Research on the Magnetic Absorption Design of Cylinder Climbing Vehicle on the Wall

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Abstract **- Cylinder climbing vehicle is a kind of industrial wall-climbing robot, which can move smoothly and flexibly on the vertical wall of the cylinder of the chemical container. It combines the design of an ordinary ground mobile machine and the design of adsorption. According to the working environment of the cylindrical climbing car and its properties, the adsorption design is selected; in the ANSYS MAXWELL 14.0 software environment, the corresponding static magnetic field simulation model is established, the variables are set according to the related environmental parameters, and the existing design is quantitatively analyzed on the wall surface. The change of the overall magnetic attraction force when keeping different distances; the performance advantages and disadvantages of the two other magnetic field arrangements of the adsorption device are discussed. In actual engineering experiments, the theoretical analysis results were verified. The adsorption device's operational reliability was confirmed, and the basis for the adjustment of the magnetic adsorption device was provided.**

Keywords - cylinder; wall-climbing robot; magnetic adsorption; static magnetic field simulation

Since the 1990s, with the rapid development of my country's modern industry Development, many famous domestic universities, research institutes, and enterprises have invested in Research and develop wall-climbing robots [1]. Wall climbing robot) refers to a self-propelled body that can climb on vertical walls and complete tasks Robotics [2]. Wall-climbing robots are also called wall mobile robots; it is a kind of specific operation under harmful, dangerous, extreme conditions, etc.

Special automated machinery; because vertical wall operations are beyond human Extreme, so it is also called extreme work robot abroad. Wall climbing machine, the robot must have the two essential functions of adsorption and movement. There are two types of attachment: negative pressure adsorption and permanent magnet adsorption. The negative pressure can be adsorbed on the wall by generating a negative pressure in the suction cup. Surface materials are limited; there are permanent magnets and electromagnets for magnetic adsorption. This method is only suitable for adsorbing magnetically permeable [2].

Wall-climbing robots are mainly used in petrochemical companies to enter large cylindrical tanks. Perform flaw detection or painting or clean and spray buildings Coating; used in the nuclear industry to inspect thickness measurement, etc.[2], can also be used for firefighting and Equipment maintenance and inspection in shipbuilding and other industries. This article focuses on Crawler type permanent magnet adsorption wall climbing for cylindrical containers in the chemical industry—The magnetic adsorption technology of the car [1,2].

1 THE STRUCTURE AND PRINCIPLE OF THE CYLINDER AND MAGNETIC CLIMBING CAR

The cylindrical storage tank is a kind of pressure vessel of storage and transportation equipment Processed from steel plates with magnetic properties, generally low alloy Carbon structural steel material, rolled and welded and post-processed to form a cylindrical shape Afterwards, the outer surface of the cylinder is treated with a coating or plating for corrosion protection[3]. Among them, the coating material's main component is organic, the coating material is metal, and individual coating materials contain nickel. The nickel element of the coating can change the magnetic permeability of the steel wall. The cylindrical shell analyzed and discussed in this article includes the wall using nickel—most of the cylindrical shells outside the element coating. Cylinders can be divided into thick-walled cylinders and thin-walled cylinders according to the shell classification, in engineering, the body's thickness in general. The radius of curvature of the surface is less than one-tenth of a thin shell, and vice versa. In chemical enterprises, the occasions where wall-climbing robots are needed are mostly medium and large cylinder equipment, and the actual thickness of the steel plate used is more than 5mm (or a cylinder with a total thickness greater than 5mm made of multilayer steel plates wall) [3,4].

Since the steel plate (magnetically conductive material) corresponding to each unit surface area of the thin-walled cylinder is small (making the magnetic force provided by the adsorption device smaller), it is more difficult for the device to achieve the same adsorption effect compared with the thick-walled cylinder of the same size. The adsorption conditions are typical and representative. In this paper, a small, thin-walled cylinder with a shell diameter of 2800mm applied to a medium-sized pressure vessel is taken as an example to analyze the adsorption device of the cylinder climbing vehicle under this working condition [5].

