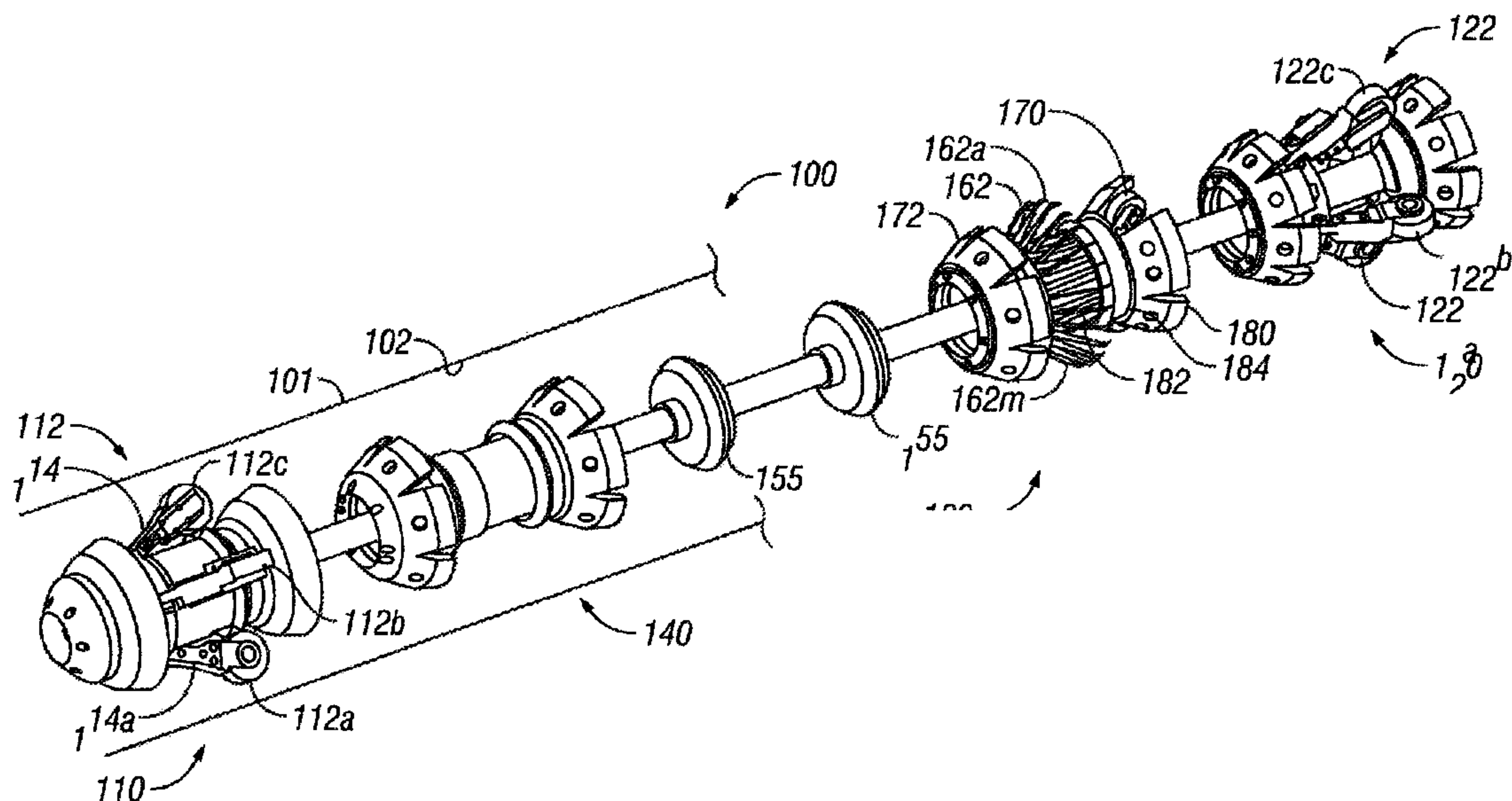




(86) Date de dépôt PCT/PCT Filing Date: 2008/03/12
(87) Date publication PCT/PCT Publication Date: 2008/09/18
(45) Date de délivrance/Issue Date: 2012/07/17
(85) Entrée phase nationale/National Entry: 2009/08/19
(86) N° demande PCT/PCT Application No.: US 2008/056605
(87) N° publication PCT/PCT Publication No.: 2008/112732
(30) Priorités/Priorities: 2007/03/12 (US60/894,414);
2008/03/11 (US12/046,044)

(51) Cl.Int./Int.Cl. *G01M 99/00* (2011.01),
F16L 55/28 (2006.01), *F16L 55/44* (2006.01),
G01N 27/02 (2006.01)
(72) Inventeurs/Inventors:
PIRNER, PAUL, CA;
AKULSHYN, VYACHESLAV, CA
(73) Propriétaire/Owner:
BAKER HUGHES INCORPORATED, US
(74) Agent: SIM & MCBURNEY

(54) Titre : ELEMENTS DE PROTECTION POUR DES DISPOSITIFS D'EXPLORATION DE CANALISATIONS
(54) Title: PROTECTION ELEMENTS FOR PIPELINE INVESTIGATION DEVICES



(57) Abrégé/Abstract:

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(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
18 September 2008 (18.09.2008)

PCT

(10) International Publication Number
WO 2008/112732 A1

(51) International Patent Classification:

G01M 19/00 (2006.01) **G01M 3/40** (2006.01)

(21) International Application Number:

PCT/US2008/056605

(22) International Filing Date: 12 March 2008 (12.03.2008)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

60/894,414 12 March 2007 (12.03.2007) US
12/046,044 11 March 2008 (11.03.2008) US

(71) Applicant (for all designated States except US): **BAKER HUGHES INCORPORATED** [US/US]; 2929 Allen Parkway, Suite 2100, Houston, TX 77019-2118 (US).

