



(86) Date de dépôt PCT/PCT Filing Date: 2015/09/07
(87) Date publication PCT/PCT Publication Date: 2016/03/17
(85) Entrée phase nationale/National Entry: 2017/03/08
(86) N° demande PCT/PCT Application No.: IB 2015/056840
(87) N° publication PCT/PCT Publication No.: 2016/038527
(30) Priorité/Priority: 2014/09/08 (CO14-198145)

(51) Cl.Int./Int.Cl. *G01M 3/28* (2006.01)
(71) Demandeur/Applicant:
UNIVERSIDAD DE MEDELLIN, CO
(72) Inventeurs/Inventors:
MONTOYA RAMIREZ, RUBEN DARIO, CO;
MONTOYA JARAMILLO, LUIS JAVIER, CO
(74) Agent: FASKEN MARTINEAU DUMOULIN LLP

(54) Titre : DISPOSITIF ET PROCEDE POUR LA DETECTION DE FUITE DE FLUIDE DANS DES TUYAUX SOUS
PRESSION

(54) Title: DEVICE AND METHOD FOR FLUID LEAKAGE DETECTION IN PRESSURIZED PIPES

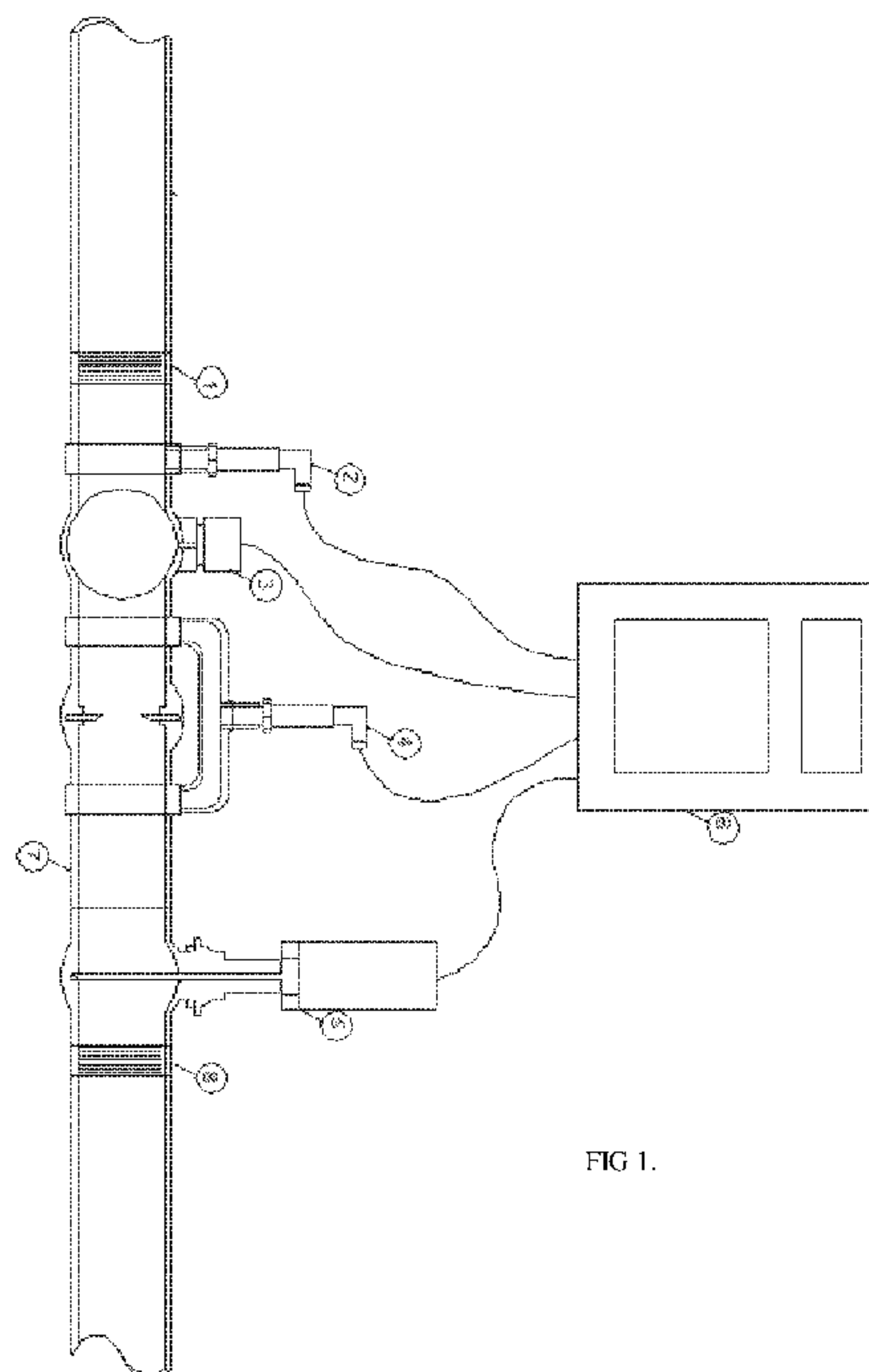


FIG 1.

(57) Abrégé/Abstract:

The present invention relates to a device and a method for identifying leaks in pressurized pipelines. The device for fluid leak detection in pressurized pipelines consists of a pressure sensor, a valve, a flow meter, a control valve and a control device. The



(57) Abrégé(suite)/Abstract(continued):

pressure sensor and the valve are arranged in order in the pipeline between the coupling through which the device is connected to the pipeline and through which fluid enters and the coupling through which fluid exits, and the other components are arranged along the pipeline. The method of the invention consists of the following steps: (A) identifying the pattern wave under leak-less conditions for various flow rates in the functional range, (B) identifying the overpressure wave during operation, (C) comparing the pattern wave identified in step (A) with the overpressure wave collected in step (B), both waves are obtained using similar flow rates in order to determine the presence or absence of leaks in the pipeline. The comparison is performed by means of a combination of the following techniques: area difference, root mean square difference, positive area difference, negative area difference, and difference between the maximum and minimum pressure peaks. In the process of determining the presence of leaks, the aforementioned comparison methods require that the user establish a threshold value that allows for leak identification when one or a combination of the values determined by said methods exceeds the established threshold percentage.

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

(19) World Intellectual Property
Organization
International Bureau(10) International Publication Number
WO 2016/038527 A1(43) International Publication Date
17 March 2016 (17.03.2016)

(51) International Patent Classification:

G01M 3/24 (2006.01) *G01M 3/28* (2006.01)

(21) International Application Number:

PCT/IB2015/056840

(22) International Filing Date:

7 September 2015 (07.09.2015)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

14-198145 8 September 2014 (08.09.2014) CO

(71) Applicant: UNIVERSIDAD DE MEDELLÍN [CO/CO];
Carrera 87 No. 30 - 65, Medellin (CO).(72) Inventors: MONTOYA RAMÍREZ, Rubén Darío; Car-
rera 87 No. 30 - 65, Medellin (CO). MONTOYA JARA-
MILLO, Luis Javier; Carrera 87 No. 30 - 65, Medellin
(CO).(74) Agent: OLARTE, Carlos R.; Carrera 5 No. 34-03, La
Merced, Bogotá, 110311 (CO).(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,
BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM,
DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,
HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR,
KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG,
MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM,
PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC,
SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,
TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ,
TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU,
TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE,
DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU,
LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,
SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ,
GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: DEVICE AND METHOD FOR FLUID LEAKAGE DETECTION IN PRESSURIZED PIPES

