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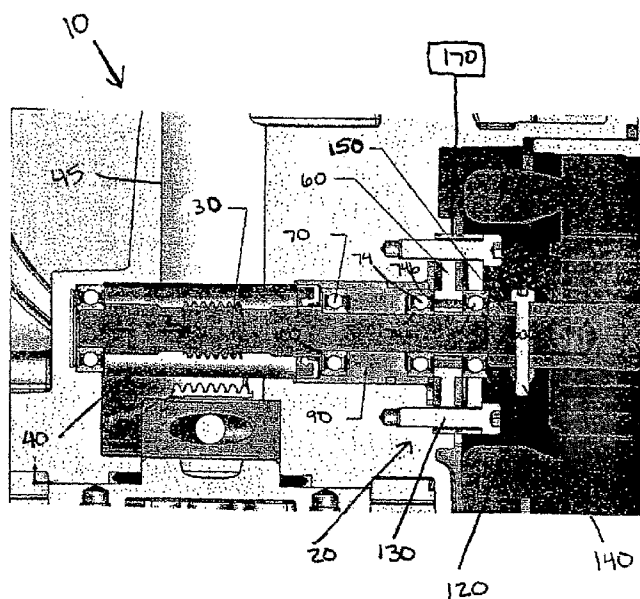
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(54) Title: LOAD MEASUREMENT METHOD AND DEVICE



(57) Abstract: A device for axial load measurement on a mechanical control device (10) having rotating shaft (30) maybe used to derive a torque measurement. A mechanical control device (10) may comprise a valve actuator for fluid flow control devices. The load measurement device may include a beam (65a) op eratively connected to a rotatable shaft and configured to deform under axial displacement of the shaft. A sensor (80) maybe coupled with the at least one beam (65a) and configured to produce an output signal related to the axial displacement of the shaft. The beam may be retained between two bearings (74) of the rotatable shaft at a first end, and fixed to the housing (120) of the mechanical control device at a second end. The first end of the beam (65a) may displace axially with the rotatable shaft. The beam (65a) may comprise a discrete segment of a uniform width and thickness.

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5 The present invention relates to a method and device for load measurement, and, more specifically, to an axial load measurement on a mechanical control device having a rotating shaft, for example, a valve actuator for fluid flow control devices. The load measurement may be used to derive a torque measurement.

Fluid flow control devices include devices for both liquids and gases. Valve actuators for fluid flow control devices are known and may be mechanically operated. For example, the valve actuator may be manually driven, operated by fluid pressure in which the shaft is connected directly or indirectly to a fluid operated piston, or be driven by an electro-hydraulic or electro-fluid means. Conventional valve actuators comprise an electrically driven input shaft, which may be rotatable at relatively high speeds with relatively low torque. The input shaft may, through reducing gears such as a worm gear or a helical screw thread and nut, rotate a relatively high torque, low speed output shaft.

20 It may be desirable to determine the torque generated by the output shaft. For example, when a valve is fully closed and seated, the torque required to open the valve may be considerably higher. Consistently monitoring the torque may indicate if a valve is wearing out or sticking. Trending patterns in the torque measurements may enable predictive maintenance. Override shut-off features may be provided if a torque
25 exceeds a predetermined allowable level.

Measurement of the axial force on the input shaft may be used to determine the torque delivered by the output shaft. The axial load multiplied by the worm gear pitch radius is the torque delivered by the output shaft.

Conventional devices for measuring the end thrust or torque of a rotating shaft are known and include a thrust-torque transducer described in U.S. Patent No. 4,182,168 to Desch. The thrust-torque transducer includes a LVDT (Linear Voltage Differential Transformer) having a movable core axially aligned with, secured to, and rotatable with the shaft, and producing an output signal corresponding to thrust or torque.

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However, in order to provide for operation of the transducer in both clockwise and counterclockwise rotations of the shaft, the Desch thrust-torque transducer requires presetting of a diaphragm of a thrust bearing. The Desch thrust-torque transducer does not detect any misalignment of the axial load on the shaft.

5 Another conventional device for indicating loading on a shaft is described in U.S. Patent No. 5,503,045 to Riester. An increased load on a worm causes axial shifting of a worm shaft and an accompanying deformation of a membranous disc mounted on the worm shaft. One side of the disc is formed with a circumferentially extending, annular recess. The central portion of the disc is fixed against axial
10 displacement relative to the worm shaft by an axial bearing situated on one side of the disc and a bushing which is disposed on the opposite side of the disc. A strain measuring strip on another side of the disc generates changes in measurements with displacement of the worm shaft. The device of Riester does not provide a method for detection of any misalignment of the load on the shaft.

15 Therefore, it would be advantageous to develop a technique for measuring the torque generated by an output shaft using the axial displacement of an input shaft, and detecting any misalignment of the load on the input shaft.

DISCLOSURE OF THE INVENTION

20 The present invention, in a number of representative embodiments, provides a load measurement method and device which may be used to determine a load, including but not limited to the load on a rotating shaft. A mechanical control device having a rotating shaft, for example, a valve actuator for fluid flow control devices, may include a load measurement device of the present invention.

25 In accordance with one embodiment of the present invention, a mechanical control device includes a shaft configured for rotation, a beam operatively connected to the shaft and configured to deform under axial displacement of the shaft, and a sensor coupled with the at least one beam and configured to produce an output signal proportional to the axial displacement of the shaft. The beam may have a substantially
30 uniform cross-section through substantially its entire length.

