Design and dynamic simulation of manipulator

Mingming Sun¹,a*, Yanan zhao¹,b, Zhonghui wang¹,c Bing Liang¹,d, LiuBao Shao¹,e

¹ School of Mechanical and Electrical Engineering, Guilin University of Electronic Science and technology, Lingchuan, Guilin, Guangxi, China

a*email: 1801201040@mails.guet.edu.cn, bemail: 954875714@qq.com

Abstract. Using a portable manipulator to take out the recovery crucible from the rare earth redox bath, its reliability is one of the bottlenecks restricting production automation. According to the production process of praseodymium and neodymium alloy, determine the mechanism design, and analyze the force to determine the motor selection. The manipulator model is established in the SolidWorks environment, the communication interface is compatible, and the adams software is imported to conduct dynamic simulation analysis of the manipulator mechanism. The manipulator opens and closes smoothly, and the output clamping force meets the theoretical value requirements. The motor is selected to meet the requirements of use.

1. Introduction
Rare earth is a rare resource with important strategic significance in modern industry, and it is widely used in high-precision fields such as aerospace and medical treatment[4]. The preparation of rare earth master alloys by molten salt electrolysis is currently an important development area due to its outstanding energy saving and emission reduction effects and cost advantages[2]. The low level of automation of rare earth and rare earth alloy electrolysis makes the electrolysis process not stable enough, and the product composition Quality fluctuates easily[3]. The current mainstream metal craftsmanship has manual scooping method and crucible method[4], that is, workers scoop out liquid metal with a spoon one by one, or use crucible tongs to pick up a crucible with liquid metal. The working method is relatively simple, but the labor intensity of the workers is high, the working environment is harsh, and there are also the siphon furnace method[5], the static pressure furnace method, but the siphon pipe is too long and it is easy to block or the siphon pipe is suddenly cold and hot. The static pressure tapping method is easy to produce gaps in the pipes, causing liquid metal to flow out when the metal is tapped.

The manipulator takes out the crucible with liquid metal instead of manual gripping by the manipulator. The manipulator is the most stable method of furnace discharge[4], but it requires high stability of the manipulator. A manipulator is now designed to replace the manual gripping of the crucible to extract the metal, and the motor is selected. Three-dimensional modeling and dynamic simulation of it, solving the force of the manipulator, verifying whether the contact force of the crucible clamped by the clamp block meets the work requirements, and provides a basis for post-processing and manufacturing.

2. Working principle of manipulator
The motor is connected to the reduction box and fixed on the motor support plate. The reduction box is connected to the lead screw to drive the lead screw to rotate. The lead screw rotates to drive the nut to move up or down. The nut moves to drive the connecting rod. The connecting rod drives the...
mechanical rod to surround the pin on the support base. Rotate to control the opening and closing of the lower part of the mechanical rod to clamp the crucible. The lead screw ensures the stability of the lead screw rotation through the upper bearing support and the lower bearing support. There are two upper and lower limit rings on the lead screw to limit the movement distance of the nut, thereby restricting the stroke of the lower part of the mechanical rod and the clamping block, positioning plate. While supporting the lower bearing support, the rotation of the nut is restricted to drive the side movement of the mechanical rod. The whole manipulator is fixed on the guide rail through a fixed plate to realize the three-dimensional movement of the manipulator.

3. Design of manipulator mechanism

3.1. Mechanism design

In the actual work process, the manipulator requires four degrees of freedom, namely the clamping mechanism and the three-dimensional motion mechanism. The clamping mechanism is a two-finger claw, the opening angle cannot be greater than 4°, and the maximum opening diameter is less than 300mm. In order to achieve the reliability of clamping the crucible, the clamping mechanism uses a DC torque motor. The self-inductance of the DC torque motor is very high. It is small, so the response is very good; its output torque is proportional to the input current and has nothing to do with the speed and position of the rotor; it can be directly connected to the load and run at low speed in the state of close to the locked rotor without gear reduction, so it is on the load shaft. It can produce a high torque to inertia ratio, and can eliminate the system error caused by the use of reduction gears[6]. The torque motor drives the lead screw to rotate, the lead screw drives the nut to move horizontally, and the mechanical rod is driven by the connecting rod to rotate the clamping block to open and close, and the clamping block just fits the crucible when it is clamped.

