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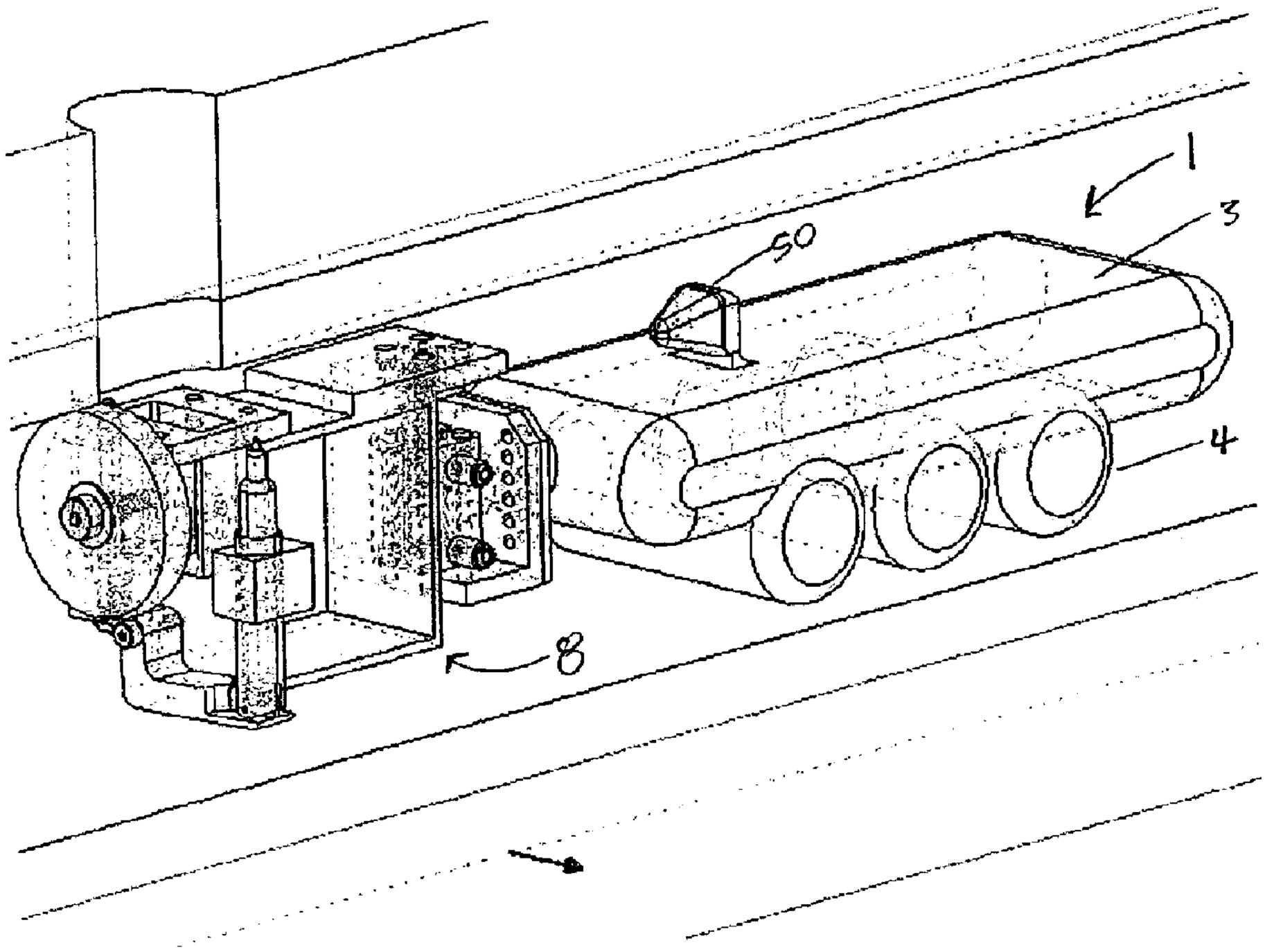
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(54) Titre : SONDE D'IMPEDANCE UNIVERSELLE PERMETTANT LA DETECTION DE CONNEXIONS LATERALES A TRAVERS DES DOUBLURES CIMENTAIRES, THERMODURCISSABLES ET THERMOPLASTIQUES

(54) Title: UNIVERSAL IMPEDANCE PROBE FOR DETECTION OF SIDE-CONNECTIONS THROUGH THERMOPLASTIC, THERMOSETTING AND CEMENTITIOUS LINERS



(57) Abrégé/Abstract:
A conduit survey apparatus having a carriage capable of movement axially down a conduit. The carrier includes a radio frequency (RF) signal generator and an RF signal detector positioned on the carriage along with a controller controlling the signal generator

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(57) Abrégé(suite)/Abstract(continued):
and signal detector. The carrier further includes a waveguide with an open throat transmitting signals from the signal generator and directing received signals to the signal detector. Finally, the carrier includes a waveguide positioner mounted on the carrier and adapted to selectively engage an interior wall of the conduit, wherein the waveguide guide is connected to the positioner such that the open throat of the waveguide is within about 1 inch of the interior wall when the positioner engages the interior wall.

ABSTRACT

A conduit survey apparatus having a carriage capable of movement axially down a conduit. The carrier includes a radio frequency (RF) signal generator and an RF signal detector positioned on the carriage along with a controller controlling the signal generator and signal detector. The carrier further includes a waveguide with an open throat transmitting signals from the signal generator and directing received signals to the signal detector. Finally, the carrier includes a waveguide positioner mounted on the carrier and adapted to selectively engage an interior wall of the conduit, wherein the waveguide guide is connected to the positioner such that the open throat of the waveguide is within about 1 inch of the interior wall when the positioner engages the interior wall.

UNIVERSAL IMPEDANCE PROBE FOR DETECTION OF SIDE-CONNECTIONS THROUGH THERMOPLASTIC, THERMOSETTING AND CEMENTITIOUS LINERS

I. Background of Invention.

A common technique for rehabilitating sewer and water pipelines is lining the deteriorated pipe using a thermoplastic, thermosetting or cementitious product. Cost-effective use of this technique requires the ability to restore side connections or lateral connections (e.g., from a residences to collector lines) using remotely controlled devices placed inside the rehabilitated pipe. This is accomplished most commonly using remotely controlled platforms that carry an assortment of cutters, drills and other devices designed to cut through the freshly installed liner and re-establish the pipe-lateral connection. Current practices generally rely on pre-installation survey where the distance from the access point to the location of the connection is measured and recorded prior to the installation of the liner. In many cases this information provides an estimate as to the approximate location of the lateral connection, but is not adequate for pin-pointing the exact location at which the blade should engage the liner.

II. Brief Description of Drawings.

Figure 1 illustrates one embodiment of a robotic conduit survey apparatus.

Figure 2 illustrates a side view of the embodiment of Figure 1.

Figure 3 illustrates a first view of the adapter body.

Figure 4 illustrates a second view of the adapter body.

Figure 5 illustrates a third view of the adapter body.

Figure 6 illustrates a second embodiment of a robotic conduit survey apparatus.

Figure 7 illustrates a cross-sectional schematic of the Figure 6 embodiment within a conduit.

Figure 8 illustrates electronic components in one embodiment of the conduit survey apparatus.

Figures 9A to 9C illustrate alternate waveguide to lateral diameter ratios.

Figure 10 illustrates a method of using a contrast liquid in one method of the invention.

Figure 11 illustrates a flow chart of one method of the present invention.

III. Detailed Description of Selected Embodiments.

One embodiment of the present invention is a method of locating side connections in a pipe (more generally referred to herein as a "conduit") having a thermosetting or thermoplastic liner previously positioned in the conduit using a near-field microwave imaging technique that employs an open-ended rectangular waveguide. The embodiment includes positioning a robotic survey apparatus within the conduit and having the apparatus travel along the conduit in order to detect the side connections (also referred to herein as "lateral connections" or simply "laterals"). Figure 1 illustrates one embodiment of such a robotic survey apparatus 1. The apparatus includes a carrier or carriage 3 which is capable of movement along the conduit. In many embodiments, the carrier 3 will be self-propelled, but in other embodiments carrier 3 has no internal drive mechanism and would need to be pulled through the conduit by tether or similar means. Carrier 3 will normally have a series of wheels 4, tracks, or other similar traction means, but could also be positioned on sled like structure if pulled through the conduit. One non-limiting example of a suitable self-propelled carrier is the Pipe RangerTM available from CUES Corporation of Orlando, Fla.

Normally carrier 3 will transport a series of electronic components to detect conditions of interest in and around the conduit. In certain embodiments such as seen in Figure 1, the carrier may incorporate a camera 50 and electronics for radio sounding of the conduit and the adjacent environment. One example of camera 50 is a cctv camera such as an OZIII optical zoom pan-and-tilt camera system available from CUES Corporation, which may include a lighting system. However, any type of camera (analog or digital) or even carriers without cameras could be employed in alternate embodiments. In the embodiment of Figure 1, camera 50 is positioned on a rotating head such that the entire inner circumference of the pipe may be viewed.