When the climbing car is working on the wall of a vertical cylindrical tank, its gravity is caused by the static friction force generated by the rubber track and the steel wall (the static friction coefficient under this condition mainly depends on the formula and variety of the rubber used. In this example, The coefficient of static friction between rubber and steel plate is 0.9) overcome, and the friction force depends on the radial component of the magnetic force as the positive pressure (the adsorption device provides the magnetic attraction force); when working on the surface of the horizontal cylindrical tank, the climbing car itself Gravity is directly overcome by the radial component of the magnetic force generated by the adsorption device. In the two working conditions, the former has higher requirements for the adsorption capacity of the adsorption device, so this article analyzes and studies the adsorption of the cylindrical climbing car on the wall of the vertical cylindrical storage tank.

In this example, the cylindrical climbing car is designed with an aluminium alloy structure, giving the frame of the whole vehicle aluminium alloy material. The frame mass is about 5.5073kg, equivalent to 55.073N of gravity, the friction coefficient between the rubber track and the steel cylinder wall is 0.9, and the required magnetic attraction FM1 = G /0.9=61.192N; In actual applications, stepping motors, servo control systems, communication devices, and non-destructive (flaw detection) testing devices and the medium and high-pressure hoses of several meters to tens of meters (available For magnetic particle testing or penetration testing) or spraying and cleaning device and its matching medium and high-pressure hoses of several meters to tens of meters long filled with liquid, in actual working conditions, a load of a complete climbing car is greater than 26kg, equivalent to 254.8N of gravity. That is, the required additional magnetic attraction force FM2 = G /0.9=283.1N. In summary, considering the necessary safety margin, the adsorption device must be able to provide a magnetic adsorption force of 300N and above. The adsorption force index of this design is set at 300N.

Based on the magnetic properties of the cylindrical wall, combined with the adsorption force index, the adsorption function of the magnetic adsorption robot, and the characteristics of the application conditions, it is confirmed that the permanent magnet adsorption design is adopted [5,6].

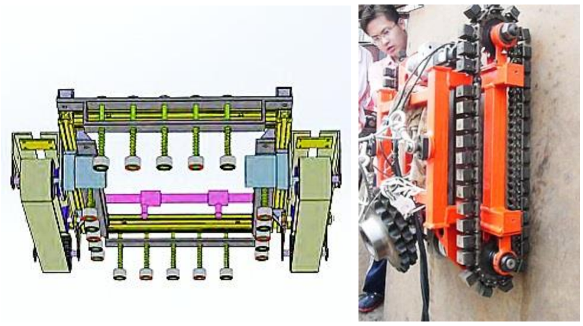

Figure 1 Climbing vehicle working condition model

The crawler-type magnetic adsorption climbing vehicle structure is shown in Figure 1, which is mainly composed of a transmission part and an adsorption device. The gravity of the climbing car is overcome by the friction force between its rubber track and steel. The magnetic attraction force determines the resistive brake force's maximum value as positive pressure. The direction is vertically upward along the cylinder axis (the positive z-axis in Figure 1). To ensure that the climbing car is firmly absorbed on the wall and not fall off, it is necessary to determine the adsorption device's adsorption capacity. The adsorption capacity of the adsorption device depends on the magnetic adsorption force generated by each group of adsorption units. The magnetic adsorption force is closely related to the gap distance between the adsorption unit and the attached steel plate. The climbing car model is shown in Figure 1. In Figure 2, the outer diameter of each permanent magnet ring unit's bottom surface is 20mm, the inner hole diameter is 6mm, and the height is 10mm. The volume is about 2713 cubic millimetres (4 rows and five columns), —20 permanent magnet units after rounding. The friction coefficient between the rubber track and the steel cylinder wall is taken as 0.9.

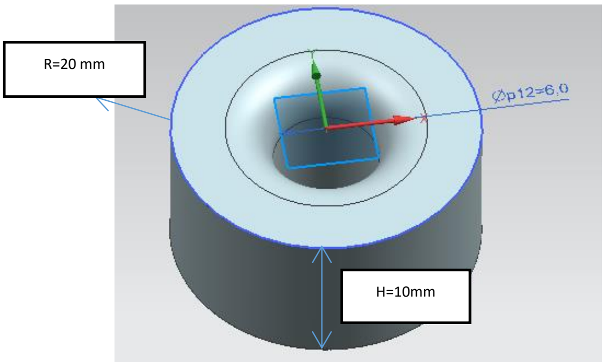

Figure 2 Permanent magnet unit

2. ANSYS MAXWELL SIMULATION ANALYSIS

2.1 Set material geometric parameters

In response to this situation's needs, use Ansys software Maxwell (version 14.0) to establish a magnetic adsorption model. (From the perspective of design safety and

