

Research on magnetic influence factors and optimal design of wall-climbing robot

Jingang Liu

Northeast Petroleum University, Daqing, China

Abstract. The adsorption stability and motion flexibility are one of the core problems restricting the development of wall-climbing robots. In order to solve the problem of wall-climbing robots, the basic structure of magnetic adsorption unit is introduced in detail. Secondly, the finite element analysis software was used to optimize the simulation of the relationship between the parameters of the magnetic adsorption unit and the magnetic adsorption force through the control variable method. After optimization, the magnetic adsorption force of the magnetic adsorption unit was significantly improved under the condition that its own volume was unchanged. Finally, the experiment is carried out to verify.

Keywords: Wall-climbing robot; magnetic adsorption unit; parametric simulation; experiment.

1. Introduction

As a kind of special robot, wall-climbing robot can realize different operation functions by loading the robot arm and other modules, and has been applied in extreme operating environments such as shipbuilding industry, nuclear industry, petrochemical industry and construction industry [1, 2]. The wall-climbing robot is adsorbed on the wall through the adsorption device, and the mobile mechanism crawls on the wall with adsorption force [3-7]. On the one hand, insufficient adsorption force will cause the robot to fall or overturn from the jacket wall; on the other hand, excessive adsorption force will lead to the increase of the volume and mass of the adsorption device, which will affect the movement flexibility of the wall-climbing robot.

By optimizing the structural parameters of the adsorption structure, the optimal solution can be obtained in the range of parameter design. Some scholars combined the above two design ideas, first improving the magnetic circuit model of the adsorption structure, and then further improving the adsorption performance by optimizing the parameters. For example, Zou Yujing [8] designed a new wheeled wall-climbing robot adapted to the outer wall of the oil tank. Based on the comparison of two magnetic circuit schemes, the finite element software was used to analyze the influence of structural parameters on the adsorption force, and the optimal structural size was obtained by the control variable method. In order to improve the adsorption effect of hull cleaning robot, Sun [9] compared three magnetic circuit models, determined the main design factors affecting the wall-climbing robot through parameter sensitivity analysis, and improved the magnetic adsorption force of the ship-wheeled wall-climbing robot through univariate analysis. Zhon [10] analyzed and compared four adsorption device design schemes, obtained the optimal design scheme through simulation software, and determined the optimal value of each parameter based on the control variable method. Therefore, the mechanical formation mechanism and analysis of the adsorption properties of wall-climbing robots have received extensive attention [11, 12].

2. Basic structural parameters of magnetic adsorption unit

2.1. Basic structure

The wall-climbing robot designed in this paper adopts a track-type magnetic adsorption system. The magnetic adsorption unit is composed of permanent magnet and yoke iron, which is fixed with the track by bolts. A rubber washer slightly higher than the magnetic adsorption unit is added between two adjacent magnetic adsorption units, which makes the magnetic adsorption unit and the magnetic wall always leave a certain gap between the magnetic adsorption unit and the magnetic wall. On the

one hand, leaving a certain gap can prevent the rupture of the permanent magnet force impact, and then play a role in protecting the permanent magnet; On the other hand, it can make the robot have a large adsorption capacity, but also ensure the flexibility of its movement. The structural arrangement is shown in Figure 1.

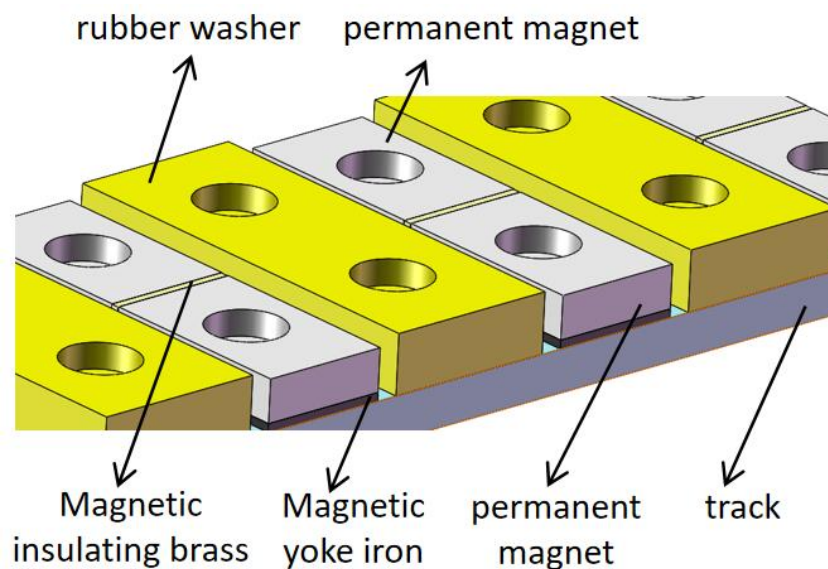


Fig 1. Composition of magnetic adsorption unit.

