AN AUTOMATED INSPECTION APPARATUS FOR NON-DESTRUCTIVE INSPECTION OF WELDS ON PIPE FOR DETECTING ONE OR MORE ANOMALIES IN PIPE

Field of Invention

The present invention relates to testing of welded joints. More particularly, the present invention relates to an automated inspection apparatus for non-destructive inspection of welds on pipes for detecting one or more anomalies in the pipes.

Background of the invention

Currently, there are several techniques such as, for example ultrasound testing (UT) and radiographic testing (RT) that are widely used for detection and verification of anomalies in structures such as pipes. However, there are several common constrains that arise with the usage of UT and RT techniques. For instance, the UT and RT techniques cause repeatability issue where the result may vary with personnel and/or equipment. Additionally, while examining welds on pipes with a diameter of 2 to 4 inches and a wall thickness of 10 to 20 milli meters by using UT techniques, there is a high probability of missing a defect on the inner surface of the weld. The use of RT techniques gives greater reliability in the examination, however, it is associated with limitations, such as, large equipment size and low inspection speed.

Therefore, in light of the foregoing discussion, there exists a need to overcome the aforementioned drawbacks associated with the conventional techniques for non-destructive inspection of welds on a pipe for detecting one or more anomalies in the pipes, especially pipes of 2 to 4 inches diameter and a wall thickness of 10 to 20.

These and other objects and advantages of the present invention will become apparent to those skilled in the art from a consideration of the following specification and claims.

Summary of the Invention

According to an aspect of the present invention, there is provided an automated inspection apparatus for non-destructive inspection of welds on a pipe for detecting one or more anomalies in a pipe. The automated inspection apparatus comprises a cylindrical magnetization unit and a sensor unit. The cylindrical magnetization unit is configured for generating a magnetic flux external to the pipe and transferring the magnetic flux inside the body of the pipe upon mounting

the automated inspection apparatus on the pipe. The cylindrical magnetization unit includes a first set of four magnets disposed on a first side edge of the cylindrical magnetization unit, where each of the first set of four magnets comprises a steel wheel from among a first set of four steel wheels, and where each of the first set of four electromagnets is attached to a first steel flange. The cylindrical magnetization unit further includes

a second set of four magnets disposed on a second side edge of the cylindrical magnetization unit, where each of the second set of four magnets comprises a steel wheel from among a second set of four steel wheels, and where each of the second set of four electromagnets is attached to a second steel flange. The cylindrical magnetization unit further includes the first steel flange disposed on the first side edge of the cylindrical magnetization unit and the second steel flange disposed on the second side edge of the cylindrical magnetization unit, for holding the first set of four magnets and the second set of four magnets respectively. The cylindrical magnetization unit further includes a set of four axels connecting the first steel flange to the second steel flange to form a cylindrical structure. The sensor unit includes one or more sensor bracelets disposed between the first set of wheels and the second set of wheels along a circumference of the pipe and configured to detect the changes in the magnetic field upon moving the cylindrical magnetization unit along a length of the pipe by detachably mounting the cylindrical magnetization unit on the pipe, to characterize the one or more anomalies in the pipe. The cylindrical magnetization unit is configured to be detachably mounted on the pipe along the circumference of the pipe and is movable along the length of the pipe for providing a uniform magnetization up to a technical saturation along an entire circumference of the pipe for detecting one or more anomalies in the pipes.

In an embodiment, the anomalies include at least one of: internal anomalies and external anomalies.

In an embodiment, the automated inspection apparatus further includes a plurality of flaps attached to the automated inspection apparatus and that are movable freely along the weld profile of the pipe upon moving the automated inspection apparatus along the length of the pipe. The one or more sensor bracelets are installed on the plurality of flaps.

In an embodiment, the sensor processing system is operatively coupled to the sensor unit for collecting, recording and processing the changes in the magnetic field in the three directions to characterize the one or more anomalies in the pipe detected by the sensor unit, where the sensor processing system includes a computing device.

In an embodiment, each of the first set of magnets and the second set of magnets comprises at least one of: an electro-magnet or a permanent magnet.

In an embodiment, the sensor unit is configured to detect the changes in the magnetic field in at least one of: an axial direction, a radial direction and a circumferential direction.