(72) Inventors: **AKULSHYN, Vyacheslav**; 3173 Hedgestone Court, Mississauga, ON L4X 2K3 (CA). **PIRNER, Paul**; 566 Comanche Road, Mississauga, Ontario L5H 1W2 (CA). **AKULSHYN, Vyacheslav**; 3173 Hedgestone Court, Mississauga, ON L4X 2K3 (CA).

(74) Agent: **LITTLEFIELD, Stephen, A.**; Baker Petrolite Division Of Baker Hughes, Incorporated, 12645 West Airport Blvd., Sugarland, TX 77478 (US).

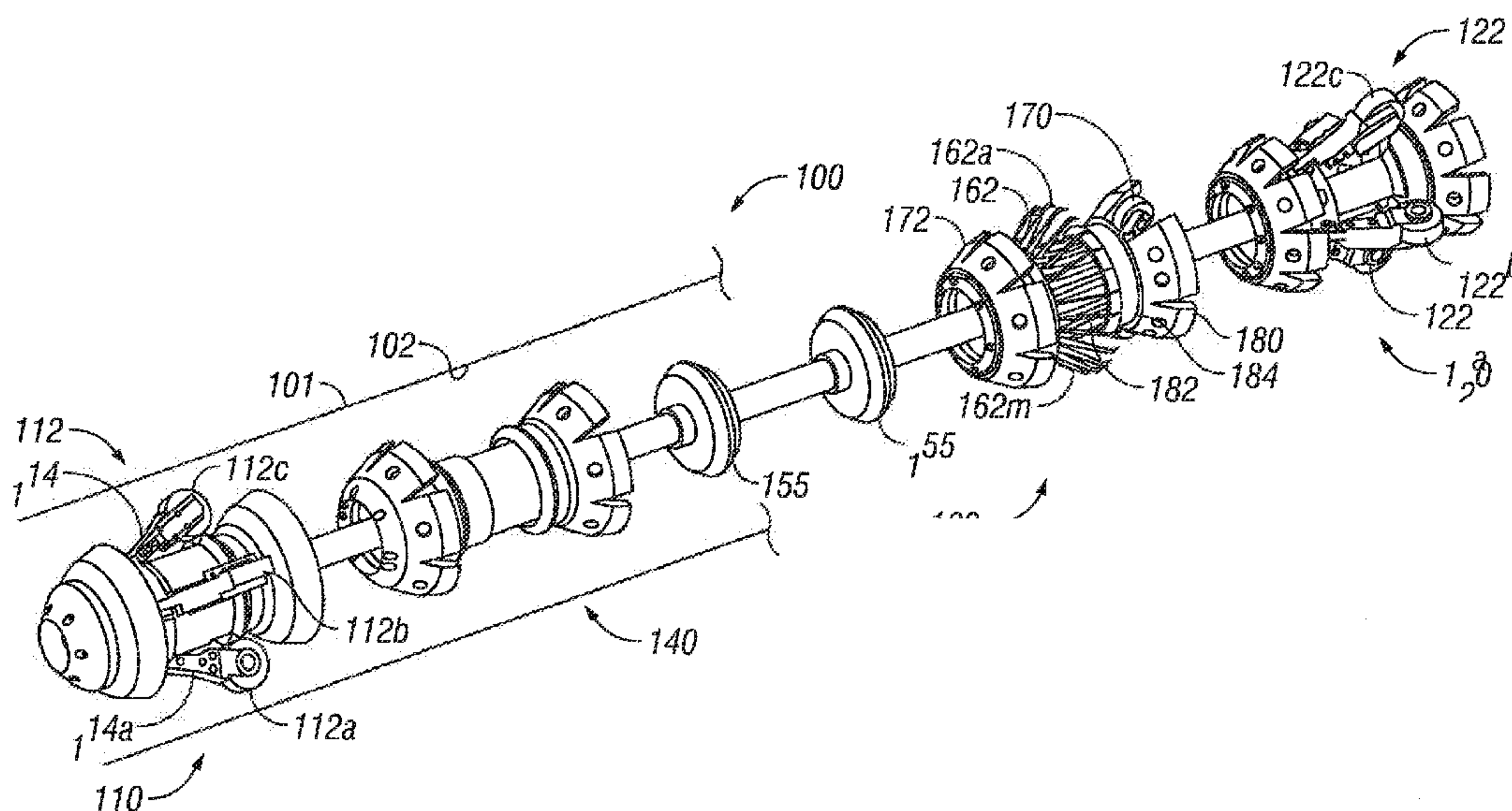
(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM,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

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, 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, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, NO, 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:

- with international search report
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

(54) Title: PROTECTION ELEMENTS FOR PIPELINE INVESTIGATION DEVICES



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PROTECTION ELEMENTS FOR PIPELINE INVESTIGATION DEVICES

BACKGROUND OF THE DISCLOSURE

Field of the Disclosure

- 5 **[0001]** The present disclosure relates to arrangements and methods for interrogation devices.

Description of the Related Art

- [0002]** Structures, such as conduits carrying fluids, degrade due to corrosion. It is often desirable to inspect and evaluate the condition of such structures.
- 10 Inspections may include an evaluation of structural integrity, the identification and quantification of undesirable materials and the analysis of the nature and extent of corrosion. The evaluation of structures may also include an assessment of the effectiveness of devices and equipment utilized to mitigate the effects of wear, minimize the occurrence of sediments and deposits and
- 15 reduce corrosion. A conduit or pipeline, such as may be employed to transport hydrocarbons, chemicals and water is one type of structure in which a periodic inspection can yield a variety of benefits such as improved service life and reduced likelihood of leaks.