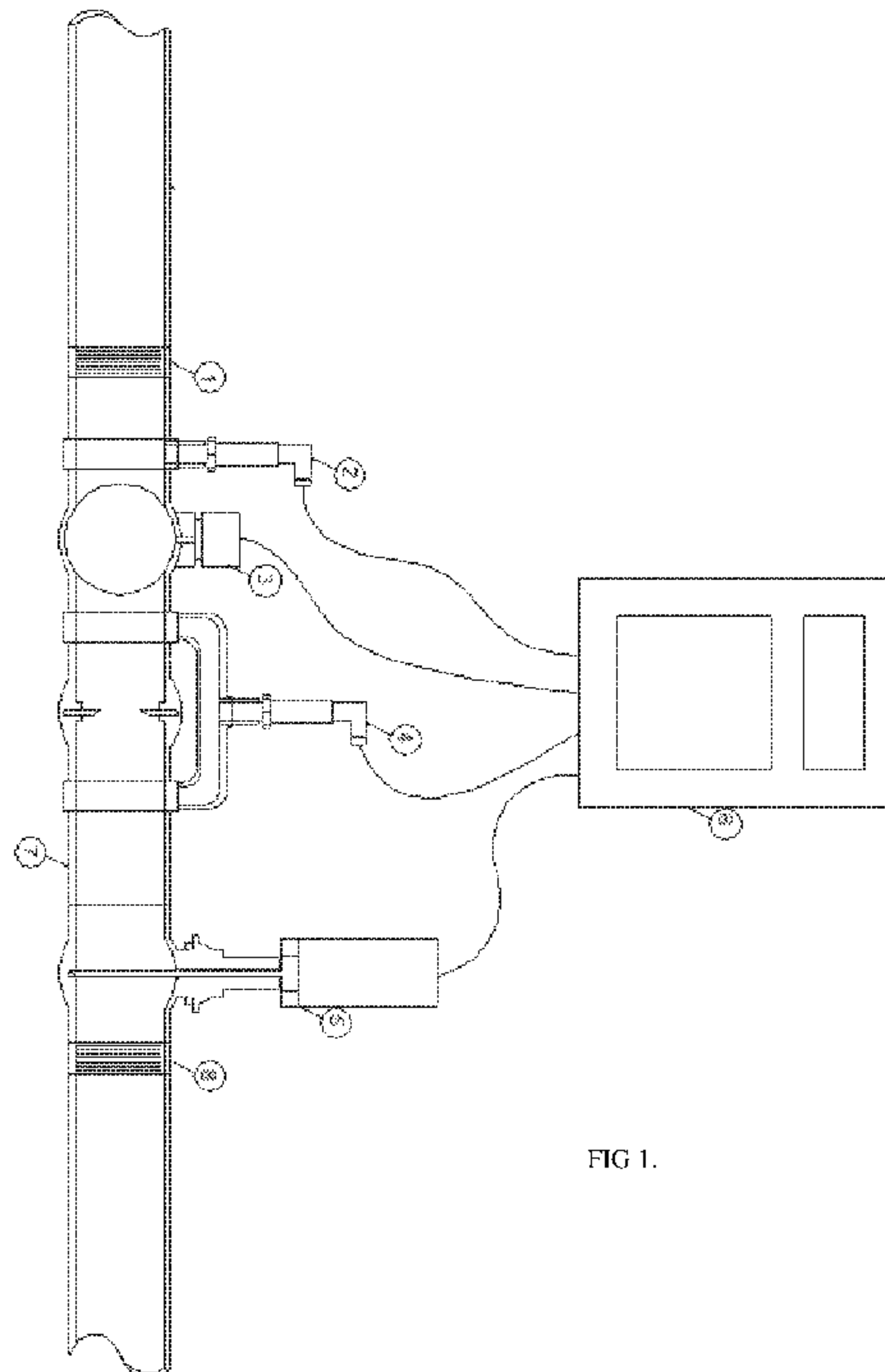


FIG 1.

(57) Abstract: The present invention relates to a device and a method for identifying leaks in pressurized pipelines. The device for fluid leak detection in pressurized pipelines consists of a pressure sensor, a valve, a flow meter, a control valve and a control device. The pressure sensor and the valve are arranged in order in the pipeline between the coupling through which the device is connected to the pipeline and through which fluid enters and the coupling through which fluid exits, and the other components are arranged along the pipeline. The method of the invention consists of the following steps: (A) identifying the pattern wave under leak-less conditions for various flow rates in the functional range, (B) identifying the overpressure wave during operation, (C) comparing the pattern wave identified in step (A) with the overpressure wave collected in step (B), both waves are obtained using similar flow rates in order to determine the presence or absence of leaks in the pipeline. The comparison is performed by means of a combination of the following techniques: area difference, root mean square difference, positive area difference, negative area difference, and difference between the maximum and minimum pressure peaks. In the process of determining the presence of leaks, the aforementioned comparison methods require that the user establish a threshold value that allows for leak identification when one or a combination of the values determined by said methods exceeds the established threshold percentage.

DEVICE AND METHOD FOR FLUID LEAKAGE DETECTION IN PRESSURIZED PIPES

Field of the Invention

5

The present invention relates to a device that detects fluid leakage in pressure pipes. This kind of technology is utilized in public utility infrastructure in water distribution systems (aqueduct and irrigation), and in similar infrastructure or in other industrial sectors that involve the transport of fluids in pressure pipes.

10

Prior Art

In pressurized fluid handling systems, leaks are common. These arise when there are holes, openings, cracks or fissures in the pipes, which allow fluids to escape when the pipes' internal pressure is greater than the external pressure. Leaks can also be related to fluids escaping from joints, gaskets, fixtures, hookups or link-ups and in many cases, are usually due to improper installation or a lack of pipe maintenance and replacement. These leaks can be particularly difficult to detect when the pipes are underground or concealed in the interior of a structure. These leaks represent a cost overrun for the service provider company, and a risk, for they lead to uncontrolled fluid spillage.

Different techniques have been developed for leakage detection in water distribution systems. Leakage detection techniques can be classified into the following three categories: direct monitoring and inspection of the pipes, external methods, and hydraulic methods.

Direct monitoring and inspection of the pipes, which includes: (a) visual techniques to identify floor surface water, or anomalous vegetation in the case of buried pipes, (b) aerial infrared photograph analysis to detect wet zones and (c) assessments of the water distribution system, performing mass balances at different points in the network or performing a statistical analysis of the logs, especially those from low

consumption times.

External methods using devices that detect pipe disturbances, which include: (a) acoustic devices that involve direct auscultation with noise amplification devices, which are classified into devices that use noise logs to locate the area of the leak, and devices that detect the exact location, which contain geophones and correlators (accelerometers or hydrophones), (b) penetrating radar techniques that detect the points along the pipe with low electrical impedance as a sign of waterlogging, (c) electromagnetic techniques to identify breaks in metal pipes, (d) leak analysis generating temperature variations using infrared thermography by sensors located outside the pipe system, (e) tracer gas injection, (f) pressure monitoring while a foam plug is forced through the main pipeline and (g) acoustic or electro-acoustic procedures.