 The mechanical control device may additionally include bearings for translating the axial displacement of the shaft to the beam. The bearings may include a

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first annular bearing disposed about the shaft and contacting a first surface of the beam, and a second annular bearing disposed about the shaft and contacting a second, opposing surface of the beam. Additionally included in the mechanical control device may be an annular body encircling the shaft, with the beam extending outwardly from the shaft toward the annular body. A portion of the beam may be fixed to the annular body. A housing may be fixed to the annular body, and configured for axial movement of the shaft relative to the housing.

The output signal of the sensor of the mechanical control device may identify any misalignment of the worm shaft. The sensor may include at least one strain gauge. The beam of the mechanical control device may include a metal, and may also include an array of discrete beams arranged in a spoke formation about the shaft.

In accordance with another embodiment of the present invention, a load sensor for measuring the axial load on a rotatable shaft includes at least one deflection beam having a first end portion thereof retained between two bearings, each bearing operatively connected to the rotatable shaft for translating axial movement of the shaft to the at least one deflection beam (as a deflection), and a sensor operatively connected to the at least one deflection beam and configured for measuring the deflection of the at least one deflection beam.

The sensor may comprise at least one strain gauge and the at least one deflection beam may comprise a discrete metal segment having a substantially uniform width and thickness therethrough. The at least one deflection beam may include a second end portion fixed to a housing for the load sensor, the housing being configured to enable relative axial displacement of the rotating shaft with respect thereto.

The load sensor may additionally include an annular body encircling the rotatable shaft. The at least one deflection beam may include an array of deflection beams arranged in a spoke formation about the shaft, extending outwardly from the shaft toward the annular body, wherein a second portion of each deflection beam is fixed to the annular body. A housing may be fixed to the annular body, the shaft being configured for axial movement relative to the housing. Each deflection beam of the array of deflection beams may include a sensor operatively connected thereto, each sensor being in communication with an output device, which relates any misalignment of the worm shaft.

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In yet another aspect, the present invention includes a method of measuring a torque delivered to a valve. A rotatable shaft may include two bearings operatively coupled to the rotatable shaft. The method includes providing at least one beam disposed between the two bearings on a first end and coupled to a fixed housing on a second end, rotating a worm gear with the shaft, the worm gear being operatively coupled with a worm wheel and shaft driving the valve, and transmitting the torque delivered to the valve into axial movement of the rotatable shaft. The method additionally includes deflecting the at least one beam with the axial movement of the shaft, which is translated to the beam with the axial displacement of the two bearings, sensing the deflection of the at least one beam, determining an axial load on the shaft using the deflection of the at least one beam, and determining the torque delivered to a valve using the axial load on the shaft and a radius of the worm gear.

In particular embodiments of the invention, providing at least one beam may comprise providing a beam of a substantially uniform width and thickness therethrough, or alternatively may comprise providing an array of beams arranged in a spoke formation about the rotatable shaft. Sensing the deflection of the at least one beam may comprise independently sensing the deflection of each beam of the array of beams.

The features, advantages, and alternative aspects of the present invention will be apparent to those skilled in the art from a consideration of the following detailed description taken in combination with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

While the specification concludes with claims particularly pointing out and distinctly claiming that which is regarded as the present invention, the advantages of this invention can be more readily ascertained from the following description of the invention when read in conjunction with the accompanying drawings in which:

FIG. 1A is a cross-sectional view of a mechanical control device and torque measurement device of the present invention;

FIG. 1B is a perspective view of the mechanical control device and torque measurement device of FIG. 1A

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FIG. 2 is a view of one embodiment of a plate of a torque measurement device of the present invention;

FIG. 3 is a view of another embodiment of a plate of a torque measurement device of the present invention;

5 FIG. 4 is a perspective view of the plate of FIG. 3 installed in a representative load measurement device of the present invention;

FIG. 5 is a perspective view of another embodiment of a load measurement device of the present invention; and

10 FIG. 6 is a view of yet another embodiment of a plate of a torque measurement device of the present invention.

BEST MODE(S) FOR CARRYING OUT THE INVENTION

Although the foregoing description contains many specifics, these should not be construed as limiting the scope of the present invention, but merely as providing
15 illustrations of some representative embodiments. Similarly, other embodiments of the invention may be devised that do not depart from the spirit or scope of the present invention. Features from different embodiments may be employed in combination. The scope of the invention is, therefore, indicated and limited only by
20 the appended claims and their legal equivalents, rather than by the foregoing description. All additions, deletions, and modifications to the invention, as disclosed herein, which fall within the meaning and scope of the claims, are to be embraced thereby.

FIG. 1A illustrates a cross section of an embodiment of a mechanical control device 10 including a torque measuring device 20 of the present invention. The
25 mechanical control device 10 may comprise a valve actuator and may be operated, by way of example, manually, by a motor, or by fluid pressure. The mechanical control device 10 comprises a rotor 150 which drives a worm shaft 30 coupled to a worm gear 40. The worm gear 40 drives and is operatively connected to an output shaft 45. As the worm shaft 30 is rotated to drive the worm gear 40, the force
30 required to drive the worm gear 40 and output shaft 45 may cause an axial displacement of the worm shaft 30 relative to a housing 120 of the mechanical control device 10. The axial movement may be registered with a plate 60. A

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portion of the plate may be fixed to the housing 120, preventing axial movement thereof. Another portion of the plate 60 may deflect with the axial displacement of the worm shaft, transferred by a ball bearing 74, 76.