The automated inspection apparatus of the present invention facilitates detection of very small defects located at great depths by using a magnetic system that provides uniform magnetization to technical saturation along the entire circumference of the pipes and scanning of the defect fields by the sensor bracelets installed along the entire circumference of the pipe. Further, the automated inspection apparatus 100 of the present invention facilitates detection of anomalies in pipes of diameter ranging between 2 to 4 inches and a wall thickness of 10 to 20 millimeter with accurate detection of defect in the inner surface of the pipes as well. Moreover, the automated inspection apparatus of the present invention has a small equipment size and higher inspection speed when compared to other known techniques. The automated inspection apparatus of the present invention facilitates reliable and accurate non-destructive identification of anomalies in the pipes, while minimizing the need for expensive verification excavations (such as for example, digging up the pipe to verify what the problem is). Also, the accurate assessment of anomalies by the automated inspection apparatus of the present invention, facilitates improvement in decision making process within a pipeline integrity management program and excavation programs can then focus on required repairs instead of calibration or exploratory digs. Moreover, the present invention provides information characterizing the anomalies based on inspection that is not only cost effective but, can also prove to be an extremely valuable building block of a pipeline integrity management program.

These and other aspects of the embodiments herein will be better appreciated and understood when considered in conjunction with the following description and the accompanying drawings. It should be understood, however, that the following descriptions, while indicating preferred embodiments and numerous specific details thereof, are given by way of illustration and not of limitation. Many changes and modifications may be made within the scope of the embodiments herein without departing from the spirit thereof, and the embodiments herein include all such modifications.

Brief Description of the Drawings

Other objects, features, and advantages of the invention will be apparent from the following description when read with reference to the accompanying drawings. In the drawings, wherein like reference numerals denote corresponding parts throughout the several views:

Figure 1 depicts a perspective view of an automated inspection apparatus for non-destructive inspection of welds for detecting one or more anomalies in the pipes, in accordance with an embodiment;

FIGURE 2 depicts the automated inspection apparatus detachably mounted on a pipe along the circumference of the pipe, in accordance with an embodiment;

FIGURE 3 and 4 depicts an exemplary embodiment of the present invention.

FIGURE 5 depicts results of an exemplary internal undercut simulation, in accordance with an exemplary scenario;

FIGURE 6 depicts exemplary graphs obtained based on the internal undercut simulation, in accordance with an embodiment;

FIGURES 7A-7B depict an exemplary scenario of detection of an external crack in a pipe using the apparatus of the present invention, in accordance with an exemplary scenario; and

FIGURES 8A-8B depict an exemplary scenario of detection of an internal corrosion together with lack of root in a pipe using the automated inspection apparatus of the present invention, in accordance with an exemplary scenario.

Detailed Description of the Preferred Embodiments

In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the invention. However, it will be understood by those of ordinary skill in the art that the invention may be practiced without these specific details. In other instances, well-known methods, procedures and/or components have not been described in detail so as not to obscure the invention. Reference will now be made in detail to the preferred embodiments of the present invention, examples of which are illustrated in the accompanying drawings.

Various embodiments of the present invention provide an automated inspection apparatus for non-destructive inspection of welds of pipes for detecting one or more anomalies in the pipes. Magnetic flux leakage (MFL) based techniques are typically employed for detecting defects in pipes with a size smaller than the size of a sensor and a scanning grid. MFL based techniques allows one to

identify small defects located at great depths. The present invention provides uniform magnetization to technical saturation along the entire circumference of the pipe for scanning of the anomalies in the pipe using magnetic sensors installed along the entire circumference of the pipe. The present invention enables detecting anomalies in pipes of around 2 to 4 inches diameter and 10 to 20 milli meter wall thickness more accurately and faster compared to other existing techniques. Further, the automated inspection apparatus of the present invention is an external inspection tool that utilizes MFL inspection principle when magnetic field is applied outside pipe. The automated inspection apparatus of the present invention works in a scanning mode when an operator pulls the automated inspection apparatus along a length of a pipe at points of welds for detecting anomalies in the pipe and a recording of the anomalies detected is transferred to a computing device for further processing. Additionally, the present invention enables obtaining a consistent and reliable set of databases for the piping integrity management aspects.

With reference to Figure 1, Figure 1 depicts a perspective view of an automated inspection apparatus 100 for non-destructive inspection of welds for detecting one or more anomalies in the pipes, in accordance with an embodiment. The anomalies include internal anomalies and/or external anomalies. The automated inspection apparatus includes a cylindrical magnetization unit and a sensor unit. The cylindrical magnetization unit is configured to generate a magnetic flux external to the pipe and transfer the magnetic flux inside the body of the pipe upon mounting the automated inspection apparatus on the pipe. The cylindrical magnetization unit includes a first set of four magnets 102 a-d disposed on a first side edge 103 of the cylindrical magnetization unit. Each of the first set of four magnets 102a-d comprises a steel wheel from among a first set of four steel wheels 104a-d. Each of the first set of four electromagnets 102a-d is attached to a first steel flange 106a. The second set of four magnets 102e-h is disposed on a second side edge 107 of the cylindrical magnetization unit.

