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Finite Element Analysis of Mobile Chassis for the Maintenance Robot with Charged Used in Substation under Idle Condition

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Finite Element Analysis of Mobile Chassis for the Maintenance Robot with Charged Used in Substation under Idle Condition

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Abstract. The Maintenance Robot with Charged is used in substations which voltage level is under 220kV.The Robot mainly performs electrified maintenance work on pillar insulators and other equipment in substations. There are many equipments in the substation, the magnetic field distribution is not uniform, and the influence of the power frequency magnetic field on the robot cannot be ignored. Statics and modal analysis with the method of finite element of the robot's mobile chassis under idle speed are carried out according to the structural characteristics and walking characteristics of the robot combined with the frequency characteristics of the power frequency magnetic field in the substation, and then the stress distribution, low-order frequencies and corresponding mode shapes of the robot's mobile chassis under idling condition are obtained, and the influence of the power frequency magnetic field in the substation on the dynamic characteristics of the robot was analyzed based on the simulation results.

1. Introduction

The robot needs to have good stability when walking in the substation. The electrical control conducts motion control of the robot from the control unit. The vibration characteristics of the mobile chassis of the robot are the inherent characteristics of the mobile chassis, determined by the structure of each part of the chassis [1]. The type of magnetic field in China's substations is the power frequency magnetic field, and the frequency is 50Hz. If the frequency of the power frequency magnetic field is close to the natural frequency of the mobile chassis of the robot, it will cause the robot to vibrate during idle and walking, which is not conducive to the stability of the robot walking and operation, and the control is difficult.

The finite element analysis of the mobile chassis is mainly focused on the static analysis and dynamic analysis of the chassis under consideration of its own gravity and external loads. The static and dynamic characteristics analysis of the chassis in the idling state have obtained the deformation and the stress distribution of the mobile chassis under the idling conditions, and then verified the rationality of structural design of the chassis. The pre-load modal analysis is performed on the basis of statics. The low-order vibration frequencies and modal vibration modes of the mobile chassis are calculated. The influence of the power frequency magnetic field in the substation on the mobile chassis of the robot in the substation is analyzed based on the calculation results. The mobile chassis for the maintenance robot with charged used in substation under idle condition is shown in Figure 1.

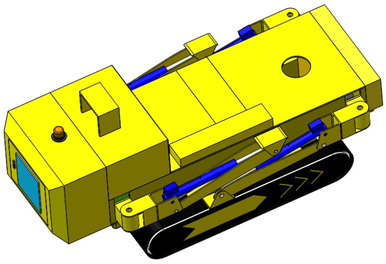

Figure 1. The mobile chassis for the robot under idle condition.

2. Theory of Finite Element Analysis

The finite element method uses the discretization theory to unitize the structure of the object. The overall stress distribution is reflected according to the force conditions of each node based on the theory of elasticity and structural mechanics. Modal analysis is the basis analysis of mechanical vibration. The structural vibration characteristics are mainly divided into vibration frequency and vibration mode. The vibration frequency and mode shape are the inherent properties of the mechanical mechanism. Each mode corresponds to a particular mode shape [2].

Vibration frequencies ω and mode shapes ϕ can be found by the following equation:

$$([K]-\omega^2[M])\{\phi\}=\{0\} \quad (1)$$

In the formula, [M] is the mass matrix and [K] is the stiffness matrix.

The low-order vibration frequencies and the corresponding vibration modes of the mobile chassis can be obtained through the modal analysis results, and then the effect of the power frequency magnetic field on the robot's mobile chassis can be obtained by comparing the low-order vibration frequencies with the power frequency.

3. Preprocessing

3.1. The establishment of finite element model

The mobile chassis finite element model is discretized on the basis of a three-dimensional model. The connection and cooperation of the mechanical structure are simplified. The connection and cooperation in the chassis are simplified by restricting the degrees of freedom. The connection and cooperation of the hydraulic cylinders on the outriggers are simplified. Components such as connecting pins, keys, and nuts are modeled and integrated. The smaller chamfers and threads are ignored in the finite element model. The finite element model of the robot's mobile chassis under idle condition is shown in Figure 2.

