Establishment of magnetic sensors in above ground marking system

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Abstract. Magnetic sensors used in Above Ground Markers (AGM) to measure the magnetic field signals are one of the main parts of AGM. By collecting the change of magnetic field parameter using magnetic sensors, AGM can record the precise time when MFL_PIG is passing by the AGM. In this paper, the magnetic sensors, such as induced coil and magneto-resistive sensor, are investigated in characteristics and performance of measurement. With advantages of low cost, high resolution and wide range of measurement, the induced coil is adopted in a novel AGM. The traction test, seal ability test and temperature test show that the AGM with induced coil as magnetic sensor works well under extreme condition and reacts to change the magnetic field with high sensibility.

1. Introduction
Pipeline transportation plays significant role in modern industry and national economy. However, pipeline accidents occur frequently due to aging, corrosion, construction defects, man-made damages which result from third party engineering construction or theft, and other reasons. Pipeline accidents may cause serious pollution of human living environment and great economic losses. Therefore, pipeline should be measured regularly to avoid these problems [1].

Among the methods of pipeline defect detection, leakage flux detection method is the most widely used one at present. The magnetic flux leakage detection system (MFL_PIG) mainly consists of three parts: the pipeline detector, the ground marking system and the data analysis software [2]. The ground marking system (also called above ground marker or AGM [3]) is the outer part of the magnetic flux leakage detection system, usually put above the pipeline and under the ground.
AGM detects the exact time when MFL_PIG passes through it, as well as marks the pipeline position points. When MFL_PIG completes the whole length of the pipeline detection, the large amount information which contains the position and corrosion characteristics of the pipeline, would be processed with the reference of position data given by above ground marker. The precise position of AGM is of extreme importance. This paper mainly discusses the magnetic sensors used in above ground marking system.

2. Detection principle of pipe leakage flux detection (MFL_PIG)
The theory of magnetic flux leakage detection is based on the fact that the ferromagnetic material is magnetized under the induction of the external magnetic field [4]. If the material is not defective, the distribution of the magnetic field lines is regular, as it is shown in figure1 (a). At the defect of the material, the magnetic field is bent due to the increase of the magnetic resistance. A portion of the
material inside the magnetic field leaks out of the material surface to form a magnetic flux leakage, see figure 1 (b).

In the process of MFL_PIG detection, the leakage of magnetic field is detected by sensors which produce corresponding induced signals. These signals are filtered, amplified, processed, and recorded in the mass memory of the detector. With the reference of the position data supplied by above ground marking system, the geometry size and severity of defects will be evaluated.

![Image](Magnetic_force_line_Pipe_Magnet.png)

(a) Detection of normal pipe(without defect)  (b) Detection of pipe with defects

**Figure 1.** Principle of leakage flux detection.

3. Magnetic sensors using in above ground markers

Magnetic sensor which is used in ground marking system to detect magnetic signals and to transfer to electric signals is the crucial part of the whole system. The magnetic sensors should have high resolution and wide detection range in order to improve the performance of the tracking and positioning. At present, the main magnetic sensors used in ground marking system are coil sensor, flux-gate, magneto-resistive sensor, hall sensor, nuclearprecession, optically pumped sensor and quantum interference devices, etc [5]. Table 1 shows the detection range and resolution of magnetic field intensity of these sensors [6]. The detection range of induced coil and Quantum interference devices-SQUID is the widest. It can be seen the resolution of the SQUID and the coil is the highest.

When pipeline leakage flux detector works inside the pipeline, the above ground markers (AGM) are buried along the pipeline. The distance between each AGM is 1 to 2 km. The length of long-range oil or gas transmission pipeline is usually dozens or hundreds of kilometers, at least dozens of AGMs are needed for one test. During the test, the AGM work in the field using the energy supplied by lithium battery they carry because the detection test usually takes several days. Therefore, low power consumption is also required for the magnetic sensors used in AGM.

| Magnetic Sensors       | Approximate detection range | Resolution          |
|------------------------|-----------------------------|---------------------|
|                        | 1nT  | 1μT  | 1mT  | 1T   | 1fT/√Hz | 1pT/√Hz | 1nT/√Hz |
| Induced Coil           |      |      |      |      |         |         |         |
| Flux-gate              |      |      |      |      |         |         |         |
| Magneto-resistive sensor |    |      |      |      |         |         |         |
| Hall-effect            |      |      |      |      |         |         |         |
| Optically pumped       |      |      |      |      |         |         |         |
| Quantum interference devices - SQUID | | | | | | | |

In the following part, the main characteristics and performance of coil sensor and magneto-resistive sensor will be investigated in detail.

