
Published: with international search report (Art. 21(3))

(54) Title: METHODS AND APPARATUS FOR LOCATING HIDDEN OR BURIED NON-CONDUCTIVE PIPES AND LEAKS THEREFROM

(57) Abstract: Methods and apparatus for locating a hidden/buried non-conductive fluid pipe (24) and leaks therefrom involve injecting a current signal (50) into fluid (26) in a hidden or buried non-conductive pipe and detecting the resulting induced magnetic field (18) to determine the location of the pipe and leaks therefrom according to the spatial variation of the intensity of the magnetic field. In one approach, a pulser (10) injects a plurality of individual electrical current pulses (50) directly into pipe water and the pulses can be returned to the pulser by a wire conductor independent from ground. A coil detector (11) senses the magnetic fields (18) created in the water in the pipe. Providing a current path through earth ground for leakage current due to water leaks in the water pipe (24) and utilizing a variable resistor (40) to control the amount of current returning to the pulser enhances leak detection.

FIG. 1
METHODS AND APPARATUS FOR LOCATING HIDDEN OR BURIED NON-
CONDUCTIVE PIPES AND LEAKS THEREFROM

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of U.S. Patent Application 13,174,552, the contents of which is hereby incorporated by reference herein in its entirety.

TECHNICAL FIELD

[0002] Embodiments relate to methods and apparatus for locating hidden or buried pipes and, more particularly, to methods and apparatus for locating non-conductive pipes, such as plastic water lines. Additionally, embodiments relate to methods and apparatus for detecting leaks in such non-conductive pipes.

BACKGROUND

[0003] Buried or hidden pipelines for distributing and removing fluids are a critical part of the infrastructure of society. Exact knowledge of their location, as well as any leaks in them, are crucial. Metallic pipes are relatively easy to locate but have largely been replaced by modern plastic pipes, such as PVC and ABS, since plastic pipe is more chemically inert, cheaper to produce, and easier to work with. Non-metallic pipes such as cementitious pipes are often used for waste water. Locating such pipelines and determining their integrity is currently problematic in applications such as old and new community water systems, RV parks, and mobile home parks, as well as in households with plastic pipes in the walls and floors.

[0004] Despite decades of research, locating these pipelines and any leaks in them remains problematic. Existing non-invasive solutions for locating non-metallic pipes include divining rods, acoustic detectors, and ground penetrating radars. None of these techniques are reliable for locating pipes or leaks, and some are prohibitively
expensive. Invasive techniques, such as insertion of foreign substances or equipment, are cumbersome and may pose health risks.

[0005] Acoustic detectors introduce an audio signal into the pipe and fluid, typically with a mechanical "thumper". The signal is detected above ground with a listening device. The thumpers can damage the pipe, the audio signals may only propagate short distances along the pipe, and the intervening material often attenuates so severely that detection is not possible. Ground-penetrating radar techniques are prohibitively expensive, and exhibit severe scattering in intervening medium.

[0006] Invasive techniques for pipe location require intrusion of the conduit. This intrusion is mechanically complicated and precautions are needed to mitigate health risks. Invasive location of leaks is typically performed by introducing a gas such as helium or nitrogen into the pipe, followed by detection at the surface using a "sniffer". This is expensive and unreliable, especially if deep snow or ice are present.

[0007] There is a need to provide an improved method and apparatus for locating hidden or buried non-conductive pipelines.

[0008] There is further a need to provide an improved method and apparatus for detecting leaks in hidden or buried non-conductive pipes.

SUMMARY OF THE INVENTION

[0009] The aforementioned aspects and other objectives and advantages can now be achieved as described herein.

[0010] According to one aspect, there is provided a method for locating a hidden or buried non-conductive fluid pipe. The method can comprise injecting a plurality of individual electrical current signal pulses into fluid in a hidden or buried non-conductive pipe; detecting a plurality of magnetic field pulses, induced by the
plurality of electrical current pulses, and emanating from fluid in the pipe; and
determining the location of the pipe according to the spatial variation of the intensity
of the magnetic field pulses.

[0011] In one embodiment, the hidden or buried non-conductive pipe is a water pipe,
such as plastic water pipe line.

[0012] The process of injecting a plurality of electrical current pulses into the fluid can
comprise injecting into the fluid a plurality of electrical current pulses having a
predetermined pulse repetition rate and/or predetermined pulse shape. In one non-
limiting example, the process of injecting into the fluid a plurality of electrical current
pulses can comprise injecting into the fluid a plurality of electrical current pulses
having a predetermined pulse repetition rate of about 1 to 10 Hertz. In another non-
limiting example, each pulse has a pulse duration of about 10-500 microseconds.

[0013] In one embodiment, the process of injecting the plurality of individual electrical
current signal pulses comprises providing an electrical current signal forward path,
independent from earth ground, from a signal terminal of the pulser to fluid in a first
end of the pipe, providing a current signal return path, independent from earth
ground, from fluid in a second end of the pipe back to a return terminal of the pulser;
injecting the plurality of individual electrical current signal pulses into the fluid via the
current signal forward path; and returning the plurality of electrical current signals
from the fluid to the pulser via the current signal return path.