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reliability, the thickness of the steel plate in this example is determined by the other parameters of the climbing car and the magnetic adsorption force, The minimum thickness at the weakest time). The wall thickness of the cylinder is selected as 5mm. Considering the non-magnetic coating or plating on the cylindrical vessel's outer surface, a particular design margin is reserved according to the actual working conditions, so The distance between the permanent magnet and the steel plate is set at 0.2mm or more. Because the trolley is mainly made of aluminium alloy or other non-magnetic properties except for the interest, other parts' magnetic permeability is ignored [7].

The analysis shows that the trolley's permanent magnet module is symmetrical in the front and rear, so two rows and five columns (10) permanent magnet units are used for simulation to calculate half of the magnetic field force of the whole device. The magnetostatic solution domain model with the percentage offset set to 100% is shown in Figure 3. Since the steel plate's adsorption force at a distance of more than 20mm from the permanent magnet is less than 1%, part of the steel plate volume is ignored, and the simplified figure 4 Shown.

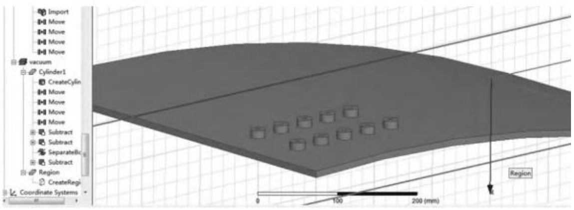

Figure 3 Initial modelling of the permanent magnet group

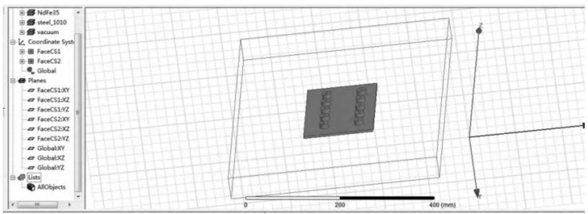

Figure 4 Final calculation model

2.2 Material property settings

The adsorption device will operate in air, permanent magnets, and adsorption walls.

2.2.1 Permanent magnet

Select (NdFe35) sintered neodymium iron boron permanent magnet material. Its performance parameters are listed in Table 1. In the modelling, the interest is magnetized along the axial direction (positive or negative x-axis direction). To obtain larger magnetic adsorption force, improved The arrangement of permanent magnets makes the magnetization direction of each adjacent unit in the permanent magnet group reversely arranged.

2.2.2 Air

The permeability of air is the same as that of vacuum, which is 4π×10-7H/m, and the relative permeability μ = 1.0000004;

In this example, the relative permeability of air is taken as μ = 1.0. Only electric and magnetic fields are defined in the air region (Region). No gravitational field or other irrelevant force fields are set.

2.2.3 Steel wall

Affected by the actual working surface, the adsorbed steel in this example is made of high-quality carbon structural steel steel1010 in the United States ASTM A576 (the same as No. 10 steel in GB711). Its B-H curve is shown in Figure 5 [13].