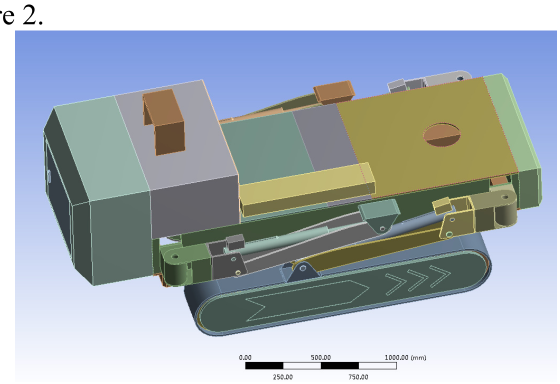

Figure 2. The finite element model of the robot's mobile chassis under idle condition.

The finite element model needs to match the material properties. Static analysis and modal analysis are linear analysis. Therefore, the properties of elastic modulus, poisson ratio, and density are mainly assigned to components. In the mobile chassis, most of the structural parts use Q345, and the crawler part uses rubber properties.

3.2. Meshing

The mesh is divided into mixed meshes with tetrahedron-based and hexahedron-assisted. Since the assembly of the mobile chassis is large, the partitioning method is divided freely, the mesh correlation is selected according to the size of the model and the calculation accuracy. Selecting the mesh correlation degree as Fine+0, and conducting local adjustment on the larger mesh, and then performing detailed refinement and encryption processing locally. The number of nodes is 209,037, and the number of cells is 84,379 after meshing. The mesh of the robot's mobile chassis under idle condition is shown in Figure 3.

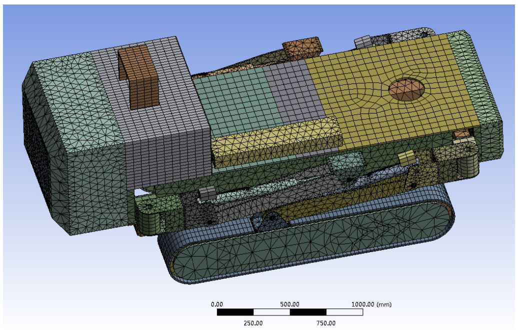

Figure 3. The mesh of the robot's mobile chassis under idle condition.

3.3. Boundary Conditions

The position of the boundary condition determines the accuracy of the calculation result. In order to simplify the calculation, the Bonded constraint is used at the contact parts, and the Bonded constraint is a linear constraint, so that the contact surface does not appear tangential sliding and normal separation, and then large separation and deformation could not occur between components in the calculation process. Since the legs are retracted during the idling state, the contact surface between the track and the ground is subjected to full restraint treatment with the Fixed, limiting the freedom of displacement to simulate the actual working conditions. Equivalent simplification is conducted to the motor and other transmission components, and the motor's mass is equivalent to 3000N, and the battery's mass is equivalent to 3000N. Due to the fact that the part of the insulated arm has not yet been deployed in the idling state, the mass of the insulated arm is equivalent to two parts, which are respectively applied to the chassis rear plate and the insulating arm support frame, totaling 8000 N. The equivalent mass of the hydraulic valve block is 300 N. The boundary conditions of the robot's mobile chassis under idle condition is shown in Figure 4.

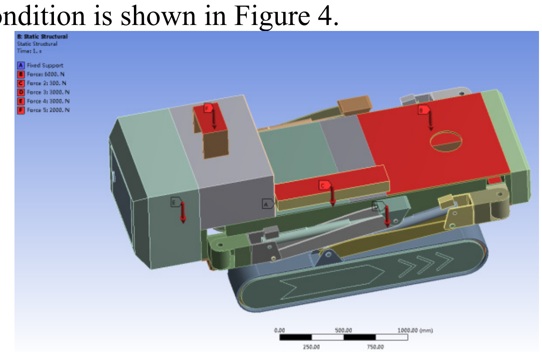

Figure 4. The boundary conditions of the robot's mobile chassis under idle condition.

4. Static Analysis

Solving calculation and post-processing operation of the robot's mobile chassis under idle condition are conducted after processing, meshing and boundary constraints imposed, and then the deformation and stress distribution could be obtained. The deformation cloud diagram of static simulation is shown in Figure 5 and the stress distribution cloud diagram of static simulation is shown in Figure 6.

