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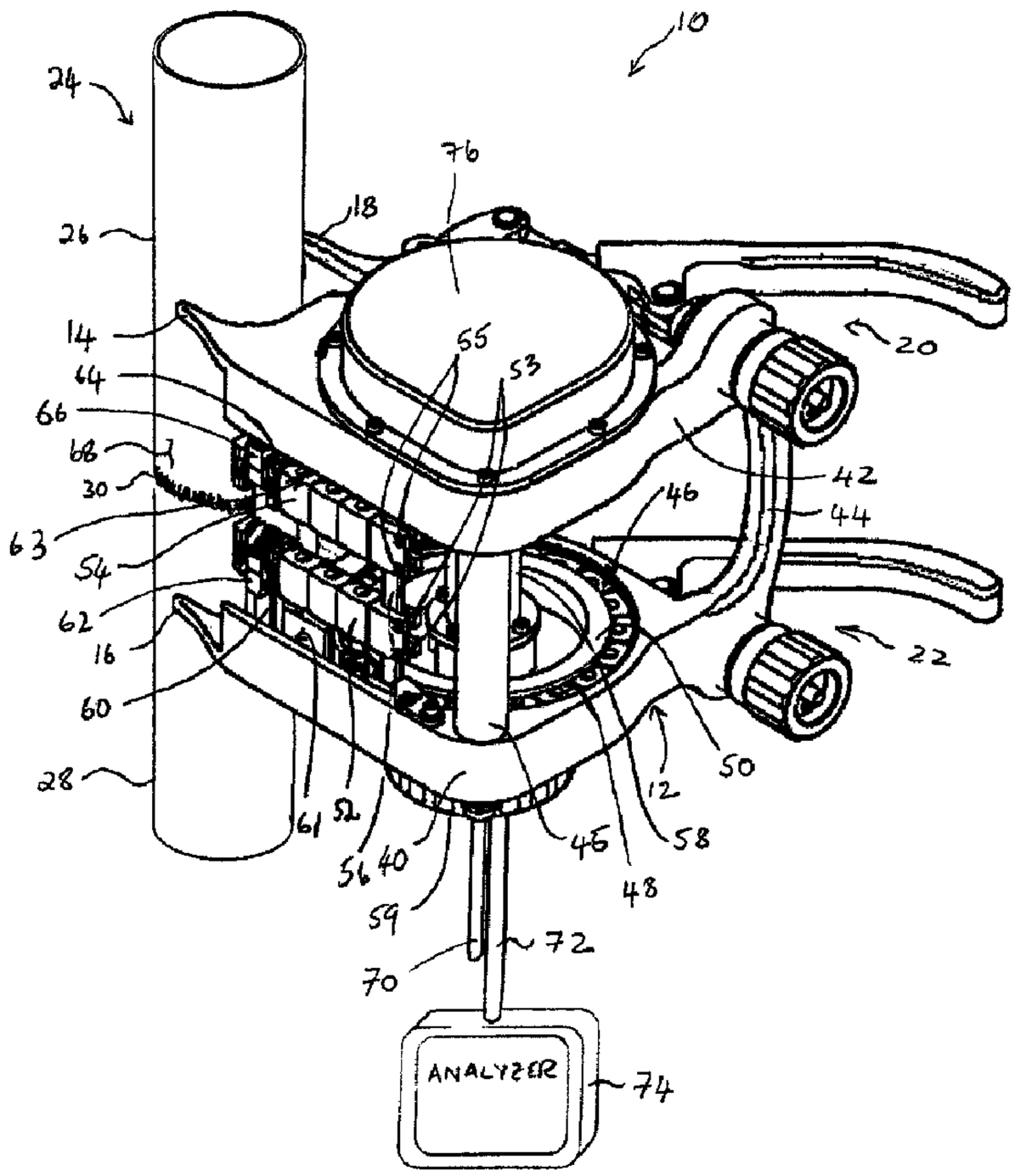

(57) Abrégé/Abstract:
A method & apparatus for conveying an ultrasonic sensor about an outer peripheral surface of a tube to perform a non-destructive evaluation thereof is disclosed. The ultrasonic sensor is mounted on a flexible tension link and the method involves extending the

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(57) Abrégé(suite)/Abstract(continued):
flexible tension link while urging an extended portion of the flexible tension link towards the outer peripheral surface of the tube at a plurality of locations along it's length, thereby causing the ultrasonic sensor to move through an arc in a direction circumferentially around the tube while maintaining ultrasonic coupling between the ultrasonic sensor and the tube.

ABSTRACT

A method & apparatus for conveying an ultrasonic sensor about an outer peripheral surface of a tube to perform a non-destructive evaluation thereof is disclosed. The ultrasonic sensor is mounted on a flexible tension link and the method involves extending the flexible tension link while urging an extended portion of the flexible tension link towards the outer peripheral surface of the tube at a plurality of locations along it's length, thereby causing the ultrasonic sensor to move through an arc in a direction circumferentially around the tube while maintaining ultrasonic coupling between the ultrasonic sensor and the tube.

METHOD AND APPARATUS FOR CONVEYING AN ULTRASONIC SENSOR ABOUT AN OUTER PERIPHERAL SURFACE OF A TUBE

BACKGROUND OF THE INVENTION

1. Field of Invention

This invention relates generally to non-destructive evaluation of tubes and more particularly to non-destructive evaluation of a tube using an ultrasonic sensor.

2. Description of Related Art

Processing plants, such as power generation petrochemical and plants for example, make extensive use of metal tubing for delivering steam and other fluids to various process steps. Commonly, such tubes are constructed by welding together sections of tubing. In most applications, and specifically in safety critical applications, each and every weld must be inspected to confirm the integrity of the weld. Such inspections may be performed during the construction or commissioning of a plant, but there is also a need for ongoing periodic inspection of welds to look for signs of corrosion and/or cracking, for example.

In many plants pluralities of tubes are run in close proximity to each other, often so closely spaced apart that access to the tube for performing an inspection of the weld may be difficult. While it is convenient to use ultrasonic non-destructive evaluation techniques for examining defects in many types of metal structures, the accessibility has limited the use of ultrasonic examination for inspecting tubes.

Accordingly, other inspection techniques such as gamma radiography have typically been used to perform such inspections. Gamma radiography involves the use of radioactive isotopes, and during radiographic inspections, radiographic shielding barriers must generally be erected to protect personnel

from harmful radiation. Accordingly, the work of welders and other construction workers may be interrupted when it becomes necessary to clear an area in proximity to a tube being inspected.

In general the use of radioactive inspection techniques may cause unacceptable health and safety risks, and regardless of storage, handling, and transportation practices that may be implemented, human error may still occur resulting in accidents.

Accordingly there is a need for improved methods of inspection of tubes.

SUMMARY OF THE INVENTION

In accordance with one aspect of the invention there is provided a method for conveying an ultrasonic sensor about an outer peripheral surface of a tube to perform a non-destructive evaluation thereof, the ultrasonic sensor being mounted on an extendible portion of a flexible tension link. The method involves extending the flexible tension link while urging the extended portion of the flexible tension link towards the outer peripheral surface of the tube at a plurality of locations along the extended portion to cause the ultrasonic sensor to move through an arc circumferentially around the tube while maintaining ultrasonic coupling between the ultrasonic sensor and the tube.

Extending may involve extending the flexible tension link to cause the ultrasonic sensor to be conveyed from a first location on the outer peripheral surface of the tube to a second location the outer peripheral surface of the tube, the second location being spaced apart from the first location by substantially one complete revolution around the circumference of the tube, and the method may further involve performing the non-destructive evaluation while retracting the flexible tension link to cause the ultrasonic sensor to move from the second location to the first location.

The method may involve causing a reference mark to be made on the tube at at least one of the first location and the second location.

The method may involve introducing an ultrasonic coupling fluid between the sensor and the outer peripheral surface of the tube to further facilitate ultrasonic coupling between the ultrasonic sensor and the tube.

Introducing the ultrasonic coupling fluid may involve delivering a flow of ultrasonic coupling fluid between the ultrasonic sensor and the outer peripheral surface of the tube.

The flexible tension link may include a plurality of linked elements and the ultrasonic sensor may be mounted on at least one of the linked elements, and maintaining ultrasonic coupling between the ultrasonic sensor and the tube may involve urging the at least one of the linked elements towards the outer peripheral surface of the tube such that the ultrasonic sensor is urged into contact with the outer peripheral surface of the tube.

The flexible tension link may include a plurality of linked elements and urging the extended portion of the flexible tension link may involve urging each of the plurality of linked elements toward the outer peripheral surface of the tube thereby causing the extended portion of the flexible tension link to wrap around the tube.

The flexible tension link may be housed in a frame and the ultrasonic sensor may be mounted on a distal end of the flexible tension link, and extending may involve causing the distal end to be extended from the frame.

A proximate end of the flexible tension link may be coupled to an actuator on the frame, and causing the distal end of the flexible tension link to be

extended may involve actuating the actuator to cause the distal end of the flexible tension link to be extended from the frame.

