

(19) World Intellectual Property
Organization
International Bureau



(43) International Publication Date
3 March 2005 (03.03.2005)

PCT

(10) International Publication Number
WO 2005/019030 A2

- (51) International Patent Classification⁷: **B64D**
- (21) International Application Number:
PCT/US2004/007331
- (22) International Filing Date: 10 March 2004 (10.03.2004)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
10/421,325 23 April 2003 (23.04.2003) US
- (71) Applicant (for all designated States except US): **LORD CORPORATION** [US/US]; 111 Lord Drive, PO Box 8012, Cary, North Carolina 27512-8012 (US).
- (72) Inventors: **ALTIERI, Russell, E.**; 129 Longbridge Drive, Cary, North Carolina 27511 (US). **KUHN, James, F.**; 5337 Woodward Drive, Erie, Pennsylvania 16509 (US). **JOLLY, Mark, R.**; Post Office Box 280, Holly Springs, North Carolina 27540 (US). **SOUTHWARD, Steve, C.**; 4117 Windling Oak Way, Apex, North Carolina 27539 (US). **BADRE-ALAM, Askari**; 205 Country Valley Court, Apex, North Carolina 27502 (US). **FOWLER, Leslie, P.**; 6008 Tierra Street NE, Apt. B, Albuquerque, New Mexico 87111 (US).
- (74) Agent: **MURPHY, Edward, F., III**; Lord Corporation, 111 Lord Drive, PO Box 8012, Cary, North Carolina 27512-8012 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— without international search report and to be republished upon receipt of that report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.



WO 2005/019030 A2

(54) Title: AIRCRAFT VEHICULAR PROPULSION SYSTEM MONITORING DEVICE AND METHOD

(57) Abstract: Methods and systems for monitoring rotating shafts and couplings in an aircraft vehicle propulsion system is described. The measurement system/method provides for accurate and precise monitoring of a rotating shaft flexible coupling in a fixed wing aircraft vehicle propulsion system. The measuring system/method provides for a high reliability short take off vertical landing fixed wing aircraft in which the vehicle's dynamically rotating drive shaft system and couplings are monitored in real time. The vehicular shaft coupling misalignment measuring system utilizes multiple positional sensors to provide highly reliable and precise determination of the dynamic characteristics of the rotating sensor target components of the propulsion system drive shaft. The relative position of the sensors is rigidly fixed externally from the rotating targets with a structural frame. The misalignment measuring system drive shaft flexible coupling which relates to a critical performance of rotating shaft coupling in the operation of an aircraft vehicle. The method/system provides for monitoring a rotating drive shaft system and dynamically measuring a rotating drive shaft coupling in a fixed wing aircraft propulsion system.

AIRCRAFT VEHICULAR PROPULSION SYSTEM MONITORING DEVICE AND METHOD

5

[0001] This invention was made with government support under contract (###F135 F-35JointStrikeFighter##), awarded by the United States Department of Defense. The United States Government may have certain rights in this invention.

Field of the Invention

10 [0002] The present invention relates to a method/system for monitoring a rotating drive shaft system. More particularly the invention relates to a method/system for dynamically monitoring a rotating coupling in an aircraft.

[0003] Additional features and advantages of the invention will be set forth in the detailed description which follows, and in part will be readily apparent to those skilled
15 in the art from that description or recognized by practicing the invention as described herein, including the detailed description which follows, the claims, as well as the appended drawings.

[0004] It is to be understood that both the foregoing general description and the following detailed description are exemplary of the invention, and are intended to
20 provide an overview or framework for understanding the nature and character of the invention as it is claimed. The accompanying drawings are included to provide a further understanding of the invention, and are incorporated in and constitute a part of this specification. The drawings illustrate various embodiments of the invention, and together with the description serve to explain the principals and operation of the
25 invention.

Background of the Invention

[0005] Reference will now be made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings.

[0006] There is a need for a vehicular system and method of accurately and economically monitoring a rotating shaft coupling of a vehicle high speed rotating shaft system. There is a need for an economically feasible method of dynamically measuring a rotating shaft of a vehicle to provide dynamic vehicular real time monitoring of rotating positional characteristics of the rotating shaft and its rotating members. There is a need for a robust system and method of measuring rotational positional dynamic characteristics of a rotating drive shaft coupling in the propulsion system of a fixed wing vertical short take off and landing aircraft vehicle. There is a need for an economic aircraft vehicular propulsion system monitoring device and method.

Summary of the Invention

15

[0007] The invention includes a V/STOL (vertical short take off and landing) fixed wing aircraft having an aircraft propulsion system with an engine and a lift fan, with the engine coupled to the lift fan with at least one drive shaft and at least one flexible coupling, the flexible coupling comprised of a first coupling hub member including a magnetic target and a second coupling hub member including a magnetic target, the first coupling hub member flexibly coupled to the second coupling hub member, the flexible coupling providing for a mechanical transfer of motive power from the engine to the lift fan, and a flexible coupling sensor rigid collar misalignment measuring system encompassing the flexible coupling, the flexible coupling sensor rigid collar comprised of a first magnetostrictive sensor, a second magnetostrictive sensor, and a third magnetostrictive sensor, the first magnetostrictive sensor, the second magnetostrictive sensor, and the third magnetostrictive sensor rigidly fixed around the collar with the sensors external of the coupling hub member magnetic targets, the first magnetostrictive sensor fixed a first fixed angular distance from the second

magnetostrictive sensor, the third magnetostrictive sensor fixed a second fixed angular distance from the second magnetostrictive sensor. The flexible coupling sensor rigid collar misalignment measuring system magnetostrictive sensors magnetically monitor a position of the first coupling hub member relative to a position of the second coupling hub member to provide a misalignment measurement of the flexible coupling which relates to a performance of the coupling in the V/STOL fixed wing aircraft.

[0008] The invention includes an aircraft vehicle propulsion system, with the vehicle propulsion system comprising an engine and a drive unit propeller, with the engine coupled to the propeller with a drive shaft and a flexible coupling, the flexible coupling comprised of a first coupling hub member and a second coupling hub member, the first coupling hub member flexibly coupled to the second coupling hub member, the flexible coupling providing for a mechanical transfer of motive power from the engine to the propeller, a flexible coupling sensor rigid collar measurement system encompassing the flexible coupling, the flexible coupling sensor rigid collar measurement system comprised of a first sensor, a second sensor, and a third sensor, the first sensor, the second sensor, and the third sensor angularly spaced and rigidly fixed around the collar wherein the sensor rigid collar system monitors the flexible coupling and provides for a noncontact measuring of a plurality of positional characteristics of the first coupling hub member and the second coupling hub member which relate to the transfer of motive power.

[0009] The invention includes a method of monitoring a vehicular propulsion system drive shaft flexible coupling. The method comprises providing a vehicular propulsion system drive shaft flexible coupling with a first coupling hub member with a sensor target and a second coupling hub member with a sensor target, providing a flexible coupling sensor rigid collar measurement system with a first sensor, a second sensor, and a third sensor, encompassing the first coupling hub member sensor target and the second coupling hub member sensor target with the flexible coupling sensor rigid collar measurement system while inhibiting a physical contact between the

flexible coupling sensor rigid collar measurement system and the vehicular propulsion system drive shaft flexible coupling, with the first sensor, the second sensor, and the third sensor angularly spaced around and external from the flexible coupling, and noncontactingly measuring a plurality of positional characteristics of the first coupling
5 hub member and the second coupling hub member to monitor a performance of the vehicular propulsion system drive shaft flexible coupling which relates to a transfer of motive power through the vehicular propulsion system drive shaft flexible coupling.

10 **[0010]** The invention includes a method of monitoring a coupling drive shaft system of a vehicle. The method including providing a vehicle drive shaft coupling system with a first rotating member with a sensor target and a second rotating member with a sensor target, providing a sensor measurement system with a first sensor, a second sensor, and a third sensor, encompassing said first rotating member sensor target and
15 said second rotating member sensor target with said sensor measurement system while inhibiting a physical contact between said measurement system and said rotating members, with said first sensor, said second sensor, and said third sensor angularly spaced around said rotating members with an angular distance less than 120 degrees, noncontactingly measuring a plurality of rotating positional characteristics of said first
20 rotating member and said second rotating member to monitor a performance of said vehicle drive shaft system which relates to a transfer of motive power through said drive shaft system, providing for a correction change in said vehicle drive shaft system when a measured rotating positional characteristic performance of said drive shaft system exceeds a measured rotating positional characteristic performance
25 limitation for the vehicle.

[0011] The invention includes a method of monitoring a vehicle drive shaft system. The method includes providing a vehicle drive shaft system with a first rotating
30 member with a magnetic sensor target and providing a sensor rigid measurement system with a magnetically biased magnetostrictive sensor proximate the first rotating

member sensor target while inhibiting a physical contact between the measurement system magnetostrictive sensor and the rotating member, magnetostrictively measuring a rotating positional characteristic of the first rotating member to monitor a performance of the vehicle drive shaft system.

5

[0012] The invention includes an aircraft vehicle rotating shaft measurement system and method for noncontactingly monitoring a rotating member including a magnetic sensor target, with the vehicular rotating shaft measurement system including a sensor rigid collar comprised of a first magnetostrictive sensor. The first magnetostrictive sensor is rigidly fixed on the sensor rigid collar proximate the rotating member, wherein the sensor rigid collar measurement system first magnetostrictive sensor noncontactingly magnetostrictively monitors a position of the rotating member sensor target to provide a measurement of a rotating positional characteristic of the first rotating member to monitor a performance of the aircraft vehicle rotating member.

15

Brief Description of the Drawings

- [0013] FIG. 1 A-B show an embodiment of the invention.
- [0014] FIG 2 A-B show an embodiment of the invention.
- [0015] FIG. 3 shows an embodiment of the invention.
- 20 [0016] FIG. 4 shows an embodiment of the invention.
- [0017] FIG. 5 A – D show and embodiment of the invention.
- [0018] FIG. 6 A – C show an embodiment of the invention.
- [0019] FIG. 7 shows an embodiment of the invention.
- [0020] FIG. 8 shows an embodiment of the invention.
- 25 [0021] FIG. 9 shows an embodiment of the invention.
- [0022] FIG. 10 shows an embodiment of the invention.
- [0023] FIG. 11 shows an embodiment of the invention.

Detailed Description of the Preferred Embodiment

[0024] The invention includes a short take off and vertical landing (V/STOL Vertical Short Take Off and Landing) fixed wing aircraft having an aircraft propulsion system with an engine and a lift fan, with the engine coupled to the lift fan with at least one drive shaft and at least one flexible coupling, the flexible coupling comprised of a first coupling hub member including a magnetic target and a second coupling hub member including a magnetic target, the first coupling hub member flexibly coupled to the second coupling hub member, the flexible coupling providing for a mechanical transfer of motive power from the engine to the lift fan, and a flexible coupling sensor rigid collar misalignment measuring system encompassing the flexible coupling, the flexible coupling sensor rigid collar comprised of a first magnetostrictive sensor, a second magnetostrictive sensor, and a third magnetostrictive sensor, the first magnetostrictive sensor, the second magnetostrictive sensor, and the third magnetostrictive sensor rigidly fixed around the collar, the first magnetostrictive sensor fixed a first fixed angular distance from the second magnetostrictive sensor, the third magnetostrictive sensor fixed a second fixed angular distance from the second magnetostrictive sensor. The flexible coupling sensor rigid collar misalignment measuring system magnetostrictive sensors magnetically monitor a position of the first coupling hub member relative to a position of the second coupling hub member to provide a misalignment measurement of the flexible coupling which relates to a performance of the coupling in the V/STOL fixed wing aircraft.

