The optimal design of the bed structure of bedstand based on ABAQUS

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Abstract. Hydraulic transmission bedstand is one kind of the most commonly used in engineering machinery companies, and the bed structure is the most important part. Based on the original hydraulic transmission bedstand bed structure and the CAE technology, the original bed structure is improved. The optimized bed greatly saves the material of the production bed and improves the seismic performance of the bed. In the end, the performance of the optimized bed was compared with the original bed.

1. Introduction
With the continuous development of science and technology, the combination of mechanical design and computer technology is becoming more and more closely, and the design tends to be complicated, agile and intelligent [1]. The traditional design method based on the simple calculation and the design experience has a large allowance in design. The bigger the design safety factor is, the higher the reliability of the product is, which wastes the material and increases the cost of the mechanical product. It is obvious that the traditional design method cannot meet the requirements of contemporary design. The finite element analysis technology is an important means and method to realize the mechanical structure design. The use of finite element analysis technology to achieve the lightweight, low cost, high-performance of mechanical products has become a new trend in today's mechanical design. In order to improve the quality of transmission products, ensure the outgoing quality and shorten the development cycle, it is necessary to test the performance of the various aspects of the transmission. Therefore, how to design a high-performance bedstand to test the assembly performance and the overall functions of transmission is particularly important. In this paper, the high-power hydraulic transmission bedstand driving and the former loading bed is the research object, using finite element analysis method to optimize the bed, to achieve lightweight design, reduce production costs and improve the quality of the whole machine. This is of great significance to improve the research development capacity of enterprise products and enhance the competitiveness of the enterprise market.

2. Working condition analysis of high-power hydraulic transmission bedstand
The structure of the high-power hydraulic transmission bedstand is shown in Fig. 1, the bedstand uses AC variable frequency motor to simulate the actual working condition, driving motor to simulate the engine power input, and loading motor to simulate the size of the load. The driving motor, the front loading motor and the transfer gear box A are installed on the bed of the same large casting, and the structure is compact, and the reliability and stability of the mechanical system are ensured better. The driving motor is connected with the input end of the test-piece through a universal drive shaft, the output
of the front loading motor is connected with the transfer gear box A through a diaphragm coupler, the output of the transfer gear A is connected with the torque sensor directly through the flange, the torque sensor output end is provided with the intermediate support 2, the intermediate support output end is connected with the output end of the test-piece. The maximum speed of the motor at the bedstand is as high as 4000r/min, which puts a higher demand for the dynamic performance of the bedstand, especially the high-speed rotation of the motor.

![Assembly drawing of high-power hydraulic transmission bedstand](image)

Figure 1. Assembly drawing of high-power hydraulic transmission bedstand

The bedstand driving and the front loading bed are mainly subjected to the gravity of the motor, the bed of driving motor, the transfer gear A, the intermediate support 2, the torque sensor and other parts in the work, which static force fully meet the strength requirements. This paper focuses on the dynamic performance of the bed.

3. Modal analysis of the bedstand bed

In the SOLIDWORKS, the 3D model of the bed is established, and the geometric model is simplified. Then, the simplified model is imported into the ABAQUS software for modal analysis, and the natural frequency and mode of vibration of the bed are obtained.

The main analysis process and parameter settings for modal analysis of the bed are as follows:

1. The material properties of the bed are defined. The bed material is HT300, the Young's modulus is $1.3 \times 10^5 MPa$, the Poisson's ratio is 0.25, and the mass density is 7350kg/m$^3$.

2. The cast-iron bed is connected to the iron plate by means of the anchor bolts, so the fixing is applied to the bolt holes and the z-direction movement of the bottom surface of the bed.