- [0003]** In some instances an inspection device, sometimes referred to as a
- 20 “pig,” is passed through the pipeline to perform one or more measurements that provide an indication of the condition of the pipeline. Some such devices utilize components that can be damaged when subjected to high mechanical loadings or to an impact of sufficient magnitude. Deformities or surface discontinuities in pipelines, among other things, can cause high mechanical
- 25 loading or undesirable impact on the inspection device, thereby damaging one or more components of the inspection device. Such a damage can result in the measurements obtained by the inspection device being inaccurate. Therefore, it is desirable to have an inspection device that provides relatively accurate measurements in such less-than-ideal operating environments.

SUMMARY OF THE DISCLOSURE

[0004] In one aspect, the present disclosure provides an apparatus for interrogating a conduit, wherein the apparatus includes at least one deformable element that engages a surface of the conduit. The apparatus
5 uses the at least one deformable element to estimate or determine a parameter of interest relating to the conduit. The apparatus further includes at least one deformation control member proximate or positioned adjacent to the at least one deformable element to protect the deformable element from one or more features of the conduit. In one aspect, the deformation control
10 element may protect the at least one deformable element by controlling the extent of the deformation experienced by the at least one deformable element. In another aspect, the at least one deformation control element may be more rigid than the at least one deformable element so that the deformation control member takes over or assumes a loading that would
15 otherwise deform the at least one deformable element to an undesirable extent. In one aspect, the at least one deformable element may be arranged in a generally circumferential manner and wherein the at least one deformation control member limits a movement or of the at least one deformable element or a reduction in a radial dimension of the at least one
20 deformable element.

[0005] In one aspect, the interrogation tool may be configured to estimate or determine an electrical property of the conduit. In one aspect, the at least one deformable element includes at least one electrically conductive element. For instance, the at least one deformable element may include a plurality of
25 electrically conductive elements that are circumferentially disposed on a radial outer surface of an annular disk. In such an arrangement, the deformation control member may be formed as an annular disk-like member that has an outer diameter smaller than an outer diameter of the plurality of electrically conductive elements. In one embodiment, the at least one deformable
30 element may include a first and a second electrically conductive contact member, each of which has an associated deformation control member. The

interrogation tool may be electrically coupled to the first and second electrically conductive contact members and determine a voltage differential along a portion of the conduit using the first and second electrically conductive contact members.

[0006] In other aspects, the disclosure provides a method of interrogating a conduit that includes: passing a device through the conduit that has a deformable element that remains substantially in contact with an internal surface of the conduit during interrogation; providing a deformation control element that reduces a mechanical load on the deformable element. In another aspect, the method includes taking an electrical measurement by the device and using the electrical measurement to estimate a property of interest or characteristic of the conduit. In one aspect, the electrical measurement may be voltage differential along a portion of the conduit. The property of interest may include an estimate of corrosion, pits, gauges, cracks or another physical condition of the conduit.

In accordance with an aspect of the present invention there is provided an apparatus for interrogating a conduit, comprising:

- (a) at least one deformable element having a plurality of electrically conductive elements engaging a surface of the conduit;
- (b) an interrogation tool configured to use the at least one deformable element to determine a parameter of interest relating to the conduit;
- (c) at least one deformation control member positioned adjacent the at least one deformable element, the deformation control member having an outer diameter smaller than an outer diameter of the plurality of electrically conductive elements and controlling a deformation of the at least one deformable element;
- (d) a support member on which the at least one deformable element and the at least one deformation control member are positioned; and

(e) a rim associated with the support member and having a radially outer surface, the plurality of electrically conductive elements being circumferentially disposed on the radially outer surface.

In accordance with a further aspect of the present invention there is provided a method for interrogating a conduit, composing:

- (a) positioning at least one deformable element and at least one deformation control member on a support member, the deformable element having a plurality of electrically conductive elements disposed circumferentially on a radially outer surface of a rim associated with the support member, the deformation control member having an outer diameter smaller than an outer diameter of the plurality of electrically conductive elements;
- (b) engaging a surface of the conduit with the at least one deformable element;
- (c) controlling a deformation of the at least one deformable element with the deformation control member; and
- (d) using the at least one deformable element to determine a parameter of interest relating to the conduit.

In accordance with a further aspect of the present invention there is provided a method for interrogating a conduit, comprising:

- (a) positioning at least one deformable element and at least one deformation control member on a support member, wherein the deformation control member is more rigid than the at least one deformable element;
- (b) moving the at least one deformable element and the at least one deformation control member inside the conduit ;
- (c) engaging an inner surface of the conduit with the at least one

3b

deformable element by radically extending the at least one deformable element wherein an electrical response of the at least one deformable element changes due to a deformation of the at least one deformable element;

(d) engaging the surface of the conduit with the at least one deformation control member; and

(e) determining a parameter of interest relating to the conduit using the electrical response of the at least one deformable element.

In accordance with a further aspect of the present invention there is provided an apparatus for interrogating a conduit, comprising:

- a first contact section having a first contact wheel;
- a second contact section positioned axially spaced apart from the first contact section, the second section having a second contact wheel;
- circuitry configured to measure an electrical voltage of the conduit using the first contact wheel and the second contact wheel and to estimate a voltage differential between the first contact wheel and the second contact wheel;
- a deformation control member associated with and controlling a deformation of one of: (i) the first contact wheel and (ii) the second contact wheel are positioned.

