Development of the Detection Arm of Multichannel Geometry Pig of Oil and Gas Pipeline

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Abstract. The geometry pig is widely used to detect pipeline geometry deformation in the field of oil and gas pipeline. As the core component, the detecting arm is very important for pipeline deformation detection. Firstly, this paper introduces the composition and principle of the detection arm system. Secondly, the design principles and methods of sensor circuit are described from the chip selection and circuit design. Finally, the layout of the spring and the key structure design method of the detection arm are discussed.

1. Introduction
Pipeline geometry deformation is a common form of pipeline defects. Serious deformation affects not only pigging, intelligent detection and other processes, but also pipeline safety [1]. The geometry pig is the most widely used in the field of pipeline geometry deformation detection. It can not only enable the pipeline operation department to grasp the information of pipeline geometry deformation, but also provide guarantee for the safe operation of intelligent detectors such as magnetic flux leakage detector and ultrasonic detector in the pipeline [2,3].

2. The detection arm system

2.1. Structure and principle
The principle of the detection arm system is based on the hall effect. The rotating magnet generates varying electromotive force inside the chip, and the rotation angle is linearized with the electromotive force. The geometry pig with ten channels is shown in the fig.1(a). As can be seen from the figure, the basic structure of the detection arm system includes detection arm, shell, hall sensor, spring, radial magnet, bracket and so on. The detection arm contacts with the pipe wall under the preload of the spring, and the shell protects the sensor from the external high-pressure environment. The radial magnet is fixed on the central axis of the detection arm to provide a radial changing magnetic field for the hall sensor, and the rotating angle of the detection arm can be recorded [4-6].
2.2. Mathematical Modeling

According to the detection principle of the geometry pig, the geometric model of the detection arm system can be simplified as shown in the fig 2. When the detection arm passes over the deformation section of the pipeline, the relation between the changing angle of the detection arm and the deformation value of the pipeline satisfies the formula (1)[7].

$$\Delta h = l \cos \alpha - l \cos(\alpha + \Delta \alpha)$$ (1)

Where, $\Delta h$ is the radical variation of the pipeline deformation; $l$ is the length of detection arm; $\Delta \alpha$ is the changing angle of the detection arm; $\alpha$ is the initial angle of the detection arm.

3. Sensor circuit design

The Angle sensor is the core detection element of the detection arm, which converts the pipe deformation into an Angle for measurement. For the design of sensor circuit, the appropriate detection chip should be selected first, and then built appropriate power supply, noise reduction peripheral circuit. Finally, making the circuit board and analyzing the detection accuracy would be done. If there are any problem, further modification are required.

3.1. Selection of the chip

(1) Common chips using angle measurement

The selection of chip requires comprehensive consideration of the detection accuracy, reliability and cost. At present, the common Angle detection chip can be divided into photoelectric coding chip and magnetic rotation coding chip. The comparison of performance parameters of above two kinds’ angle detection chips is shown in the table.1.

| Form                        | Detection accuracy | Application environment                                      | Cost    |
|-----------------------------|--------------------|-------------------------------------------------------------|---------|
| Photoelectric coding chip   | up to 0.036 °      | Susceptible to temperature, humidity, sundries and other    | Expensive |
|                             |                    | environmental factors                                       |         |
| Magnetic rotation coding chip| Up to 0.1°         | Use normally in indoor environment, high reliability        | Cheap   |

Although the detection accuracy of magnetic rotation coding chip is slightly lower, according to the theoretical calculation, the accuracy reach 0.5 °meets the detection requirements of pipeline geometry
deformation. In addition, magnetic rotation coding chip also has the advantages of good compatibility to the environment, cheap price, so magnetic rotation coding chip is priority selection.

2) Magnetic rotation coding chip-316BCG

In this paper, 316BCG magnetic rotary coding chip produced by Melexis is selected and the chip integrates hall detection, operational amplification, A/D conversion and D/A conversion and other functions. The chip is small in size and has a strong anti-interference ability. It can measure a small angle in the harsh environment and be able to measure a high precision absolute angle position information from 0° to 360°. The chip is shown in fig.3 (a).

3.2. Circuits design

The pin distribution structure of the chip is shown in fig.3. (b). In the process of designing the circuit diagram, in order to stabilize the input voltage, a small capacitor can be added between the input voltage (Vss) and the ground (Vdd), which is selected as 10nF according to the recommended value in the chip specification. If the pin of the chip is suspended, it may be interfered by the outside, so it should be avoided as much as possible. Unused input pins in this circuit, such as Test0, Test1, and SCLK, can be connected directly to the ground. Since the default mode of operation is selected in the circuit, the function selection pin Switch is also directly connected to the ground wire. Pin Vdig is the unused output port, and a capacitor is added between it and the ground. In order to stabilize the output voltage and filter out the ripple circuit interference, a filter capacitor should be added between the analog output pin out and the ground. The circuit is designed as shown in fig.3.(b).

![316BCG](image)

(a) 316BCG

(b) The pin distribution structure of the chip

(c) The PCB of the circuit

The overall outline design of the circuit board is circular. In order to minimize the size of the circuit board, the circuit is used in the packaging model 0603 chip capacitance. The printed sensor PCB is shown in figure 3 (c).