3. In order to obtain accurate and reliable calculation results, the model is fine meshed, and 109497 C3D10M entity modified units and 175233 nodes are generated. After the mesh is checked, the job is created and submitted for analysis. Table 1 for the bed of the first four orders of natural frequencies, Fig.2 for the bed of the first two modes of vibration.

| Table 1. The bed of the first four orders of natural frequencies |
|---------------------------------------------------------------|
| Order | 1       | 2      | 3      | 4       |
|-------|---------|--------|--------|---------|
| Frequency/Hz | 295.69 | 359.08 | 369.04 | 371.37 |
The maximum speed of the bedstand is 4000r/min, the maximum frequency of the excitation force is 66.6Hz, which is much lower than the first-order natural frequency of the bed. Only the low order natural frequencies can coincide with the excitation force frequency to cause resonance, so the first-order natural frequency of the bed is studied in the following research. As shown in Fig. 2, the first-order vibration mode is shown to be the rocking vibration of the bed along the Z axis, and the maximum amplitude is at the bed of ribbed slab. The second-order of vibration mode of is shown to be the torsional vibration of the bed around the Y axis, and the maximum amplitude is at the central ribbed slab. The rocking vibration and the torsional vibration at ribbed slab are relatively large compared to the rest of the bed, which is the weak link in the bed structure. At the same time, the vibration of the bed must affect the parts connected with it to reduce the detection accuracy of the bedstand, which should be taken seriously and improved.

4. Optimal design of the bedstand bed

Through the vibration diagram of the bed, it can be seen that the ribbed slab is the weak links of the bed structure, so it is the direction of the bed optimization according to the bearing characteristics. The next optimization is based on the following optimization route:

1. The influence of different ribbed slab arrangement on the dynamic performance of the bed is studied.
2. The influence of different constraint arrangement on the dynamic performance of the bed is studied.
3. The topology of the bed is optimized to analyze the distribution trend of the material, and a new bed structure is proposed.
4. The influence of different thickness and height ribbed slab on the dynamic performance of the bed are studied.

4.1. Optimal Design of Ribbed Slab Arrangement

In the design of the bed structure of cast iron, the internal support structure of cast iron bed is especially important. The basic idea of the meta-structure is that a structure decomposes on its constituent form and eventually obtains some of the most basic unit structures [2]. According to the commonly used six kinds of cast iron bed meta-structure established six kinds of bed structure shown in Fig. 3 [3]. The dimensional parameters of the meta-structure are as follows: Length L is 455mm, width B is 237.5mm, thickness of ribbed slab T is 50mm, height of ribbed slab H is 270mm, wall thickness T1 is 60mm, the minor diameter of the cylindrical ribbed slab d is 150mm, the major diameter of the cylindrical ribbed slab D is 250mm. Six kinds of bed structures were introduced into ABAQUS for modal analysis. The results are shown in Table 2.
Figure 3. Six bedstand beds based on meta-structure

| Table 2. The first-order natural frequency of each bed structure |
|---------------------------------------------------------------|
| Bed structure | 1   | 2   | 3   | 4   | 5   | 6   |
|----------------|-----|-----|-----|-----|-----|-----|
| First-order natural frequency/Hz | 286.96 | 282.38 | 276.37 | 274 | 286.13 | 287.27 |

Compare the analysis results in table 2: The first-order natural frequency of the bed structure 6 is the highest, and the first-order natural frequency of the bed structure 1 is the second. Although the first-order natural frequency of the bed structure 6 is the highest, the bed structure 6 is complicated in structure, difficult to manufacture, has a long manufacturing cycle and a high manufacturing cost, and the difference in the first-order natural frequencies of the two bed structures is small. So choose the cost-effective bed structure 1 to further optimize. It can be seen that the blind increase in the number of ribbed slab does not necessarily increase the dynamic performance and greatly increases the manufacturing cost.

4.1. Optimal Design of Constraint Arrangement
The bed is connected to the iron plate by means of anchor bolts. The minimum T-slot spacing on the iron plate is 150mm, so the bolt hole spacing should be a multiple of the minimum T-slot spacing. The original bed in the bottom of the bed evenly symmetrical distribution of 8 bolt holes with fore-and-aft clearance of 900mm. Now, without changing the position of the 4 front and rear bolt holes, taking the fore-and-aft clearance of the middle two bolt holes as variables, the modal analysis of the bed with different bolt hole spacing is carried out, and the influence of different bolt hole spacing on the dynamic performance of the bed is studied.
Figure 4. Effect of bolt hole spacing on the dynamic performance of the bed

As shown in Fig. 4, the first-order natural frequency of the bed increases first and then decreases with the increase of the spacing, and reaches the maximum value when the spacing is 900mm. It can be seen that the dynamic performance of the bed is optimal when the number of the bed constraints is not increased and the bolt holes are uniformly distributed. On the basis of this conclusion, the constraint arrangement shown in Fig. 5 is proposed. With this constraint arrangement, the first-order natural frequency of the bed is raised to 331 Hz, which means that it is quick to increase the vibration resistance of the bed by increasing the constraint of the bed and making it evenly distributed.