The embodiment of Figure 1 includes radio sounding equipment positioned in an adapter body 8, which attached to carrier 3 via support arm 6 (Figure 2). Figures 3-5 illustrate more detailed views of one embodiment of adapter body 8 positioned in a conduit 100. In Figure 3, the adapter body 8 includes a connecting bracket 11 which attaches to carrier 3's support arm 6. The adapter body includes waveguide 12 and waveguide positioner 9. It will be understood that in many of the embodiments described herein, the "waveguide" includes a shaped tube with an open-end for directing the signal. In the embodiment seen in Figure 3, waveguide positioner 9 is a disc or wheel shaped

positioner 10. The lift apparatus 45 is positioned between connecting bracket 11 and an upper plate of adapter body 8. Figure 3 suggests how lift base 46 is positioned on connector bracket 11 and lift arm 47 connects to the upper plate of adapter body 8. A solenoid or other linear actuator will extend.

Viewing Figure 2, it will be understood that when lift arm 47 is raised, disc shaped positioner 10 is raised into place against the inner conduit surface, and the positioner 10 will generally maintain the open throat 13 (Figure 5) of waveguide 12 relatively close to, but not touching the inner conduit surface in order to optimize the transmission and receipt of signals from waveguide 12. It will also be understood that a rotative mechanism on carrier 3 engages support arm 6. Thus, support arm 3 and adapter body 8 may be rotated relative to carrier 3. Rotation of adapter body 8 allows position wheel 10 (and waveguide 12) to traverse the entire inner circumference of conduit 100.

In most embodiments, the distance waveguide 12 is spaced from the inner conduit surface which is less than two inches, more preferably less than about one inch, and most preferably, less than about 0.5 inches. Because of irregularities along the inner conduit/liner surface, about 0.2 inches may be practical limit of how close the waveguide can travel against the inner wall. Therefore, in many embodiments, the preferred distance of the waveguide 12 from the inner pipe surface is between about 0.2 and 0.5 inches. However, there can be other embodiments where the waveguide can actually contact the conduit/liner surface and actually function as described herein.

The particular waveguide utilized could vary from embodiment to embodiment. In the illustrated embodiments, WR-137 (5.82 GHz to 8.2 GHz (C band)) and WR-90 are two non-limiting examples. The wave guides may have rectangular cross-sections (such as WR-137 and WR-90) or other shaped cross-sections (e.g., circular). Many embodiments will have a cross-sectional area of between about 0.25 and about 2.5 in2 (although other embodiments could be outside this range and the dimensions of the waveguide are typically a function of the operating frequency range). In certain embodiments, there will be a given ratio of wave guide size to the diameter of the lateral expected to be encountered. In certain embodiments, the waveguide is metal or metal lined and hollow or filled with a dielectric material. The three configurations seen in Figures 9A to 9C (showing rectangular waveguide 12 and lateral pipe 105) give varying degrees of resolution. The Figure 9C configuration gives the highest resolution in terms of picking up the edges of the lateral. In certain embodiments utilizing rectangular waveguides, the long

dimension of the wave guide is between 30% and 100% of the diameter of the lateral intersecting the conduit. In other embodiments, the short dimension of the rectangular waveguide is 90% to 140% of the diameter of the side connecting member.

In the embodiment of Figure 1, the adapter body 8 will also house the electronics associated with the radio sounding. For example, the circuitry forming an RF signal generator and an RF signal detector together with the controller controlling the signal generator and signal detector may be positioned in the adapter body 8. Figure 8 is a block diagram illustrating the electronic components associated with one embodiment of the signal generating and receiving circuitry. The waveguide 12 receives the outgoing signal from a signal generation unit (or signal generator), which in Figure 8 is formed by digital-to-analog converter 32, wideband voltage controlled oscillator (VCO) 33, bandpass filter 34, and wideband circulator 35. In this configuration, the VCO typically generates the signal, the digital-to-analog converter instructs the VCO when to generate the signal (in essence acting as a form of trigger), and the circulator redirects the signal from the VCO to the waveguide. The circulator, as its name implies, "circulates" the signal by forwarding the outgoing signal to the waveguide and forwarding the received signal to amplifier. Thus, the circulator has two paths - one for the incoming signal and another for the outgoing signal.

Likewise, the returning signal received by the waveguide 12 is fed to the signal detector which in this embodiment is formed by logarithmic power detector 41, wideband circulator 35 and scaling amplifier 42 (generally forming a signal detector). Naturally, these components in Figure 8 are only one example of a signal generator and signal detector. Any conventional or future developed circuitry performing within the parameters described herein could act as the signal generator and signal detector. The controller (or microcontroller) 31 controls the activation of the signal generator and processes the signals received from the signal detector. In one embodiment, the wideband circulator may be a MIDICO part no: M3C4080 - 4 GHz to 8 GHz; the logarithmic detector an Analog Devices AD8318 - 1 MHz to 8 GHz; the voltage controlled oscillator a RFMD UMZ-T2-447-016-G - 6.6 GHz to 8.1 GHz; and the controller a Texas Instruments - C2000 - Picolo series microcontroller.

In many embodiments, the frequency of the signal output by the frequency generator will be between about 3.95 and about 12.40 GHz (i.e., band designation C to X) and more preferably between about 5.85 to about 8.20 GHz. From 5.85 GHz to 8.20 GHz,

the waves passing through the cavity will have the dominant mode. Frequencies above 8.20 GHz can still pass through the cavity but they may switch in to higher order modes which increases signal losses. Generally, the preferred signal frequency is primarily dependent on three factors: 1) it is preferably above the cut-off frequency of the waveguide so it can better propagate inside the cavity; 2) it is preferably within the range such that they exist as dominant modes; and, 3) it is preferably frequencies that can penetrate through materials forming the liners. For instance, high frequencies like 30 GHz may not have enough penetration depth to pass through the entire thickness of the liner (typically between 0.25 to 1.0 inches but can be as much as 3.0 inches or as little as 0.1 inch). Controller 31 may also activate or receive data from other components utilized by the conduit survey apparatus. For example, Figure 8 illustrates controller 31 communicating with inertial measurement sensor 39 (for determining position of carrier, waveguide, and camera as described in more details below), communicating with solenoid driver 24 (which powers the solenoid 22 for the marking device as described below) and activating appropriate LED status lights to indicate various conditions.

Figures 3-5 also illustrate how this embodiment of adapter body 8 includes a mechanism for visually marking the liner surface (e.g., at the point where a side connecting conduit or other item of interest is identified) so that a camera controlled cutting or drilling device (described below) can cut through the liner at the marked location. The marking mechanism includes the pivoting link 21 connected to the adapter body 8 with a marking device 20 (Figure 3) connected to one end of the pivoting link 21 and an activating device 22 (Figure 4 -- a solenoid driven activator in this example) connected to the other end of the pivoting link 21. The connecting pin 23 pivotally connects pivoting link 21 to the adapter body 8. When it is desired to mark a particular location on the inner surface of the liner, solenoid activator 22 is extended pushing one end of the pivoting link 21 downward and raising the marker 20 upwards to engage the liner surface. The actual manner of marking is not critical and various embodiments may include marking with an ink, paint, dye marking device, or a heated tip that burns the surface of the conduit at the location of interest or simply making a mechanical indention which may be detected by a camera or other device capable of sensing the indention.

Figure 6 illustrates an alternate embodiment of conduit survey apparatus of the current invention. In Figure 6, the carrier 3 includes a camera 50 and a power/data transmission cord 5 extending to a control station outside of the conduit. In this

embodiment, the waveguide 12 is connected to a rotating collar 15 on the carrier 3. The waveguide 12 is connected to collar 15 by the support arm 16 which positions the waveguide 12 against the inner surface of the lined conduit 100. In this embodiment, support arm 16 is retractable in order that the waveguide 12 may be moved out of contact with the liner surface when the carrier is moving down the conduit and then brought into contact with the liner surface when radio sounding operations begin. Preferably, support arm is spring biased toward the liner surface such that the waveguide 12 can deflect away from the wall when surface irregularities are encountered, but still remains in contact with the liner surface. The waveguide 12 may be run over the entire circumference of the inner conduit surface by the rotation of rotating collar 15. Figure 7 best illustrates how a series of rollers 17 may be connected to the waveguide 12 in order to maintain the open throat of the waveguide slightly offset from the surface of liner 101 (e.g., the 0.2 to 0.5, less than 1, or less than 2 inches) as described above. The electronics described above in reference to Figure 8 may be positioned within the carrier or, if the waveguide housing is large enough, within that housing. The embodiment of Figures 6 and 7 also differs from that of Figure 1 in that the former is equipped with a drill or cutter 25. In this embodiment, drill/cutter 25 is a telescoping device which can be extend outward to engage and cut the liner and retract inward when not in use. While Figures 1 and 6 suggest a cutter and marker on different survey apparatuses, obviously other embodiments of the survey apparatus could include both a cutter and a marker on the same device.