2.2. Permanent magnet materials and magnetic circuit

The robot chooses NdFeB N52 as the permanent magnet, and its performance parameters are shown in Table 1. Q235 steel is used to increase magnetic flux and reduce magnetic leakage. Magnetic insulation plate selected brass; the working air gap medium is air, and its relative permeability is 1.

The permanent magnet circuit selects the type B circuit with dense magnetic field lines and high magnetic induction intensity in the working face. The magnetic circuit structure is mainly composed of two permanent magnets and a yoke iron, so that while generating the same magnetic adsorption force, the area of a single magnetic block is relatively reduced, the magnetic potential loss coefficient is small, and the magnetic leakage is small.

Table 1. Performance parameters of NdFeB N52.

characteristic parameter	value
Relative permeability/T	1.42~1.47
intrinsic coercive force /(kA/m)	≥ 876
magnitude/(kA/m)	≥ 836
maximum magnetic energy product /(kJ/m ³)	390~422
maximum working temperature /°C	80

3. Parametric analysis and optimal design of magnetic adsorption unit

The adsorption force of the magnetic adsorption unit is mainly related to the volume of the permanent magnet and the length of the gap. In addition, the thickness of the magnetic yoke iron and magnetic insulating brass also have an effect on the magnetic adsorption force. In order to obtain a reasonable design size, the key design parameters of the magnetic adsorption unit and the influence of each key parameter on the magnetic adsorption unit is quantitatively analyzed. The initial cross-section parameters of the permanent magnet adsorption unit are shown in Table 2. L1 is the length of the permanent magnet, W1 is the width of the permanent magnet, H1 is the height of the permanent magnet, H2 is the thickness of the magnetic yoke iron, H3 is the air gap spacing (the height gap between the rubber washer and the magnetic adsorption unit), L2 is the length of the magnetic insulating brass, and H4 is the wall thickness.

Table 2. Initial cross-section parameters.

L1/mm	W1/mm	H1/mm	H2/mm	H3/mm	L2/mm
25	15	5	1	2	1

3.1. Effect of magnet volume on magnetic adsorption force

In order to facilitate the observation of the changing relationship between the adsorption stability and motion flexibility of the magnetic adsorption unit, the concept of magnetic mass ratio was introduced and defined as the ratio of the adsorption force of a single magnetic adsorption unit to its own weight. With the control variable method, the variation range of each design parameter was changed respectively while other parameters were guaranteed to be initial values, and parametric simulation was carried out by AnsysEM software to obtain the influence of each parameter on the adsorption force and the magneto-mass ratio, as shown in Fig.3. Among them, the change range of L1 is 20-30mm, the change range of W1 is 10-20mm, the change range of H1 is 1-8mm and the change range of H2 is 1-2mm.

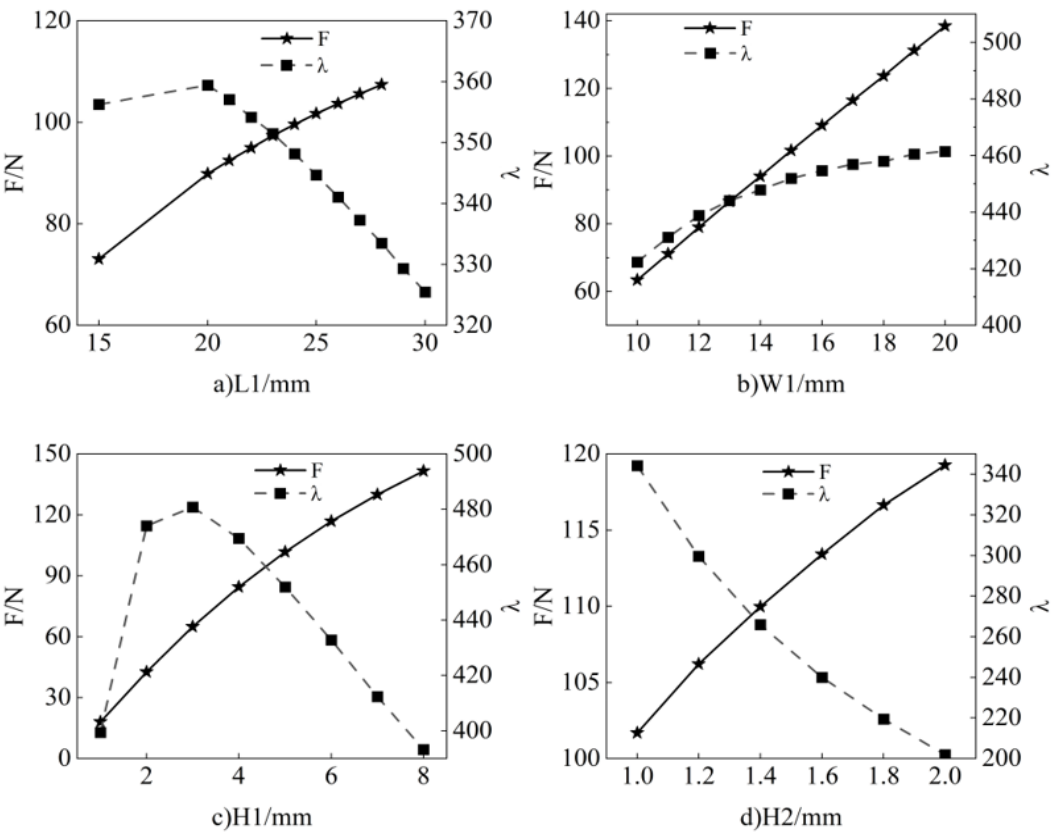


Fig 2. Effects of various parameters on adsorption force and magneto-mass ratio.

