Research and application of the influence of workbench stiffness on the quality of integral door ring hot stamping forming in mechanical servo hot stamping press

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This paper investigates the impact of workbench stiffness on the quality of integral door ring hot stamping forming in a mechanical servo hot stamping press and proposes a compensation control technology. The paper begins by introducing the current status and development trend of ultra-high-strength steel hot forming and the advantages and challenges of integral door rings. The deformation problem of workbench stiffness in hot stamping press is analyzed, and solutions for improving stiffness are proposed. By optimizing the design of the base structure and implementing hydraulic cylinder compensation technology, the stiffness of the press workbench is enhanced, and deformation is controlled. Experimental validation of the optimization scheme demonstrates improved consistency in door ring hot stamping forming quality and production efficiency.

Keywords: Mechanical servo press; Integral door ring; Ultra-high-strength steel; Stiffness improvement; Workbench optimization design.

1. Introduction

In recent years, the rapid development of new energy vehicles has driven the demand for lightweight automobiles with long-range capabilities. Ultra-high-strength steel is widely used in automobiles as it reduces vehicle weight without compromising safety. The reliable hot forming production line is crucial for the forming of ultra-high-strength steel. Foreign suppliers of hot forming production lines include Benteler, Schuler, AP&T, and Gestamp, and domestic companies have also collaborated with universities in the research and development of hot stamping production lines [1-5].

With the advancement of hot stamping presses, companies have developed various hot stamping production lines using different research and development approaches. Currently, the most commonly used types are three-cylinder high-speed hydraulic presses, five-cylinder high-speed hydraulic presses, and four-point structure servo presses. For instance, as depicted in Figure 1, A hot stamping production line, which is based on a box-type furnace, is equipped with a high-speed hot stamping servo press that is suitable for mass production of hot stamping parts. Servo presses have gained advantages in terms of precision, responsiveness, and energy efficiency. Figure 2 shows the multi-link four-point structure servo press produced by Ningbo Jinda Forming Equipment Co., Ltd.

As hot stamping presses continue to evolve, hot forming processes are also undergoing constant innovation and development. The hot stamping forming of automotive structural parts has progressed from simple single-piece forming and one-die-multiple-parts forming

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to more intricate laser-welded multi-component integrated hot stamping. This technology allows for the design of parts that meet safety and energy absorption requirements by utilizing materials with different strength levels and thicknesses for different sections of the hot-formed parts. After laser welding and hot stamping forming, large parts exhibit distinct mechanical properties, thereby contributing to the improvement of automotive safety and lightweighting [6-7].

Fig. 1. Overall structure of the mechanical servo press

Fig. 2. Main drive system of the servo press

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2. Development Trend of Integral Door Ring Hot Stamping Forming with UHSS

Automotive door rings are essential components of the frame structure. Traditional door rings are assembled by mechanically fixing or welding multiple hot-stamped forming parts together, resulting in weak joints that are vulnerable during vehicle collisions. Integral door rings, on the other hand, utilize lasers to weld different parts of high-strength steel materials together before performing stamping forming, replacing traditional door rings. Integral door rings offer advantages such as reduced weight and improved performance compared to traditional door rings [7-8]. These advantages align with the requirements of automotive parts for low weight and high rigidity, making integral door rings increasingly popular. However, each segment of the integral door ring has different materials, shapes, and thicknesses, as well as a large size. |. This complexity, along with high equipment requirements, limits the application of integral door rings with ultra-high-strength steel [9].

As domestic hot stamping production lines and forming processes have become more mature, the use of high-strength steel in automobiles has become more widespread, placing higher demands on production line efficiency. The one-die-multiple-parts forming solution has been adopted by customers due to its higher production efficiency, which also requires a larger workbench and a higher tonnage press. The body of the press needs to have higher stiffness to meet the requirements of forming accuracy and product quality consistency [10].

