Design of Integrated Impeller Processing Fixture and Force Analysis of Key Parts

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Abstract. This paper designs a box-type fixture based on SolidWorks software so as to provide a special fixture for stable and fast positioning of integrated impeller processing. It uses mechanics to analyze the force of the central axis, and the Simulation module to conduct stress and strain calculation. Example verifies the feasibility of the design. The design analysis provides a theoretical basis for the integrated impeller processing industry and is practical for its reference value.

1. Introduction
The integral impeller is an important part in the turbo engine, the supercharger and other power engines, whose processing quality directly affects the engine’s thrust-to-weight ratio and mechanical efficiency [1-2]. Its machining accuracy is affected by many factors, such as machining methods, tools, machine tool models, etc. In addition, the fixture is also an important factor in this regard.

Good fixtures make machining more efficient and accurate. Many scholars at home and abroad have done research on the structural design and force analysis of the fixture. For example, Mads [3] et al. proposed a reconfigurable fixture aiming at part welding process, which performs well in terms of variability. Hans et al. [4] introduced the intelligent fixture and analyzed the typical method of design, and the influence of the fixture on the vibration and deformation of the workpiece using finite element simulation. Michael et al. [5] proposed a fixture planning and design system, and conducted a test on the typical box parts in the industry, which turns out good.

In conclusion, fixture is very important for processing parts. Some research has been done at home and abroad. However, most of the research on the integrated impeller is concerned with the profile design, strength analysis or numerical control machining of the blade [6-8], but few of it is about the design of special fixtures for integrated impeller processing. To this end, this paper proposes a box-type design method for the integral impeller, carries out in detail the structure, size and force analysis of the important parts of the fixture, and carries out finite element calculation through the SolidWorks Simulation module. The fixture design analysis is proved to be correct by the example.

2. Overall Design of the Integrated Impeller Fixture
From the half-sectional two-dimensional view of the integrated impeller (Figure 1), we can see that in the axial direction, the impeller has a 221 mm-long central hole Φ55 mm, a circular boss 6 mm high at the small end. The diameter of the top surface of the boss is Φ70 mm, and that of the bottom surface is Φ119 mm. Three M8 threaded holes are evenly distributed on the bottom surface. Based on the above...
characteristics, this paper designs a central shaft with a shoulder to position quickly in its axial and radial direction, multiple disc-type end caps fixed by bolt and nut to support the impeller workpiece, and a box-type fixture connected to the machine base by bolts. The overall assembly of the fixture is shown in Figure 2.

In figure 2. 1 refers to first end cover, 2 second end cover, 3 fixing seat, 4 third end cover, 5 integrated impeller, 6 fourth end cover, 7 central shaft, 8 key, 9 bolt, 10 nut.

2.1. Key parts design and 3D modeling
The dimensions of the fourth end cover 6 can be determined based on the size of the small end boss of the impeller. In the radial direction, the diameter of the central hole is Φ55 mm, the same as the diameter of the central hole of the integrated impeller; the diameter of the groove of the fourth end cover 6 is Φ70 mm, the same as the diameter of the top surface of the boss. The outer diameter is Φ119 mm, the same as the diameter of the bottom surface of the boss. The center position of the stepped hole on the fourth end cover 6 is Φ92 mm, the same as the center position of the threaded hole of the M8. In the axial direction, the groove depth on the fourth end cover 6 is 6 mm, the same as the height of the boss. According to general mechanical parts design, the total thickness on the fourth end cover 6 should be greater than 2 times the depth of the groove. To ensure the rigidity of the part, the total thickness is designed to be 21 mm. Its two-dimensional and three-dimensional maps are shown in Figure 3.
The first end cover 1 (Fig. 4 (a)), the second end cover 2 (Fig. 4 (b)), and the third end cover 4 (Fig. 4 (c)) are respectively designed according to the design method of the fourth end cover 6. In order to make the integrated impeller workpiece suitable to different center holes with different sizes, a larger through hole is designed on the body 3 (Fig. 5), whose two ends are used together with the second end cover 2 and the third end cover 4. When clamping the integral impellers of different sizes, it is only necessary to adjust the size of the central hole of the second end cover 2 and the third end cover 4. At the four corners of the bottom of the clip body 3, through holes are provided to connect and fix with the machine tool.

Figure 4. Three-dimensional view of the first end cover 1, the second end cover 2 and the third end cover 4.

Figure 5. Fixture 3D map.

