Weak magnetic stress internal detection technology of the long gas and oil pipelines

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January 7, 2019

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Abstract牋 The weak magnetic stress internal detection technology is in the weak magnetic environment also in the geomagnetic field environment. The weak magnetic stress internal detection technology is to detect the stress damage area and the stress damage degree of the member by detecting the weak magnetic signal on the surface of the stress concentration region of the ferromagnetic metal member. Weak magnetic stress internal detection technology of the pipeline can effectively detect the stress concentration regions where the pipeline has not formed macroscopic defects, and advance the pipeline safety alarm time, which makes up for the weaknesses of the traditional magnetic flux leakage internal detection technology. In this paper, the key technologies of the weak magnetic stress internal detection are stated. The detection mechanism, influencing factors and engineering tests of weak magnetic stress detection technology are deeply analyzed. Furthermore, the future development direction of the weak magnetic stress internal detection technology is proposed.

Keywords: Magnetic signal; Geomagnetic field; Pipeline inner- detection; Stress concentration; Lift-off value

1 Introduction

Stress concentration is an essential reason for sudden accidents in long oil and gas pipelines. In particular, a large number of stress concentration regions exist in the process of pipe manufacture and construction of new pipelines. Some stress concentration areas have reached the critical yield points, leading to the occurrence of sudden accidents after the pipeline is put into production [1-3].Conventional non-destructive testing technology including magnetic powder, magnetic flux leakage, eddy current, and infiltration, etc. They all have played a significant role in defect monitoring, accident prevention and other side effects of the pipeline. However, only macroscopic defects can be found, It is impossible to carry out effective evaluation of the stress concentration regions of the unformed defect due to construction, welding, foundation settlement, internal media pressure, thermal expansion and other factors, thus sudden accidents caused by stress damage cannot be avoided[4-5]. From the analysis of pipeline accidents in recent years, it is obvious that new pipeline accidents happen frequently, and no macroscopic defects are formed at this time [6-8]. Weak magnetic method can effectively judge the stress concentration area of ferromagnetic metal components and evaluate the service life of ferromagnetic components. It has the advantages of light equipment, no special magnetization, fast and convenient detection, high sensitivity, etc. Thus, this technology has been widely valued by domestic and foreign scholars [9-10].

Based on the weak magnetic stress detection technology, we analyzes the influencing factors of pipeline weak magnetic stress detection technology, summarizes the engineering application of pipeline weak magnetic stress detection technology, and proposes the future prospect of pipeline weak magnetic stress detection technology in this paper.

2 Weak magnetic stress internal detection technology of pipeline

2.1 Weak magnetic stress internal detection mechanism of pipeline

The weak magnetic detection method is to determine the stress damage regions and the degree of stress damage of the workpiece by detecting a weak magnetic signal in the stress concentration region of the ferromagnetic metal components in the geomagnetic environment [11-14].Under the combined action of the geomagnetic field and the applied load, the magnetic domain in stress concentration regions will cause the magnetostriction. As a result, the magnetic domain lattice will be orientation and irreversible reorientation, and will form additional magnetic poles in the stress and deformation concentration regions. This phenomenon macroscopic displays an abnormality of the magnetic field *Hp* around the component, that is the tangential magnetic signal component at the maximum stress concentration region appears an extremum $Hp(x)=Hp_{max}$ and the normal magnetic signal component *Hp(y)* changes sign and has zero value in the abnormal region[15-17]. According to the ferromagnetic theory [18-19], the stress causes change of the shape and distribution of the magnetic domain inside the ferromagnetic component and the self-magnetization increases in the form of a leakage magnetic field on the surface of the ferromagnetic component in the geomagnetic environment, especially the signal normal component *Hp(y)* crosses zero and the tangential component reaches a maximum at the defect and stress concentration regions, as shown in Figure 1.

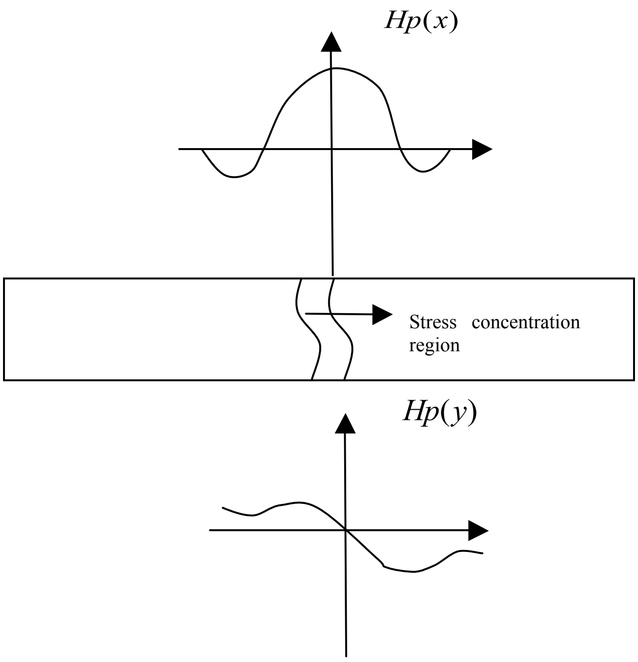

Fig. 1 Weak magnetic signal characteristics.

