Design and analysis of the variable-axis structure before and after the large magnetic block of the charging and discharging magnetic adsorption robot

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Abstract: The new type of magnetic adsorption robot for charging and discharging the outer surface of ships has unique advantages in derusting the outer surface of ships. Due to the relatively large volume of the charging and discharging magnetic block, it is difficult to rotate around the bearings at the front and rear ends through the track. This paper designs a variable axis structure for large magnetic blocks before and after walking. Use NX to complete the construction of the 3D model, and import the 3D model into ANSYS for structural analysis through the association with ANSYS-Workbench. The deformation and stress analysis of parts provide theoretical support for the safety and stability of the Variable axis structure.

1. INTRODUCTION
The ship wall rust removal and wall climbing robot is the executive mechanism of the ultra-high pressure water jet wall climbing and rust removal equipment on the ship wall. It is the carrier of the ship wall rust cleaning and cleaning device. The main function is to carry the ship wall rust cleaning and cleaning device to make it on the ship wall. Effective rust removal [1]. For ship repair, cleaning up marine organisms and rust on the surface of the ship is an important part of ship repair. The quality of ship rust removal directly affects the effect of ship painting. Therefore, to improve the service life of ships, ship rust removal occupies an important position for the shipbuilding industry [2-4]. In the process of ship rust removal, the environmental pollution caused by manual sandblasting and rust removal is very serious, endangering the health of workers, the efficiency of rust removal is low, and the cost of manual high-pressure water rust removal is too high, unsafe, and easy to return to rust [5-7]. Climbing robots can replace personnel to complete highly dangerous tasks that require strength, such as cleaning and inspecting high-rise buildings, evaluating and diagnosing storage tanks in nuclear power plants and petrochemical facilities, and welding and maintaining ship hulls [8-11]. Therefore, in-depth research and analysis of wall-climbing robots are needed.

The key to reliable robot adsorption is sufficient adsorption force, so the design of the adsorption mechanism has always been the core part of the research on magnetic adsorption wall-climbing robots. QingPei Zhang et al [12] studied a magnetic wall climbing robot. The magnetic attraction module and walking module of the robot are designed, the force state of the wall-climbing robot is analyzed, and the magnetic attraction module is simulated and optimized using ANSOFT Maxwell software. Xin Lai et al [13] designed a non-contact permanent magnet adsorption type wall-climbing robot and used Comsol software to analyze the layout of the permanent magnet adsorption part. The finite element simulation
of the adsorption force generated by the permanent magnet adsorption unit is carried out. Finally, verify the accuracy of the design by comparing actual test and simulation results. Qiang Zhou et al. [14] designed a new type of negative pressure adsorption mechanism applied to climbing robots. This mechanism uses the rotational inertia effect of air to generate and maintain negative pressure and adsorption force. The most important feature of the adsorption unit is that it can run without touching the wall, fundamentally solving these technical problems related to traditional climbing robots. Well-known institutes in the field of robotics in Europe and the United States have done a lot of research on basic theories and experiments [15-16]. Kohei Omoto et al. [17] studied the real-time motion generation of humanoid robots climbing walls. Apply nonlinear model predictive control (NMPC) to optimize climbing path and limb movement at the same time. Utilizing the introduction of potential functions on the wall and state-related weights, the method of online configuration of NMPC performance indicators, complex wall models and limited future control inputs are optimized at each sampling time of NMPC and simulated. The behavior of the climbing robot to show that the calculation time is almost the same as the sampling period. Ravindra Singh Bisht et al. [18] conducted a safety study on the core-based wheel mechanism, and also studied the influence of static and dynamic coefficient of friction (COF) on the vertical surface motion of climbing robots. The wheel mechanism designed and developed has been further demonstrated through the use of a four-wheel differential drive prototype climbing robot. First, a safe navigation test was performed on a 2-D frame plane wall structure, and then a safe navigation test was performed on a 3-D frame wall structure. It was found from laboratory experiments that based on these wheel mechanisms, climbing robots can safely navigate remotely on the flat surfaces of these selected structures. Anwar Sahbel et al. [19] developed an optimal design for the magnetic adhesion mechanism on the iron surface to maximize the magnetic adhesion force. This in turn maximizes the payload that the climbing robot can carry. Experiments have been designed using Response Surface Methodology (RSM) to study the effects of determined independent parameters (i.e., distance between magnets, air gap, and yoke thickness) that affect the response variable (i.e., magnetic adhesion). A quadratic regression model has been developed to express the empirical relationship between the response variable and the independent variable. Statistical analysis of predictive models has been studied using analysis of variance (ANOVA). In order to check the adequacy of the predicted quadratic model, verification experiments have been carried out under different conditions, in which the experimental results show response values similar to the predicted model response. Numerical optimization has been applied to predict the optimal variable conditions for maximum adhesion and air gap, resulting in an adhesion of 240.3 N at a distance of 20 mm between magnets, an air gap of 18.5 mm, and a yoke thickness of 8.3 mm. The optimal conditions have been numerically verified using a commercial finite element simulator. The numerically optimized design parameters have been used to design and build prototype wall climbing robots.

