Modal Analysis of Components and Whole of Gear Pump

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Abstract. The vibration characteristics of Gear pump are studied to avoid the Damage of parts caused by resonance. The modal of Pump body, driving gear shaft, Driven gear shaft and Gear pump are analyzed by using the Workbench module of ansys14.0 analysis software, Statistics of the first ten natural frequencies and the maximum total deformation data, Analyze the modal shape diagram. Comprehensive analysis results, There is a big gap between the natural frequency and the working frequency, the gear pump will not resonate, The local position of the parts and the whole of the gear pump will be deformed, but will not cause damage to the gear pump, and will not affect the performance of the gear pump. Computer aided research of vibration characteristics can shorten the research period and avoid safety problems.

1. Modal analysis of Pump body

The speed of gear pump is 2000r / min, the working frequency is 33.3hz, If the natural frequency of the pump body is equal to or close to the working frequency, resonance will occur, which will cause problems such as gear pump shaking, bolt failure, etc. UG nx10.0 is used to model gear pump, ANSYS / UG interface is used to import ANSYS 14.0 software workbench module, modal analysis.

The vibration characteristics of gear pump body have an important influence on the working performance of gear pump. Resonance will aggravate the damage speed of the pump body, study the natural frequency of the pump body modal, and prevent resonance. Analyze the vibration mode diagram [1] of the pump body to find out the position where the structural rigidity of the pump body is relatively weak.

The pump body is made of nodular cast iron, model QT450-10, and the material properties are shown in Table 1. The trellis partition size of the pump body is 6.0mm, the number of nodes generated is 39800, and the number of units is 23521, The finite element modal of the pump body is generated and the free modal of the pump body is analyzed. See Table 2 for the first ten order of the statistical natural frequency and the maximum total deformation of pump body, and figure 1 to 4 for the modal shape of partial pump body.

Table 1. Material properties of nodular cast iron pump body

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

The natural frequency of rigid body mode is zero. Analysis table 2 shows that the first three natural frequencies are zero, and their modal are considered as rigid body modal, and the gear pump will not
produce resonance. The natural frequencies of order 4 to 6 are within 0.003hz, and those of order 7 to 10 are greater than 3000hz, which are very different from the working frequency of gear pump (33.3hz). Therefore, the pump body itself is stressed, but it will not rotate or move, and the pump body will not resonate with the gear pump.

Table 2. Natural frequency and maximum total deformation of pump body

| Order | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Natural frequency | 0   | 0   | 0   | 0.001 | 0.002 | 0.0027 | 3.341 | 19.6 | 79.46 | 7946.7 | 9204.9 |
| Maximum total deformation | 20.858 | 19.779 | 22.495 | 17.542 | 18.825 | 17.186 | 26.575 | 28.661 | 44.966 | 28.118 |

Figure 1. Sixth order modal shape

Figure 2. Seventh order modal shape

Figure 3. Eighth order modal shape

Figure 4. Tenth order modal shape

Analyze the vibration mode diagram of Pump body, as shown in Figure 1 to 4. The vibration modal of Pump body in stages 1 to 6 is the external expansion of the gear pump cavity, which conforms to the actual working condition of the external expansion of the gear pump cavity. The mode shape of the 7th order modal is that the four screw holes of Pump body produce torsion along the z-axis. The mode shapes of the 8th and 9th order modal are the up and down oscillations in the middle of the upper end of the pump body. The modal shape of the 10th order is that the oil inlet end is twisted along the x-axis. According to the comprehensive analysis, the vibration of the pump body is mainly the external side and the upper end face of the cavity, and there is obvious local vibration at the screw hole and the middle of the upper end face, and there is torsion at the oil inlet end. It shows that the rigidity of the pump body structure is locally low, and the structural size of the outside and the middle of the upper end face of the pump body is optimized [2], and the rigidity distribution is uniform.

2. Modal analysis of gear shaft

The gear shaft has driving gear shaft and driven gear shaft, commonly used carburizing steel, model 20CrMnTi, carbon content is 0.17% - 0.24%, surface carburizing and hardening, high stability, stronger fatigue resistance, material properties are shown in Table 3.

The driving gear shaft directly receives the external input power, the working state is rotation, the vibration characteristics affect the performance of the driving gear shaft, and the resonance aggravates the gear teeth damage. Analyze the driving gear shaft modal [3] to prevent resonance. Analyze the
vibration mode diagram of the driving gear shaft, understand the position where the structural rigidity of the driving gear shaft is relatively weak, and predict the damage of the driving gear shaft.

Table 3. Material properties of carburized steel gear shaft

| Material Science | Yield limit (MPa) | Modulus of elasticity (Pa) | Poisson's ratio | Density (kg/m³) |
|------------------|-------------------|----------------------------|----------------|-----------------|
| 20CrMnTi         | 835               | 2.12E+11                    | 0.289          | 7860            |

The trellis partition size of the driving gear shaft is 4.0mm, the number of nodes generated is 31825, and the number of units is 17757, and the finite element model of the driving gear shaft is generated. Analyze the constraint modal of the driving gear shaft, and see Table 4 for the first ten order of the statistical natural frequency and the maximum total deformation of driving gear shaft. See Figure 5 to 10 for the modal shape of partial driving gear shaft.