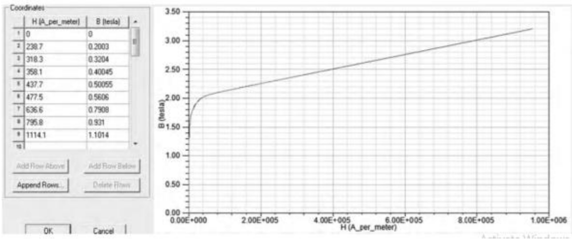

Figure 5 B-H characteristic curve of Steel1010

2.3 Parametric scan settings

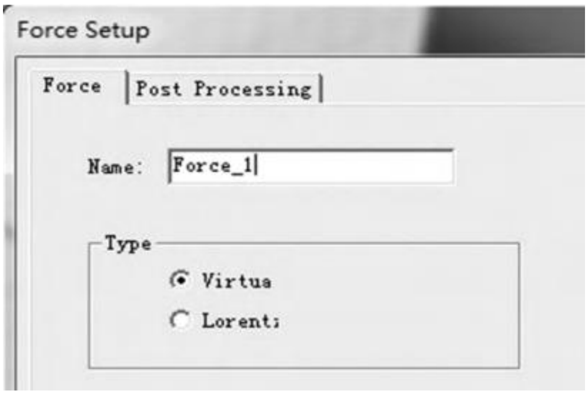

Figure 6 Force setting of steel plate

As shown in Figure 6, the field force on the steel plate is defined as Force_1 (Virtua) (no Lorentz power in the macroscopic upper air domain), the steel plate has no external charge, and the minimum distance between the steel plate and the permanent magnet is set to 0.2mm+mx (actual In the working condition, there must be no magnetic coating or plating on the cylindrical wall, so 0.2mm non-magnetic layer margin is reserved), the defined variable MX is 0.1mm~1.7mm (Figure 6), and it is executed every 0.2mm step (Perlinearstep) The first parameter scan. Use maxwell14.0 to simulate the magnetic field distribution in the air region (Region) defined in Figure 2, Then click parameter analysis to make the

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software accurately calculate the force field (i.e., magnetic field) in the airport (i.e., the magnetic field) applied to the steel plate under different spacings according to the magnetic field distribution and spacing settings in the airfield, namely Force 1; the magnetic field force is shown in Figure 10 is obtained, Although the pitch MX changes in size [5,7].

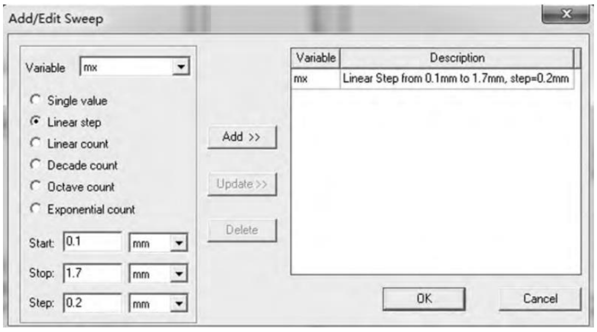

Figure 7 Variable definition

Table 1 Permanent magnet parameters

Type	Residual Induction Br （KGs）	CoerciveForce bHe（KOe）	Coercive ForceiGe（KOe）	Squareness（Hk/iHe）	Energy Product（BH）max.（MGOe）	Max. Operating. temp（℃）	Density（g/cm）
N35	11.7-12.3	10.7-12.0	≥12	≥0.85	33-36	80	≥7.40

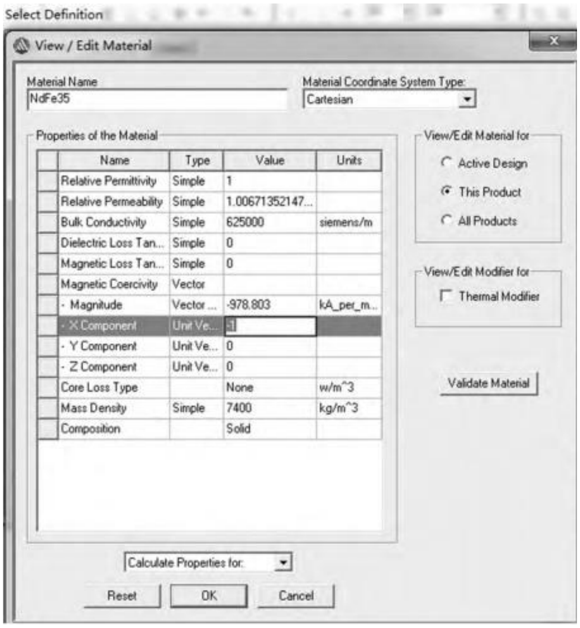

Figure 8 Magnetization direction setting

To determine whether each adjacent unit's magnetization direction in the permanent magnet group is reversed, it has more vital magnetic adsorption ability. The magnetization direction of all magnets is redefined as the negative x-axis direction. As shown in Figure 8, keep the variable MX unchanged, and execute the first, second parameter scan.

Redefine the variable (Figure 9) MX from 1.7mm to 3.9 mm, and perform the third parameterized scan analysis every 0.2mm (per linear step) to calculate the magnetic field force, respectively, as shown in Figure10-12.