The method may involve clamping the frame to the outer peripheral surface of the tube before extending the flexible tension link.

The outer periphery of the tube may include an accessible portion and an inaccessible portion, the inaccessible portion including a portion of the outer periphery of the tube having limited access due to a surrounding environment, and the clamping may involve clamping the frame to the accessible portion of the outer periphery of the tube.

The ultrasonic sensor may include a first ultrasonic sensor and the flexible tension link may include a first flexible tension link and the method may further include a second ultrasonic sensor mounted on a second flexible tension link, the first and second ultrasonic sensors being spaced apart, the method further involving extending the second flexible tension link while urging a second extended portion of the second flexible tension link towards the outer peripheral surface of the tube at a plurality of locations along the second extended portion to cause the second ultrasonic sensor to move through an arc circumferentially around the tube while maintaining ultrasonic coupling between the second ultrasonic sensor and the tube.

The method may involve locating a circumferential position of the ultrasonic sensor on the peripheral surface of the tube.

Locating the circumferential position may involve determining a displacement of the flexible tension link.

Determining the displacement may involve coupling an encoder to the flexible tension link, the encoder being operable to produce a position signal representing the displacement.

The ultrasonic sensor may be coupled to an analyzer, the analyzer being operable to transmit electrical stimuli to the ultrasonic sensor and to receive electrical signals from the ultrasonic sensor representing results of the non-destructive evaluation of the tube, and the method may further involve receiving the position signal at the analyzer and correlating the results with the circumferential position of the ultrasonic sensor.

In accordance with another aspect of the invention there is provided an apparatus for conveying an ultrasonic sensor about an outer peripheral surface of a tube to perform a non-destructive evaluation thereof. The apparatus includes a frame operably configured to engage the tube and a flexible tension link housed in the frame, the flexible tension link being operably configured to permit the ultrasonic sensor to be mounted thereto. The apparatus also includes an actuator coupled to the flexible tension link and operable to cause the flexible tension link to extend from the frame. The flexible tension link is operably configured to urge an extended portion of the flexible tension link towards the outer peripheral surface of the tube at a plurality of locations along the extended portion to cause the ultrasonic sensor to move through an arc circumferentially around the tube while maintaining ultrasonic coupling between the ultrasonic sensor and the tube.

The actuator is operably configured to extend the flexible tension link to cause the ultrasonic sensor to be conveyed from a first location on the outer peripheral surface of the tube to a second location the outer peripheral surface of the tube, the second location being spaced apart from the first location by substantially one complete revolution around the circumference of the tube, the actuator further being operably configured to retract the flexible

tension link to cause the ultrasonic sensor to move from the second location to the first location while performing the non-destructive evaluation of the tube.

The apparatus may include a coupling fluid supply line operably configured to introduce an ultrasonic coupling fluid between the ultrasonic sensor and the outer peripheral surface of the tube to further facilitate ultrasonic coupling between the ultrasonic sensor and the tube.

The ultrasonic coupling fluid may include water.

The flexible tension link may include a plurality of linked elements and the ultrasonic sensor may be mounted on at least one of the linked elements, the at least one linked element further including a spring operable to urge the at least one of the linked element towards the outer peripheral surface of the tube such that the ultrasonic sensor is urged into contact with the outer peripheral surface of the tube.

The flexible tension link may include a plurality of linked elements and the apparatus may further include a plurality of springs operating between the linked elements to urge the extended portion of the flexible tension link toward the outer peripheral surface of the tube such that the extended portion wraps around the tube when the flexible tension link is extended.

The ultrasonic sensor may be mounted on a distal end of the flexible tension link and the actuator may be coupled to a proximate end of the flexible tension link and actuating the actuator may cause the proximate end to be displaced thereby causing the distal end is extended from the frame.

The actuator may include a rotateable drum located in the frame, the proximate end of the flexible tension link being coupled to the drum and an un-extended portion of the flexible tension link may wrap around the drum.

The frame may further include a clamp operable to clamp the frame to the outer peripheral surface of the tube.

The clamp may be operably configured to clamp the frame to an accessible portion of the outer periphery of the tube.

The ultrasonic sensor may include a first ultrasonic sensor and the flexible tension link may include a first flexible tension link and the apparatus may further include a second ultrasonic sensor mounted on a second flexible tension link, the first and second ultrasonic sensors being spaced apart, the apparatus further including a second flexible tension link housed in the frame, the second flexible tension link being operably configured to permit the second ultrasonic sensor to be mounted thereto, the flexible tension link being coupled to the actuator, the actuator being operable to cause the second flexible tension link to be extended from the frame. The second flexible tension link may be operably configured to urge a second extended portion of the second flexible tension link towards the outer peripheral surface of the tube at a plurality of locations along the second extended portion to cause the second ultrasonic sensor to move through an arc circumferentially around the tube while maintaining ultrasonic coupling between the second ultrasonic sensor and the tube.

The apparatus may include an encoder, coupled to one of the flexible tension link, the actuator, and the ultrasonic sensor, the encoder being operably configured to produce a position signal representing a circumferential position of the ultrasonic sensor on the peripheral surface of the tube.

The apparatus may include an analyzer coupled to the ultrasonic sensor, the analyzer being operable to transmit electrical stimuli to the ultrasonic sensor and to receive electrical signals from the ultrasonic sensor representing results of the non-destructive evaluation of the tube, the analyzer further comprising an input for receiving the position signal from the encoder, the analyzer being operably configured to correlate the results with the circumferential position of the ultrasonic sensor.

In accordance with another aspect of the invention there is provided an apparatus for conveying an ultrasonic sensor about an outer peripheral surface of a tube to perform a non-destructive evaluation thereof. The apparatus includes a frame operably configured to engage the tube and a flexible tension link housed in the frame, the flexible tension link being operably configured to permit the ultrasonic sensor to be mounted thereto. The apparatus also includes provisions for extending the flexible tension link from the frame and provisions for urging an extended portion of the flexible tension link towards the outer peripheral surface of the tube at a plurality of locations along the extended portion to cause the ultrasonic sensor to move through an arc circumferentially around the tube while maintaining ultrasonic coupling between the ultrasonic sensor and the tube.

Other aspects and features of the present invention will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

In drawings which illustrate embodiments of the invention,

Figure **1** is a perspective view of an apparatus in accordance with an embodiment of the invention for conveying an ultrasonic sensor about an outer peripheral surface of a tube;

Figure **2** is a top view of the apparatus shown in Figure **1**;

Figure **3** is a side view of the apparatus shown in Figure **1** with a frame portion removed;

Figure **4** is a perspective view of a portion of flexible tension link used in the apparatus shown in Figure **1**;

Figure **5** is a cross sectional view of a welded tube; and

Figure **6** is a process flowchart schematically depicting a process for performing a non-destructive evaluation of a tube, in accordance with an embodiment of the invention.

DETAILED DESCRIPTION

Referring to Figure **1**, an apparatus for conveying an ultrasonic sensor about an outer peripheral surface of a tube **24** according to a first embodiment of the invention is shown generally at **10**. In the embodiment shown, the tube **24** includes a first tube portion **26** and a second tube portion **28**, the first and second tube portions being joined by a weld **30**. The apparatus **10** is used to evaluate the quality of the weld **30**, using ultrasonic non-destructive evaluation techniques.

The apparatus **10** includes a frame **12** and in this embodiment, the frame **12** includes a first frame portion **40** and a second frame portion **42**. The first and second frame portions **40** and **42** are spaced apart by a plurality of cross members (only two cross members **44** and **45** shown in Figure **1**).

The frame **12** includes a pair of fixed clamp jaws **14** and **16** and a pair of spaced apart moveable clamp jaws **18,** only one of which is shown in Figure **1**. Each of the moveable clamp jaws **18** has an associated clamp actuator **20** and **22** respectively. The clamp actuators **20** and **22** are operable to actuate the moveable jaws **18** to clamp the frame **12** to the tube **24** on which it is desired to perform a non destructive evaluation.

The clamp actuator **20** is shown in greater detail in Figure **2**, and includes a lever **80** which is coupled to the moveable jaw **18** by a linkage **82** fastened between the lever and the moveable jaw at first and second pivot pins **84** and **86**. The clamp actuator also includes an adjustment screw **88** which is coupled to the lever **80** at a third pivot pin **90** to move the third pivot pin toward and away from the first pivot pin **84**.

The clamp actuator **20** operates as an over-center clamp, and when the lever **80** is shifted toward the frame **12**, the second pivot pin **86** is moved away from the frame **12** to a position **92** (shown in broken outline) causing the moveable jaw **18** to be urged toward the fixed jaw **14**, thus clamping to the tube **24**. Since the second pivot pin **86** is shifted past a center line **94** (drawn between the first pivot pin **84** and the third pivot pin **90**) the lever **80** becomes locked in the location shown in broken outline. The adjustment screw **88** is operable to shift the location of third pivot pin **90** in the direction indicated by the arrow **96**, facilitating clamping to tubes of varying diameter, and also facilitating adjustment of a clamping force for a particular tube diameter. Applying a force to the lever **80** in a direction away from the frame **12**, causes the second pivot pin **86** to move past the center line **94** toward the frame, thus unlocking the moveable clamp jaw **18**.