4. Coil sensors using in above ground markers

4.1. Working principle
The use of induction coil to measure the magnetic field has been widely used for a long time. The working principle of induction coil measuring magnetic field is based on Faraday’s law of electromagnetic induction. The alternating magnetic field induces a voltage in the coil, and the intensity of the alternating magnetic field can be obtained by measuring the voltage.

Table 2 compares the characteristics and performance of coil, flux gate sensor, and magneto-resistive sensors, which could be used in above ground marking system.

| Characteristics                  | Coil    | Flux-gate | Magneto-resistive sensor |
|----------------------------------|---------|-----------|--------------------------|
| Resolution                      | High    | High      | Relatively High          |
| Energy Consuming                | Low     | Relatively low | Relatively high      |
| Volume                          | Big     | Small     | Small                    |
| Cost                            | Low     | Relatively low | High                  |
| Detection Range of magnetic field intensity | $10^{-10}$–$10^{0}$Oe | $10^{-10}$–$10^{-6}$Oe | $10^{-10}$–$10^{-6}$Oe |

Induction coil is classified into two kinds: hollow coil and magnetic core coil. Hollow coil usually has large volume, having better linearity, but lower sensitivity comparing with magnetic core coil. Core coil adds a magnetic core in the hollow coil. The linearity of core coil is not as good as hollow core, but the sensitivity is better. In MFL_PIG detection, the magnetic core induction coil is used. The typical core coil includes the core, coil, shielding, and shell composition, etc.

The equation of the induced electromotive force on the core coil is:

$$e(t) = -N \frac{d\Phi}{dt} = -NS \frac{dB}{dt} = -\mu_c NS \frac{dH}{dt}$$  \hspace{1cm} (1)

Where: N is the number of turns of the coil; S is the cross-sectional area of the coil; $\mu_c$ is the effective permeability of the core, which is related to the material and size of the core.

4.2. Characteristics and performance

Induced coil, as a traditional passive magnetic sensor, has advantages of high resolution, low cost, low power consumption, wide measurement range, high accuracy, and easy to manufacture, which enables it to be widely used in measurement of magnetic field. However, the volume of induced coil is relatively big comparing with other magnetic sensors, which limits its application.

For the application in magnetic field detection of above ground marker, the volume of induced coil is acceptable if it is carefully designed in shape.

After considering all the advantages and disadvantages of the magneto-resistive sensor and induced coil sensor, induced coil is adopted as the magnetic sensor in design of above ground markers.

5. Experiment and discussion

In order to test whether the AGM and the main clock can meet the technical specifications and the stability of the work in various environments, a series of reliability tests have been designed and completed. It verified that the above ground marker using induced coil sensor meet the requirements of leakage flux detection for pipeline. Some of the tests, which was carried out to test the performance of above ground markers with induced coil sensors are listed below.

5.1. Traction Experiment

The AGMs are placed parallel to each other and perpendicular to the travel path of the test magnet which is placed on a small cart moving back and force to stimulate MFL_PIG. The poles of the MFL_PIG were simulated by using a NdFeB magnet with a magnetic pole pitch of 40 cm. The experiment results of traction experiment are shown in Table 3.
5.2. **Seal ability test**

Due to the harsh environment of the site, the above ground markers are most likely to withstand rain or soak, so the marker should have good sealing performance to protect the components it contains. During the seal ability test, the marker is set to work mode and placed in sealed compartment after tightening the coil cover and bottom cover. The pressure in the compartment is 1MPa, which is equivalent to the pressure at the depth of 100m. After one hour, open the sealed compartment and observe whether the seams are leaked and check if the marker is working properly.

