Concept Design of Movable Beam of Hydraulic Press

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Abstract. The hydraulic press movable beam is one of the key components of the hydraulic press; its design quality impacts the accuracy of the workpiece that the press suppressed. In this paper, first, with maximum deflection and material strength as constraints, mechanical model of the movable beam is established; next, the concept design model of the moveable beam structure is established; the relationship among the force of the side cylinder, the thickness of the inclined plate, outer plate is established also. Taking movable beam of the 100MN type THP10-10000 isothermal forging hydraulic press as an example, the conceptual design result is given. This concept design method mentoned in the paper has general meaning and can apply to other similar product design.

1 Introduction

Conceptual design situated at the beginning of product design, is most important stage in the entire design process. A good concept design result can improve the quality of follow-up technical design, detailed design, reasonable technology and processing, as well as reduced the cost [1,2,3] fundamentally. Conceptual design stage is the most creative stage in the process of product design also. At present, in traditional hydraulic machine design process, case based reasoning method as conceptual design solution is commonly used mostly, which exists problem of hydraulic press designer rely on the personal experience mostly and design results can not actively and accurately controlled. How to design from the product function demands and how to solve the mapping mechanism from the demand of the product function to the structure are the difficulty and direction in the research of the hydraulic machine's conceptual design. Therefore, this paper puts forward a hydraulic press movable beam concept design method [4]. Hydraulic pressure has four main parts: upper beam, lower beam, upright column and movable beam. So the movable beam is key component of pressure. The movable beam situated at the nearest place to the workpiece, so its design quality direct influence the precision of workpiece. In this article, a new concept design method is put forwarded out, and apply this method to the design of movable beam. The concept design method has universal significance in mechanical design, and can be used in other similar mechanical part's concept design.

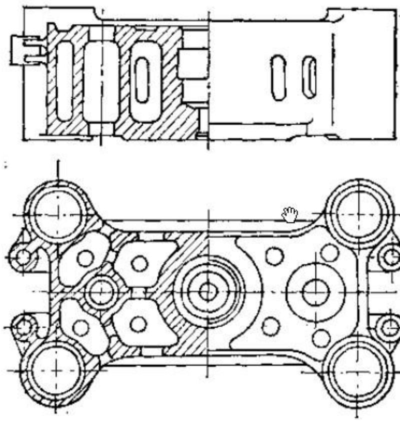
2 Conceptual design of movable beam

2.1 Mechanical model of movable beam

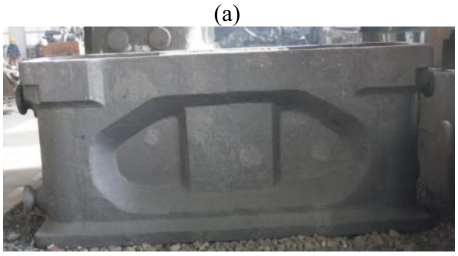
Mechanical model of the hydraulic press components adopted the following basic assumptions: continuous uniform hypothesis ; isotropic assumption; small deformation hypothesis ; deform of the geometry and size of the object is very small compared with the original size; the moving beams of the hydraulic press is regarded as beam.

There are many structural type of movable beam,while Fig. 1 is a conventional movable beam drawing[5]. Its outer contour profile is very big,which made its weight is heavy. In order to reduce weight, it is made with box shape. stiffened plate is added in it ; at load bearing place, the stiffened plate arranged intense so as to increase ragid and reduce stress, at other place, the stiffened plate arranged sparse. Rational arrengement of stiffened plate made the movable beam weight reducd, at the same time made the movable beam has sufficient strength and uniform stiffness. The movable beam has three contour profile dimention, its length dimention depend on work cylinders arrengement and the center distance of the columns, narrow side size usually is smaller than length side, and high dimention diffinition depend on the strength of material.

In the ideal condition, the beam has no constraint in the right and left, front and back direction; at upper side, the beam contacts with pistons, bearing the load from the piston; at lower side, the beam contacts with mould, bearing the load from the mold ; therefore the movable beam subjected to bending, shear and compression, and then produced the corresponding deformations.

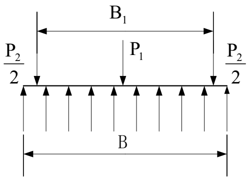


(a)

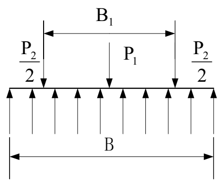


(b)

Figure 1. Movable beam



(a)



(b)