The apparatus **10** further includes a first flexible tension link **46** and a first drum **50**. The first drum **50** is located in the first frame portion **40**. In the embodiment shown in Figure **1**, the flexible tension link **46** includes a first

portion **48**, which is wrapped around and coupled to the first drum **50**. The flexible tension link **46** also includes a second portion **52**, which is spaced inwardly from the first frame portion **40**.

The apparatus **10** is shown in Figure **3** with the frame **12** removed to more clearly show elements which are obscured by the second frame portion **42** in Figure **1**. Referring to Figure **3**, the apparatus **10** further includes a second flexible tension link **47** and a second drum **51**. The second drum **51** is located in the second frame portion **42** (shown in Figure **1**). The second flexible tension link **47** includes a first portion **49**, which is wrapped around and coupled to the second drum **51**.

Referring back to Figure **1**, the second tension link **47** also includes a second portion **54**, which is spaced inwardly from the second frame portion **42**.

The apparatus **10** further includes a bar **56**, which is coupled to the first portions **48** and **49** of the first and second flexible tension links **46** and **47**. The second portions **52** and **54** of the first and second flexible tension links **46** and **47** are slideably mounted on the bar **56** and each include a pair of fasteners **53** and **55** for securing the second portions at desired positions on the bar **56**. Each of the second portions **52** and **54** may be positioned on the bar **56** by loosening the fasteners **53** and **55**, sliding the second portions to respective desired positions on the bar **56**, and then tightening the fasteners, thus securing the second portions to the bar in a desired spacing.

The spaced apart second portions **52** and **54** of the first and second flexible tension links permit the second portions to be extended through substantially a complete revolution around the circumference of the tube **24**, without being impeded by the first portions **48** and **49** of the first and second flexible tension links **46** and **47**.

As best shown in Figure **3**, the apparatus **10** also includes an actuator shaft **58** and an actuator knob **59**. The actuator knob **59** is coupled to the actuator shaft **58**. The actuator shaft **58** is located between, and coupled to, the first drum **50** and the second drum **51**. When the actuator knob **59** is rotated thus rotating the first and second drums **50** and **51**, the first and second portions **48** and **49** of the first and second flexible tension links **46** and **47** are extended (or retracted) thus extending (or retracting) the bar **56** and the second portions **52** and **54** of the first and second flexible tension links respectively.

Referring back to Figure **1**, the first frame portion **40** further includes a first guide **61** and the second frame portion **42** includes a second guide **63**. Referring now to Figure **2**, the first guide **61** includes a channel **65** (shown in hidden detail in Figure **2**), which guides the flexible tension link **46** between the drum **50** and the tube **24**. Similarly the second guide **63** includes a channel (not shown), which guides the flexible tension link **47** between the drum **51** and the tube **24**.

Referring now to Figure **4**, the second portion **52** of the first flexible tension link **46** includes a distal linked element **60**. The distal linked element **60** includes a mounting face **69** for mounting an ultrasonic sensor **62**. The ultrasonic sensor **62** includes a threaded hole (not shown) and is secured to the mounting face **69** by a threaded fastener **67** through the distal linked element **60**.

Referring back to Figure **1**, the second portion **54** of the second flexible tension link **47** also includes a distal linked element **64** (similar to the element **60** shown in Figure **4**) for mounting an ultrasonic sensor **66**.

In accordance with one aspect of the invention, the flexible tension links **46** and **47** are operably configured to urge an extended portion of each of the flexible tension links towards an outer peripheral surface **68** of the tube **24** at a plurality of locations along the extended portion to cause the ultrasonic

sensor **62** and **66** to move through an arc circumferentially around the tube while maintaining ultrasonic coupling between the ultrasonic sensor and the tube.

Referring to Figure **4**, the second portion **52** of the flexible tension link **46** is shown in greater detail. The second portion **52** includes the distal linked element **60**, and four linked elements **100**, **102, 104**, and **105**. In general the flexible tension link **46** may include many linked elements similar to the linked elements **100** – **104**. The distal linked element **60** is pivotally connected to the linked element **100** using a pin **106**. Similarly the linked elements **100** and **102** are pivotally connected using a pin **108**, and the linked elements **102** and **104** are pivotally connected using a pin **110**.

In the embodiment shown in Figure **4**, the linked element **104** is connected to a linked element **105** using a pin **109**. The linked element **105** includes a slot **107**, which is shaped to receive the bar 56 for facilitating sliding connection of the linked element **105** to the bar **56** (as shown in Figure **1** and as described above).

The second portion **54** of the second flexible tension link **47** is identical to the second portion **52** of the flexible tension link **46**.

The second portion **52** of the flexible tension link **46** also includes first, second third, and fourth helical spring pairs **112**, **114**, **116** and **117** at first, second, third and fourth locations **118, 120, 122**, and **123** respectively, along the length of the flexible tension link. In general, further spring pairs may be located between other linked elements along the flexible tension link **47**. The first spring pair **112** is operable to urge the distal linked element **60** and the linked element **100** apart, the second spring pair **114** is operable to urge the linked element **100** and the linked element **102** apart, the third spring pair **116** is operable to urge the linked element **102** and the linked element **104** apart,

and the fourth spring pair **117** is operable to urge the linked element **104** and the linked element **105** apart, thus causing the flexible tension link **46** to take on an arc shape that generally wraps around and conforms to the peripheral surface **68** of the tube **24** being evaluated, thus causing the ultrasonic sensor **62** to move through an arc circumferentially around the tube. The first spring pair **112** is further operable to urge the ultrasonic sensor **62** into contact with the peripheral surface **68** of the tube **24**, thus facilitating ultrasonic coupling between the sensor and the tube.

Still referring to Figure **4**, in one embodiment the ultrasonic sensor **62** includes first and second coupling fluid ports **124** and **126** for introducing an ultrasonic coupling fluid between the sensor and the outer peripheral surface **68** of the tube to further facilitate ultrasonic coupling between the ultrasonic sensor and the tube. In this embodiment the ultrasonic coupling fluid comprises water, and the water is allowed to flow between the sensor and the outer peripheral surface **68** while performing the non destructive evaluation of the tube **24**.

The ultrasonic sensor **62** also includes an electrical signal connector **128** for connecting a signal cable (not shown) for transmitting electrical stimuli to the ultrasonic sensor for receiving electrical signals from the ultrasonic sensor representing results of the non-destructive evaluation of the tube.

In this embodiment the linked elements **100** and **102** further include conduits **130** and **132** through which the coupling fluid supply line and the signal line may be threaded. Other linked elements may also include a conduit, thus allowing the coupling fluid supply line and the signal line to be run along the length of the flexible tension links **46** and **47** to couple to the sensors **62** and **66**.

Referring back to Figure **1**, the apparatus **10** further includes a main coupling fluid supply line **70**. The main coupling fluid supply line **70** includes a “Y” or

"T" coupling (not shown) which splits the main fluid supply line into two separate supply lines for supplying coupling fluid to each of the sensors **62** and **66** respectively through the first and second coupling fluid ports.

The apparatus **10** also includes a main signal line **72**, which includes a plurality of signal conductors including first signal conductors for coupling to the sensor **62**, second signal conductors for coupling to the sensor **66**, and third signal conductors for coupling to a rotary encoder **76**, which is described later herein.

The main signal line **72** is coupled to an analyzer **74**. The analyzer **74** includes circuitry which is operable to transmit electrical stimuli to the ultrasonic sensors **62** and **66** and circuitry which is operable to receive electrical signals from the ultrasonic sensor representing results of the non-destructive evaluation of the tube. The analyzer further includes circuitry and/or microprocessor circuits for analyzing the return signals and displaying an inspection result. Such analyzers for interfacing to one or more phased array ultrasonic sensors are commonly available, and in one embodiment the analyzer used may be a **32**-channel ultrasound phased-array instrument (model number X-**32**) available from Harfang Microtechniques of Quebec Canada.

Referring to Figure **3**, the apparatus **10** further includes a rotary encoder **76**, having a position signal output **77**. The rotary encoder is coupled to the actuator shaft **58** and produces a position signal at the output **77** representing a displacement of the first and second flexible tension links when the actuator knob **59** is rotated. In this embodiment the encoder used is model number S**6**S supplied by US Digital of Vancouver, WA. The **6**S**6** encoder is a high resolution rotary to digital converter which produces TTL-compatible signal outputs representing an angular position and/or velocity of the actuator shaft

58, and hence the position of first drum **50** and the second drum **51**, which are coupled to the actuator shaft.