The deflection of the plate 60 may cause a significant strain therein, which
5 may, in turn, be measured using a sensor 80 (see FIG. 2). The sensor 80 may have an output that may be translated into the axial load on the worm shaft 30. The axial load, when multiplied by the worm gear pitch radius, is the torque delivered by the worm gear 40 to the output shaft 45. The axial movement of the worm shaft 30 may occur in either direction, depending on the direction of rotation of the worm shaft 30
10 and subsequent rotation of the output shaft 45. An output device 170 may be provided to display information such as, by way of example, the strain of the plate 60, the axial load of the worm shaft 30, and/or the torque on the output shaft 45.

The worm shaft 30 shown in FIG. 1A rotates within a sleeve 90 on
15 bearings 70, 74, and 76, which by way of example can include ball bearings. A perspective view is shown in FIG. 1B. Driving the worm gear 40, which in turn drives the output shaft 45, applies an axial load on the worm shaft 30. The axial load forces the worm shaft 30 to displace axially. The worm shaft 30 may be displaced in two opposing axial directions, shown by arrows 1 and 2, and the
20 plate 60 may be deflected toward two different positions. During rotation, the worm shaft 30 may be displaced to the left, as shown by arrow 1. The axial load may be transferred to the plate 60 via the rotor 150. An attachment element 140 secures the worm shaft 30 to the rotor 150. The attachment element 140 may comprise, for example, a bolt or a screw. The worm shaft 30 pulls on the attachment element 140.
25 The attachment element 140 causes the rotor 150 to axially displace with the worm shaft 30 and the rotor 150 presses against the bearing 76. The bearing 76 pushes on the plate 60, causing the plate to deflect toward a first flexed position. An inner race 76a of the bearing 76 is flush with, and rotates with, the worm shaft 30. An outer race 76b of the bearing 76 contacts and pushes on the plate 60. The plate 60
30 does not rotate since the outer circumference of the plate 60 is fixed to the housing 120 with attachment elements 130. A sensor 80 may determine the strain on the plate 60 to determine the axial load on the worm shaft 30.

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Alternatively, the worm shaft may rotate in the opposite direction, turning the output shaft 45 in the opposite direction. The worm shaft is thus axially loaded to the right, in the direction of arrow 2. The worm shaft 30 is displaced to the right and a shoulder 100 of the worm shaft 30 may press against the bearing 70. The
5 shoulder 100 comprises a radial face of the worm shaft 30 at a junction of a portion of the worm shaft 30 having a smaller diameter and a portion of the worm shaft 30 having a larger diameter. The bearing 70 presses against the sleeve 90, causing matching axial displacement of the worm shaft 30 and the sleeve 90. The sleeve 90 and the bearing 74 thus undergo substantially the same axial displacement as the
10 worm shaft 30, forcing the bearing 74 against the plate 60, and causing the plate to deflect toward the second flexed position. The inner race 74a of the bearing 74 is flush with, and rotates with, the worm shaft 30. The outer race 74b of the bearing 74 contacts the sleeve 90 and the plate 60, transmitting the axial load thereto. The first flexed position of the plate 60 may correspond to a closing force being applied to the
15 valve (not shown) via the mechanical control device 10, and the second flexed position may correspond to an opening force being applied to the valve, or vice versa, depending on the direction of the threads of the worm shaft 30 and the configuration of the valve in communication with the valve actuator.

The sleeve 90, as depicted, does not rotate with the worm shaft 30.
20 However, it is understood that a sleeve which rotates in conjunction with the worm shaft 30 is within the scope of the present invention. In addition, it is within the scope of the present invention to include a second sleeve about the worm shaft 30, between the rotor 150 and the bearing 76. Thus, a sleeve (and not the rotor) may transmit the axial load to the plate 60 from the worm shaft 30 when experiencing an
25 applied load in the direction of arrow 1.

An axial bearing may be positioned between the rotor 150 and the device operating the mechanical control device 10, such as a motor, enabling the rotor to move axially relative to the operating device. Thus any outside axial forces on the operating device may also be absorbed with the axial bearing and do not affect the
30 measurement of the axial load.

FIG. 2 depicts a plate 60a according to a particular embodiment of the present invention. The plate 60a is substantially planar, comprising an annular

body 62a and an array of four discrete inwardly protruding beams 65a. Each beam 65a may have a substantially rectangular cross-section may be disposed at a right angle to each adjacent beam 65a. The annular body 62a and the inwardly protruding beams 65a may be contiguous, formed from a single piece of material, such as, for example, a metal disc. For example, the plate 60a may be formed by stamping, forging, or laser cutting. Alternatively, the beams 65a may be attached to the annular body 62a, such as with an adhesive or an attachment element. The beams 65a may be formed of the same material as the annular body 62a or can be formed from a different material. By way of example, suitable materials for the annular body 62a and beams 65a include a metal, such as copper, aluminum, steel, stainless steel, or a polymer. The inwardly protruding beams 65a may be removable and replaceable.

