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Structure Design and Research of Magnetic Attraction Wall Climbing Robot

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Abstract

In order to meet the needs of LPG spherical tank inspection, a magnetic adsorption wall climbing robot was studied in this paper. The magnetic attraction module and walking module of the robot were designed, and the force state of the wall-climbing robot is analyzed, which provides reasonable data for the selection of the track material and the determination of the friction coefficient. The magnetic attraction module was simulated and optimized using ANSOFT Maxwell software, which provided a theoretical basis for the selection and installation of the magnet.

Keywords

Wall-climbing robot; Magnetic adsorption; Magnetic circuit; Magnetic field optimization.

1. Introduction

With the continuous development of science and technology and the continuous improvement of the overall education level, for some high-risk jobs and heavy labor, people have gradually started to use some automated machinery to replace people's labor, and the application of wall-climbing robots is one of them. As a special type of robot, the wall climbing robot can work on high and steep walls to replace human work and achieve human liberation. With the development of material technology, the performance of permanent magnets has become more and more excellent, and has been widely used. The permanent magnet adsorption device is a very important category in the application of permanent magnets, mainly used in wall-climbing robots, permanent magnet chucks, magnetic fixtures, lifting devices, permanent magnet contactors, etc. The adsorption capacity of the permanent magnet adsorption device for ferromagnetic materials is better than that of the vacuum adsorption device. Compared with the electromagnetic adsorption device, the permanent magnet adsorption device has a smaller weight and volume, does not need a power supply and cooling equipment, and has no safety hazards due to accidental power failure and loss of adsorption. Therefore, the permanent magnet adsorption device has broad application prospects.

2. Research status of wall climbing robot

At present, research on wall-climbing robots mainly focuses on adsorption mode, driving mechanism and robot body structure. According to the adsorption method, it can be divided into: negative pressure adsorption type, micro needle adsorption type, grip type, binder adsorption type, magnetic adsorption type, etc. [1]. Research on magnetic adsorption type wall-climbing robots has achieved many results, and the application scenarios are becoming more and more extensive. Among them, the United States Helical Robotics and other companies developed a series of robots for wall crawling, such as HR-MP20, using permanent magnet adsorption, using wheeled mobile [2-3]. Harbin Institute of Technology successfully developed a water-cooled wall-climbing robot for detecting and cleaning

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the water-cooled wall of a thermal power plant boiler. The main structure of the robot is a double crawler structure, and the adsorption of the tank wall is achieved by 30 permanent magnet disks [4]. In 2011, Hefei General Machinery Research Institute developed a magnetic gap type wall climbing robot [5]. This magnetic gap type wall climbing robot combines vacuum suction type and magnetic suction type to complement and enhance the adsorption force of the robot. The magnetic crawler contact wall surface adsorption is changed to the magnetic block alone and is not directly in contact with the wall surface, and the magnetic gap effect is changed by adjusting the gap. The robot has a mass of 75kg and can carry ultra-high pressure hoses of several tens of meters long during operation.

3. Structural design of magnetic adsorption type wall climbing robot

3.1 Track module working principle and its structural design

As shown in Figure. 1 , it is a three-dimensional structure diagram of a robot crawler module, which mainly includes: a crawler belt, a magnet, a frame, a motor, and the like. The track module described in this paper can be applied to the magnetic wall surface experimental platform, which can realize the forward and backward functions. When there is a difference between the two drive motors, the turning function can be realized.

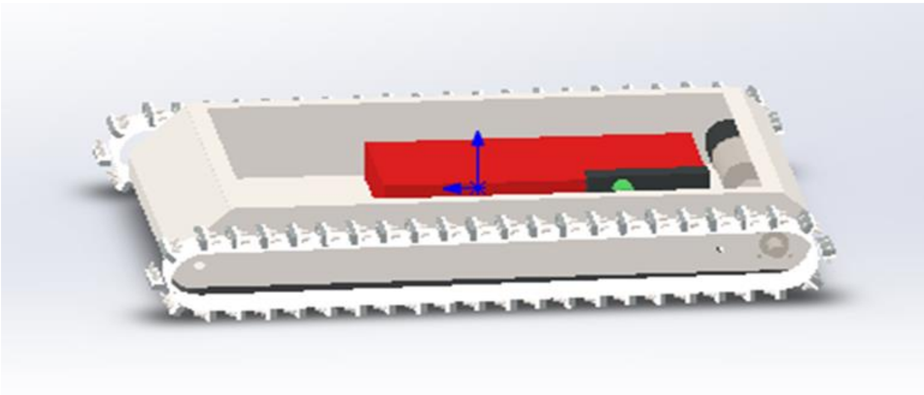

Figure 1. Three-dimensional structure diagram of the wall climbing robot

3.2 Analysis of safe adsorption conditions of vertical wall

The force of the track is related to the angle between the track and the contact wall, but each force can always simplify the decomposition. Only the force of the single robot track module on the vertical plane is discussed here.

