Finite Element Analysis and Optimization of CBY-100 Gear Pump Body

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Abstract. The research of Gear Pump lightweight can save material and reduce weight on the premise of meeting performance requirements. Use ANSYS14.0 Software finite element analysis CBY-100 gear Pump body, the Stress and Displacement of QT450-10 material Pump body were analyzed to meet the requirements of strength and rigidity. The same method of analysis, the Stress and Displacement of the Pump body are optimized to determine the optimal structure size which meets the requirements of strength and rigidity; the Stress and Displacement of ZL111 cast aluminum Pump body also meet the requirements of strength and rigidity, complete the lightweight design of gear pump. CAD improves research efficiency, reduces research cost and promotes technological innovation.

1. Finite Element Analysis of Pump Body

UG NX8.5 is used to complete the 3D modeling of gear pump, The ANSYS / UG interface is used to import the Ansys14.0 software workbench module, The pump body is made of nodular cast iron, model QT450-10, and the material properties are shown in Table 1. The mesh size of the pump body definition is 6.0mm, the number of nodes generated is 39800, and the number of elements is 23521. The finite element model of the pump body[1] is shown in Figure 1.

Table 1. Ductile iron pump body material properties.

| Material Science | Yield limit(MPa) | Modulus of elasticity(Pa) | Poisson's ratio | Density( kg/m³) |
|------------------|------------------|---------------------------|----------------|----------------|
| QT450-10         | 310              | 1.69E+11                  | 0.257          | 7060           |

Apply a load of 25MPa to the Working face of the Pump body, The upper and lower end faces of the Pump body and the end faces of the Oil inlet and Discharge ports are fixed and constrained, Analysis of rigidity and strength[2] of CBY-100 Pump body.
As shown in Fig. 2 to 5, the stress and equivalent stress distribution nephogram of X, Y, and Z axes of the Pump body. The maximum X-axis stress of the Pump body is located at the outer edge of the Hydraulic oil inlet end, the maximum Y-axis stress of the Pump body is located at the inner edge of the Hydraulic oil outlet end, the maximum Z-axis stress of the Pump body is located at the upper edge, and the maximum equivalent stress of the Pump body is located at the inner edge of the Hydraulic oil outlet end.

Table 2. Pump stress distribution.

| Stress type | Equivalent stress | X axis | Y axis | Z axis |
|-------------|-------------------|--------|--------|--------|
| Maximum stress value (MPa) | 67.099 | 64.273 | 36.949 | 52.28 |

The statistics of the maximum stress is shown in Table 2. The maximum stress of the pump body is equivalent stress, and the value is 67.099 MPa. The yield limit of the material is 310 MPa. If the safety factor is 2, the allowable stress is 155 MPa. The maximum stress of the Pump body is within the allowable stress range of the pump body, and the design of the pump body meets the strength requirements.

Although the design of the pump body meets the strength conditions, there is a stress concentration, which is easy to crack or intensify the wear of the pump body and reduce the life of the pump body. Therefore, it is necessary to further optimize the pump body size and improve its stress distribution. Most of the pump body is located in the low stress area, and the structural strength still has a large surplus. It can be considered to reduce its structural size on the premise of meeting the working strength of the pump body, so as to save materials and reduce weight.
As shown in Fig. 6 to 9, the displacement and the overall displacement distribution of the X, Y, and Z axes of the Pump body. The maximum displacement of the X axis of the pump body appears on the side of the pump body near the hydraulic oil inlet end and the inner side of the oil outlet. The maximum displacement values of Y-axis Z-axis and the whole are at the inner edge of the hydraulic oil outlet end.

Table 3. Pump displacement distribution.

| Displacement type | Resultant displacement | X axis  | Y axis  | Z axis  |
|-------------------|------------------------|---------|---------|---------|
| Maximum displacement (mm) | 0.00888 | 0.00095 | 0.00877 | 0.00243 |

The statistics of the maximum displacement is shown in Table 3. The displacement in Y direction is closest to the combined displacement, with a value of 0.00877mm. The maximum displacement of the Pump body is the combined displacement, which is 0.00888mm, This value is smaller than the structural size of the pump body, which is within the allowable range of design, so the pump body meets the rigidity condition.

2. Optimum Design of Pump Body
Under the condition that the rigidity and strength requirements of the pump body are met, From the two directions of structure size and material, further improve the pump body optimization design [3]

2.1. Structure Optimization of Pump Body
In the analysis of the Strength and Rigidity of the Pump body, it is found that most of the Pump body is in the low stress area, Especially at the oil inlet end of the Pump body, the wall thickness of the Pump body has a large surplus, which can appropriately reduce its thickness; there is a stress concentration and a large stress at the Inner edge of the oil outlet end of the Pump body, which can appropriately increase its thickness and make it smooth. See Figure 10 for the improvement position of pump body structure size.

Analyze the Structural dimensions of CBY-100 External Gear Pump body, and Select the actual optimized dimensions of some Pump bodies as shown in Table 4.

The WORKBENCH module of Ansys14.0 software is used to apply the same Pressure of 25MPa to the Working face of the Pump body, and the same steps as the Original size of the Pump body. The Finite element analysis of the size improved Pump body is completed, Analyze the strength and rigidity of the Selected size Pump body.

Figure 8. Z direction displacement contours.  Figure 9. Overall pump displacement contours.

