Design of Precise Control and Dynamic Simulation of Manipulator for Die-casting Mould

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Abstract. To meet the demand of the enterprise for the die-casting machine, the overall structure of the manipulator and the controller of each joint were designed. Firstly, the solid model of the manipulator is established; and then, the simplified manipulator model was for dynamics simulation; Finally, through a combination of structural dynamics and dynamics control, established the cooperative control system of the manipulator, designed parameters of each joint motion controller and applied to cooperative control system simulation, joint simulation of manipulator is realized. The simulation results show that the manipulator system has good fast response characteristics and trajectory tracking characteristics, and the overall force results are in accordance with the theory.

1. Introduction
During the die-casting production, in order to save costs and achieve automated production, enterprises needs of the robot are growing. As we know robot is a complex system, the traditional mechanical design means in the structural design and control system design can not meet the requirements, so it would be necessary to build a virtual prototyping system for a robot, before creating a solid prototype. Wu Xing has used multi-objective genetic algorithm to optimize the servo controller PID parameter method to achieve servo. Yu Xiao has used POS optimization algorithm to achieve the optimization of the robot parameters. Chen Gang has studied the joint simulation of 7-DOF manipulator based on ADAMS and MATLAB, and the dynamic response characteristics of the manipulator are obtained by the virtual prototype system analysis. Chen Shuijin used the method of co simulation of virtual prototype based on ADAMS and MATLAB to establish a three degree of freedom manipulator model. The joint simulation control of virtual prototyping is helpful to shorten the overall cycle of the design and improve the overall performance of the manipulator, which is beneficial to the overall research and development of the manipulator.

2. Structural design and dynamic analysis of manipulator

2.1. Structural Design and Working Principle of Manipulator
According to the actual environment of enterprise production and demand conditions, the simplified model of the manipulator design process including a total of five pairs, of which four rotations and a ball screw (in the simulation will be simplified for the mobile side between the rail and the slider), and to establish three-dimensional model in UG environment, such as shown in figure 1:
The main design parameters of the manipulator are shown in Table 1.

Table 1. Main parameters of manipulator.

| Parameters      | Values                  |
|-----------------|-------------------------|
| height (mm)     | 1544                    |
| length (mm)     | 1740                    |
| width (mm)      | 765                     |
| arm length (mm) | 1008                    |
| guide rail length (mm) | 1250         |
| working space (mm³) | 1405x1008x60       |
| Working period (s) | 15                      |
| Work efficiency | 2/15s                   |

The main working principle of the manipulator: The support frame 2 can be moved up and down or rotation according to the actual production, and it can not be considered once the position has been determined.

The working principle of the manipulator can be simplified as follows: the tail motor 3 drives the screw 9 to rotate, and the slider system 4 is moved back and forth on the guide rail 10 by the ball screw. After the mechanical gripper 7 getting the mould parts, the nozzle 8 is moved back and forth the slider system to clean the mould parts, and then rotating cap 5 is rotated with the mechanical arm 6 and the mechanical gripper 7 puts down the parts. Finally, the entire system back to the initial position, to achieve periodic pickup movement.

2.2 Dynamics Simulation of the Manipulator

By defining the material of each component, the moment of inertia and other related properties, the motion pairs are set up and the relevant drivers are used to ensure that the model import process is not distorted and the mechanical movement is effective. And according to the design trajectory of the manipulator, the driving function of the manipulator is set up. Among them, the mechanical gripper's motion function is taken as an example: \( \text{STEP}( \text{time}, 0 , 0 , 1 , -0.23 ) + \text{STEP}( \text{time}, 2.5 , 0 , 3 , 0.23 ) + \text{STEP}( \text{time}, 8.5 , 0 , 9 , -0.23 ) \). The simulation results, including the angular velocity, velocity and displacement curve of motion simulation, and the trajectory of the mechanical gripper are in good agreement with the design expectations, which indicates that the connection and driver settings are reasonable. The manipulator model can simulate the motion according to the given driving function. The result shows that it can be used as the subsystem of the next joint simulation.

3. The design of the dynamic system

To achieve the coordination simulation of the control system and the dynamics system, it is necessary to introduce the dynamics model of the manipulator into Matlab, and the dynamics system works as the mechanical sub-model of the control system so that the data can be successfully exchanged. In particular, 20 state variables are established through the Adams / control module, including four torque
variables, a driving force variable, 10 position variables, 5 (angle) speed variable. The specific settings are shown in Table 2