Each of the second set of four magnets 102e-h comprises a steel wheel from among a second set of four steel wheels (not shown). Each of the second set of four electromagnets 102e-h is attached to a second steel flange 106b. In an embodiment, each of the first set of magnets 102a-d and the second set of magnets 102 e-h is an electromagnet. In an embodiment, each of the first set of magnets 102 a-d and the second set of magnets 102e-h is a permanent magnet.

A set of four axels 108a-d connect the first steel flange 106a to the second steel flange 106b forming a cylindrical structure. The sensor unit includes one or more sensor bracelets disposed between the first set of wheels 104 a-d and the second set of wheels along a circumference of the pipe and is configured to detect the changes in the magnetic field (in for example axial, radial, or circumferential directions) to characterize the one or more anomalies in the pipe. The sensor

bracelets include for example, 3D Hall sensors. In an embodiment, 128 – 384 sensor bracelets are included. The cylindrical magnetization unit is configured to be detachably mounted on the pipe along the circumference of the pipe and is movable along the length of the pipe, for providing a uniform magnetization up to a technical saturation along an entire circumference of the pipe.

The automated inspection apparatus 100, further includes a plurality of flaps attached to the automated inspection apparatus and that are movable freely along the weld profile of the pipe upon moving the automated inspection apparatus 100 along the length of the pipe, where the one or more sensor bracelets are installed on the plurality of flaps.

In an embodiment, the cylindrical magnetization unit creates a magnetic circuit along with a pipe wall. As the automated inspection apparatus 100 is moved along the pipe, the sensor unit detects the interruptions in the magnetic circuit. Interruptions are typically caused by metal loss and that in most cases is corrosion or manufacturing defects. The feature indication or "reading" includes its length by width by depth as well as the position of the anomaly/feature. In exemplary scenarios, mechanical damages such as shovel gouges can also be detected, where a metal loss in a magnetic circuit is
analogous to a rock in a stream. Magnetism needs metal to flow and in the absence of it, the flow of magnetism will go around, over or under to maintain its relative path from one magnet to another, similar to the flow of water around a rock in a stream. In an embodiment, the sensor unit detects the changes in the magnetic field in the three directions including, for example, an axial, a radial, or a circumferential direction to characterize the anomaly.

In an embodiment, the automated inspection apparatus 100 further includes a sensor processing system operatively coupled to the sensor unit for collecting, recording and processing the changes in the magnetic field in the three directions to characterize the one or more anomalies in the pipe detected by the sensor unit. In an embodiment, the sensor processing system comprises a computing device. In an embodiment the computing device may be remote and may be communicatively coupled to the sensor unit via a communication network. The communication network may include a wired network or a wireless network.

The automated inspection apparatus 100 of the present invention facilitates detection of very small defects located at great depths by using a magnetic system that provides uniform magnetization to technical saturation along the entire circumference of the pipes and scanning of the defect fields by the sensor bracelets installed along the entire circumference of the pipe. Further, the automated

inspection apparatus 100 of the present invention facilitates detection of anomalies in pipes of diameter ranging between 2 to 4 inches and a wall thickness of 10 to 20 millimeter with accurate detection of defect in the inner surface of the pipes as well. Moreover, the automated inspection apparatus 100 of the present invention has a small equipment size and higher inspection speed when compared to other known techniques. The automated inspection apparatus 100 of the present invention facilitate reliable and accurate non-destructive identification of anomalies in the pipes, while minimizing the need for expensive verification excavations (such as for example, digging up the pipe to verify what the problem is). Also, the accurate assessment of anomalies by the automated inspection apparatus 100 of the present invention, facilitates improvement in decision making process within a pipeline integrity management program and excavation programs can then focus on required repairs instead of calibration or exploratory digs. Moreover, the present invention provides information characterizing the anomalies based on inspection that is not only cost effective but, can also prove to be an extremely valuable building block of a pipeline integrity management program.