The inwardly protruding beams 65a provide a passageway 110 for the worm shaft 30 (not shown in FIG. 2) to extend therethrough. The inwardly protruding beams 65a may be arranged in a spoke formation within the central opening of the annular body 62a. However, the beams 65a need not join at the center of the annular body 62a central opening; rather, the center may comprise the open passageway 110. The ends of the beams 65a distal from the annular body 62a are free to displace under the load of the axial displacement of the worm shaft 30, transferred by the bearings 74, 76. (See FIG. 1A.) Each beam 65a may have a substantially uniform thickness t and width w along the length l of the beam 65a.

FIG. 2 depicts (with shading) the strain under deflection on the annular body 62a and each beam 65a of the plate 60a. The darkly shaded portions represent the portions under the greatest strain, and the lighter shaded areas show the portions under less strain. The plate 60a is depicted with four apertures 50 through the annular body 62a, enabling the plate 60a to be secured to a housing 120 (see FIG. 1A) of the mechanical control device 10. Attachment elements 130, for example bolts, pins, or screws, may be used to secure the plate 60a. The plate 60a may be secured by methods other than attachment elements, such as, for example, by brazing or welding.

During use, the motor may turn the worm shaft 30, which rotates the output shaft 45. The force causing the output shaft 45 to turn causes an axial movement of

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the worm shaft 30. The sleeve 90 on the worm shaft 30 also moves axially, pushing the bearings 74 against each beam 65a of the array. Each beam 65a flexes, with the portion of the beam 65a that is in contact with the bearing being displaced with the axial movement of the shaft. The annular body 62a of the plate 60a is fixed to the housing and is not displaced. Thus, each beam 65a deflects or flexes, causing a strain therein. The strain within each beam 65a may be measured using a sensor 80. Each beam 65a may include a sensor 80 or, alternatively, only one beam may include a sensor 80.

Including a sensor 80 on a plurality of beams 65a of the array of beams enables independent measurements of the stress and/or strain on each of the plurality of beams 65a. Each beam 65a of the array of beams 65a is discrete and the array may surround the worm shaft 30. Each beam 65a may undergo the axial displacement of the worm shaft 30 at separate locations about the circumference of the worm shaft 30. Thus, if the worm shaft 30 bends, or assumes any other misalignment of the axial load, the sensors 80 on each beam 65a may sense different measurements. Comparing the measurements further enables a determination of any misalignment of the axial load on the worm shaft 30. The sensors may be configured to cancel out any misalignment and to provide a signal corresponding to a reading incorporating any misalignment. Alternatively, a separate signal may be provided, warning of the misalignment.

FIG. 3 depicts another embodiment of a plate 60b according to the present invention. The plate 60b comprises a substantially planar annular body 62b having four discrete inwardly protruding beams 65b. Each beam 65b may have a substantially rectangular cross-section and may be disposed at a right angle to each adjacent beam 65b. The corners 66b at the junction of the annular body 62b and inwardly protruding beams 65b are chamfered. The chamfering may reduce the stress on the plate 60b at the corners 66b. The inwardly protruding beams provide a passageway 110 for the worm shaft 30 (not shown in FIG. 3) to extend therethrough. The plate 60b shows the stress under deflection of the annular body 62b and each beam 65b with shading. The darkly shaded portions represent the portions under the greatest stress, and the lightly shaded area show the portions under less stress. The plate 60b is depicted with four apertures 50, enabling the plate 60b to be secured to a

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housing 120 (see FIG. 1A) of the mechanical control device 10. Attachment elements 130, for example bolts or screws, may be used to secure the plate 60b.

FIG. 4 is a perspective view of the plate of FIG. 3 installed in a load measurement device 20b of the present invention. The rotor 150 protrudes from the center of the plate 60b. A portion of the worm shaft 30 is encased within the rotor 150 and secured thereto with attachment element 140. The bearing 76 encircles the worm shaft 30. A distal end of the rotor abuts the bearing 76, transmitting any axial load in the direction of arrow 1 (see FIG. 1A) thereto. The outside race 76b of the bearing contacts the surface of each beam 65b on a first portion distal from the annular body 62b. Each beam 65b may include a second portion secured to the annular body 62b, which does not undergo displacement since the annular body 62b is fixed to the housing 120. The first portions of the beams 65b displace with the bearing 76, while the second portions of the beams 65b are secured to the fixed annular body 62b. Thus, the beams 65b deflect or flex, which places the beam under a strain. The strain may be measured with a sensor 80, such as a strain gage.

FIG. 5 is a perspective view of a load measurement device 20c according to a particular embodiment of the invention. Plate 60c comprises an array of three discrete beams 65c disposed in a spaced-apart configuration, each beam 65c extending outwardly from the worm shaft 30. Although the present embodiment is shown with three beams 65c, it is understood that any number of beams 65c can be used. Each discrete beam may be secured to the housing 120 with an attachment element 160. Each beam 65c may have a sensor 80 mounted thereon or, alternatively, only one or two of the beams 65c may include a sensor 80. The sensor 80 may include a plurality of sensors disposed in a plurality of locations on the beam 65c. In one embodiment, the sensors 80 may be located in the areas of maximum strain. The beams 65c do not contact the worm shaft 30, however any axial load applied to the worm shaft 30 may be transferred to the beams 65c via the bearing 74. The beams 65c do not completely encircle the worm shaft 30, rather each beam 65c is separately spaced.