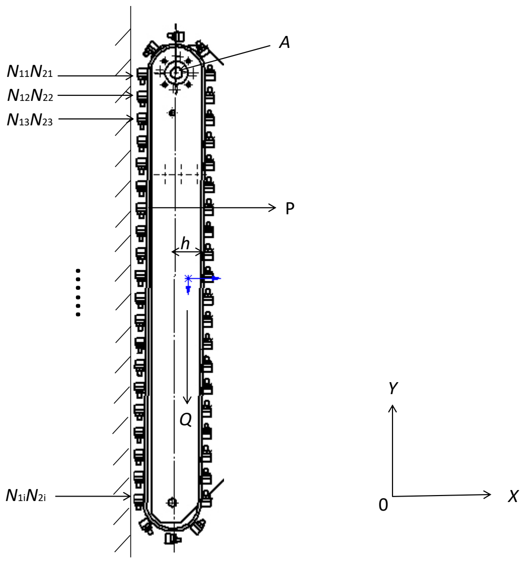

Figure 2. Vertical wall adsorption force analysis diagram of wall climbing robot

$N_{1i}N_{2i}$ -Two tracks of permanent magnets and wall forces;

P - the suction provided by the permanent magnet adsorption device on the wall;

Q - the total weight of the wall climbing robot;

h - the distance of the gravity-shifting axis of the climbing wall robot;

A - Climbing robot longitudinal flip limit point

According to the force analysis, you can get:

$$\Sigma X = 0, P - \sum_{i=1}^{n} N_{1i} - \sum_{i=1}^{n} N_{2i} = 0$$
$$\Sigma Y = 0, Q - \sum_{i=1}^{n} F_{1i} - \sum_{i=1}^{n} F_{2i} = 0$$
$$F_{1i} \le f \cdot N_{1i}$$
$$F_{2i} \le f \cdot N_{2i}$$

Where: n - the number of permanent magnets that are simultaneously attracted to the single track and the wall; f - static friction coefficient.

Assuming that the adsorption forces of the permanent magnets are the same, you can make:

$$N_{11} = N_{12} = \cdots = N_{1i} = N_1 \quad (5)$$
$$N_{21} = N_{22} = \cdots = N_{2i} = N_2 \quad (6)$$

From formula (1-4), we can get:

$$nN_1 \cdot f + nN_2 \cdot f \ge Q \quad (7)$$

from $N_1 = N_2$ you can get：

$$2nN_1 \cdot f \ge Q_{2i} \quad (8)$$

Where: N_1 - The adsorption force of a single permanent magnet under the slip instability limit state.

got the answer:

$$N_1 \ge \frac{Q}{2n \cdot f} \quad (9)$$

3.3 Vertical capsizing

The condition that the wall-climbing robot body does not undergo vertical overturning (that is, the wall-climbing robot does not disengage from the wall in the longitudinal stationary adsorption state) is: ∑MA≥ 0(each parameter is shown in Figure 3), which can be obtained by calculation:

$$2\times(N\times 0 + N\times P' + N\times 2P' +$$
$$... + N\times n-1P') - Q \cdot L \ge 0$$
$$\frac{n(n-1) \cdot N \cdot N \cdot P'}{4} - Q \cdot L \ge 0$$
$$N_2 \ge \frac{4QL}{n(n-1)P'}$$

In the formula: N_2-the adsorption force of a single permanent magnet in the state of longitudinal overturning instability.

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3.4 Lateral capsizing

The condition that the wall-climbing robot body does not overturn (that is, the wall-climbing robot does not detach from the wall under the state of horizontal static adsorption) is: $\sum M_B \geq 0$.

The force analysis is shown in the figure below.