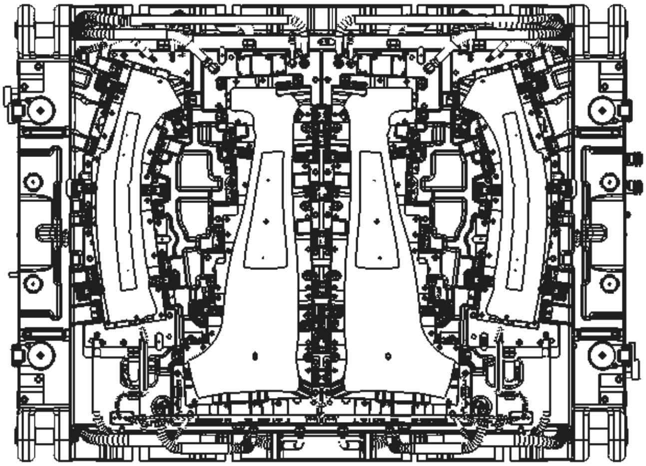

Fig. 3. Arrangement of the mold for one die and four parts

3. Hot stamping of multiple parts in one mold and integral door ring part

To adapt to the development requirements of one-die-multiple-parts hot stamping forming, the authors have developed the SL4-1200 four-point large workbench multi-link servo press, which is primarily used for one-die-four-parts ultra-high-strength steel hot stamping forming, as shown in Figure 4. The servo press adopts four-motor synchronous drive + reducer + heavy-duty screw pair + multi-link structure to drive the main slide, and its main drive system is shown in Figure 5. Due to the high cost of low-speed high-torque motors and driving, the multi-motor synchronous drive technology can effectively reduce the cost of the servo press.

3.1. *Existing Problems and Stiffness Deformation Analysis*

During the initial trial stage, the qualification rate of hot stamping products was low. After analyzing the non-conforming products, stamping equipment, and mold inspections, it was found that the mold center position could not be completely closed when the press slide was at the bottom dead center, resulting in incomplete stamping at the middle position of the product and causing product non-conformity. Based on the actual situation of this problem, the deformation of the main rib plate at different positions of the press workbench center was measured before and after stamping (see Table 1), and it was found that the depression at the center position of the press body was 0.19mm.

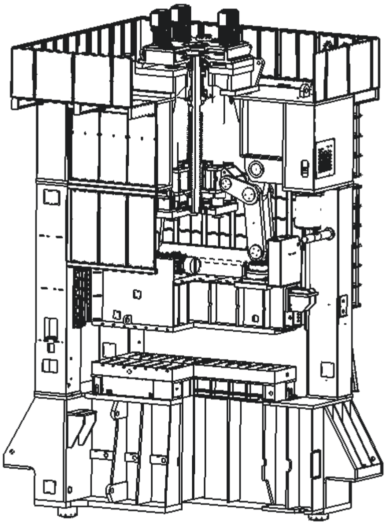

Fig. 4 Structure of Mechanical Servo Press.

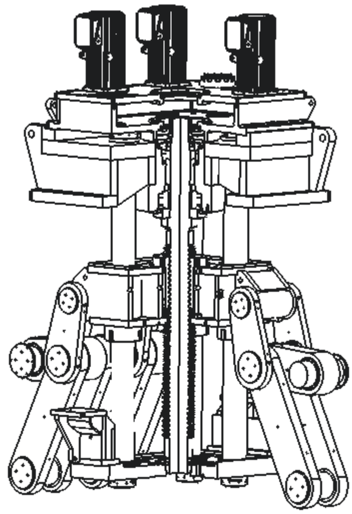

Fig. 5. Main drive system of the servo press.

