Effect of Preload on Frame Stiffness of 1600 kN Closed Double Point Mechanical Press

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Abstract—A 1600kN closed double point press is used for the punching process of U-shaped longitudinal beam and more than 10 independent die frames are arranged. Different holes require different punching forces, and multi-station punching will cause eccentric loads, while preload and off-centre load are important factors affecting the precision of the combined frame of closed press. In this paper, a 1600kN press combined frame is designed based on the U-shaped longitudinal beam punching process and the three dimensional model of 1600kN press frame is established by Solidworks. The finite element analysis of preload, symmetrical load and off-centre load was carried out by Ansys Workbench. The deformation of upper beam in Z direction and the relationship between eccentric load factor $i$ and the maximum deformation difference $\Delta h$ can be obtained, which has important application value to improve the manufacturing accuracy of this type of press.

1.Introduction
It is a developing trend to adopt closed double point multi-position press for the U-shaped longitudinal beam punching process, which can significantly improve punching efficiency. The stiffness of frame refers to the relative displacement of the center line of the upper beam when static uniform load is applied, including the tensile deformation in the vertical direction and the angular deformation with asymmetric left and right deformation [1-3]. Closed double-point multi-position presses mostly adopt combined frame. Punching with different diameters requires different punching forces, and multi-position punching will cause off-centre loads, which will cause angular deformation of the frame and affect the service life of the die and product quality. Vertical deformation caused by working loads can affect the service life of the frame [4-6]. Off-centre load and preload have great influence on the stiffness deformation of combined frame, which will affect the precision of press[7-8].

In this paper, by studying the influence of preload and off-center load on the frame stiffness, reducing the deformation of the frame of press is beneficial to improve the accuracy of the U-shaped longitudinal beam punching.

2.Structure of Frame
Fig.1 shows the combined frame of 1600kN closed double-point press. This combined frame consists of upper beam, lower beam, column, tie rod and nut. The total assembly height is 4700mm, length is 3500mm, width is 2500mm, and the tie rod diameter is $\Phi 100$mm.
3. Finite Element Analysis Model

3.1. Geometric model
As shown in Fig.2, the assembly consists of 4 pull rods and pre-tightening nuts at the upper and lower ends to connect the lower beam, left and right columns and upper beam from bottom to top, with a total of 16 parts. Under the condition that the finite element simulation results are not affected, according to Saint Venant's Principle, the three-dimensional model of the frame parts is simplified, and this paper uses Solidworks to complete the geometric modeling.

3.2. Material properties
Different materials are used for each part of the press frame. Q235A is used for the upper beam, lower beam and column. The density is $\rho = 7860 \text{ kg/m}^3$, the elastic modulus $E = 212 \text{ GPa}$, the Poisson's ratio $\mu = 0.288$, and the yield strength is 235 MPa. The material used for the pull rod and the pre-tightening nut is 45 steel, the density is $\rho = 7890 \text{ kg/m}^3$, the elastic modulus $E = 209 \text{ GPa}$, the Poisson's ratio $\mu = 0.269$, and the yield strength is 355 MPa.

3.3. Mesh generation
In this paper, solid unit Solid187 and tetrahedral grid are selected to divide, and the overall grid size is 80mm. The mesh size of the parts with smaller diameter, such as pull rod and nut, is 40mm. The mesh size of the bottom surface of the upper beam is 15mm, with a total of 527,663 nodes and 297,895 units.

3.4. Contact constraints and loads
According to the actual installation requirements, the bottom of the lower beam is fixed supported with six degrees of freedom. The contact mode of each component is face-face; The contact type of beam and column and nut is Rough; The contact type between the pull rod and the column and beam is Frictional and the friction coefficient is 0.2. The contact type of nut and tie rod is Bonded.

The pretension force of the tie rod is $F_0$, and its value is calculated by empirical formula (1). Where $k$ is the preload coefficient, usually 1.5; $F$ is the nominal pressure and its value is 1600kN.

$$F_0 = k \cdot F$$ (1)

As shown in Fig.3, asymmetric punching of multi-station press leads to off-center load, so $F_1$ and $F_2$ values are different. The degree of off-center load is represented by eccentric load factor $i$, and its value is calculated as shown in Formula (2). Among them, the value of $i(i \geq 1)$ changes under different off-center load conditions, but $F_1 + F_2 = F$ and the distance between $F_1$ and $F_2$ is 1500mm. The larger $i$ is, the more serious the off-center load degree is.

$$i = \frac{F_2}{F_1}$$ (2)
Fig. 2 Geometric model
1-Pull rod 2-Preload nut 3-Uppper beam
4-Column 5-Lower beam

Fig. 3 Load acting on press frame
1-Pull rod 2-Preload nut 3-Uppper beam
4-Column 5-Lower beam