2.2 Weak magnetic stress internal detection technology of the pipeline

The pipeline weak magnetic internal detection system applies the principle of weak magnetic detection and uses the media conveyed in the pipeline as the power to complete the non-destructive testing evaluation of the pipeline. The pipeline weak magnetic internal detection system mainly includes three parts: the pipeline weak magnetic internal detection device, the mileage calibration device and the data analysis and processing system. The structure diagram of the weak magnetic internal detection device of the pipeline is shown in Figure 2.

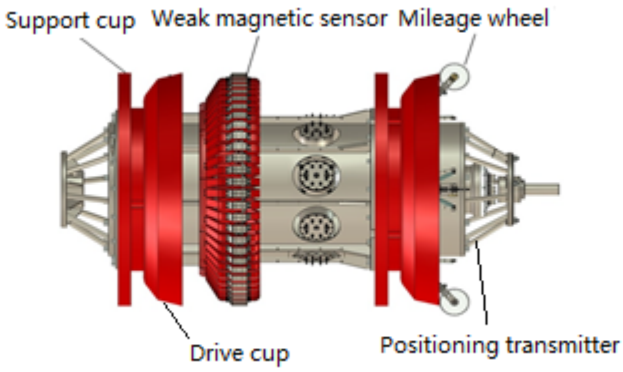

Fig. 2. Structure diagram of the weak magnetic internal detection device of the pipeline

The pipeline weak magnetic stress internal detection device mainly realizes the detection of the stress concentration regions on the pipeline and ensures the stable running of the detector. The device mainly includes four parts: a driving unit, a measuring unit, a computer unit, and a power supply unit.

The mileage calibration device precisely locate of the stress concentration regions on the pipeline and the particular components of the pipeline. It is mainly composed of three parts: the external marking of the pipeline, the synchronous time calibration inside and outside the pipeline and the odometer wheelsrecord. All these three elements work together to record the mileage and other information.

The data analysis and processing system carry out the work of visual processing of the weak magnetic data detect by the weak magnetic sensor and generate the final test results of the pipeline stress concentration regions. The weak magnetic sensor detect the data that is displayed on the computer after a series of processing. The data interpreter can visually observe the distribution of the stress concentration regions. At the same time, the interface displays the mileage information. The location of the stress concentration regions is determined and marked by mileage information, providing a basis for the detection or evaluation of pipeline service life [20-21].

3 Influencing factors in the internal detection of weak magnetic stress

The pipeline internal detection environment is complicated. During the detection process, there is a lift-off value between the weak magnetic stress detection probe and the pipe wall. The detection signal is affected by external magnetic field strength, probe lift-off value, the value of the external load and detection temperature. The external magnetic field strength and probe lift-off value have the most significant influence on the detection signal. Therefore, we focuses on the analysis of the influence of the external magnetic field strength and the probe lift-off value on the weak magnetic signal in this paper.

3.1 Influence of external magnetic field on weak magnetic signal

In order to study the magnetic signal distribution in the stress concentration regions, a magnetostatic model of the steel plate with stress concentration regions is established. The size of steel plate is 470mm*50mm*14.7mm, and the size of stress concentration region is 10mm*10mm*5mm. According to the actual physical properties of X70 steel, the Poisson's ratio of the material properties is set to 0.28, and the elastic modulus is 2×10^{6} for simulation. The magnetostatic model diagram is shown in Figure 3.

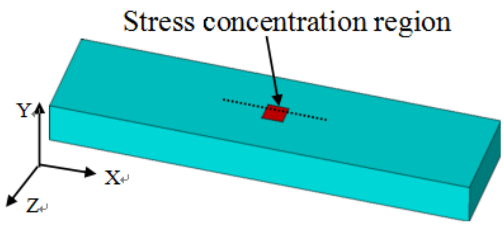

Fig. 3 Steel plate magnetostatic model of the stress concentration.

The scanning path is set in the direction of the tensile force of 1mm lift-off above the steel plate research area, and the variation of magnetic memory signal B above this path under different external magnetic field strength is studied. The results of the study area in the geomagnetic field environment are shown in Figure 4. The amplitude of the magnetic signal increases and the signal characteristics become more pronounced with the increase of the stress.