According to the literature review [12-19], it can be observed that there is no attempt to study the crawler-type charging and discharging magnetic adsorption wall climbing robot, and the lifting mechanism of the magnetic block is not designed. Therefore, the focus of this article is to design a front and rear variable axis mechanism for large magnetic blocks to be applied to a new type of magnetic adsorption wall-climbing robot, and to conduct a static structural analysis.

2. METHODOLOGY

2.1 Structural design and model modeling

The magnetic block lifting structure is designed, which is mainly composed of crankshaft, shift fork, bearing support, and bearing rod, and NX software is used for assembly, because the software has a good two-way interaction with ANSYS, which is convenient for the following main components of the magnetic block lifting structure. The force-bearing component is subjected to force analysis, and the assembly drawing model is shown in Figure 1.
In the entire magnetic lifting structure, the shift fork is most prone to deformation and fatigue failure, so the finite element analysis is performed on the shift fork. For analysis, the NX software is used for modeling and then imported into ANSYS. The 3D model of the shift fork and its dimensions are as follows As shown in Figures 2, 3.

![Assembly drawing model](image)

**Figure 1:** Assembly drawing model

2.2 **Finite Element Analysis**

Finite element Analysis is a numerical approach described by partial differential equations for investigating and solving problems to its approximate exact solution [20]. Solving engineering problems involving complex structures is a good attribute of the FEM. ANSYS software is a FEA software package that generates equations which solves and controls the conducts of the elements [21].

First link ANSYS with NX, build a 3D model of the fork part in NX, then import it into ANSYS software and open it through SpaceClaim.

The mechanical properties of the materials of the analyzed parts are shown in Table 1.

| Young’s modulus | 2.09E+11 Pa |
|-----------------|-------------|

| Density         | 7890 kg/m³ |
|-----------------|------------|
| Poisson’s ratio | 0.269      |
| Elastic modulus | 2.1E+11 Pa |
| Shear modulus   | 1.78E+08 Pa|
| Tensile strength| 3.55E+08 Pa|
| Ultimate shear strength | 1.46E+08 Pa|

Depending on the aim of the analysis, some mechanical properties such as density, strength and coefficient of thermal expansion definition is optional [22]. When using ANSYS software to perform mechanical analysis on structures, the accuracy of the material mechanical performance index is very
important. Material deformation to due uniform volume and opposing forces are described by the bulk and shear modulus respectively. Two other essential properties that determine when the material loses its elastic behaviour and the maximum stress a material can undergo are the yields and tensile strength respectively [23].

Meshing involves breaking the model or structure into tiny elements to analyse each of the components is known as meshing [24]. It is a discrete realisation of the structure, which helps in solving the exact model solutions. The smaller the meshing size, the higher the computational time and accuracy of the analysis result [25]. Use ANSYS to mesh the shift fork in the magnetic block lifting structure. The mesh can be divided into two different forms: triangle or rectangle. In this paper, we use a triangular mesh and the specified mesh size is 10mm. Figure 4 shows the shift fork structure after meshing. After the mesh is divided, set constraints and loads according to the actual working conditions. The fixed constraint on the middle hole is shown in Figure 5, and Figure 6 shows that a force of 490N is simultaneously loaded on the left and right of the shift fork for static analysis.

![Figure 4: Meshed structure](image1)

![Figure 5: Fixed Support](image2)

3. RESULT AND DISCUSSION

Use ANSYS software for mechanics, and choose ASTM 1045 as the material. During the entire working process, the shift fork receives the greatest force in the initial position when it is lifted up, including the gravity of the magnetic block, the magnetic attraction force of the magnetic block and the steel plate, and the gravity of the bearing rod. The gravity of the shift fork is ignored. A total force of approximately 980N is applied to the system along the negative direction of the Y axis.

The static analysis results of the shift fork are obtained by the above method: from the total deformation of the shift fork as shown in Figure 7 (a), it can be seen that the maximum deformation is 0.78604mm, and the total deformation of the shift fork is within the acceptable range. Figure 7(b) shows that when a total force of 980N is applied to the left end of the shift fork, the maximum value of the equivalent stress is 168.73Mpa, and the equivalent stress appears at the end of the shift fork link. The maximum equivalent elastic strain is 8.1163e-4. Table 2 lists the measured parameters of the static analysis of the shift fork in the variable shaft structure before and after the large magnetic block travels.
Table 2: Measurement parameters of shift fork in magnetic block lifting structure

| Parameters                | Value                          |
|---------------------------|--------------------------------|
| Force                     | 0 N to 980N                    |
| Equivalent stress         | (Maximum value) 168.73Mpa      |
| Equivalent Elastic strain | (Maximum value) 8.1163e-4       |
| Total deformation          | 0.78604mm                      |

Figure 7: (a) Total Deformation; (b) Equivalent stress; (c) Equivalent Elastic Strain

4. CONCLUSION

This paper designs the variable-axis structure before and after the large magnetic block of the charging and discharging magnetic adsorption robot, and uses ANSYS software to analyze the static structure of its main force parts. Analyzing the total deformation, equivalent stress and equivalent strain parameters, it is found that the maximum deformation is 0.78604mm, the maximum stress is 168.73N/m2, and the maximum equivalent elastic strain is 8.1163e-4. It is found that all measurement parameters are allowed within the scope, the expected design goal was achieved, and the problem that the charging and discharging magnetic adsorption robot could not be turned due to the large magnetic block was solved.

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