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A detection system for pipeline direction based on shielded geomagnetic field

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ABSTRACT

An oil pipeline direction inspector is presented in this paper. The oil propels the enclosed spherical detector moving inside the pipeline. According to field needs, many kinds of sensors can be added to the system besides the core navigation module. We calculate the pipeline direction using the magnetic field inside the pipeline, combining with other mileage measurement methods, to calculate the three-dimensional position eventually. *T*he relationship between the trend of pipeline and the magnetic field is analyzed based on the magneto static shielding theory. Through many repeated experiments inside the underground piping system, the analysis of collected experimental data shows that although the pipeline is made from ferromagnetic material, the magnetic field still exists inside the pipeline. There is a certain mathematical relationship between the magnetic field and the pipeline *direction*, and this could be used to inspect the direction of the pipeline. A series of trial in buried pipelines have been done, showing that the system is of good accuracy and reliability.

1. Introduction

The trend and location of actual pipelines can deviate a little from the theoretical designed path, because of the changes of terrain in the pipeline construction site. With the increase of pipelines' service time, part of design data of pipelines' path lose and many pipeline pegs are damaged or disappear, thus resulting in many position information of the pipelines in the ground become agnostic [1–3]. In this case, it is very difficult to locate rapidly a failure point if there is a barbaric construction, a corrosion leakage or a pipeline damage caused by natural disasters. Therefore, speedily locating the position of underground pipelines seems essential and will greatly enhance the on-site maintenance efficiency, and reduce the suffering area of environmental pollution and the product loss [4–6].

Currently the most common method of detecting the position of pipelines usually use an outside pipe detector, which is operated by a trained worker to make a blanket search along the possible pipeline on the ground. Obviously this method is susceptible to the weather, the landscape, and the ground coverings, and its low efficiency cause it can just be applied for short-distance of small-scale detection of the trend of pipeline or the pipeline corrosion [7,8]. So it is very attractive if we can position the pipelines full line using an in pipe detector which is promoted by gas or oil in the pipeline. Mileage wheel [9] and inertial navigation [10] is commonly used for pipelines positioning by an in pipe detector. Mileage wheel can only determine the one-dimensional distance between the detector and the original point along the pipeline, but cannot determine the three-dimensional position. Inertial navigation usually requires GPS information or above ground makers [11–13], otherwise there will be a large accumulation of errors and it cannot be used for long distance navigation. However, high-frequency electromagnetic wave is reflected at the interface between the pipeline and the medium, and the intensity of remainder electromagnetic wave penetrated through pipelines is very weak. The isolation of internal and external electromagnetic field can prevent the influence of high-frequency electromagnetic on in pipe detector effectively, but can also cause electromagnetic communication system such as GPS could not be applied to pipeline inner detector.

Ferromagnetic pipeline also has shielding effect on the geomagnetic field [14], but the permeability of oil pipelines is not high enough to shield the geomagnetic field completely. And what draws more attention is that, as the direction of the pipeline changes, the remained magnetic field inside the pipeline varies. So we propose to analyze the mathematical relation between the trend of the pipeline and the magnetic field inside the pipeline, based on the magneto static shielding theory [15–18], and then calculate the spatial position of the pipeline combining with other mileage measurement methods.

This paper presents our work not only on the mathematical derivation, but also on a pipeline trend inspection system, mainly

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including an enclosed spherical detector, which can be put into the pipeline from one end of the pipeline, and a data processing computer. The spherical detector is propelled forward by the oil moving along the pipeline, and records the intensity of geomagnetic field, acceleration and other sensor information inside the pipeline at the same time. After retrieved from the end of the pipeline, these data are exported into the host computer, and further analyses are then executed base on our mathematical derivation. Many kinds of sensors could be added to the system besides the core navigation module according to field demands. A series of experiments in buried pipelines have been done using the inspection system, and the result shows great accuracy and reliability of the system.

2. Magnetic shielding effect of oil pipeline

As shown in Fig. 1, in rectangular coordinate system $o\xi\eta\varsigma$, axis $\vec{\varsigma}$ is parallel to the pipe axis, and axis $\vec{\xi}$ is horizontal. Orthogonal decomposition of geomagnetic field $\vec{B}$ is,

$$\vec{B} = |B|\cdot[\cos\delta\cdot\sin\phi \quad \sin\delta \quad \cos\delta\cdot\cos\phi] \tag{1}$$

In which, δ is the geomagnetic inclination, and ϕ is the angle between the pipe axis and the projection of $\vec{B}$ on plane $\xi o\varsigma$;

Geomagnetic field can be considered as homogeneous at a small geographic area. But if ferromagnetic material was placed into this area, magnetic induction lines will change their direction and concentrate in the ferromagnetic material, which will lead to the distribution of magnetic field change remarkably. Ferromagnetic material shields only the normal component of magnetic intensity near its surface, but does not shield the tangential component [4,9]. So $\vec{B_\varsigma}$ will remain unchanged basically, but $\vec{B_\xi}$ and $\vec{B_\eta}$ will attenuate dramatically, which are perpendicular to the pipe axis.

