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Optimization Design of Noise in a Certain Rotor Oil Pupm Assembly

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Abstract

To solve the noise problem of a certain rotor oil pump during the experimental process, this article analyzes the source and characteristics of noise through the oil pan noise spectrum obtained from engine bench experiments and the noise mechanism of the oil pump; Targeted noise improvements have been made to the design of the rotary oil pump based on the source of noise. The experimental results showed that after the structural adjustment of the rotary oil pump was implemented, there was no significant change in the pressure fluctuation in the trapped oil area, but the noise was significantly reduced. This indicates that the optimization scheme has successfully improved the overall acoustic performance of the oil pump, providing a new direction for similar structural acoustic optimization.

Keywords

Rotor Oil Pump; Noise Optimization; Oil Pump Optimization; Noise Mechanism.

1. Introduction

A rotor oil pump is one of the key parts of the engine lubrication system, which is mainly composed of several parts such as pump body, inner rotor, outer rotor and pump cover. The oil pumps commonly used in engines are mainly divided into rotor pumps, gear pumps and vane pumps. Because of its streamlined structure, smaller volume and larger oil delivery, rotor pumps are commonly used in small and medium - sized engines. Due to the precise and complex design and manufacturing process of rotor oil pumps, it is easy to have problems such as driving gear contact noise, internal and external rotor mesh noise and the structure of the pump body radiation noise, which will have a negative impact on the vibration characteristics of the engine[1]; therefore, the noise control of the oil pump is a key issue in the study of the comfort of the engine vibration noise[2].

Domestically, for the oil pump noise problem, Lv Jianzhong et al. used CFD to analyze the pump body structure and put forward the optimization design scheme, and compared the noise test results before and after the optimization, which confirmed the effectiveness of the optimization strategy[3]. Li Yanpeng et al. aimed at the noise order problem of the engine rotor - type oil pump, used simulation methods to analyze the internal pressure distribution of the oil pump, and put forward the “nose” structure to improve the pressure fluctuations in the internal cavity[4]. Ma Fuyin studied the NVH problem of the oil pump, and solved the oil extractor failure caused by the oil pump by designing the vibration noise experiment of the oil pump[5]. Fu Xi and others, aiming to solve the engine front end whistling sound problem, by analyzing the noise formation mechanism of the rotor oil pump, proposed to improve the gear parameters to solve the noise problem[6].

On the foreign side, SANG et al. designed a new structure and established its theoretical equations to reduce the noise of the oil pump, and verified the feasibility of its structure through experiments[7]. FROSINA et al. pointed out that the key to the vibration and noise of the oil pump lies in its lubrication state, so they used mathematical modeling to analyze the lubrication cycle of the oil pump and compared the simulation data with the results of the actual hydraulic test, thus providing theoretical support on how to reduce the vibration of the oil pump[8].

In this paper, the noise mechanism of the rotor oil pump is analyzed firstly. Based on the engine front - end bench noise experiment, the main source of noise is analyzed to be the oil pump, and the unloading groove position is found to be related to the noise in the NVH test experiment of the oil pump. So the unloading groove position is adjusted and optimized with the optimization goal of reducing the noise of the oil pump. Finally, through the analysis of the spectrogram obtained from the engine bench test and the comparison with the vibration order slices, it is found that the acoustic characteristics of the oil pump assembly structure have been improved. The optimization scheme of adjusting the unloading groove to the middle of the 14 degree arc has the most significant effect on reducing the noise of the rotor oil pump.

2. Rotor Oil Pump Noise Mechanism Analysis

2.1. Noise Concept

Noise is a sound wave whose frequency, strength and weakness change irregularly and chaotically. Physiologically speaking, any sound that prevents people from normal rest, study and work, as well as the sound that interferes with the sound that people want to hear is noise. In this sense, there are many sources of noise, such as: the sound of cars on the street, the sound of talking in a quiet library, the sound of machines at a construction site, and the sound of a neighbor's television set that is too loud are all noise. In the field of communications, the energy field that interferes with the transmission of a signal is called noise. People generally use decibels (dB) to measure the intensity of noise, and the signal-to-noise ratio (S/N) to measure how much noise affects the useful signal.

2.2. Types of Noise

The noise types of the rotor oil pump assembly are more diverse. The common noise types mainly include mechanical noise, combustion noise, and fluid noise. These noises are mainly caused by defects in the oil pump itself, the meshing of external drive gears, and other reasons.