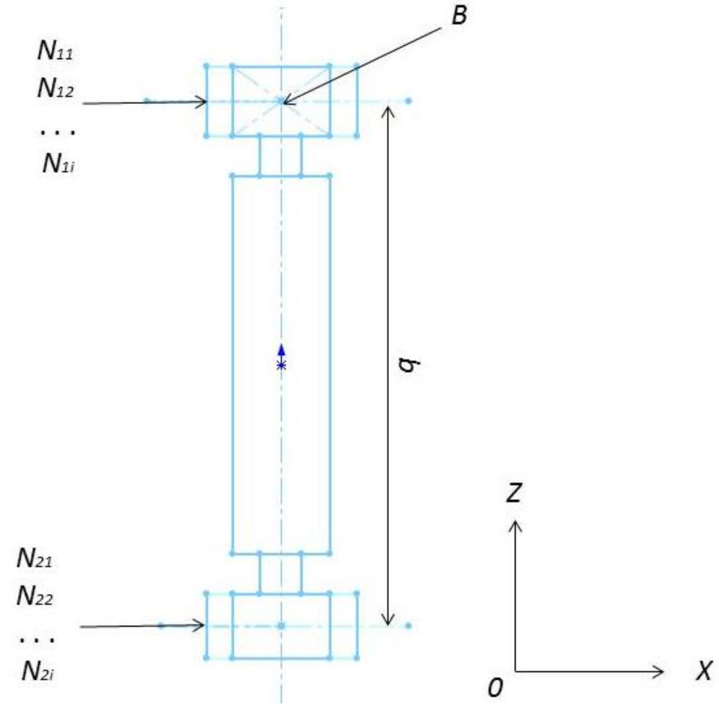

Figure 3. Analysis of lateral adsorption force of wall

N_{1i} N_{2i}-The force of the permanent magnets on a single track and the wall surface; b-the distance between the two crawler adsorption centers of the wall-climbing robot;

According to the parameters above, we can get:

$$n \times N \times 0 + n \times N \times B - Q \cdot L \geq 0$$

$$n \cdot N \cdot B - Q \cdot L \geq 0$$

$$N_3 \geq \frac{QL}{nB}$$

In the formula: N_3—the adsorption force of a single permanent magnet in the limit state of lateral overturning instability.

3.5 Calculation of instability extreme value in stationary adsorption state

According to the above analysis of the common instability of the wall climbing robot, considering the safety factor, the maximum adsorption force required by the wall climbing robot is:

$$N \geq K \cdot \max\left\{ \frac{Q}{2n \cdot f}, \frac{4QL}{nn-1P'}, \frac{QL}{nB} \right\}$$

Where: K—safety factor.

According to the design parameters: Q = 400 N, L = 60 mm, p' = 33 mm, n = 20, B = 30, f = 0.5, and K = 1.5. Substituting the parameters into equation above gives: N ≥ 30 N.

It can be seen that in order to achieve stable adsorption of the wall-climbing robot, the adsorption force N ≥ 30 N required by each adsorption unit that adheres to the wall surface for adsorption.

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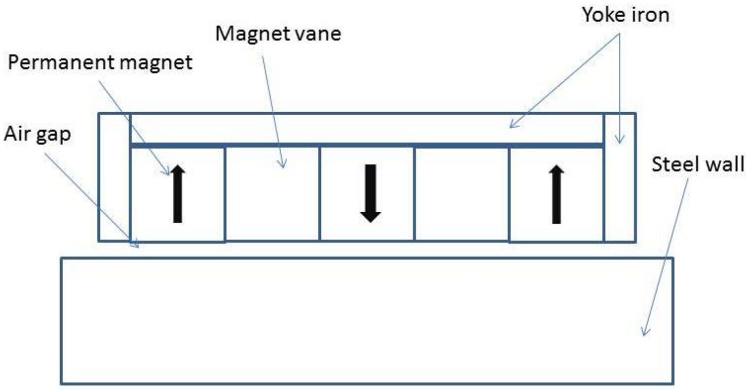
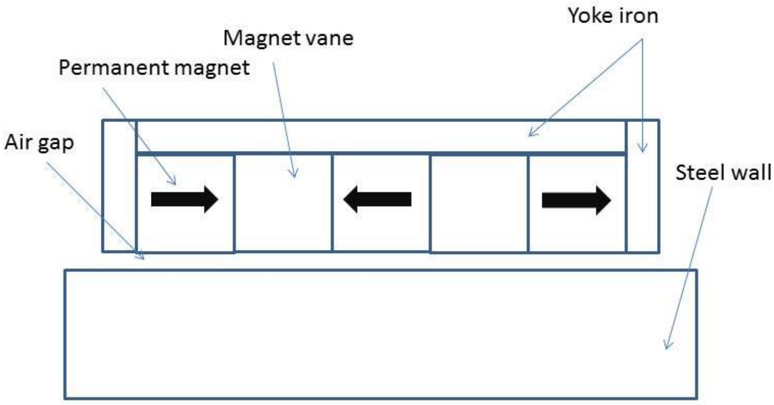
4. Wall climbing robot structure optimization

