Conceptual Design of the Cold Heading Machine Servo System Based on NX-MCD

Rongkang Qin and Chunxiang Dai
Mechanical Manufacturing and Automation Institute of Shanghai University, No149 YanChang Road, Shanghai, China
E-mail: qinrongkang@shu.edu.cn

Abstract. This paper researches concept design of the transmission mechanism of cold heading machine based on servo control theory. The servo motor is used instead of the traditional three-phase motor and flywheel, and parallel drives are adopted to replace series or series-parallel drives. The mechanical movement of each part is driven by a separate control motor and the motion is coordinated by PLC. The movement curve of the main slide can be determined by the processing requirements. It saves a lot of gears, bearings and shaft parts which are used to change speed and direction. Through virtually debugging the servo system with MCD (Mechatronics Concept Design) which is a module of UG (Unigraphics NX), the design cost is greatly reduced. The debugging results show that the system can meet the processing requirements of the cold heading machine.

1. Introduction
The traditional cold heading machine usually uses a three-phase motor with constant speed as a driver, and combines with the energy storage function of the flywheel to complete the cold heading. However, due to the existence of them, the motion curve of the slide block of the cold heading machine can't be changed according to different processing requirements; the flexibility is so poor that the demand for the development of the modern market cannot be met.

At present, servo technology shows advantages of high productivity, high flexibility and precise control on cold heading machine, but its application on multi-station cold heading machines is in a process of gradual development[1][2]. The application of servo technology in the multi-station cold heading machine is mainly in three parts: the clamp transmission system, the feed system and the slider system. The domestic servo system is mainly used in the servo feeding mechanism, and actually belongs to a semi-servo. Whether the slider is driven by a servo drive is an important criterion for distinguishing between full-servo and semi-servo cold heading machine[3].

This paper adopts MCD to decompose the design requirements of the cold heading machine, combine the servo motor with the PLC and the data acquisition card to form a closed-loop system composed of shunt feedback loop. Compared with the traditional cold heading machine system, the transmission chain is short, the error is small, the transmission efficiency is improved, and the mechanical mechanism is greatly simplified.

2. The concept design of the servo system of the cold heading machine

2.1. The working principle of the traditional cold heading machine
The traditional cold heading machine mainly consists of four parts: gear mechanism, crank-slider mechanism, cam mechanism and ratchet mechanism. Figure 1 shows the working principle of the cold heading machine.

The spindle motor transmits power to the main crankshaft via a pulley, and the clutch connects or cuts off the power, so as to realize the start or stop of the cold heading machine. Raw material is fed by ratchet mechanism. The cam is driven by the middle shaft driven by the main crank through the gear pair to realize the cutting action of the cutting tool. At the same time, the ejection mechanism push the formed part out of the mould and the part is transported by manipulator. The upsetting operation and the ejection action should be in order, so it is necessary to adjust the angle between the master and slave gear when the prototype is assembled to achieve the ideal action sequence.

![Working principle of cold heading machine](image)

The power system of the cold heading machine consists of a three-phase motor and a complex mechanical transmission mechanism. Because the transmission mechanism can only output a fixed rotational speed, a complicated shift mechanism needs to be added if a variety of rotational speeds are required, which will increases the complexity of the mechanism and the transmission error. In addition, when the flywheel transfers energy to the slider, it will affect the equipment life.

2.2. The functional and logical designs of the servo system of cold heading machine

Teamcenter (The product lifecycle management software of Siemens PLM Software) can transform design requirements into a requirement model that can be accepted by NX manager, and the requirement document can be imported into Teamcenter through MCD to complete the repeated modification of the requirement model [4]. The "input and output method" is applied to determine the material flow as the mainstream, analyze the requirement model of the cold heading machine and determine the main function is to produce fasteners such as bolts and nuts. During the working process of the cold heading machine, the ejection mechanism sends the material into the mould. After upsetting, the manipulator sends the parts from mould to the next workstation. The function design of the servo system for the cold heading machine needs three actions: feeding, upsetting and blanking. Figure 2 shows the function model of the cold heading machine constructed through the demand model.