[0025] As shown in FIG. 1, the invention includes a short take off and vertical landing (V/STOL Vertical Short Take Off and Landing) fixed wing aircraft 20 having an aircraft propulsion system 22 with an engine 24 and a lift fan 26, with the engine coupled to the lift fan with at least one drive shaft 28 and at least one flexible coupling 30. As shown in FIG. 1B, flexible coupling 30 is comprised of a first coupling hub member 32 and a second coupling hub member 34. The coupling hub members include sensor targets 36, preferably the sensor targets have magnetic properties, and preferably are comprised of a magnetically conducting material or are comprised of at

least one magnet. The preferred magnetically conducting material are ferrous, preferably ferrous metals of iron or steel. The preferred at least one magnet is a permanent magnet. Sensor targets 36 preferably are electromagnetic (EM) radiation spectrum detectable sensor targets which can be detected by electromagnetic sensors

5 40, most preferably sensor targets 36 are magnetic property targets which can be detected by an EM magnetostrictive sensor 40. The first coupling hub member 32 including its sensors target 36 is flexibly coupled to the second coupling hub member 34 which includes a sensor target 36 with the flexible coupling providing for a mechanical transfer of motive power from engine 24 to lift fan 26. The invention

10 includes a coupling sensor rigid collar misalignment measuring system 38 encompassing flexible coupling 30. Flexible coupling sensor rigid collar measuring system 38 is comprised of a first EM sensor 40, a second EM sensor 40, and a third EM sensor 40. Preferably, the EM sensors 40 are magnetostrictive sensors. First, second, and third magnetostrictive sensors 40 are rigidly fixed around collar 38 with

15 the magnetostrictive sensors external from the magnetostrictive sensor targets 36 with first sensor 40 fixed a first fixed angular spacing distance from second sensor 40 and third sensor 40 fixed a second fixed angular spacing distance from second sensor 40. Preferably first, second, and third magnetostrictive sensors 40 are equally spaced apart with the first fixed angular spacing distance equal to the second fixed angular

20 spacing distance. Sensors 40 are rigidly fixed and spaced apart at angular spacing distances around collar 38 to provide for sensing first coupling hub member 32 and second coupling hub member 34. First, second, and third magnetostrictive sensors 40 are spaced apart and external from sensor targets 36 which sensors 40 detecting the position of sensor targets 36 along their longitudinal lengths. First, second, and third

25 magnetostrictive sensors 40 are angularly spaced around sensor targets 36 with sensors 40 detecting the position of sensor targets 36 along their longitudinal magnetostrictive waveguide body lengths to provide a first measured distance between the sensor targets 36, a second measured distance between the sensor targets 36, and a third measured distance between the sensor targets 36, that provide a plurality of

30 simultaneous measured distances from the rotating shaft first coupling hub member 32 to the rotating shaft second coupling hub member 34 that are than transformed into an

angular misalignment angle and an axial displacement distance for the rotating shaft coupling 30. In an embodiment as shown in FIG. 2, the fixed angular distances are 120°. Preferably fixed angular distances spacing of sensors 40 is at least 45°, and preferably less than 120°. Preferably the fixed angular distance of sensors 40 is in the range between 60° to 120°. Preferably, sensor rigid collar measuring system 38 has at least three sensors 40. In a preferred embodiment sensor rigid collar measuring system 38 has four sensors 40. In a preferred embodiment sensor rigid collar measuring system 38 has five sensors 40. Preferably rigid collar measuring system 38 has “n” sensors with $n \geq 3$ and the “n” sensors separated by a fixed angular distance ϕ_n with $\phi_n \geq 90^\circ / (n - 1)$, more preferably $\phi_n \geq 120^\circ / (n - 1)$. Magnetostrictive sensors 40 rigidly fixed and spaced apart on collar 38 utilize magnetism to monitor a position of first coupling hub member 32 relative to a position of a second coupling hub member 34 to provide a misalignment measurement of flexible coupling 30 with relates to the performance of coupling 30 in aircraft vehicle 20 and the transfer of propulsion system power from engine 24 to propelling drive unit rotor lift fan 26. Sensors 40 magnetically detect the position of the coupling hub member target, preferably utilizing magnetostriction deformation within the sensors.

[0026] As shown in FIG. 1 – 2, the engine 24 output shaft is coupled through a first coupling 30 with a coupling sensor rigid collar misalignment measurement system 38 to a first end of drive shaft 28. At the other end of rotating drive shaft 28, drive shaft 28 is coupled through a second rotating coupling 30 with a coupling sensor rigid collar misalignment measurement system 38 to the rotating input shaft of lift fan 26 with engine 24 driving the rotation of lift fan 26. The second coupling shaft is inputted into a clutch that turns lift fan 26 that provides vertical thrust for aircraft vehicle 20 that allows for short take off and vertical landing of the aircraft. Coupling sensor rigid collar measurement system 38 provides accurate and precise noncontact measuring and monitoring of the performance of coupling 30 in the operation of the aircraft. The flexible coupling sensor rigid collar misalignment measuring system magnetostrictive sensors 40 magnetically monitor a position of the first coupling hub

member 32 relative to a position of the second coupling hub member 34 to provide a misalignment measurement of the flexible coupling 30, and its drive shafts, which relates to the performance of the coupling in the aircraft. FIG. 3 shows an embodiment of the invention with three magnetostrictive sensors 40 equally spaced
5 around the collar of coupling sensor rigid misalignment measurement system 38 with the sensors fixed with an angular distance of 120 degrees. FIG. 4 shows magnetostrictive sensor 40 noncontactingly electromagnetically sensing hub member sensor target 36 with the interaction of magnetic fields. In a preferred embodiment of the invention the magnetostrictive sensor 40 is used to magnetostrictively determine
10 the location of magnetic ring 44 of sensor target 36 along the longitudinal length of magnetostrictive sensor element body. Preferably the magnetostrictive sensors 40 are used to determine the location of two separated rotating shaft coupling hub members (32,34) by magnetostrictively determining the location of two magnetic rings 44 of two separated rotating shaft sensor targets 36 along the longitudinal length of the
15 magnetostrictive sensor element body. An electromagnetic interrogation pulse from the magnetostrictive sensor element head forms an interrogation pulse magnetic field along the entire length of the sensor element body which interacts with the rotating sensor target 36 magnetic field of the coupling hub sensor target magnetic ring 44 to form a magnetically induced strain pulse wave in the sensor 40. From its interacting
20 magnetic fields (interaction of interrogation pulse magnetic field with the magnetic field of the rotating coupling hub sensor target magnetic ring) induced origination point the magnetically induced strain pulse wave travels at sonic speed along the magnetostrictive sensor waveguide body length to the sensor element detection head sense EM coil. The magnetically induced strain pulse wave travel time is used to
25 determine the length of the travel along the sensor 40 that indicates the position of the induced origination point along the length of sensor waveguide body and the position of the coupling hub sensor target magnetic ring. Preferably the travel times of two magnetically induced strain pulse waves from the two separated sensor target magnetic rings 44 is utilized to monitor the separation distance between the two
30 separated rotating shaft coupling hub members (32,34).

[0027] FIG. 5A-D show embodiments of the invention which utilize a magnetically biased magnetostrictive sensor 40 to magnetostrictively detect the magnetic property sensor target 36 of rotating coupling hub member 32. Bias magnet 50 is provided proximate magnetostrictive sensor 40 to produce a magnetic field proximate magnetically conducting ferrous material hub member sensor target 36. Bias magnet 50 and rotating moving magnetically conducting ferrous sensor target 36 form a magnetic circuit with magnetically conducting ferrous sensor target 36 creating a field concentration in magnetostrictive sensor 40 at its location along the longitudinal length of magnetostrictive sensor 40 to provide for magnetostrictive detection of the target. With such an embodiment the magnetic sensor target 36 of rotating coupling hub member 32 does not need to include a permanent magnet, preferably with the magnetic sensor target 36 being the ferrous material which forms part of rotating coupling hub member 32. Permanent bias magnet 50 bias the magnetostrictive sensor 40 such that there is no relative motion between the permanent bias magnet and the magnetostrictive sensor. The magnetically conducting ferrous target moving in proximity to the magnetically-biased magnetostrictive sensor 40 creates local magnetic field concentrations at the sensor waveguide body that cause magnetically induced strain pulse wave acoustic reflections within the magnetostrictive material sensor waveguide body thus providing position measurement of the target 36 along the longitudinal length of magnetostrictive sensor 40. Such an embodiment of the invention eliminates the need for a moving permanent magnet ring 44 incorporated into rotating coupling hub members 32,34, since the magnetic property magnetically conducting ferrous material component of the rotating members is the magnetostrictive sensor target 36. In preferred embodiments the biasing magnet 50 subjects the magnetostrictive sensor 40 to a magnetic field in the range of 10-50 G (such as at point a in FIG.5A), and the magnetically conducting ferrous target 36 creates local magnetic field concentrations in the range of 100-200 G proximate sensor 40 at its longitudinal location along the sensor body (such as at point b in FIG.5A).

30

[0028] Preferably the first coupling hub member 32 has an outer circumference perimeter 42 and the first coupling hub member magnetic target 36 comprises a magnetic ring 44 proximate the first coupling hub member outer circumference perimeter and the second coupling hub member 34 has an outer circumference perimeter 42 and the second coupling hub member magnetic target 36 comprises a magnetic ring 44 proximate the second coupling hub member outer circumference perimeter. Preferably the first magnetostrictive sensor 40 extends over the first coupling hub member magnetic ring 44 and the second coupling hub member magnetic ring 44, the second magnetostrictive sensor 40 extends over the first coupling hub member magnetic ring 44 and the second coupling hub member magnetic ring 44, and the third magnetostrictive sensor 40 extends over the first coupling hub member magnetic ring 44 and the second coupling hub member magnetic ring 44. The magnetic ring 44 can be a continuous magnet or segmented magnets. It is desirable to keep the magnetic field around the perimeter of the ring as uniform as possible and it is preferred to minimize the number of segments and minimize any gap between segments. Such gaps can be reduced by using scarf-cut ends on the magnets (magnets cut at 45° on the ends and butted against one another during installation into the ring on the hub). In an embodiment the magnetic ring rotating member sensor target is the rotating coupling hub member itself, preferably with such rotating member sensor target coupling hubs being ferrous. In an embodiment the magnetic ring rotating member sensor target is the rotating coupling hub member itself, preferably with such rotating member sensor target coupling hubs being magnetic. The coupling hub members can be non-ferrous with a separate magnetic ring sensor target being combined with a nonmagnetic nonferrous hub member. The magnetic ring is proximate the coupling hub member outer circumference perimeter. In an embodiment the magnetic ring is on the outer perimeter of the hub. In an embodiment the magnetic ring is integrated into the non-ferrous titanium hub proximate the outer perimeter and distal from drive shaft inner axis and not actually on the hub outer circumference perimeter. Preferably the first magnetostrictive sensor 40 is fixed in longitudinally parallel alignment with the second magnetostrictive sensor 40 and the third magnetostrictive sensor 40 is fixed in

longitudinally parallel alignment the second magnetostrictive sensor 40, with the third magnetostrictive sensor 40 fixed in longitudinally parallel alignment with the first magnetostrictive sensor 40. The sensors 40 are preferably longitudinally aligned in parallel. In an embodiment the longitudinally aligned sensors 40 are straight. In an
5 embodiment the longitudinally aligned sensors 40 are curved. In a curved sensor embodiment the longitudinally aligned sensors 40 are curved such that the sensors bulge out in the vicinity of the hub members and the ends are radially closer to the drive shafts. With curved sensor embodiments the longitudinally aligned sensors 40 have a curvature that avoids and inhibits physical contact with a rotating shaft system
10 component such as a hub member, a flexible coupling member, a shaft member, or other nearby components. Preferably the flexible coupling sensor rigid collar misalignment measuring system 38 provides for noncontactingly measuring with the magnetostrictive sensors 40 a plurality of distances from the first coupling hub member rotating sensor target to the second coupling hub member rotating sensor
15 target to provide a misalignment angle $\theta_{misalignment}$ between the first rotating coupling hub member and the second rotating coupling hub member. Preferably the flexible coupling sensor rigid collar misalignment measuring system 38 encompassing the flexible coupling 30 is physically separated from the flexible coupling 30 wherein physical mechanical contact between the flexible coupling sensor rigid collar
20 misalignment measuring system 38 and the flexible coupling 30 is inhibited. Preferably flexible coupling 30 couples a first drive shaft 28 to a second drive 28 with the magnetostrictive sensor fingers 40 fixed on annular support members of collar 38 with the sensor fingers 40 in parallel longitudinal alignment with the drive shafts, with such alignment substantially parallel with the drive shafts when the misalignment
25 angle is not zero. In an embodiment the flexible coupling sensor rigid collar 38 is a continuous uninterrupted ring, with the collar comprising a complete circle with sensors 40 at 120 degrees fixed angular distances. In a preferred embodiment the flexible coupling sensor rigid collar 38 is an interrupted ring, such as horseshoe arc cradle, with sensors 40 at fixed angular distances less than 120 degrees.