There are a number of factors that will influence the efficiency of magnetic shield, and the main elements are magnetic permeability of the pipeline material, thickness of the pipeline, the angle between the geomagnetic field and the pipeline axis, etc. In our research, the intensity ratio of magnetic field $\vec{B'}$ inside and magnetic field $\vec{B}$ outside is defined as attenuation coefficient λ, and the pipeline is assumed as an indefinitely long magnetic cylindrical cavity.

The thickness of cylindrical cavity wall is denoted as t, and the average radius is denoted as R. The pipelines used in industrial field basically meet the conditions of thin wall, large radius and high relative permeability, which means $a^2 \approx b^2 \approx R^2$ and $\mu_r \gg 1$, so

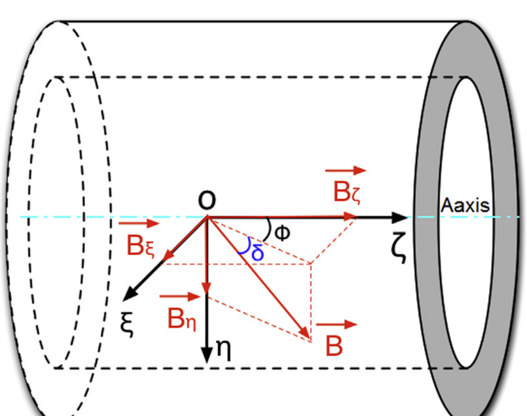

Fig. 1. Coordinate system inside the pipeline.

Fig. 2. Detector inside the pipeline launcher.

$$\lambda = \frac{\left|\vec{B'}\right|}{\left|\vec{B}\right|} \approx \frac{2R}{2R + \mu_r t} \tag{2}$$

in which,

$\vec{B'}$ — Magnetic intensity vector inside the cylindrical cavity;
$\vec{B}$ — Magnetic intensity vector outside the cylindrical cavity;
a — Inside diameter of the cylindrical cavity;
b — Outside diameter of the cylindrical cavity;
μ_r — Relative permeability of magnetic material [19,20];

Magnetic field components $\vec{B_\xi}$ and $\vec{B_\eta}$ which are perpendicular to the pipe axis attenuate greatly inside the pipe. $\vec{B_\varsigma}$ may also be influenced because the pipeline is an enclosed system. Attenuation coefficient μ is added, which is close to 1. The total magnetic field $\vec{B}$ attenuates into $\vec{B'}$ in the pipeline.

$$\vec{B'} = |B|\cdot[\lambda\cdot\cos\delta\cdot\sin\phi \quad \lambda\cdot\sin\delta \quad \mu\cdot\cos\delta\cdot\cos\phi] \tag{3}$$

3. System principle

This design of direction inspection system for oil pipeline is to improve and redesign traditional PIG (Pipeline Inspection Gauge). The internal part of the device includes accelerometer, gyroscope and magnetometer. They continuously record all the information inside the pipeline, while the detector is moving along the pipeline. Fig. 2 shows the detector inside the pipeline launcher.

The main function of the detector's hardware circuit is to achieve synchronous acquisition of several sensors' data. A typical data acquisition system of the hardware circuit includes the following modules: the sensor signal processing, processor module, memory module, external interface module and power module. The basic

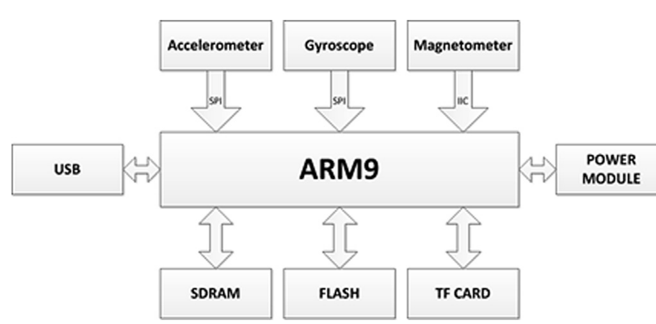

Fig. 3. Detector hardware architecture diagram.