The position signal output **77** is coupled to the analyzer **74** via the third signal conductors in the main signal line **72** for transmitting the position signal to the analyzer. The analyzer **74** is operably configured to receive the position signal and to calculate the displacement of the first and second flexible tension links using the diameter of the first and second drums to convert angular position received from the encoder into a corresponding linear displacement of the flexible tension links.

The sensors **62** and **66** are shown in greater detail in Figure **5**. Referring to Figure **5**, each of the sensors **62** and **66** is mounted on wedges **140** and **142** respectively. Each of the wedges **140** and **142** includes an angled face **144** and **146** respectively. In one embodiment sensors **62** and **66** include a plurality of sensor elements (not shown) arranged in an array proximate the angled faces **144** and **146**. Such multiple-element sensors are suitable for operation as a phased array, where the timing of excitation pulses sent to each of the sensor elements by the analyzer **74**, may be controlled to focus and direct resulting ultrasonic beams **148** and **150** within a wall **152** of the tube **24**, thus facilitating scanning of the sides of the weld **30** for defects.

<u>Operation</u>

The operation of the apparatus **10** shown in Figure **1** is described with reference to Figure **6** and Figures **1** - **5**. The operation of the apparatus **10** is described in connection with the inspection of a weld joining two tubular sections although it should be understood that the apparatus may be used to evaluate defects in tubes other than weld related defects.

Referring to Figure **6**, a process for performing an ultrasonic non-destructive evaluation of a tube weld is shown generally at **160**. As shown at **162**, the

process begins with preparing the surface of the tube to be inspected, which involves ensuring that the peripheral surface **68** over which the sensors **62** and **66** will be conveyed is free of weld spatter, dirt, grease, loose scale etc.

As shown at **164**, where the weld **30** is only accessible from one side due to the surrounding environment, the apparatus **10** may be configured for single sided inspection at **166** by configuring the analyzer **74** to ignore the result from one of the sensors, and/or by removing the inactive sensor from the apparatus **10**. The remaining description of the operation assumes that the apparatus **10** is configured for double sided inspection as shown at **168**.

As shown at **170**, the process continues with configuring the analyzer **74** and the apparatus **10** for correct sensor spacing, the type of sensor being used, etc. For example, referring to Figure **5**, the spacing "D**1**" and "D**2**" between the wedges **140** and **142** and a centerline **154** of the weld **30** should be within certain ranges, depending on a thickness "T" of the wall **152**. Accordingly, if the spacing of the wedges **140** and **142** is not within the acceptable range, then the spacing of the second portions **52** and **54** of the first and second flexible tension links **47** and **47** may require adjustment as described above. It may be necessary to enter other information regarding the sensor configuration, such as angle of the angled faces **144** and **146**, into the analyzer prior to performing the inspection.

Returning to Figure **6** as shown at **172** the apparatus is then clamped to the tube **24** as described above, taking care to ensure that the spacing "D**1**" and "D**2**" (shown in Figure **5**) remain in the appropriate ranges (i.e. the apparatus is clamped in alignment with the centerline **154** of the weld **30**). Alternatively, the configuration shown at **170** may be performed after clamping the apparatus **10** to the tube **24**, should the access be sufficient to permit configuration of sensor spacing after clamping.

As shown at **174**, the process continues by extending the flexible tension links **46** and **47** by rotating the actuator knob **59**. The flexible tension links **46** and **47** are extended by one full revolution around the circumference of the tube **24** to a starting position for the inspection of the tube **24**.

Referring to Figure **4**, as the flexible tension links are extended, the extended portion (e.g. the second portion **52**) is urged towards the outer peripheral surface **68** of the tube **24** at a plurality of locations (e.g. the locations **118**, **120** and **122**) along the extended portion. This causes the sensor **62** to be urged into contact with the tube **24** while the second portion **52** wraps around the tube thus moving through an arc circumferentially around the tube. Advantageously, this allows the apparatus **10** to be used to perform inspections on a range of different tube diameters.

Referring back to Figure **6**, as shown at **176**, a reference mark is then made to indicate the position of the sensors **62** and **66** at the starting position for the inspection. The reference mark may be useful if a defect is found in the tube **24**, since the location of the defect indicated by the analyzer **74** is generally referenced to the start position. Accordingly should it be necessary to correct the defect or to cut the tube **24** for further inspection, the position of the defect, as indicated by the analyzer, may be located on the tube by measuring from the reference mark.

As shown at **178**, at this stage in the process, the ultrasonic coupling fluid supply is activated to supply coupling fluid between the sensors **62** and **66** and the peripheral surface **68** of the tube **24**.

As shown at **180**, the inspection then commences by activating the analyzer **74**. Generally activating the inspection involves pressing a “Start”, “Record” or other button on the analyzer **74** to cause the analyzer to generate

excitation signals and receive return signals from the sensors **62** and **66** and the encoder **76**.

As shown at **182**, the actuator knob **59** is then rotated to cause the flexible tension links **46** and **47** to be retracted into the frame **12**, thus causing the sensors **62** and **66** to move through an arc in a direction circumferentially around the tube while maintaining ultrasonic coupling between the ultrasonic sensors and the tube **24**. Once inspection has commenced the analyzer **74** monitors the position signal received from the encoder **76**, from which the analyzer is able to determine a real time velocity of the sensors along the peripheral surface **68**, and to provide feedback to the operator. The feedback may take the form of a plurality of indicator lights that show, for example, an indication such as "too fast", "too slow", or "correct" retraction speed. If the sensors **62** and **66** are conveyed too fast over the peripheral surface **68**, defects may be missed.

As the flexible tension links **46** and **47** are retracted into the frame **12**, the analyzer provides excitation signals to the sensors **62** and **66**, which cause the ultrasonic beams **148** and **150** to be scanned over the weld **30** (as shown in Figure **5**). The sensors **62** and **66** also generate return signals, which are received by the analyzer **74**, correlated with the position signal, and presented to the operator as data or a graphical interpretation thereof showing the result of the inspection.

While retracting the flexible tension links **46** and **47**, the extended portions of the flexible tension links are urged towards the outer peripheral surface of the tube at a plurality of locations along the extended portion, as described above in connection with the extension, shown at **174**.

Once the flexible tension links **46** and **47** have been fully retracted into the frame **12**, the analyzer **74** is de-activated to indicate the end of the inspection,

as shown at **184**. The apparatus may then be unclamped and removed from the tube **24**.

It has been discovered that it is advantageous to perform the inspection while retracting the flexible tension links **46** and **47**, since the retraction movement is smoother than the extension movement. While it is possible to perform the inspection when extending the flexible tension links **46** and **47**, it was found that the sensors **62** and **66** are more likely to stick while being extended, resulting in a less smooth movement and thus affecting the inspection result.

Advantageously, the relatively low profile of the sensors **62** and **66**, shown in Figure **5**, and the mounting of the sensors on distal ends of the flexible tension links **46** and **47**, permits inspection of a tube **24**, even where the tube is surrounded by other tubes (such as tubes **98** and **99** shown in Figure **2**). In one embodiment the sensors **62** and **66** and the flexible tension links **46** and **47** have a profile height of less than **0.5** inches, allowing inspection of tubes that are spaced apart from the tube **24** by as little as **0.5** inches.

Alternative embodiments

While the apparatus **10** has been described with reference to a hand operated actuator knob **59** for extending and retracting the flexible tension links **46** and **47**, the actuator shaft **58** may also be coupled to a motor or other mechanism for automatically extending and retracting the flexible tension links.

While the apparatus **10** has been described as being configured using two phased array sensors **62** and **66**, the apparatus may also be configured with a single sensor (or more than two sensors), and the sensor need not be a phased array ultrasonic sensor. Furthermore while the apparatus **10** includes a flexible tension link **46** and **47** having first and second spaced apart portions the sensor may also be mounted on a flexible tension link having only a single, in-line portion. However, such a configuration may not permit a full

scan of the circumference of the tube **24**, without unclamping, shifting circumferentially, and then re-clamping the apparatus.

While specific embodiments of the invention have been described and illustrated, such embodiments should be considered illustrative of the invention only and not as limiting the invention as construed in accordance with the accompanying claims.

What is claimed is:

1. A method for conveying an ultrasonic sensor about an outer peripheral surface of a tube to perform a non-destructive evaluation thereof, the ultrasonic sensor being mounted on an extendible portion of a flexible tension link, the method comprising:

extending the flexible tension link while urging the extended portion of the flexible tension link towards the outer peripheral surface of the tube at a plurality of locations along the extended portion to cause the ultrasonic sensor to move through an arc circumferentially around the tube while maintaining ultrasonic coupling between the ultrasonic sensor and the tube.

2. The method of claim **1** wherein said extending comprises extending the flexible tension link to cause the ultrasonic sensor to be conveyed from a first location on the outer peripheral surface of the tube to a second location the outer peripheral surface of the tube, said second location being spaced apart from said first location by substantially one complete revolution around the circumference of the tube, and further comprising performing the non-destructive evaluation while retracting the flexible tension link to cause the ultrasonic sensor to move from said second location to said first location.