[0014] The process of providing the current signal return path independent from the
earth ground can comprise electrically connecting a conductive return wire between
the fluid at the pipe second end and the pulser return terminal. In one non-limiting
example, electrically connecting the conductive wire between the fluid at the pipe
second end and the pulser comprises connecting one end of a connective wire to the
pulser; and either inserting the other end of the conductive return wire into the fluid
inside the second pipe end; or attaching the conductive return wire to a second
conductive member at the pipe second end, the second conductive member being in
physical contact with the fluid inside the pipe first end.

[0015] Alternatively, the process of injecting the plurality of individual electrical current signal pulses can comprise providing an electrical current signal forward path from the pulser to fluid in first end of the pipe, providing a current signal return path from fluid in a second end of the pipe back to the pulser; wherein either the forward current signal path or the return current signal path is via earth ground; injecting the plurality of individual electrical current signal pulses into the fluid via the current signal forward path; and returning the plurality of electrical current signals from the fluid to the pulser via the current signal return path.

[0016] The method can further comprise determining the location of at least one leak from the pipe according to the spatial variation of the intensity of the magnetic field pulses. In one embodiment, determining the location of at least one leak from the pipe according to the spatial variation of the intensity of the magnetic field pulses comprises: adjusting the amount of electrical resistance between earth ground and a return terminal of a pulser for injecting the plurality of individual electrical current pulses in order to control the current exiting the pipe through the at least one leak and returning to the pulser through earth ground; and determining a location at which the detected magnetic field pulse strength is substantially reduced or becomes undetectable as a result of reducing the current returning to the pulser to thereby determine the location of a fluid leak from the pipe.

[0017] The method can further comprise detecting a hidden or buried conductive fitting or valve, carried on the pipe and in electrical contact with the pipe fluid inside the pipe, according to the detected spatial variation in the magnetic field.

[0018] In one embodiment, the process of injecting the plurality of electrical current signal pulses into the fluid comprises providing a pulser for applying high voltage pulses; applying the plurality of high voltage signal pulses from the pulser across the pipe fluid extending between the pipe ends.
According to another aspect, there is provided a method for locating a hidden or buried non-conductive fluid pipe. The method can comprise: providing an electrical current signal forward path, independent from earth ground, from a power supply to fluid in a first end of a hidden or buried non-conductive pipe, providing a current signal return path, independent from earth ground, from fluid in a second end of the pipe back to the power supply; injecting an electrical current into the pipe fluid via the current signal forward path; returning the electrical current from the fluid to the power supply via the current signal return path; detecting a magnetic field induced by the electrical current and emanating from fluid in the pipe; and determining the location of the pipe according to the spatial variation of the intensity of the magnetic field.

In one embodiment, the process of injecting the electrical current into the pipe fluid comprises injecting a plurality of individual electrical current pulses from a pulser to the pipe fluid via the current signal forward path; and wherein returning the electrical current from the fluid to the power supply comprises returning the plurality of electrical current pulses from the pipe fluid to the pulser via the current signal return path.

According to yet another aspect, there is provided a pipe locator apparatus for locating a hidden or buried non-conductive pipe. The apparatus can comprise a pulser for injecting a plurality of individual electrical current signal pulses into fluid in a hidden or buried non-conductive pipe; and a detector for detecting a plurality of magnetic field pulses, induced by the plurality of electrical current pulses, and emanating from the fluid in the pipe; whereby, in use, operation of the pulser injects the plurality of electrical current pulses into fluid in the pipe, and whereby movement of the detector over a surface area in the vicinity of the pipe detects the corresponding magnetic field pulses emanating from the pipe fluid, and the spatial variation of the intensities of the magnetic field pulses, to indicate the location of the hidden or buried pipe and/or the location of a leak in the pipe.

The pulser can be configured to inject into the fluid a plurality of electrical
current pulses having a predetermined pulse repetition rate and/or predetermined pulse shape. In one non-limiting example, the pulser is configured to inject into the fluid a plurality of electrical current pulses comprises having a predetermined pulse repetition rate of about 1 to 10 Hertz. Also in one non-limiting example, the pulser is configured to inject a plurality of electrical current pulses each having a pulse duration in about the 10 to 500 microsecond range.

[0023] In one embodiment, the apparatus further comprises an electrical current signal forward path from the pulser to fluid in a first end of the pipe, the electrical current signal forward path being independent from earth ground; an electrical current signal return path from fluid in a second end of the pipe back to the pulser; the electrical current signal return path being independent from earth ground; and wherein the pulser is configured to inject the plurality of individual electrical current signal pulses into the fluid via the current signal forward path and return the plurality of electrical current signals from the fluid to the pulser via the current signal return path.

[0024] The apparatus can further comprise a variable resistor device operably coupled between the pulser and earth ground for adjusting the amount of electrical resistance between the pulser and earth ground to control the current exiting the pipe through the at least one leak and returning to the pulser through earth ground; whereby, in use, adjusting the variable resistor device to reduce the current returning to the pulser results in the detected magnetic field pulse intensities being greatly reduced or becoming undetectable at a location of the at least one fluid leak.

[0025] In one embodiment, pulser is a portable battery powered pulser and/or the detector is a battery powered portable detector.

[0026] According to yet another aspect, there is provided a pulser for use in locating a hidden or buried non-conductive pipe. The pulser can be configured for injecting a plurality of individual electrical current signal pulses into fluid in the hidden or buried non-conductive pipe. The pulser can have features similar to the pulser of the
aforementioned pipe locator.