4.1 Magnetic circuit design of magnetic adsorption unit

The magnetic circuit of the permanent magnet refers to the path of the magnetic flux passing through the magnetic medium. The magnetic lines of force emanating from the inside of the permanent magnet are led to the working gap requiring magnetic force through the yoke with strong magnetic permeability, and then returned to the permanent magnet through the magnetic conductive material. Thereby forming a closed magnetic line circuit. A suitable selection of the magnetic circuit structure can operate the magnet at the maximum magnetic energy point of the permanent magnet. The magnetic flux density in the working air gap is increased to maximize the performance of the permanent magnet, and the adsorption performance of the wall-climbing robot on the steel wall is reliable, so the design of the magnetic circuit is the core of the permanent magnet adsorption unit design. The magnetic circuit is mainly composed of a permanent magnet, a magnetic yoke, and a magnetic material. As shown in Fig. 3, the direction indicated by the arrow is the direction in which the permanent magnet is magnetized, and the shape of the permanent magnet material is selected to be square to facilitate the processing and installation of the material.



(a) Traditional magnetic circuit



(b) New magnetic circuit

Figure 3. New magnetic circuit and traditional magnetic circuit schematic

The magnetic circuit design model of the conventional type and the new magnetic adsorption unit shown in Fig. 3 (a) and Fig. 3 (b). The conventional type adopts a radial magnetization mode, and the distribution of the magnetic lines of force is guided by the magnetically permeable material separated by the magnetic isolation material between the permanent magnets. The new unit adopts axial magnetization, the permanent magnets are connected by magnetically conductive materials, and the upper part is made of magnetic isolation material to reduce the magnetic leakage of the structure.

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In order to better compare the traditional magnetic flux lines and magnetic induction intensity distribution. The ANSOFT Maxwell module was used to model and analyze the two magnetic circuits in the same structure size.

