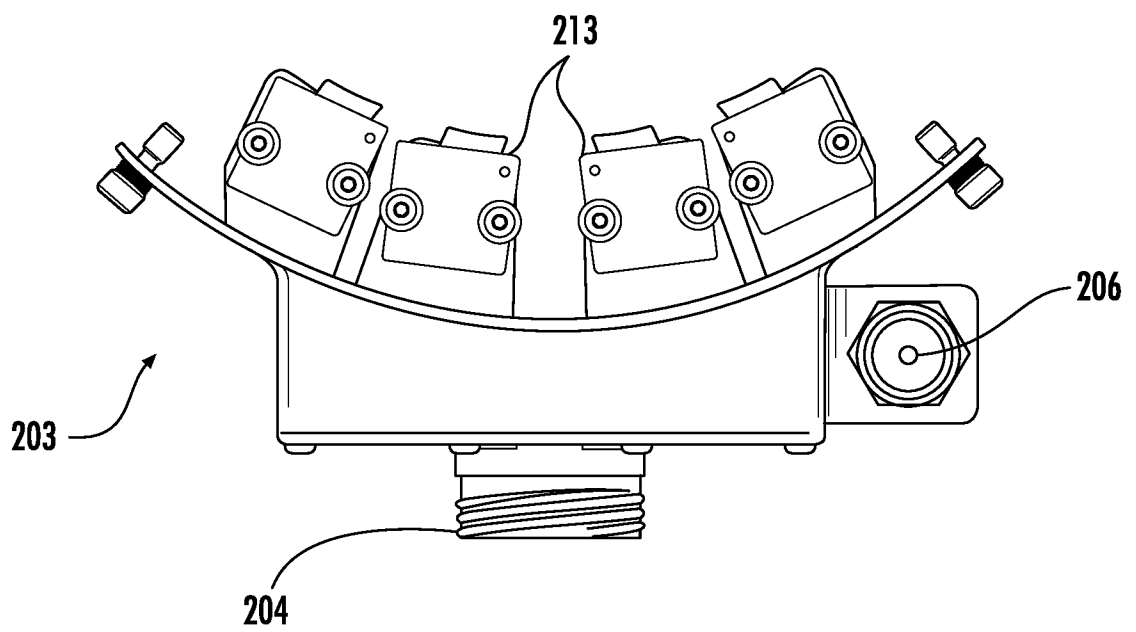
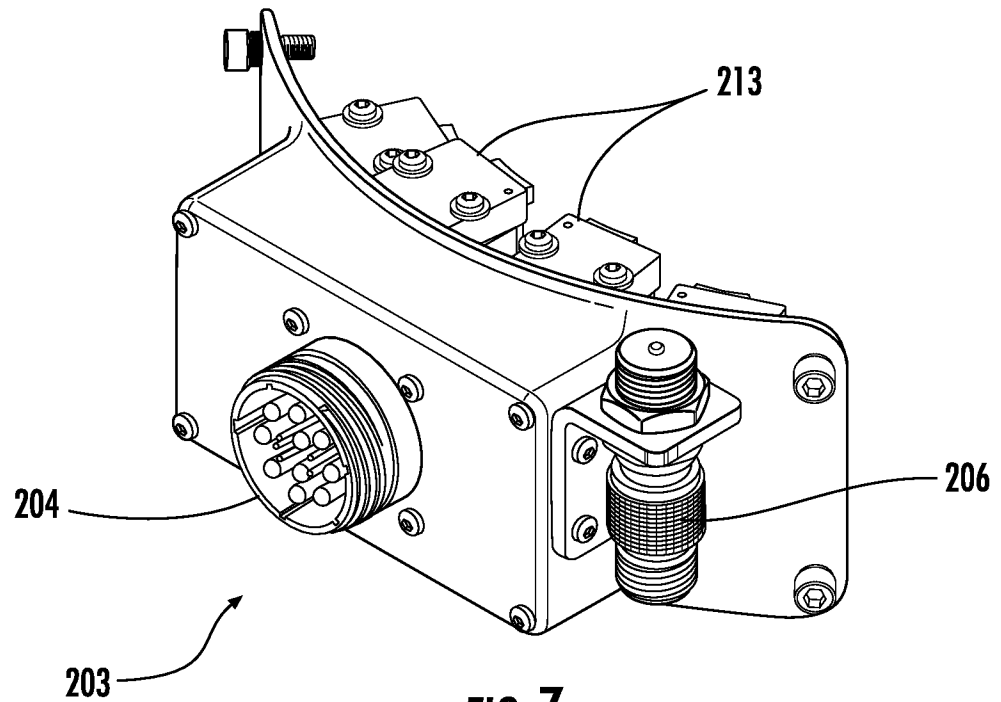
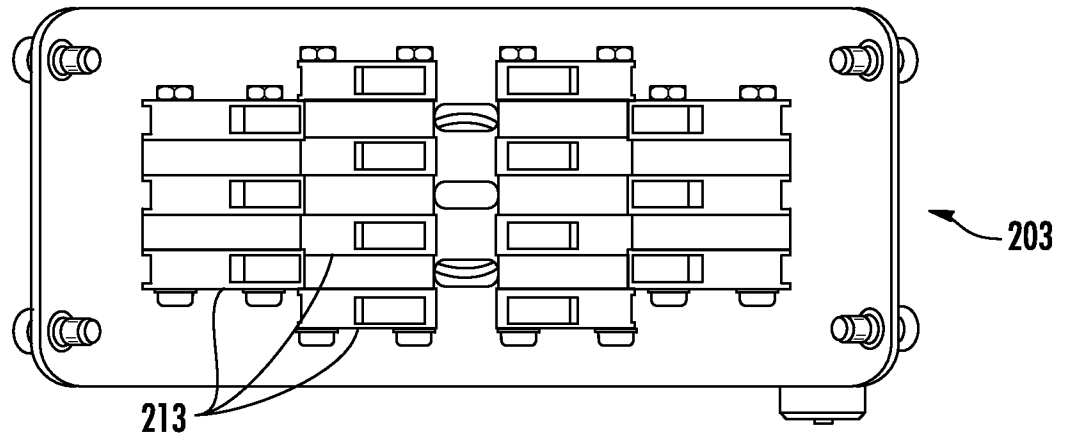