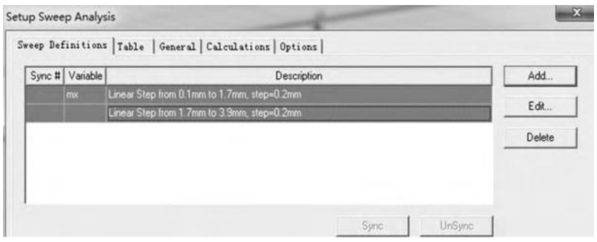

Figure 9 Add variable range.

2.4 Analysis of simulation results

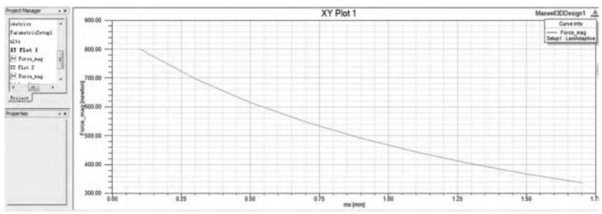

Figure 10 Magnetic force-spacing curve when the magnetization direction of the permanent magnet unit is wholly parallel and reversed along the axis

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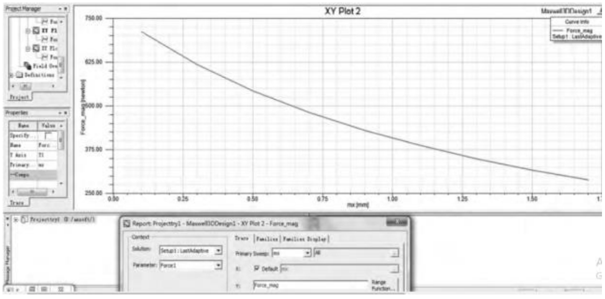

Figure 11 Magnetic force-spacing curve when the magnetization direction of the permanent magnet unit is the same [10]

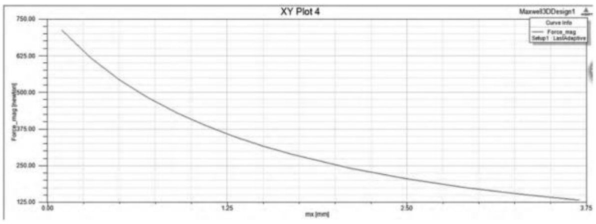

Figure 12 Magnetic force-spacing curve when the pitch change range is broad (0.3~3.7mm)

2.4.1 The effect of spacing on magnetic adsorption force

Under certain conditions of the total number of permanent magnet units (20) and the thickness of the walking wall (5mm), the law of the magnetic adsorption force of the adsorption device with the spacing parameter MX is analyzed.

From the curves in Figure 10 and Figure 11, it can be seen that the magnetic attraction force varies significantly with distance from 0.2mm to 1.45mm, from 800N to 375N. The magnetic pressure decreases rapidly with the increase of length and is still more fantastic than required. The adsorption force value is 61.2N.

Under working conditions, the relationship between the magnetic field force and the distance between the magnet and the steel plate is shown in Figure 12. When the space is more significant than (1.25+0.2) 1.45mm, the magnetic force changes gradually with the distance MX. When the distance is more significant than 3.7mm and less than 4.1mm, the magnetic force is stable at 125N, which is greater than the positive pressure of 61.2N required by the whole vehicle, which can ensure that the cylindrical climbing vehicle under this structure is stably absorbed on the wall without falling off [8].

2.4.2 The influence of permanent magnet pole arrangement on magnetic attraction

Comparing Fig. 11 and Fig. 12, it can be found that when the magnetization directions of adjacent permanent magnets are parallel and opposite to each other, the magnetic field force increases by nearly 100N compared with the case where the magnetization directions of all permanent magnets are uniform. In Fig 11, it can be found that the curve corresponding to the uniform arrangement of magnetization directions has an overall downward shift of nearly 100N, so the improvement of the magnetic adsorption capacity by this arrangement of magnetic poles is a fixed value.

2.4.3 Verification of adsorption device

As shown in the magnetic force-spacing curve in Figure 10, when the adsorption spacing is within 1.75mm, the adsorption device can provide an adsorption force of more than 330N; as shown in Figure 11, even if the magnetization direction of the permanent magnet unit is the same when the adsorption spacing is 1.35mm When it is within, the adsorption device can also provide an adsorption force of more than 300N; the adsorption device meets the requirements of the adsorption force index, and the design is qualified.

