PAPER • OPEN ACCESS

The ADAMS kinematics optimization simulation of the twin-motor spiral pair direct-driven press

The ADAMS kinematics optimization simulation of the twin-motor spiral pair direct-driven press

Xian Jia*, Yi Zhao, HongChun Lei and Lu Zhao

School of Engineering, Xi'an Siyuan University, Xi'an, Shaanxi, 710038, China

*Corresponding author's e-mail: yangxw@mail.xjtu.edu.cn

Abstract: With rapid development of global manufacturing industry, the demand for stamping parts has increased greatly. In order to meet the requirements of high precision and low cost, famous manufacturers have adopted direct-driven presses as the focus of technology development. In this paper, the drive system's mechanical structure of the twin-motor spiral servo direct-driven press based on the principle of the electric spindle is designed, and the kinematics model of the press is established. Using ADAMS software to simulate the stamping and engraving functions of the press, the motor is simulated at the rated conditions, the motion curve of the slider is simulated, and the electronic rated power and rated speed of the press are checked; The work process of stamping and engraving is optimized, and the optimized slider motion curve is calculated and compared, which provides a good foundation for the development and promotion of the twin-motor spiral pair direct-driven press.

1. Introduction

The rapid development of the global machinery manufacturing industry promotes the growing demand for stamping parts, especially in light industries, such as automobiles and instruments. Facing the increasingly competitive global market, stamping parts are required not only in large quantities but also in high precision and low cost[1]. Although the traditional mechanical crank press features in simple structure, its single motion characteristics and limited processing range cannot meet the requirements of the rapid and changeable product stamping process. Along with the progress of the stamping process, the multi-link press has been the research focus for a long time because it is able to complete a variety of complex movements with high mechanics and kinematics performance. However, as the multi-link press is equipped with long kinematic chain, it is accompanied with higher accumulative error about clearance between rotating pairs, which reduces the transmission stability and leads to the relatively low accuracy[2].

With the development of the frequency conversion technology, electronic technology and computer control technology, the Computer Numerical Control (abbreviated as CNC) technology driven by servo motor has been widely used in the modern manufacturing industries and has become the core technology[3]. At present, the alternating current (abbreviated as AC) servo press has been combined with the modern control system and has been driven directly by the AC servo motor, which meets the requirements of various products and materials' stamping process, and provides a broad prospect for broadening the new forming process and mold manufacturing methods.

2. The servo press adopts the principle of electric spindle

The direct drive is a new servo control method developed in various fields in recent years. The direct drive and the zero transmission mean to remove all intermediate mechanical transmission links between the power device and the working mechanism[4], and enable the motor to drive directly the executive mechanism. The high-speed motorized spindle is the core function component of the high precision CNC machine tool[5], which interprets excellently the direct drive and the zero transmission.

The electric spindle fuses the machine tool spindle and the motor[6]. The "zero transmission" structure, integrating "the original motive parts-transmission parts-executive parts", pushes the high speed machining technology to a new level[7]. Therefore, the motor is the key component to adopt the servo press based on the principle of motorized electric spindle. The permanent magnet synchronous servo system is the main direction of contemporary high-performance servo system[8], and it is usually employed.

3. The driving system's mechanical structure of the twin-motor spiral pair servo direct-driven press
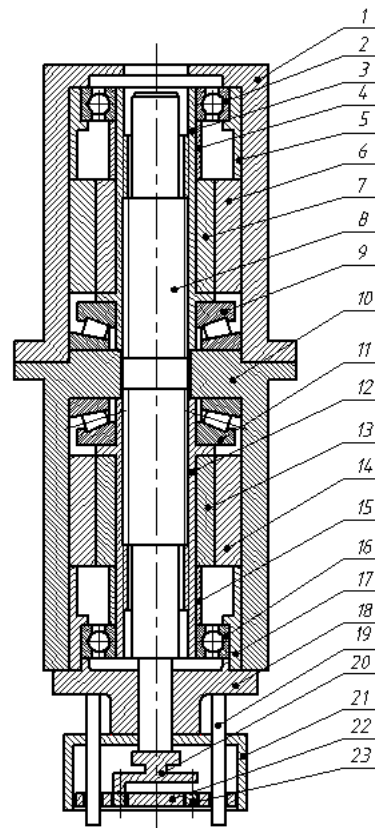
Figure 1 is the driving system's mechanical structure of the twin-motor spiral pair servo direct-driven press. Being guided by the principle of the electric spindle, it renders the electronic rotors of the two switching flux permanent magnet motors fixed with the upper and lower nuts, and enables the motor to drive directly the screw up and down to complete the stamping, and has a considerable improvement in the aspects of energy saving as well as flexible production performance[9]. The direct-driven stamping system replaces the traditional crank slider classic stamping system, gives full play to the characteristics of the AC servo motor.