[0027] According to yet another aspect, there is provided a detector for use in locating a hidden or buried non-conductive pipe. The detector can be configured for detecting a plurality of magnetic field pulses, induced by a plurality of electrical current pulses, and emanating from said fluid in said pipe. The detector can have features similar to the detector of the aforementioned pipe locator apparatus.

**BRIEF DESCRIPTION OF THE DRAWINGS**

[0028] A complete understanding of the present invention may be obtained by reference to the accompanying drawings, when considered in conjunction with the subsequent, detailed description, in which:

[0029] FIG. 1 is an illustration of a apparatus for locating a hidden or buried non-conductive pipe line according to one embodiment;

[0030] FIG. 2 illustrates exemplary signals at different stages of signal processing in the receiver of the apparatus of FIG. 1;

[0031] FIG. 3 illustrates a flow chart of a method for locating a hidden or buried non-conductive pipe according to one embodiment;

[0032] FIG. 4 is an illustration of a apparatus for locating a hidden or buried non-conductive pipe line and leak therefrom according to another embodiment; and

[0033] FIG. 5 is a method for locating a leak from a hidden or buried non-conductive pipe according to one embodiment;

[0034] FIG. 6 is an example of a pulser of the apparatus of FIG. 1 according to one embodiment; and
[0035] FIG. 7 is an example of a receiver of the apparatus of FIG. 1 according to one embodiment.

[0036] For purposes of clarity and brevity, like elements and components will bear the same designations and numbering throughout the Figures.

DETAILED DESCRIPTION

[0037] In the following description, for purposes of explanation and not limitation, specific details are set forth, such as particular embodiments, procedures, techniques, etc. in order to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the present invention may be practiced in other embodiments that depart from these specific details.

[0038] Technical features of this application can be used to construct methods and apparatus for locating hidden or buried non-conductive pipes and/or leaks therefrom. In one approach, location of a hidden or buried non-conductive fluid pipe and/or a leak therefrom is achieved by injecting a plurality of individual electrical current signal pulses into fluid, such as water, in a hidden or buried non-conductive pipe and detecting the magnetic field pulses induced by the electrical current pulses and emanating from fluid in the pipe. The location of the pipe and/or the location of the leak in the pipe is determined according to the spatial variation of the intensity of the magnetic field pulses.

[0039] For example, in one non-limiting approach, there is provided a portable apparatus for locating hidden or buried water lines by the use of a high voltage pulser, an inductive coil detector, an amplifier, and an indicator, such as a light emitting diode indicator. The high voltage pulser injects a high voltage pulse directly onto a conductive fitting in contact with the water in the pipe. The coil detector senses the magnetic fields created in the water in the pipe. The amplifier amplifies
the voltages created by the inductive coil detector and the indicator indicates the presence of pulsed magnetic fields in the water created by the pulsed currents injected in the water by the high voltage pulser. In one non-limiting example, a variable resistor, such as a potentiometer, and a ground rod are provided as a means of regulating the pulsed current leakage from water leaks to earth ground so leaks in the pipe can be detected. In another non-limiting example, a ground return of signals in the apparatus is independent from ground (for example a hard wired ground return) and improves the efficiency of the locating apparatus by reducing the loading effect of the water line capacitance to ground, on the high voltage pulser.

[0040] An apparatus for locating a non-conductive hidden or buried pipe and leak therefrom according to one embodiment will now be described with reference to FIG. 1 of the accompanying drawings. Apparatus 1 has a pulser 10 and a receiver 12. Pulser 10 is configured to inject individual pulses 50 of electrical current through fluid 26 in a hidden or buried non-conductive pipe 24 in order to induce corresponding magnetic field pulses that emanate from fluid 26 along pipe 24. Note that whilst in the embodiment of the apparatus of FIG. 1, individual electrical current signal pulses are provided by pulser 10, in an alternative embodiment, a continuous electrical current signal may be injected into the pipe fluid by a power supply other than that of a pulser.

[0041] Receiver 12 is configured to sense magnetic fields and distinguish therefrom the emanating magnetic field pulses caused by the injected electrical current pulses. Location of pipe 24 is determined from the variation in the intensity or strength of the detected magnetic field pulses as a function of the position of a detector 11 of the receiver 12 in the vicinity of the pipe. Pulser 10 is conductively coupled to both ends 30,31 of a section of pipe 24 in a manner that provides a reliable and efficient current path from pulser 10 through pipe fluid 26 along pipe 24 and back to pulser 10. In the embodiment of apparatus 1 of FIG. 1, a loop current signal path is provided that is independent from earth ground for allowing the current signal to flow from pulser 10, through pipe fluid extending from pipe first end 30 to pipe second end 31, remote from pipe end 30, and return back to pulser 10.
In the embodiment of apparatus 1 of FIG. 1, pulser 10 and receiver 12 are operated above ground 25 (the earth) and the non-conductive pipe 24 is buried in the ground. However, pipe 24 may be buried in or hidden behind other materials such that it is substantially concealed from view. By way of non-limiting example, pipe 24 may be hidden or buried to the extent that a wall covers the pipe or the pipe is located underneath the floor of a building or other type of structure. Non-conductive pipe 24 is fabricated from a non-conductive material such as a plastic, concrete, cement or other material. Furthermore, in the non-limiting example of FIG. 1, pipe 24 is a water pipe used to pipe substantially pure water, such as tap water, which has a low electrical conductivity and which has not been electrically enhanced by adding electrolytes or mixing the water with conductive fluid etc. However, pipe 24 may be configured to pipe other types of fluid 26. For example, fluid 26 may be oil, sewage, water or oil based solutions etc, or other liquids or fluids that have a higher or lower conductivity than water.