FIGURE 2 depicts the automated inspection apparatus 100 detachably mounted on a pipe 202 along the circumference of the pipe 202, in accordance with an embodiment. The automated inspection apparatus 100 generates a magnetic flux external to the pipe 202 and transfers the magnetic flux inside the body of the pipe 202 upon mounting the automated inspection apparatus 100 on the pipe 202. The automated inspection apparatus 100 is movable along the length of the pipe 202 for providing a uniform magnetization up to a technical saturation along an entire circumference of the pipe 202. In an embodiment, the automated inspection apparatus 100 is detachably attached to the pipe 202 by opening the first steel flange 106a and the second steel flange 106b and lowering the automated inspection apparatus 100 from above the pipe 202 without disconnecting the pipe 202 from an existing system that the pipe 202 is attached to.
FIGURE 3 and FIGURE 4 depicts an exemplary embodiment of the present invention.

The automated inspection apparatus 100 is designed as a handheld device, that can scan a weld by pulling it manually, that enables achieving required crack as well as other specification parameters. In an embodiment, the automated inspection apparatus 100 of the present invention supports a tool design specification including for example: permanent magnetic field: 100 – 200 ampere/centimeter (A/cm) (outside weld area), length: < 300 milli meter, weight: < 20 kilo grams, number of sensors: 128 – 384, sensor type: 3D Hall Sensor, noise level: < 1 A/cm, at 1 sigma. The magnetization field value as well as Hall sensor sensitivity and noise levels are key design parameters achieved by the automated inspection apparatus 100 and in order to connect these

parameters with requirements for girth welds anomalies detection a computer simulation is performed. Among all girth weld anomalies, cracks have lowest signal possible. In an example computer simulation, a finite element modelling using ELMER Finite Element Method (FEM) software was performed for the absolute crack anomaly and other internal anomalies signal simulation having magnetization level starting from 100 till 200 A/cm for the automated inspection apparatus 100. The results of the exemplary internal undercut simulation are depicted in FIG. 5.

FIGURE 5 depicts results of an exemplary internal undercut simulation 500, in accordance with an exemplary scenario. More particularly, FIGURE. 5 depicts a finite element method (FEM) simulation of three-dimensional (3D) metal forming.

FIGURE 6 depicts exemplary graphs obtained based on the internal undercut simulation 500 for a pipe with a wall thickness 10 milli meter internal undercut (depth 2mm). The graph depicts a first curve 602 corresponding to a signal at a weld area without anomaly and a second curve 604 corresponding to a misalignment area, and a third curve 606 corresponding to a subtraction result.

FIGURES 7A-7B depict an exemplary scenario of detection of an external crack in a pipe using the apparatus of the present invention, in accordance with an exemplary scenario. In the exemplary scenario depicted in FIGURES 7A-7B, a set of artificial anomalies 702 were manufactured on 89x12mm pipe girth weld in order to test a principle and device operation. The results obtained are depicted in the graphs 704 and 706 of FIGURE. 7B.
FIGURES 8A-8B depict an exemplary scenario of detection of an internal corrosion together with lack of root 802 in a pipe using the automated inspection apparatus 100 of the present invention, in accordance with an exemplary scenario. The results obtained are depicted in graphs 804 and 806 of FIGURE 8B.

Various embodiments of the present technology enable facilitates detection of very small defects located at great depths by using a magnetic system that provides uniform magnetization to technical saturation along the entire circumference of the pipes and scanning of the defect fields by the sensor bracelets installed along the entire circumference of the pipe. Further, the automated inspection apparatus 100 of the present invention facilitates detection of anomalies in pipes of diameter ranging between 2 to 4 inches and a wall thickness of 10 to 20 millimeter with accurate detection of defect in the inner surface of the pipes as well. Moreover, the automated inspection apparatus 100 of the present invention has a small equipment size and higher inspection speed when compared to other known techniques. The automated inspection apparatus 100 of the present

invention facilitate reliable and accurate non-destructive identification of anomalies in the pipes, while minimizing the need for expensive verification excavations (such as for example, digging up the pipe to verify what the problem is). Also, the accurate assessment of anomalies by the automated inspection apparatus 100 of the present invention, facilitates improvement in decision making process within a pipeline integrity management program and excavation programs can then focus on required repairs instead of calibration or exploratory digs. Moreover, the present invention provides information characterizing the anomalies based on inspection that is not only cost effective but, can also prove to be an extremely valuable building block of a pipeline integrity management program.

As will be readily apparent to those skilled in the art, the present invention may easily be produced in other specific forms without departing from its essential characteristics. The present embodiments are, therefore, to be considered as merely illustrative and not restrictive, the scope of the invention being indicated by the claims rather than the foregoing description, and all changes which come within therefore intended to be embraced therein.