It focuses all control problems on the control of the AC servo motor, and can easily change the direction and speed of the executive element.

The driving system is equipped with a lead screw whose upper and lower parts are provided with two threads with different rotation directions. These two working conditions are as follows:

(1) The stamping condition. The upper screw nut and the lower screw nut rotate in reverse, and the screw drives the punch to make the linear motion. The screw rises or falls so that it realizes the press through reciprocating linear motion.

(2) The die changing condition. Many dies are installed in the turret head, and the upper and lower screw nuts rotate with the homonymous rotation but the punch does not move. The screw rod, lower ball bearing, lower bearing sleeve, bearing end cap, guide column, punch sleeve, swivel head and die rotate all make rotational motion together with the upper and lower screw nuts. The required die is transferred to the underside of the punch through numerical control instruction, which realizes the change of the die.

1-the upper cabinet, 2-the upper ball bearing, 3-the upper screw nut, 4-the upper aluminum
sheath, 5-the upper bearing sleeve, 6-the upper servo motor stator, 7-the upper servo motor
rotor, 8-the screw, 9-the upper roller bearing, 10-the lower cabinet, 11-the lower roller
bearing, 12-the lower screw nut, 13-the lower servo motor rotor, 14-the lower servo motor
stator, 15-the lower aluminum-clad uranium, 16-the lower ball bearing, 17-the lower
bearing sleeve, 18-the bearing end cover, 19-the guide pillar, 20-the punch, 21-the punch
sheath, 22-the turret, 23-the die

Figure 1. The drive system's mechanical structure of the spiral servo direct-driven press.

4. The Design theory of the twin-motor spiral servo direct-driven press

The spiral pair direct-driven press studied in this paper has a ram pressure of 200kN, which requires
the completion of two different functions, i.e., the low-frequency stamping and the high-frequency
engraving. Its main technical parameters are shown in table 1.

Table 1. The main technical parameters of 200kN rotary head press.

Ram Pressure (kN)	Stamping		Engraving	
	Pressure Trip (mm)	Stamping Times (time/min)	Pressure Trip (mm)	Stamping Times (time/min)
200	4	400	0.2	1200

The rated torque of the selected magnetic flux AC servo motor with single switch is 600 N · m.
The rated speed is 500r/min (52.3rad/s). The calculated press's total moment of inertia is 0.3kg·m^2.
The lead screw is 20mm.

4.1 The dynamic and kinematic equations of the press
The dynamic equation of the motor-driven screw's rotation process is as follows:

$$T_0 - T_f = \sum I \frac{d\omega}{dt} = \varepsilon \sum I \qquad (1)$$

In the equation, T_0 is the driving torque of the motor, T_f is the frictional resisting moment, $\sum I$ is the total rational inertia, ε is the angular acceleration, and ω is the angular velocity.

Since the moment generated by 200kN load is much larger than the frictional resisting moment, it can be approximately considered as $T_f=0$.

The kinetic equation of non-loaded acceleration is:

$$T_0 = \sum I \frac{d\omega}{dt} = \varepsilon \sum I \qquad (2)$$

The dynamic equation of loaded acceleration is:

$$T_0 - T_t = \sum I \frac{d\omega}{dt} = \varepsilon \sum I \qquad (3)$$

Here, T_t is the load torque.

The kinematic equation of the screw is as follows:

$$\varphi = \varphi_0 + \frac{1}{2}\varepsilon t^2 \qquad (4)$$

$$\varphi = \frac{S}{P_n} \times 2\pi \qquad (5)$$

Here, φ is the angle of lead screw rotation, and S is the stroke of lead screw.

4.2The kinematic simulation and optimization of the press

In order to reduce vibration and impact, improve the workpiece quality, and increase the die life, it requires that the punch displacement curve is smooth, the velocity curve is continuous, and the acceleration curve has no mutation.

4.2.1The stamping function. The stamping times is 400 times /min, the operating stroke is 5mm, and the pressure stroke is 4mm.

In order to check whether motor designed with the rated torque and rotational speed can finish the stamping function, it assumes that the motor has been working in the rated conditions, and the preliminary design of the whole stroke movement process is as follows: the motor completes the accelerated displacement of 1 mm with non-loaded at the rated torque → the motor accelerated with load to the motor's rated speed at the rated torque → the motor rotates at a constant rated speed → the motor decelerates with loaded from the rated speed to zero at the rated torque. The motion process of the whole return stroke is as follows: the motor accelerates with non-loaded to the rated speed at the rated torque → the motor rotates at a constant rated speed → the motor decelerates with non-loaded from the rated speed to zero at the rated torque.