30

[0029] The invention includes a monitored vehicle propulsion system. The propulsion system 22 comprises an engine 24 and a propeller 26 for producing a propelling motive force. The engine 24 is coupled to propeller 26 such as a lift fan, a rotor, a drive unit, or other mover that produces a thrust or force for propelling and controlling the motion of the vehicle. The engine 24 is coupled to the propeller 26 with a drive shaft 28 and at least one flexible coupling 30. The flexible coupling 30 is comprised of a first coupling hub member 32 and a second coupling hub member 34 with the first coupling hub member flexibly coupled to the second coupling hub member. The flexible coupling 30 provides for the mechanical transfer of motive power from the engine 24 to the propeller 26. The propulsion system includes a flexible coupling sensor rigid annular collar measurement system 38 encompassing the flexible coupling 30 with the flexible coupling sensor rigid collar measurement system comprised of a first electromagnetic EM sensor 40, a second electromagnetic EM sensor 40, and a third electromagnetic EM sensor 40, with the first sensor, the second sensor, and the third sensor angularly spaced and rigidly fixed around the collar wherein the sensor rigid collar system 38 monitors the flexible coupling and provides for a noncontact electromagnetic measuring of multiple positional characteristics of the first coupling hub member 32 and the second coupling hub member 34 which relate to the transfer of motive power from the engine to the propeller. Preferably, the EM sensors 40 are magnetostrictive sensors. Sensors 40 are rigidly fixed around collar 38 with first sensor 40 fixed a first fixed angular distance from second sensor 40 and the third sensor 40 fixed a second fixed angular distance from the second sensor 40. Preferably the first, second, and third sensors 40 are equally spaced apart with the first fixed angular distance equal to the second fixed angular distance. In an embodiment the fixed angular distances spacing of sensors 40 is in the range between 60° to 120° . Preferably, sensor rigid collar measuring system 38 has at least three sensors 40. In a preferred embodiment system 38 has four sensors 40. In a preferred embodiment rigid collar measuring system 38 has five sensors 40. Preferably rigid collar measuring system 38 has “n” sensors with $n \geq 3$ and the “n” sensors separated by a fixed angular distance $\varnothing_n$ with $\varnothing_n \geq 90^\circ / (n - 1)$, more preferably $\varnothing_n \geq 120^\circ / (n - 1)$. In a preferred embodiment angular distance

spacing is in the range between 60-120 degrees, preferably 70-120, more preferably 80-120. In a preferred embodiment the angular distance spacing is about 80 (80 ± 10) degrees. In a preferred embodiment the angular distance spacing is about 90 (90 ± 10) degrees. In a preferred embodiment the angular distance spacing is less than 120
5 degrees.

[0030] The invention includes a method of monitoring a vehicular propulsion system. The method includes monitoring a vehicular propulsion system 22 having a drive shaft flexible coupling 30. The method includes providing a vehicular
10 propulsion system drive shaft flexible coupling 30 with a first coupling hub member 32 with an electromagnetic sensor target and a second coupling hub member 34 with an electromagnetic sensor target and providing a flexible coupling sensor rigid annular collar measurement system 38 with a first electromagnetic sensor 40, a second electromagnetic sensor 40, and a third electromagnetic sensor 40. The method
15 includes encompassing the first coupling hub member sensor target 36 and the second coupling hub member sensor target 36 with the flexible coupling sensor rigid annular collar measurement system 38 while inhibiting a physical contact between the flexible coupling sensor rigid annular collar measurement system and the vehicular propulsion system drive shaft flexible coupling with the first sensor 40, the second sensor 40, and
20 the third sensor 40 angularly spaced around the flexible coupling 30. The method includes noncontactingly measuring multiple positional characteristics of the first coupling hub member 32 and the second coupling hub member 34 to monitor performance of the vehicular propulsion system drive shaft flexible coupling that relates to the transfer of motive power through the vehicular propulsion system drive
25 shaft flexible coupling 30. Sensors 40 are rigidly fixed around the collar of rigid annular collar measurement system 38 with first sensor 40 fixed a first fixed angular distance from second sensor 40 and the third sensor 40 fixed a second fixed angular distance from the second sensor 40. Preferably the first, second, and third sensors 40 are equally spaced apart with the first fixed angular distance equal to the second fixed
30 angular distance. In a preferred embodiment the fixed angular distances spacing of sensors 40 is in the range between 60° to 120° . Preferably, sensor rigid collar

measuring system 38 has at least three sensors 40. In a preferred embodiment system 38 has four sensors 40. In a preferred embodiment rigid collar measuring system 38 has five sensors 40. Preferably rigid collar measuring system 38 has “n” sensors with $n \geq 3$ and the “n” sensors separated by a fixed angular distance Θ_n with $\Theta_n \geq 90^\circ / (n - 1)$, more preferably $\Theta_n \geq 120^\circ / (n - 1)$. In a preferred embodiment angular distance spacing is in the range between 60-120 degrees, preferably 70-120, more preferably 80-120. In a preferred embodiment the angular distance spacing is about 80 (80 ± 10) degrees. In a preferred embodiment the angular distance spacing is about 90 (90 ± 10) degrees. In a preferred embodiment the angular distance spacing is less than 120 degrees. In an embodiment the first coupling hub member and the second coupling hub member are magnetic. In an embodiment the first coupling hub member and the second coupling hub member are ferrous. In an embodiment the electromagnetic sensor targets are ferrous target rings attached to the coupling hub members. In an embodiment the electromagnetic sensor targets are magnetic target rings attached to the coupling hub members. Preferably the first coupling hub member 32 has an outer circumference perimeter and the first coupling hub member sensor target 36 is a magnetic ring proximate the first coupling hub member outer circumference perimeter, the second coupling hub member 34 has an outer circumference perimeter and the second coupling hub member sensor target is a magnetic ring proximate the second coupling hub member outer circumference perimeter, with the first, second, and third sensors 40 comprising magnetostrictive sensors that extend over the first coupling hub member magnetic ring sensor target and the second coupling hub member magnetic ring sensor target, and noncontactingly measuring includes magnetostrictively sensing distances from the first coupling hub member magnetic ring target to the second coupling hub member magnetic ring target. Noncontactingly measuring preferably includes magnetostrictively measuring the position of the first coupling hub member sensor target and the second coupling hub member sensor target, preferably with the first magnetostrictive sensor, the second magnetostrictive sensor, and the third magnetostrictive sensor fixed in parallel longitudinal alignment. Preferably noncontactingly measuring includes magnetostrictively measuring a plurality of distances from the first coupling hub member to the second coupling hub

member to provide a misalignment angle $\theta_{misalignment}$ between the first coupling hub member and the second coupling hub member. In a preferred embodiment of the method the sensors are magnetostrictive sensors fixed in parallel alignment with the second magnetostrictive sensor and the third magnetostrictive sensor fixed in parallel alignment, and measuring the rotating shaft coupling includes magnetostrictively measuring a plurality of distances from the first coupling hub member sensor target to the second coupling hub member sensor target, and transforming the magnetostrictively measured distances into an angular misalignment angle and an axial displacement distance between the first coupling hub and the second coupling hub member.

[0031] The invention includes a method of monitoring a vehicle drive shaft coupling. The method includes providing a drive shaft coupling 30 with a first coupling hub member 32 with an electromagnetic EM sensor target and a second coupling hub member 34 with an electromagnetic EM sensor target, providing a coupling sensor rigid annular collar measurement system 38 with a first electromagnetic EM sensor 40, a second sensor 40, and a third sensor 40, and encompassing the first coupling hub member sensor target and the second coupling hub member sensor target with the coupling sensor rigid collar measurement system 38 while inhibiting a physical contact between the coupling sensor rigid collar measurement system and the rotating drive shaft coupling, with the first, second, and third sensors angularly spaced externally around the coupling. The method includes noncontactingly electromagnetically measuring a plurality of positional characteristics of the first coupling hub member and the second coupling hub member to monitor a performance of the drive shaft coupling which relates to the transfer of motive power through the drive shaft coupling. Sensors 40 are rigidly fixed around the collar of rigid annular collar measurement system 38 with first sensor 40 fixed a first fixed angular distance from second sensor 40 and the third sensor 40 fixed a second fixed angular distance from the second sensor 40. Preferably the first, second, and third sensors 40 are equally spaced apart with the first fixed angular distance equal to the second fixed angular distance. In a preferred embodiment the fixed angular distances spacing of

sensors 40 is in the range between 60° to 120° . Preferably, sensor rigid collar measuring system 38 has at least three sensors 40. In a preferred embodiment system 38 has four sensors 40. In a preferred embodiment rigid collar measuring system 38 has five sensors 40. Preferably rigid collar measuring system 38 has “n” sensors with
5 $n \geq 3$ and the “n” sensors separated by a fixed angular distance $\varnothing_n$ with $\varnothing_n \geq 90^\circ / (n - 1)$, more preferably $\varnothing_n \geq 120^\circ / (n - 1)$. In a preferred embodiment angular distance spacing is in the range between 60-120 degrees, preferably 70-120, more preferably 80-120. In a preferred embodiment the angular distance spacing is about 80 (80 ± 10) degrees. In a preferred embodiment the angular distance spacing is about 90 (90 ± 10)
10 degrees. In a preferred embodiment the angular distance spacing is less than 120 degrees. In an embodiment the first coupling hub member and the second coupling hub member are magnetic. In an embodiment the first coupling hub member and the second coupling hub member are ferrous. In an embodiment the electromagnetic (EM) sensor targets are ferrous target rings attached to the coupling hub members. In an
15 embodiment the electromagnetic (EM) sensor targets are magnetic target rings attached to the coupling hub members. Preferably the first coupling hub member 32 has an outer circumference perimeter and the first coupling hub member sensor target 36 is a magnetic ring proximate the first coupling hub member outer circumference perimeter, the second coupling hub member 34 has an outer circumference perimeter
20 and the second coupling hub member sensor target is a magnetic ring proximate the second coupling hub member outer circumference perimeter, with the first, second, and third magnetostrictive sensors 40 extending over the first coupling hub member magnetic ring sensor target and the second coupling hub member magnetic ring sensor target, and noncontactingly measuring includes magnetostrictively sensing distances
25 from the first coupling hub member magnetic ring target to the second coupling hub member magnetic ring target. Noncontactingly measuring preferably includes magnetostrictively measuring the position of the first coupling hub member sensor target and the second coupling hub member sensor target, preferably with the first magnetostrictive sensor, the second magnetostrictive sensor, and the third
30 magnetostrictive sensor fixed in parallel longitudinal alignment. Preferably noncontactingly measuring includes magnetostrictively measuring a plurality of

distances from the first coupling hub member to the second coupling hub member to provide a misalignment angle $\theta_{misalignment}$ between the first coupling hub member plane and the second coupling hub member plane. Preferably the method includes measuring a plurality of distances from the first coupling hub member to the second coupling hub member with the sensors and transforming the plurality of measured distances into an angular misalignment angle and an axial displacement distance between the rotating shaft coupling hub members.