3. The method of claim **2** further comprising causing a reference mark to be made on the tube at at least one of said first location and said second location.

4. The method of claim **1** further comprising introducing an ultrasonic coupling fluid between the sensor and the outer peripheral surface of

the tube to further facilitate ultrasonic coupling between the ultrasonic sensor and the tube.

5. The method of claim **2** wherein introducing said ultrasonic coupling fluid comprises delivering a flow of ultrasonic coupling fluid between the ultrasonic sensor and the outer peripheral surface of the tube.

6. The method of claim **1** wherein the flexible tension link comprises a plurality of linked elements and the ultrasonic sensor is mounted on at least one of said linked elements, and wherein maintaining ultrasonic coupling between the ultrasonic sensor and the tube comprises urging said at least one of said linked elements towards the outer peripheral surface of the tube such that the ultrasonic sensor is urged into contact with the outer peripheral surface of the tube.

7. The method of claim **1** wherein the flexible tension link comprises a plurality of linked elements and wherein urging said extended portion of the flexible tension link comprises urging each of said plurality of linked elements toward the outer peripheral surface of the tube thereby causing said extended portion of the flexible tension link to wrap around the tube.

8. The method of claim **1** wherein the flexible tension link is housed in a frame and the ultrasonic sensor is mounted on a distal end of the flexible tension link and wherein extending comprises causing said distal end to be extended from said frame.

9. The method of claim **8** wherein a proximate end of the flexible tension link is coupled to an actuator on the frame, and wherein causing said distal end of the flexible tension link to be extended comprises

actuating said actuator to cause said distal end of the flexible tension link to be extended from said frame.

10. The method of claim **8** further comprising clamping said frame to the outer peripheral surface of the tube before extending the flexible tension link.

11. The method of claim **10** wherein the outer periphery of the tube comprises an accessible portion and an inaccessible portion, said inaccessible portion comprising a portion of the outer periphery of said tube having limited access due to a surrounding environment, and wherein said clamping comprises clamping said frame to said accessible portion of the outer periphery of the tube.

12. The method of claim **1** wherein the ultrasonic sensor comprises a first ultrasonic sensor and the flexible tension link comprises a first flexible tension link and further comprising a second ultrasonic sensor mounted on a second flexible tension link, said first and second ultrasonic sensors being spaced apart, the method further comprising:

extending the second flexible tension link while urging a second extended portion of the second flexible tension link towards the outer peripheral surface of the tube at a plurality of locations along the second extended portion to cause the second ultrasonic sensor to move through an arc circumferentially around the tube while maintaining ultrasonic coupling between the second ultrasonic sensor and the tube.

13. The method of claim **1** further comprising locating a circumferential position of the ultrasonic sensor on the peripheral surface of the tube.

14. The method of claim **13** wherein locating said circumferential position comprises determining a displacement of the flexible tension link.

15. The method of claim **14** wherein determining said displacement comprises coupling an encoder to the flexible tension link, said encoder being operable to produce a position signal representing said displacement.

16. The method of claim **15** wherein the ultrasonic sensor is coupled to an analyzer, said analyzer being operable to transmit electrical stimuli to the ultrasonic sensor and to receive electrical signals from the ultrasonic sensor representing results of the non-destructive evaluation of the tube, and further comprising receiving said position signal at the analyzer and correlating said results with said circumferential position of the ultrasonic sensor.

17. An apparatus for conveying an ultrasonic sensor about an outer peripheral surface of a tube to perform a non-destructive evaluation thereof, the apparatus comprising:

a frame operably configured to engage the tube;

a flexible tension link housed in said frame, said flexible tension link being operably configured to permit the ultrasonic sensor to be mounted thereto;

an actuator coupled to said flexible tension link and operable to cause said flexible tension link to extend said frame;

said flexible tension link being operably configured to urge an extended portion of the flexible tension link towards the outer peripheral surface of the tube at a plurality of locations along the

extended portion to cause the ultrasonic sensor to move through an arc circumferentially around the tube while maintaining ultrasonic coupling between the ultrasonic sensor and the tube.

18. The apparatus of claim **17** wherein said actuator is operably configured to extend the flexible tension link to cause the ultrasonic sensor to be conveyed from a first location on the outer peripheral surface of the tube to a second location the outer peripheral surface of the tube, said second location being spaced apart from said first location by substantially one complete revolution around the circumference of the tube, said actuator further being operably configured to retract the flexible tension link to cause the ultrasonic sensor to move from said second location to said first location while performing the non-destructive evaluation of the tube.

19. The apparatus of claim **17** further comprising a coupling fluid supply line operably configured to introduce an ultrasonic coupling fluid between the ultrasonic sensor and the outer peripheral surface of the tube to further facilitate ultrasonic coupling between the ultrasonic sensor and the tube.

20. The apparatus of claim **19** wherein said ultrasonic coupling fluid comprises water.

21. The apparatus of claim **17** wherein said flexible tension link comprises a plurality of linked elements and the ultrasonic sensor is mounted on at least one of said linked elements, said at least one of said linked element further comprising a spring operable to urge said at least one linked element towards the outer peripheral surface of the tube such that the ultrasonic sensor is urged into contact with the outer peripheral surface of the tube.

22. The apparatus of claim **17** wherein said flexible tension link comprises a plurality of linked elements and further comprising a plurality of springs operating between said linked elements to urge said extended portion of the flexible tension link toward the outer peripheral surface of the tube such that said extended portion wraps around the tube when the flexible tension link is extended.

23. The apparatus of claim **17** wherein the ultrasonic sensor is mounted on a distal end of said flexible tension link and wherein said actuator is coupled to a proximate end of said flexible tension link and whereby actuating said actuator causes said proximate end to be displaced thereby causing said distal end is extended from said frame.

24. The apparatus of claim **23** wherein said actuator comprises a rotateable drum located in said frame, said proximate end of said flexible tension link being coupled to said drum and wherein an un-extended portion of said flexible tension link wraps around said drum.

25. The apparatus of claim **23** wherein said frame further comprises a clamp operable to clamp the frame to the outer peripheral surface of the tube.

26. The apparatus of claim **25** wherein said clamp is operably configured to clamp said frame to an accessible portion of the outer periphery of the tube.

27. The apparatus of claim **17** wherein the ultrasonic sensor comprises a first ultrasonic sensor and said flexible tension link comprises a first flexible tension link and further comprising a second ultrasonic sensor mounted on a second flexible tension link, said first and second

ultrasonic sensors being spaced apart, the apparatus further comprising:

a second flexible tension link housed in said frame, said second flexible tension link being operably configured to permit the second ultrasonic sensor to be mounted thereto;

said flexible tension link being coupled to said actuator, said actuator being operable to cause said second flexible tension link to be extended from said frame;

said second flexible tension link being operably configured to urge a second extended portion of the second flexible tension link towards the outer peripheral surface of the tube at a plurality of locations along the second extended portion to cause the second ultrasonic sensor to move through an arc circumferentially around the tube while maintaining ultrasonic coupling between the second ultrasonic sensor and the tube.

28. The apparatus of claim **17** further comprising an encoder, coupled to one of said flexible tension link, said actuator, and the ultrasonic sensor, said encoder being operably configured to produce a position signal representing a circumferential position of the ultrasonic sensor on the peripheral surface of the tube.

29. The apparatus of claim **28** further comprising an analyzer coupled to the ultrasonic sensor, said analyzer being operable to transmit electrical stimuli to the ultrasonic sensor and to receive electrical signals from the ultrasonic sensor representing results of the non-destructive evaluation of the tube, said analyzer further comprising an input for receiving said position signal from said encoder, said analyzer

being operably configured to correlate said results with said circumferential position of the ultrasonic sensor.