The center shaft (Fig. 6) is the most important part of the fixture, through which the integral impeller can be quickly positioned. Firstly, a Φ65 mm shoulder is designed, whose two ends are positioned, with one on the fixture and the other on the entire impeller. The two ends are provided with key grooves for connecting with the first end cover 1 and the fourth end cover 6 through key 8. At the same time, the two ends have threads that are locked with nut for fixture assembly.

Figure 6. Two-dimensional map of center axis.

In order to make installation easier and reduce machining surface, a long groove is arranged in the middle of the shaft and the impeller, that is to set the diameter of the shaft to Φ54.5 mm, smaller than Φ55 mm, the diameter of the center hole. There is no requirement for machining precision of the part. The same principle is applied to the design of the other end.

2.2. Force analysis of the central axis
Force analysis of the central axis is conducted based on Figure 2, as shown in Figure 7, which is a force diagram of the central axis, wherein the pressure $F_N$ is derived from the gravity of the integral impeller.
The central shaft needs to meet certain strength and stiffness requirements in order to work stably. The strength of the shaft, or the stress calibration formula (1) and the stiffness, or the deflection check formula (2), can be gained according to material mechanics [9].

\[
\begin{align*}
  y &= \frac{F_N a^2 (L + a)}{3 E L} \leq [y] \\
  \sigma &= \frac{M}{W} \leq \sigma_s
\end{align*}
\]

Where:
- \( y \) is the deflection of the shaft in the y direction, mm;
- \( F_N \) is the positive pressure on the shaft, N;
- \( a \) is the distance from the point of force on the shaft to the nearest hinge, mm;
- \( L \) is the distance between two fixed supports (hinge), mm;
- \( E \) is the elastic modulus of the shaft material, MPa;
- \([y]\) is the allowable deflection of the shaft, mm;
- \( \sigma \) is the bending stress experienced by the shaft, MPa;
- \( M \) is the bending moment of the shaft, N.m;
- \( W \) is the bending section coefficient of the shaft, mm³;
- \( \sigma_s \) is the yield limit stress, MPa.

3. Analysis of Static Finite Element

SolidWorks Simulation module is used to perform finite element analysis on the central axis of the fixture core, which mainly about stress and deformation of the central axis under static conditions. The central axis material designed in this paper is selected as No. 45 steel, with elastic modulus \( E \) 210 GPa, Poisson’s ratio \( \mu \) 0.31, the yield strength \( \sigma_s \) 355 MPa, and mass density 7.85 g/cm³.

3.1. Grid division

Set the size of cell to 8 mm, while the tolerance of 0.4 mm, and Jacobian point of 4 points. After the grid is divided, the total number of nodes is 49295, and that of cell is 31407. The grid is of high quality. The model is as shown in the Figure 8.
3.2. **Applying constraint and load**
The constraint and load are applied to the model according to the actual situation of the shaft. As shown in Figure 9, the green arrow $R_x$ is the supported and fixed part of the fixture to the shaft while the pink arrow $F_N$ is the pressure applied to the shaft by impeller. The integrated impeller weighs 88 kg, so the pressure $F_N$ is 862.4 N.

![Figure 9. Model of center axis constraint and load application.](image)

3.3. **Calculation**
The result is shown in Figure 10 (stress diagram) and Figure 11 (displacement diagram). According to calculation, the part with the strongest force on the central axis is located near the shoulder of the integral impeller at the 29491th node, whose size is $6.696e+05 \, \text{N/m}^2$, smaller than the yield force of $3.550e+08 \, \text{N/m}^2$, satisfying the strength condition formula (1). Its maximum combined displacement is $2.450e-03 \, \text{mm}$ at the end of axis (the 3038th node). According to material mechanics [9], the strain of the shaft is $3.367e-06$, smaller than the allowable strain of common axis of $0.2e-03$, satisfying the rigid conditional formula (2).

![Figure 10. Stress map.](image)  ![Figure 11. Combined displacement map.](image)

4. **Example**
According to the above-mentioned analysis, each part is machined and assembled as a whole, as shown in Figure 12.
5. Conclusion
(1) SolidWorks is used to design the special fixture of the integrated impeller and conduct 3D modeling.
(2) The strength and stiffness formula of the central axis is calculated and analyzed by Simulation module, indicating that the maximum stress of the central axis is 6.696e+05 N/m² near the shoulder; the maximum strain is 03.367e-06 at the end of the shaft. Both of them meet the working requirements of common shafts.
(3) The whole impeller fixture can be assembled, proving that the design and analysis is reasonable and feasible.

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