[0007] It should be understood that examples of the more important features of the disclosure have been summarized rather broadly in order that detailed description thereof that follows may be better understood, and in order that the contributions to the art may be appreciated. There are, of course, additional features of the disclosure that will be described hereinafter and which will form the subject of the claims appended hereto.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] For detailed understanding of the present disclosure, references

should be made to the following detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings, in which like elements have been given like numerals and wherein:

Fig. 1 schematically illustrates an isometric view of one embodiment of an interrogation device made according to the present disclosure;

Fig. 2A illustrates a side view of one embodiment of a deformation control member made according to the present disclosure; and

Fig. 2B illustrates a sectional view of the **Fig. 2A** embodiment.

DESCRIPTION OF THE DISCLOSURE

5 **[0009]** The present disclosure relates to devices and methods for protecting one or more elements of a device for investigating a structure. The present disclosure is susceptible to embodiments of different forms. There are shown in the drawings, and herein will be described in detail, specific embodiments of the present disclosure with the understanding that the present disclosure is
10 to be considered an exemplification of the principles of the disclosure, and is not intended to limit the disclosure to that illustrated and described herein.

[0010] **Fig. 1** schematically illustrates an isometric view of one embodiment **100** of an interrogation device or tool made according to the present disclosure. The device **100** may be utilized to estimate one or more properties
15 of interest, characteristic or condition of a conduit, such as conduit **101**. The conduit **101** may be any desired conduit or a tubular, such as a fluid conveying duct or piping in a building, surface or buried pipeline or a portion of a wellbore tubular such as production tubing, coiled tubing, casing or drill pipe. In any case, it may be desirable to investigate the conduit **101** to assess
20 its structural integrity and overall condition. Exemplary conditions of interest include the geometry of the tubular including internal diameters, wall thickness, and the thickness of linings. Other exemplary conditions of interest may include a physical state of the tubular including, but not limited to, the presence of deformities, wear, damage, corrosion, cracks, pitting, scaling.
25 Still other conditions of interest may include the presence of debris or deposits of unwanted materials.

[0011] In some situations, a corrosion inhibiting device such as a cathodic protection system may be employed to control the corrosion of metal surfaces of a conduit formed of steel tubulars. As is known, cathodic protection

systems convert a surface susceptible to corrosion into a cathode of an electrochemical cell. Exemplary uses of cathodic protection systems include water/fuel pipelines and storage tanks, steel pier piles, ships, offshore oil platforms, subsea wells, land oil well casings, and wellbore tubulars such as casings, liners, coiled tubing, etc. Periodically, it may be desired to monitor and evaluate the effectiveness of such a protection system. The devices used to assess the effectiveness of cathodic protection systems are discussed below. However, it should be understood that the teachings of the present disclosure can be applied to any situation wherein a tool or device is operated in a conduit.

[0012] The device **100** is shown to include a front or first contact section **110** and a back or second contact section **120**. Each contact section may include one or more contact devices, such as contact wheels, **112a-112c** (for ease of explanation, such wheels are herein sometimes individually and/or collectively denoted by numeral **112**) in the front contact section and wheels **122a-122c** (for convenience, such wheels are herein sometimes individually and/or collectively denoted by numeral **122**) in the back contact section **120**. The two contact sections **110**, **120** are spaced apart longitudinally by a desired distance. The distance may be any desired distance, which may typically vary from one to three meters. In operation, the tool **100** moves inside a conduit, such as conduit **101**, to be interrogated along the direction of the front section **110**. Electrical measurements, such as voltage differential, made between the wheels **112** of the front contact section and the wheels **122** of the back contact section **122** are utilized to estimate a parameter of interest or characteristic of the conduit. The operation of the tool **100** and the wheels is further described in more detail later.

[0013] The tool **100** is further shown to include a section **140** that in one aspect may include a power source that supplies electrical power to the various electrical and electronic devices in the tool **100**. The power source may be a turbine that is operated by fluid flow in the conduit **101**. In other embodiments, a local power source such as a battery (not shown) may be

used. A section, such as section **160** in the tool, may include a caliper **162** that provides measurements for estimating the internal dimensions of the conduit **101**. The caliper **162** may include a plurality of contacts **162a-162m**, each contact providing a measure of the diameter of the conduit **101**. The
5 section **160** also is shown to include an odometer **170** that provides information relating to the travel distance of the tool **100** in the conduit **101**. The odometer **170** may be any suitable device that provides a distance measurement. Calipers and odometers are known in the art and are thus not described in detail herein. Elements **155** are used in the tool **100** to provide
10 mechanical support to the tool **100**.

[0014] Suitable electrical and electronic circuits **180** may be housed in the section **180** or at any other suitable locations in the tool **100**. In general, the circuits **180** include a circuit that measures voltage differential between the contact wheels **112** and **122** periodically or substantially continuously when
15 the tool **100** is moving in the conduit **101**. The circuit **180** also may include a processor **182**, such as a microprocessor, one or more memory devices, such as solid state memory devices, and programs and algorithms, which are used by the processor to implement the methods and operations of the tool **100** and to estimate the parameters of interest or the characteristics of the conduit
20 **101**, as desired.