There are many different manners in which the conduit survey device can be employed to detect side connections, the condition of the conduit, or the condition of the substrate/soil surrounding the conduit. The survey device could be employed in conduits constructed of any number of different materials, including polymer pipe, metal pipe (ferrous and non-ferrous), concrete pipe, clay pipe, asbestos cement pipe, or "Orangeburg" pipe (coal tar impregnated wood fiber pipe). Polymer pipes may include conduits constructed primarily of a plastic, or a thermoplastic, or a thermosetting, or a fiberglass reinforced plastic. The conduits being surveyed may be of any type, non-limiting examples including gas lines, culverts, storm drains, sewer pipes, or plastic conduits placed to carry electrical cables or telecommunication cables.

One embodiment of the current invention is a method of locating side connections in a conduit having a plastic liner previously positioned in the conduit. While the particular type of plastic liner is not critical to the invention, non-limiting examples of

plastic liners may include thermosetting liners (i.e., cure in place pipe), thermoplastic liners (HDPE, PVC), glass fiber reinforced plastics (GFRP), spray applied or extruded in place epoxy, polyurea and polyurethane coatings. Initially, a survey apparatus such as described above is positioned within the conduit. Often, the user controlling the survey apparatus may direct the carrier down the conduit to an approximate position where the side connection is estimated to be, for example, the approximate location of the side connection as established based on pre-lining measurements. One means of determining the position of the survey apparatus in the conduit may be an inertial measurement senor 39 referenced in Figure 8. Next, the waveguide will be directed against the liner surface and the RF signal will be transmitted through the waveguide toward the liner surface. The reflected signal received by the RF signal detector will be analyzed to determine a change in at least one electro-magnetic property in a space behind the liner. In certain embodiments, the change in electro-magnetic property is a change in dielectric constant. For example, the change in dielectric constant may be detected by the controller reading a change in power of the reflected signal, normally quantified as a change in voltage.

The rotative orientation of the waveguide along the circumference of the inner conduit wall may be determined by another inertial measurement sensor for each signal reflection received. Thus, reflected signal readings will have at least two spatial parameters associated with the readings: a lateral distance along the length of the conduit and the angular position along the arc of the circumference of the conduit at that lateral location. Although inertial measurement sensors are referenced in Figure 8, any type of "displacement" sensor which can indicate the spatial parameters described herein could be employed with the apparatuses and methods of the current invention.

There are many procedures which can be used to detect changes in the properties of the conduit and surrounding areas. In one embodiment, the waveguide is rotated 360 degrees while moving forward so as to carry out inspection using a helical path. In certain embodiments, the method will include taking a first series of circumferential readings at a first radial increment where the increment is equal to or less than a diameter of an expected side connection. Once the approximate location of the side connection is detected, a second series of circumferential readings are taken (at that approximate location) using a second radial increment smaller than the first radial increment.

In certain embodiments, the method of detecting side connections will include positioning the apparatus in a conduit having a first dielectric constant and a side conduit

forming the side connection of interest having a material with a second dielectric constant positioned within the side conduit. Figure 10 suggests how main conduit 100 is intersected by side connection 105. In order to enhance the contrast between the main conduit and the side connection, a second material 110 with a significantly different dielectric constant from the main conduit is placed inside connection 105. In one embodiment, this second material may be water. More preferably, this material takes the form of a liquid filled "plug" containing a saline solution or water with other conductive metal salt crystals.

Figure 11 illustrates one example process which the survey apparatus might employ in scanning for lateral connections. First, the carrier is moved to an approximate location of the lateral (typically within 6-12 inches of the lateral) established by pre-installation CCTV survey data or otherwise. The waveguide then is engaged against the inner conduit surface and rotated using larger radial increments. Following each revolution, the carrier 10 moves linearly along the conduit at increments equal to or smaller than the width of the waveguide. Once an approximate location of the lateral is determined, the apparatus performs a more detailed inspection with finer radial sweeps to determine the edges of the lateral. The location and orientation of the lateral is marked using a mechanical indentation, an ink-based marker, paint or other method. Finally, a cutter device is aligned with center of suspected location of the lateral and the cutter cuts an opening through the liner. In one alternative process, the laterals may have plugs inserted in them prior to the lining process where the plugs are filled with saline solution or another material of a comparatively different dielectric constant.

Although the above description is in terms of certain specific embodiments, those skilled in the art will recognize many modifications and variations that can be made upon the disclosed inventive concept. For example, while certain methods described above relate to finding side connections in conduits repaired with a plastic liner, other methods may include locating voids/low density areas outside of plastic pipes, detecting "cross-bores" (i.e, the paths of two conduits intersect, as sometimes happens during trenchless installations using a Horizontal Directional Drilling (HDD) method), and locating poor areas of compaction around large diameter thermoplastic culvert structures. All such modifications and variations are intended to come within the scope of the following claims.

CLAIMS:

1. A method of locating side connections in a conduit having a plastic liner previously positioned in the conduit, the method comprising the steps of:

a. positioning an waveguide probe within the conduit, the probe comprising:

i. an RF signal generator;

ii. an RF signal detector;

iii. a controller controlling the signal generator and signal detector;

iv. an open-ended rectangular waveguide transmitting signals from the signal generator and to signal detector;

v. a probe carriage capable of movement axially down the conduit and positioning the waveguide adjacent to the liner surface and moving the waveguide in a generally circumferential direction along the liner surface;

b. moving the waveguide along the liner surface;

c. transmitting an RF signal through the wave guide toward the liner surface;

d. measuring a reflected signal from the RF transmission;

e. analyzing the reflected signal to determine a change in at least one electro-magnetic property in a space behind the liner.

2. The method of claim 1 wherein the change in electro-magnetic property is dielectric constant.

3. The method of claim 2 wherein the controller determines a change in the dielectric constant by detecting a change in power of the reflected signal.

4. The method of claim 3 wherein the decrease in power is quantified as a change in voltage.

5. The method of claim 1 wherein the conduit comprises one from the group consisting of: a polymer pipe; a metal pipe (ferrous and non-ferrous); a concrete pipe; a clay pipe; an asbestos cement pipe; or an Orangeburg pipe.

6. The method of claim 1 wherein the liner comprises one from the group consisting of thermosetting liners, thermoplastic liners, glass fiber reinforced plastics, spray applied epoxy, extruded in place epoxy, polyurea and polyurethane coatings.

7. The method of claim 1 wherein the transmitted RF signal is within the range of about 3GHz to about 20 GHz.

8. The method of claim 7 wherein the transmitted RF signal is within the range of about 5.85 to about 8.20 GHz.

9. The method of claim 1 wherein the waveguide is rectangular or circular in cross-sectional shape.

10. The method of claim 8 wherein the waveguide has a cross-sectional area of about 0.25 in2 to about 2.5 in2.

11. The method of claim 1 wherein the probe carriage further includes a cutter device capable of forming an aperture in the liner.

12. The method of claim 1 wherein the waveguide includes at least one roller positioned to contact the liner surface.

13. The method of claim 1 wherein the probe includes a first displacement sensor detecting movement long the length of the conduit and a second displacement sensor detecting movement along the circumference of the liner surface.

14. The method of claim 1 wherein the conduit in which the probe is positioned has a first dielectric constant and a side conduit forming the side connection has a material with a second dielectric constant positioned within the side conduit.

15. The method of claim 14 wherein the material with a second dielectric constant is water.

16. The method of claim 14 wherein the second material is a plug containing a saline solution or conductive metal salt crystals.

17. The method of claim 1 wherein the waveguide is rectangular and the long dimension of the waveguide is between 30% and 100% of than the diameter of a side connecting member intersecting the conduit.

18. The method of claim 1 wherein a short dimension of a rectangular waveguide is 90% to 140% of the diameter of the side connecting member.

19. The method of claim 1 wherein the conduit is constructed primarily of a plastic, a thermoplastic, or a fiberglass reinforced plastic.

20. A method of detecting a change in electrical properties in the environment outside of a conduit, the method comprising the steps of:

a. positioning an probe within the conduit, the probe comprising:

i. an RF signal generator;

ii. an RF signal detector;

iii. a controller controlling the signal generator and signal detector;

iv. a waveguide transmitting signals from the signal generator and to the signal detector;

v. a probe carriage capable of movement axially down the conduit and positioning the waveguide adjacent to the liner surface and moving the waveguide in a generally circumferential direction along the liner surface;

b. moving the waveguide along the liner surface;

c. transmitting an RF signal through the wave guide toward the liner surface;

d. measuring a reflected signal from the RF transmission;

e. analyzing the reflected signal to determine a change in at least one electro-magnetic property in a space behind the liner.

21. The method of claim 20, wherein the change of electro-magnetic properties is detected as the probe transitions from a location where soil is outside the conduit to a location where a void space is outside the conduit.