3.2. Material selection

Since the purpose of the manipulator design requires the crucible to be clamped in the electrolytic cell, the optimal reaction temperature for molten salt metal electrolysis in the 6kA neodymium praseodymium electrolytic cell is about 1050°C[7], so the mechanical rod clamped by the manipulator is required to use high temperature resistant materials. Aiming at the existing workers using Q235 steel crucible tongs to grip the crucible, in addition to considering the difficulty, cost and quality of the material, Q235 steel is selected as the material of the manipulator, which can meet the conditions of about 1050°C and meet the stress condition[8].

3.3. Motor selection

The design requirements of the manipulator are shown in Table 1, for which the torque motor is selected. Figure 1 shows the schematic diagram when the manipulator just grabs the crucible, where $a=70\text{mm}$, $b=360\text{mm}$, $c=920\text{mm}$, $r=40\text{mm}$, and the range of $\alpha$ is $45^\circ$ to $50^\circ$. During the clamping work, when only two clamping blocks are in contact with the crucible, the clamping blocks are attached to the outer surface of the crucible.

![Figure 1](image_url) Schematic diagram of manipulator claw taking weight
Table 1  Design requirements of the manipulator

| Name parameter | Drive mode  | Degree of freedom | Load (kg) |
|----------------|-------------|--------------------|-----------|
|                | Motor drive | 1                  | 20        |

At this time, the clamping force of the clamping head is the largest, so select this moment for force calculation. Since the connecting rod and the mechanical rod are exactly the same in the design, the force of the two clamps is the same at this time, which can be calculated as follows:

$$2c \cdot N = F(r + a \cdot \sin \alpha) \quad (1)$$

The pulling force of the lead screw is:

$$F = \frac{2c \cdot N}{r + a \cdot \sin \alpha} \quad (2)$$

Since the effect of overcoming the neutrality of the object mainly depends on the friction between the chuck and the weight, the formula is as follows:

$$N = \frac{mg}{f} \quad (3)$$

$\alpha$: The friction coefficient of the chuck, take 0.1;

In actual work, in order to ensure the safety and reliability of the work, the safety factor and mechanical efficiency need to be considered. The actual tension of the threaded screw can be obtained by the following formula:

$$F_{\text{actual}} = \frac{FK_2}{\eta} \quad (4)$$

$\eta$: mechanical efficiency of the hand, take 0.9;

$K_1$: safety factor, generally 1.2−2, here take 1.2;

$K_2$: Working condition coefficient, mainly considering the influence of inertial force, $K_2$ can be approximated by the following formula, $K_2=1+a/g$, where $g$ is the acceleration due to gravity, and $a$ is the maximum acceleration when the object is grasped. The workpiece moves very slowly, basically in a state of uniform motion, so $a$ is $0.2 \text{ m/s}^2$.

$$T_a = (F_a \cdot l)/(2 \cdot 3.14 \cdot n) \quad (5)$$

$T_a$: driving torque;

$F_a$: the resultant axial force ($F_a = F_{\text{actual}} + \mu mg$, $\mu$: the comprehensive friction coefficient of the guide is 0.2, the mass of the moving workpiece in $m$ is $\text{kg}$);

$L$: Lead screw lead mm, take 6mm;

$n$: The positive efficiency of the feed screw, take 0.32;

Based on the above calculation results, the torque motor 100TP40GV22 is preliminarily selected to be combined with a right-angle air reduction gearbox, and the reduction ratio is 1:20. The basic parameters are shown in Table 2.

Table 2  Basic parameters of the motor used by the manipulator

| Name parameter | Maximum short-time working voltage (V) | Maximum output power (w) | Maximum allowable torque (Nm) |
|----------------|----------------------------------------|--------------------------|-------------------------------|
|                | 220                                    | 40                       | 40                            |

4. Kinetic analysis

4.1. Dynamic simulation

From the above calculations, when grabbing a 20kg weight, the stepper motor needs at least 40Nm output torque. In order to verify the working state of the manipulator claw under the 40Nm torque, the manipulator 3D model established in the SolidWorks software is imported into the Adams software for power Scientific analysis. In order to accurately reflect the output force of the manipulator under this torque, a spring is added between the clamping blocks. In order to simplify the model, all the pins between the connecting rods of the manipulator were removed, and a rotating pair was added instead; a rotating pair was added to the output shaft of the reducer connected to the motor, giving a torque of
40 Nm; between the output shaft of the reducer and the screw. The physical contact is applied between the clamp block and the spring; the thread pair connection is applied between the screw and the nut. Simulate the actual contact and clamping process of the manipulator.