Table 4. Optimal dimensions of some Pump bodies.

| Dimensions | X axis | Y axis | Z axis |
|------------|-------|-------|-------|
| Thickness Increase |  |  |  |
| Thickness Reduction |  |  |  |

Figure 10. Pump model optimum position.
Table 4. Optimization of pump size case.

| Project                      | Size one | Size two | Size three | Size four |
|------------------------------|----------|----------|------------|-----------|
| Thickness Increase (mm)      | 0.5      | 0.6      | 0.7        | 0.8       |
| Thickness Reduction (mm)     | 4.0      | 5.0      | 6.0        | 7.0       |

Figure 11. Pump equivalent stress contours of size one.

Figure 12. Overall pump displacement contours of size one.

Figure 13. Pump equivalent stress contours of size two.

Figure 14. Overall pump displacement contours of size two.

Figure 15. Pump equivalent stress contours of size three.

Figure 16. Overall pump displacement contours of size three.

Figure 17. Pump equivalent stress contours of size four.

Figure 18. Overall pump displacement contours of size four.

There is still stress concentration in the Pump body of all sizes, and there is no obvious change in the position. The maximum stress is located in the Inner side of the oil outlet, which conforms to the actual working condition of the maximum local pressure at the oil outlet of the pump body.
Table 5. Optimize size pump stress distribution.

| Maximum stress value(MPa) | Equivalent stress | X axis | Y axis | Z axis |
|---------------------------|------------------|--------|--------|--------|
| Size one                  | 112.5            | 110.22 | 61.178 | 75.454 |
| Size two                  | 134.72           | 130.83 | 73.618 | 95.788 |
| Size three                | 152.32           | 146.68 | 83.72  | 115.54 |
| Size four                 | 169.13           | 162.79 | 93.191 | 130.71 |

See Table 5 for the Statistics of stress distribution of Optimized Pump body. The maximum stress of Pump body is Equivalent stress, the allowable stress of QT450-10 material is 155MPa, and the Equivalent stress of size 5 Pump body is 152.32 MPa, which is closest to the allowable stress, It can meet the requirements of Pump body Strength within its scope.

Table 6. Optimize size distribution of the displacement pump.

| Maximum displacement(mm) | Resultant displacement | X axis | Y axis | Z axis |
|---------------------------|------------------------|--------|--------|--------|
| Size one                  | 0.01486                | 0.00099| 0.01097| 0.00313|
| Size two                  | 0.01781                | 0.00199| 0.01756| 0.00498|
| Size three                | 0.02015                | 0.00238| 0.01989| 0.00555|
| Size four                 | 0.02237                | 0.00311| 0.0221 | 0.00612|

The maximum displacement of the Pump body is located at the Joint of the oil outlet and the cavity. See Table 6 for the statistics of optimized displacement distribution of pump body. The maximum displacement of size three Pump body is 0.02015mm, this value is smaller than the structure size of the pump body, within the allowable range of design, and meets the requirements of the Rigidity of the Pump body.

2.2. Finite Element Analysis of Cast Aluminum Pump Body

Considering the working condition of the Pump body, the cast aluminum material, model ZL111, material properties are shown in Table 7, and compared with the raw material Q450-10 by finite element analysis[4].

Table 7. Cast aluminum pump body material properties.

| Material Science | Yield limit(MPa) | Modulus of elasticity(Pa) | Poisson's ratio | Density(kg/m³) |
|------------------|------------------|---------------------------|----------------|----------------|
| ZL111            | 140              | 0.7E+11                   | 0.34           | 2760           |

The yield limit of cast aluminum material is 140MPa, the safety factor is 2, and the allowable stress is 70MPa. Applying 25MPa pressure to the working face of the Pump body, using the same finite element analysis method as that of the Ductile iron Pump body, the strength and rigidity of the cast aluminum Pump body are analyzed.

![Figure 19. Pump equivalent stress contours.](image1)

![Figure 20. Overall pump displacement contours.](image2)
The equivalent stress distribution of cast aluminum Pump body is shown in Fig. 19, and the overall displacement distribution is shown in Fig. 20. The maximum stress and displacement are still concentrated at the oil outlet end, not changed due to the Replacement of materials[5].

### Table 8. Cast aluminum pump body stress distribution.

| Stress type | Equivalent stress | X axis | Y axis | Z axis |
|-------------|-------------------|--------|--------|--------|
| Maximum stress value (MPa) | 64.362 | 67.56 | 37.787 | 55.474 |

The statistics of maximum stress is shown in Table 8. The maximum equivalent stress of Pump body is 64.362 MPa, The maximum stress in X direction is greater than the maximum equivalent stress of the pump body, which is 67.56 MPa, The maximum stress of the Pump body is in the X direction of the Pump body, which is still within the allowable stress range of 70MPa of cast aluminum Pump body, meeting the strength demand of the Pump body.

### Table 9. Cast aluminum pump body displacement distribution.

| Displacement type | Resultant displacement | X axis | Y axis | Z axis |
|-------------------|------------------------|--------|--------|--------|
| Maximum displacement (mm) | 0.02191 | 0.00235 | 0.02158 | 0.00634 |

The summary of the maximum displacement is shown in Table 9. The maximum displacement of Y-axis is the closest to the combined displacement, which is 0.02158mm, The maximum displacement of the Pump body is still the combined displacement, which is 0.02191mm, The displacement is larger than the Deformation of 0.00888mm of Ductile iron material, but it is still smaller than the Structural size of the Pump body. Within the design allowable value, the Pump body still meets the Rigidity requirements.

3. References

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