22. The method of claim 21, wherein the conduit is a gas line, a culvert, storm drain, or sewer pipe.

23. The method of claim 22 wherein the conduit is constructed primarily of a plastic, a thermoplastic, or a fiberglass reinforced plastic.

24. The method of claim 20, wherein the conduit is a plastic conduit placed to carry electrical cables or telecommunication cables.

25. The method of claim 20, wherein the change of electro-magnetic properties is detected related to a void, but a circumferential location of the void is not determined.

26. The method of claim 20, wherein the probe is initially positioned at an estimated location approximate an expected side connection prior to attempting a significant number of readings of surrounding conditions.

27. The method of claim 20, further taking a first series of circumferential readings at a first radial increment where the increment is equal to or less than a diameter of an expected side connection.

28. The method of claim 27, wherein once the approximate location of the side connection is detected, taking a second series of circumferential readings at a second radial increment smaller than the first radial increment.

29. The method of claim 11, further marking the location of a side connection by either, making a mechanical indention, burn mark using an electrically heated tip or marking with an ink, paint, or dye marking device.

30. The method of claim 29, further using a camera to align the cutting device with the mark and cutting through a liner within the conduit.

31. A conduit survey apparatus comprising:

a. a carriage capable of movement axially down the conduit;

b. an RF signal generator and an RF signal detector positioned on the carriage;

c. a controller controlling the signal generator and signal detector;

d. a waveguide with an open throat transmitting signals from the signal generator and directing received signals to the signal detector, and

e. a waveguide positioner mounted on the carrier and adapted to selectively engage an interior wall of the conduit, wherein the waveguide guide is connected to the positioner such that the open throat of the waveguide is within about 1 inch of the interior wall when the positioner engages the interior wall.

32. The conduit survey apparatus of claim 31 wherein the waveguide positioner is disc-shaped and both the waveguide positioner and the waveguide are positioned on an adapter body.

33. The conduit survey apparatus of claim 31 wherein the waveguide positioner comprises at least two rollers attached to the waveguide.

34. The conduit survey apparatus of claim 31 wherein a support arm extends from the carriage and an adapter body is positioned on the support arm, and wherein the RF signal generator, the RF signal detector, the controller, the waveguide, and the waveguide positioner mounted on the adapter body.

35. The conduit survey apparatus of claim 34 wherein a support arm is capable of moving the adapter body in a rotative direction relative to a conduit inner surface.

