A New Magnetic levitation System for Pipeline Inspection

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Abstract. Through simulation design and simulation calculation, a new magnetic suspension system for pipeline detection is proposed. The system is convenient to carry pipeline detection device and realize the detection of pipeline interior. In this paper, the theoretical principle of the system is discussed, the model is simulated by using the simulation software, and the control method of the system is analyzed theoretically.

1. Overview
Due to the late start of PE pipeline in China, there is still a big gap between domestic and foreign countries in the production and detection of PE pipeline. At present, manual sampling and ultrasonic testing are still the main detection methods in China, but manual sampling inspection is time-consuming and inefficient, and ultrasonic testing is expensive and needs long-term maintenance. With the growth of national economy, the demand of domestic plastic pipeline is increasing, which leads to more attention to the upgrading of PE pipe detection technology, especially after a series of national strategic projects such as West to East Gas Transmission and Sichuan East gas transmission, this kind of demand is more urgent.

Magnetic levitation is a method that uses electromagnetic field to levitate ferromagnetic objects without space contact with the float. It has been widely used in magnetic bearings and maglev trains. Magnetic levitation is in the active stage of research, and various new technologies based on magnetic levitation emerge in endlessly. In this paper, a new type of magnetic levitation platform is designed, which can be used for the detection of pipeline interior.

2. Magnetic Suspension System for Pipeline Inspection
The magnetic levitation system introduced in this paper is based on the principle of push-down magnetic levitation, that is, the repulsion force between permanent magnets is used to provide float buoyancy for the suspension platform. The system is mainly composed of two parts, namely, the power part with permanent magnet as the main body at the bottom, and the control part composed of control circuit to control the horizontal force of float. Its basic structure is shown in Fig. 1.
2.1 Overview of Suspension Principle
As shown in the Fig. 2, it is the magnetic field excited by the levitation magnetic circuit and the permanent magnet of the suspension platform, and the upper part is the magnetic field excited by the magnetic suspension platform. At the bottom is a ring type Nd-Fe-B permanent magnet, which excites a magnetic field, namely the stator magnetic ring magnetic field. The direction of the magnetic induction line of the magnetic field is opposite to that of the magnetic induction line of the floating platform, so the electromagnetic force is generated. When the electromagnetic force $= \left( \text{mass of the moving platform} \right) \times \left( \text{the acceleration of gravity} \right)$, the magnetic suspension platform will remain stable in the vertical direction and reach a state of suspension.

2.2 Simulation Analysis of Magnetic Levitation Model
Comsol Multiphysics software is used to model and simulate the maglev platform. Using the magnetic field and no current interface of the AD/DC module in Comsol, without considering the influence of the power coil, the magnetic field produced by alternating current will not appear in the model, so the steady state research is chosen in the research module.

Taking N52 NdFeB permanent magnet with the strongest magnetism as the simulation object, the relative permeability and residual flux density are set as 1.08 and 1.49 Tesla respectively in COMSOL Multiphysics. At the same time, magnetization is only carried out in the desired ideal condition, i.e. the Z-axis direction.

In this scheme, the thrust of the float comes from the sum of the repulsive forces from all directions. In the ideal state, the resultant force of the repulsive force of the float in the X, Y directions is 0, and the final effect on the float is to produce an upward thrust. The project team set the outer diameter of the ring permanent magnet is 400mm, the inner diameter is 240mm and the thickness is 34mm.

Under the above conditions, simulation analysis is carried out, and the distribution of Y-Z plane magnetic field is shown in Fig. 3.
Then, the force of the float is calculated in COMSOL, and the conclusion is drawn: under the assumed model size, the suspension force on the suspension body in the vertical direction of Z-axis is 106.20N.

2.3 Selection of Geometric Parameters of Maglev Foundation Platform and Its Influence on Suspension Force.

After determining the use of ring permanent magnet to provide levitation force for the float, in order to select the appropriate size, the structure of the Maglev Platform needs to be analyzed systematically to determine the size distribution of each structure of the Maglev Platform. In this paper, in order to get the geometric parameters that are beneficial to suspension, the geometric parameters of permanent magnet are controlled by variable control method, and the influence of various factors on levitation force is separated from each other. By changing only one factor at a time, the influence of different size parameters of Maglev Platform on suspension force is simulated and analyzed.

2.3.1 Influence of Thickness of Lower Stator Magnetic Ring on Suspension Force

In order to study the influence of the height distance of the lower stator magnetic ring on the suspension force. We keep the outer diameter of the stator magnetic ring as 400mm and the inner diameter as 240mm, and change the thickness of the magnetic ring with a gradient of 5mm to obtain the data in the table below.

| size (mm) | 5    | 10   | 15    |
|----------|------|------|-------|
| force (N) | 5.14 | 20.369 | 49.06 |
| size (mm) | 20   | 25   | 30    |
| force (N) | 72.019 | 114.74 | 119.76 |
| size (mm) | 35   | 40   | 45    |
| force (N) | 124.79 | 126.6 | 128.53 |

According to the data analysis in the table above, it is concluded that the levitation force first increases gradually with the increase of the height of the lower stator magnetic ring, and then tends to be stable. The variation trend of levitation force with the increase of stator magnetic ring height is shown in Fig. 4.
Fig. 4 Variation Trend of Suspension Force with the Increase of Stator Magnetic Ring Height

The significance of this data analysis is to understand the influence of the thickness change of stator magnetic ring on the suspension force. According to the trend chart, when the thickness of the magnetic ring is small, increasing the thickness of the magnetic ring can quickly improve the levitation force. However, when the thickness reaches a certain value, the improvement of levitation force caused by increasing the thickness is very limited, so we must find other methods to improve the suspension force.