**Table 3. Result of traction experiment**

| AGM | Item | Hour | Minute | MC value | Traction times | Time Interval/s | Layout position |
|-----|------|------|--------|----------|---------------|----------------|----------------|
| 8   | 003  | 11   | 51     | 00042504 | 1             | 0              | 0.5m, Right below the pipe |
|     | 002  | 12   | 15     | 00182730 | 2             | 1402.26        | Facing, 3.6m     |
|     | 000  | 13   | 26     | 00613596 | 3             | 4308.86        | Facing, 4m      |
|     | 006  | 13   | 53     | 0071675  | 4             | 1580.79        | Facing, 4m      |
| 9   | 006  | 18   | 22     | 00041059 | 1             | 0              | 0.5m, Right below the pipe |
|     | 000  | 19   | 57     | 00612333 | 3             | 3995.81        | Horizontal along the axis, 1m |
| 2   | 001  | 12   | 11     | 00044781 | 1             | 0              | 0.5m, Right below the pipe |
|     | 005  | 12   | 39     | 00214939 | 2             | 1701.58        | 1.4m            |
|     | 004  | 13   | 46     | 00616271 | 3             | 4013.32        | Perpendicular, 1m |
| 1   | 001  | 13   | 31     | 00024222 | 1             | 0              | Facing, 2.7m     |
|     | 000  | 14   | 38     | 00425560 | 2             | 4013.36        | Facing, 4m      |
|     | 004  | 15   | 04     | 00583619 | 3             | 1580.59        | Facing, 4m      |
| 5   | 006  | 12   | 12     | 00057370 | 1             | 0              | 0.5m, Right below the pipe |
|     | 000  | 13   | 14     | 00428957 | 3             | 3715.87        | Perpendicular, 1m |

5.3. **Temperature test**

Since the working environment of the above ground marker is in the wild, or even the desert and ice sheets, it is required to work in a wide temperature range. To verify the temperature performance of the instrument, the above ground marker were put into temperature thermostat test chamber with temperature range can be set from -40 to 130 °C. The temperature stability in the chamber is 0.1 °C. The experiment results of temperature experiment are shown in Table 4.

**Table 4. Result of temperature experiment**

| Temperature/ °C | AGM | Start Time | Passing Time | MC (Passing) | MC (difference) | Note |
|-----------------|-----|------------|--------------|--------------|----------------|------|
| 70              | A   | 9:30       | 10:00        | 330987       | 300742         | Highest |
|                 | B   | 9:30       | 10:00        | 331002       | 300757         |       |
| 50              | A   | 10:15      | 10:45        | 601481       | 571236         | Normal |
|                 | B   | 10:15      | 10:45        | 601494       | 571249         |       |
| 20              | A   | 11:02      | 11:30        | 872023       | 841778         |       |
|                 | B   | 11:02      | 11:30        | 872039       | 841794         |       |
| 0               | A   | 11:40      | 12:15        | 1142641      | 1112396        |       |
|                 | B   | 11:40      | 12:15        | 1142653      | 1112408        |       |
| -10             | A   | 12:31      | 13:00        | 1411781      | 1381536        |       |
|                 | B   | 12:31      | 13:00        | 1411790      | 1381545        |       |
| -20             | A   | 13:20      | 13:50        | 1712792      | 1682547        | Lowest |
|                 | B   | 13:20      | 13:50        | 1712808      | 1682563        |       |

Note: 1. The synchronization time of the AGMs is 9:10, and value of MC is 30245.
2. MC (difference) is the difference between the synchronization moment and when the stimulating magnet passing by.
During the temperature experiment, the main clock (MC) is synchronized with the two above
ground markers - A and B at room temperature, and the PIG magnetic pole is simulated with a small
magnet passing through the ends of the coils of ground markers. First, the induced electromotive force
waveform was recorded at room temperature. Then, put the markers into thermostat test chamber with
the end of the coil towards the observation window, and adjust the temperature in accordance with the
order from high temperature to low temperature. After adjusting the temperature of the thermostat
chamber, make the markers work for half an hour, and record the waveform when the small magnet
passing by.

5.4. Experimental results and analysis
Above ground markers using induced coil as magnetic sensor to collect the magnetic signal when
MFL_PIG passing by the AGMs works well during the traction test. The newly designed AGM also
passed the extreme temperature test and seal ability test with ideal result.

It is to be mentioned that the traction test carried out in this paper is based on that the above ground
markers are placed perpendicularly to the axis of the pipeline. If the AGMs are laid deflected to the
pipeline because of the subsidence of the AGMs in the soil, errors may occur. And the error is
proportional to the deflected angle. The detailed information of the experiment with different layout of
the above ground marker are investigated in other articles, see reference [7].

6. Conclusion
As a magnetic sensor, induced coil has the advantage of low cost, simple structure, wide measurement
range and high resolution. After being carefully designed in structure, it can be put inside a cup-shaped
AGM to measure the change of magnetic induction of the field. It fulfils the requirements of magnetic
sensors used in AGM in traction test, temperature test and seal ability test.

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