Methods based on flow hydraulics and the pressure transients caused by changes in the operation of the steady-state hydraulic flow in pipelines. These changes generate a pressure wave that propagates along the pipes, flowing through them until it reaches the boundary, where it is reflected. This wave is affected by the features of the pipes. One of these pressure surges is known as "water hammer." It can be caused by the sudden valve closure. The speed at which this wave propagates depends on fluid density, pipe elasticity, pressure, fluid viscosity and temperature, among others. The pressure wave generated by this phenomenon reacts to the geometric properties of the pipeline and flow characteristics, which is why changes in these properties change how the wave propagates. If there are no disruptions in the features of the system, the pressure wave's structure and propagation will remain the same. Any change in the physical structure of the pipeline, such as a leak, causes disturbances in the pressure wave, and since the generated pressure wave propagates through the fluid and is reflected when it reaches a boundary and travels through the pipeline, the analysis of this pressure signal can be used to detect leaks (Beck, S.B.M. Taghvaei, M. & Boxall, J.B., 2006). The disturbances caused by the leaks are reflected in the pressure wave as an indication of the presence of flow discontinuities caused by a dissipation of energy at that point (Montoya, L.J,

Montoya, R., 2010) and cause some of the waves to be reflected back towards the transient's point of origin. Large leaks cause major disturbances in pressure gradients, but small leaks are more difficult to detect, so various types of pressure signal analysis must be employed to distinguish the presence of these disturbances. These
5 detection techniques can be grouped into two methods: (a) the inverse transient analysis method and (b) the impulse response method.

By analyzing the pressure wave in pipelines during a hydraulic transient, various authors have documented different ways of identifying leaks by means of these
10 techniques based on flow hydraulics. Several of the authors focus on analyzing disturbances in the flow and in the pressure due to pipeline leaks, and solving the inverse problem by minimizing the differences between calculated and measured pressure drops under steady-state or transient flow conditions. This technique is known as the inverse hydraulic transient analysis (Liggett, J. Chen, L.C, 1994), and
15 jointly uses an optimization algorithm to minimize the quadratic differences between the measured and calculated pressure drop, and the use of an analytical method for solving the hydraulic transient, which has been refined by using various methods to optimize it for the objective function used in the comparison. Other improvements of these methods have also been reported, using new measurement devices and
20 improvements to the model used in the theoretical calculation of the flow during the transient event. A thorough review of these methods can be found in Colombo, A., Lee, P., & Karney, B. (2009). The inverse transient analysis techniques use the pressure signal and an analysis thereof, involve numeric simulation and calibrating the system for said cases, and also require pressure monitoring at different nodes or
25 points in the system. Improving upon this, there are other techniques from the frequency domain, which use the history of pressure signals at a single point and employ a device that periodically activates the pressure wave. Using these techniques, the presence of leaks is reflected in the presence of pressure peaks in other amplitudes on the frequency diagram of the experimental signal. The
30 disturbance that affects the pressure wave can be used in detecting it by means of various mathematical methods or techniques to analyze the wave in the frequency domain (Mpesha, W., Gassman, S., & Chaudhry, M., 2001), such as the impulse

response method (Ferrante, M., & Brunone, B., 2003). Other methods with the same functional principles use the frequency response diagram, in which the presence of pipeline leaks can be seen as a pattern of resonance peaks that can be used as leak indicators (Lee, P. J., Vítkovský, J. P., Lambert, M. F., Simpson, A. R., & Liggett, J. A., 2005).

Beck et al. (2006) present the development of a device for pipeline leak detection that uses a cepstrum analysis of the wave pressure signal to detect leaks by analyzing the delay between the original wave and its refractions (Taghvaei, M., Beck, S., & Staszewski, W., 2006).

In summary, the technology that uses the aforementioned pressure signal are based on comparing the pressure signals obtained with the theoretical signal (inverse hydraulic transient analysis method) or analyzing the amplified pressure disturbance caused by consecutive pulses (impulse response methods), these can be distinguished mainly by the data analysis method they use to detect the irregularity caused by the leak. The aforementioned techniques require sophisticated analytical methods, and in some cases, considerable processing capacity.

The following documents were referenced in the Prior Art section:

- S. B. M. Beck, M. Taghvaei and J. B. Boxall. UK Patent 244955 (WO2008075066A2), 2006.
- Montoya, L.J. y Montoya, R. (2010) Efecto de la presión sobre las fugas de agua en un sistema de tuberías simple. "The effect of pressure on water leaks in a simple pipeline system." Revista Ingenierías Universidad de Medellín vol. 11, No. 20 pp. 77 - 86 - ISSN 1692 - 3324 - Jan - June, 2012/258 p. Medellín, Colombia
- J. Liggett and L.-C. Chen. (1994). Inverse transient analysis in pipe networks. Journal of Hydraulic Engineering, vol. 120, n° 8, pp. 934-955
- Colombo, A., Lee, P., and Karney, B. (2009). A selective literature review of

transient-based leak detection methods . Journal of Hydro-environment Research. , 212-227.

5 Mpesha, W., Gassman, S., and Chaudhry, M. (2001). Leak Detection in Pipes by Frequency Response Method. Journal of Hydraulic Engineering, 127(2), 134-147.

M. Ferrante and B. Brunone. (2003). Pipe system diagnosis and leak detection by unsteady-state tests. 1. Harmonic analysis. Advances in Water Resources, pp. 95-105.

10

P. J. Lee, J. P. Vítkovský, M. F. Lambert, A. R. Simpson and J. A. Liggett. (2005). Leak location using the pattern of the frequency response diagram in pipelines: a numerical study. Journal of Sound and Vibration, vol. 284, p. 1051–1073.

15 M. Taghvaei, S. Beck y W. Staszewski. (2006). Leak detection in pipelines using cepstrum analysis. Measurement Science and Technology, vol. 17, pp. 367-372, 2006.

Brief description of the figures

20

Figure 1 shows a diagram of an embodiment of the device of the present invention, and its coupling to a pressurized pipe.

Brief description of the invention

25

The present invention is a device and a method for identifying leaks in pressurized pipelines using the water hammer phenomenon.

30

The leak identification method consists of comparing the overpressure waves generated during the water hammer phenomenon. The overpressure waves to be compared are waves obtained during a period with no pipeline leaks, called pattern waves, and waves obtained while the system is running and may or may not have

pipeline leaks, called overpressure waves.

The method can use the following techniques to compare the waves:

- i) area difference,
- 5 ii) root mean square difference,
- iii) positive area difference,
- iv) negative area difference, and
- v) the difference between the maximum and minimum pressure peaks.

10 The result of these techniques is then compared to an established threshold. The presence or absence of leaks is determined based on this comparison.

The object device of the invention is capable of capturing the information needed to carry out the method, and of running the method of the present invention, which
15 contains a pressure sensor, a valve that generates the water hammer, a flow meter, a control valve and a control device.

Detailed description of the invention

20 The present invention is a device and a method for identifying leaks in pressurized pipelines. The device identifies leaks by comparing the overpressure signal generated by a wave in a leak-less pipeline and the overpressure signal generated by a wave in a pipeline with leaks. Unlike inverse hydraulic transient analysis techniques, the device does not solve the system analytically, but instead performs a previous
25 identification of the system, which uses a pattern signal that will be used for future system checks, thereby making it possible to detect leaks by using various techniques to analyze the overpressure signal.