Analysis of the motion sequence of the cold heading machine: before heading, the material is sent to the mould; if there is unprocessed material in the mould, the upsetting mechanism synchronously complete the upsetting; if heading completed, the ejection mechanism synchronously takes the parts to next workstation, and the next process begins [5]. Figure 3 is the logical tree created in MCD.
The kinetic scheme is determined according to the function model. The parallel transmission is adopted in this paper to reduce the transfer node of motion [6]. When the servo motor starts, the motor drives the crankshaft and the crank-slider mechanism drives the slider. The status of the servo motor is controlled by the servo driver, and the PLC performs analog input and output of the servo driver to indirectly control the operation of servo motor [7]. The application of servo motor can simplify the transmission scheme of the cold heading machine, remove pulleys and use the servo motor to drive the crank mechanism through the coupling, which can greatly reduce the error caused by the mechanical transmission. In addition, the servo control can program the trajectory of the slider to realize any process trajectory. Since the servo motor can switch forward and reverse at any time, the moving mould can move toward the workpiece in the mould at an arbitrary speed and return before any contact when adjusting the mould.

2.3. The control and communication design of the servo system of the cold heading machine

The servo control system of the cold heading machine mainly includes monitoring and controlling the rotation angle of the spindle, monitoring the displacement and speed of the slider, and monitoring the cold upsetting force of the moulds. As shown in figure 4, the system is a closed loop system composed of shunt feedback. The system can be divided into 3 modules: data acquisition module, control module and execution module [8].
communication interface, then the motor drive the mechanical equipment and the motor's status is fed back to the servo driver by its own encoder to carry out closed loop control. This paper divides servo motor into spindle motor, feeding motor and ejection motor according to the driven objects.

![Figure 5. Structure of the servo system of the cold heading machine.](image)

This article mainly focuses on the spindle servo system and need to achieve control objective quickly and accurately. Therefore, the SIEMENS SINAMIC S120 AC servo controller and S7-300 PLC are used. It is preliminarily determined that the working rhythm of the cold heading machine is 60pcs/min, the stroke of the slider is 165mm, and the nominal work stroke is 5mm.

The displacement of the end-actuator is corresponding to the rotation angle of the spindle motor. The servo control takes the rotation angle of the spindle motor as the trace volume, and the angle signal of the rotary encoder is sent to the PLC by the servo driver. The PLC program sends the logical instructions that triggered by the spindle rotation angle to other actuators, and performs the corresponding action to control the movement of the feeding mechanism and the ejection mechanism [9][10].

PLC is connected with servo controller through Profinet communication interface, and used as IO controller to output analog data to servo controller. The servo controller calculates the received analog quantity and drives the servo motor to the corresponding rotation speed. The servo motor detects the speed information through the encoder and feeds it back to the servo driver to form a closed-loop feedback system to achieve accurate control of the speed [11][12].

### 3. Debugging and result analysis of the servo system of the cold heading machine

This article uses PLCSIM to run the PLC program instead of the real PLC, and realizes the communication between PLCSIM and MCD by Siemens PLCSIM OPC. Through the Signal Mapping function, the PLC signal is matched with each physical quantity defined in the MCD model. The connection between the PLC program and the virtual prototyping model in the computer is completed, which means that the PLC can directly drive the three-dimensional model to implement virtual debugging. Figures 6 is the PletSim operation panel during debugging, and carry out logical instruction by editing each switch quantity. Finally, the three-dimensional conceptual design model of the servo cold heading machine completed the purpose of virtual debugging.

Detailed parameters were obtained through virtual debugging and simulation, which provided powerful help for the design of servo system of cold heading. The correctness of the automation program is verified by comparing the motion trajectory defined in the theoretical design with the motion trajectory generated by the external control device.
Output the sampling data of slider of the cold heading machine as a CSV file, draw the data into a chart by MATLAB and the correctness of the design can be verified by comparing the chart with the motion curve of the slider designed in the theoretical design. Figure 7 compares the displacement-time curve of slider of cold heading machine drove by PLC with the planned trajectory curve. It is known from the figure that the design trajectory of the cold heading slider is very close to the actual output trajectory.

Figure 7. Comparison of slider motion curve of cold heading machine.

4. Conclusion
In this paper, servo motor, servo driver and PLC are used as the core components. The parameters required by the servo motor are indirectly set through the PN port communication to meet the control requirements. The SIEMENS SINAMIC S120 AC servo controller and S7-300 PLC are used to improve the reliability and accuracy of system which meets the needs of industrial sites. In addition, PLCSIM is used instead of real PLC to realize the debugging and verification of automated motion programs, called as virtual debug. Finally, a convenient and effective method to verify and evaluate the design of the cold heading machine through the automatic debugging of the virtual prototype is achieved.
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