The beams 65c need not be secured to an annular body, such as the beams 65a and 65b depicted in FIGS. 3, 4, and 5. The beams 65c may each

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comprise an elongated body, having a substantially uniform cross-section therethrough. A first portion of each beam 65c may be free to axially displace with the worm shaft 30, under the axial load transferred by bearing 74. A second portion of each beam 65c, at an opposite end longitudinally from the first portion, may be secured to the housing 120 with an attachment element 160. The worm shaft 30 may be axially displaced relative to the housing 120 under the axial load. The first portion of each beam 65c may be displaced relative to the housing 120 with the worm shaft 30. The second portion of each beam 65c can be secured to the housing and can be prevented from being displaced. Thus, each beam 65c may deflect, causing strain therein. The strain may be measured with the sensor 80.

A plate 60 may include any number of beams 65. For example the plate 60b depicted in FIG. 4 includes an array of four beams 65b, and the plate 60c depicted in FIG. 5 includes an array of three beams 65c. Additionally, a plate having only a single beam is within the scope of the present invention.

Measuring the direct reaction forces on internal components of a mechanical control device, such as the axial load on a worm shaft 30, is an accurate method of determining the torque that the mechanical control device is delivering to an output shaft. This measurement is independent of gear efficiency, gear speed, motor torque, and motor applied line power. A beam 65a, 65b, 65c of a load measurement device 20, 20b, 20c of the present invention may be formed so that the deflection caused by the axial load on the worm shaft 30 creates enough strain to obtain an electronic signal with the sensor 80, but not enough to cause a permanent strain or deflection to the beam 65a, 65b, 65c. The worm gear 40, driven by the worm shaft 30, may be a shell type or may be integral to the worm shaft 30.

FIG. 6 depicts a plate 60d according to a particular embodiment of the present invention. The plate 60d is annular, having a passageway 110d for the worm shaft 30 (not shown in FIG. 6) to extend therethrough. The annular plate 60d may be contiguous, formed from a single piece of material, such as, for example, a metal disc. For example, the plate 60d may be formed by stamping, forging, or laser cutting. By way of example, suitable materials for the plate 60d include a metal, such as copper, aluminum, steel, stainless steel or a polymer. The plate 60d may include apertures 50 therethrough, enabling the plate 60d to be secured to a

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housing 120 (see FIG. 1A) of the mechanical control device 10. A sensor 80 may be positioned in an area of maximum strain on the plate 60d, near an aperture 80.

Although the foregoing description contains many specifics, these are not to be construed as limiting the scope of the present invention, but merely as providing certain
5 representative embodiments. Similarly, other embodiments of the invention can be devised which do not depart from the spirit or scope of the present invention. The scope of the invention is, therefore, indicated and limited only by the appended claims and their legal equivalents, rather than by the foregoing description. All additions,
deletions, and modifications to the invention, as disclosed herein, which fall within the
10 meaning and scope of the claims, are encompassed by the present invention.

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CLAIMS

What is claimed is:

- 5 1. A mechanical control device comprising:
 a shaft configured for rotation;
 at least one beam operatively connected to the shaft and configured to deform
 under axial displacement of the shaft; and
 a sensor coupled with the at least one beam and configured to produce an
10 output signal proportional to the axial displacement of the shaft.
2. The mechanical control device of claim 1, wherein the at least one
 beam has a substantially uniform cross-section through an entire length of the at least
 one beam.
- 15 3. The mechanical control device of claim 1, further comprising bearings
 for translating the axial displacement of the shaft to the at least one beam.
4. The mechanical control device of claim 3, wherein the bearings
20 comprise an annular bearing disposed about the shaft and contacting a first surface of
 the at least one beam, and another annular bearing disposed about the shaft and
 contacting a second, opposing surface of the at least one beam.
5. The mechanical control device of claim 1, further comprising:
25 an annular body encircling the shaft, the at least one beam extending outwardly
 from the shaft toward the annular body, and a portion of the at least one beam fixed to
 the annular body; and
 a housing fixed to the annular body, the housing configured for axial movement
 of the shaft relative to the housing.
- 30 6. The mechanical control device of claim 1, wherein the output signal
 relates any misalignment of the worm shaft.

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7. The mechanical control device of claim 7, wherein the sensor comprises at least one strain gauge.

5 8. The mechanical control device of claim 1, wherein the at least one beam comprises a metal.

9. The mechanical control device of claim 1, wherein the at least one beam comprises an array of discrete beams arranged in a spoke formation about the
10 shaft.

10. A load sensor for measuring the axial load on a rotatable shaft, comprising:

at least one deflection beam having a first end portion thereof retained between
15 two bearings, each bearing operatively connected to the rotatable shaft for translating axial movement of the shaft to a deflection of the at least one deflection beam; and
a sensor operatively connected to the at least one deflection beam and
configured for measuring the deflection of the at least one deflection beam.

20 11. The load sensor of claim 10, wherein the sensor comprises at least one strain gauge.

12. The load sensor of claim 10, wherein the at least one deflection beam comprises a discrete segment of a substantially uniform width and thickness
25 therethrough.

13. The load sensor of claim 10, wherein the at least one deflection beam comprises a metal.

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14. The load sensor of claim 10, wherein the at least one deflection beam includes a second end portion fixed to a housing for the load sensor, the housing configured to enable relative axial displacement of the rotating shaft with respect thereto.