Figure 2. Force analysis of movable beam

For single cylinder hydraulic press, usually check the extrusion stress on the bearing surface when designing. In this paper, taking three cylinder hydraulic press as an example. According to the relationship between the size of the movable beam and the mould size, the force of the movable beam has two forms. One type is the size of the movable beam and mould nearly equal, which makes area of force exert on the movable beam from the mould and piston very closer, then the movable beam mainly bear extrusion force, consequently occurs compressive deformation; at this situation, bending deformation by the action of bending moment is not considered; From Fig..1, we extract force model using material mechanics method. force exert on the movable slide is shown in Figure 2(a), considering the mold stiffness is much smaller than the movable beam, lower side of the movable beam can be considered as bearing uniform load; considering horizontal plate thick is much smaller than the hight of vertical plate, so we ignore the effect of horizontal plate, just take into account the vertical plate. The vertical plate of movable beam meet the extrusion conditions as

$$\frac{P_1+P_2}{A_{sb\min}} \le [\sigma_{sb}] \tag{1}$$

Where, P_1—the master cylinder pressure, N;

P_2—Side cylinder pressure, N;

$[\sigma_{sb}]$—allowable extrusion stress, MPa.

Another situation is the range of mould exert force on the movable beam is not the same with the area of force that the plunger on movable range, and a lot of difference existed; considering mold stiffness much less than the movable beam, and movable beam lower side subjected to uniform load, beam will occur bend deformation, and then the movable beam bearing bending moment. the movable beam bearing force is shown in Figure 2(b).

As for the Figure 2(b) shown, the maximum bending moment occure in the middle of beam. Through a set of calculation, the middle section bending moment is as following

$$M=\frac{1}{8}P_1B+\frac{1}{8}P_2(B-2B_1)$$

The maximum bending deflection in the middle is

$$f_{sb}=\frac{3P_1B^3}{384EJ}+\frac{3P_2}{384EJ}\left[3B^2-4B_1^2(3B-B_1)\right] \tag{2}$$

Where, f_{sb} ——Center deformation of the movable beam, mm;

B —— center distance of both sides limit block, mm;

B_1 ——center distance of two side cylinder, mm.

the condition of shear stress strength must meet the requirement : $\tau=\frac{1.5Q}{A}\le[\tau]$. While stress $Q={P}/{2}$, Change the above formula, the shear area isas following :

$$A\ge\frac{1.5P}{2[\tau]} \tag{3}$$

Where, $[\tau]$ ——the allowable shear stress, Mpa ;

P ——the cylinder pressure, N.

According to the formula of the tensile strength, the moment of inertia of the cross section is satisfied.

$$I_Z\ge\frac{\left[\frac{1}{8}P_1B+\frac{1}{8}P_2(B-2B_1)\right]y}{[\sigma]} \tag{4}$$

Where, $[\sigma]$ ——the allowable bending stress, MPa;

y ——The distance from the neutral axis of the cross section.

From Formula(1), we can see that when the nominal load is determined, movable beam structure must enture that the movable beam deflection does not exceed the maximum allowable value; at the same time, when designing the movable beam section, the cross-sectional area and moment of inertia must also satisfy requirement of Formula (2) and Formula (3).

2.2 Conceptual design model of movable beam

Apply the above concept design method to the design of movable beam. the movable beam with cylinders as an example; its stress type is shown in Figure 2(a). Typical structure with cylinder block is shown in Figure 3. The master cylinder seated in the center, the side cylinders distributed separately around it. Refering to the oil cylinder design method, the design of the main cylinder is given, while design the thickness of the beam vertical platea based on the side cylinder pressure. According to Figure 2, we considered that the four piston apply totally forces on the corresponding four vertical plates, and the contact length is the same as the four piston diameter. Considering the material extrusion stress, the relationship between the force of the side cylinder and the thickness of the vertical plate is established as following:

$$t \geq \frac{P_2}{8d[\sigma_{sb}]} \tag{4}$$

where, d —the piston diameter of the side cylinder, mm;

$[\sigma_{sb}]$—material extrusion stress, MPa;

t —the thickness of vertical plate, mm.

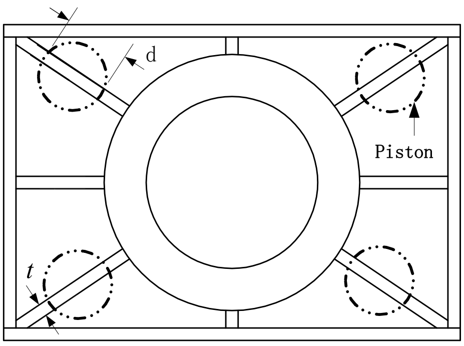


Figure 3. Typical structure of movable beam with cylinder block

Taking movable beam on the THP10-10000 type 100MN isothermal forging hydraulic press as an example, the length of movable beam is 3180mm, the width is 3500mm ; the master cylinder is piston driven, which provide the maximum load of 60Mn; the four other auxiliary hydraulic cylinder are piston driven, whicn providing the maximum load of 40Mn totally. The inner diameter of the master cylinder is 1060mm, and the diameter of the auxiliary cylinder is 795mm. Define the inner and around virtical plate are the same thickness. For material of Q235 steel, the allowable extrusion stress is $[\sigma_{sb}] = 175\text{MPa}$. The above value is brought into the Formula (4), can obtaine the following result :

$$t \geq 80\text{mm}$$

From the material saving and the weight reducing considering, the minimum value is selected. So we determined the thickness of theinner and around vertical plate is 80mm.