In accordance with FIG. 1, the device consists of:

- 30 - a pressure sensor (2),
- a valve (3).
- a flow meter (4),

- a control valve (5),
- a control device (6), and
- a pipeline (7).

5 In accordance with FIG. 1, the pipeline (7) has two couplings (1) and (8), one at each end of the pipeline (7). The device is connected to the pressurized pipeline that is checked for leaks at coupling (1), so that water can flow into the pipeline, and the pipeline through which fluid will exit the pipeline (7) is attached at coupling (8). The pipeline (7) material can be steel, copper, bronze, aluminum, polyvinyl chloride, high
 10 density polyethylene and a combination thereof. Combination refers to a pipeline (7) composed of segments made of different materials. Preferably, the pipeline (9) material is polyvinyl chloride or high density polyethylene. In one embodiment of the invention, the pipeline (7) has a circular cross section. In one embodiment of the invention, the internal diameter of the pipeline (7) is greater than or equal to 6mm, the internal
 15 diameter is preferably between 6mm and 200mm.

In accordance with FIG. 1, the pressure sensor (2) is operationally arranged along the pipeline (7) in order to measure the pressure, in the vicinity of the end where coupling (1) is located. The pressure sensor (2) measures relative pressures with positive or
 20 negative values. In one embodiment of the invention, the pressure sensor (2) measures relative pressures from -68.95 kPa up to 689.50 kPa, and puts out an analog signal between 4 and 20 mA, which should have a precision greater than or equal to 0.5% and at least a 0.005 s response time between data, which are transmitted to the control device (6) to be stored and later analyzed.

25

In accordance with FIG. 1, looking at the device in the pipeline (7) from coupling (1) through which fluid enters toward coupling (8) through which fluid exits, valve (3) is operationally arranged along the pipeline (7) after the pressure sensor (2). The valve (3) must be closed within a maximum time that satisfies the Joukowski inequality ($T_c <$
 30 $2L/a$, where L is the length of the pipeline and a is the speed of sound in the fluid in the pipeline) to ensure generation of the water hammer that will be used in the process of detecting leaks in the pipeline (7). In one embodiment of the invention, the valve (3) is a

solenoid valve controlled by the control device (6). In one embodiment of the invention, the maximum closing time is 0.5 s.

In accordance with FIG. 1, a flow meter (4) must be installed at one point in the pipeline (7). The flow measurements are used in step (A) and step (B) to determine the pressure of the overpressure wave used in the comparison in step (C), all of which will be explained hereinafter. In one embodiment of the invention, the flow meter (4) logs the flow measurement in the control device (6) before the valve (3) closes. The flow meter (4) is selected from the group consisting of: a flow meter, an ultrasonic flow meter, a turbine flow meter, a differential pressure flow meter with a diaphragm or an orifice plate, a flow nozzle, a Venturi tube and a volumetric flow meter.

In accordance with FIG. 1, looking at the pipeline (7) from coupling (1) through which fluid enters toward coupling (8) through which fluid exits, the control valve (5) is operationally arranged along the pipeline (7). The control valve (5) is used in step (A) and step (B) to force different flow rates and thus obtain different overpressure waves. The control valve (5) is selected from the group consisting of: a gate valve, a ball valve and a throttle valve. In one embodiment of the invention, the control valve (5) is operated by means of the control device (6).

In accordance with FIG. 1, all or some of the following components are connected to the control device (6): the pressure sensor (2), the valve (3), the flow meter (4) and the control valve (5), depending on the configuration that the controller of the device desires. In one embodiment of the invention, the control device (6) is comprised of nine modules that are integrated to acquire and process data during the water hammer generated in the pipe subject to leak identification, upon valve (3) closure. The modules that make up the control device (6) are:

- 1) a module that processes the signals obtained by the control device (6),
- 2) a data storage module: signals that correspond to pressures and flow rates, checks are made. In one embodiment of the invention, this corresponds to a SD memory,

- 3) a module that acquires the signals provided by the pressure sensor (2). In one embodiment of the invention, overpressure data must be collected at 0.00001s intervals with a 12 bit minimum resolution.
- 4) a module that controls the opening and closing of the valve (3),
- 5) a module that controls the opening and closing of the control valve (5),
- 6) a visualization module, in one embodiment of the invention, this module is a 4x20 character LCD screen,
- 7) a data entry interface module, in one embodiment of the invention this module is a membrane keyboard,
- 8) a module that acquires the signals provided by the flow meter (4).
- 9) a data output module, in one embodiment of the invention, this module is a USB-UART port.

The aforementioned modules can be placed inside a box to protect them from dust, impact, among others.

In one embodiment of the invention, considering the direction of flow through the device, the pressure sensor (2) is placed before the valve (3), and the other components are arranged along the pipeline (7).

The control device (6) can compare the overpressure wave and the pattern wave.

The method for fluid leak detection in pressurized pipelines consists of the following steps:

- A) Identifying the pattern wave,
- B) Identifying the overpressure wave, and
- C) Comparing the pattern wave to the overpressure wave;

The method performs a comparison between the overpressure wave obtained for a given flow rate, called the overpressure wave, and the overpressure signal, called the pattern wave (previously obtained in step (A)) for a similar flow rate, based on a permissible variation of 5% for the present invention. It also allows for comparison using various

analytical methods and yields the percent difference, which enables detection of the leak.

To carry out step (a), the valve (3) must be open when the sub-steps are executed to
5 allow fluid to flow into the pipeline (7), and the following sub-steps are performed:

a) the user determines the value of the following variables: wait time T1, collection time T2, sampling step ΔT and flow rate for which pattern waves (called Nflowrates) will be identified and stored in the control device (6);

10 b) opening the control valve (5) to various widths that correspond to the flow rates that will be assigned a pattern wave to be used later in the leak identification process;

c) waiting for time T1 after the control valve (5) opens;

d) recording the flow rate by means of a flow meter (4) and storing it in the
15 electronic control device (6);

e) closing the valve (3) after a period of time T1 elapses;

f) obtaining and recording data from the pressure sensor (2), for a period of time T2;

g) repeating sub-steps b) through f) of step (A), using the same flow rate from
20 sub-step b) of step (A) and comparing it to the wave obtained in sub-step f) of step (A). If the difference between the pattern wave obtained in these two repetitions is not greater than 1%, it is recorded as a pattern wave. Otherwise, a new sequence of sub-steps b) through f) of step (A) is repeated. This information is stored in the control device (6); and

25 h) modifying the flow rate by varying the control valve opening for the various flow rates and sub-steps c) through f) of step (A) are repeated in order to obtain the other pattern waves needed. In one embodiment of the invention, the control valve is varied until the number of flow rates established for pattern wave identification is met. Covering the system's entire range of operational flow rates is recommended.

30

After obtaining the records of the pattern waves for each established flow rate, the user executes step (B): identifying the overpressure wave, which is performed while the

system is running routinely. To carry out step (B), the valve (3) must be open and the following sub-steps are performed:

- a) opening the control valve (5) to reach a flow rate pre-determined by the user;
- 5 b) waiting for period of time T1 after the control valve (5) opens;
- c) recording the system's flow rate (Qo) by means of the flow meter (4);
- d) closing the valve (3) after a period of time T1 elapses; and
- e) obtaining and recording data from the pressure sensor (2) for a period of time T2; this information is stored in the electronic control device (6).

10

When step (B) is completed, the valve (3) is opened to allow the system to operate normally.

