Numerical Study on Dynamic Noise and Radiated Noise of Oil Sump

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ABSTRACT

This paper studies EQ4H engine oil pan. Finite element method and boundary element method are utilized to calculate and predict the vibration and noise radiation of the oil pan. Based on the analysis results, the oil pan is optimized and redesigned. By comparing the vibration and noise performance of the oil pan before and after optimization, the effectiveness of the optimized design is verified.

1. INTRODUCTION

In the radiation noise of the engine surface, the radiation noise of the thin-walled parts such as the head cover and the oil sump occupies a considerable proportion. The radiation noise of the oil sump accounts for about 20% of the total radiation noise of the whole machine [1].

In this paper, based on the combination of finite element method and boundary element method, the dynamic characteristics and radiation noise of the oil-containing oil sump are analyzed.

2. OIL SUMP CONSTRAINED MODAL ANALYSIS

The oil sump is a sheet metal part, and the shell part is separated by a shell unit with a thickness of 1.6 mm. The sump of the oil sump is separated by a quadrilateral unit (Fig. 1). The oil sump material is steel with a modulus of elasticity of 210 GPa,
a Poisson's ratio of 0.28 and a density of 7900 kg/m$^3$. The actual operation of the oil sump has a certain quality of oil. The coupling of the oil changes the mass and stiffness distribution of the oil sump, which changes the modal parameters of the oil sump. The research object of this paper is the oil sump with 10kg oil, which hereinafter referred to as the oil sump. Based on the Hyperworks software to obtain the additional mass matrix of the oil by the boundary element theory, and then the kinetic equation is solved by the finite element method to obtain the modal parameters of the oil sump. Constraint all the degrees of freedom of the 22 bolts of the oil sump (FIG. 2), some natural frequencies of the oil sump constrained modal analysis are shown in Table I, which is original structure frequency. The second-order excitation frequency range of EQ4H model is 50-176.6 Hz, at which time the engine speed is idling 750r/min to the maximum speed 2650r/min. The first-order natural frequency of the oil-containing oil sump constrained mode is 165 Hz, which is within the excitation range and is prone to resonance [2].

3. FREQUENCY RESPONSE ANALYSIS AND RADIATION SOUND FIELD ANALYSIS OF OIL PAN

3.1 Oil Sump Frequency Response Analysis

The vibration excitation of the oil sump is derived from 22 bolts. The acceleration response of the 22 bolts is measured by the vibration acceleration test of the oil sump. The test is performed at an engine speed of 1500 r/min and a power of 92.67 kW. The z-direction acceleration spectrum of some bolts is shown in Fig. 3. Select the center point of the surface where the oil pan may vibrate as a response point, a total of five as shown in Fig. 4. The frequency response analysis method adopts the modal superposition method, the damping coefficient is set to 0.005, and the upper frequency limit is set to 2000 Hz [3]. The calculation shows that the location of the larger acceleration are the center point of the bottom and side planes of the oil sump, whose direction is perpendicular to the surface. As shown in Fig. 5, the y direction of the response points 1, 2; the z-direction acceleration of the
response point 4 are large. At frequencies of 164.6 Hz and 260 Hz, the y-direction acceleration of the oil sump reaches 96.1 m/s² and 152.5 m/s². At the frequencies of 289.2 Hz, 323.3 Hz, and 529.1 Hz, the z-direction acceleration of the oil sump are higher, which reached 105.1m/s², 59m/s², 99.4m/s².

Figure 3. Part of measurement z-direction acceleration spectrum.

Figure 4. Response point location diagram.

(a) Response point 1 acceleration response  
(b) Response point 2 acceleration response  
(c) Response point 4 acceleration response

Figure 5. Response point acceleration response.