4.2. Analysis of simulation results
When the motor output shaft is loaded with a torque of 40 Nm, it follows the constant torque input. The time domain diagram of the output clamping force of the screw clamping spring is shown in Figure 2. When 0-0.6s, the output force is 760 Nm. The main reason is that the reaction force of the spring on the clamping block is less than the output force of the screw during this period, and the clamping block itself has a certain inertial force. The change curve of the angular velocity of the motor shaft clearly reflects the force change of the manipulator under the reaction force of the spring. After 0.6 s, the angular velocity is basically stable to 0, which proves the force balance. At this time, the output force of the clamping block is basically equal to the spring reaction force, and the clamping state is stable. At this time, the output force curve of the screw rod is stable at about 650Nm. It is consistent with the required value in the theoretical calculation and can well meet the design requirements. As shown in Figure 3, the contact force of the clamping block and the crucible is in contact at 0.6s. At this time, the clamping force of the clamping block is 2100N, which meets the requirement of clamping a 20kg crucible. The angular velocity of the motor shaft fluctuates around 0. The reason is that the manipulator has chosen to grab the workpiece as a spring, and the clamping block has an initial speed. Therefore, the clamping force and the spring support force balance are more than clamping rigid parts. Obvious vibration factors, but no adverse effects on the force and motion simulation results of the reaction chuck.

![Figure 2](image) Time domain diagram of clamping force
5. Conclusion
This paper selects the motor type of the design manipulator, designs the grasping structure on the mechanism according to the actual situation, and uses Adams to analyze the dynamics of the structure, mainly analyzing whether the output force of the manipulator meets the engineering requirements. The results show that: The motor is selected successfully, and the selected motor can provide the gripping force required for the manipulator design; The manipulator has a reasonable structure design. Under the output torque of the motor, the mechanism runs smoothly and the output force is stable. The torque changes little during the entire movement, Meet the design requirements; The entire manipulator design can provide a basis for manipulator processing and motor purchase.

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References
[1] Zhao Erxiong, Luo Guoping, Zhang Xianheng, Liu Yubao, Miao Xuchen. Preparation methods of highpurity rare earth metals and the latest development trend [J]. Metallic Functional Materials, 2019, 26(03): 47-52.
[2] Pang Siming, Yan Shihong, Li Zongan, Chen Dehong, Xu Lihai, Zhao Bin. Development on Molten Salt Electrolytic Methods and Technology for Preparing Rare Earth Metals and Alloys in China [J]. Rare Metals, 2011, 35(03): 440-450.
[3] Guo Tan, Wang Shidong, Ye Xiushen, Li Quan, Liu Haining, Guo Min, Wu Zhijian. Research progress in the preparation of rare earth alloys by molten salt electrolysis method [J]. Science in China: Chemistry, 2012, 42(09):1328-1336.
[4] Liu Yubao, Chen Guohua, Yu Bing, Zhang Wencan, Liang Xingfang, Chen Yuxin. Research Progress of Tapping Technology for Molten Salt Electrolytic Preparation of Rare Earth Metals[J]. Rare Earth, 2018, 39(02): 134-140.
[5] Pang Qishou, Li Yuefei, Li Yuze, Xiong Yunpeng, Zhang Hao. Numerical Simulation of Discharge Process of Rare Earth Neodymium Electrolyzer in Fluoride Molten Salt System[J]. Journal of the Chinese Rare Earth Society, 2020, 38(02): 190-195.
[6] Pang Xinliang, Zhao Weiwei, Fan Dapeng, et al. Application Research of DC Moment Motor on Airborne Opto-Electronic Servo System [J]. Infrared Technology, 2007, 29(10):573-578.
[7] Chen Guohua, Wang Xiaoping, Liu Yubao, Zhao Erxiong, Yu Bing, Li Kun. Preparation of Pr-Nd-Dy Alloys by Molten Salt Electrolysis[J].Rare Earth, 2015, 36(01):80-84.
[8] Man Yuan, Li Xiankui, Yang Ladao. Research on Elevated Temperature Characteristics of
[9] Li Fajia, Zhu Rupeng, Bao Heyun, Xiang Changle, Liu Hui. Dynamics Characteristics and Experiment Research on Planetary Gear System[J]. Journal of Nanjing University of Aeronautics and Astronautics, 2012, 44(04): 511-519.