The ADAMS software simulation is carried out on the preliminary design process of the press's stamping function, which results in the movement curve of the punch shown in the figure 2.
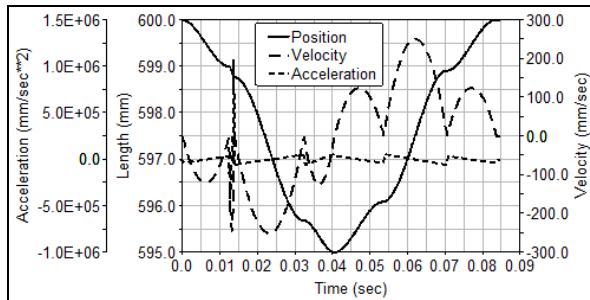
Figure 2. The preliminarily designed motion characteristic curve of the stamping function.

Figure 3. The movement characteristic curve of the stamping function after optimization.

It can be seen from figure 2 that the motor can complete a stamping action within 0.084s under the rated conditions. The speed and acceleration curves of the punch are continuous, and the displacement curve of the punch is smooth. There is no rigid impact during the whole process of the engraving, and the motion characteristic is better. But the curve of punch stamping in the period of load acceleration, $a_{max}=1.06\times10^6$mm/s^2, $v_{max}=250.2$mm/s, the punch speed changes quickly, the punch acceleration is excessively large, and the impact vibration is large. The quality of the punch reduces, so does the die life.

In order to get a better stamping effect, the whole process of stamping function is optimized, so that the stamping process (including the loaded acceleration, the uniform speed and the loaded deceleration) is slowed down as much as possible and its acceleration reduces. The ADAMS software simulation is carried out on the optimized stamping process, and the movement curve of the punch is shown in figure 3. After the optimization, the press can complete a stamping action within the required 0.15s. In the whole stamping process, $a_{max}=1.59\times10^4$mm/s^2, $v_{max}=99.54$mm/s, the displacement curve becomes slow, the maximum speed and acceleration are greatly reduced, the quality of the stamping parts is improved, and the die life is increased.
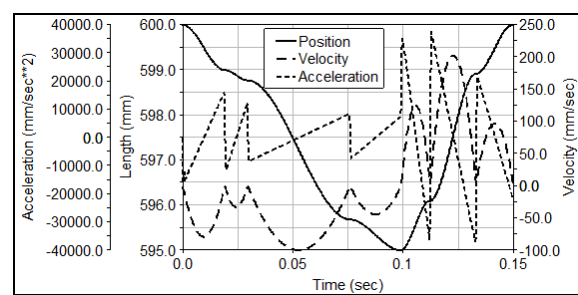
4.2.2The engraving function. The engraving times are 1200 times /min, the working stroke is 1.2mm, and the pressure stroke is 0.2mm.

In order to check whether motor designed with the rated torque and rotational speed can finish the engraving function, it assumes that the motor has been working in the rated conditions, and it ensures the speed of the load reduction process just completes the whole pressure stroke 0.2 mm, the speed reduces from ω to 0. The preliminary design of the whole stroke movement process is: the motor accelerated with non-loaded to ω at the rated torque load → the motor rotates at a constant rated speed ω → the motor decelerates with loaded from ω to zero at the rated torque, which completes the pressure stroke 0.2mm. The motion process of the whole return stroke is as follows: the motor completes one half operating stroke by accelerating with non-loaded at the rated torque → the motor completes another half operating stroke by decelerating with non-loaded at the rated torque.

The ADAMS software simulation is carried out on the preliminary design process of the press's stamping function, which results in the movement curve of the punch shown in the figure 4.
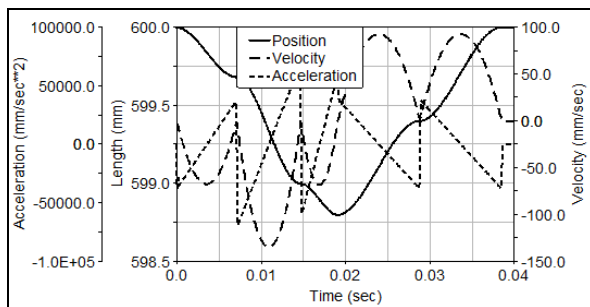
Figure 4. The preliminarily designed motion characteristic curve of the engraving function.
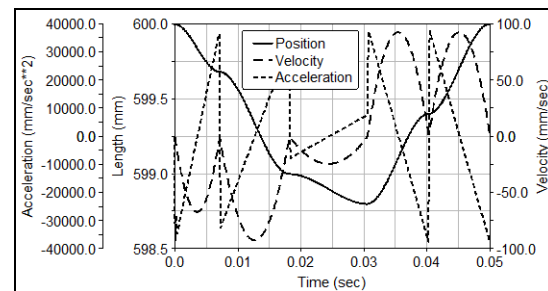

Figure 5. The movement characteristic curve of the engraving function after optimization.