[0032] The invention includes a method of monitoring a vehicle flexible coupling drive shaft system with rotating members. The method includes providing a drive shaft coupling system with a first rotating member 32 with an electromagnetic EM sensor target and a second rotating member 34 with a electromagnetic EM sensor target, providing a sensor rigid collar measurement system 38 with a first electromagnetic EM sensor 40, a second sensor 40, and a third sensor 40, encompassing the first rotating member sensor target and the second rotating member sensor target with the sensor rigid collar measurement system while inhibiting a physical contact between the sensor rigid collar measurement system and the rotating members, with the first, second, and the third sensors angularly spaced around the first rotating member and the second rotating member, and noncontactingly measuring a plurality of rotating positional characteristics of the first rotating member 32 and the second rotating member 34 to monitor a performance of the drive shaft system which relates to a transfer of motive power through the vehicle drive shaft system, and then providing for a correction change in the vehicle drive shaft system when a measured rotating positional characteristic performance of the vehicle drive shaft system exceeds a measured rotating positional characteristic performance limitation. When the sensor rigid collar measurement system 38 measures a rotating positional characteristic performance exceeding a performance limitation then proper corrective action is initiated. In an embodiment, when the sensor rigid collar measurement system 38 measures a rotating positional characteristic performance of coupling 30 with the misalignment angle $\theta_{misalignment}$ between the first rotating coupling hub member and the second rotating coupling hub member exceeding a misalignment

angle limitation, use of the flexible coupling 30 in the vehicle drive shaft propulsion system 22 is limited until the coupling 30 is replaced or other corrective action is taken to correct the exceeding of the misalignment angle performance limitation. The flexible coupling drive shaft monitoring system and method provides for a correction
5 in the vehicle drive shaft system, correction or replacement of a vehicle system element, and checking the vehicle drive shaft system for operational problems.

[0033] The invention includes a method of monitoring a vehicle drive shaft system. The method includes providing a vehicle drive shaft system 28 with a first rotating
10 member 32 with a magnetic sensor target 36 and providing a sensor rigid measurement system 38 with a magnetostrictive sensor 40 proximate the first rotating member sensor target 36 while inhibiting a physical contact between the measurement system magnetostrictive sensor 40 and the rotating member 32, magnetostrictively measuring a rotating positional characteristic of the first rotating member 32 to
15 monitor a performance of the vehicle drive shaft system 28. The method includes providing a vehicle shaft system with at least a first rotating member with a magnetic sensor target, providing a sensor rigid measurement system with at least a first magnetostrictive sensor proximate to and external from the first rotating member sensor target while inhibiting a physical contact between the measurement system
20 magnetostrictive sensor and the rotating member, and magnetostrictively measuring a dynamic rotating positional characteristic of the rotating member to dynamically monitor a performance of the vehicle rotating shaft system.

[0034] The invention includes a method of measuring a vehicle rotating shaft. The
25 method includes providing a shaft with a first rotating member with a magnetic sensor target and providing a sensor measurement system with a magnetostrictive sensor proximate the first rotating member sensor target while inhibiting a physical contact between the measurement system magnetostrictive sensor and the rotating member, and magnetostrictively measuring a rotating positional characteristic of the first
30 rotating member to dynamically measure the vehicle rotating shaft. Preferably the method includes measuring a plurality of distances along the shaft that relate to the

sensed magnetic sensor target rotating member and transforming the plurality of measured distances to provide an angular misalignment angle for the vehicle rotating shaft. Preferably the method includes measuring a plurality of distances along the shaft that relate to the sensed magnetic sensor target rotating member and transforming the plurality of measured distances to provide an axial displacement distance for the rotating shaft. The invention includes a dynamic method of measuring a vehicle rotating shaft. The method includes providing a shaft with a first rotating member with a sensor target and a second rotating member with a sensor target, preferably with the sensor targets magnetic. Preferably the rotating member sensor targets are disks, preferably magnetic sensor target disks. The method includes providing a sensor measurement system with at least a first sensor proximate the first rotating member sensor target and the second rotating member sensor target, and measuring a plurality of distances from the first rotating member sensor target to the second rotating member sensor target and transforming these measured distances into a dynamic rotating positional characteristic of the vehicle rotating shaft. Preferably the at least first sensor proximate the first rotating member sensor target and the second rotating member sensor target is a magnetostrictive sensor, preferably with the at least first magnetostrictive sensor external from the magnetic sensor target. Preferably transforming the plurality of measured distances into a dynamic rotating positional characteristic of the rotating shaft includes transforming the plurality of measured distances into an axial displacement distance of the rotating shaft. Preferably transforming the plurality of measured distances into a dynamic rotating positional characteristic of the rotating shaft includes transforming the plurality of measured distances into an angular misalignment angle of the rotating shaft. Preferably measuring the plurality of distances from the first rotating member sensor target to the second rotating member sensor target includes magnetically detecting the first rotating member sensor target and the second rotating member sensor target. Preferably measuring the plurality of distances from the first rotating member sensor target to the second rotating member sensor target includes magnetostrictively sensing the targets, preferably with a plurality of magnetostrictive sensors positioned proximate and

external from the first rotating member sensor target and the second rotating member sensor target.

[0035] The invention includes a vehicular rotating shaft measurement system for noncontactingly monitoring a rotating member 32 including a magnetic sensor target 36, with the rotating shaft measurement system including a sensor rigid collar 38 comprised of a first magnetostrictive sensor 40. The first magnetostrictive sensor 40 is rigidly fixed on the sensor rigid collar proximate the rotating member 32, wherein the sensor rigid collar measurement system first magnetostrictive sensor 40 noncontactingly magnetostrictively monitors a position of the rotating member sensor target 36 to provide a measurement of a rotating positional characteristic of the first rotating member 32 to monitor a performance of the rotating member.

[0036] The invention includes a vehicle shaft coupling measurement system for noncontactingly monitoring a flexible coupling. The vehicle shaft coupling measurement system 38 is for measurement of a flexible coupling 30 with a first coupling hub member 32 including a magnetic target and a second coupling hub member 34 including a magnetic target, with the first coupling hub member flexibly coupled to the second coupling hub member. The flexible coupling sensor rigid collar misalignment measuring system 38 encompasses the flexible coupling 30 with a first EM magnetostrictive sensor 40, a second EM magnetostrictive sensor 40, and a third EM magnetostrictive sensor 40 rigidly fixed around the system collar, with the first sensor 40 fixed a first fixed angular distance from the second sensor 40, and the third sensor 40 fixed a second fixed angular distance from the second sensor 40. The flexible coupling sensor rigid collar misalignment measuring system magnetostrictive sensors 40 noncontactingly monitor a position of the first coupling hub member 32 relative to a position of the second coupling hub member 34 to provide a misalignment measurement of the flexible coupling which relates to a performance of the coupling 30. The first coupling hub member 32 has an outer circumference perimeter and the first coupling hub member target is a magnetic ring proximate the first coupling hub member outer circumference perimeter, and the second coupling

hub member 34 has an outer circumference perimeter and the second coupling hub member target is a magnetic ring proximate the second coupling hub member outer circumference perimeter. The first magnetostrictive sensor 40 extends over the first coupling hub member magnetic ring and the second coupling hub member magnetic ring, the second magnetostrictive sensor 40 extends over the first coupling hub member magnetic ring and the second coupling hub member magnetic ring, and the third magnetostrictive sensor 40 extends over the first coupling hub member magnetic ring and the second coupling hub member magnetic ring. The first magnetostrictive sensor 40 is fixed in parallel alignment with the second magnetostrictive sensor 40 and the third magnetostrictive sensor 40. Preferably the flexible coupling sensor rigid collar misalignment measuring system 38 noncontactingly measuring a plurality of positional distances of the first coupling hub member magnetic ring and the second coupling hub member magnetic ring along the longitudinal length of the magnetostrictive sensors 40 to provide a misalignment angle $\theta_{\text{misalignment}}$ between the first coupling hub member and the second coupling hub member. The flexible coupling sensor rigid collar misalignment measuring system provides for measurement of the position of the first target relative to the sensors and for measurement of the position of the second target relative to the sensors. The flexible coupling sensor rigid collar misalignment measuring system can provide for an absolute measurement of the target positions and for the relative measurement of the target positions. The flexible coupling sensor rigid collar misalignment measuring system 38 encompassing the flexible coupling 30 is physically separated from the flexible coupling with physical mechanical contact between the flexible coupling sensor rigid collar misalignment measuring system and the flexible coupling inhibited. Preferably the flexible coupling 30 couples a first drive shaft 28 to a second drive shaft 28 with the magnetostrictive sensor 40 fixed on an annular support members with the sensors 40 in parallel alignment with the drive shafts when the misalignment angle of the drive shafts is zero and in substantially parallel alignment with the drive shafts when the misalignment angle of the drive shafts is not zero. In an embodiment flexible coupling sensor rigid collar 38 is a continuous uninterrupted ring with sensors 40 at 120 degree fixed angular distances. In a preferred embodiment flexible coupling

sensor rigid collar 38 is an interrupted ring, such as a horseshoe arc cradle with sensors 40 at fixed angular distances less than 120 degree.

[0037] The invention includes a method of measuring a vehicle rotating shaft system.

- 5 The method can be used to dynamically measure a vehicle rotating shaft system with a coupling or without a coupling. The method includes dynamically sensing a plurality of positional distances to provide three measured distances between two sensor targets spaced along the length of the rotating shaft, with the three measured distances angularly separated. The three measured distances are transformed into angular
- 10 misalignment of the rotating shaft and axial displacement (distance) of the rotating shaft. The method includes providing a shaft 28 with a first rotating member 32 with a sensor target disk 1 and a second rotating member 34 with a sensor target disk 2. As shown in FIG. 6, rotating shaft 28 has a mean distance d_0 between the centers of rotating member sensor disk target 32 (center of disk-1 having a radius R) and rotating
- 15 member sensor disk target 34 (center of disk-2 having a radius R). Three measured distances d_1 , d_2 , d_3 between the circumference perimeter of the disks are obtained from three angularly separated sensors 40 (sensor #1, sensor #2, sensor #3) (angular location of the sensors shown in FIG. 6B-6C). The misalignment of the rotating shaft 28 is calculated in the method with the assumption that disk-1 is always perpendicular
- 20 to the coordinate frame (X Y Z), that disk-2 rotates with respect to XYZ by an amount of θ_x , θ_y , and disk-2 is separated from disk-1 by distance d_0 at the shaft. The three measured distances d_1 , d_2 , d_3 obtained from the sensors 40 are transformed with the following geometric equations and matrix transforms:

$$\begin{aligned}
 d_1 &= d_o + R \cos(\phi_1) \theta_y + R \sin(\phi_1) \theta_x \\
 d_2 &= d_o + R \cos(\phi_2) \theta_y + R \sin(\phi_2) \theta_x \\
 d_3 &= d_o + R \cos(\phi_3) \theta_y + R \sin(\phi_3) \theta_x
 \end{aligned}$$

25

$$\begin{Bmatrix} d_1 \\ d_2 \\ d_3 \end{Bmatrix} = \begin{bmatrix} 1 & R \cos(\phi_1) & R \sin(\phi_1) \\ 1 & R \cos(\phi_2) & R \sin(\phi_2) \\ 1 & R \cos(\phi_3) & R \sin(\phi_3) \end{bmatrix} \begin{Bmatrix} d_o \\ \theta_y \\ \theta_x \end{Bmatrix}$$

$$A = \begin{bmatrix} 1 & R \cos(\phi_1) & R \sin(\phi_1) \\ 1 & R \cos(\phi_2) & R \sin(\phi_1) \\ 1 & R \cos(\phi_3) & R \sin(\phi_1) \end{bmatrix}$$

$$\begin{Bmatrix} d_o \\ \theta_y \\ \theta_x \end{Bmatrix} = A^{-1} \begin{Bmatrix} d_1 \\ d_2 \\ d_3 \end{Bmatrix}$$

$$\theta = \sqrt{\theta_x^2 + \theta_y^2}$$

5

[0038] Using the A matrix, the three measured distances are transformed to provide the angular misalignment of the rotating shaft and axial displacement distance of the rotating shaft between the rotating members 32, 34. FIG. 7 shows another
 10 embodiment with three angularly separated sensors 40 fixed around the rotating shaft's first rotating member 32 sensor target disk and the second rotating member 34 sensor target disk providing three measured distances d_1 , d_2 , d_3 which are transformed to provide the axial displacement and angular alignment of rotating coupling 30 or rotating shaft 28. As shown in FIG. 8-9 misalignment is computed by
 15 measuring the relative displacements $\{d_1, d_2, d_3\}$ between the two disks at three points around the perimeter. These displacements are measured by timing the interval between the target disks, and multiplying this result by the wave speed:

$$d_n (\text{in}) = c \left(\frac{\text{in}}{\text{sec}} \right) \times \Delta t (\text{sec}) \quad (1)$$