Then, step (C) is carried out, in which the pattern wave identified in step (A) for a certain operational flow rate is compared with the overpressure wave (obtained at similar flow rates) identified in step (B). The following sub-steps are performed:

- a) selecting a pattern wave obtained in step (A) from those stored in the electronic device (6), with a flow rate of no less than 5% in comparison to flow rate (Qo) at which the overpressure wave was collected in step (B),
- 20 b) evaluating the differences between the pattern wave and the overpressure wave using various comparison methods,
- c) the user establishes a threshold value to determine when the differences are significant, and
- 25 d) identifying the presence or absence if the differences obtained from various methods exceed the threshold established in sub-step c) of step (C).

T1 is the time needed for the flow rate to stabilize after the operation of a regulatory element in the system, and T2 is equal to the time that elapsed from valve closure until the pressure settles at a stable value (with deviations between consecutive measurements of less than 1%) and which leads to the dissipation of more than 95% of the maximum pressure value of the overpressure wave. In one embodiment of the

30

invention, T1 is set to 30s and T2 is set to 15s.

The comparison between the pattern wave identified in step (A) and the overpressure wave obtained at flow rates similar to that obtained for the operation identified in step (B) is performed by means of one or a combination of the techniques from the group consisting of:

- i. area difference,
- ii. root mean square difference,
- 10 iii. positive area difference,
- iv. negative area difference, and
- v. the difference between the maximum and minimum pressure peaks.

All of these techniques are described below.

15

- i. area difference.

This technique calculates the areas of the overpressure wave and the pattern wave, and then normalizes their difference by comparing it to the area of the pattern wave.

20

N data are taken from the overpressure wave collected in step (B), which, for the purposes of the description, will be called P_i for $i=1,2,\dots,N$, spread over a time interval ΔT , and which are obtained at an operational flow rate Q_o . N pressure data are taken from the pattern wave collected in step (A) and used in sub-step (b) of step (C), which, for the purposes of the description, will be called $P_{patterni}$ for $i=1,2,\dots,N$, are spread over a time interval, ΔT , and which are obtained at a flow rate Q , similar to Q_o , that is, with a difference of less than 5%. The area of the pattern wave is calculated like A pattern:

$$A_{pattern} = \sum_{i=1}^N P_{patterni} \times \Delta T$$

30

and the area of the overpressure wave during the operation is defined as

$$A = \sum_{i=1}^N P_i \times \Delta T$$

The percent difference between the areas is estimated in the following way

5

$$\%Dif A = \left| \frac{A_{pattern} - A}{A_{pattern}} \right| \times 100$$

ii. root mean square difference,

10 This technique calculates the root mean square of the collected overpressure wave and of the pattern wave, and then normalizes their difference.

N data are taken from the overpressure wave collected in step (B), which, for the purposes of the description, will be called P_i for $i=1,2,\dots,N$, spread over a time interval ΔT , and which are obtained at an operational flow rate Q_0 . N pressure data are taken from the pattern wave collected in step (A) and selected in sub-step (b) of step (C), which, for the purposes of the description, will be called $P_{patterni}$ para $i=1,2,\dots,N$, are spread over a time interval ΔT , and which are obtained at a flow rate Q , similar to Q_0 , that is, with a difference of less than 5%. The root mean square error is calculated by:

20

$$RMS_{pattern} = \sqrt{\frac{\sum_{i=1}^N P_{patterni}^2}{N}}$$

and the root mean square error of the overpressure wave during operation is defined as

$$RMS = \sqrt{\frac{\sum_{i=1}^N P_i^2}{N}}$$

The percent difference of the root mean square is calculated by:

$$\%Dif\ RMS = \left| \frac{RMS_{pattern} - RMS}{RMS_{pattern}} \right| \times 100$$

iii. positive area difference,

This technique calculates the areas with positive values above the hydrostatic pressure of the overpressure wave and the pattern wave, and then normalizes their difference by comparing it to the area of the pattern wave.

N data are taken from the overpressure wave collected in step (B), which, for the purposes of the description, will be called P_i for $i=1,2,\dots,N$, spread over a time interval ΔT , and which are obtained at an operational flow rate Q_o . N pressure data are taken from the pattern wave collected in step (A) and selected in sub-step (b) of step (C), which, for the purposes of the description, will be called $P_{patterni}$ for $i=1,2,\dots,N$, are spread over a time interval ΔT , and which are obtained at a flow rate Q , similar to Q_o , that is, with a difference of less than 5%. The equilibrium pressure is found after the valve (3) closes, using the average of the pressure values from the overpressure wave, obtained after a period of time T_2 after the valve (3) closes, which, for the purposes of the description, is recorded as the hydrostatic pressure and called P_h . The positive area of the pattern wave is calculated only taking into account the pressure values that are above P_h , in the following way

$$A_{pattern+} = \sum_{\substack{i=1 \\ \text{If } P_{patterni} - P_h > 0}}^N (P_{patterni} - P_h) \times \Delta T$$

and the positive area for the overpressure wave would be given by the expression

$$A_+ = \sum_{\substack{i=1 \\ \text{If } P_i - P_h > 0}}^N (P_i - P_h) \times \Delta T$$

The percent difference between the areas is estimated using the following expression:

$$\%Dif\ A_+ = \left| \frac{A_{pattern+} - A_+}{A_{pattern+}} \right| \times 100$$

iv. Negative area difference.

This technique calculates the areas with negative values below the hydrostatic pressure of the overpressure wave and the pattern wave, and then normalizes their difference by comparing it to the area of the pattern wave.

N data are taken from the overpressure wave collected in step (B), which, for the purposes of the description, will be called P_i for $i=1,2\dots N$, spread over a time interval ΔT , and which are obtained at an operational flow rate Q_o . N pressure data are taken from the pattern wave collected in step (A) and selected in sub-step (b) of step (C), which, for the purposes of the description, will be called $P_{patterni}$ para $i=1,2\dots N$, are spread over a time interval ΔT , and which are obtained at a flow rate Q , similar to Q_o , that is, with a difference of less than 5%. The equilibrium pressure is found after the valve (3) closes, using the average of the pressure values from the overpressure wave, obtained after a period of time T_2 after the valve (3) closes, which, for the purposes of the description, is recorded as the hydrostatic pressure and called P_h . The negative area of the pattern wave is calculated only taking into account the pressure values that are below P_h

$$A_{pattern-} = \sum_{i=1}^N (P_h - P_{patterni}) \times \Delta T$$

If $P_{patterni} - P_h < 0$

and the negative area for the overpressure wave would be

$$A_+ = \sum_{i=1}^N (P_h - P_i) \times \Delta T$$

If $P_i - P_h < 0$

The percent difference between the areas is estimated in the following way

$$\%Dif A_+ = \left| \frac{A_{pattern-} - A_-}{A_{pattern-}} \right| \times 100$$

v. The difference between the maximum and minimum pressure peaks.

- 5 This technique calculates the difference between the maximum or minimum peaks of the overpressure wave, normalized by the amplitude of each peak. In one embodiment of the invention, this is done for the first four peaks, and is presented below as a model, without any loss of generality, since it can be done with a greater number of minimum and maximum pressure peaks.