Figure 5. New constraint arrangement

4.2. Topology optimization

Topology optimization is based on the initial model in the optimization iteration cycle, and under the premise of satisfying the optimization constraints, constantly modify the material properties of the specified optimization area unit, effectively remove the unit from the analysis model to obtain the optimal design.
Figure 6. The iteration of optimization

The model of the new constraint arrangement is optimized for the object. Maximize the natural frequency for the target, the volume of the original volume of 50% for the constraint, freeze the bed of the top area, set the bed structure symmetry. From the iterative process shown in Fig. 6, it can be seen that the material on both sides of the bed is mainly removed after the beginning of iteration, and then the material in the lower part of the bed is removed, the transverse rib are all removed, the lower part of the longitudinal rib has a tendency to remove a trapezoidal block, and the height of ribbed slab is also removed. The height of ribbed slab in the back will be studied in detail. Topological optimization results are mostly irregular spatial structures, therefore, the results of topology optimization need to be abstracted and simplified [4]. Abstract simplified bed model shown in Fig. 7, the first-order natural frequency of the bed is 352.55Hz by modal analysis. The model obtained by topology optimization can improve the dynamic performance while reducing the weight.

Figure 7. Topology optimization model

4.3. Size optimization
Because ribbed slab is the weak links of the bed, and in the iterative process of topology optimization, it can be seen that ribbed slab also has the optimized space. Therefore, in this paper, the height of ribbed slab H and the thickness of the ribbed slab T as the object of study, using the same analysis method for different height and thickness of ribbed slab are analyzed, the curve shown in Fig. 8.
Figure 8. The effect of the height and the thickness of ribbed slab on the bed frequency
As you can see from Fig. 8, In the case where the thickness of ribbed slab is constant, with the increase of the height of ribbed slab, the first-order natural frequency of the bed increases first and then decreases. When the height of ribbed slab is 300mm or 310mm, the first-order natural frequency reaches the highest value, and the rate of increase of the different thickness ribbed slab is almost the same, and the decreasing rate decreases with the increase of the thickness of ribbed slab. In the case of the same height of ribbed slab, the first-order natural frequency of the bed increases with the increase of the thickness of ribbed slab, and the amplitude of the increase is smaller and smaller. Considering the specific working conditions, the height of ribbed slab H is 290mm and the thickness of ribbed slab T is 60mm are taken as the results of the optimization of the bed. When the weight of the bed is reduced by 17.75%, the first-order natural frequency is increased by 26.27%, and the optimized scheme is reasonable and feasible. Compare the parameters before and after optimization as shown in Table 3.

Table 3. Comparison of parameters before and after the bed optimization

| Project                          | Before optimization | Optimized | Difference          |
|---------------------------------|---------------------|-----------|---------------------|
| Weight/Kg                       | 6480                | 5330      | 1150, reduce 17.75% |
| First-order natural frequency/Hz| 295.69              | 373.37    | 77.69, increase 26.27% |

5. Conclusion
In this paper, the finite element analysis method is used to analyze the dynamic characteristics of the bed structure, and a new optimization route is put forward for the optimization design of the bed structure. The following conclusions can be drawn in the optimization process:
(1) The bed with the cross-shaped ribbed slab as the meta-structure can obtain better dynamic performance in the case of simple structure, simple manufacturing, short manufacturing cycle and low manufacturing cost, and has high cost-performance.
(2) In the design of the bed, a reasonable increase in the bed of the constraints and uniform distribution of constraints can quickly improve the bed of the anti-vibration ability.
(3) From the topology optimization process can be seen in the lower part of the trapezoidal block, on both sides of the bed and the transverse rib, longitudinal rib does not contribute to the dynamic performance of the bed, can be removed to reduce weight and improve the bed anti vibration ability.

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