20

where $n = \{1, 2, 3\}$ is the sensor number, and c is a known wave speed (for magnetostrictive sensors 40 the known sonic speed of the magnetically induced strain pulse wave in the magnetostrictive sensor waveguide body). For this analysis, it is
 25 convenient to assume that one disk is always oriented perfectly in the x - y plane and the other disk is at some angle relative to the x - y plane as shown in FIG. 8 (Vector diagram for locating points on a target disk). The three points at the perimeter of a

target disk are represented by vectors in the absolute x - y - z coordinate system. For a general disk, as shown in FIG.8 these vectors are given by:

$$\begin{aligned} \mathbf{V}_1 &= [\Delta x_{AB} + r_o \cos \phi_1] \hat{x} + [\Delta y_{AB} + r_o \sin \phi_1] \hat{y} + [d_1] \hat{z} \\ \mathbf{V}_2 &= [\Delta x_{AB} + r_o \cos \phi_2] \hat{x} + [\Delta y_{AB} + r_o \sin \phi_2] \hat{y} + [d_2] \hat{z} \\ \mathbf{V}_3 &= [\Delta x_{AB} + r_o \cos \phi_3] \hat{x} + [\Delta y_{AB} + r_o \sin \phi_3] \hat{y} + [d_3] \hat{z} \end{aligned} \quad (2)$$

where r_o is the nominal radius of the target disk, $\hat{x}$, $\hat{y}$, and $\hat{z}$ are unit vectors in the x -, y -, and z -directions respectively, and Δx_{AB} and Δy_{AB} are the relative displacements between disk A and disk B in the x - and y - directions respectively. To compute the normal vector for the misaligned disk, we need two vectors residing on the disk itself. FIG. 9 (Vector diagram for computing a normal vector on a target disk) indicates that there are three possibilities available:

$$\begin{aligned} \mathbf{V}_{21} &= \mathbf{V}_2 - \mathbf{V}_1 = r_o [\cos \phi_2 - \cos \phi_1] \hat{x} + r_o [\sin \phi_2 - \sin \phi_1] \hat{y} + [d_2 - d_1] \hat{z} \\ \mathbf{V}_{32} &= \mathbf{V}_3 - \mathbf{V}_2 = r_o [\cos \phi_3 - \cos \phi_2] \hat{x} + r_o [\sin \phi_3 - \sin \phi_2] \hat{y} + [d_3 - d_2] \hat{z} \\ \mathbf{V}_{13} &= \mathbf{V}_1 - \mathbf{V}_3 = r_o [\cos \phi_1 - \cos \phi_3] \hat{x} + r_o [\sin \phi_1 - \sin \phi_3] \hat{y} + [d_1 - d_3] \hat{z} \end{aligned} \quad (3)$$

The normal vectors for Disk A and B are then computed as:

$$\begin{aligned} \mathbf{N}_A &= 0\hat{x} + 0\hat{y} + 1\hat{z} \\ \mathbf{N}_B &= \mathbf{V}_{32B} \times \mathbf{V}_{21B} = \mathbf{V}_{13B} \times \mathbf{V}_{32B} = \mathbf{V}_{21B} \times \mathbf{V}_{13B} \end{aligned} \quad (4)$$

Any of the three vector cross-products should give the same answer. Preferably the method takes full advantage of this redundancy (the three vector cross-products giving the same answer) by either averaging them or using the additional measurements to diagnose any potential problems with the system. Finally, the angular deviation $\theta_{\text{alignment}}$ between the two normal vectors, representing the *primary* measure of misalignment, is computed as

$$\theta_{\text{alignment}} = \cos^{-1} \left(\frac{\mathbf{N}_A \cdot \mathbf{N}_B}{|\mathbf{N}_A| |\mathbf{N}_B|} \right) \quad (5)$$

FIG.10-11 show a further method of transforming the three measured distances into the dynamic rotating positional characteristics of the rotating shaft to provide an angular misalignment and an axial displacement. The points P represent the locations

on each flange (32,34) of coupling 30 over which the three magnetostrictive sensors 40 lie. Sensor 1 lies over points P1O and P1I, Sensor 2 lies over points P2O and P2I, and Sensor 3 lies over points P3O and P3I. The points are established on each flange at predetermined angles, Φ , as shown in Figure 11. These represent the fixed angular spacing of the sensors 40 when installed in a cradle frame fixture of coupling sensor rigid collar misalignment measurement system 38. The two flanges (inboard flange and outboard flange) are free to rotate and translate and therefore have unique coordinate systems {A} and {B}. We arbitrarily select coordinate system {A} and proceed to define all points of interest in this coordinate system. Therefore,

10

$${}^A P1I = {}^A \mathbf{T}_B {}^B P1I = \begin{bmatrix} {}^A \mathbf{R}_B & {}^A P_{Borig} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} {}^B P1I \\ 1 \end{bmatrix}$$

(Eqn. 1)

in which the transformation matrix $\mathbf{T}$ is comprised of both rotational and translational components. The rotation matrix is represented by

15

$${}^A \mathbf{R}_B = {}^A \mathbf{R}_{xyz}(\theta_x, \theta_y, \theta_z) = \mathbf{R}_z(\theta_z) \mathbf{R}_y(\theta_y) \mathbf{R}_x(\theta_x)$$

20

and for this case $\theta_z = 0$ so the rotation matrix becomes

$${}^A \mathbf{R}_B = \begin{bmatrix} c\theta_y & 0 & s\theta_y \\ 0 & 1 & 0 \\ -s\theta_y & 0 & c\theta_y \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & c\theta_x & -s\theta_x \\ 0 & s\theta_x & c\theta_x \end{bmatrix} = \begin{bmatrix} c\theta_y & s\theta_y s\theta_x & s\theta_y c\theta_x \\ 0 & c\theta_x & -s\theta_x \\ -s\theta_y & c\theta_y s\theta_x & c\theta_y c\theta_x \end{bmatrix}.$$

The point on the inboard flange can be explicitly written in the {B} coordinate

$$\text{system: } {}^B P1I = \begin{bmatrix} R_B c\phi_{1I} \\ R_B s\phi_{1I} \\ 0 \end{bmatrix}.$$

25

Similarly,

$${}^A P1O = \begin{bmatrix} R_A c\phi_{1O} \\ R_A s\phi_{1O} \\ 0 \end{bmatrix}.$$

30 We then find d_1 using vector math:

$$d_1 = {}^A P1I - {}^A P1O$$

Write Eqn. 1 for points P1, P2, and P3 to solve for d_o (axial displacement) and θ_x and θ_y . The angular misalignment is then

5 $\theta = \sqrt{\theta_x^2 + \theta_y^2}$

[0039] Such transforming of a plurality of noncontactingly measured distances from a first rotating coupling hub target and a second rotating coupling hub target of shaft
10 28 provide for a dynamic monitoring of an angular misalignment angle and an axial displacement distance between first and second rotating target members of a vehicle rotating shaft to provide valuable rotating positional characteristics of the vehicle shaft and its performance in the rotating shaft system of the vehicle.

15

[0040] It will be apparent to those skilled in the art that various modifications and variations can be made to the present invention without departing from the spirit and scope of the invention. Thus, it is intended that the present invention cover the modifications and variations of this invention provided they come within the scope of
20 the appended claims and their equivalents.

CLAIMS

1. A V/STOL fixed wing aircraft, said aircraft comprising an engine and a lift fan, said engine coupled to said lift fan with at least one drive shaft and at least one flexible coupling, said flexible coupling comprised of a first coupling hub member including a magnetic property target and a second coupling hub member including a magnetic property target, said first coupling hub member flexibly coupled to said second coupling hub member, said flexible coupling providing for a mechanical transfer of motive power from said engine to said lift fan, a flexible coupling sensor rigid collar misalignment measuring system encompassing said flexible coupling, said flexible coupling sensor rigid collar comprised of a first magnetostrictive sensor, a second magnetostrictive sensor, and a third magnetostrictive sensor, said first magnetostrictive sensor, said second magnetostrictive sensor, and said third magnetostrictive sensor rigidly fixed around said collar, said first magnetostrictive sensor fixed a first fixed angular distance from said second magnetostrictive sensor, said third magnetostrictive sensor fixed a second fixed angular distance from said second magnetostrictive sensor, wherein said flexible coupling sensor rigid collar misalignment measuring system magnetostrictive sensors magnetically monitor a position of said first coupling hub member and a position of said second coupling hub member to provide a misalignment measurement of said flexible coupling which relates to a performance of said coupling in said V/STOL fixed wing aircraft.

2. A V/STOL fixed wing aircraft as claimed in claim 1, wherein said first coupling hub member has an outer circumference perimeter and said first coupling hub member magnetic target comprises a magnetic ring proximate said first coupling hub member outer circumference perimeter, said second coupling hub member has an outer circumference perimeter and said second coupling hub member magnetic target comprises a magnetic ring proximate said second coupling hub member outer circumference perimeter, said first magnetostrictive sensor externally extending over said first coupling hub member magnetic ring

and said second coupling hub member magnetic ring, said second magnetostrictive sensor externally extending over said first coupling hub member magnetic ring and said second coupling hub member magnetic ring, and said third magnetostrictive sensor extending externally over said first coupling hub member magnetic ring and said second coupling hub member magnetic ring.

3. A V/STOL fixed wing aircraft as claimed in claim 2, wherein said first magnetostrictive sensor is fixed in parallel alignment with said second magnetostrictive sensor, said third magnetostrictive sensor fixed in parallel alignment said second magnetostrictive sensor, said third magnetostrictive sensor fixed in parallel alignment with said first magnetostrictive sensor.

4. A V/STOL fixed wing aircraft as claimed in claim 3, wherein said flexible coupling sensor rigid collar misalignment measuring system noncontactingly measures a plurality of distances of said first coupling hub member magnetic ring and said second coupling hub member magnetic ring to provide a misalignment angle between said first coupling hub member and said second coupling hub member.

5. A V/STOL fixed wing aircraft as claimed in claim 1, wherein said flexible coupling sensor rigid collar misalignment measuring system encompassing said flexible coupling is physically separated from said flexible coupling wherein physical mechanical contact between said flexible coupling sensor rigid collar misalignment measuring system and said flexible coupling is inhibited.

6. A V/STOL fixed wing aircraft as claimed in claim 1, wherein said magnetostrictive sensors noncontactingly measure a plurality of positional distances of said first coupling hub target and said second coupling hub target to provide an angular misalignment angle and an axial displacement distance between said first coupling hub and said second coupling hub member.

7. A vehicle propulsion system, said propulsion system comprising an engine and a propeller, said engine coupled to said propeller with a drive shaft and a flexible coupling, said flexible coupling comprised of a first coupling hub member and a second coupling hub member, said first coupling hub member flexibly coupled to
5 said second coupling hub member, said flexible coupling providing for a mechanical transfer of motive power from said engine to said propeller, a flexible coupling sensor rigid collar measurement system encompassing said flexible coupling, said flexible coupling sensor rigid collar measurement system comprised of a first sensor, a second sensor, and a third sensor, said first sensor, said second
10 sensor, and said third sensor spaced and rigidly fixed around said collar wherein said sensor rigid collar system monitors said flexible coupling and provides for a noncontact measuring of a plurality of positional characteristics of said first coupling hub member and said second coupling hub member which relate to said transfer of motive power.

15

8. A method of monitoring a vehicular propulsion system drive shaft flexible coupling, said method comprising providing a vehicular propulsion system drive shaft flexible coupling with a first coupling hub member with a sensor target and a second coupling hub member with a sensor target, providing a flexible coupling
20 sensor rigid collar measurement system with a first sensor, a second sensor, and a third sensor, encompassing said first coupling hub member sensor target and said second coupling hub member sensor target with said flexible coupling sensor rigid collar measurement system while inhibiting a physical contact between said flexible coupling sensor rigid collar measurement system and said vehicular
25 propulsion system drive shaft flexible coupling, with said first sensor, said second sensor, and said third sensor angularly spaced around and external from said flexible coupling, noncontactingly measuring a plurality of positional characteristics of said first coupling hub member and said second coupling hub member to monitor a performance of said vehicular propulsion system drive shaft
30 flexible coupling which relates to a transfer of motive power through said vehicular propulsion system drive shaft flexible coupling.