[0015] Still referring to Fig. 1, the front contact section **110** is shown to include four contact wheels **112** and similarly the back contact section **120** is shown to include four contact wheels **122**. For the purpose of this disclosure, at least one wheel is utilized in each of the front and the back sections and
25 when more than one wheel is utilized, such wheels may be oriented in any suitable manner. In one aspect, each wheel **112** and **122** includes a metallic surface or element that comes in contact with the conduit **101**, which is typically a metallic conduit. The metallic element in one aspect may be metallic bristles along the outer periphery of the wheels. A support member, such as member **114a** shown for the wheel **112a**, extends the wheel radially.
30 As the tool **100** moves in the conduit **101**, the support member **114a** extend

- their corresponding wheels **112** toward the inside of the conduit **101** and each of the wheels comes in contact with an inner surface **102** of the conduit **101** and rotates as the tool moves longitudinally along the conduit axis. When the conduit has cathodic protection, the current from the cathodic protection system creates a voltage difference between a wheel in the front section and a wheel in the back section. A voltage measuring device **172** in the tool **100** measures the voltage differential between two contact points formed by the front and the back wheels to evaluate or estimate the condition of the conduit's cathodic protection system.
- 10 **[0016]** The processor **182** of the circuits **180** may be configured to process the measurements using one or more programs provided to the processor to and estimate one or more characteristics of the conduit. The processor also may estimate the internal dimensions of the conduit from the caliper **162** measurement and the distance from the odometer **170** proximate the
- 15 estimated characteristics. The processor **182** may also include communication devices for providing bi-directional data among the devices in the tool **100** and between the tool **100** and a controller outside the conduit **101**. The tool **100** also may include one or more devices **184** for determining a position, location or orientation of the interrogation device **20**, such as an
- 20 odometer, a GPS unit, etc. Still other on-board devices may include sensors for measuring parameters of interest such as conduit parameters (e.g., geometry, thickness, etc.), environmental parameters (etc., pressure, temperature), electrical and material properties of the conduit or material in the conduit, etc.
- 25 **[0017]** When physical faults exist in the conduit inside, the contact elements may be subjected to undue physical force. A protection mechanism may be used to protect such contact elements, as described in more detail in reference to **Figs. 2A** and **2B**. Positioned adjacent to one or more of the contact elements **112**, and **122** are deformation control members that control
- 30 the deformation of the contact elements. In some arrangements, the contact elements **112** and **122** may be formed of bristles or other flexible elements

that change shape or deform if subjected to a suitably high loading. Exemplary deformations include, but are not limited to, bending, twisting, elongation, compression. In many situations, the interior **102** of the conduit **101** may include features that may cause such a loading and deform the contract elements **112** and **122**. The loading may be a radial and/or an axial loading. For instance, the surface **102** may include a radially inwardly projecting feature such as a weld or "icicle" or a surface discontinuity associated with a T-joint. As the tool traverses the conduit **101**, the contact elements **112** and **122** may deform upon impact with these features. Because the voltage differential measurements taken by the tool **100** may be very small, such as on the order of microvolts, even relatively small deformations, such as on the order of a few millimeters, may have a detrimental impact on the accuracy of the measurements of the tool **100**. Accordingly, in one aspect, the deformation control members, are constructed to assume or bear a portion of a loading that would otherwise deform the contact elements **112** and **122**. The reduction of loading reduces the risk that the measurements of the tool **100** may be compromised.

[0018] Referring now to **Figs. 2A** and **2B**, there is shown one embodiment of a deformation control member **270** for controlling a deformation of an exemplary contact element **272**. The contact element **272** includes an annular support or rim **274** on which are mounted the conductive metal bristles **276**. The deformation control member **270** includes a first and second annular disk member **278**, **280**, each being positioned on opposing sides of the contact element **272**. The disk members **278**, **280** are at least partially formed of a material that is more rigid than the material forming the bristles **276** and have an outer diameter selected to limit a radial deformation of the bristles **276** to an amount denoted by letter **D**. The relatively greater rigidity allows the disk members **278**, **280** to bear a relatively greater compressive loading without deforming and allows the disk members **278**, **280** to bear a loading that would otherwise deform the bristles **276** in excess of the amount of numeral **D**. Thus, in one aspect, the bristles **276** bear a first loading and the disk members **278**, **280** eventually bear any loading beyond a threshold value

above the first loading. For instance, while an excessive loading may initially be applied to the deformable elements, that excessive loading will be fully borne by the disk members after that excessive loading has caused a maximum deformation **D**. The value of **D** may be selected, for example, by
5 first determining a maximum error that may be acceptable for the measurements, determining a magnitude of deformation associated with the maximum acceptable error and selecting a value for **D** that is no greater than the determined maximum deformation. Other suitable methodologies may also be utilized to select a value for **D**.

10 **[0019]** It should be understood that the deformation control member **270** is susceptible to numerous variations. For instance, as schematically illustrated in **Fig. 1**, the deformation control member **270** can include a single disk or as illustrated in **Figs. 2A-B** can include a plurality of disks. Furthermore, the disks can be fixed to and rotate with the contact element, e.g., contact
15 element **272**, or be fixed on a bearing element (not shown) that permits the deformation control member **270** to rotate at a speed different from the contact element. In still other embodiments, the deformation control member **270** may be integrated within the contact elements itself. For instance, one or more relatively rigid members (not shown) may be interposed within the
20 bristles **276**. The rigid members, which may be bristles, solid or semi-solid members, can bear the loading that would otherwise deform the electrically conductive elements **276** beyond acceptable amounts. Further, while the disks have been shown as contiguous circumferential members, the deformation control members may be strategically positioned at selected
25 locations. That is, in embodiments, the deformation control members can comprise one or more segments, rather than a complete disk.

[0020] In the illustrated embodiments, the deformation control member **270** is shown as having an outer diameter that is smaller than the diameter of the contact elements. However, it should be understood that only the load
30 bearing portion of the deformation control member **270** is positioned at a radially recessed position relative to the outer diameter of the contact

member. That is, the deformation control member 270 may include a layer of material that deflects or deforms to the same or greater amount than the contact member in the region of numeral D. Such a region can, for example, provide a sufficient barrier for providing a pressure differential but still permit
5 the contact elements to form an electrically conductive junction with the tubular 101.