In order to provide the loop current path that is independent from earth ground, an electrical current signal forward path 13 is formed for electrical current to flow independent from earth ground between a signal terminal of pulser 10 and fluid located inside pipe first end 30. An electrical current signal return path 16 is formed for electrical current to flow independent from earth ground between fluid located inside pipe second end 31 and a return terminal of pulser 10.

In FIG. 1, the electrical current signal forward path is provided by a first conductive electrical connection, such as a conductive signal wire, interconnecting the pulser signal terminal and a first electrically conductive member 14 without relying on a connection through earth ground. Member 14 is located at pipe first end 30 and in physical contact with pipe fluid 26 inside end 30. Alternatively, first conductive electrical connection is formed by inserting a distal end of the signal wire of pulser 10 into the fluid located inside pipe first end 30. In FIG. 1, electrical current signal return path 16 is provided by a second electrical connection, such as a conductive return wire, interconnecting the pulser return terminal and a second electrically conductive member 15 without relying on a connection through earth ground. Member 15 is located at pipe second end 31 and in physical contact with
pipe fluid 26 inside second end 31. Alternatively, second conductive electrical
connection is formed by inserting a distal end of the return signal wire of pulser 10
into fluid located inside pipe second end 31.

[0045] First conductive member 14 and/or second conductive member 15 may be
already present in the pipe apparatus or made to fit the system. One or both of first
and second conductive members 14, 15 can be for example an electrode inserted in
the pipe end such that the electrode is in physical contact with pipe fluid 26, or can
be a conductive fitting carried on the pipe end with or without electrodes carried
thereon. Non-limiting examples of such conductive fittings are metal pipe valves,
metal pipe connectors, and pipe flow meters etc.

[0046] One or both of the electrical current forward and return paths 13, 16 are
electrically isolated from earth ground depending on the pipe apparatus configuration
and ease of isolation. In FIG.1, both pipe ends 30,31 and first and second
conductive members 14,15 are initially located under ground. If the first conductive
connection is not already isolated from Earth ground, the earth around the first
conductive member 14 and pipe first end 30 can be excavated. In another non-
limiting application example, pipe first and second ends 30, 31 together with first and
second conductive members 14, 15 are initially already visible and isolated from
ground so that excavation of the earth to isolate the connections is unnecessary.

[0047] Turning now to pulser 10 in more detail, pulser 10 is configured to generate
an electrical current signal in the water along the pipe. The electrical current signal is
an on/off type signal, such as a series of individual pulses spaced apart in time, or a
chopped continuous signal. In FIG. 1, pulser 10 has a power supply source that
produces periodic electrical pulses.

[0048] FIG. 6 illustrates the primary components of pulser 10 according to one non-
limiting example. Pulser 10 has a timer 60, electronic switch 61, and battery 62 all of
which are operably coupled to a high voltage transformer 63. In the non-limiting
example of FIG. 1, the pulser 10 is a high voltage battery powered portable pulser.
Pulser 10 is configured to generate voltage pulses that repeat at low rates. The high
voltage pulses generated by the pulser of FIG. 1 are unipolar. The electrical power in fluid 26 can exceed kilowatts and poses a serious safety problem with continuous alternating cycle voltages/currents. The repetition rate may for example be about 1-100 Hertz. The pulse duration may for example be in the 10 to 500 microsecond range. By adopting unipolar voltage pulses at repetition rates of a few Hertz, power is reduced significantly (for example 1000x), to non-lethal levels. For example, the pulses can repeat at 3 to 4 hertz. This also allows the use of batteries as a power source, making the apparatus hand-portable.

[0049] The characteristics of the high voltage pulses are predetermined. For example, pulser 10 can be configured to produce a periodic electrical pulse of up to about 30 kV at a rate of 3 hertz and a pulse duration of about 100 microseconds. These predetermined high voltage pulses are introduced into water 26. The introduced voltage pulses produce corresponding electrical current pulses 50 in water 26, which in turn, induce magnetic field pulses that can be detected by receiver 12 that is located above the ground surface.

[0050] Referring now to receiver 12 in more detail, receiver 12 is a portable battery powered receiver including a detector that detects magnetic fields. FIG. 7 illustrates the primary components of the receiver 12 according to one embodiment. Receiver 12 has a coil detector 11, and an amplifier 70 and indicator 17 operably coupled to the coil detector. In the non-limiting example of the apparatus of FIG. 1, the surface magnetic field is typically sensed with an inductive search coil 11. The sensitivity of receiver 12 using a search coil 11 increases with frequency, but signal attenuation in the intervening soil also increases. As explained in more detail below, electrical current pulses 50 in water 26 are designed to maximize detection sensitivity while keeping soil attenuation negligible.

