Lightweight Design of Vertical Lathe Bed for Repairing Wheel based on ANSYS Workbench

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Abstract—The casting bed of vertical lathe for repairing wheel hub is optimized to realize the lightweight design. The optimal selection scheme is optimized to improve the first natural frequency and reduce weight. Multi-objective genetic algorithm is based on the general algorithm of genetic algorithm to solve the problem. The five important dimensions of the bed structure are multi-objective optimized to determine the best optimization scheme. According to the results of multi-objective optimization design of bed, the optimal design scheme based on objective optimization is obtained. After the parameters are rounded, the casting bed is brought into the whole machine model, and the static analysis of the whole machine is carried out to check the safety of the structure.

1. INTRODUCTION
Optimization design is based on mathematical optimization theory and finite element method. Under the premise of satisfying all kinds of constraints, the optimal scheme that meets the optimization objective is explored[1]. The most commonly used structural optimization methods are structural type optimization, shape optimization, size optimization, topology and layout optimization. The optimization objectives are to reduce the deformation of parts, reduce the weight and improve the first-order natural frequency of parts[2].

In this paper, the casting bed of vertical lathe is taken as the optimization object. The multi-objective optimization of important dimensions of bed structure is carried out. Through the optimization design, the dynamic characteristics of the lathe structure are improved, and the lightweight design of the lathe is realized.

2. MULTI-OBJECTIVE OPTIMIZATION OF IMPORTANT DIMENSIONS OF BED STRUCTURE
The thickness and size of the support plate for the best selection shall be adjusted to the best to further improve the overall dynamic performance and rigidity of the bed. Therefore, the multi-objective driving optimization in the design space module of the simulation software is required for size optimization[3].

2.1. establishment of objective function for bed optimization
The extraction of design variables is completed in the pre-processing stage of optimization. In view of the complexity of the bed structure, the model is built in the three-dimensional software, and several key dimensions of the bed are marked as optimized dimensions, which are named P1, P2, P3, P4 and...
P5. The specific location corresponding figure is shown in Figure 1. The optimized bed model is imported into the design space module of the simulation software for size optimization.

![Figure 1. Optimized dimension location](image)

The optimal design can be expressed by establishing the correct mathematical model, which is convenient for processing and calculation to establish the target variables. The idea of bed optimization is to improve the first-order natural frequency of bed and reduce the weight of bed by changing the thickness of rib plate at the important position of bed. Therefore, the following parameters are selected as optimization parameters in multi-objective drive optimization.

- **Design variable**: \( P_1, P_2, P_3, P_4, P_5 \);
- **Target variable**: The first natural frequency and weight of the bed under the constraint;
- **Constraint condition**: Constraints are the variation range of design variables.

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\begin{align*}
P_1 &= 60\text{mm} \quad 50 \leq P_1 \leq 70 \\
P_2 &= 20\text{mm} \quad 14 \leq P_2 \leq 26 \\
P_3 &= 20\text{mm} \quad 14 \leq P_3 \leq 26 \\
P_4 &= 40\text{mm} \quad 30 \leq P_4 \leq 50 \\
P_5 &= 130\text{mm} \quad 110 \leq P_5 \leq 150 
\end{align*}
\]

The multi-objective optimization design of bed is based on the modal analysis of bed. The bed model is built by SolidWorks, and then directly imported into ANSYS Workbench. Before being imported into the 3D model, the features and dimensions need to be renamed in SolidWorks to realize dimension recognition and data sharing with ANSYS Workbench.

### 2.2. Sensitivity analysis

The total of 27 groups of design sample points can be obtained by 5 input parameters. Based on the solution results of 27 groups of design sample points, the sensitivity of five design variables \( P_1, P_2, P_3, P_4 \) and \( P_5 \) to the optimization target can be obtained. The sensitivity histogram is shown in Figure 2.
As can be seen from the figure, P2 has the highest sensitivity to the first natural frequency of the bed, followed by P3. The greater the sensitivity value is, the greater the influence on the first natural frequency is. The sensitivity of P5 is negative. The first natural frequency decreases faster with the increase of P5. P1, P2, P3, P4 have positive sensitivity to the structural weight of the bed, and the greater the sensitivity value, the greater the impact on the weight of the bed.