[0021] Furthermore, it should be appreciated that the teachings of the present disclose may be applied to any measurement device wherein a deformable element or member used is used to determine or estimate one or more
10 parameters of a structure. For instance, a deformation of a member may change an electrical response or material property of that member, which may in turn degrade measurements obtained using that member. For such measurement devices, a deformation control member may be used to limit a deformation encountered by that member to an acceptable or predetermined
15 range.

[0022] Thus, in aspects, the disclosure provides a tool that includes laterally spaced electrical contact points that come in contact with internal surfaces of a conduit. In one aspect, the contacts may be wheels that press against the conduit inside and rotate as the tool moves in the conduit, which movement
20 may be due to a fluid flowing through the conduit or by another mechanism. In one aspect, the wheels include an element that deforms as it presses against the conduit inside. In one aspect, a deformation control member is placed proximate or adjacent each of the deformable contact member that controls or inhibits the deformation of the contact members beyond a selected amount.
25 The tool in other aspects may include one or more other devices or sensors, such a caliper for measuring internal dimension of the conduit, an odometer to determine distance or location of the internal characteristics of the conduit, and sensors for measuring temperature, pressure, etc. of the fluid flowing through the conduit.

30 **[0023]** In another aspect, the disclosure provides an apparatus for interrogating a conduit that includes: at least one deformable element that

may engage a surface of the conduit; an interrogation tool coupled to the at least one deformable element that uses the at least one deformable element to determine a parameter of interest relating to the conduit; and at least one deformation control member positioned adjacent the at least one deformable element, wherein the deformation control member controls a deformation of the at least one deformable element. The at least one deformable element may include one or more electrically conductive elements which are circumferentially disposed on a radial outer surface of a rim and wherein the deformation control member is formed as an annular member having an outer diameter smaller than an outer diameter of the electrically conductive elements.

[0024] The tool is electrically coupled to the conduit via the first and second electrically conductive contact members and determines a voltage differential along a portion of the conduit using the first and second electrically conductive contact members. The deformation control member may be more rigid than the at least one deformable element. The deformation control member may limit a reduction in a radial dimension of the at least one deformable element or any other aspect thereof.

[0025] In another aspect, a method is disclosed that includes: engaging a surface of the conduit with at least one deformable element; controlling a deformation of the at least one deformable element with a deformation control member; and using an electrical measurement from the at least one deformable element to estimate a parameter of interest relating to the conduit. In one aspect, the parameter of interest may be voltage differential. In another aspect, controlling the deformation may include limiting the deformation to a predetermined value or positioning the at least one deformable element to receive a loading above a predetermined value. In another aspect, the method may further include propelling the at least one deformable element through a bore of the conduit.

[0026] The foregoing description is directed to particular embodiments of the present disclosure for the purpose of illustration and explanation. It will be

apparent, however, to one skilled in the art that many modifications and changes to the embodiment set forth above are possible. It is intended that the following claims be interpreted to embrace all such modifications and changes.

Claims

1. An apparatus for interrogating a conduit, comprising:
 - (a) at least one deformable element having a plurality of electrically conductive elements engaging a surface of the conduit;
 - (b) an interrogation tool configured to use the at least one deformable element to determine a parameter of interest relating to the conduit; and
 - (c) at least one deformation control member positioned adjacent the at least one deformable element, the deformation control member having an outer diameter smaller than an outer diameter of the plurality of electrically conductive elements and controlling a deformation of the at least one deformable element;
 - (d) a support member on which the at least one deformable element and the at least one deformation control member are positioned; and
 - (e) a rim associated with the support member and having a radially outer surface, the plurality of electrically conductive elements being circumferentially disposed on the radially outer surface.
2. The apparatus of claim 1, wherein the at least one deformation control member is fixed to the at least one deformable element.
3. The apparatus of claim 1, wherein the deformation control member rotates with the at least one deformable element.
4. The apparatus of claim 1, wherein the at least one deformable element includes a first and a second electrically conductive contact member and wherein the at least one deformation control member includes at least a first deformation control member associated with the first electrically conductive contact member and a second deformation control member associated with the second electrically conductive contact member.
5. The apparatus of claim 4, wherein the interrogation tool is electrically coupled to the first and second electrically conductive contact members and determines a voltage differential along a portion of the conduit using the first and second electrically conductive contact members.
6. The apparatus of claim 1, wherein the deformation control member is more rigid than the at least one deformable element.

7. The apparatus of claim 1, wherein the deformation control member limits a reduction in a radial dimension of the at least one deformable element.

8. The apparatus of any one of claims 1 to 7, wherein the support member is an annular support member.

9. The apparatus of any one of claims 1 to 8, wherein the support member is a contact wheel.

10. A method for interrogating a conduit, composing:

- (a) positioning at least one deformable element and at least one deformation control member on a support member, the deformable element having a plurality of electrically conductive elements disposed circumferentially on a radially outer surface of a rim associated with the support member, the deformation control member having an outer diameter smaller than an outer diameter of the plurality of electrically conductive elements;
- (b) engaging a surface of the conduit with the at least one deformable element;
- (c) controlling a deformation of the at least one deformable element with the deformation control member; and
- (d) using the at least one deformable element to determine a parameter of interest relating to the conduit.

11. The method of claim 10, wherein the support member is an annular support member.

12. The method of claim 10, wherein the support member is a contact wheel.

13. The method of claim 10, further comprising measuring an electrical voltage of the conduit using the at least one deformable element.

