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THERMAL ANALYSIS OF RARE EARTH ELECTROLYTIC ROBOTS UNDER HIGH TEMPERATURE ENVIRONMENT

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Rare earth electrolysis robot is an automatic equipment that can realize the process of crucible extraction and dumping of casting mold in electrolytic tank under high temperature and dusty environment. Based on ANSYS software and APDL language, the thermal-structural coupling simulation analysis of the rare earth electrolysis robot is carried out to construct the temperature distribution and thermal deformation model of the robot, and the thermal deformation error and connecting rod machining error are considered comprehensively to obtain the linkage length dimension error model, which provides some theoretical basis for the robot error compensation to improve the accuracy.

Keywords: electrolytic robot, thermal analysis, high temperature, finite element method, error

INTRODUCTION

According to the requirements of Made in China 2035, it is a critical period for the development of intelligent equipment in China, and it is imperative to accelerate the equipment upgrade in the rare earth electrolysis industry.

The research difficulty of the rare earth electrolysis robot is how to ensure that the robot can operate normally under high temperature environment and can complete the expected action, so it is necessary to study the thermal deformation of the robot walking mechanism.

At present, ANSYS is more and more widely used in the world. At the same time, the research of robot thermal error has been developed rapidly at home and abroad.

J. Li used Workbench to thermally analyze the robot for hot machining parts and obtained a cloud map of the overall temperature field distribution of the robot. [1] X.L. Zhang conducted a thermal analysis of the rare earth electrolyzer and obtained a cloud map of the temperature field distribution of the rare earth electrolyzer. [2] G.T. Jiao combined the operating environment temperature and other factors to derive the corresponding error of the connecting rod structure parameters. [3] R. Li created the robot's heating error model and the thermal deformation error model influenced by the environmental temperature to calculate the error of robot's own heating and environmental temperature changes. [4]

W.S. Song conducted a thermal-structural coupling analysis on the joint part of the starboard antenna drive mechanism, and summarized the thermal deformation after the solution as the equivalent structural parameter error together with the structural parameter error into a comprehensive error. [5]

C.Gong integrated the flexibility error and temperature error, and established a temperature error prediction model for robots using the orthogonal regression method. [6] E. Lubrano studied the thermal characteristics of a three-degree-of-freedom parallel robot using an external laser interferometry system, a temperature sensor, and developed a model of the thermal characteristics. [7]

This paper takes the rare earth electrolysis robot and electrolyte in the rare earth electrolysis cell as the research object, establishes the temperature distribution and thermal deformation model of the rare earth electrolysis robot using the finite element method, and calculates the error of the length and size of the robot's connecting rod according to the formula of the length and size error of the connecting rod.

Temperature field simulation of rare earth electrolytic robot

When the robot starts working and its fixture is not yet in contact with the molten electrolyte, there are several heat transfer scenarios to be considered: 1. radiative heat exchange between the electrolytic solution and the robot; 2. heat convection between the rare earth electrolytic robot and the air; 3. heat transfer inside the rare earth electrolytic robot.

The rare earth electrolytic cell of a company is shown in Figure 1.

The rare-earth electrolyzer consists of graphite tank, outer wall of the tank, steel tank, electrolyte, etc. The outer wall of the electrolyzer is made of insulating

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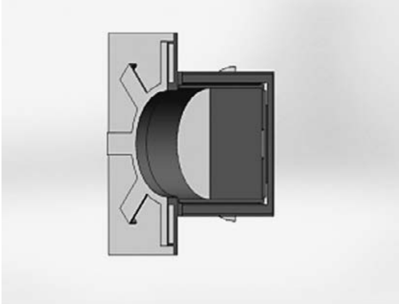

Figure 1 Rare-earth electrolyzer

brick, which can play a good role in heat insulation, so only the upper surface of the molten electrolyte (1 030° C), the outer wall of the electrolyzer (60 °C) and the steel plate on the upper part of the tank (300 °C) are used as heat sources for thermal analysis of the rare-earth electrolyzer robot in this paper.Since the overall structure of the rare earth electrolysis robot is huge and has many parts, it cannot be directly imported into ANSYS Workbench for calculation. It is necessary to simplify the rare earth electrolysis robot model to some extent and delete the features and parts in the model such as threaded holes, bolts, chamfers and recesses that have less influence on the structural performance,so as to reduce the occupation of computer memory, improve its calculation speed and shorten the time of simulation.By reviewing the relevant literature, the thermal physical parameters of the robot and various major materials of the electrolytic cell [2, 8, 9] were obtained as shown in Table 1:

Table 1 **Material thermal property parameters**

Content	253MA	Structural steel	HP-8 micarex	Molten Salt Metals	Insulation brick
Thermal conductivity /w·m^{-1}·k^{-1}	15	43,12	0,58	236	0,5
Density/kg·m^{-3}	7800	7850	2700	700	130
Specific heat /kj·kg^{-1}·k^{-1}	0,5	0,465	0,871	27,4	0,867
Emissivity	0,6	0,4	0,75	0,879	0,85

In the thermal analysis module, the load is applied and the convection is set first: the air temperature is 35°C, the density is 1,205 kg/m^3 and the convective heat transfer coefficient is 5 W/m^2·°C.

Then the thermal load is applied: the initial temperature of the rare earth electrolytic robot is 30 °C, the temperature of the outer wall of the electrolytic cell is 60 °C, the temperature of the bottom of the cell is 160 °C, the temperature of the upper part of the cell is taken as the temperature of the steel plate of the conventional structure of the cell whose size is 300 °C, and the temperature of the molten electrolyte is 1 030 °C [10].

Since the surface roughness of the mating surface between each part of the rare earth electrolytic robot is generally Ra6,3, which is relatively smooth, the contact thermal resistance between the metal materials can be disregarded. While HP-8 hard gold mica plate as a synthetic material with relatively rough surface, it is necessary to set a contact thermal resistance of 10 000 W/m^2·°C on the contact surface.Set the APDL command for thermal analysis. To save calculation time, select the Gauss-Seidel solver for calculation. On the premise of ensuring calculation convergence, set the maximum iteration number to 1 000, convergence tolerance, and relaxation factor to 0,1.The temperature clouds of the rare earth electrolytic robot were obtained after simulation analysis as shown in Figure 2 and Figure 3.

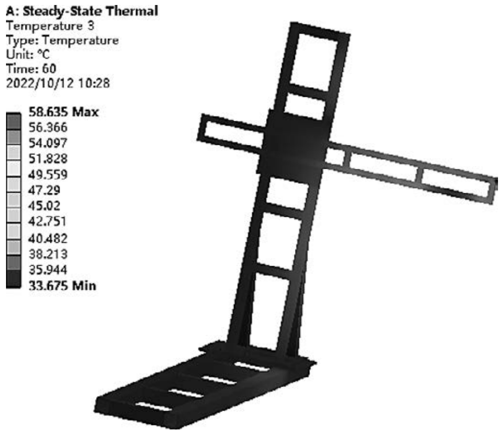

Figure 2 Temperature of Rare earth electrolytic robot

Figure 3 Temperature of End effector

When the temperature of the rare earth electrolysis robot reached the steady state, it can be seen from Figure 1 that the temperature of the rare earth electrolysis robot was highest at the nearest part of the electrolyzer, with a value of 58,635 °C. As the distance became farther, the influence of the high temperature environment of the robot gradually weakened, and the lowest temperature was 34,919 °C.

Similarly, it can be seen from Figure.2 that the temperature of the end part of the fixture of the rare earth electrolysis robot facing the furnace mouth reached a maximum of 72,281 °C, while the temperature of the part of the fixture away from the electrolyzer was around 35 °C.

Heat deformation analysis

From the temperature cloud above, we can find that the molten electrolyte, the upper steel plate of the elec-