Table 1: Stiffness measurement data of the press workbench

No.	Point 1	Point 2	Point 3
1	0.42	0.61	0.44
2	0.43	0.62	0.43
3	0.42	0.61	0.43

3.2. *Analysis of Stiffness Improvement*

Based on the above analysis, it is concluded that the existing stiffness of the press body cannot meet the requirements of the one-die-four-parts mold. Therefore, it is necessary to optimize the design of the existing base stiffness, with a preliminary target stiffness of 1/12,000. The press base includes the movable workbench and the base. By adding reinforcement ribs to these two parts, the overall stiffness of the base is increased, reducing the deformation of the base during the stamping process and ensuring the normal closure of the mold. As shown in Figure 6, a pad (blue part) is added below the main rib plate of the movable workbench to increase the contact area between the workbench and the base, ensuring a more uniform load during stamping. As shown in Figure 7, additional reinforcement ribs (blue part) are added to the middle cavity of the base, effectively increasing the stiffness of the base. After the modifications are completed, finite element static analysis is performed on the model, and the results are compared with the pre-optimization results.

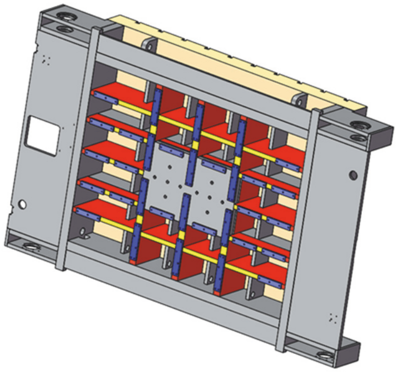

Fig.6. Optimization of the movable workbench structure

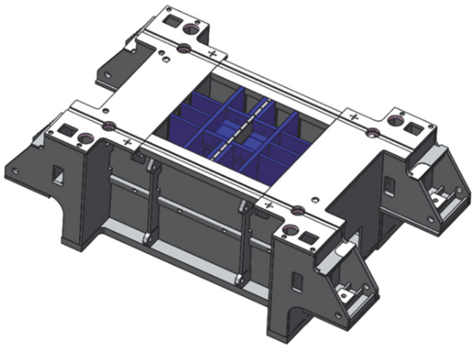

Fig. 7. Optimization of the press base structure

The movable workbench and the base are combined as one unit, and finite element analysis software is used to perform finite element static analysis on the model. During the analysis process, support constraints are added to the four support surfaces of the base, and a load of 12,000KN is applied according to the actual size of the mold seat. Then, the model is divided into meshes for analysis and calculation, and the analysis results are shown in Figure 8. The theoretical data obtained from the pre-optimization and post-optimization analyses are summarized in Table 2. By analyzing the data, it can be seen that the maximum relative depression in the middle of the theoretical workbench surface is about 0.055mm after optimization, which is significantly reduced compared to the deformation of 0.155mm before optimization, about one-third of the reinforcement. The stiffness of the base has been greatly improved. The smaller maximum deformation can effectively promote the successful closure of the mold, thereby improving the yield rate of the integral door ring hot stamping.

Table 2: Comparison of data before and after the optimization of press stiffness

	Measurement position	Point 1	Point 2	point3
Before optimization	Front main reinforcement plate	0.39	0.55	0.40
	Rear main reinforcement plate	0.40	0.55	0.41
After optimization	Front main reinforcement plate	0.41	0.465	0.41
	Rear main reinforcement plate	0.40	0.465	0.41