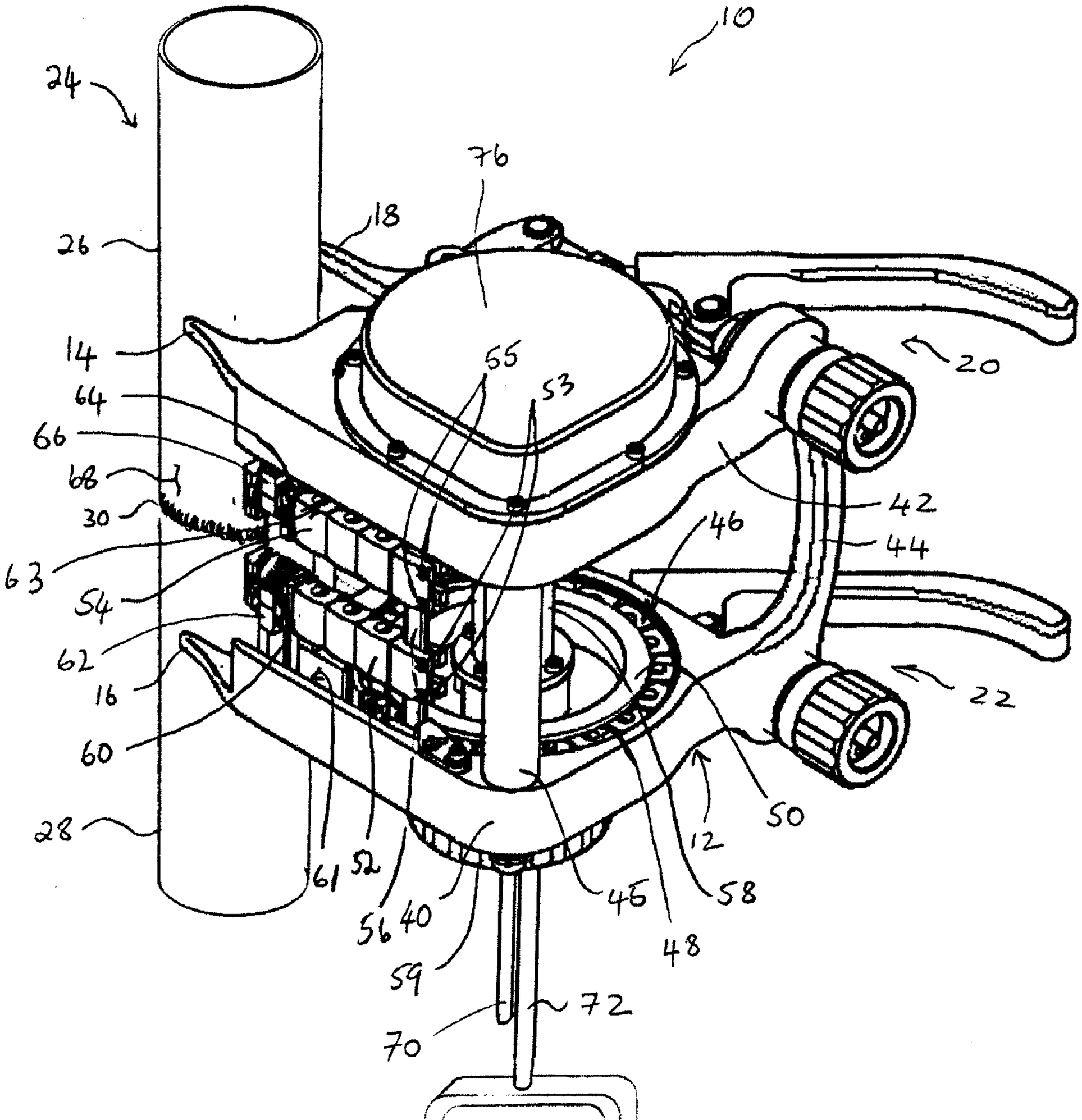
30. An apparatus for conveying an ultrasonic sensor about an outer peripheral surface of a tube to perform a non-destructive evaluation thereof, the apparatus comprising:

a frame operably configured to engage the tube;

a flexible tension link housed in said frame, said flexible tension link being operably configured to permit the ultrasonic sensor to be mounted thereto;

means for extending the flexible tension link from said frame;

means for urging an extended portion of the flexible tension link towards the outer peripheral surface of the tube at a plurality of locations along the extended portion to cause the ultrasonic sensor to move through an arc circumferentially around the tube while maintaining ultrasonic coupling between the ultrasonic sensor and the tube.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ANALYZER
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FIG. 1