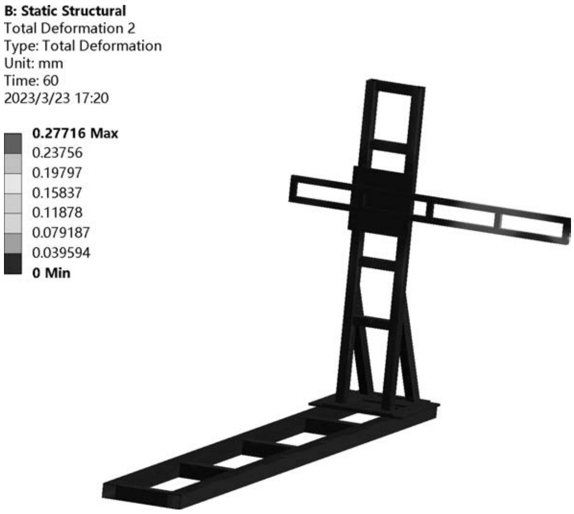

Figure 4 Heat deformation of robot

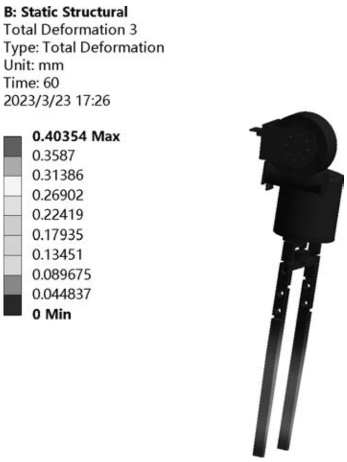

Figure 5 Heat deformation of End effector

trolyzer and other heat sources transfer heat to the rare-earth electrolytic robot through heat transfer such as radiation heat exchange, which makes its temperature change significantly, and since the main material of the rare-earth electrolytic robot is carbon structural steel, this temperature change is very likely to cause thermal deformation of the robot connecting rod.

Due to the complexity of the structure of the rare-earth electrolysis robot, this paper performs a coupled thermal-structural analysis of the rare-earth electrolysis robot based on its temperature field simulation to study the amount of thermal deformation of the robot in a high-temperature environment.

The temperature field simulation results obtained from the thermal analysis are passed to the statics module to obtain the thermal deformation of the robot under thermal stress, and the deformation diagrams of the rare earth electrolysis robot are obtained as shown in Figures 4,5.

As can be seen from the thermal deformation cloud map in Figure 4,5, the position where the robot walking mechanism has the maximum thermal deformation is directly opposite the electrolytic cell slot, and its value is 0,20566 mm. Moreover, the part with the largest deformation of the robot is the part with the largest temperature change above. The position where the maximum thermal deformation of the end effector occurs is the lower end of the actuator closest to the molten electrolyte, with a value of 0,40354 mm. Moreover, the position where the robot deforms the most is the position where the temperature changes the most in the above.

Parameter error analysis of robot connecting rod structure

In the working environment of a rare earth electrolysis robot, there is a molten electrolyte at 1 030 °C in the rare earth electrolysis tank. This electrolyte will transfer heat to the robot through radiation and heat transfer, resulting in changes in its own temperature, resulting in deformation of the connecting rod and joint expansion.

Changes in the size of the connecting rod will affect the robot's motion accuracy, and joint expansion may cause the robot to jam, Therefore, in order to ensure that the rare earth electrolysis robot can complete the expected work, it is necessary to conduct thermal error analysis on the robot.

According to the current precision parameters of industrial robots, the processing error parameters of each connecting rod of the rare earth electrolytic robot are set as 0,01mm in this paper.

The error curve of the robot walking mechanism obtained by MATLAB simulation is shown in Figure 6:

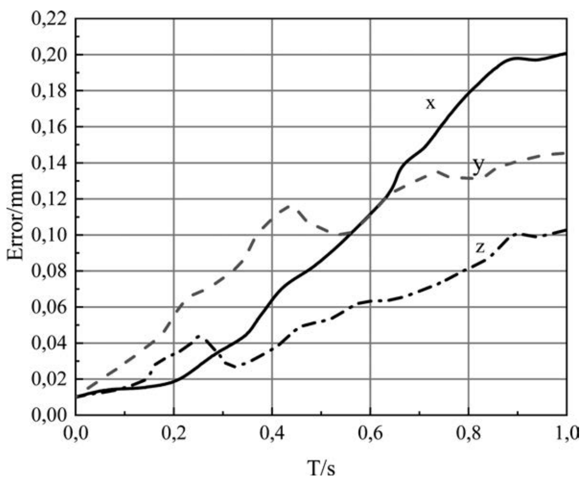

Figure 6 Length dimension error curve of connecting rod of walking mechanism

The maximum error of the connecting rod of the robot walking mechanism in the x direction is 0,20155 mm, the maximum error of the connecting rod in the y direction is 0,1453 mm, and the maximum error of the connecting rod in the z direction is 0,101732 mm.

According to engineering practice, the error of straightness and parallelism of the general guide rail is less than 0,5 mm, and the maximum error of the connecting rod of the rare earth electrolytic robot is 0,20155 mm in the x direction, much lower than 0,5 mm, which meets the requirements.

CONCLUSION

Based on the temperature distribution model and the thermal deformation model of the rare earth electrolytic robot, the connecting rod error model of the rare earth electrolytic robot considering the thermal deformation is obtained, which provides a certain reference for the subsequent comprehensive position and pose error analysis and error compensation of the robot end.

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Note: The responsible translator for English language is Y. BIAN – Hebei Normal University, China