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15. The load sensor of claim 10, further comprising:
an annular body encircling the rotatable shaft, the at least one deflection beam comprising an array of deflection beams arranged in a spoke formation about the shaft, extending outwardly from the shaft toward the annular body, wherein a second portion
10 of each deflection beam is fixed to the annular body; and
a housing fixed to the annular body, the shaft configured for axial movement relative to the housing.

16. The load sensor of claim 15, wherein each deflection beam of the array
15 of deflection beams includes a sensor operatively connected thereto, each sensor in communication with an output device.

17. A method of measuring a torque delivered to a valve, comprising:
providing a rotatable shaft having two bearings operatively coupled thereto;
20 providing at least one beam disposed between the two bearings on a first end and coupled to a fixed housing on a second end;
rotating a worm gear with the shaft, the worm gear operatively coupled with a worm wheel and shaft driving the valve;
transmitting the torque delivered to the valve into axial movement of the
25 rotatable shaft;
sensing deflection of the at least one beam due to axial displacement of the two bearings and axial movement of the shaft;
determining an axial load on the shaft using the deflection of the at least one beam; and
30 determining the torque delivered to a valve using the axial load on the shaft and a radius of the worm gear.

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18. The method of claim 17, wherein providing at least one beam comprises providing a beam of a substantially uniform width and thickness therethrough.

5 19. The method of claim 17, wherein providing at least one beam comprises providing an array of beams arranged in a spoke formation about the rotatable shaft.

10 20. The method of claim 19, wherein sensing the deflection of the at least one beam comprises independently sensing the deflection of each beam of the array of beams.

21. A mechanical control device comprising:
a shaft configured for rotation;
15 an annular plate operatively connected to the shaft and configured to deform under axial displacement of the shaft; and
a sensor coupled with the annular plate and configured to produce an output signal proportional to the axial displacement of the shaft.

20 22. The mechanical control device of claim 21, further comprising:
a central passageway through the annular plate; and
at least one circumferentially positioned aperture through the annular plate.

25 23. The mechanical control device of claim 22, wherein the sensor is positioned on the annular plate radially between the central passageway and the at least one circumferentially positioned aperture.

AMENDED CLAIMS

received by the International Bureau on 22 December 2006 (22.12.06)

7. The mechanical control device of claim 1, wherein the sensor comprises at least one strain gauge.

5 8. The mechanical control device of claim 1, wherein the at least one beam comprises a metal.

9. The mechanical control device of claim 1, wherein the at least one beam comprises an array of discrete beams arranged in a spoke formation about the
10 shaft.

10. A load sensor for measuring the axial load on a rotatable shaft, comprising:

at least one deflection beam having a first end portion thereof retained between
15 two bearings, each bearing operatively connected to the rotatable shaft for translating axial movement of the shaft to a deflection of the at least one deflection beam; and
a sensor operatively connected to the at least one deflection beam and configured for measuring the deflection of the at least one deflection beam.

20 11. The load sensor of claim 10, wherein the sensor comprises at least one strain gauge.

12. The load sensor of claim 10, wherein the at least one deflection beam comprises a discrete segment of a substantially uniform width and thickness
25 therethrough.

13. The load sensor of claim 10, wherein the at least one deflection beam comprises a metal.

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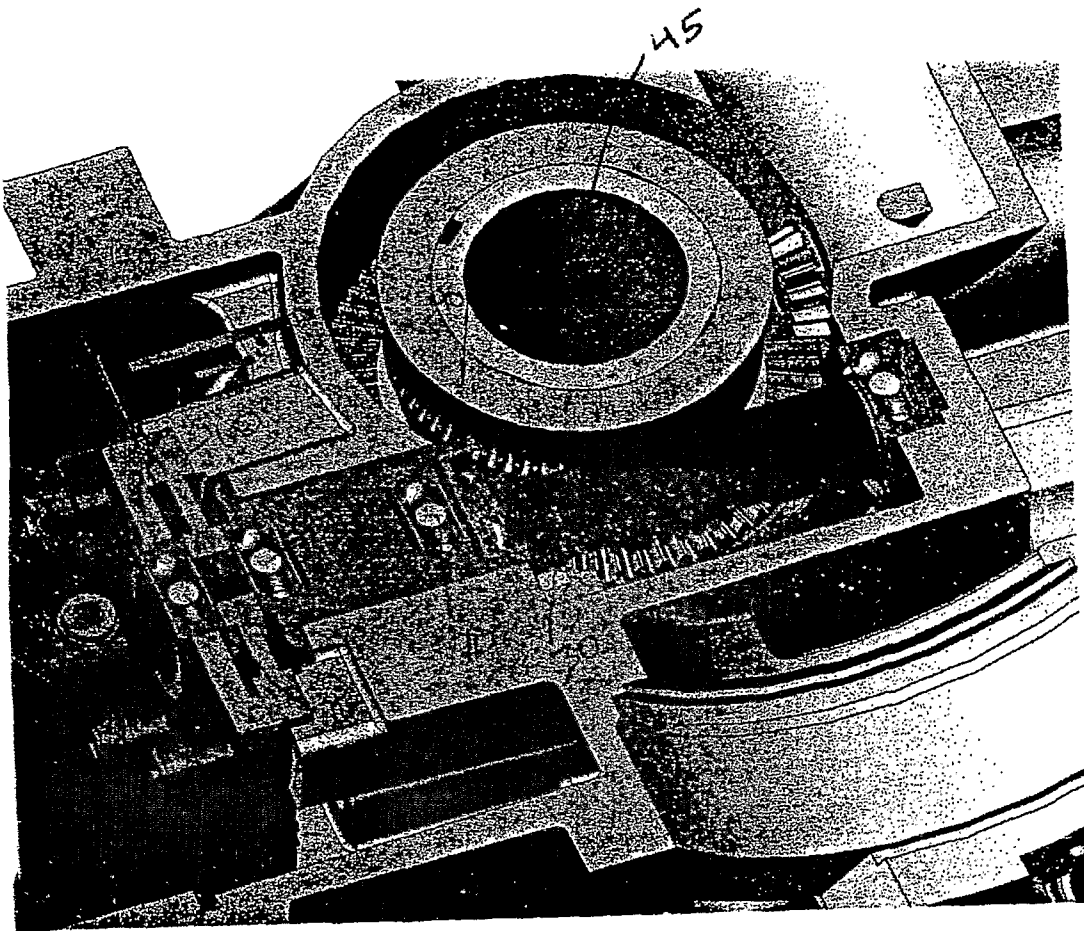