[0051] Receiver 12 has an amplifier that amplifies electrical voltage pulses produced in the search coil 11. FIGS. 2A-2C illustrate exemplary sensed signals at different stages of signal processing by receiver 12. Signals at the receiver 12 not only contain the magnetic pulses 18 as detected by the search coil 11 but also contain
interfering signals from power lines and communication lines, common in all communities. Such signals sensed by search coil 11, including signal 18 representing a magnetic field pulse induced by current pulse 50, are shown in FIG. 2A as a sine wave and variable duration square wave bursts, respectively. The signals include unwanted interference signals resulting from power lines and communication signals. The power line signal is 60 Hz. The communication signal bursts contain high frequency (greater than 1 MHz) signals that for the sake of clarity are not shown in Fig. 2A and Fig. 2B. The signals sensed by search coil 11 are amplified in the receiver amplifier and rectified by a diode. The resulting amplified and rectified signals including signal 19 corresponding to the magnetic field pulse are depicted in FIG. 2B. The filtered signal 20 after an offset adjustment in the amplifier represents the magnetic field pulse induced by the pulser (see FIG. 2C). Receiver 12 has an indicator 17 that indicates the presence of the magnetic field pulses. In the non-limiting example of the apparatus of FIG. 1, indicator 17 is an LED indicator. Other indicators, such as an audible indicator or LCD displays may be adopted instead of the LED. Circuitry of receiver 12 is configured to cause the LED to flash each time a magnetic field pulse is detected by the receiver. Alternatively, the circuitry can be configured to trigger the indicator to indicate the location of the pipe as a result of the circuitry determining the spatial variation in magnetic field strength due to the pipe being detected.

[0052] Receiver 12 detects the magnetic fields emanating from the water, amplifies the voltages produced up to about 10^6 times, and indicates the presence of the pulsed magnetic fields. The currents through water 26, large enough to create detectable magnetic fields, can range from about 10 - 60 milliamperes depending on the resistively of water 26 and length and diameter of pipe 24.

[0053] In one non-limiting example of the apparatus of FIG. 1, high voltage pulser 10 produces a pulse of up to 30 kV that is connected to the water in the pipe. The initial pulse is created and timed with a digital timer circuit which triggers a 600 Volt solid state relay causing a current from a battery to flow through the primary of an autotransformer for 10 milliseconds at 3 Hertz. The interruption of the primary current at the end of the trigger pulse causes a primary voltage pulse of 600 volts across
primary windings. The voltage pulse across the primary windings causes a
delayed secondary winding pulse voltage of up to 30 kilovolts, which is injected into the water
in the plastic pipe by the connection to a conductive member in contact with the
water. The secondary voltage pulse induces a pulsed current shown schematically
on FIG. 1 as a current pulse 50 that travels through water 26 creating the pulsed
magnetic field. The capacitive currents allowed by the significant capacitance 28
between water 26 in pipe 24 and earth ground 25 can be more than ten times higher
than the currents through water 26 so using a wire return increases pulse current
through the water line and reduces loading on the high voltage pulser 10.

[0054] By way of another non-limiting example, the high voltage pulser 10 produces
periodic electrical pulses of up to 30 kilovolts at a rate of 3 Hertz, and pulse durations
of about 100 microseconds. These voltage pulses are introduced into the water pipe
24 with an electrode that is present in the piping apparatus or one made to fit the
system. These voltage pulses produce current pulses in the water that produce
magnetic fields that can be detected by the receiver amplifier 12. The pulse voltages
are sufficient to produce current pulses with detectable magnetic fields in water
pipelines more than 1,000 feet long. The current pulses propagating along the line
are low frequency, with a center frequency of about 3.5 kiloHertz, and narrow band,
with a bandwidth of about 30 Hertz. The low frequency content and narrow
bandwidth ensure efficient magnetic signal propagation through the soil. Further, the
pulse frequency is maximally separated from the 60 Hz power line and the high
frequency communication line interfering signals. The pulsed magnetic fields are
detected on either side of the buried line and a loss of signal is apparent directly over
the line.

[0055] Reference will now be made to a method 300 for locating a hidden or buried
non-conductive pipe according to one embodiment. Method 300 will be described in
more detail with reference to an implementation in the apparatus 1 of FIG. 1. FIG. 3
depicts a flow chart outlining method 300.

[0056] A pulser 10 is provided (301). Forward and return electrical current signal
paths between the pulser and pipe fluid are provided. For example forward and
return electrical current signal paths are provided independent from earth ground (302), as already described above with reference to FIG. 1. Individual electrical current pulses with predetermined characteristics are injected by pulser 10 into the pipe fluid (303) to induce current pulses 50 in pipe fluid. Examples of such predetermined pulse characteristics are described above with reference to apparatus 1 of FIG. 1. Injection of the electrical current pulses can be achieved for example by applying high voltage pulses as described above with reference to FIG. 1. Magnetic fields in vicinity of pipe are sensed by the receiver 12 (304). To this end, coil 11 is maneuvered over the surface of the ground in the suspected location of the pipe and detects magnetic fields including the magnetic field pulses induced by the pulser. Receiver 12 distinguishes magnetic field pulses induced by current pulses 50 in pipe fluid 26 (305). This is achieved by the receiver signal processing for example in the manner described above with reference to apparatus 1. Intensity of magnetic field pulses is for example indicated by receiver 12. The presence of each of the magnetic field pulses induced by the pulser can for example be indicated by a flash of the receiver LED and the strength or intensity of each magnetic field pulse indicated by a corresponding LED brightness. The receiver detector is maneuvered to detect spatial variation in intensity of magnetic field pulses (306). The pipe location is determined according to spatial variation in intensity of magnetic field pulses (307). The location of the pipe is determined by maneuvering the receiver search coil. The intensity of the magnetic pulses increases as the pipe location is approached. For location of the pipe, the pulsed magnetic fields are detected on either side of the buried line and the signal is either a null or a maximum, (depending on the search coil axis orientation) directly over the line.