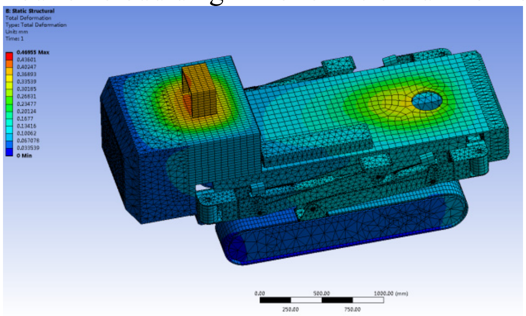

Figure 5. The deformation cloud diagram of static simulation of the robot's mobile chassis.

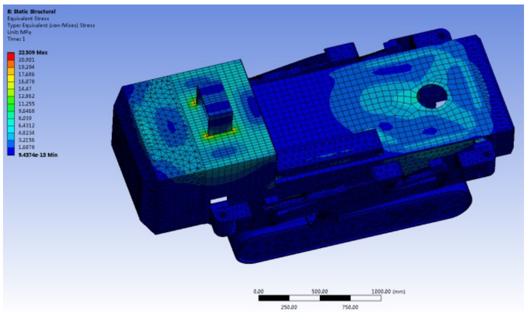

Figure 6. The stress distribution cloud diagram of static simulation of the robot's mobile chassis.

It can be seen that the maximum deformation occurs in the motor mounting plate and the battery shell upper plate of the chassis in the idling state, and the maximum deformation is about 0.45 mm. From the static simulation stress distribution cloud diagram, it can be seen that the overall stress distribution of the chassis is uniform, and stress concentration occurs at the base part of the battery holder. The maximum stress is 22.5 MPa. Since the material of the track bracket is Q345 and the yield strength is 345 MPa, the calculated maximum stress is far less than the yield strength, and then the work requirements are satisfied.

5. Modal Analysis with Preload

The modal analysis of the chassis was performed on this basis of the static analysis with the model, grid and boundary conditions unchanged. The robot's mobile chassis under idle condition is calculated and post-processed after appropriate preprocessing. The low-order modes have a greater influence on the structure according to the vibration theory and then the modes from first to sixth are extracted in the solution process. The low-order vibration frequencies are shown in Table 1, and the corresponding mode shapes are shown in Figure 7.

Table 1. The low-order vibration frequencies of the robot's mobile chassis.

Order	Frequency /Hz	Maximum displacement /mm
1	5.96	0.88
2	10.57	1.00
3	13.06	0.71