10

N data are taken from the overpressure wave collected in step (B), which, for the purposes of the description, will be called P_i for $i=1,2,\dots,N$, spread over a time interval ΔT , and which are obtained at an operational flow rate Q_0 . N pressure data are taken from the pattern wave collected in step (A) and selected in sub-step (b) of step (C),
 15 which, for the purposes of the description, will be called $P_{\text{pattern}i}$ for $i=1,2,\dots,N$, are spread over a time interval, ΔT , and which are obtained at a flow rate Q , similar to Q_0 , that is, with a difference of less than 5%. The first maximum pressure peak of the pattern wave is calculated as follows:

20

$$P_{\text{peak pattern max 1}} = \max\{P_{\text{pattern}i}\} \text{ For } i=1:N$$

and its position in the series of pressures would be expressed as $n_{\text{pattern max 1}}$.

The first minimum pressure peak of the pattern wave is calculated as follows:

25

$$P_{\text{peak pattern min 1}} = \min\{P_{\text{pattern}i}\} \text{ For } i=n_{\text{pattern max 1}}:N$$

and its position in the series of pressures would be $n_{\text{pattern min 1}}$.

The second maximum pressure peak of the pattern wave is calculated as follows:

30

$$P_{\text{peak pattern max 2}} = \max\{P_{\text{pattern}i}\} \text{ For } i=n_{\text{pattern min 1}}:N$$

and its position in the series of pressures would be $n_{\text{pattern max 2}}$.

The second minimum pressure peak of the pattern wave is calculated as follows:

$$5 \quad P_{\text{peak pattern min 2}} = \min\{P_{\text{pattern } i}\} \text{ For } i=n_{\text{pattern max 2}}:N$$

and its position in the series of pressures would be $n_{\text{pattern min 2}}$.

The third maximum pressure peak of the pattern wave is calculated as follows:

$$10 \quad P_{\text{peak pattern max 3}} = \max\{P_{\text{pattern } i}\} \text{ For } i=n_{\text{pattern min 3}}:N$$

and its position in the series of pressures would be $n_{\text{pattern max 3}}$.

15 The third minimum pressure peak of the pattern wave is calculated as follows:

$$P_{\text{peak pattern min 3}} = \min\{P_{\text{pattern } i}\} \text{ For } i=n_{\text{pattern max 3}}:N$$

and its position in the series of pressures would be $n_{\text{pattern min 3}}$.

20 The fourth maximum pressure peak of the pattern wave is calculated as follows:

$$P_{\text{peak pattern max 4}} = \max\{P_{\text{pattern } i}\} \text{ For } i=n_{\text{pattern min 3}}:N$$

25 and its position in the series of pressures would be $n_{\text{pattern max 4}}$.

The fourth minimum pressure peak of the pattern wave is calculated as follows:

$$P_{\text{peak pattern min 4}} = \min\{P_{\text{pattern } i}\} \text{ For } i=n_{\text{pattern max 4}}:N$$

30 and its position in the series of pressures would be $n_{\text{pattern min 4}}$.

The first maximum pressure peak of the overpressure wave is calculated as follows:

$$P_{\text{peak max 1}} = \max\{P_i\} \text{ For } i=1:N$$

and its position in the series of pressures would be $n_{\text{max 1}}$.

5

The first minimum pressure peak of the overpressure wave is calculated as follows:

$$P_{\text{peak min 1}} = \min\{P_i\} \text{ For } i=n_{\text{max 1}}:N$$

10 and its position in the series of pressures would be $n_{\text{min 1}}$.

The second maximum pressure peak of the overpressure wave is calculated as follows:

$$P_{\text{peak max 2}} = \max\{P_i\} \text{ For } i=n_{\text{min 1}}:N$$

15

and its position in the series of pressures would be $n_{\text{max 2}}$.

The second minimum pressure peak of the overpressure wave is calculated as follows:

20

$$P_{\text{peak min 2}} = \min\{P_i\} \text{ For } i=n_{\text{max 2}}:N$$

and its position in the series of pressures would be $n_{\text{min 2}}$.

The third maximum pressure peak of the overpressure wave is calculated as follows:

25

$$P_{\text{peak max 3}} = \max\{P_i\} \text{ For } i=n_{\text{min 2}}:N$$

and its position in the series of pressures would be $n_{\text{max 3}}$.

30 The third minimum pressure peak of the overpressure wave is calculated as follows:

$$P_{\text{peak min 3}} = \min\{P_i\} \text{ For } i=n_{\text{max 3}}:N$$

and its position in the series of pressures would be $n_{\min 3}$.

The fourth maximum pressure peak of the overpressure wave is calculated as follows:

5

$$P_{\text{peak max 4}} = \max\{P_i\} \text{ For } i=n_{\min 3}:N$$

and its position in the series of pressures would be $n_{\max 4}$.

10 The fourth minimum pressure peak of the overpressure wave is calculated as follows:

$$P_{\text{peak min 4}} = \min\{P_i\} \text{ For } i=n_{\max 4}:N$$

and its position in the series of pressures would be $n_{\min 4}$.

15

After calculating maximum and minimum pressure peaks, the percent differences for each pressure peak is calculated as follows:

$$\%Dif P_{\text{peak max } j} = \left| \frac{P_{\text{peak pattern max } j} - P_{\text{peak max } j}}{P_{\text{peak pattern max } j}} \right| \times 100 \text{ for the 4 peaks (j = 1 through 4)}$$

$$\%Dif P_{\text{peak min } j} = \left| \frac{P_{\text{peak pattern min } j} - P_{\text{peak min } j}}{P_{\text{peak pattern min } j}} \right| \times 100 \text{ for the 4 peaks (j = 1 through 4)}$$

20

The greatest of these values is taken as the pressure peak difference.

Based on a user-defined threshold percentage, called U_h for the purposes of the description, the presence of a leak in the system is accepted or rejected based on one or
 25 more of the methods defined in sub-step (b) of step (C). For percent dissipation values greater than the threshold, the presence of a leak in the system is accepted. Otherwise, the presence of a leak in the pressure system is rejected.

This threshold percentage U_h can be determined by means of statistical analyses
 30 conducted in a lab and using previous analyses of the system, all with the goal of

determining a threshold percentage based on which the presence of a leak in the system is obvious (sub-stage d of step C).

In one embodiment of the invention, the presence of a leak is detected when the differences from at least three of the techniques in sub-step (b) of step (C) exceed a threshold previously established by the user in sub-step (c) of step (C).

The analysis module of the device can be used for the comparison to find leaks.

10

Definitions:

15 Operational flow rate: this flow rate is defined as the volume per unit of time along pipeline (7) passing through at any given moment in time as stationary flow before initiating test and with the valve (3).

Overpressure wave: a wave produced during the hydraulic transient phenomenon measured by the pressure sensor (2). It is the wave identified in step (B).

Pattern wave: an overpressure wave produced by sudden valve (3) closure during the water hammer phenomenon, for a given operational flow rate without any leaks in the system. It is the wave identified in step (A).

25

Time T1: the length of time during which water must be allowed to flow after the valve (3) is open and before the closing procedure, with the goal of establishing the steady-state flow rate in the pipeline.

30 Time T2: the length of time during which the records generated by the pressure sensor (2) are stored and includes the water hammer in the pipeline (until the pressure reaches a hydrostatic pressure above that which produced a dissipation of more than 95% of the

maximum pressure value of the overpressure wave).

Example

- 5 An experimental arrangement was assembled. This arrangement contained a pipeline with an approximate length of 80 meters, made of polypropylene with a nominal diameter of 63mm, which was made to leak through a 3/16" orifice.