3.3. Simulation of magnetic field

316BCG needs 15-75mt magnetic field to work properly, so the magnetic field strength after the magnet penetrates the seal plate needs to be guaranteed to reach 15-75mT. Ansoft software is used to simulate the strength of static magnetic field. In Ansoft software, the model of cylindrical magnet, sealed aluminum plate, magnetic rotation coding chip and air are established and then the parameters of each model is set separately. The material of the magnet was NdFe35. The relative permeability was 1.099, and the coercivity was -8.9*10-5a /m. The relative permeability of aluminum is 1.001. Both the air and the chip have a relative permeability of 1.000. Fig.4 (a) shows the simulation results of the two-dimensional model, and the distribution of magnetic induction lines in the whole space is shown in the figure.
Fig. 4 The magnetic field simulation results of the radical magnet rotating above the chip

It can be seen from the figure that the aluminum alloy sealing plate basically does not affect the distribution of the original magnetic line. A 3D model is established, and the parameters are set basically the same as those in the 2D model. The results of simulating the magnetic field intensity on the surface of the sensor chip are shown in figure 4 (b).

4. The design of the detection arm structure

4.1. Layout of spring

The detection arm needs to keep in close contact with the pipe wall by the elastic force of the spring, so the installation mode and stiffness of the spring have a great influence on the accuracy of the detection arm. The spring can be arranged between the detection arm shaft and the tube wall or above the shaft. The two structures are shown in figure 5.

Fig. 5. Spring layout of the detection arm system

According to the direction of force on the spring to be divided, the two kinds of arrangement of the spring are respectively tension spring and compression spring. The advantages of tension spring are simple structure and convenient installation. The disadvantage is that the connection is not reliable, and in the case of severe vibration is easy to fall off. Furthermore, the pre-tightening force can not be adjusted. The advantages of the pressure spring are reliable installation, low risk of shedding, high reliability and good passability. The disadvantage is the complex structure. Under comprehensive consideration, it is prior to choose the pressure spring layout.

4.2. The overall structure of the detection arm

To ensure the overall structural strength of the inspection arm, the main part of the base is processed by a single solid aluminum block. In order to prevent scratching the inner wall of the pipe and reduce the wear of the swing arm itself, the roller type structure is adopted. The 3D model of the detection arm is shown in fig. 6.
4.3. Intensity check of key structure

The main function of the chip cover is to protect the sensor circuit. In order to ensure the detection arm can work normally under high pressure environment, it is necessary to check its deformation and strength. Intensity check is carried out in ANSYS WorkBench. First, the material is set as 45 steel and the elastic modulus is $2.1 \times 10^{11}$ Pa. The poisson's ratio is 0.3. And then, set the unit, import the 3d model, divide the parts into several simpler parts, divide the grid and assign materials. Finally, a uniform load of 10 MPa is applied on the upper surface and side of the chip cover. The fixed constraint is set at the bolt hole connected to the base, and the results of deformation and stress obtained after calculation are shown in fig.7.

As can be seen from figure 7, the maximum deformation occurs in the middle of the top of the chip cover, and the deformation is 0.005mm. The value is small, and the sensor circuit will not be damaged due to compression deformation. It can be seen from fig.7(b) that the maximum stress still appears in the middle of the top, and the maximum stress is 84.4 MPa, less than the yield limit of 45 steel ($=355$ MPa), and no failure will occur.

5. Conclusion

In this paper, the development method of the detection arm of the geometry pig for oil and gas pipelines are studied. The composition and principle of the detection arm system are introduced. The design principle and method of sensor circuit are presented, including chip selection and circuit structure design. The design principle of the key structure of the detection arm is proposed, and the key components of the detection arm are optimized by analyzing the magnetic field strength and structure strength. The research content of this paper has important guidance and reference significance for the development of the detection arm of multichannel oil and gas pipeline geometry pig.
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References

[1] A.P. Teixeira, C. Guedes Soares, T.A. Netto, et al. Reliability of pipelines with corrosion defects, International Journal of Pressure Vessels and Piping. 85(2008) 228-237.
[2] G. Canavese, L. Scaltrito, S. Ferrero. A novel smart caliper foam pig for low-cost pipeline inspection—PartA: Design and laboratory characterization. 127(2015) 311-317.
[3] C. Ramella, G. Canavese, S. Corbellini. A novel smart caliper foam pig for low-cost pipeline inspection – PartB: Field test and data processing. 133(2015) 771-776.
[4] Dong Kyu Kim, Sung Ho Cho, Seoung Soo Park, et al. Design and Implementation of 30” Geometry PIG, KSME International Journal. 17(2003) 629-636.
[5] Claudio Camerini, Jean Pierre von der Weid, Miguel Freitas, et al. Feeler Pig: a Simple Way to Detect and Size Internal Corrosion. In: International Pipeline Conference, Calgary, Alberta, Canada, September 29-October, 2008, paper no.64626.
[6] Dong Kyu Kim, Sung Ho Cho, Seoung Soo Park. Development of the Caliper System for a Geometry Pig Based on Magnetic Field Analysis, KSME International Journal. 12(2003) 1835-1843.
[7] Xiaolong Li, Shimin Zhang, Shuhai Liu. An experimental evaluation of the probe dynamics as a probe pig inspects internal convex defects in oil and gas pipelines, Journal of Natural Gas Science and Engineering. 26(2015) 229-239.
[8] Dennis R. Smith, Tulsa, Okla. BEND DETECTOR PIG. Patented Jun. 5, 1990. United States Patent.
[9] Jeffrey S. Rosenberg, Kevin W. Lockyear. PIPELINE GEOMETRY PIG. Patented Sep. 4, 1990. United States Patent.
[10] Albert B. Cox, Wilmington, Calif. CALIPER. Patented Feb.11,1936. United States Patent.