4	15.21	2.22
5	24.25	2.20
6	29.33	2.10

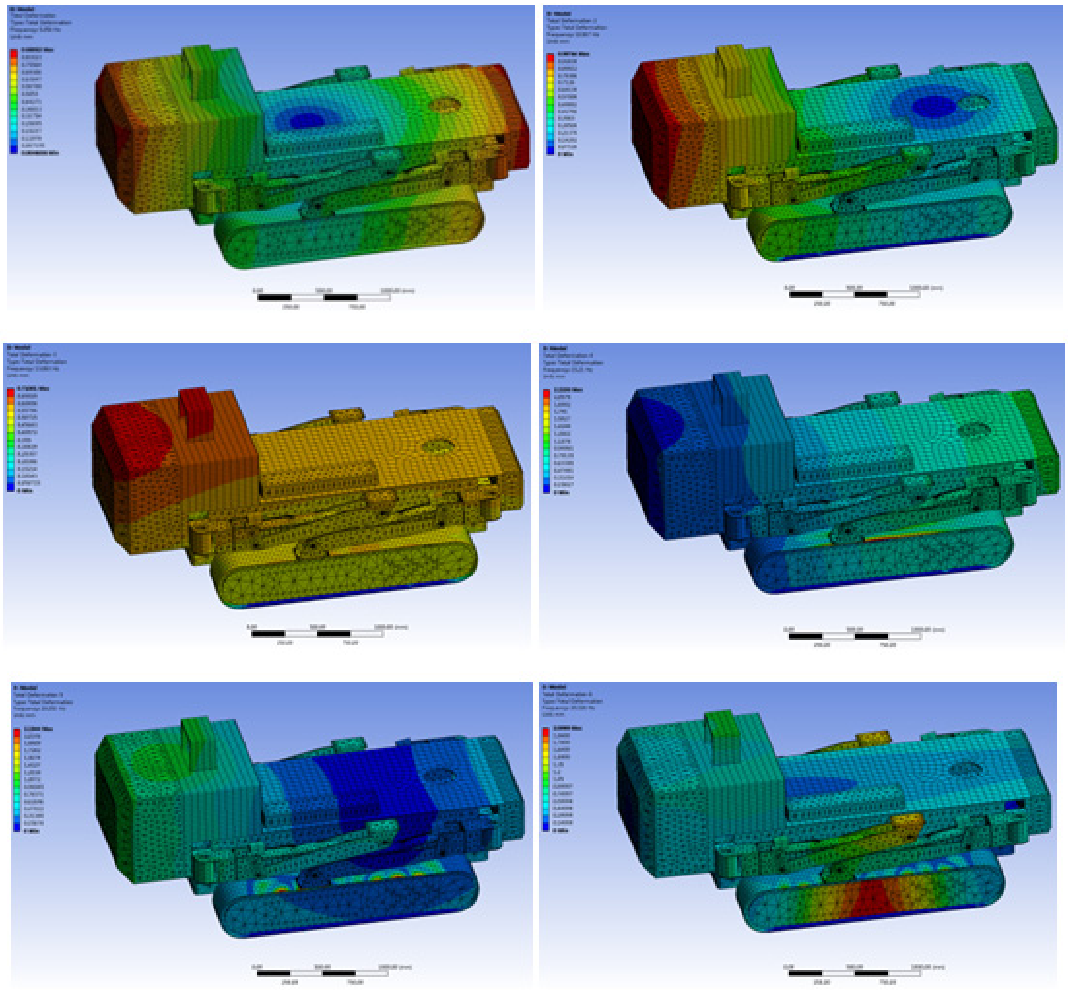

Figure 7. The mode shapes of the robot's mobile chassis.

It can be seen from the Table 1 and Fig.7:

The first-order vibration frequency is 5.96 Hz. The vibration is represented by the left and right rotation vibration around the vertical center axis of the chassis. The front toolbox and rear battery door of the chassis vibrate have the largest deform, and the maximum vibration displacement is 0.88mm.

The second-order vibration frequency is 10.57 Hz. The vibration is expressed as the left and right rotating vibration around the rotation axis of the vertical axis of the chassis which closes to the mounting position where the insulating arm is mounted. The rear battery door's vibration is maximum, and the maximum displacement of vibration is 1.00mm;

The third-order vibration frequency is 13.06 Hz. The vibration performance is based on the contact surface between the track and the ground, and the entire chassis of the mobile chassis vibrates back and forth. The rear battery upper plate and the insulating arm support frame have the highest vibration, and the maximum vibration displacement is 0.71 mm;

The fourth-order vibration frequency is 15.21 Hz. The vibration performance is the front part of the mobile chassis rotates vibration left and right around the vertical axis of the chassis (near the battery mounting position). The upper part of the crawler on both sides has the highest vibration, and the maximum displacement of the vibration is 2.22mm.

The fifth-order vibration frequency is 24.25 Hz. The vibration performance is pitching vibration before and after around the horizontal axis of the chassis. The upper track on both sides of the maximum vibration, vibration maximum displacement of 2.20mm;

The sixth-order vibration frequency is 29.33 Hz. The vibration performance is torsional vibration left and right around the horizontal axis of the chassis. The outer part of the crawler baffle has the largest vibration and the maximum displacement of the vibration is 2.10mm.

The low-order vibration frequency range of the moving chassis in the idle state is 5.96~29.33Hz, which is far less than the frequency of the power frequency magnetic field 50Hz. Therefore, the power frequency magnetic field has little effect on the mobile chassis of the robot. And then the robot has good stability during the idling process.

6. Conclusion

The finite element method is used to analyze the static and modal analysis of the robot's mobile chassis under idle condition in this paper. The stress distribution of the robot's mobile chassis is obtained, and the rationality of the structural design is verified. The power frequency magnetic field in the substation has little effect on the robot movement state by comparing the frequency of the power frequency magnetic field with the low-order vibration frequency of the robot's mobile chassis. The robot would have good stability during idling and walking state, and the simulation results could provide a theoretical basis for motion control.

Acknowledgments

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