2.3.2 Influence of Outer Diameter and Inner Diameter of Lower Stator Magnetic Ring on Suspension Force

First, keep the inner diameter and thickness of stator magnetic ring unchanged, and change the thickness of magnetic ring by changing the outer diameter of magnetic ring. First, fix the inner diameter value of 240mm and the thickness of 34mm, and gradually change the outer diameter of magnetic ring with a gradient of 10mm, and obtain the data in the table below.

| size (mm) | 330  | 340  | 350  |
|----------|------|------|------|
| force (N) | 23.376 | 39.654 | 44.037 |
| size (mm) | 360  | 370  | 380  |
| force (N) | 71.455 | 88.9  | 96.173 |
| size (mm) | 390  | 400  | 410  |
| force (N) | 106.2 | 107.79 | 109.23 |

The variation trend of levitation force when the outer diameter of stator magnetic ring increases is shown in Fig. 5.

Fig. 5 Variation Trend of Suspension Force When the Outer Diameter of Stator Magnetic Ring Increases

When the inner diameter is constant, increasing the value of the outer diameter can improve the levitation force, but the obvious slowing down trace can be seen from the trend diagram. The farther the
position of the suspension is, the less the influence on the magnetic field environment near the suspension is. It can be concluded that with the increase of the outer diameter of the lower stator magnetic ring, the levitation force will always maintain a stable size.

The difference between the outer diameter and the inner diameter, that is, the width of the ring, is taken as the abscissa and the levitation force as the ordinate to draw the trend diagram. Multiple curves can be obtained by selecting different inner diameter values. The variation trend of levitation force with the increase of ring width at different inner diameters is shown in Fig. 6.

![Fig. 6 Variation Trend of Levitation Force with the Increase of Ring Width at Different Inner Diameters](image)

From each curve individually, with the increase of ring width, the value of levitation force also increases, but the increasing range tends to be gentle, which is consistent with the situation described in the previous trend diagram of outer diameter increase. However, if the width of the ring is regarded as a fixed value and the curves are compared longitudinally, it can be found that no matter what the width of the ring is, when the inner diameter of the ring is 320mm, the levitation force generated by the ring magnet is greater than that when the inner diameter is other values. This shows that the levitation force increases first and then decreases with the increase of the inner diameter of the ring when the width of the ring is the same.

According to the above rules, the outer diameter of the ring permanent magnet is 350mm, the inner diameter is 250mm and the thickness is 20mm. At this time, the buoyancy of the ring permanent magnet to the float is 35.426n, which is greater than 33.117n of the gravity of the float, which basically meets the system requirements.

### 2.4 Design of control part of magnetic suspension system

The balance state of magnetic suspension system is an unstable state. When the system is disturbed by external interference, the system does not have the ability to recover itself, which leads to the system losing balance. The nonlinear characteristics of magnetic field determine the strong nonlinearity of magnetic levitation system. Therefore, the magnetic suspension system is a congenital open-loop unstable system. To achieve stable suspension, the controller must be used to realize the closed-loop feedback control of the system. The control process is shown in Fig. 7.

![Figure 7 Suspension Control Diagram](image)
When the suspension moves to the left, the electromagnet on the left will repulse the suspension, while the electromagnet on the right will attract the suspension. Therefore, the resultant force on the suspension is right. As the suspension gets closer to the center, the size of the electromagnet will also change, and finally the suspension will be stabilized in the center. If the suspension body shifts to the right, the current direction of the electromagnetic coil needs to be changed to make the right electromagnet produce repulsion force, and the left electromagnet generates repulsion force.

In order to obtain the drift of the float, two hall sensors are arranged in the direction perpendicular to the x-axis and y-axis respectively. The magnetic induction intensity in the horizontal direction of the float is sampled in real-time, and the analog voltage signal is output. The ADC sampling channel of MCU samples the analog voltage signal output from Hall sensor, calculates it through its built-in PID algorithm, and outputs PWM signal. The driving circuit controls the MOSFET in H-bridge drive circuit to turn on by PWM signal input from MCU, so as to realize the control of forward and reverse current and size of current. The output current is directly connected to the electromagnet coil. In order to reduce the influence of the driving circuit on the front control circuit, the optocoupler is used to isolate the controller from the main circuit.

3. Innovation
(1) This system makes full use of the feature that there is no space contact between the floater and the magnetic suspension base in the magnetic suspension system, and improves it, and uses it in the pipeline detection. Compared with the previous pipeline detection methods, the float is suspended inside the pipeline and controlled by the magnetic levitation platform outside the pipeline. By using this method, the float can go deep into the pipeline to detect the inner wall of the pipeline, which easily overcomes the problem of the closed space inside the pipeline, which is difficult to be detected by ordinary detection methods.

(2) Through software simulation, the system improves the suspension height of the float and realizes the large gap magnetic suspension. At the same time, the digital circuit control system is introduced and PID controller is used to realize the precise control of the horizontal direction of the float, which greatly ensures the stability of the internal suspension platform of the pipeline, and realizes the precision of the pipeline internal detection module Quasi positioning provides a guarantee.

4. Conclusion
Because of the internal sealing characteristics of the pipeline, the common pipeline detection can only detect the outside of the pipeline. The new magnetic levitation platform introduced in this paper can carry the pipeline detection device suspended in the center of the pipeline, which overcomes the problem that the detection device cannot be fixed during the internal detection of the pipeline. The magnetic levitation system has simple structure and clear hierarchy, which is easy to combine with the existing pipeline detection device to realize the accurate detection of pipeline inner wall. The system has a broad application prospect, and is suitable for the detection of most PE pipes.

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