FIG. 6

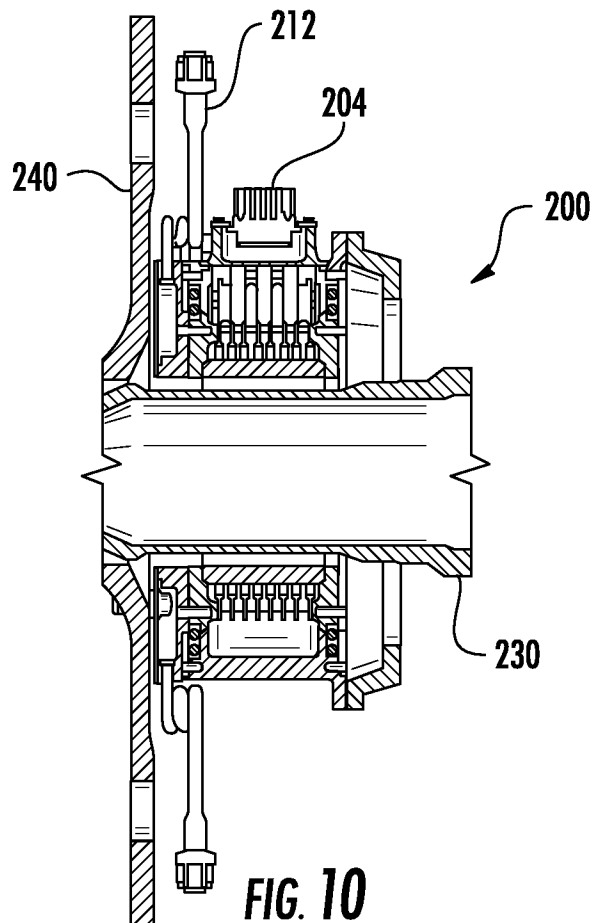
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**FIG. 9**



**FIG. 10**

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