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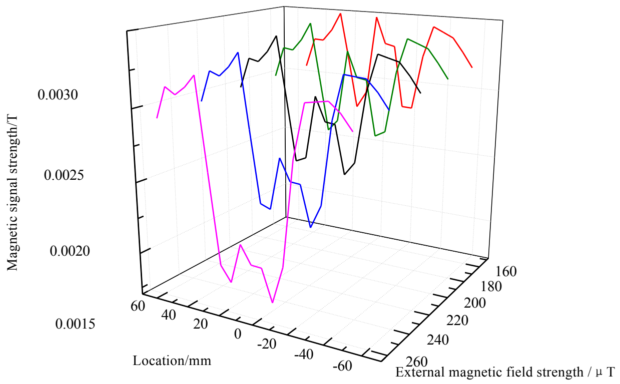


Fig. 4 Magnetic relations in the environment of the geomagnetic field

In order to research the influence of external magnetic field on the magnetic signal in the study area, the spatial magnetic field strength should be increased in the case of the same degree of stress concentration. The magnetic curve under the action of different external magnetic fields is shown in Figure 5. In this figure, the stress concentration region is in the range of -5 mm to 5 mm on the abscissa.

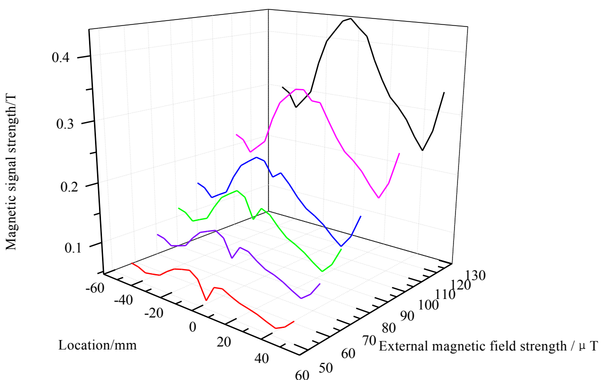


Fig. 5 Magnetics curve under different magnetic field strengths

It can be seen from Fig. 5that the value of the magnetic signal on the surface of the stress concentration area increases as the external magnetic field strength increases. However, the difference between the magnetic signal in the stress concentration region and the nearby signal reduces; when the external magnetic field reaches the maximum, the signal in the stress concentration region is unrecognizable, and the magnetic memory signal feature is covered.

3.2 Influence of lift-off on weak magnetic signal

In order to study the variation law of magnetic signal under different lift-off values, the variation law of the magnetic signal in the range of the lift-off value of 0-15 mm is shown in Fig. 6 in the case of a certain degree of stress concentration.In the figure, the X coordinate 180-220mm is the stress concentration region. It can be seen from Fig. 6 that there is still a magnetic signal when the measuring point has a certain lift-off value from the surface, and when the lift-off value is small, the stress concentration region can be clearly distinguished. The magnetic induction intensity gradually decreases with gradual increase of the lift-off value. When the lift-off value is less than 10 mm, it can be seen that the curve calculated by the model has excellent repeatability and the stress concentration regions can be identified. As the lift-off increases, the magnetic induction intensity of the steel plate surface decreases significantly, the identificationlevel of the stress concentration zone decreases, and the magnetic signal is undetectable.

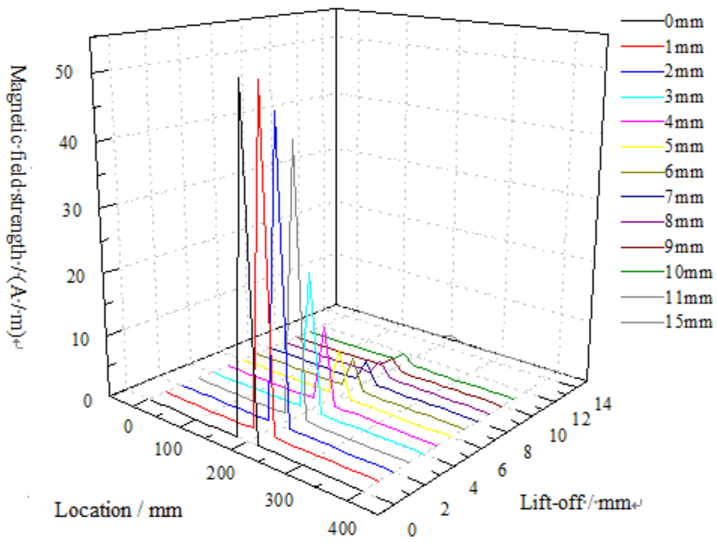
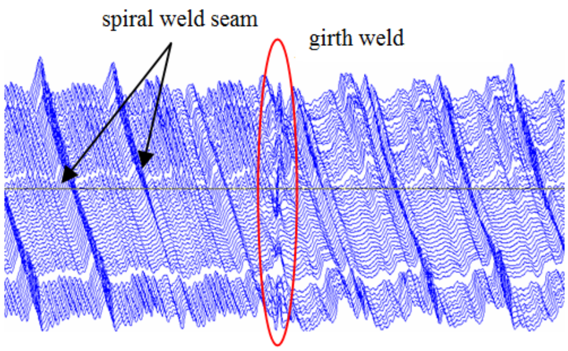