Table 4. Natural frequency and maximum total deformation of driving gear shaft

| Order | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     | 10    |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|       | Natural frequency | 0    | 1052.7 | 1052.8 | 4195.6 | 4196.4 | 46937.1 | 18062.9 | 8064.1 | 8180.8 | 12312 |
|       | Maximum total deformation | 46.59 | 31.689 | 31.688 | 43.368 | 43.494 | 43.317 | 42.246 | 41.648 | 28.271 | 43.988 |

Figure 5. First order modal shape  
Figure 6. Second order modal shape  
Figure 7. Fourth order modal shape  
Figure 8. Sixth order modal shape  
Figure 9. Seventh order modal shape  
Figure 10. Ninth order modal shape
The X, Y and Z axis displacements of the two end faces of the driving gear shaft are zero mm constraints, X-axis, Y-axis rotation fixed constraint. Lock the gear shaft 5 degrees of freedom. Only the z-axis rotation motion state is retained. Analysis table 4 shows that the first order natural frequency of the driving gear shaft is zero, and the modal is regarded as rigid body modal, there is no resonance. The natural frequencies above the first order are all above 1000Hz, which is quite different from the working frequency of gear pump (33.3hz). The driving gear shaft will not resonate with the gear pump.

Analyze the vibration mode diagram of driving gear shaft, as shown in Figure 5 to 10. In first order modal shape, The deformation at the top of gear teeth is the largest, which is in line with the actual working condition that the material at the top of the gear is the least and the force at the top is the largest in the working process. The second and third order modal shape, the gear shaft bending, the maximum deformation in the dynamic input side. The fourth, fifth, seventh and eighth order modal shape, the gear shaft is twisted in Z direction. The sixth and tenth order modal shape, power input end spline expansion. The Ninth order modal shape, The gear teeth are forced to expand. Comprehensive analysis, first order rigid body modal, The stress and deformation of the gear shaft are concentrated on the top of the gear teeth, The rest of the deformation is mainly due to the torsion in the process of rotation, The centralized position is spline, input gear shaft and gear teeth.

Driven gear shaft is driven by driving gear shaft and rotates passively, The vibration characteristics are similar to the driving gear shaft, In the same modal analysis as the driving gear shaft, the driven gear shaft will not resonate with the gear pump, and the stress deformation is similar to the driving gear shaft.

3. Overall modal analysis of gear pump

Gear pump fixed pump body, end cover, driving and driven gear shaft rotation, vibration characteristics affect the life and stability of gear pump. Analyze the overall modal of gear pump\textsuperscript{[4]}, optimize the structure and prevent resonance.

The trellis partition size of the gear pump is 6.0mm, the number of nodes generated is 150560, and the number of units is 86661, Analyze the free modal of gear pump, The first ten order of the statistical natural frequency and the maximum total deformation are shown in Table 5, and the overall modal shapes of partial gear pumps are shown in Figure 11 to 14.

| Order | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   |
|-------|------|------|------|------|------|------|------|------|------|------|
| Natural frequency | 0    | 0.00210 | 0.00311 | 13.191 | 18.428 | 25.96 | 2899.3 | 2909.8 | 4701.2 | 5294.5 |
| Maximum total deformation | 7.4104 | 7.4104 | 7.4104 | 15.882 | 16.158 | 14.209 | 100.97 | 100.71 | 78.671 | 78.522 |

Figure 11. Third order modal shape
Figure 12. Fourth order modal shape

Figure 13. Seventh order modal shape

Figure 14. Tenth order modal shape

Analysis table 5 shows that the first order natural frequency of gear pump is zero, which is regarded as rigid body mode. The second and third order natural frequencies are all within 0.004hz, and the seventh to tenth order natural frequencies are all greater than 2800hz, which are very different from the gear pump working frequency (33.3hz) and will not produce resonance. The natural frequency of the 4th to 6th order is close to the working frequency of the gear pump, there is a risk of resonance and further optimization of the structure is needed to avoid resonance.

Analyze the vibration modal diagram of gear pump, as shown in Figure 11 to 14, The first three order modal shape have no stress deformation. Fourth to sixth order modal shape, the pump body, the end cover edge and the gear shaft spline are forced to expand outwards. The 7th and 8th order modal shape, the spline of the gear shaft is bent. The 9th and 10th order modal shape, one side of the end cover is twisted. Comprehensive analysis shows that the main deformation of the gear pump is at the spline position of the gear shaft and the edge of the end cover.

4. Conclusions
The modal of pump body, driving gear shaft, driven gear shaft and gear pump are analyzed. The first ten order natural frequencies, maximum total deformations and modal shapes are studied. The analysis results show that there is a big difference between the natural frequency and the working frequency, and the gear pump will not resonate, The local position of the gear pump parts and the whole will produce deformation, but will not cause damage to the gear pump, and will not affect the performance of the gear pump.
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