3. EXPERIMENT DEMONSTRATION

Figure 13 shows an example of the adsorption of a cylindrical climbing car made of aluminium alloy frame, standard bolts and nuts, rubber tracks, and neodymium iron boron magnets. The cylindrical wall is a medium-sized cylindrical container. Part of, the magnetization direction of the permanent magnet unit in the adsorption device is entirely parallel and reversed along the axis, which theoretically corresponds to the curve shown in Figure 10.

In Figure 14, it can be seen that when there is only one tweet of the house group and the setting is at a distance of 2.5 mm ~ 3.75 mm. the cylindrical climbing car is stably adsorbed on the steel cylinder without falling; this experimental phenomenon strongly supports the previous simulation analysis Preliminary results [9].

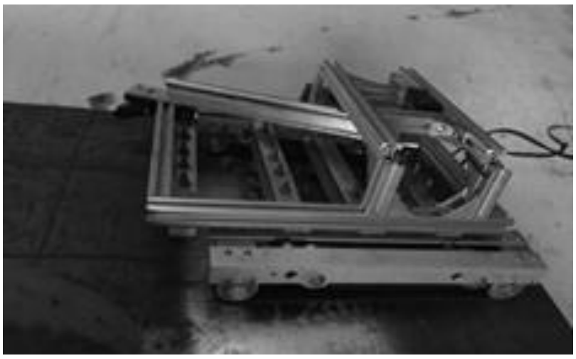

Figure 13 Adsorption test of cylinder climbing car

The institutions in the two figures do not include large mass loads such as motors, various detection modules, communication modules, and power supply modules (such as communication and power supply cables) that are necessary to be equipped under actual working conditions, taking into account the impact of safety margins such as wind load Factors: the heavy objects with masses of 27kg, 57kg and 73kg are respectively tied to the permanent

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magnet group of the adsorption device. The climbing distances of 1.7mm, 0.8mm, and 0.3mm are set accordingly. Climb the aluminium alloy frame to verify the graphical results of the simulation analysis [11].

First, manually adjust the spacing MX to 1.7mm, and manually screw the ten bolts used to fix the permanent magnet. After observing the tension of the springs on all the adjusting bolts, confirm that the spacing adjustment is completed; then select the track and the trolley, Load (tie) a 27kg load and observe that the car body hardly moves, which proves feasible. Then adjust the spacing MX to about 0.8mm, load a pack of 57kg, and observe the same results as above. Finally, adjust the spacing MX to about 0.3mm, load 73kg load, and follow the same results as above. [8,9] The three marks of the field experiment are basically in line with the data of the corresponding three landmark points on the magnetic force-spacing curve generated by the software (close to the two ends and the midpoint on the curve in Figure 10), which proves the correctness of the previous simulation analysis results[12].

Figure 14 Adsorption live (close-up view)

Combining the above experimental process and the structure of the adsorption device shown in Figure 14, it was evident that an appropriate servo mechanism can be added or modified based on the existing adsorption device, referring to the curvature of the wall and turning these bolts individually or locally according to the control requirements. Based on the working principle of the micrometre, the distance between the adsorption device (permanent magnet) and the wall surface can be controlled with different accuracy by adjusting the number of screwing turns of the bolt connection. So that the climbing car: 1) When working on a thicker cylindrical wall, refer to Figure 9-12 to increase the distance appropriately; 2) On the cylindrical surface of different sizes (that is, different radii, different radians), it can achieve an approximate circle. The permanent magnet unit of the arc is arranged in space; 3) When the load of the climbing car changes with time, the distance of the adsorption device can be changed almost in real-time with the help of the control system; to reduce the excess friction, it can ensure the climbing car's Stable adsorption can reduce the power consumption of the electric motor of the power unit, reduce unnecessary stress on the mainframe structure of the climbing vehicle, and increase the service life of the cylindrical climbing vehicle.

4 CONCLUSION

(1) The finite element calculation software ANSYS MAXWELL was used to simulate the vehicle, and the effect of the parameter change of the distance between the adsorption device and the cylinder without welding seam on the magnetic adsorption force of the car was predicted, which reflected the overall adsorption device under working conditions. The reliability of the suction of the whole vehicle when lifting relative to the cylinder wall provides a basis for the adjustment range of the height of the suction device close to the wall.

(2) Based on the results of the graphs and practical experience, the cylindrical climbing car can carry loads with a mass of less than 73kg under normal adsorption conditions.

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