[0057] The spatial variation in magnetic field signal pulses that is indicative of the presence of the pipe may be detected manually by the user viewing the indications of magnetic field intensities on the detector. Alternatively or additionally, circuitry in the detector can be configured to determine if there is a spatial variation in magnetic field signal pulses indicative of the presence of the pipe and to trigger the indicator when such determination is made by the circuitry.
In an alternative embodiment, method 300 may be implemented using a continuous electrical current signal rather than individual pulses.

By adopting electrical current signal forward and return paths 13, 16 independent from earth ground, all electrical currents contribute to the magnetic field. There is no surface magnetic field if the pipe is buried to the depth of the Earth ground return current, since the currents cancel (exactly equal, in opposite directions). Further, the fluid conducts electrical current in both directions away from the point where voltage is applied. If the pipeline contains branches (e.g., residential water distribution pipes), electric current flows in all branches so that apparatus 1 can be utilized to detect pipe branches and leaks therefrom. The current in any direction or branch is determined by the resistance to Earth return in that direction or branch. If the pipe resides in the ground plane, or if it is desired to locate pipe in a particular direction or branch, the return current path provided by the wire return makes location possible.

Furthermore, providing current signal forward and return paths independent from earth ground allows waste current from capacitive coupling to be eliminated and the current path to be controlled. Providing a full, reliable electrical current signal loop path from pulser to pipe fluid and back to pulser in this manner allows location of the pipeline in branched fluid distribution apparatus with maximal detection sensitivity.

An apparatus 100 for locating hidden or buried non-conductive pipes and leaks according to an alternative embodiment is illustrated in FIG. 4. Apparatus 100 has current return path provided through earth ground connection from the second conductive member 15 back to pulser 10 via a variable resistor device 40, such as for example a potentiometer. In the example of FIG. 4, second conductive member 15 is a metal or other conductive pipe fitting such as a pipe valve or meter, or an electrode, already carried on or located at the buried pipe second end and in contact with earth ground. However, the second conductive member 15 can alternatively be
electrically connected to earth ground via a ground rod or other device
interconnecting the second member and earth ground.

[0062] Method 300 of FIG. 3 can be implemented in the apparatus 100 according to
one embodiment wherein in process 302, the return electrical current signal path
provided between the pulser and pipe fluid (302) is via earth ground.

[0063] In the event of a leak from the pipe, the reduction in electric current in the fluid
past the leak may be partial to full. If the leak only partially reduces the continuing
electric current, the reduction of magnetic signature signals the leak and the
continuing current allows further location of the pipe past the leak. In the case of full
reduction, the magnetic signal beyond the leak disappears, the leak is located, and a
new electrical connection to the fluid must be made for location of the pipe beyond
the leak. The electrical current and associated magnetic field expand in area around
the leak location and, if detectable, the sensed area indicates the severity of the
leak.

[0064] Apparatus 100 has a leak detecting feature to enable a more efficient location
of a leak 27 from the buried pipe. The variable resistance device 40 is configured to
control the pulse current flowing through a capacitance 28 of water to earth ground
and any leaking water pulse currents back through ground to the high voltage pulser
10 via the variable resistance device 40. Continuous electrical current may be used
as alternative to individual pulses in other embodiments. A reduction or loss of
signal will be apparent after a leak location as illustrated by pulse signal 50 shown in
FIG. 1 before and after leak 27. The variable resistance device 40 can be utilized to
reduce current until detected magnetic field pulses remain detectable before the leak
but become undetectable past the leak.

[0065] A method 500 for detecting one or more leaks from a hidden or buried non-
conductive pipe according to one embodiment will now be described. Method 500
can be implemented in apparatus 100 of FIG. 4 for example. As outlined in the flow
chart of FIG. 5, pulser 10 injects the plurality of individual electrical current pulses in
the pipe fluid (501). Receiver detector is maneuvered to detect spatial variation in
intensity of magnetic field pulses (502), the amount of electrical resistance between the pulser and Earth ground is adjusted to control the current exiting the pipe through a leak and returning to the pulser through Earth ground (503). The detector is maneuvered to determine the location at which the detected magnetic field pulse strength is substantially reduced or becomes undetectable as a result of reducing the current returning to the pulser (504). This location at which the detected magnetic field pulse strength is substantially reduced or becomes undetectable as a result of adjusting the variable resistance is the location of the leak. In an alternative embodiment, method 500 may be implemented with a continuous electrical current signal rather than individual pulses.

[0066] By way of example in FIG. 4, for location of a leak, a reduction or cut off in pulse strength is detected to the side of the leak location towards the second pipe end 31 and an increase in pulse strength or an appearance of a pulse signal is detected to the side of the leak towards the first pipe end 30. A potentiometer 40 can be utilized to reduce current until detected magnetic field pulses become undetectable or minimal as the leak location is passed.

[0067] Methods 300 & 500 for locating the pipe and/or leak according to alternative embodiments may be implemented apparatus other than the embodiments of the apparatus 1 and 100 described hereinbefore.