The process begins with step (A), for which standard curves were made for the flow
10 rates reported in Table 1. These standard curves were stored in the control device (6).

Table 1 Flow rates for which standard curves were obtained.

Pattern	Flow Rate (L/s)
1	3.85
2	4.14
3	4.42

15

The following values were set to obtain the pattern waves:

T1: 20s

Flow rate: The corresponding values from Table 1 were entered for each case.

T2: 30s

20

For step (B), for each flow rate reported in Table 1, two additional experiments without a leak were performed in order to determine if they would be reported as not detected (NO) after the analyses, and three experiments with an induced leak in the pipeline, in order to show whether they would be reported as detected (YES). In Table 2, a
25 summary of the 15 experiments with 3 flow rates is presented. These were obtained in the case of a leak created by a 3/16" circular orifice in the pipeline.

Table 2. Flow rates and experiment summary.

Experiment	Flow Rate (L/s)	Experiment performed with or without a leak
1	3.85	Leak
2	3.85	Leak
3	3.85	Leak
4	3.85	No leak
5	3.85	No leak
6	4.14	Leak
7	4.14	Leak
8	4.14	Leak
9	4.14	No leak
10	4.14	No leak
11	4.42	Leak
12	4.42	Leak
13	4.42	Leak
14	4.42	No leak
15	4.42	No leak

For sub-step (b) of step (C), the six comparison methods were selected. The results of the comparisons (with their respective methods) are shown in Table 3.

5 Table 3. Results of the analysis using different methods

Experiment	Flow Rate (L/s)	Experiment with or without leak	% Area	% RMS	% positive area	% negative area	% minimum peaks	% max. peak 2
1	3.85	Leak	5.2197	4.8994	1.7789	83.2945	32.5183	36.7543
2	3.85	Leak	7.2124	4.8742	5.0496	61.0894	30.6866	39.1106
3	3.85	Leak	5.1071	4.257	2.1399	82.0957	30.6866	35.9689
4	3.85	No leak	1.4138	0.5557	1.5422	0.9931	1.3744	23.2464

5	3.85	No leak	0.5253	0.4885	0.8184	4.1323	0.9159	2,199
6	4.14	Leak	10.5247	5.0405	9,055	49.4059	30.2087	43.8557
7	4.14	Leak	13.1006	5.6918	11.6356	48.4732	28.5306	44.4502
8	4.14	Leak	12.9314	5.2554	11.6823	45.1051	26.4326	44.1529
9	4.14	No leak	1.1101	0.0739	1.6764	7.1359	2.0981	0
10	4.14	No leak	0.3335	0.2144	0,909	7.9321	0	3,865
11	4.42	Leak	9.3027	2.8049	7.9602	42.6967	22.4338	39.2674
12	4.42	Leak	10.2382	2.4867	8.4321	49.0128	24.6323	38.3251
13	4.42	Leak	8.6901	1.8982	5.8514	58.7947	21.9935	36.2829
14	4.42	No leak	0,555	1.3756	0.1437	5.6751	0.4393	5.9685
15	4.42	No leak	1.2131	1.752	1.398	1.1908	0.4393	1.0995

In sub-step (c) of step (C), a threshold U_h of 5% was determined.

In sub-step (d) of step (C), the comparison was performed in order to identify the leak.

- 5 The criterion for the existence of a leak was established to be: at least three of the six methods yielded a difference greater than the established threshold. Table 5 shows consolidated information of detection using the different methods and consolidated information of leak detection, YES indicating it was detected and NO indicating it was not detected.

10

Table 5. Consolidated information of differences greater than 5% for leak detection.

	Flow	Experiment	%	%	%	%	%	%	
Experiment	Rate (L/s)	with or without leak	Area	RMS	negative area	negative area	minimum peaks	max. peak	Leak
1	3.85	Leak	YES	YES	YES	YES	YES	YES	YES
2	3.85	Leak	YES	YES	YES	YES	YES	YES	YES
3	3.85		YES	NO	NO	YES	YES	YES	YES
4	3.85	No leak	NO	NO	NO	NO	NO	YES	NO
5	3.85	No leak	NO	NO	NO	NO	NO	NO	NO

6	4.14	Leak	YES	YES	YES	YES	YES	YES	YES
7	4.14	Leak	YES	YES	YES	YES	YES	YES	YES
8	4.14	Leak	YES	YES	YES	YES	YES	YES	YES
9	4.14	No leak	NO	NO	NO	YES	NO	NO	NO
10	4.14	No leak	NO	NO	NO	YES	NO	NO	NO
11	4.42	Leak	YES	NO	YES	YES	YES	YES	YES
12	4.42	Leak	YES	NO	YES	YES	YES	YES	YES
13	4.42	Leak	YES	NO	YES	YES	YES	YES	YES
14	4.42	No leak	NO	NO	NO	YES	NO	YES	NO
15	4.42	No leak	NO	NO	NO	NO	NO	NO	NO

5

10

15

20

25

30

CLAIMS

1. A device for fluid leak detection in pressurized pipelines, consisting of:
 - 5 a pressure sensor (2);
 - a valve;
 - a flow meter;
 - a control valve;
 - a control device connected to the pressure sensor;
- 10 in which the pressure sensor and the valve are arranged in order as above in the pipeline, between the coupling through which the device is connected to the pipeline and through which fluid enters and the coupling through which fluid exits, and the other components are arranged along the pipeline.
- 15 2. The device claimed in Claim 1, characterized because the pipeline material is selected from the group consisting of: polyvinyl chloride, high-density polyethylene, steel, copper, bronze, aluminum, iron and a combination thereof.
- 20 3. The device claimed in Claim 1, characterized because the pipeline has a circular cross section with an internal diameter greater than or equal to 6mm.
4. The device claimed in Claim 3, characterized because the pipeline's internal diameter is between 6mm and 254mm.
- 25 5. The device claimed in Claim 1, characterized because the pressure sensor measures negative relative pressures and positive relative pressures.
6. The device claimed in Claim 1, characterized because the valve's closing time
- 30 satisfies Joukowski's inequality ($T_c < 2L/a$)
7. The device claimed in Claim 1, characterized because the flow meter is selected

from the group consisting of: a flow meter, an ultrasonic flow meter, a turbine flow meter, a differential pressure flow meter with a diaphragm or an orifice, a flow nozzle, a Venturi tube and a volumetric flow meter.

5 8. The device claimed in Claim 1, characterized because the control valve is selected from the group consisting of: a gate valve, a ball valve and a throttle valve.

9. The device claimed in Claim 1, in which the control device contains:

10 a module that acquires the signals provided by the pressure sensor;
 a module that acquires the signals provided by the flow meter;
 a module that controls the opening and closing of the valve;
 a module that controls the opening and closing of the control valve;
 a data entry interface module;
 15 a module that processes the received signals;
 a data visualization module;
 a data storage module; and
 a data output module.

20

10. The device claimed in Claim 9, characterized because the following are connected to the control device:

the pressure sensor;
 25 the flow meter;
 the valve; and
 the control valve.

11. A method for fluid leak detection in pressurized pipelines performed by the
 30 device from Claim 1, comprising the following steps:

a) identifying the pattern wave,

- b) identifying the overpressure wave; and
- c) comparing the pattern wave identified in step (A) for an operational flow rate with the overpressure wave identified in step (B) using one or a combination of the techniques from the group consisting of: area difference, root mean square difference, positive area difference, negative area difference, and difference between the maximum and minimum pressure peaks.