3.2 Sound Field Analysis of Oil Pan

The boundary element method is used to calculate the radiated noise of the oil pan, and an infinitely large rigid symmetry plane is set at the upper surface of the oil pan to simulate the sound field inside the oil pan [4]. The boundary element grid is meshed with a mesh size of 15 mm, and the semi-anechoic chamber model of the oil-shell boundary element is shown in Fig. 6. The acceleration of each node of the
finite element model is interpolated into the boundary element model of the oil sump, and the noise radiated sound field in the range of 0-1000 Hz of the oil sump is obtained, and the total sound power level curve at the oil sump field point is obtained as shown in Fig. 7. The frequency points of the sound power extremes are 164 Hz, 262 Hz, 290 Hz, 324 Hz, 530 Hz, and the sound power levels are 84.44 dB, 96.15 dB, 83.03 dB, 91.43 dB, and 85.57 dB. According to the acoustic calculation, the total sound power level of the oil pan is 102.38 dB. The sound pressure cloud maps of the field at 5 frequency points are shown in Fig. 8. It indicates that the central part of the bottom and side planes of the oil sump has a large vibrational acceleration and a large surface area, so the radiation noise is large.
4. OIL SUMP TOPOGRAPHY OPTIMIZATION

Topography optimization for thin-walled structures and sheet metal parts, the layout of the ribs can be quickly determined at the initial stage of design. The vibration acceleration and radiation noise peaks of the oil sump are concentrated near five frequency points, which respectively correspond to the natural frequencies of the first, third, fifth, seventh and thirteenth order of the constrained mode, and the maximum weight of the fifth-order frequency is the target. The function optimizes the shape of the oil pan. The bottom and side plane portions of the oil pan are set as design areas, and the rest are non-design areas. The maximum height of the ribs is 10 mm, the minimum rib width is 10 mm, and the draft angle is 60 degrees. After 19 iterations, the oil sump topography optimization results are shown in Fig. 9. The red position in the figure is the preferred rib area. The oil pan is designed twice by CATIA software, as shown in Fig. 10. The A, B and C areas in the figure refer to the rib width of 60mm, 50mm, 40mm, the rib height is 10mm, and the rib angle is 60 degree.

![Figure 9. Oil sump topography optimization cloud map.](image1)

![Figure 10. Oil sump secondary design model.](image2)

The finite element and boundary element models of the reconstructed oil-bearing oil sump are established, and the constrained mode, frequency response and radiation noise are analyzed respectively (Table I). The natural frequency values of the oil sump are greatly improved, and the first-order frequency of the optimized structure reaches 230.9 Hz, avoiding the excitation frequency of the engine. The frequency response analysis before and after optimization shows that the maximum acceleration response is greatly reduced. As the natural frequency of the oil sump changes, the resonance point will change, and the acceleration peak will be offset by the frequency point (Fig. 11).
TABLE I. COMPARISON OF MODAL FREQUENCY OF OIL SUMP.

| Order | Original Structure (Hz) | Optimized Structure (Hz) | Frequency increase value (Hz) |
|-------|-------------------------|--------------------------|-----------------------------|
| 1     | 165                     | 230.9                    | 65.9                        |
| 2     | 253.1                   | 342.6                    | 89.5                        |
| 3     | 260.8                   | 353.4                    | 92.6                        |
| 4     | 282.3                   | 376.8                    | 94.5                        |
| 5     | 290                     | 398.5                    | 108.5                       |
| 6     | 306.9                   | 440.8                    | 133.9                       |
| 7     | 323.5                   | 483                      | 159.5                       |
| 13    | 529.9                   | 622.3                    | 92.4                        |

Figure 11. Comparison of response point acceleration of oil pan before and after optimization (from left to right response point 1 (y direction), 2 (y direction), 4 (z direction)).

The comparison of the sound power level spectrum at the oil sump field before and after optimization is shown in Fig. 12. The crude oil sump has the highest sound pressure at 262 Hz and 324 Hz, and the sound pressure at 262 Hz and 324 Hz before and after optimization is compared, as shown in Fig. 8(b), (d) and Fig. 13. The noise peaks of the five frequency points mentioned above are reduced to different degrees. Due to the natural frequency variation of the structure, the noise of the natural frequency of the optimized structure is increased, but the sound power of the entire frequency band is reduced. The total radiated noise of the oil sump after optimization is 99.35 dB. Compared with the original structure, it is reduced by 3.03 dB.
5. CONCLUSIONS

(1) After the shape optimization, the natural frequency of the oil sump is significantly improved, the vibration acceleration peak is significantly decreased, and the radiated noise sound power is significantly reduced.

(2) In this paper, the combination of finite element, boundary element and optimization is used to analyze the vibration characteristics and radiation noise of oil-containing oil sump, which provides guidance for studying the vibration and noise of other engine parts.

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