FIG. 1B

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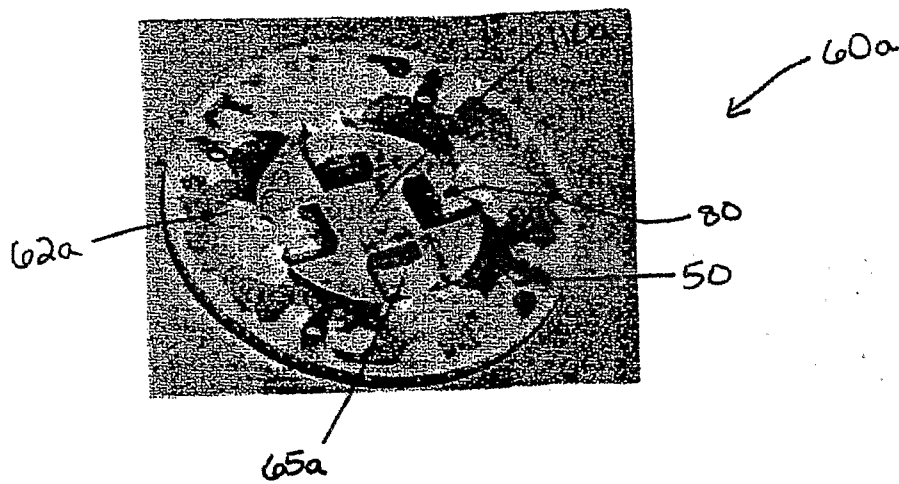


FIG. 2

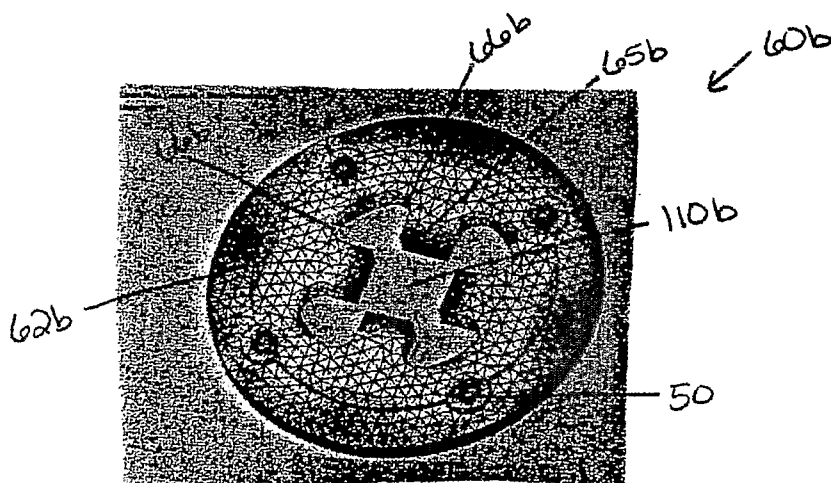
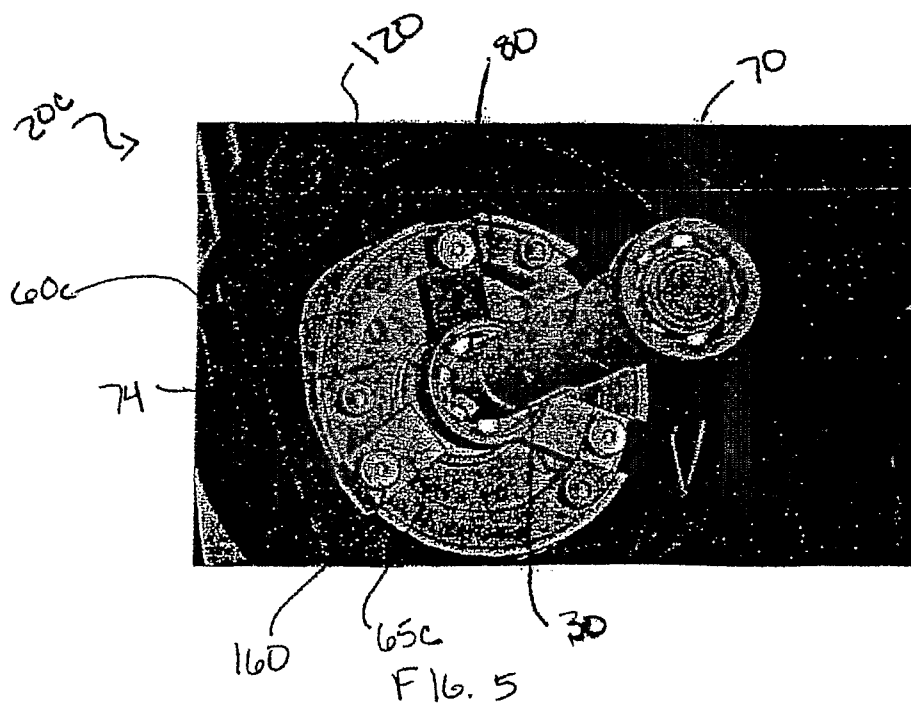
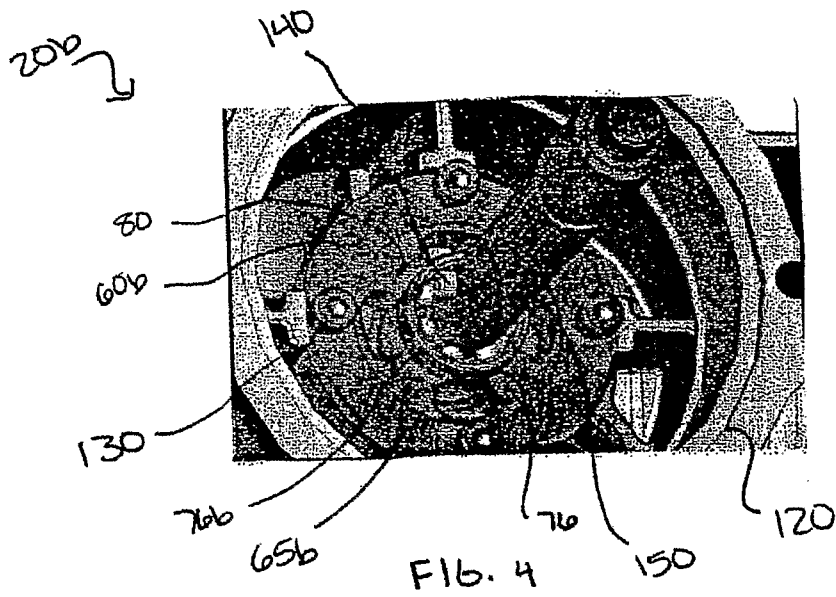