Table 2. Settings of the State variable

| Num | NAME                           | Attributes |
|-----|--------------------------------|------------|
| 1   | DGripper Rotate Ome            | INPUT      |
| 2   | DGripper Rotate Ang            | INPUT      |
| 3   | UpGripper Rotate Ome           | INPUT      |
| 4   | UpGripper Rotate Ang           | INPUT      |
| 5   | Rotating cap Rotate Ome        | INPUT      |
| 6   | Rotating cap Rotate Ang        | INPUT      |
| 7   | Mechanical arm Rotate Ome      | INPUT      |
| 8   | Mechanical arm Rotate Ang      | INPUT      |
| 9   | Slider Move Vel                | INPUT      |
| 10  | Slider Move Pos                | INPUT      |
| 11  | Torque DGripper                | OUTPUT     |
| 12  | Torque UpGripper               | OUTPUT     |
| 13  | Torque Mechanical arm          | OUTPUT     |
| 14  | Torque Rotating cap            | OUTPUT     |
| 15  | Force Slider                   | OUTPUT     |
| 16  | DGripper Ang                   | OUTPUT     |
| 17  | UpGripper Ang                  | OUTPUT     |
| 18  | Rotating cap Rotate Ang        | OUTPUT     |
| 19  | Mechanical arm Rotate Ang      | OUTPUT     |
| 20  | Slider Move Pos                | OUTPUT     |

The motion of the joint is driven according to the instruction of the variable, and then a complete closed loop control is realized through the feedback system to realize the precise control. After the status variable setting is complete, 10 input variables and 10 output variables are set up and showed in the control system. The mechanical subsystem shown in Figure 2 and Figure 3
4. The design of the control system

The manipulator system has the characteristics of strong coupling, which should be passed into a linear multivariable system in the process of joint simulation. The PD controller is used to control the movement of each joint to realize the precise control of the whole manipulator\cite{7,8}.

Specifically, the manipulator is controlled by PD in ADAMS, and the actual motion is planned in SIMULINK, the control principle is as follows:

\[ F = k_p(x_d - x_m) + k_d(\dot{x}_d - \dot{x}_m) \]  
\[ \tau = k_p(\theta_d - \theta_m) + k_d(\dot{\theta}_d - \dot{\theta}_m) \]  

Among them, \( x_d \), \( x_m \), \( \theta_d \) and \( \theta_m \) are locations and speeds of planning in simulink, \( x_m \), \( \dot{x}_m \), \( \theta_m \) and \( \dot{\theta}_m \) are the actual measured values in ADAMS. Due to the influence of gravity on the mechanical gripper, the controller requires gravity compensation, which has little effect on the overall controller of the manipulator and is complicated. In order to reduce the interference of the gravity to the analysis results, the quality of the mechanical grippers are reduced to 10% of its true quality. The control system of the joint simulation as follows:

**Figure 4.** Control system design.

The Joint simulation control system using PD controller is divided into three sections, including the ADAMS dynamics module, Simulink function frame and related results. Firstly, the motion functions of each joint movement are designed though the FCN module of SIMULINK, and then the functions are input to ADAMS dynamics module. Finally, the trajectory and force condition of the main joint of the manipulator are obtained by simulation.
5. The Realization and Result Analysis of Joint Simulation

In order to verify the accuracy and rationality of the design of the robot joint simulation control system, run Simulink and set the step length to 0.005, and set the simulation time to 15 s. FIG. 5 FIG. 8 owns the input (Angle) displacement curve of the main moving parts of the manipulator and the tracking (angular) displacement curve after its simulation. (the movement of the lower jaw is essentially the same as that of the upper claw, just study the movement of the upper paw in this case)

Compare and analyze The expected trajectory of the design and The trajectory of the simulation results of the main components, and the overshoot was not more than 16.7%.

It shows that the design of the controller can meet the requirements of the controller’s fast response to the controller and the precise trajectory tracking.

The input variable of the controller is the (angular) displacement and (angular) velocity of each joint. Through the joint simulation, the force of each joint in the motion is obtained. FIG. 9 - FIG12 shows the force and withstand torque of each joint component.
Taking the slider as an example, the displacement function of the slider as the following:

\[ \text{Dist}=\frac{0.3}{2}(\text{time}-2)/(2\pi)\sin(2\pi\text{time}/2) \]  

(3)

\[ \text{Dist}=0.3 \]  

(4)

\[ \text{Dist}=0.3-(0.3/2)*((\text{time}-4)-1)/(2\pi)\sin(2\pi((\text{time}-4))) \]  

(5)

\[ \text{Dist}=(0.3/2)+(0.3/2)((\text{time}-5)-1)/(2\pi)\sin(2\pi((\text{time}-5))) \]  

(6)

\[ \text{Dist}=0.3-(0.3/2*((\text{time}-6)-1)/(2\pi)\sin(2\pi((\text{time}-6))) \]  

(7)

Compare and analyze the displacement driven functions of the slider input and the forces curve of the slider, basically in line with the theory of the force of the slider. Therefore, a joint simulation system based on Adams and matlab can be used to simulate the movement of manipulator preferably.
6. Summary
The motion simulation model uses the PD controllers, and the results of joint simulation analysis show that the controller has good fast response and trajectory tracking characteristics, and finally gets the force of the main joints, which lays the foundation for the development of manipulator entity prototype. On this basis, in order to improve the motion accuracy of the manipulator, reduce the vibration of the manipulator, the focus of future research is the movement of each joint motion optimization parameters, to improve the motion accuracy of manipulator in the engineering work.

7. References
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