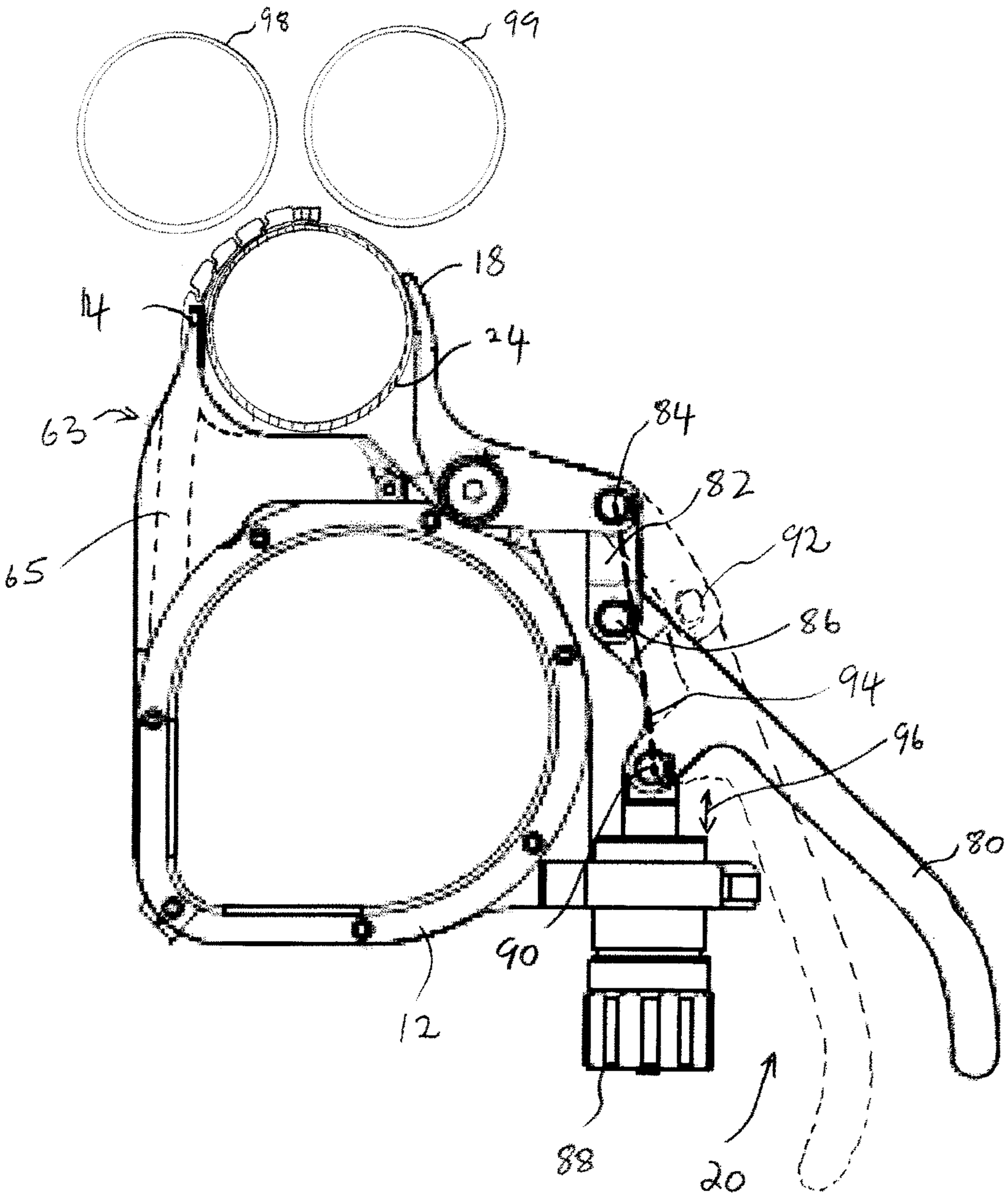

FIG. 2

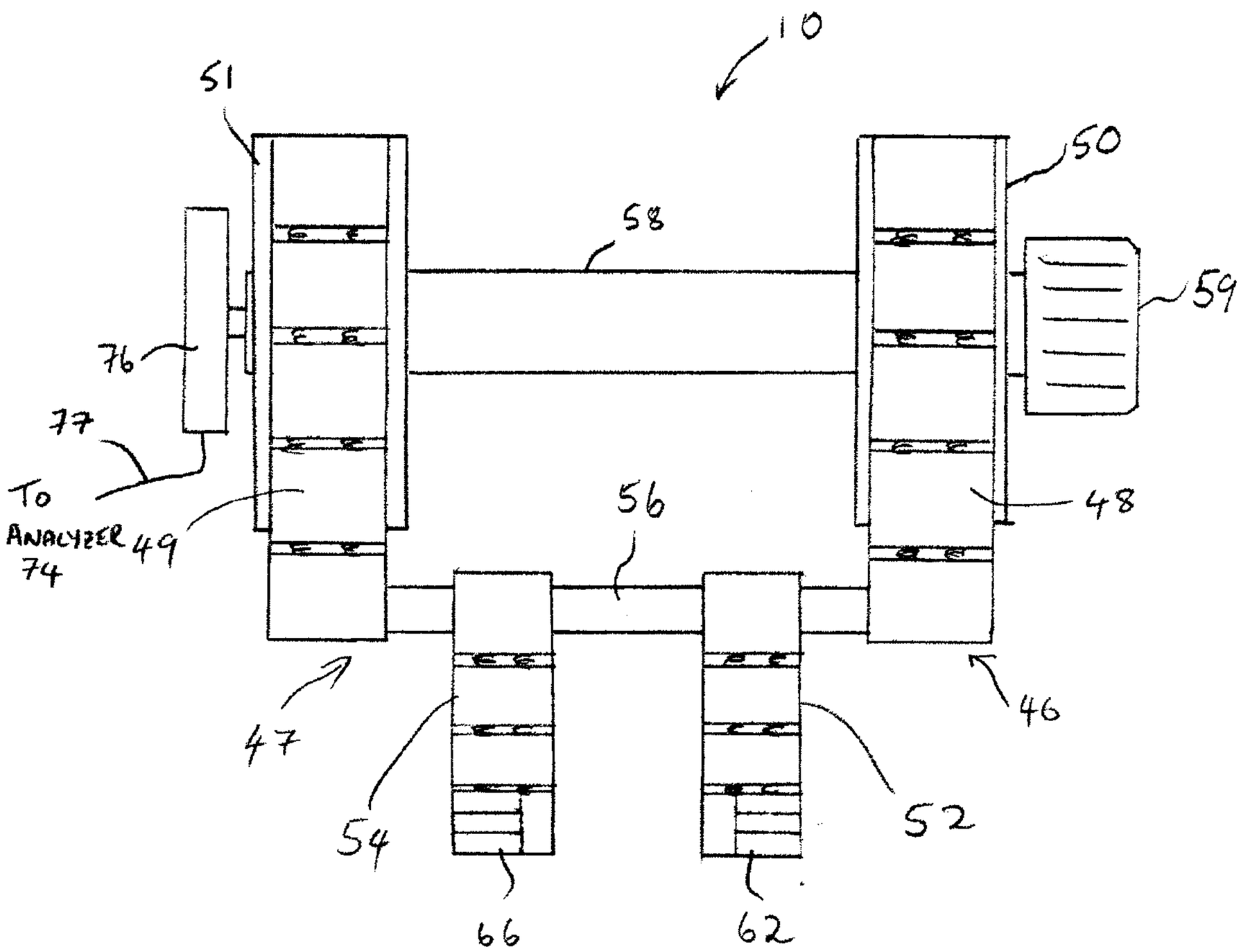

FIG. 3

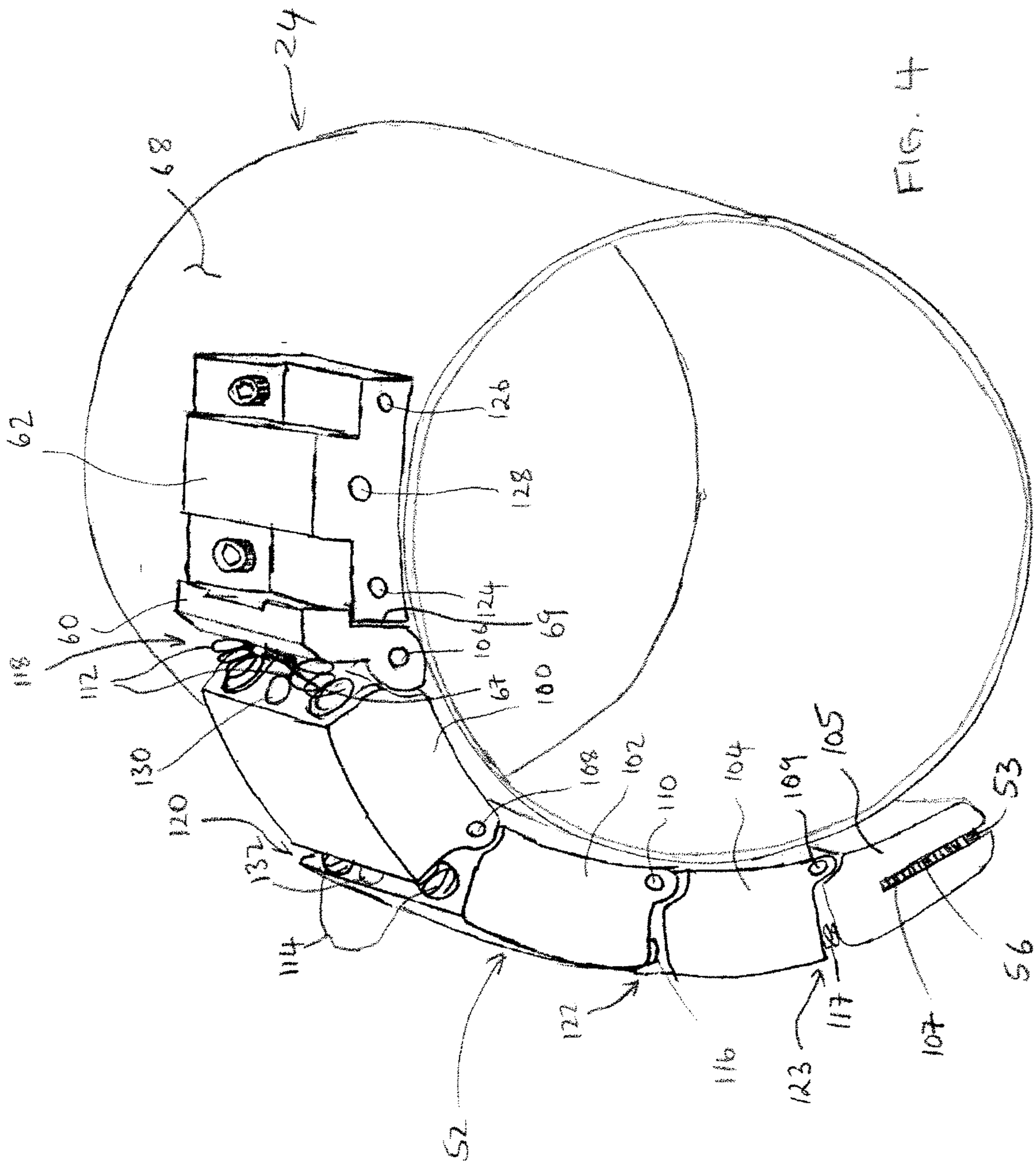
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FIG. 4