FIG. 3

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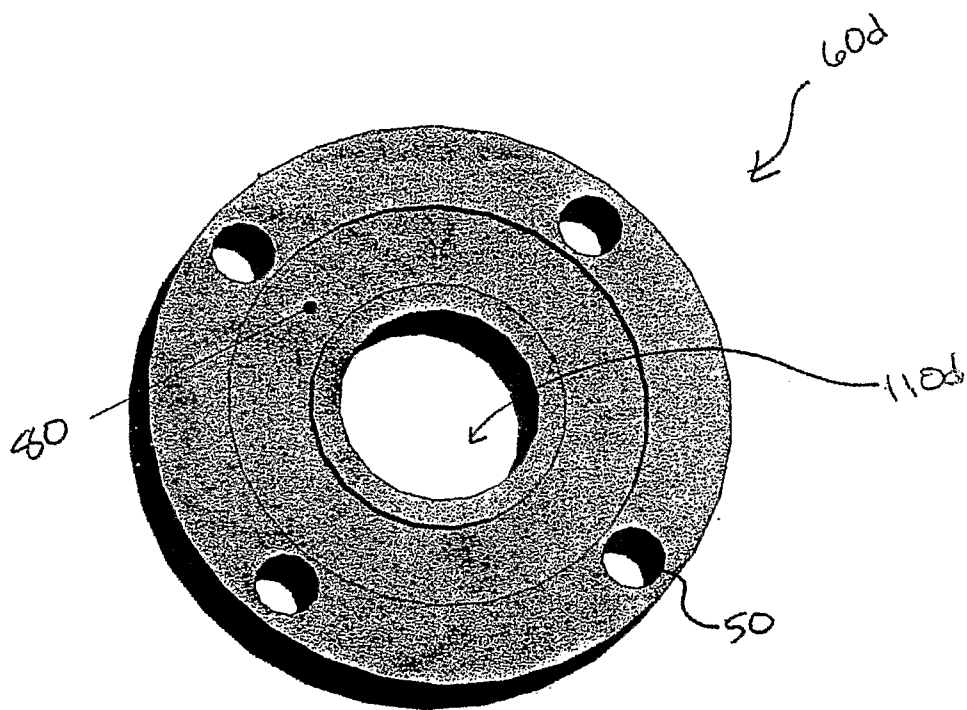


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US06/08030

A. CLASSIFICATION OF SUBJECT MATTER

IPC: G01N 3/20(2006.01)

USPC: 73/854

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 73/862.49

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EAST

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4,168,160 (STOFERLE et al) 18 September 1979 (18.9.1979), column 4, lines 32 - 45 and 56 - 53).	1-23

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:

"A"	document defining the general state of the art which is not considered to be of particular relevance	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E"	earlier application or patent published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"O"	document referring to an oral disclosure, use, exhibition or other means	"&"	document member of the same patent family
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

17 August 2006 (17.08.2006)

Date of mailing of the international search report

24 OCT 2006

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