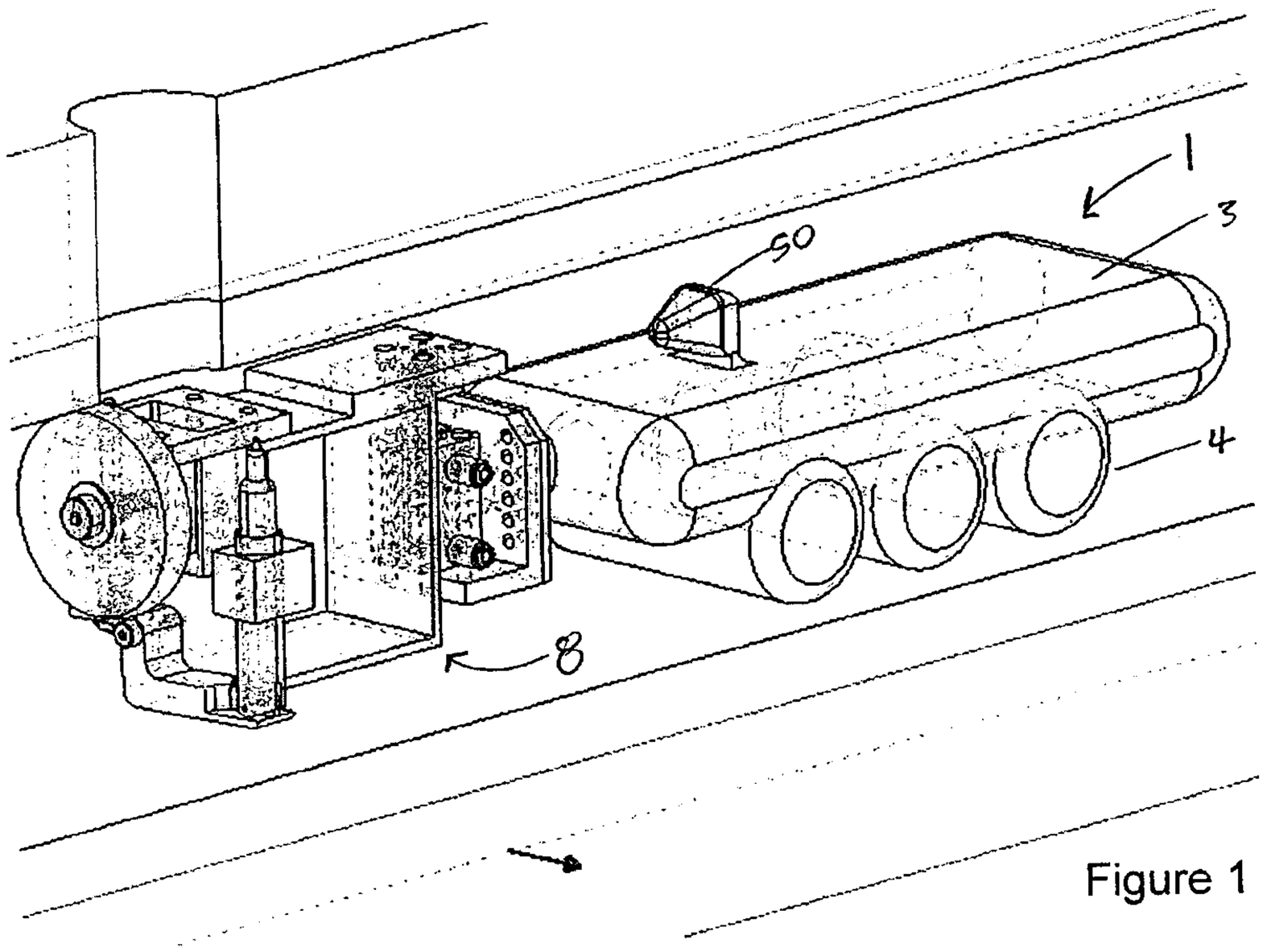


Figure 1

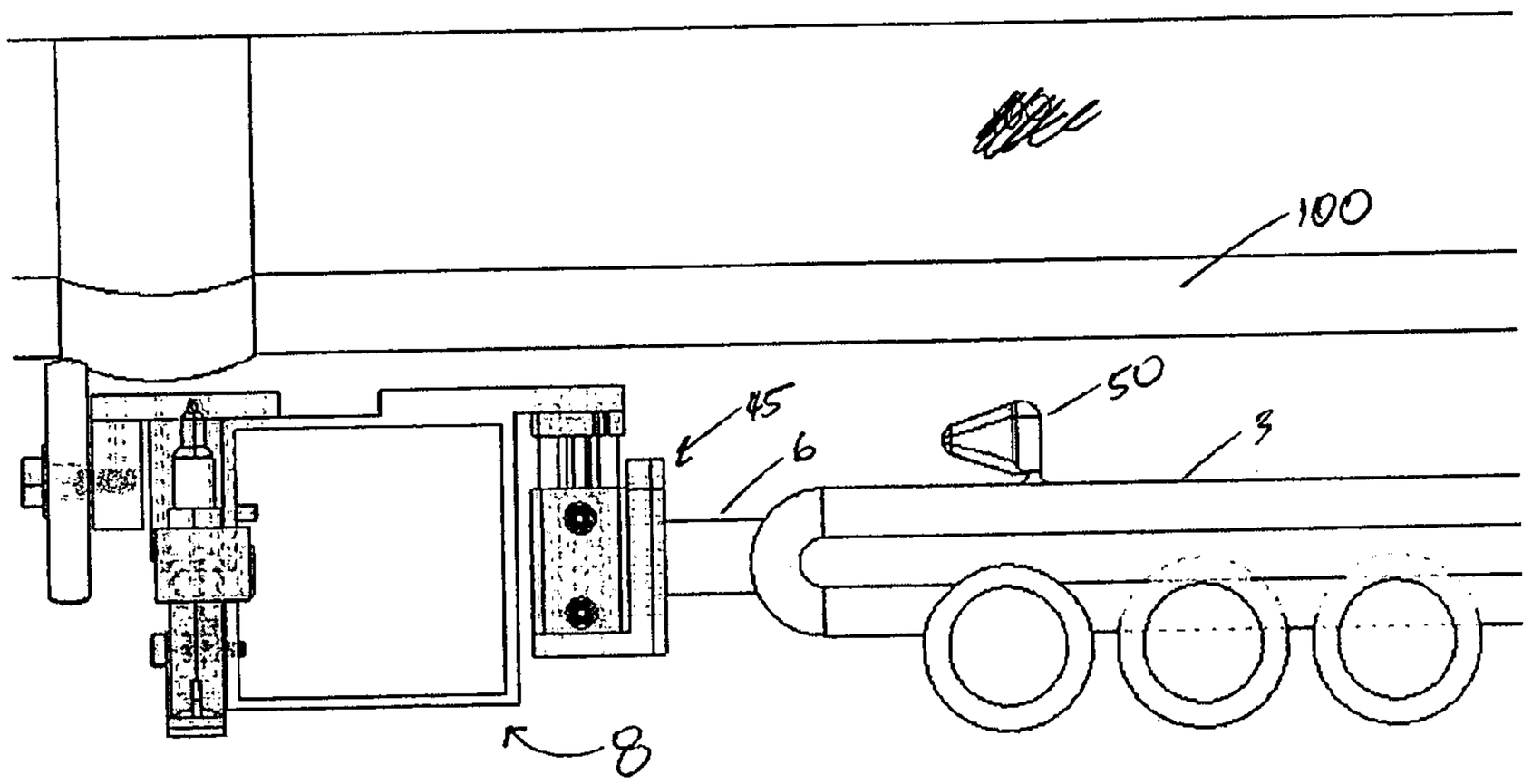


Figure 2

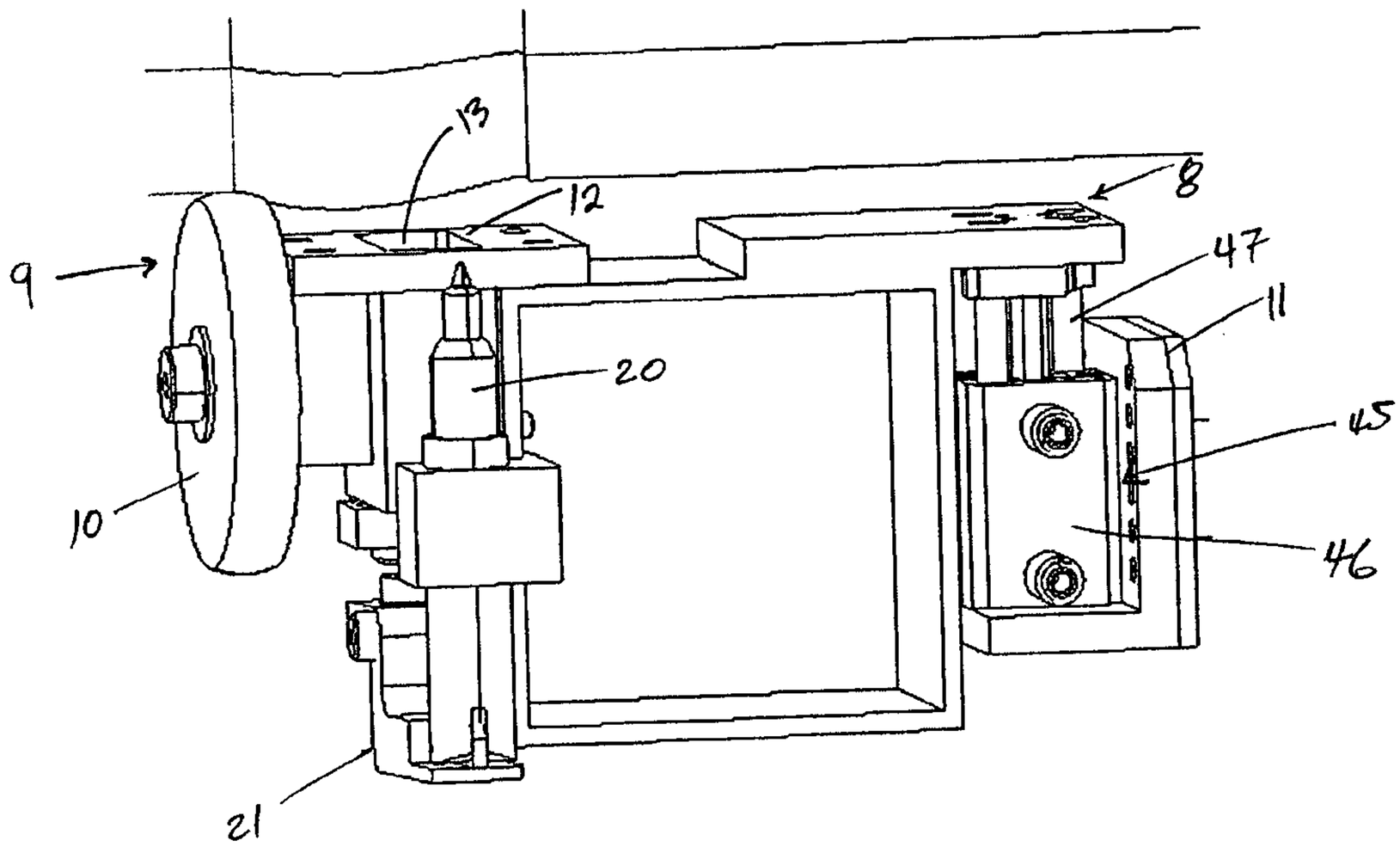


Figure 3