It can be seen from Fig.2 that the adsorption force is positively correlated with the length of magnet, the width of magnet, the height of magnet and the thickness of yoke iron, and the adsorption force increases with the increase of the size. When the length of the magnet is increased, the magnetic mass ratio of the permanent magnet adsorption unit first increases and then decreases, which is because the magnetic force line of the B loop is mainly concentrated in the middle and both ends of the magnetic adsorption unit, and with the increase of the length of the magnet, the magnetic loop in the middle and both ends does not change, and the utilization rate is reduced, so the length of the magnet should not be too long. When the height of the magnet increases from 1mm to 3mm, the adsorption force increases from 18N to 65N, the adsorption force increases 3.6 times, and the magneto-mass ratio also increases rapidly. At this stage, the utilization rate of the magnet is high, because the magnetic induction intensity in the working face continues to increase, when the height of the magnet continues to increase, although the adsorption force is still increasing, the magnetic mass ratio rapidly decreases,

because the magnetic induction intensity in the working face of the magnetic adsorption unit tends to be saturated at this time, and the contribution of the magnet height to the magnetic adsorption force decreases.

3.2. Optimized design of key parameters of magnetic adsorption unit

In order to obtain the optimal structural parameters, in addition to keeping the volume of the magnetic adsorption unit unchanged, the yoke iron height is set to 1mm, and the variable range is set only for the magnet length $L1$, the magnet width $W1$ and the magnet height $H1$. Then, the multi-factor design method was used to optimize the magnetic length $L1$, magnetic width $W1$ and magnetic height $H1$, and the three-dimensional graph between $L1$, $W1$, $H1$ and adsorption force F was obtained, as shown in Fig.3.

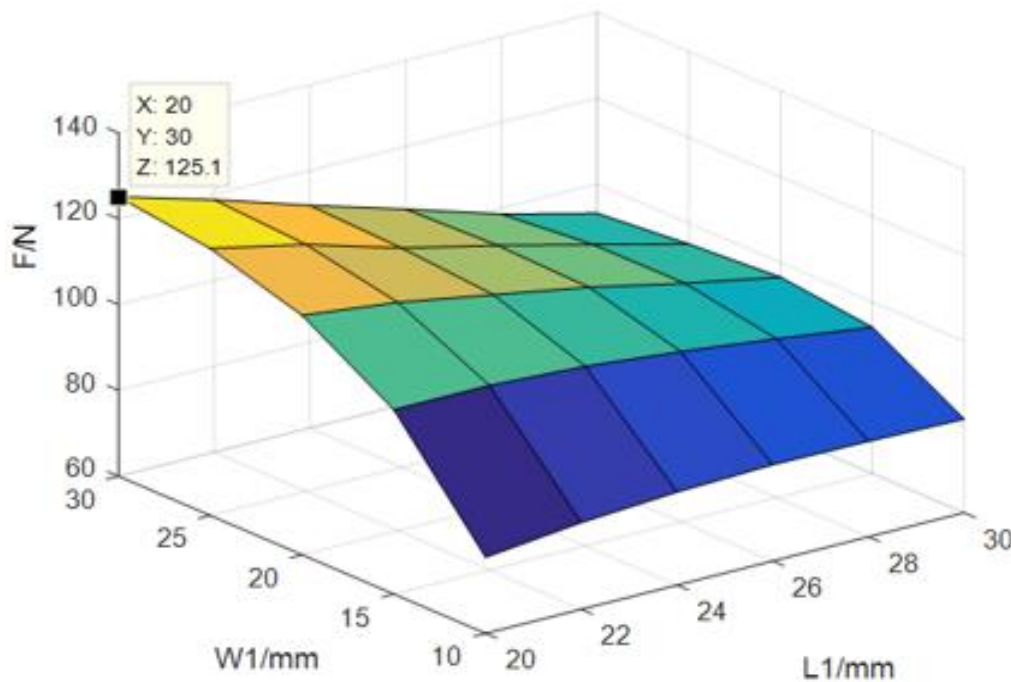


Fig 3. Relationship among $L1$, $W1$, $H1$ and F .

4. Summary

The finite element method was used to conduct parametric modeling, magnetic circuit simulation and adsorption force calculation for the permanent magnet adsorption unit. The contribution relationship of various structural parameters to the adsorption force was studied, and the working principle of the adsorption unit was verified. The structural parameters were optimized and designed through a multi-factor design optimization method, so that the adsorption force was greatly improved.

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