9. A method as claimed in claim 8 wherein said first coupling hub member and said second coupling hub member have a magnetic property.

5 10. A method as claimed in claim 8 wherein said first coupling hub member has an outer circumference perimeter and said first coupling hub member sensor target comprises a magnetic ring proximate said first coupling hub member outer circumference perimeter, said second coupling hub member has an outer circumference perimeter and said second coupling hub member sensor target
10 comprises a magnetic ring proximate said second coupling hub member outer circumference perimeter, said first sensor, said second sensor, and said third sensor are magnetostrictive sensors and externally extend over said first coupling hub member magnetic ring sensor target and said second coupling hub member magnetic ring sensor target, and noncontactingly measuring includes magnetically
15 measuring a plurality of distances of said first coupling hub member magnetic ring to said second coupling hub member magnetic ring with said magnetostrictive sensors

20 11. A method as claimed in claim 8 wherein noncontactingly measuring includes magnetostrictively measuring the position of said first coupling hub member sensor target and said second coupling hub member sensor target.

25 12. A method as claimed in claim 8 wherein noncontactingly measuring includes magnetostrictively measuring a plurality of distances of said first coupling hub member and said second coupling hub member to provide a misalignment angle between said first coupling hub member and said second coupling hub member.

30 13. A method as claimed in claim 11 wherein said first sensor is a magnetostrictive sensor, said second sensor is a magnetostrictive sensor, said third sensor is a magnetostrictive sensor, and said first magnetostrictive sensor is fixed in alignment with said second magnetostrictive sensor and said third

magnetostrictive sensor fixed in alignment said second magnetostrictive sensor and said third magnetostrictive sensor fixed in alignment with said first magnetostrictive sensor, and magnetostrictively measuring the position of said first coupling hub member sensor target and said second coupling hub member sensor target includes measuring a plurality of distances of said first coupling hub member sensor target and said second coupling hub member sensor target, and transforming said plurality of measured distances to provide an angular misalignment angle and an axial displacement distance between said first coupling hub and said second coupling hub member.

10

14. A method of monitoring a vehicle drive shaft coupling, said method comprising providing a drive shaft coupling with a first coupling hub member with a sensor target and a second coupling hub member with a sensor target, providing a coupling sensor rigid collar measurement system with a first sensor, a second sensor, and a third sensor, encompassing said first coupling hub member sensor target and said second coupling hub member sensor target with said coupling sensor rigid collar measurement system while inhibiting a physical contact between said coupling sensor rigid collar measurement system and said drive shaft coupling, with said first sensor, said second sensor, and said third sensor angularly spaced around said coupling, noncontactingly measuring a plurality of positional characteristics of said first coupling hub member and said second coupling hub member to monitor a performance of said drive shaft coupling which relates to a transfer of motive power through said drive shaft coupling.

20
25

15. A method as claimed in claim 14 wherein said first coupling hub member and said second coupling hub member are magnetic.

30

16. A method as claimed in claim 14 wherein said first coupling hub member has an outer circumference perimeter and said first coupling hub member sensor target comprises a magnetic ring proximate said first coupling hub member outer

circumference perimeter, said second coupling hub member has an outer circumference perimeter and said second coupling hub member sensor target comprises a magnetic ring proximate said second coupling hub member outer circumference perimeter, said first sensor, said second sensor, and said third sensor are magnetostrictive sensors and extend over said first coupling hub member magnetic ring sensor target and said second coupling hub member magnetic ring sensor target, and noncontactingly measuring includes magnetically measuring a plurality of positional distances of said first coupling hub member magnetic ring and said second coupling hub member magnetic ring with said magnetostrictive sensors.

17. A method as claimed in claim 14 wherein noncontactingly measuring includes magnetostrictively measuring the position of said first coupling hub member sensor target and said second coupling hub member sensor target.

18. A method as claimed in claim 14 wherein noncontactingly measuring includes measuring a plurality of distances of said first coupling hub member and said second coupling hub member with said sensors to provide a misalignment angle between said first coupling hub member and said second coupling hub member.

19. A method as claimed in claim 17 wherein said first sensor is a magnetostrictive sensor, said second sensor is a magnetostrictive sensor, said third sensor is a magnetostrictive sensor, and said first magnetostrictive sensor is fixed in alignment with said second magnetostrictive sensor and said third magnetostrictive sensor fixed in alignment said second magnetostrictive sensor and said third magnetostrictive sensor fixed in alignment with said first magnetostrictive sensor.

20. A method as claimed in claim 14 wherein measuring includes measuring a plurality of distances of said first coupling hub member and said second coupling hub member with said sensors and transforming said plurality of measured

distances to provide an angular misalignment angle and an axial displacement distance between said first coupling hub and said second coupling hub member.

21. A method of monitoring a shaft system with rotating members, said method comprising providing a shaft system with a first rotating member with a sensor target and a second rotating member with a sensor target, providing a sensor measurement system with a first sensor, a second sensor, and a third sensor, encompassing said first rotating member sensor target and said second rotating member sensor target with said sensor measurement system while inhibiting a physical contact between said measurement system and said rotating members, with said first sensor, said second sensor, and said third sensor angularly spaced around said first rotating member and said second rotating member with an angular distance less than 120 degrees, noncontactingly measuring a plurality of rotating positional characteristics of said first rotating member and said second rotating member to monitor a performance of said shaft system, providing for a correction change in said shaft system when a measured rotating positional characteristic performance of said shaft system exceeds a measured rotating positional characteristic performance limitation.

22. A method of monitoring a shaft system, said method comprising providing a shaft system with a first rotating member with a magnetic sensor target, providing a sensor measurement system with a magnetically biased magnetostrictive sensor proximate said first rotating member sensor target while inhibiting a physical contact between said measurement system magnetically biased magnetostrictive sensor and said rotating member, magnetostrictively measuring a rotating positional characteristic of said first rotating member to monitor a performance of said shaft system.

23. A method of measuring a vehicle rotating shaft, said method comprising providing a vehicle shaft with a first rotating member with a sensor target, providing a sensor measurement system with a magnetostrictive sensor proximate

said first rotating member sensor target while inhibiting a physical contact between said measurement system magnetostrictive sensor and said rotating member, magnetostrictively measuring a rotating positional characteristic of said first rotating member to measure said vehicle rotating shaft.

5

24. A method as claimed in claim 23 wherein measuring a rotating positional characteristic of said first rotating member to measure said rotating shaft includes measuring a plurality of distances and transforming said plurality of measured distances to provide an angular misalignment angle.

10

25. A method as claimed in claim 23 wherein measuring a rotating positional characteristic of said first rotating member to measure said rotating shaft includes measuring a plurality of distances and transforming said plurality of measured distances to provide an axial displacement distance.

15

26. A method of measuring an aircraft vehicle rotating shaft, said method comprising providing an aircraft vehicle shaft with a first rotating member with a sensor target and a second rotating member with a sensor target, providing a sensor measurement system with at least a first sensor proximate said first rotating member sensor target and said second rotating member sensor target and measuring a plurality of distances of said first rotating member sensor target and said second rotating member sensor target and transforming said plurality of measured distances into a dynamic rotating positional characteristic of said aircraft vehicle rotating shaft.

20

27. A method as claimed in claim 26, wherein transforming said plurality of measured distances into a dynamic rotating positional characteristic of said rotating shaft includes transforming said plurality of measured distances into an axial displacement distance.

25

30

28. A method as claimed in claim 26, wherein transforming said plurality of measured distances into a dynamic rotating positional characteristic of said rotating shaft includes transforming said plurality of measured distances into an angular misalignment angle.

5

29. A method as claimed in claim 26 wherein said first rotating member sensor target is a disk and said second rotating member sensor target is a disk.

10

30. A method as claimed in claim 26 wherein measuring a plurality of distances of said first rotating member sensor target and said second rotating member sensor target includes magnetically detecting said first rotating member sensor target and said second rotating member sensor target.

15

31. A method as claimed in claim 26 wherein measuring a plurality of distances of said first rotating member sensor target and said second rotating member sensor target includes magnetostrictively sensing said targets.

20

32. A method as claimed in claim 26 wherein measuring a plurality of distances of said first rotating member sensor target and said second rotating member sensor target includes magnetostrictively sensing said targets with a plurality of magnetostrictive sensors positioned proximate and external from said first rotating member sensor target and said second rotating member sensor target.

25

33. A vehicle rotating shaft measurement system for noncontactingly monitoring a rotating member including a sensor target, said vehicle rotating shaft measurement system including at least a first magnetostrictive sensor, said first magnetostrictive sensor rigidly fixed relative to and proximate said rotating member, wherein said measurement system first magnetostrictive sensor magnetostrictively monitors a position of said rotating member sensor target to provide a measurement of a dynamic rotating positional characteristic of said first rotating member.

30

34. A shaft coupling measurement system for noncontactingly monitoring a coupling, said coupling comprised of a first coupling hub member including a target and a second coupling hub member including a target, said first coupling
5 hub member coupled to said second coupling hub member, a coupling sensor misalignment measuring system encompassing said coupling, said coupling sensor misalignment measuring system comprised of a first magnetostrictive sensor, a second magnetostrictive sensor, and a third magnetostrictive sensor, said first
10 magnetostrictive sensor fixed a first fixed angular distance less than 120 degrees from said second magnetostrictive sensor, said third magnetostrictive sensor fixed a second fixed angular distance less than 120 degrees from said second magnetostrictive sensor, wherein said misalignment measuring system magnetostrictive sensors noncontactingly monitor a position of said first coupling
15 hub member and a position of said second coupling hub member to provide a misalignment measurement of said coupling which relates to a performance of said coupling.

20 35. A shaft coupling measurement system as claimed in claim 34, wherein said misalignment measuring system noncontactingly measures a plurality of distances of said coupling hub members with said magnetostrictive sensors and transforms said distances into a dynamic angular misalignment angle.