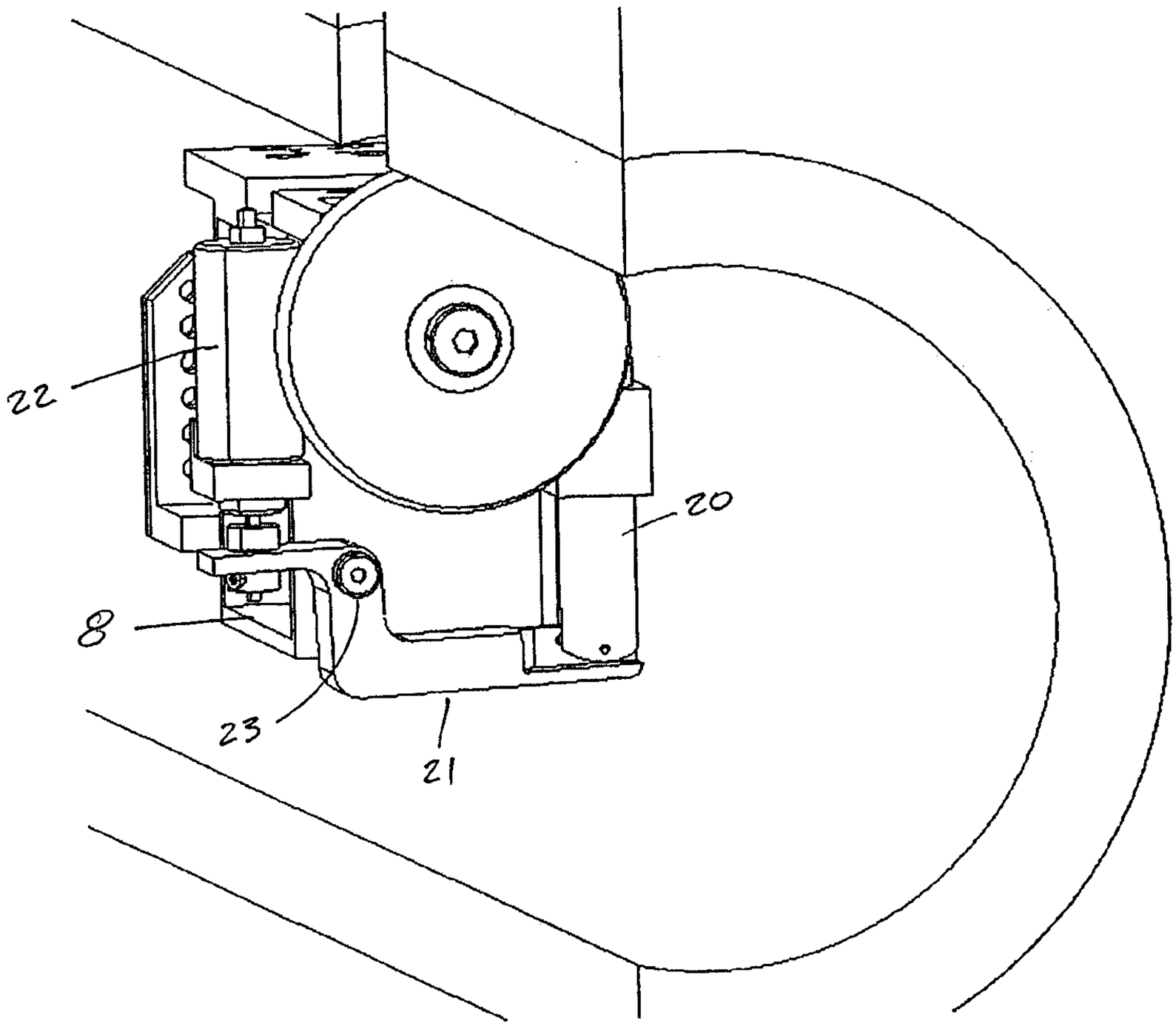


Figure 4

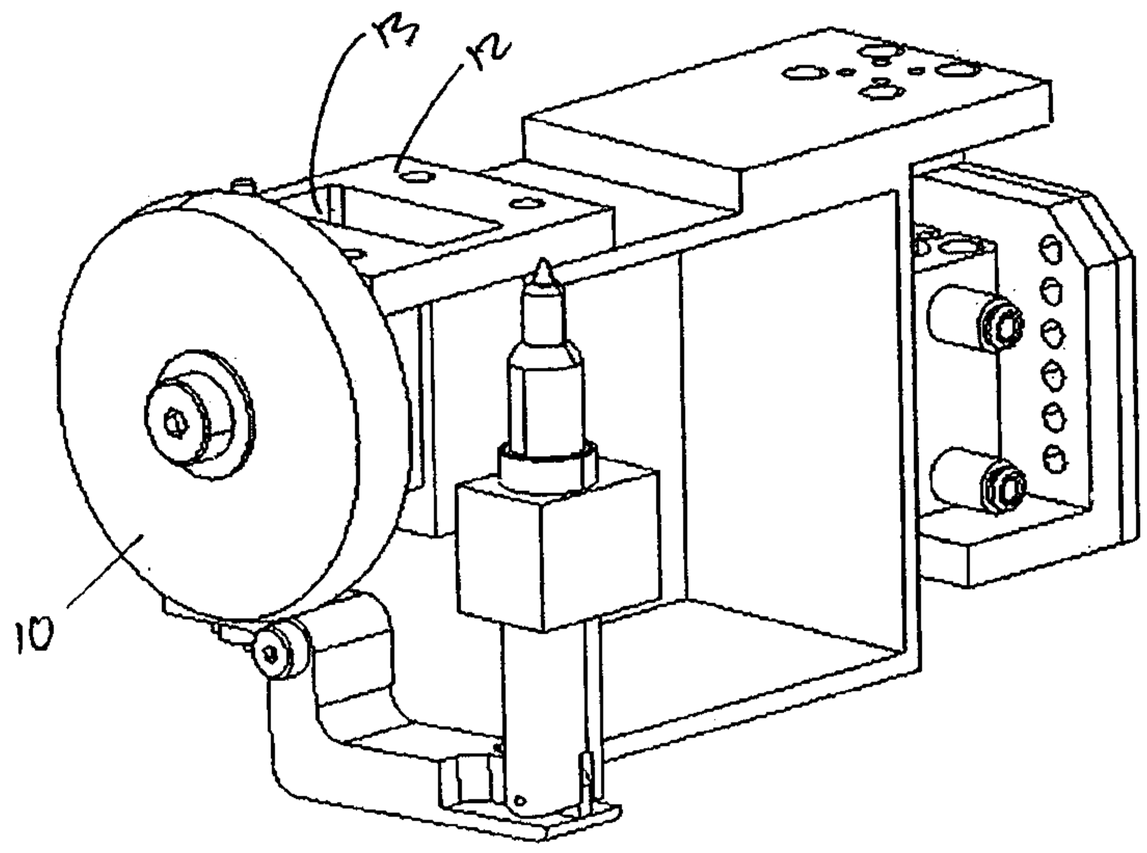


Figure 5

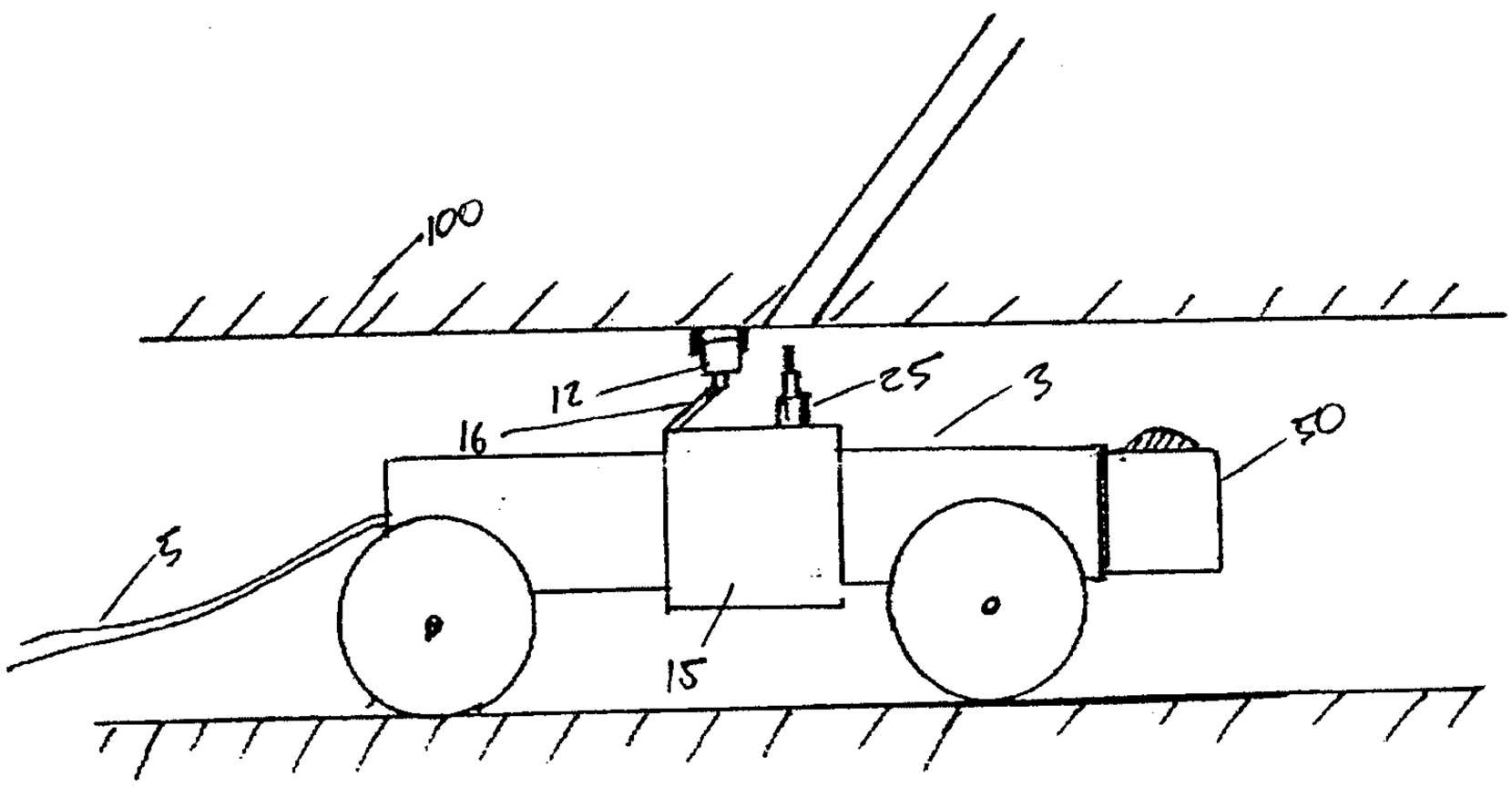


Figure 6