Apply the above concept design method to the struture design of movable beam(Figure 2(b)). At this type, deformation and stress must be calculated considered, and satify the deformation and stress requirement simultimosly. design steps is the same as the tredition beam design method, so there is not described detailed there.

2.3 Prototype design of movable beam

By establishing the mechanical model of movable beam, the moment of inertia of the component section is calculated, and the initial size of the equivalent section is determined. On the basis of conceptual design prototype, the prototype design of the hydraulic press's movable beam can be further carried out. As to the conceptual prototype design, the structural prototype design needs to be designed according to the concept prototype; this phrase usually needs to combine with the previous case experience to complete.

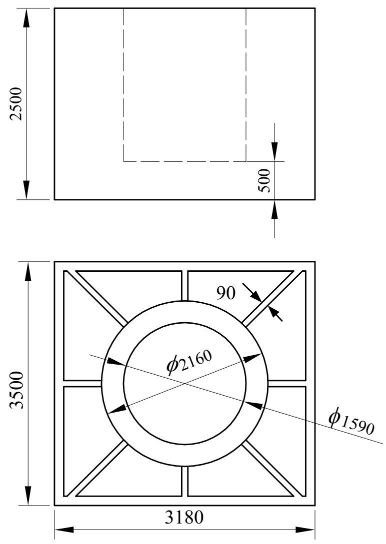


Figure 4. The prototype of the active beam structure

In the concept design phase, hydraulic pressure's movable beam geometry information is incomplete, so when establishing the preliminary structural design of the prototype, a certain amount of geometric information must added to prototype [6], such as: distance between longitudinal and transverse ribs, rib plate size and so on. Taking the movable beam on the 100MN type THP10-10000 isothermal forging hydraulic press as an example, taking into account the above fact, the structure prototype of the movable beam of the hydraulic press is shown in Fig. 4. This design result is the initial scheme comparing with the optimization design of the movable beam of the hydraulic press. According to this, the structure design, detailed design and optimization design can be carried out successively.

The structure design includes function and structure mapping, preliminary structure design, scheme layout. Detailed design is the structure of the specific products, process details. When conducting constrained structure optimization, the unimportant detail structure needs to ignore. Based on this, movable beam initial structure is shown on Fig. 5.

2.4 Case study

In Fig. 5, the size of the middle cylinder can be calculated according to the strength of the cylinders, not as a variable parameter. Besides that, there are still much variable structures, which have great influence on the movable beam strength.

Combined with the specific structure of the movable beam, the thickness of the outer plate of the moving beam and the thickness of the inclined plate thickness of the moving beam are selected as the control variables. Determine the key variables that affecting the performance of the active beam structure is the thickness of the outer plate x_1 and the thickness of the inclined plate x_2.

By calculating the volume of moving beam, the mass of moving beam is described as

$$m_{mb} = \left(1755636648 + 7567400x_1 + 2503642x_2\right) \times 7.8 \times 10^{-9} \quad (5)$$

where, x_1 —the outer plate, mm;

x_2 —inclined plate, mm;

m_{mb} —the mass of moving beam, kg.

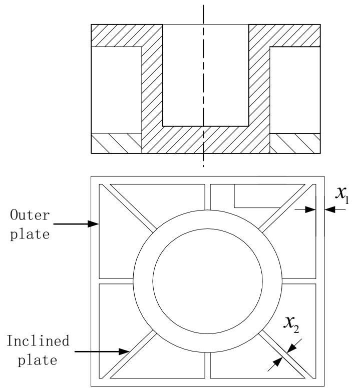


Figure 5. Movable beam parameters

Tradition methods of design and calculation of press are based on old experience, according to the original condition and data, or referring to the same type of press[7,8]. When conducting design, some parameters are chosen as the initial conditions, and give the design result. Next, the strength and stiffness of the moving beam are checked.

The design result using this method is only one feasible plan, not an optimal result. So there using the optimization design method to conduct the active beam design. There must add other equation: mass equation of upper beam, lower beam and column, deformation equation of upper beam, lower beam and column, the range of each variable, constraint conditions of deformation. The minimum mass and minimum deformation as the optimization goal, the structure optimization of the hydraulic press is conducted. Obtained that the outer plate thickness x_1 is 95 mm, the thickness of the inclined plate x_2 is 85 mm.

3 Conclusions

Taken material maximum allowable stress as constraint, constructed the movable beam mechanical model, established relational formula between sectional area and moment of inertia. The relationship between the force of the side cylinder and the thickness of the inclined plate and outer plate is established, and then the concept design model of the movable beam is obtained. The conceptual design method is used to the 100MN type THP10-10000 isothermal forging hydraulic press, and the concept design results of moving beam is obtained. This concept design method has general meaning and can apply to other similar product design.

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