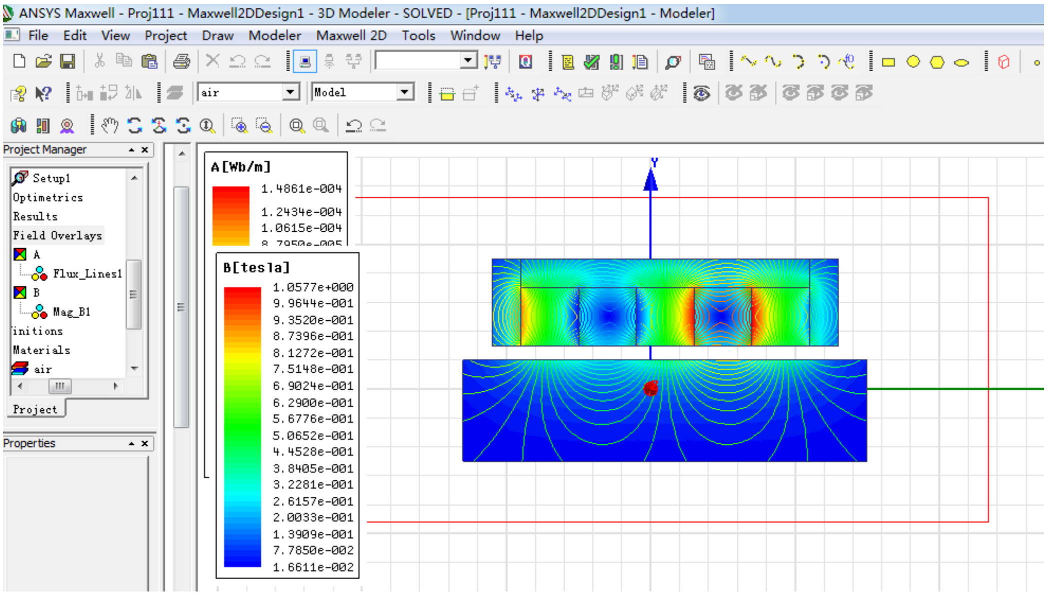

Figure 4 Traditional magnetic circuit

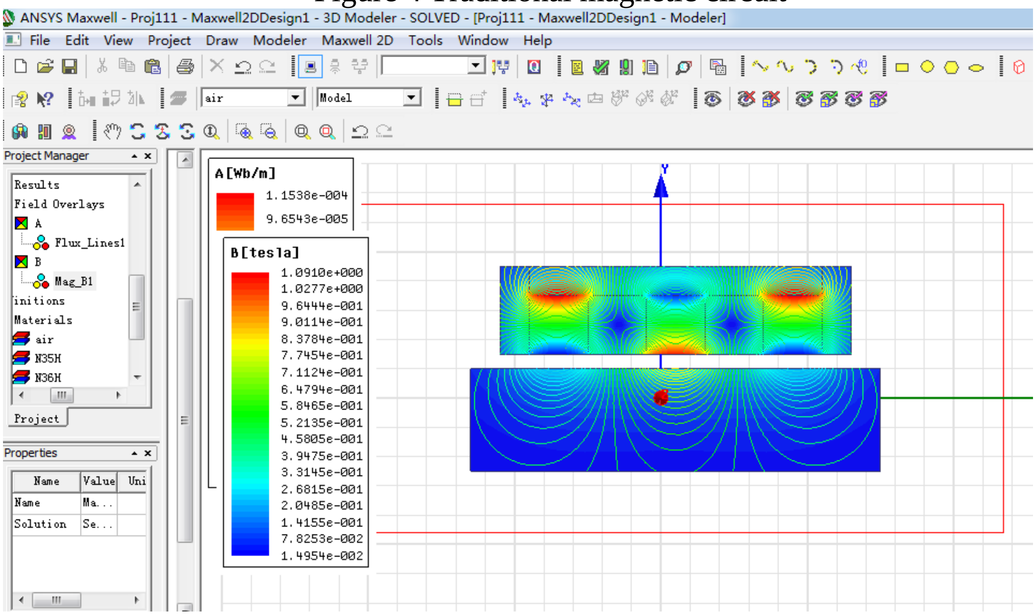

Figure 5 New magnetic circuit

As shown in FIG. 5, the magnetic isolation material on the top of the new magnetic circuit effectively reduces the magnetic flux leakage to the air. The yoke function with high intermediate permeability is to change the magnetic field lines of the permanent magnet from the horizontal direction to the vertical direction and lead it to the working air gap. At the same time, if the yoke-free magnetic poles are opposite to each other, the magnets need to be protected by a large external force. The installation clearance is extremely small to avoid magnetic leakage. When installing, the two yokes are first attached to the intermediate magnet, and then the magnets on both sides are installed. The guiding magnets on both sides reduce the magnetic leakage at the end, and have a magnetic collecting effect, which leads the magnetic lines of force to the steel wall, which helps to improve the magnetic attraction of the unit. This design structure uses a combination of internal and external magnetic modes, making full use of their respective advantages. On the one hand, the inner magnetic structure formed by the magnetic isolation material on the top side of the array, the yoke in the middle and the yoke on both sides reduces the magnetic flux of the magnetic flux leakage, and the magnetic lines of

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the permanent magnet are utilized efficiently. On the other hand, the working side permanent magnet and the steel wall surface contact as the main adsorption surface form an external magnetic structure, which enhances the effective working air gap magnetic flux and reduces the yoke required for the conventional permanent magnet adsorption unit.

Compare the magnetic induction and magnetic line distribution of the two magnetic circuits in Figure 4 and Figure 5. The maximum magnetic induction produced is 1.058T for the conventional type and 1.091T for the new type. Although the difference between the two is not large, the magnetic flux of the traditional magnetic circuit generates magnetism through the upper yoke. Therefore, in order to avoid magnetic saturation, the demand for the yoke is more, and the new maximum magnetic induction is mainly concentrated in the working gap. Therefore, less yoke is required, magnetic loss is reduced, and the utilization rate of the permanent magnet is high. Compared with the distribution of magnetic induction intensity, the magnetic induction intensity generated by the new magnetic circuit in the steel wall is evener than that of the conventional type, and the influence range is deep. Therefore, the new magnetic circuit is more suitable for the change of the working air gap caused by the unevenness of the steel surface.

At the same time, the ratio of the length of the magnet to the length of the yoke core should be controlled within a reasonable range, and the permanent magnet should be kept in contact with the steel wall as much as possible.

5. Conclusion

Through the structural design and analysis of the magnetic adsorption type wall-climbing robot, this paper designs a climbing wall structure with better adsorption force by means of Solidworks, Maxwell and other software:

(1) The structure has high flexibility, and the contact between the track and the wall surface ensures the stability of the robot's adsorption and crawling;

(2) The force analysis of the wall-climbing robot in the static state is carried out, which provides reasonable data for the selection of the track material and the determination of the friction coefficient.

(3) Using ANSYS to simulate and analyze the magnetic circuit, it provides a theoretical basis for the selection and installation of magnets, which is beneficial to the optimization of wall-climbing robots.

The crawler type magnetic absorbing wall climbing robot can produce a large adsorption force, has a large walking speed, and has a strong ability to cross obstacles, so it has a broad development prospect.

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