Fig. 6 The variation law of magnetic signal under different lift-off values

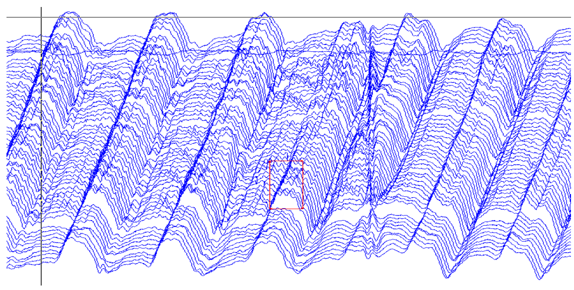
4 Engineering application of the weak magnetic stress internal detection technology

In 2017, the Φ1219 weak magnetic stress internal detection equipment was developed in Shenyang University of Technology and carried out the internal testing service for the third line of the West-East Lianmuqin – Liaodun - Yandun - Hongliu -Guazhou Station in China. According to the amplitude gradient change of the weak magnetic signal, the stress concentration regions level is judged, the data belongs to the normal range, and the data detection is completed.

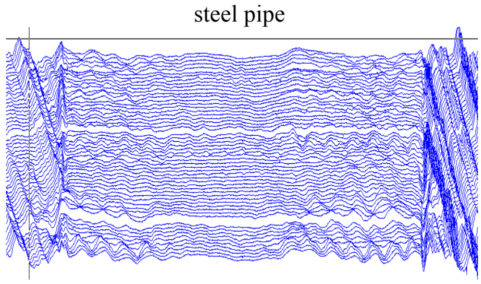
After the pipeline weak magnetic stress detector is operated in the pipeline, an image of the weak magnetic signal can be obtained according to the detected amplitude of the weak magnetic signal. The magnetic memory internal detection signal image of the pipeline are shown in Fig. 7.



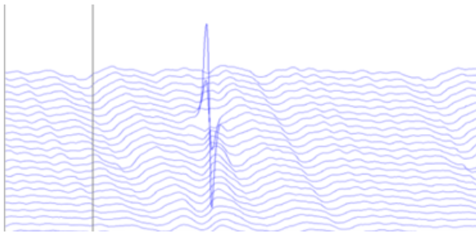
（a）Weak magnetic signal near the girth weld



（b）Characteristics of stress concentration signal caused by indentation at the end of the steel pipe



（c）Signal characteristics of the elbow



（d）Obvious stress concentration region

Fig. 7. Weak magnetic stress internal derection signal of the pipeline

The weak magnetic stress internal detecting device is composed of a plurality of weak magnetic sensors as shown in Fig. 2. As can be seen from Fig. 7, under the detection of a multi-channel probe, each line the data detected by a weak magnetic sensor. The signals noted in the figures are different weak magnetic signal characteristics by different typical features of the pipe. The weak magnetic internal detection technology is very sensitive to the stress concentration region. The weak magnetic signal at the stress concentration region and the weak magnetic signal at the non-stress concentration region are significantly different. This makes it possible to clearly distinguish between the girth weld, the spiral weld seam, the elbow, and the like.

5 Future prospects

At present, the weak magnetic stress internal detection technology of the pipeline has made great achievements in engineering application, however, further research is still needed in theory and engineering applications, mainly in the following three points:

(1) Study on the formation mechanism of weak magnetic stress signals. It is difficult to establish the magnetomechanics coupling relationship in the traditional theory. The mechanism of weak magnetic signal generation in stress concentration regions is not unified, and the mechanism research of weak magnetic stress detection technology is still a severe problem.

(2) Method for judging the stress level of weak magnetic signals. The pipe forms stress concentrations under various loading conditions. When the stress concentration is at different stages, the material microstructure changes and the corresponding weak magnetic stress detection signal characteristics are different. According to this, we can effectively identify and process the weak magnetic signals at different stages and divide the stress level in different stages base on the characteristic parameters of weak magnetic signals that

is the key scientific problem of component life evaluation.

(3) Automatic recognition method of weak magnetic signals. At present, the identification of the internal detection data in the weak magnetic stress of long oil and gas pipelines relies on artificial recognition, which has the disadvantages of low efficiency and large error. Realizing automatic recognition of massive data in pipeline weak magnetic stress will significantly improve data interpretation efficiency and reduce human error.

The weak magnetic stress detection technology has an excellent engineering application effect and extensive development and application space in the pipeline internal inspection field; the research of basic theory is the key to the development and application of this technology.

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