2.2.1. Mechanical Noise

Mechanical noise mainly includes vibration noise and friction noise. During the suction and pressure oil cycle of the oil pump, there are extrusion, friction and interference between the teeth of the inner and outer rotors, which results in vibration and generates noise through mechanical transmission or radiation. The sliding rate is an important indicator of the meshing transmission of the inner and outer rotors. The larger the sliding rate of the teeth of the inner and outer rotors, the greater the relative friction between them, the more serious the impact of meshing will be, and the louder the noise. The sliding rates of the inner and outer rotors are expressed by σ_1 and σ_2 respectively:

$$\sigma_1 = \lim_{\Delta S_1 \to 0} \frac{\Delta S_1 - \Delta S_2}{\Delta S_1} = \frac{ds_1 - ds_2}{ds_1} \tag{1}$$

$$\sigma_2 = \lim_{\Delta S_2 \to 0} \frac{\Delta S_2 - \Delta S_1}{\Delta S_2} = \frac{ds_2 - ds_1}{ds_2} \tag{2}$$

where is the distance between the inner rotor tooth profile from the contact point to the contact point . is the distance between the inner rotor tooth profile from the contact point to the contact point .The , position is schematically shown in Fig.1.

In the design of internal and external rotor, in order to meet the premise of displacement, the general creation of the coefficient k value range of 1.1-2.0, k value is too small will cause the tooth contact stress increase, wear and easy to occur top-cutting phenomenon, k value is too large, the contact point of the force will be significantly increased, so the appropriate selection of the value of k, the reduction of noise has a certain effect[9].

$$e = \sqrt{Q/(4PibZ(k-h))} \tag{3}$$

formulas: e is the rotor eccentricity, Q is the rotor displacement, b is the tooth width, k is the creation coefficient, h is the arc diameter coefficient, Z is the number of outer rotor teeth.

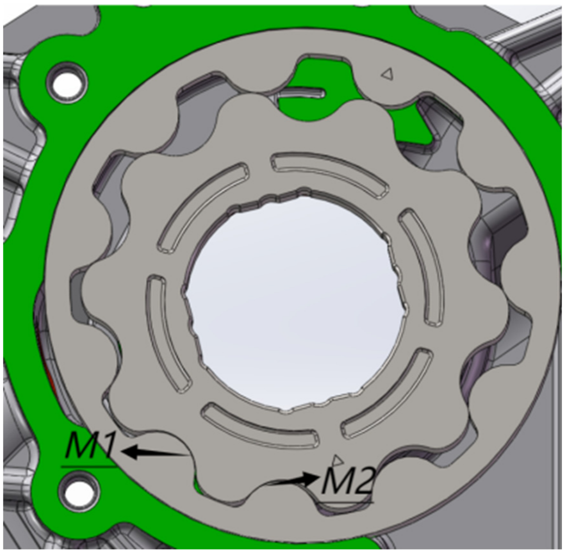

Figure 1. Schematic diagram of inner and outer rotor engagement

2.2.2. Fluid Noise

Fluid noise is mainly due to the movement of fluid and solid boundary interactions and turbulence within the fluid and the radiation noise caused by the excitation mechanism is mainly due to the relative motion of the solid and fluid and the fluid's own irregular movement provoked by the internal stress and pressure perturbation of the fluid in the medium of the transfer of the fluid noise in the field of oil pumps are mainly pump oil noise and cavitation noise. For the oil pump such pump structure, because its role is to suck the fluid into the cavity, and then press out a higher pressure of the fluid, the fluid in the pump will be due to the pressure of a huge change, this change will have a great impact on the mutual engagement of the rotor, high pressure cavity fluid to produce a large fluid pressure, and low pressure cavity is no fluid pressure or even a negative pressure, which will result in the rotor meshing system load imbalance, thus leading to body vibration and fluid pressure, and the fluid will be the main source of noise. This will lead to unbalanced load on the rotor meshing system, resulting in vibration of the body and excessive impact of the fluid on the rotor, thus generating noise.

Pump oil noise is mainly related to the oil pump trapped oil area pressure impact, trapped oil area schematic shown in Figure 2, in the oil from the suction area movement to the pressure oil area in the process, in the upper sealing island will gradually form a closed trapped oil area, the emergence of trapped oil phenomenon, in the oil pump suction process, the trapped oil area volume will be continuously reduced, and due to the incompressibility of the oil and the pump endface and the rotor of the two between the gap is small, trapped in the area of the oil there is a buildup of the phenomenon of work material, thus resulting in the body vibration and excessive fluid impact on the rotor, thus generating noise. There is the phenomenon of work material accumulation, which leads to a sharp rise in the pressure level of the trapped oil area; and in the process of the rotor will be running from the trapped oil area to the pressure oil area, the work material in the trapped oil area will be drained to the pressure oil area, at this time, the trapped oil area of the pressure is significantly reduced, resulting in huge pressure fluctuations on the rotor to bring about the impact of the noise generated by the fluid. Trapped oil phenomenon can not be completely eliminated, but through a reasonable structural design to reduce the harm, usually in the upper sealing island and the pressure oil zone at the introduction of the unloading tank to reduce the maximum pressure of the trapped oil zone to achieve the effect of noise reduction.