25

30

FIG. 1A

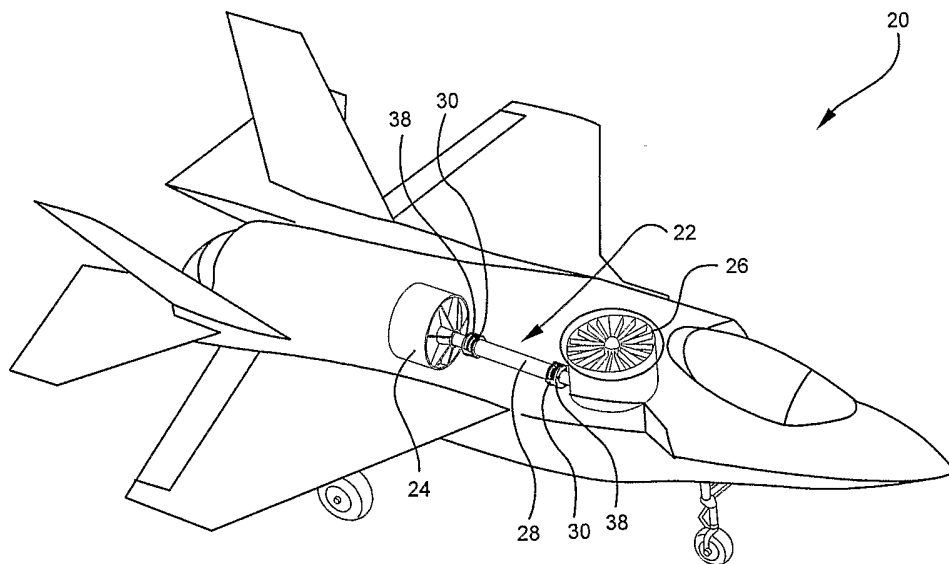


FIG. 1B

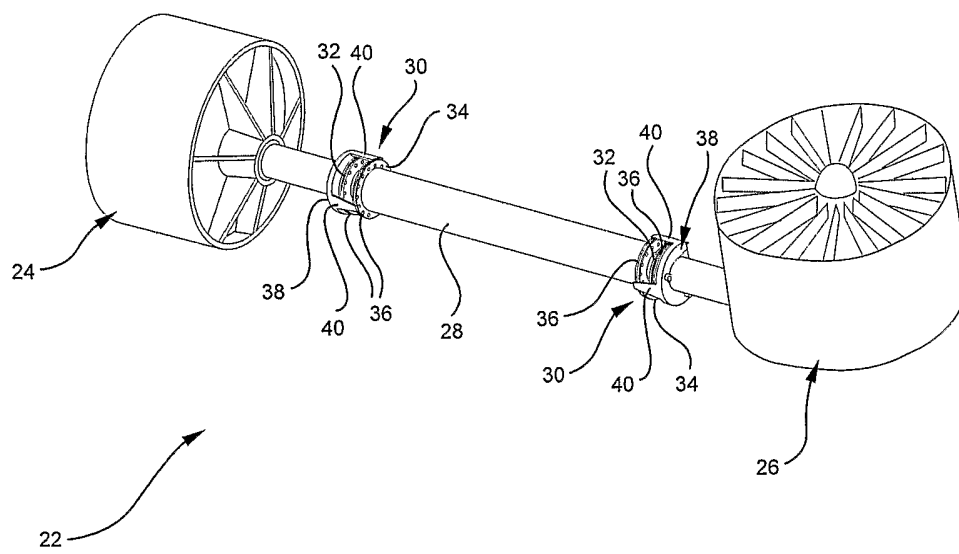


FIG. 2A

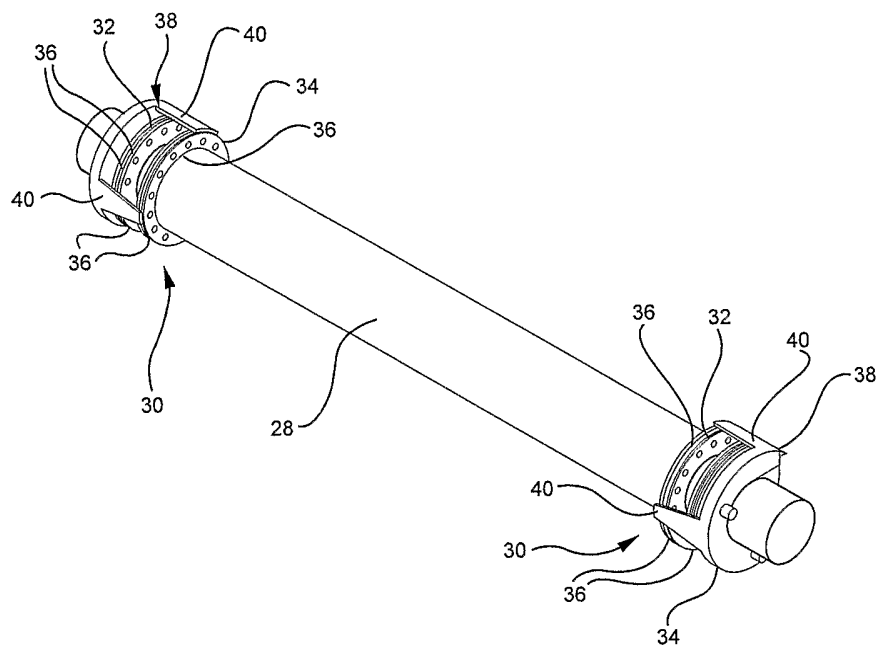


FIG. 2B

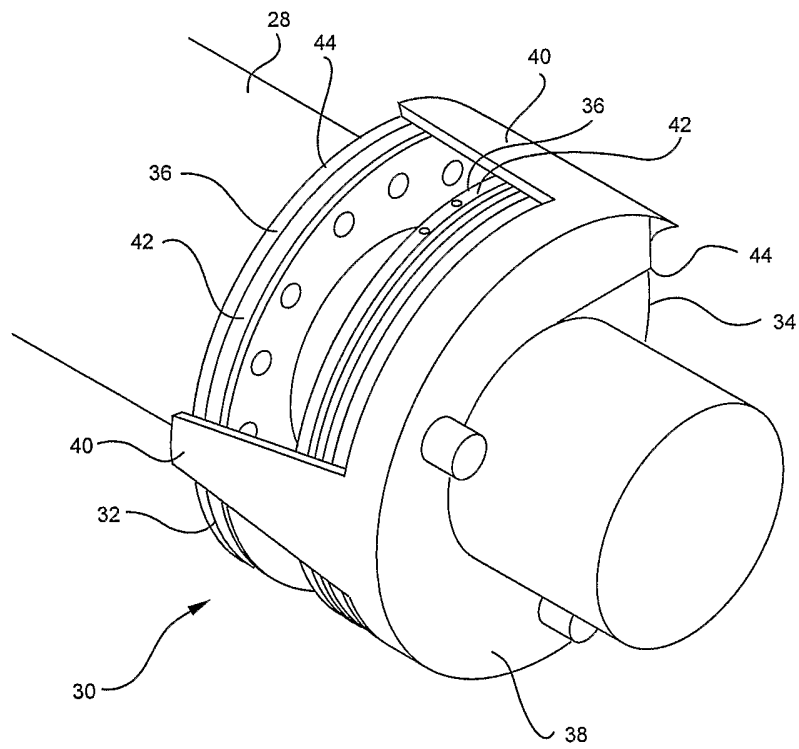


FIG. 3

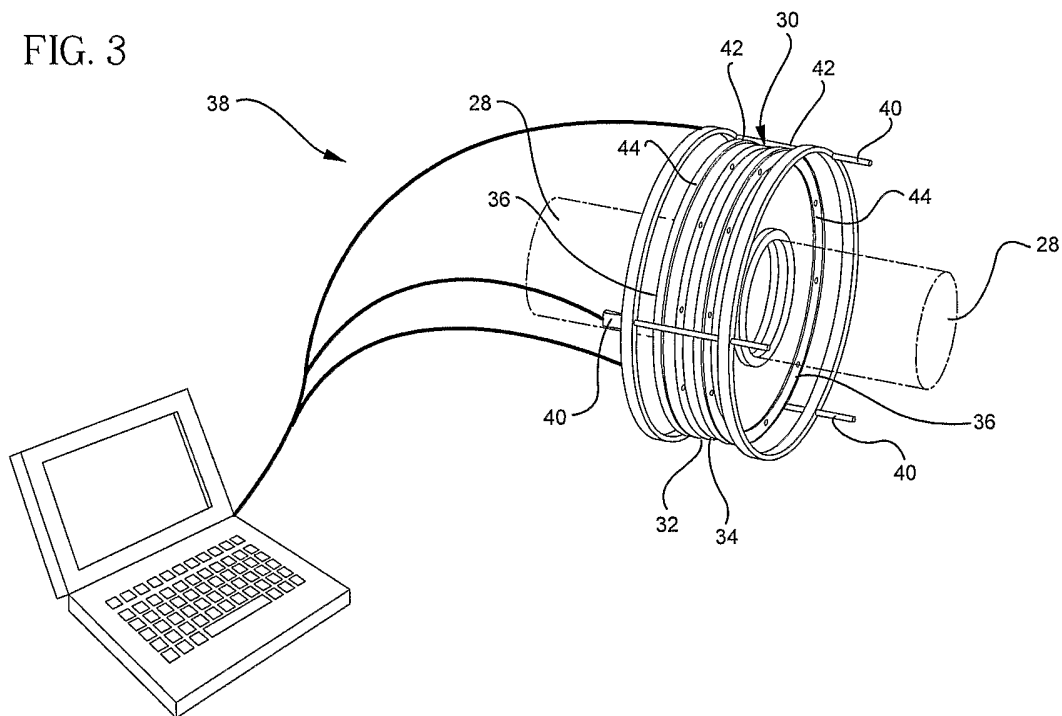


FIG. 4

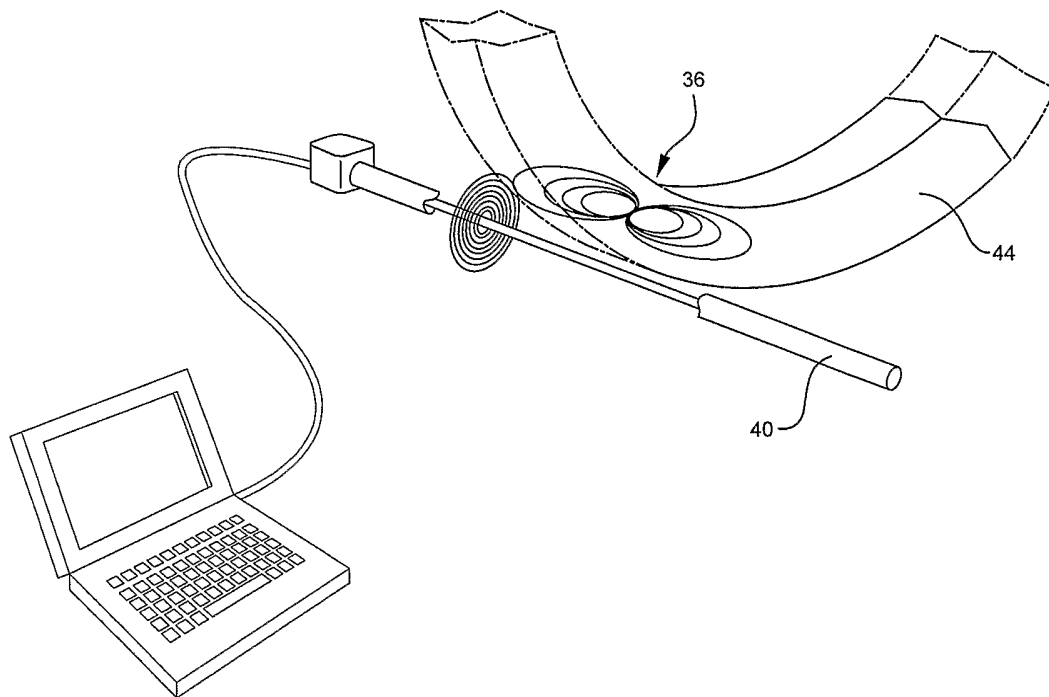


FIG. 5A

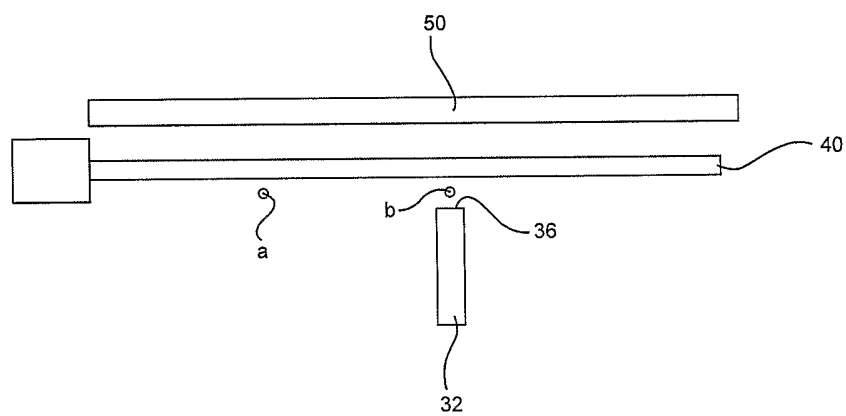


FIG. 5B

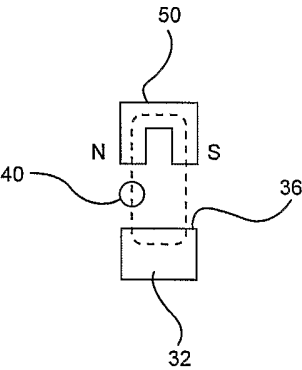


FIG. 5C