2.3. analysis of optimization results
The final step of size optimization is to predict the optimal solution of the target variable and get the optimal sample of each design variable. The multi-objective optimization setting interface is shown in Figure 3.
There are three optimization methods: screening optimization, multi-objective genetic algorithm and Quadratic Lagrangian nonlinear programming. Multi-objective genetic algorithm is based on the general algorithm of genetic algorithm to solve the problem. It supports a variety of objectives and constraints, and its purpose is to find the global optimization. It requires continuous input of parameters. This method is more accurate, which is very suitable for calculating the global maximum and minimum values, while avoiding the defects of local optimum. In this paper, the multi-objective genetic algorithm is selected to optimize the size, and the influence column in the search for optimization is set as the advanced status item \(^4\). The optimal solution star graph is shown in Figure 4.

![Figure 3. parameter setting of multi-objective genetic algorithm](image1)

![Figure 4. Target driven optimization results](image2)
From the star chart of the optimal solution in Fig.3, it can be concluded that the quality of candidate design point 3 is the best optimization scheme. Considering the actual production factors, it is necessary to round the size. Compared it with the natural frequency before optimization, the first-order natural frequency is increased by 4.89%, and the bed weight is reduced by 3.81%, the results are shown in Table 1.

### TABLE 1. COMPARISON OF VARIABLES BEFORE AND AFTER OPTIMIZATION

|            | P1/mm | P2/mm | P3/mm | P4/mm | P5/mm | First natural frequency /Hz | Mass /kg |
|------------|-------|-------|-------|-------|-------|----------------------------|----------|
| Current    | 60    | 20    | 20    | 40    | 130   | 221.54                      | 712.6    |
| Optimal    | 50.2  | 25.4  | 14.3  | 30.2  | 110   | 240.71                      | 687.6    |
| Round      | 50    | 25    | 15    | 30    | 110   | 232.37                      | 685.5    |

3. VERIFICATION OF THE WHOLE MACHINE AFTER BED OPTIMIZATION

The gravity of the whole machine can be realized by the acceleration of the loading force. The cutting force and torque are respectively applied at the location of the turning tool and the spindle of the worktable to simulate the load on the turning tool and the worktable in the actual processing. According to the calculation formula of main cutting force (1) and the empirical formula of machine tool cutting end face (2), the main cutting force \( F_x = 405 \text{ N} \), cutting component in the direction of cutting \( F_x = 102 \text{ N} \), and cutting component in the direction of vertical cutting \( F_y = 1.62 \text{ (N)} \).

\[
F_x = 9.81 C_p a_p^{x_k} f_f^{x_r} (60 v)^{n_k} K_F \\
F_x : F_y = 1 : 0.25 : 0.4
\]

It can be seen from Figure 5 and Figure 6 that the maximum deformation of the whole machine and the maximum deformation position of the bed have not changed, and the numerical change is very small, which shows that the optimized bed meets the requirements.

Figure 5. The deformation of the lathe
4. CONCLUSION

Based on the sensitivity analysis and response surface optimization method, the optimal solution star graph is obtained, and the design point 3 is determined as the optimal scheme. According to the optimized size of the structure, the model is rebuilt and the optimization model is tested. Compared with before and after the bed structure optimization, the bed mass is 685.53kg, the weight loss ratio is 3.81%, the first-order natural frequency is 232.37Hz, and the first-order natural frequency is improved by 4.81%.

REFERENCES

[1] Liu Chengying, Tan Feng, Wang Liping. Study on multi-objective optimization of machine bed based on sensitivity analysis [J]. Modular machine tool and automatic processing technology, 2015 (03): 1-4

[2] Huang Jianguo, Yan Zhonghuai, Wang Xinwei, LV Hong, Lin Lin. Structural optimization design of a vertical machining center [J]. Development and innovation of mechanical and electrical products, 2019,32 (06): 88-90

[3] Tu Xiyao, Xue Jiahan, Hu Qi, Li Jiajun, Wang Guoqiao. Discussion on the new development of mechanical structure design and manufacturing technology of CNC machine tools [J]. Nanfang agricultural machinery, 2019,50 (21): 100

[4] Pan Shiqun, Chen pan, Zhang Xiaoming. Structural optimization and verification of vmc1000l vertical machining center [J]. New technology and new products in China, 2019 (19): 54-56

[5] Wang Jianhua, Zhong Liangwei, Wang Shuwen, Gu Deren. Study on Optimization of dynamic characteristics of machine tools based on finite element method [J]. Agricultural equipment and vehicle engineering, 2019,57 (10): 24-28