It can be seen from the figure 4 that the motor can complete an engraving action within 0.0385s under the rated conditions. In the whole pressure stroke (the loaded deceleration), $a_{max}=6.56\times10^4\text{mm/s}^2$, $v_{max} =68.13\text{mm/s}$. The speed changes quickly, the punch acceleration is excessively large, and the impact vibration is large. By lengthening the pressure stroke time within the allowed range, the engraving process can be slowed down as much as possible in order to obtain a better engraving effect. The ADAMS software simulation is carried out on the optimized engraving process, and the movement curve of the punch is shown in the figure 5. After the optimization, the press can complete an engraving action within the required 0.05s. In the whole engraving process, $a_{max}=7.67\times10^3\text{mm/s}^2$, $v_{max}=24.2\text{mm/s}$, the displacement curve becomes slow, and the maximum speed and acceleration are greatly reduced. The quality of the engraving parts is improved, so does the die life.

5. Conclusion

(1) It completes the driving system's mechanical structure of the twin-motor spiral pair servo direct-driven press. The driving system is equipped with a screw rod whose upper and lower parts are equipped with two threads of different rotation directions. The upper and lower nuts rotate in reverse. The lead screw drives the punch to do a straight line movement through rising or falling, so the lead screw realizes the stamping function. The upper and lower nuts rotate in the same direction, and the screw rod, the fourth bearing, the lower bearing sleeve, the bearing end cap, the guide pillar, the punch sleeve, the turret head and the die all rotate together with the nuts. The die can be changed by turning the required die under the punch at any time through the CNC programmed instruction.

(2) It optimizes the stamping and engraving processes of the twin-motor spiral pair servo direct-driven press with the nominal pressure of 200 kN. The ADAMS software simulates these optimized results, and makes the comparative analysis of the movement characteristic curves of the pre-optimization and the post-optimization. The results show that the pressure stroke displacement curve slows after the optimization, and the maximum velocity and maximum acceleration greatly reduces, and the stamping parts' quality improves, so does the die life.

References
[1] Peng, Y.H., He, Y.Y., Li, Z.F. (2016) Study on the bottom dead center accuracy of multi-link press machine composed of series four-bar linkage. Journal of Machine Design, 33: 97–100.
[2] Zheng, E.L., Zhang, H., Zhu, Y. (2017) Dynamic Modeling and Simulation of Flexible Multi-link Mechanism including Joints with Clearance for Ultra-precision Press. Transactions of the Chinese Society for Agricultural Machinery, 48: 375–385.

[3] Yang, L. (2016) An algorithm of straight-line approaching with approximate equal-error for BHF control based on servo drive. Manufacturing Technology & Machine Tool, 6: 151–156.

[4] Zhao, S.D., Zhang,P., Fan, S.Q. (2018) Discussion on intelligent forging equipment and approaches of its implementation. Forging & Stamping Technology, 43: 32–48.

[5] Zhao, S.D., Jia, X. (2017) Research Progress and Development Trend of Intelligent Manufacturing and its Core Information Equipment. Mechanical Science and Technology for Aerospace Engineering, 36: 1–16.

[6] Chen, H.X., Zhang, Y., Li, W.B. (2018) Thermal assembly deformation control of high speed precision motorized spindle and rotor. Manufacturing Technology & Machine Tool, 10: 120–123.

[7] Li, H.H., Wang, F. (2018) An experimental study on multi-structural coupling loss factors of machine spindle. Journal of Vibration and Shock, 37: 98–103.

[8] Liu, J.F., Liao, Q., Lai, T. (2018) Influence of inertia effects on dynamic behaviors of motorized spindle. Journal of national university of defense technology, 40: 121–126.

[9] Xin, X.N., He, L., Wang, H.Z. (2010) Summary for Control Strategies of Permanent Magnet Synchronous Motor AC Servo System. Small & Special Electrical Machines, 2: 67–70.