[0068] It should be appreciated that the apparatus of FIGS. 1 and 4 and methods of FIGS. 3 and 5 are only exemplary and are not intended to assert or imply any limitation with regard to the environments in which aspects or embodiments of the methods and apparatus for locating pipes and/or leaks may be implemented. Modifications to the depicted environments may be made without departing from the spirit and scope of the present invention. By way of non-limiting example, the aforementioned leak detection feature and method for detecting leaks using the leak detection feature may also be implemented in the apparatus of FIG. 1 by modifying apparatus 1 to including the variable resistor device between the pulser and earth ground. Also by way of non-limiting example, apparatus 100 of FIG. 4 may be
configured without the use of a variable resistor device. A continuity test to determine the resistance between the local attachment point and Earth ground is performed before any location of buried water line is attempted. If there is a direct short, the point of contact must be isolated from Earth ground. If open, knowledge of distant attachment point is required. The alternative embodiments in which the apparatus is configured with an Earth ground return without a return wire are useful if a distant attachment point is not available (for instance, if unknown).

[0069] Other methods and apparatus are envisaged that permit an electrical current signal, in the form of pulses or otherwise, to be injected into fluid located inside a buried non-conductive pipe, magnetic field induced by the injected electrical current to be detected, and the location of the pipe and/or the location of a leak in the pipe to be determined according to the spatial variation of the intensity of the detected magnetic field.

[0070] It will be appreciated that variations of the above-disclosed and other features and functions, or alternatives thereof, may be desirably combined into many other different apparatus or applications. Also, that various presently unforeseen or unanticipated alternatives, modifications, variations or improvements therein may be subsequently made by those skilled in the art, which are also intended to be encompassed by the following, claims.
What is claimed is:

1. A method for locating a hidden or buried non-conductive fluid pipe, comprising:

   injecting a plurality of individual electrical current signal pulses into fluid in a hidden or buried non-conductive pipe;

   detecting a plurality of magnetic field pulses, induced by said plurality of electrical current pulses, and emanating from fluid in said pipe; and

   determining the location of said pipe according to the spatial variation of the intensity of said magnetic field pulses.

2. The method of claim 1, wherein injecting a plurality of electrical current pulses into said fluid comprises injecting into said fluid a plurality of electrical current pulses having a predetermined pulse repetition rate and/or predetermined pulse shape.

3. The method of claim 1, wherein injecting into said fluid a plurality of electrical current pulses comprises injecting into said fluid a plurality of electrical current pulses having a predetermined pulse repetition rate of about 1 to 100 Hertz.

4. The method of claim 1, wherein injecting into said fluid a plurality of electrical current pulses comprises injecting into said fluid a plurality of electrical current pulses each having a pulse duration of about 10 - 500 microseconds.

5. The method of claim 1, further comprising

   wherein injecting said plurality of individual electrical current signal pulses comprises

   providing an electrical current signal forward path, independent from earth ground, from a signal terminal of said pulser to fluid in a first end of said pipe,
providing a current signal return path, independent from earth ground, from fluid in a second end of said pipe back to a return terminal of said pulser;

injecting said plurality of individual electrical current signal pulses into said fluid via said current signal forward path; and

returning said plurality of electrical current signals from said fluid to said pulser via said current signal return path.

6. The method of claim 5, wherein providing said current signal return path independent from said earth ground comprises electrically connecting a conductive return wire between said fluid at said pipe second end and said pulser return terminal.

7. The method of claim 6, wherein electrically connecting said conductive wire between said fluid at said pipe second end and said pulser comprises

connecting one end of a connective wire to said pulser; and

either inserting the other end of said conductive return wire into the fluid inside said second pipe end; or

attaching said conductive return wire to a second conductive member at said pipe second end, said second conductive member being in physical contact with said fluid inside said pipe first end.

8. The method of claim 1, wherein injecting said plurality of electrical current signal pulses into said fluid comprises:

providing a pulser for applying high voltage pulses;

applying said plurality of high voltage signal pulses from said pulser across said pipe fluid extending between said pipe ends.

9. The method of claim 1, wherein

wherein injecting said plurality of individual electrical current signal pulses
comprises

providing an electrical current signal forward path from said pulser to fluid in first end of said pipe,

providing a current signal return path from fluid in a second end of said pipe back to said pulser; wherein either said forward current signal path or said return current signal path is via earth ground;

injecting said plurality of individual electrical current signal pulses into said fluid via said current signal forward path; and

returning said plurality of electrical current signals from said fluid to said pulser via said current signal return path.

10. The method of claim 1 further comprising determining the location of at least one leak from said pipe according to the spatial variation of the intensity of said magnetic field pulses.

11. The method of claim 10, wherein determining the location of at least one leak from said pipe according to the spatial variation of the intensity of said magnetic field pulses comprises:

adjusting the amount of electrical resistance between earth ground and a return terminal of a pulser for injecting said plurality of individual electrical current pulses in order to control the current exiting the pipe through said at least one leak and returning to said pulser through earth ground; and

determining a location at which the detected magnetic field pulse strength is substantially reduced or becomes undetectable as a result of reducing said current returning to said pulser to thereby determine the location of a fluid leak from said pipe.

12. The method of claim 1, further comprising detecting a hidden or buried conductive fitting or valve, carried on said pipe and in electrical contact with said pipe fluid inside said pipe, according to said detected spatial variation in said magnetic
field.

13. The method of claim 1, wherein injecting a plurality of individual electrical current signal pulses into fluid in a hidden or buried non-conductive pipe comprises injecting said plurality of individual electrical current signal pulses into water in said hidden or buried non-conductive pipe.