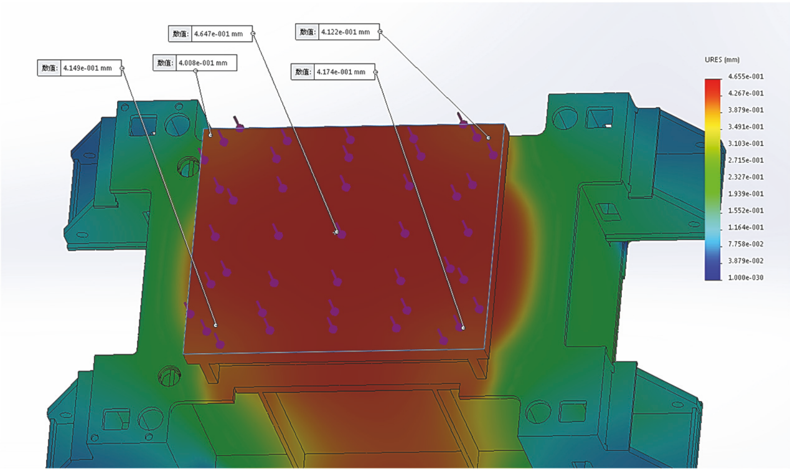

Fig. 8. Analysis results of the stiffness of the movable workbench and the base

3.3. *Hydraulic Cylinder Compensation Technology*

After the optimization of the base is completed, the stiffness of the base has been significantly improved. In order to further improve the qualification rate of the stamped products, a dynamic compensation scheme using hydraulic cylinders is proposed. As shown in Figure 9, deflection compensation cylinders are installed inside the base. In the non-working state, the plane of the cylinders is not higher than the plane of the base, which does not affect the movement of the workbench. There are two sets of cylinders, with a nominal force of 1600 KN for each set.

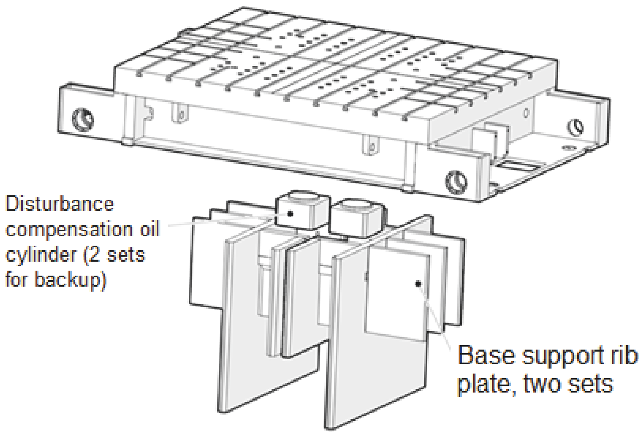

Fig. 9. Schematic diagram of the deflection compensation cylinders in the base.

This deformation compensation control technology is used in the hot forming and stamping process to achieve precise measurement and monitoring of the mold closure and the rigidity of the large table press. It continuously updates the compensation algorithm in real-time and achieves accurate control and compensation of the deformation in the process of forming the door ring by adjusting the control pressure of the two sets of hydraulic cylinders.

After the implementation of the scheme, a stamping test was conducted on the large table multi-link servo press. The experimental results show that this technology effectively improves the consistency of the door ring's hot forming quality and reduces the product's defective production rate.

4. Conclusion and Discussion

This paper investigates the impact of workbench stiffness on the quality of integral door ring hot stamping forming in a mechanical servo hot stamping press and proposes a compensation control technology. The development of one-die-four-parts hot stamping forming has increased the requirements for high tonnage and large workbench presses. With the increase in workbench size, the stiffness requirements for the press are higher than those for traditional large workbench presses. By analyzing the one-die-four-parts hot stamping forming project, it was found that the maximum relative deformation of the base directly affects the yield rate of the product. Therefore, in the design of large workbench presses, the stiffness standards should be increased, and it is recommended that the workbench and slide deflection be better than 1/12,000. At the same time, the deformation compensation control technology can accurately control and compensate for the deformation during the forming of the door ring by setting multiple bottom-positioned cylinders between the workbench and the lower mold, controlling the contact stress during mold closure, and meeting the requirements of strength zoning of hot-formed parts by adjusting the cylinder pressure.

Optimization of the mold solution is also crucial for improving the forming quality and production efficiency of automotive door rings. The one-die-four-parts mold can use a split and adjustable mold seat structure, which can independently adjust each stamping position of the workpiece, thereby further enhancing the forming quality and production efficiency of hot stamping.

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