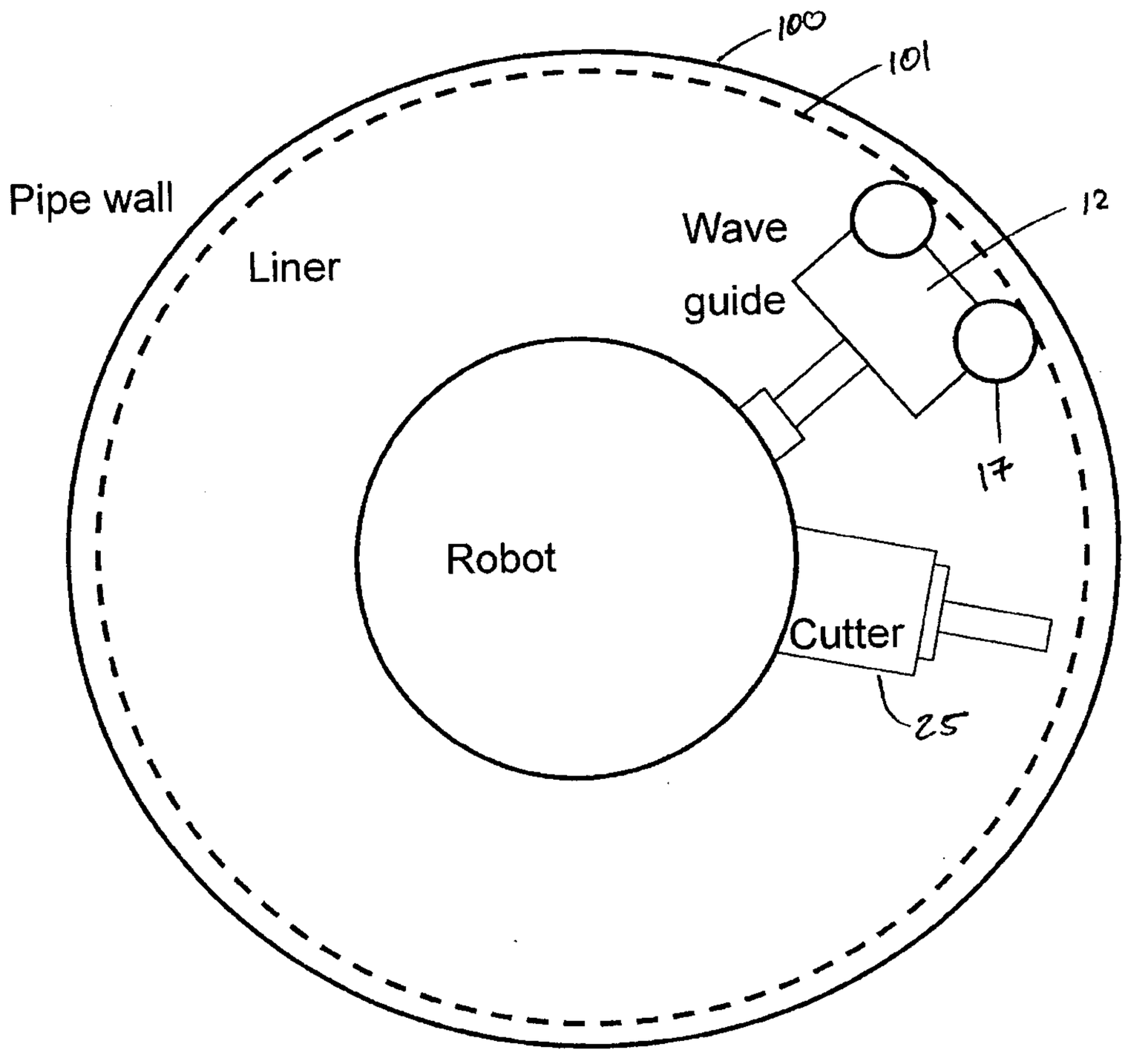


Figure 7

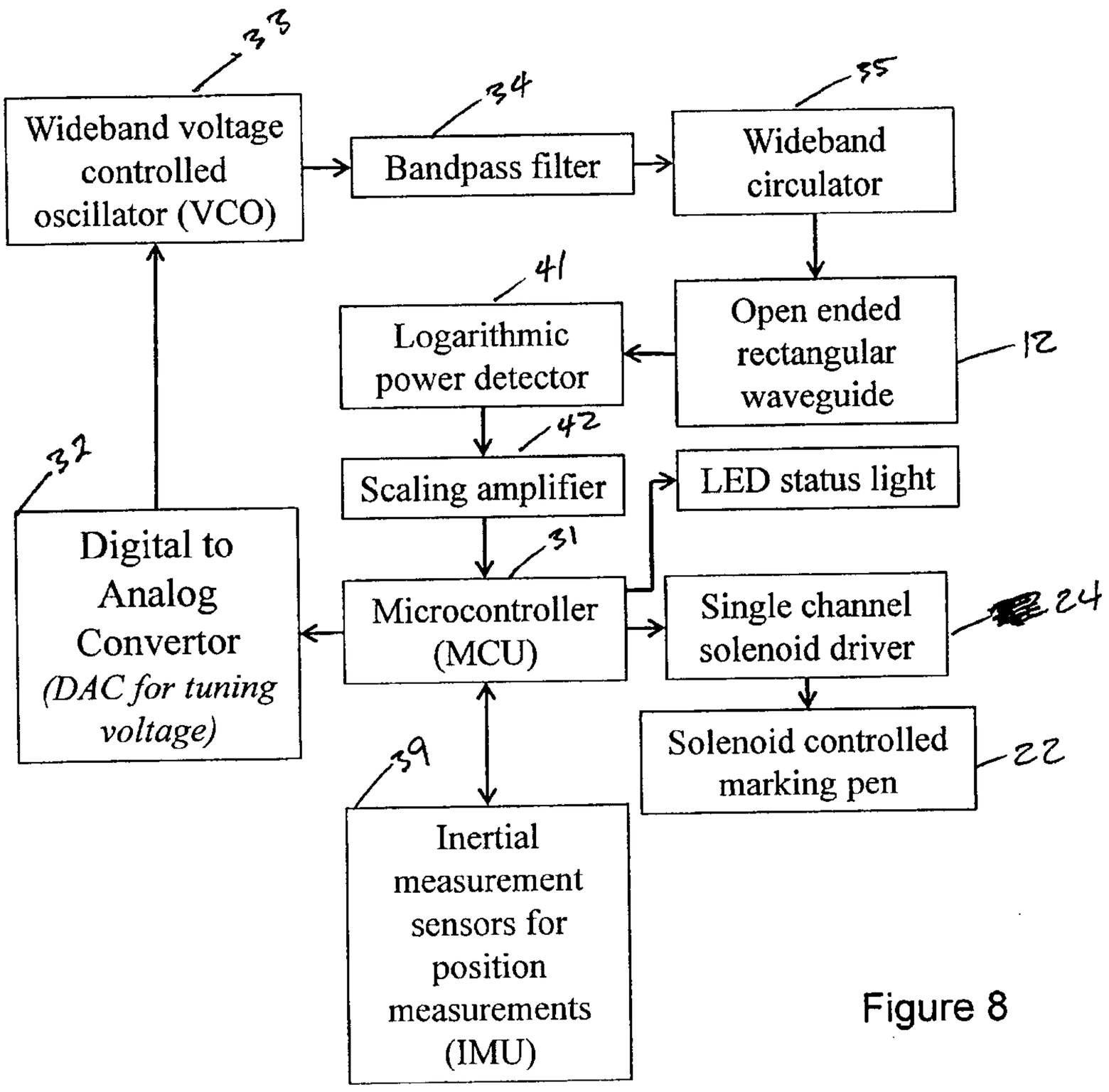
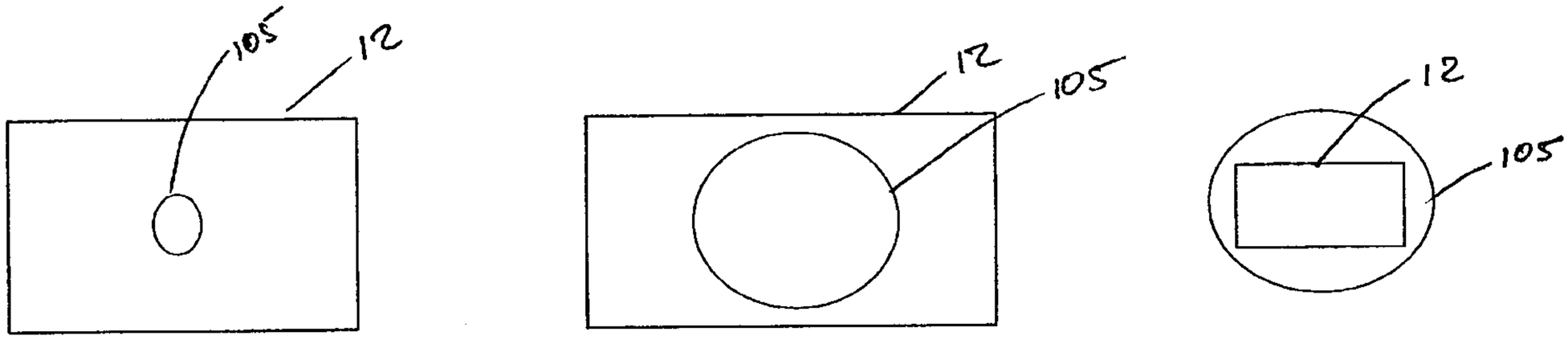
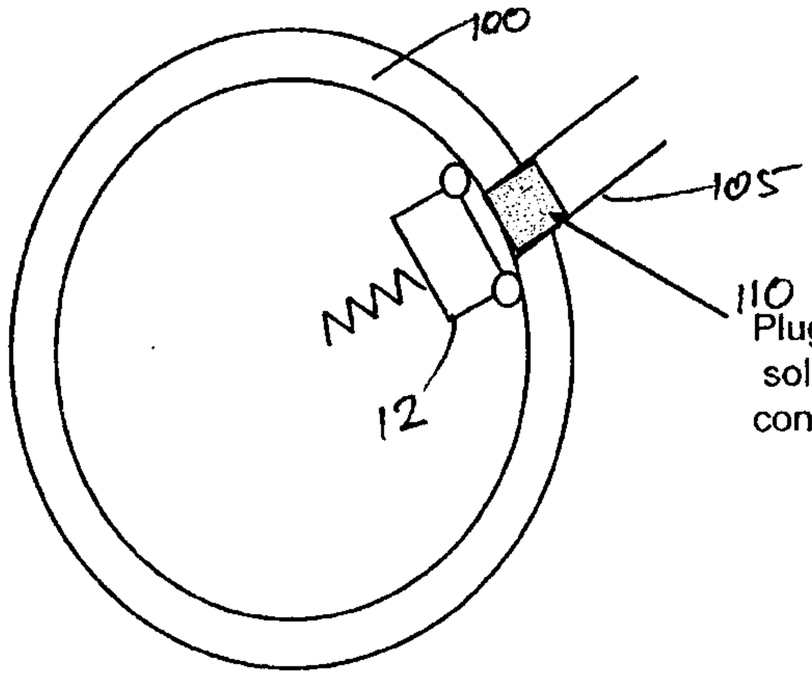