14. A method for locating a hidden or buried non-conductive fluid pipe comprising:

  providing an electrical current signal forward path, independent from earth ground, from a power supply to fluid in a first end of a hidden or buried non-conductive pipe,

  providing a current signal return path, independent from earth ground, from fluid in a second end of said pipe back to said power supply;

  injecting an electrical current into said pipe fluid via said current signal forward path;

  returning said electrical current from said fluid to said power supply via said current signal return path;

  detecting a magnetic field induced by said electrical current and emanating from fluid in said pipe; and

  determining the location of said pipe according to the spatial variation of the intensity of said magnetic field.

15. The method of claim 14, wherein injecting said electrical current into said pipe fluid comprises injecting a plurality of individual electrical current pulses from a pulser to said pipe fluid via said current signal forward path; and

  wherein returning said electrical current from said fluid to said power supply comprises returning said plurality of electrical current pulses from said pipe fluid to said pulser via said current signal return path.

16. A pipe locator apparatus for locating a hidden or buried non-conductive pipe,
said apparatus comprising:

- a pulser for injecting a plurality of individual electrical current signal pulses into fluid in a hidden or buried non-conductive pipe; and

- a detector for detecting a plurality of magnetic field pulses, induced by said plurality of electrical current pulses, and emanating from said fluid in said pipe;

whereby, in use, operation of said pulser injects said plurality of electrical current pulses into fluid in said pipe, and whereby movement of said detector over a surface area in the vicinity of said pipe detects said corresponding magnetic field pulses emanating from the pipe fluid, and the spatial variation of the intensities of said magnetic field pulses, to indicate the location of said hidden or buried pipe, and/or the location of a leak in said pipe.

17. The apparatus of claim 16,

wherein said pulser is configured to inject into said fluid a plurality of electrical current pulses having a predetermined pulse repetition rate and/or predetermined pulse shape.

18. The apparatus of claim 17, wherein said pulser is configured to inject into said fluid a plurality of electrical current pulses comprises having a predetermined pulse repetition rate of about 1 to 10 Hertz.

19. The apparatus of claim 17, wherein said pulser is configured to inject a plurality of electrical current pulses each having a pulse duration in about the 10 to 500 microsecond range

20. The apparatus of claim 16, further comprising

- an electrical current signal forward path from said pulser to fluid in a first end of said pipe, said electrical current signal forward path being independent from earth ground;

- an electrical current signal return path from fluid in a second end of said pipe
back to said pulser; said electrical current signal return path being independent from earth ground; and

wherein said pulser is configured to inject said plurality of individual electrical current signal pulses into said fluid via said current signal forward path and return said plurality of electrical current signals from said fluid to said pulser via said current signal return path.

21. The apparatus of claim 16 further comprising a variable resistor device operably coupled between said pulser and earth ground for adjusting the amount of electrical resistance between the pulser and earth ground to control the current exiting the pipe through said at least one leak and returning to said pulser through earth ground; whereby, in use,

adjusting said variable resistor device to reduce the current returning to said pulser results in the detected magnetic field pulse intensities being greatly reduced or becoming undetectable at a location of said at least one fluid leak.

22. The apparatus of claim 16, wherein said pulser is a portable battery powered pulser and/or wherein said detector is a battery powered portable detector.
provide pulser

provide forward and return current signal paths between pulser and pipe fluid

inject individual current pulses with predetermined characteristics across pipe fluid

sense magnetic fields in vicinity of pipe

distinguish magnetic field pulses induced by current pulses

maneuver detector to detect spatial variation in intensity of magnetic field pulses

determine pipe location according to spatial variation in intensity of magnetic field pulses

FIG. 3
500

501
Inject plurality of current pulses in pipe fluid

502
maneuver detector to detect spatial variation in intensity of magnetic field pulses

503
adjust amount of electrical resistance between the pulser and Earth ground to control the current exiting the pipe through leak and returning via ground

504
determine location where magnetic field pulse strength is substantially reduced or becomes undetectable

FIG. 5
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

G01 V 3/06 (2006.01)

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G01V 3/00, 3/02, 3/06, 3/10, 3/11

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

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

RUPAT, RUABRU, RUPAT OLD, RUABU I, Esp@cenet, PAJ, USPTO DB, PatSearch

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>RU 2207594 C2 (SHUKHOSTANOV VLADIMIR KISTUEVICH et al.) 27.06.2003, claims, p. 2, right col., line 12 - p. 3, left col., lines 1-3, drawing</td>
<td>1-10, 12-20, 22</td>
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<tr>
<td>A</td>
<td></td>
<td>11.21</td>
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<tr>
<td>Y</td>
<td>RU 2302649 C2 (SMIRNOV S.S.) 10.07.2007, p. 4, lines 28-29</td>
<td>1-10, 12, 13, 15-20,22</td>
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<td>A</td>
<td></td>
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<td>Y</td>
<td>JP 7260743 A (HITACHI LTD) 13.10.1995, fig. 1</td>
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<td>Y</td>
<td>US 6734674 B1 (JARED H. STRUSE et al.) 11.05.2004, claim 1, fig. 1, col. 2, lines</td>
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<td></td>
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<tr>
<td>Y</td>
<td>US 6529006 B1 (PAUL HAYES) 04.03.2003, col. 5, lines 3 1-34</td>
<td>22</td>
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</table>

Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

30 August 2012 (30.08.2012)

Date of mailing of the international search report

20 September 2012 (20.09.2012)

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