14. The method of claim 10, wherein the parameter of interest is a voltage differential.

15. The method of claim 10, wherein controlling the deformation includes limiting the deformation to a predetermined value.

16. The method of claim 10, wherein controlling the deformation includes positioning the at least one deformable element to absorb a loading above a predetermined value.

17. The method of claim 10, further comprising propelling the at least one deformable element through a bore of the conduit.

18. The method of claim 10, wherein controlling the deformation includes:
bearing a first load with the at least one deformable element; and

bearing a second loading with the at least one deformation control element for a loading beyond a threshold value to thereby limit the deformation to a predetermined value.

19. A method for interrogating a conduit, comprising:

- (a) positioning at least one deformable element and at least one deformation control member on a support member, wherein the deformation control member is more rigid than the at least one deformable element;
- (b) moving the at least one deformable element and the at least one deformation control member inside the conduit ;
- (c) engaging an inner surface of the conduit with the at least one deformable element by radically extending the at least one deformable element wherein an electrical response of the at least one deformable element changes due to a deformation of the at least one deformable element;
- (d) engaging the surface of the conduit with the at least one deformation control member; and
- (e) determining a parameter of interest relating to the conduit using the electrical response of the at least one deformable element.

20. The method of claim 19, further comprising moving a second deformable element inside the conduit, the second deformable element being axially spaced apart from the at least one deformable element, measuring an electric voltage differential across a portion of the conduit using the at least one deformable element and the second deformable element.

21. The method of claim 19, wherein the parameter of interest is a voltage differential.

22. The method of claim 19, further comprising controlling the deformation by:
bearing a first load with the at least one deformable element; and

bearing a second loading with the at least one deformation control element for a loading beyond a threshold value to thereby limit the deformation to a predetermined value, wherein the first and the second loading are caused by an inwardly projecting feature on the inner surface of the conduit.

23. The method of claim 19, wherein controlling deformation includes positioning the at least one deformable element to absorb a loading above a predetermined value.

24. An apparatus for interrogating a conduit, comprising:

- a first contact section having a first contact wheel;

- a second contact section positioned axially spaced apart from the first contact section, the second section having a second contact wheel;
- circuitry configured to measure an electrical voltage of the conduit using the first contact wheel and the second contact wheel and to estimate a voltage differential between the first contact wheel and the second contact wheel;
- a deformation control member associated with and controlling a deformation of one of: (i) the first contact wheel and (ii) the second contact wheel are positioned.

25. The apparatus of claims 24, wherein the first contact wheel and the second contact wheel each include a plurality of electrically conductive elements.

26. The apparatus of claim 24, wherein the deformation control member has an outer diameter smaller than an outer diameter of one of: (i) the first contact wheel, and (ii) the second contact wheel.

27. The apparatus of claim 26, wherein the deformation control member is an annular ring-shaped member that is fixed to one of: (i) the first contact wheel and (ii) the second contact wheel.

28. The apparatus of claim 27, wherein the first contact wheel and the second contact wheel each include a plurality of electrically conductive elements and wherein the annular ring-shaped member is more rigid than the plurality of electrically conductive elements.

29. The apparatus of claim 24, wherein the first contact section includes plurality of contact wheels, each including an associated deformation control member.

30. The apparatus of claim 24, wherein the second contact section includes a plurality of contact wheels, each including an associated deformation control member.