33
Wideband voltage controlled oscillator (VCO)
34
Bandpass filter
35
Wideband circulator
41
Logarithmic power detector
Open ended rectangular waveguide
12
42
Scaling amplifier
LED status light
32
Digital to Analog Convertor (DAC for tuning voltage)
31
Microcontroller (MCU)
Single channel solenoid driver
24
Solenoid controlled marking pen
22
39
Inertial measurement sensors for position measurements (IMU)

Figure 8



Figures 9A – 9C



Plug with contrast (liquid or solid with a high dielectric constant) conductive liquid

Figure 10

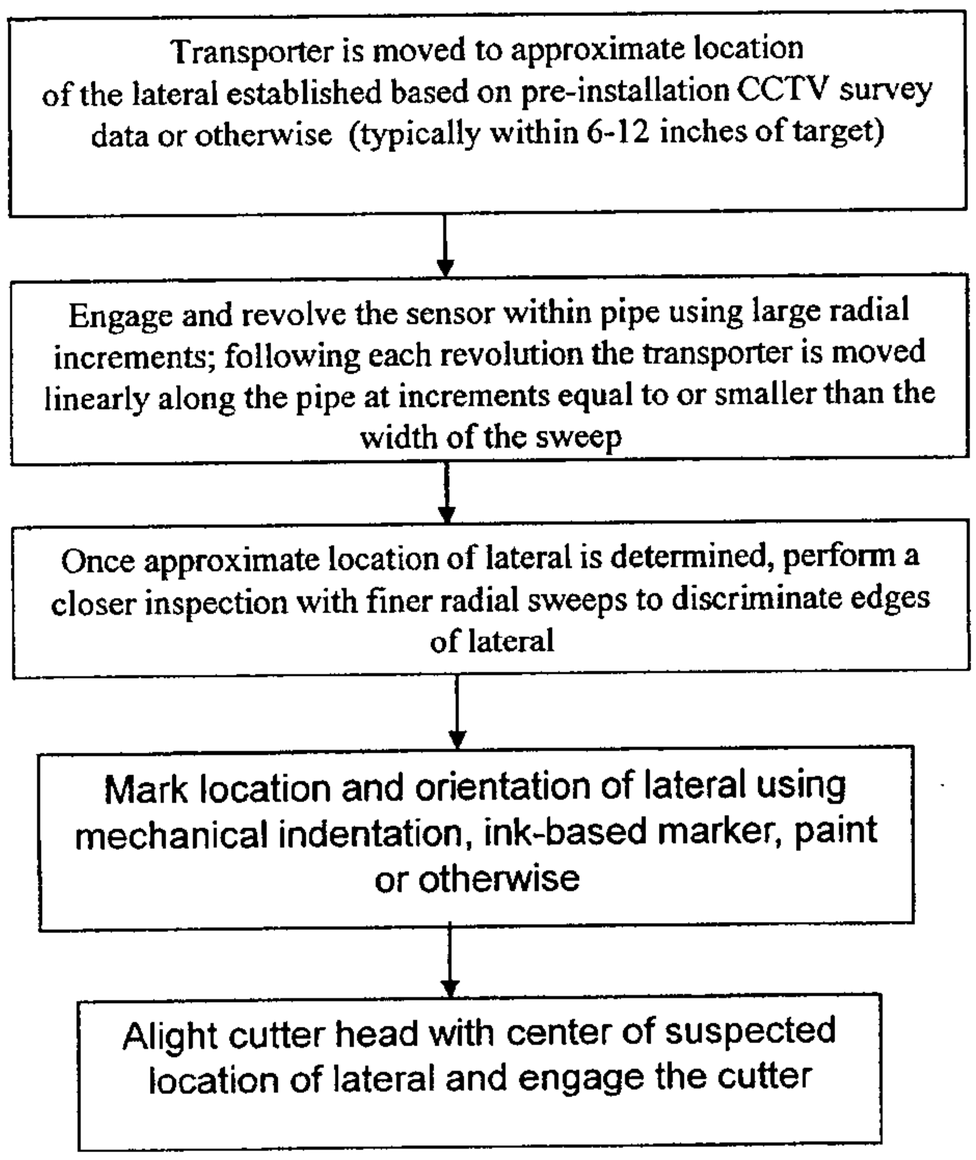
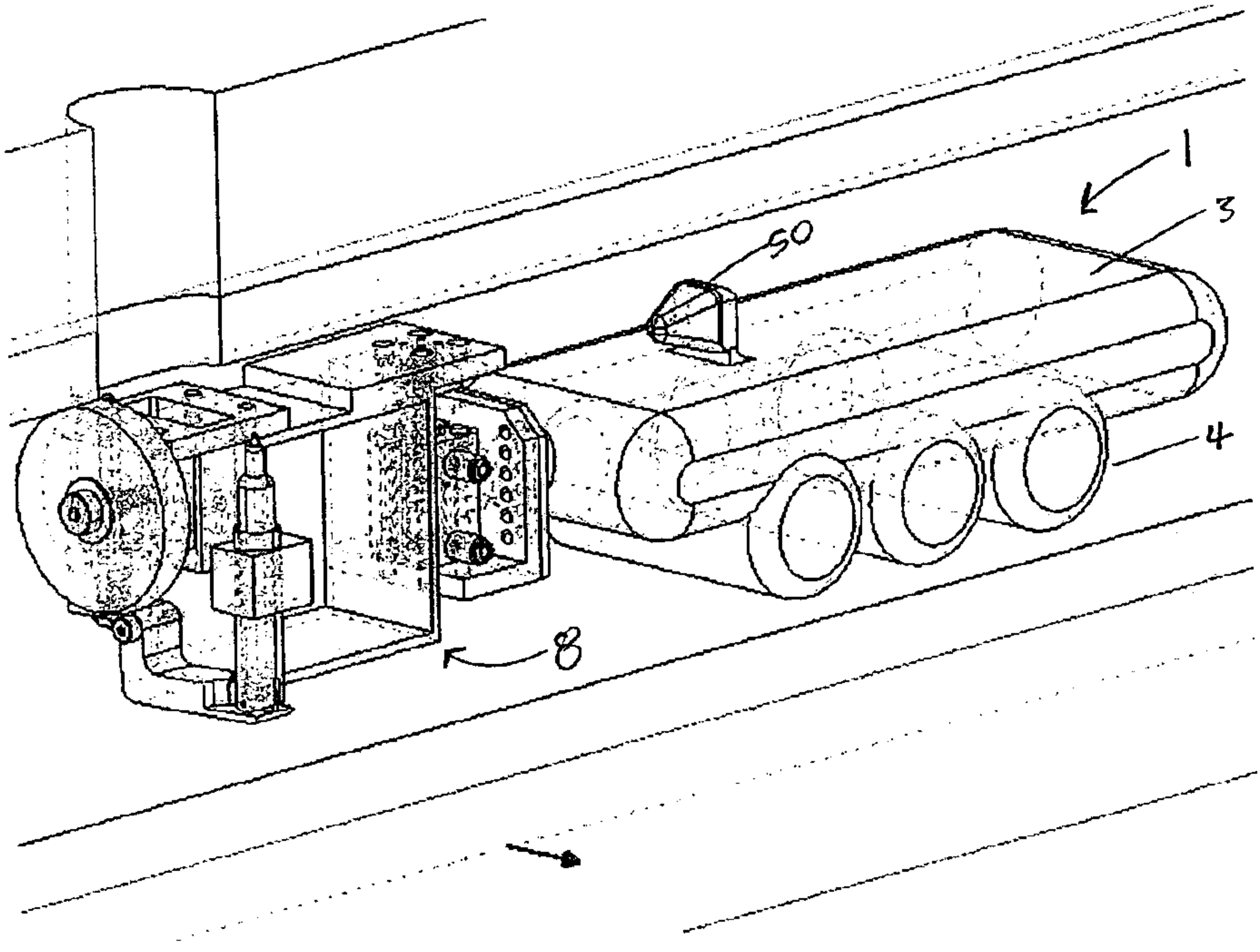

Transporter is moved to approximate location of the lateral established based on pre-installation CCTV survey data or otherwise (typically within 6-12 inches of target)
Engage and revolve the sensor within pipe using large radial increments; following each revolution the transporter is moved linearly along the pipe at increments equal to or smaller than the width of the sweep
Once approximate location of lateral is determined, perform a closer inspection with finer radial sweeps to discriminate edges of lateral
Mark location and orientation of lateral using mechanical indentation, ink-based marker, paint or otherwise
Alight cutter head with center of suspected location of lateral and engage the cutter

Figure 11


1
3
50
4
8