12. The method claimed in Claim 11, characterized because step (A) contains the following sup-steps:

- a) the user determines the value of the following variables: wait time T1, collection time T2, sampling step ΔT and Nflowrates;
- b) opening the control valve to various widths that correspond to the flow rates that will be assigned a pattern wave to be used later in the leak identification process;
- c) waiting for time T1 after the control valve opens;
- d) recording the flow rate by means of a flow meter and storing it in the electronic control device;
- e) closing the valve after a period of time T1 elapses;
- f) obtaining and recording data from the pressure sensor, for a period of time T2;
- g) repeating sub-steps b) through f) of step (A), using the same flow rate as in sub-step b) of step (A) and comparing with the wave obtained in sub-step f) of step (A), if the difference between the pattern wave obtained in these two repetitions is not greater than 1%, it is recorded as a pattern wave. Otherwise, a new sequence of sub-steps b) through f) of step (A) is repeated; and,
- h) modifying the flow rate by varying the control valve opening for the various flow rates and sub-steps c) through f) of step (A) are repeated in order to obtain the other pattern waves needed;

wherein the valve is open when the sub-steps begin to be performed.

13. The method claimed in Claim 11, characterized because step (B) consists of the following sub-steps:

- 5 a) opening the control valve to reach a flow rate pre-determined by the user;
- b) waiting for time T1 after the control valve opens;
- c) recording the system's flow rate (Q_0) by means of the flow meter;
- d) closing the valve after a period of time T1 elapses; and,
- e) obtaining and recording data from the pressure sensor, for a period of
- 10 time T2;

wherein the valve is open when the sub-steps begin to be performed.

14. The method claimed in Claim 11, characterized because step (C) consists of the following sub-steps:

- a) selecting a pattern wave from among those stored in the electronic device, obtained during step (A), with a flow rate that does not differ by more than 5% from the flow rate (Q_0) with which the overpressure wave was collected during step
- 20 (B);
- b) evaluating the differences between the pattern wave and the overpressure wave using various comparison techniques;
- c) the user establishes a threshold value to determine when the differences are significant; and,
- 25 d) identifying the presence or absence of the leak if the differences from various methods exceed the threshold established in sub-step c) of step (C);

wherein in sub-step b) one or a combination of the following techniques are selected: area difference, root mean square difference, positive area difference, negative area

30 difference, and difference between the maximum and minimum pressure peaks.

15. The method claimed in Claims 12 and 13, characterized because in sub-step (a) of

step (A) and in sub-step (b) of step (B), time T1 is equal to 30s.

16. The method claimed in Claims 12 and 13, characterized because in sub-step (a)
of step (A) and in sub-step (e) of step (B), time T2 is equal to the time during which the
5 pressure transient occurs.

17. The method claimed in Claims 12 and 13, characterized because time T2 is
equal to the time elapsed from valve closure until the pressure reaches a stable value
and that leads to a dissipation of more than 95% of the maximum pressure value of the
10 overpressure wave.

18. The method claimed in Claims 12 and 13, characterized because in sub-step (a)
of step (A) and in sub-step (e) of step (B), time T2 is between 15s and 30s.

15 19. The method claimed in Claim 11, characterized because in sub-step (d) of step
(C), the presence of a leak is indicated when the difference from one or more of the
techniques from step (C) exceeds the threshold percentage previously established by the
user in sub-step (c) of step (C).

20

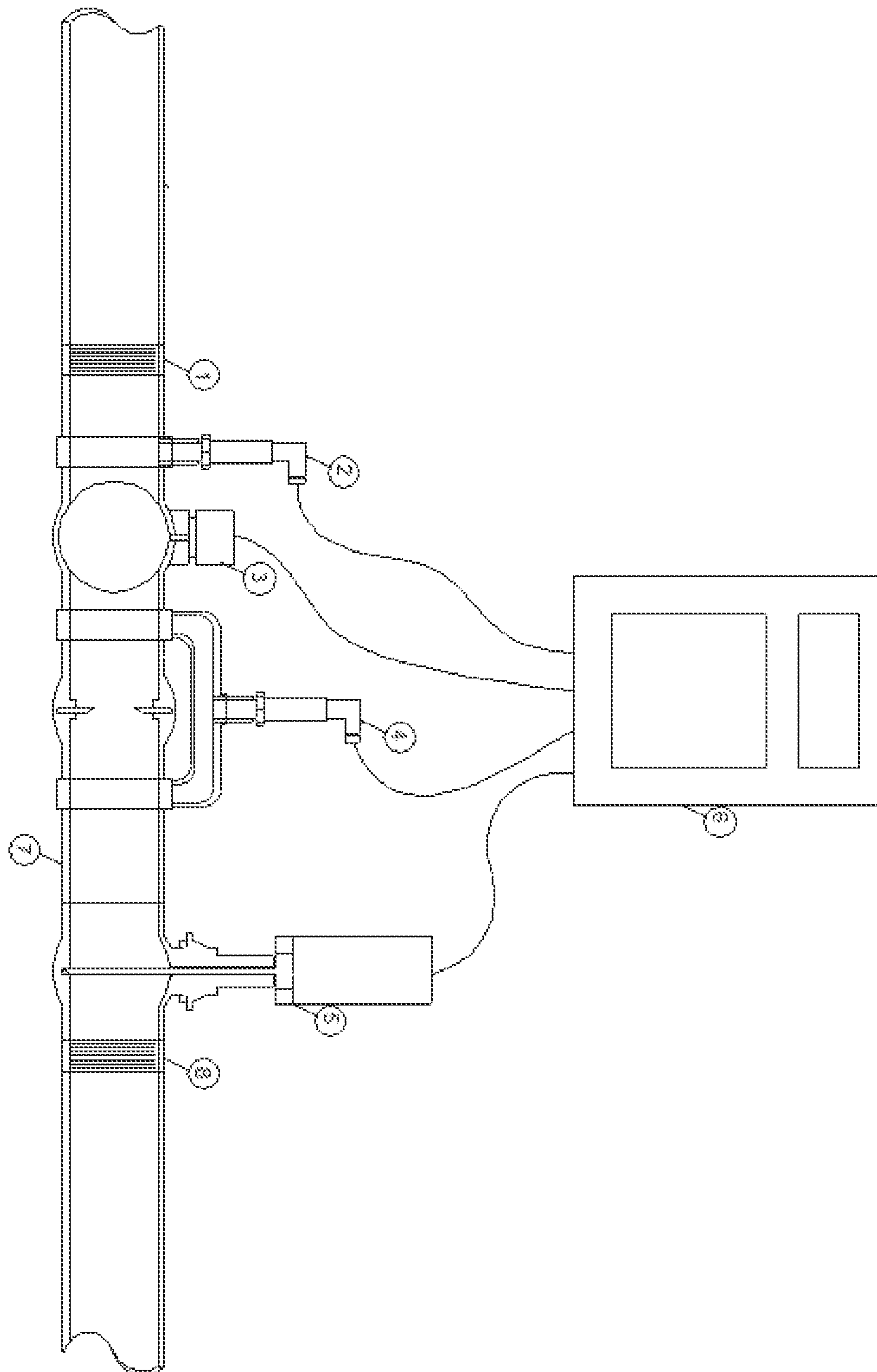


FIG 1.