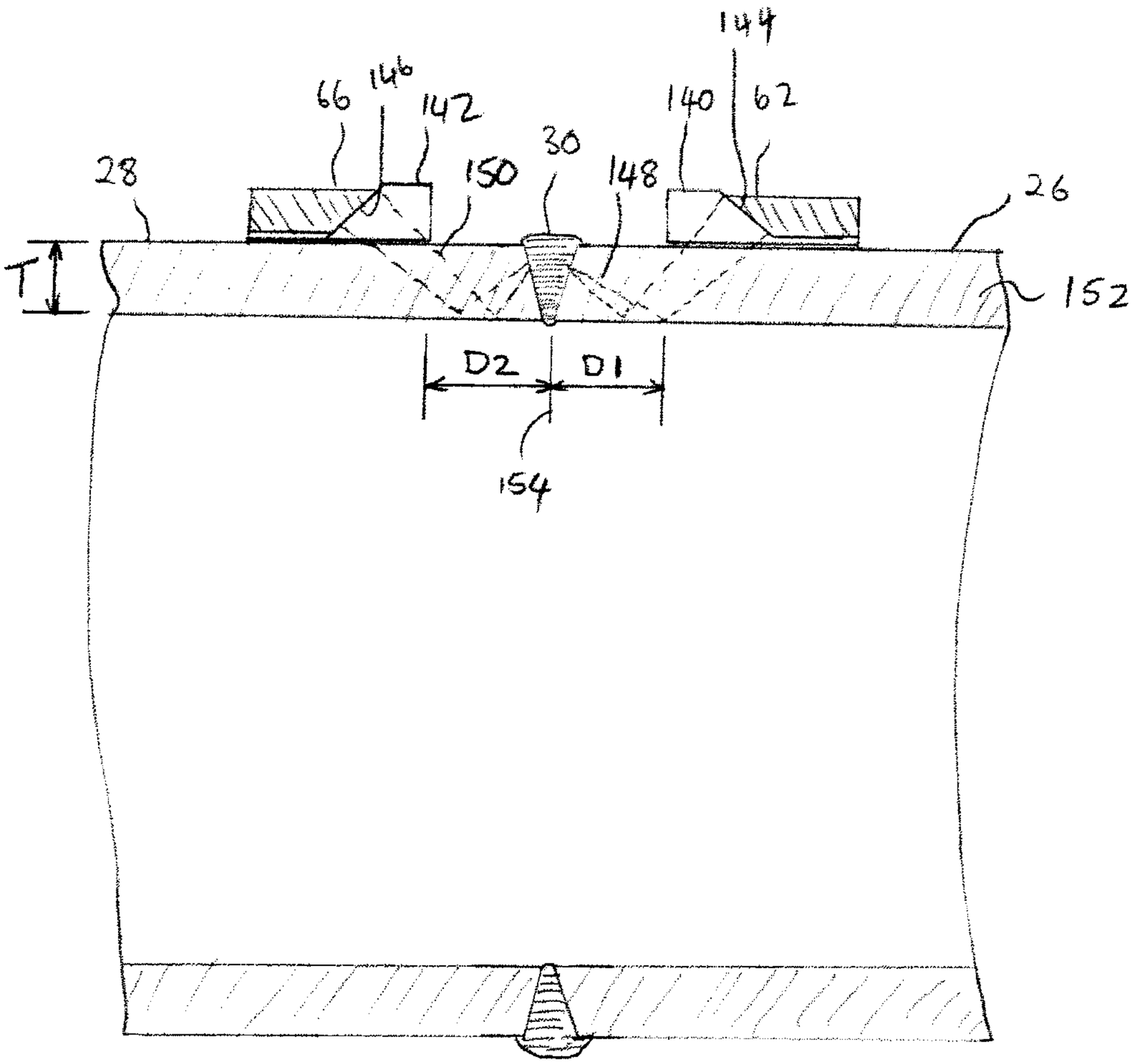


FIG. 5

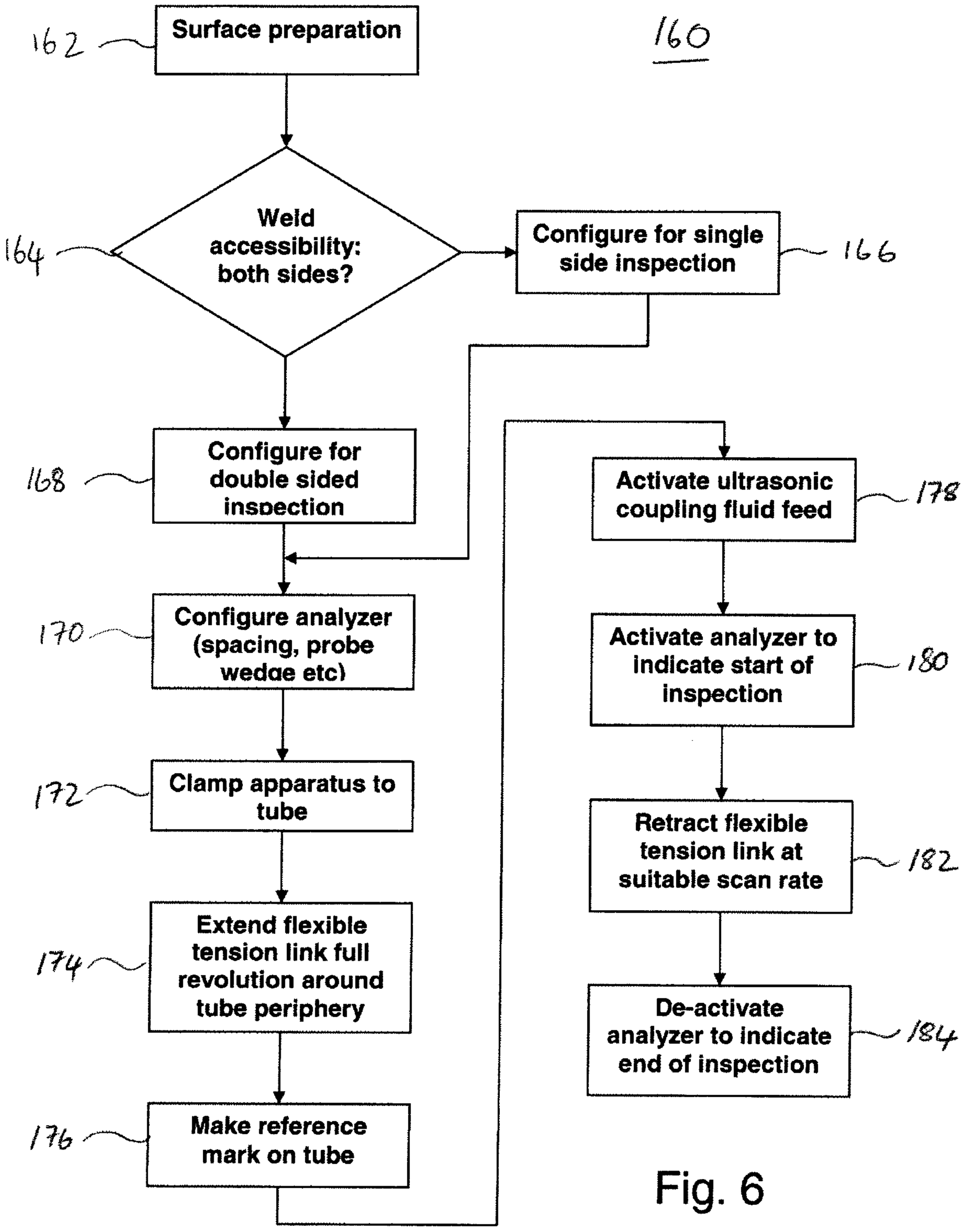
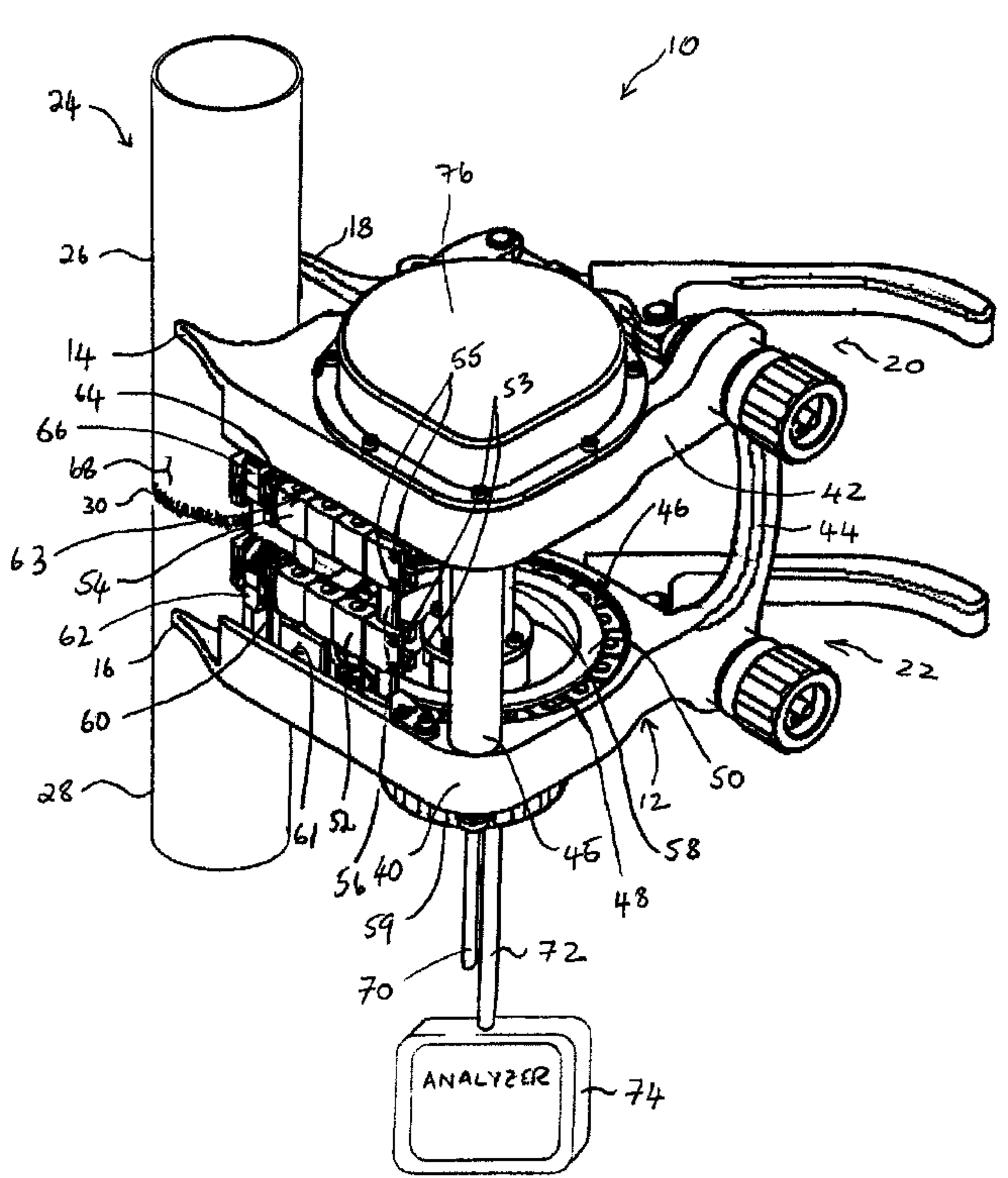

160
162
Surface preparation
164
Weld accessibility: both sides?
166
Configure for single side inspection
168
Configure for double sided inspection
170
Configure analyzer (spacing, probe wedge etc)
172
Clamp apparatus to tube
174
Extend flexible tension link full revolution around tube periphery
176
Make reference mark on tube
178
Activate ultrasonic coupling fluid feed
180
Activate analyzer to indicate start of inspection
182
Retract flexible tension link at suitable scan rate
184
De-activate analyzer to indicate end of inspection

Fig. 6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ANALYZER
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