The contact surface and key points between the upper beam and the column are shown in Fig. 4 and Fig. 5, where key points A, A’ and B, B’ are the midpoints of the side. The deformation of the center line A-A’ along the Z direction of the upper beam is represented by $\Delta h$, and the numerical calculation is shown in Formula (3). Where $h_1$ is the deformation value of the upper beam after loading, mm; and $h_0$ is the deformation value of the upper beam under preload condition, mm. The maximum difference of deformation at each point is expressed by $\Delta H$, and the numerical calculation is shown in Formula (4), where $h_{\text{max}}$ and $h_{\text{min}}$ respectively represent the maximum and minimum deformation values of the point on the center line A-A’ along the Z direction, mm.

$$\Delta h = h_1 - h_0$$  \hspace{1cm} (3)

$$\Delta H = \Delta h_{\text{max}} - \Delta h_{\text{min}}$$  \hspace{1cm} (4)

Fig. 4 Key points on the contact surface of the beam
Fig. 5 Key points on column contact surface

4. Results and Analysis

The deformation of the center line A-A’ along the Z direction $\Delta h$ and the maximum difference of deformation at each point $\Delta H$ can be extracted by loading different loads on the frame or preloading different preloads on the pull rod. In this paper, the deformation of upper beam is analyzed and discussed by finite element method under different load conditions of press.

4.1. Constant preload (symmetric load applied)

As shown in Fig. 6 and Fig. 7, when the preload coefficient is $k=1.5$, with the increase of symmetric load $F$, the deformation $\Delta h$ of the center line A-A’ along the Z direction of the upper beam is symmetrical along the X coordinate, with large deformation in the middle and small deformation on both sides. The maximum deformation difference $\Delta H$ of each point also increases gradually.
4.2. Nominal force loading (preload force changed)

When \( F_1 = F_2 = 800 \text{kN}, F = 1600 \text{kN} \), by changing the size of the preload coefficient \( k \), the distribution law of the influence of the preload coefficient \( k \) on the deformation \( \Delta h \) of the Central Line segment A-A’ of the upper beam in the Z direction along the X coordinate is studied. As shown in Fig.8, with the increase of preload coefficient, the deformation of each point on the center line A-A’ of the upper beam increases. As shown in Fig.9, as the preload coefficient \( k \) increases, the maximum difference \( \Delta H \) of deformation at each point gradually decreases.

4.3. Off-centre load

From the analysis of girder punching process, \( i \) should be 1 to 3. In the case of eccentric load, with the change of \( i = F_2 / F_1 \), different preloading forces are applied to ensure that the contact pressure at key point B and B’ is exactly 0, then the critical preloading coefficient is \( k' \), as shown in Table 1. Under critical preload conditions of different bias loads, the deformation \( \Delta h \) of the center line A-A’ of the upper beam in the Z direction along the X coordinate is shown in Fig.10. The deformation on the left side of the origin is decreasing and the deformation on the right side is increasing. The influence curve of bias load coefficient \( i \) on the maximum difference of deformation in the Z direction \( \Delta H \) is shown in Fig.11. With the increase of eccentric load factor \( i \), the maximum difference of deformation \( \Delta H \) is increasing.

| Variable name                  | Name of the unit | Numerical value |
|--------------------------------|-----------------|-----------------|
| Eccentric load factor \( i \)   | -               | 1.29 1.67 2.2   |
| Off-centre load \( F_1 \)       | kN              | 800 700 600 500 |
| Off-centre load \( F_2 \)       | kN              | 800 900 1000 1100 |
| Critical preload coefficient \( k' \) | -            | 2.4 2.475 2.625 2.775 2.925 |
5.Conclusion
In this paper, the three dimensional model of the combined frame of 1600kN closed double-point press was established, and the statics analysis of the prestressed combined frame was carried out by Ansys Workbench, and the following conclusions were drawn:

(1) Under the condition of constant preload, with the increase of symmetric load, the deformation $\Delta h$ of the center line A-A’ along the Z direction of the upper beam increases, the left and right sides are symmetrical, the middle deformation is larger and the two sides are smaller, and the maximum difference of deformation $\Delta H$ at each point also increases gradually.

(2) Under the condition that symmetric load is nominal force, with the increase of preload coefficient $k$, the deformation $\Delta h$ of center line A-A’ along the Z direction decreases, and the maximum difference of deformation $\Delta H$ at each point also decreases gradually.

(3) When the eccentricity coefficient $i$ is 1 to 3 and the critical preload condition, the maximum difference of deformation $\Delta H$ at each point on the center line A-A’ of the upper beam increases gradually with the increase of eccentric load factor $i$, so when the maximum value of eccentric load factor $i=3$, the preload coefficient $k=3$ should be taken to ensure the accuracy of the press, which is of great theoretical value to improve the efficiency and precision of the U-shaped longitudinal beam punching.

Acknowledgments
This work was financially supported by High Quality Courses Project for Graduate Education of Shandong Province No. SDYKC17039.

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