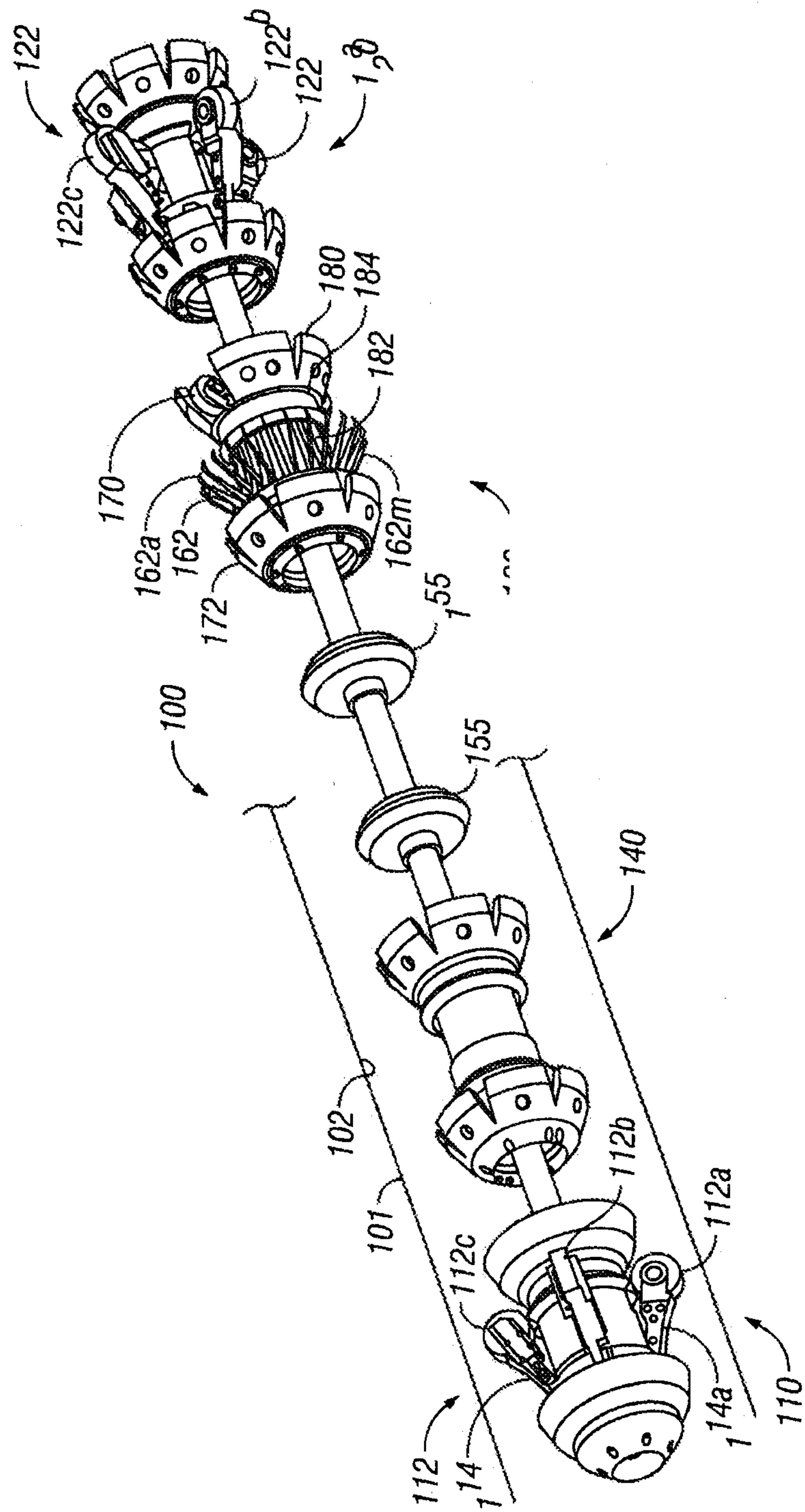
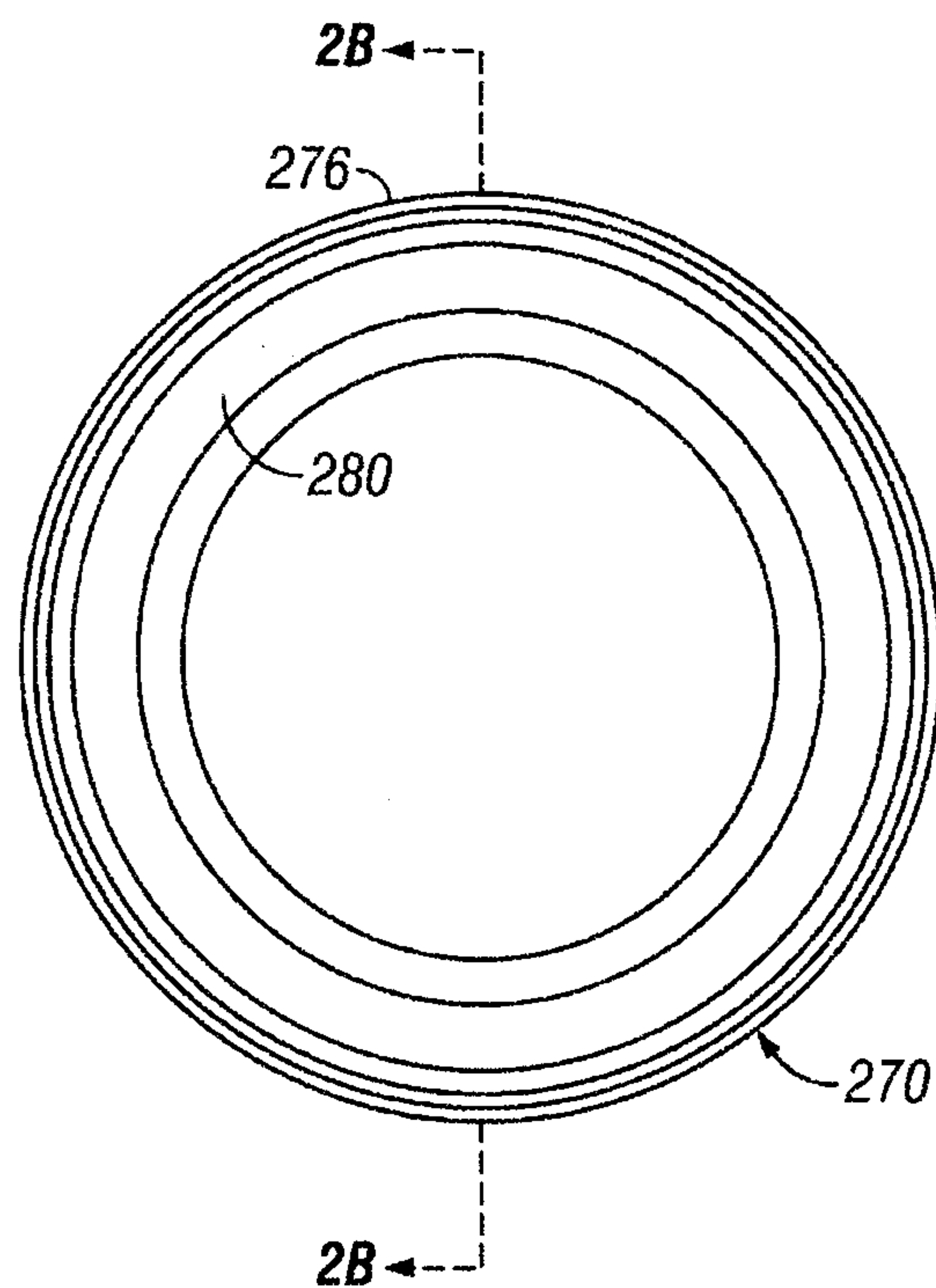


FIG. 1

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FIG. 2**FIG. 2B**