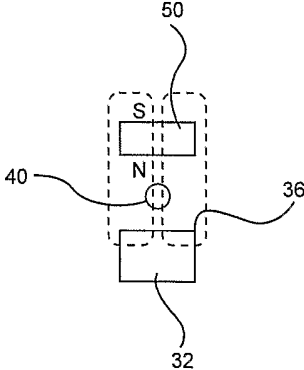


FIG. 5D

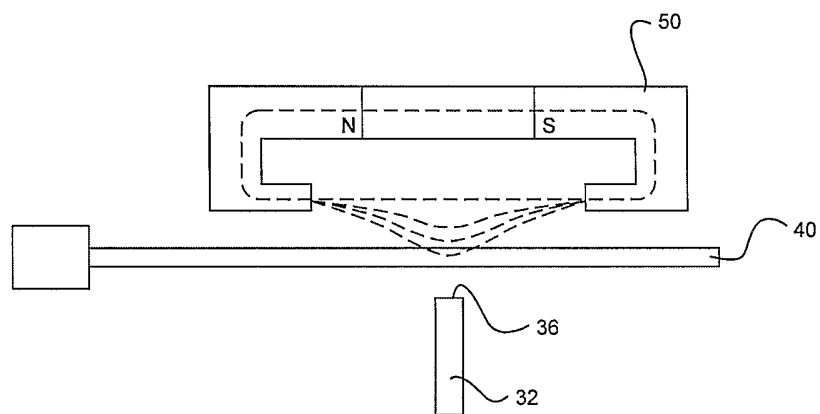


FIG. 6A

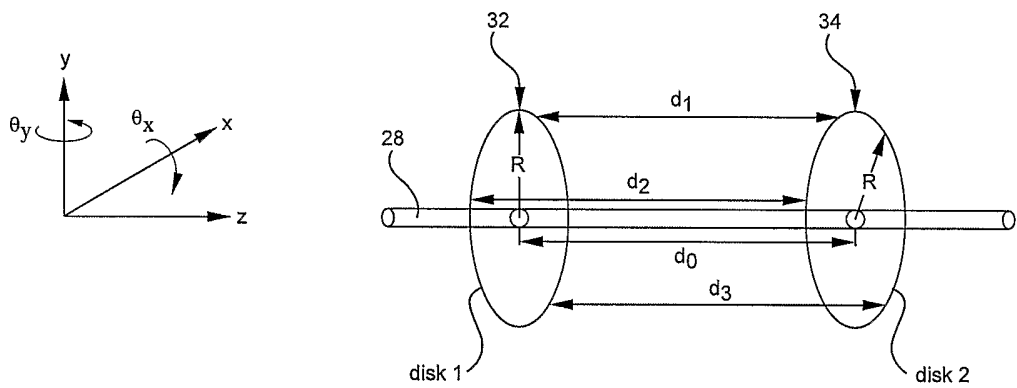


FIG. 6B

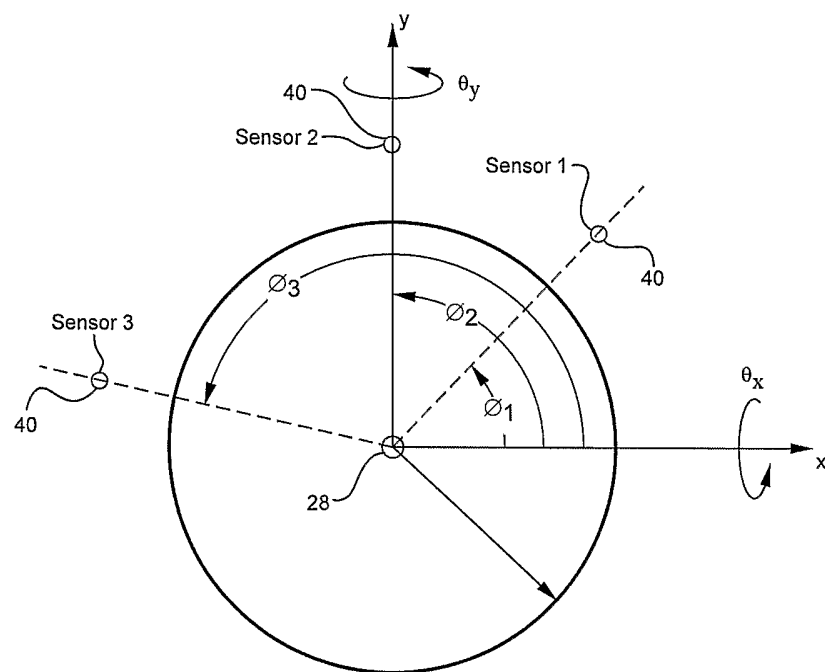


FIG. 6C

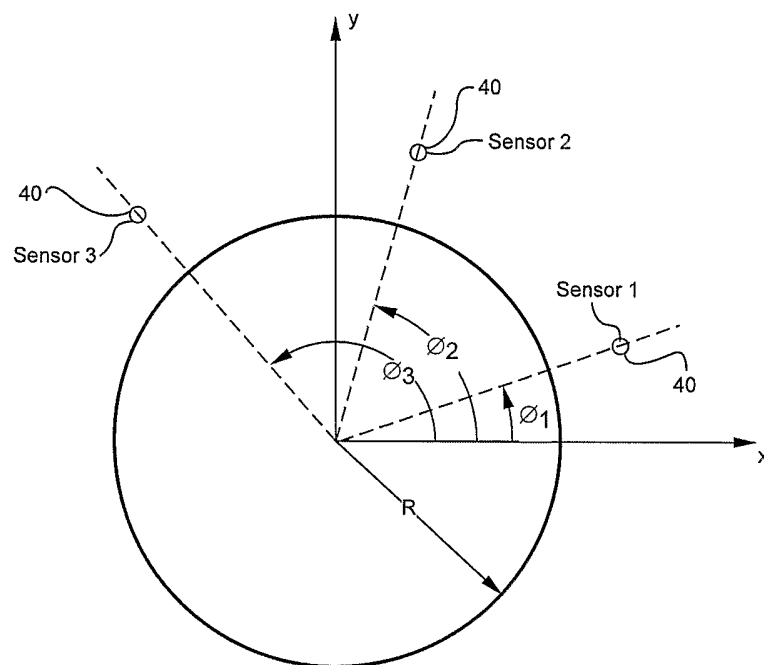


FIG. 7

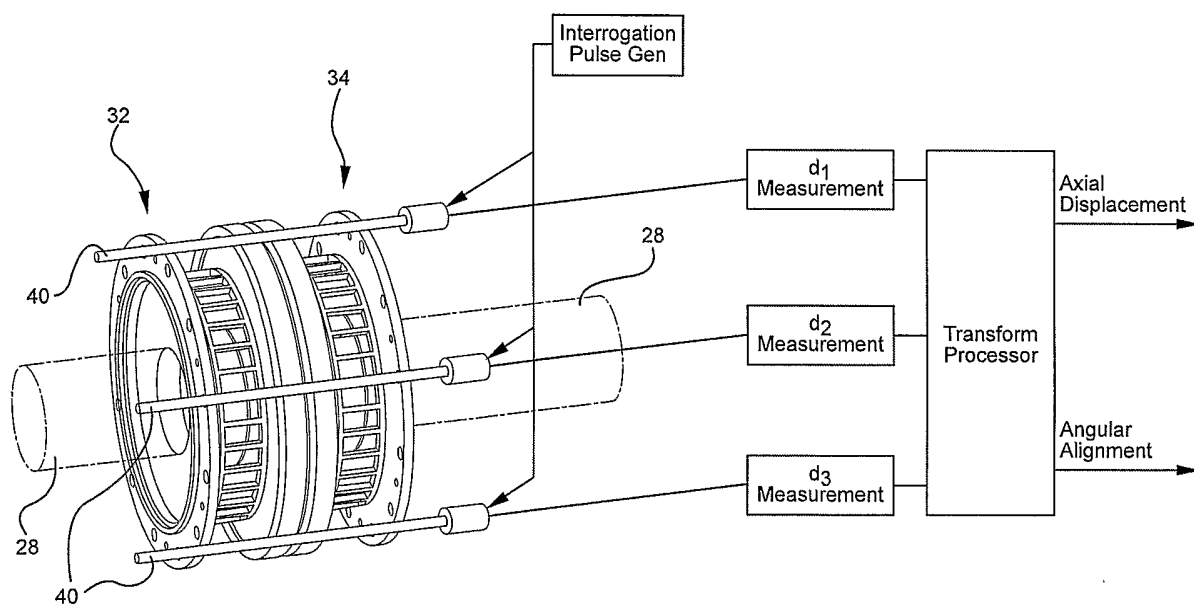


FIG. 8

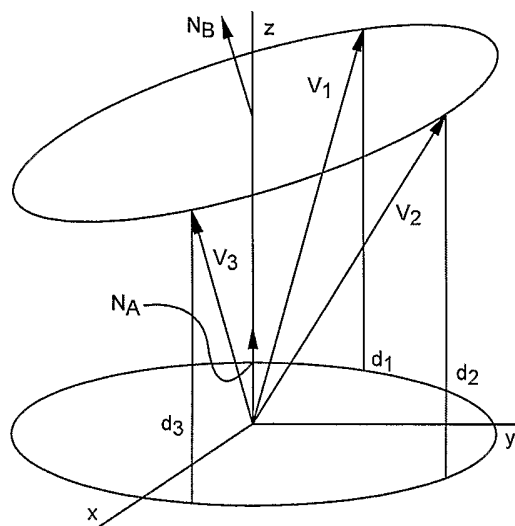


FIG. 9

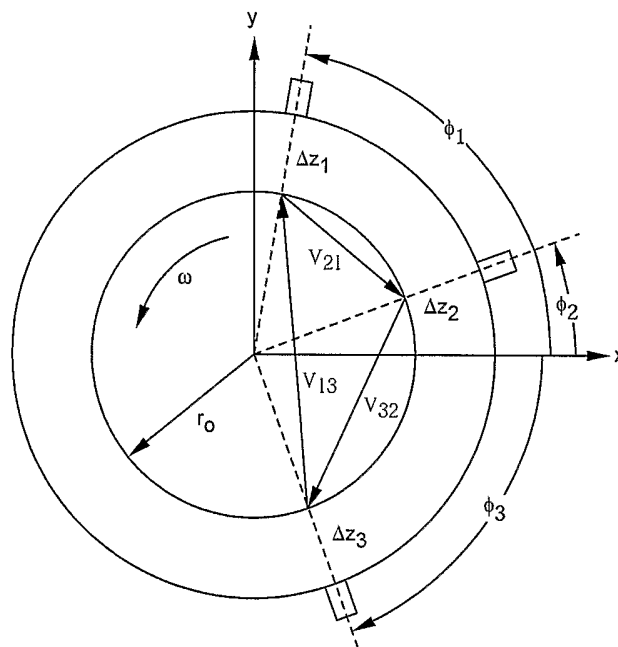


FIG. 10

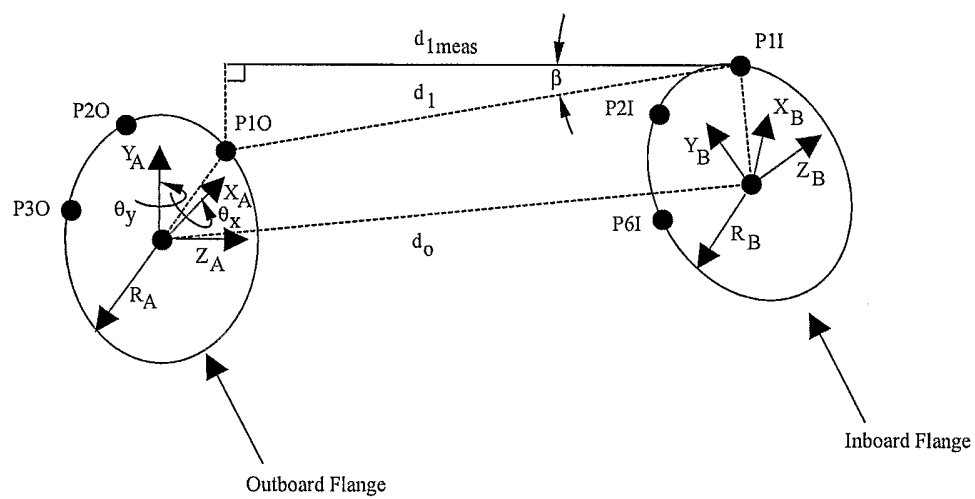


FIG. 11