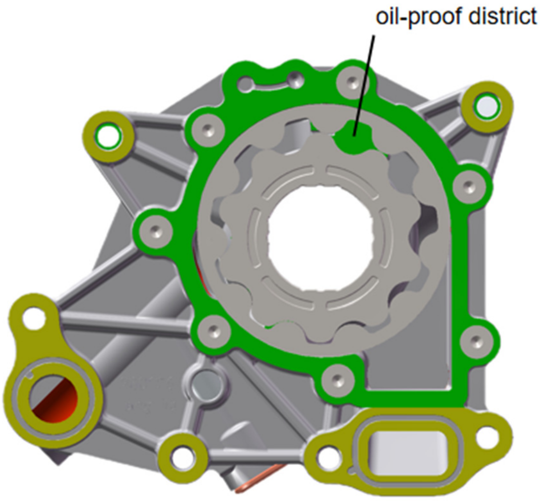

Figure 2. Schematic diagram of the trapped oil area

Cavitation noise is generated due to a certain temperature, when the pressure inside the fluid is less than the critical gasification pressure, there will be a gasification phenomenon that occurs inside the fluid, the gas aggregation occurs cavities, when the cavities move to the high-pressure region, the rapid collapse phenomenon occurs, and the mass point inside the liquid in the great impact, collision of the pump body surfaces and internal parts, thus generating the cavitation noise. Singhal [10] proposed a total Cavitation model proposed by Singhal provides a good model for studying the cavitation phenomenon, and its expression is as follows

$$\frac{\partial}{\partial t}\int_{\Omega t}\rho f_v d\Omega+\int_{\sigma}\rho((\vec{v}-\vec{v}_{\sigma})\cdot\vec{n})f_v d\sigma = \int_{\sigma}\left(D_f+\frac{\mu_t}{\sigma_f}\right)\cdot\left(\nabla f_v\cdot\vec{n}\right)d\sigma+\int_{\Omega}\left(R_e-R_c\right)d\Omega+\int_{\Omega}(S_V)d\Omega \tag{4}$$

where σ is the external surface area of the control fluid, $\vec{v}$ and $\overrightarrow{v_\sigma}$ are vector velocities, f_v is the gas mass fraction, Ω is the control fluid volume, D_f is the vapor diffusion ratio, μ_t is the fluid viscosity, σ_f is the turbulent Schmidt number, $\vec{n}$ is the normal vector, S_v is the source of the vapor, R_c is the vapor condensation rate and R_e is the vapor generation rate.

2.2.3. Combustion Noise

Combustion noise is mainly caused by the combustion of the structure radiation noise. As the pressure in the cylinder rises rapidly during engine combustion, a series of moving parts transfer the pressure to the cylinder block cylinder head, causing vibration of the engine surface, thus radiating noise. Combustion noise is mainly related to the highest pressure of the outbreak and the duration of the pressure, which can be reduced by lowering the rate of change of the engine pressure or improve the structural rigidity of the engine to reduce the noise.

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3. Noise Reduction Measures and Noise Source Investigation of the Oil Pump

Modal analysis is a mathematical method to measure the intrinsic vibration properties of a structure, to determine the eigenfrequency of the structure by solving the eigenvalues of the system matrix equation, and to provide a basis for the design and improvement of the oil pump. When analyzing the modal state, because the damping of the oil pump has little effect on its modal frequency and vibration pattern, the damping case is not considered, and the matrix expression is:

$$[M]\{\ddot{x}\}+[K]\{x\}=0 \tag{5}$$

3.1. Oil Pump Foundation Noise Reduction Measures

Starting from the above oil pump noise mechanism, in the design of the initial version of the oil pump, the following measures are used to avoid the generation of noise. In order to avoid the occurrence of vortex in the pump cavity, cavitation and other phenomena caused by noise, in the oil pump chamber using the slope over the way, and the use of this way can also reduce the impact on the oil cavity to avoid structural changes within the cavity; in order to avoid an instantaneous increase in the amount of oil in the oil trap area, which leads to excessive pressure fluctuations within the oil trap area triggered by the noise, in the suction chamber at the end of the use of the “nose bridge In order to avoid the noise caused by the large pressure fluctuation in the oil trap area due to the instantaneous increase of oil volume in the oil trap area, a “nose beam” structure is adopted at the end of the suction chamber, which can make the oil from the low-pressure area to the high-pressure area over smoothly to avoid the noise. In order to avoid noise caused by excessive pressure in the trapped oil area, the unloading groove structure is added at the oil pressure chamber and the trapped oil area, which reduces the maximum pressure in the trapped oil area by releasing the pressure in advance to avoid noise caused by excessive pressure fluctuation in the trapped oil area.

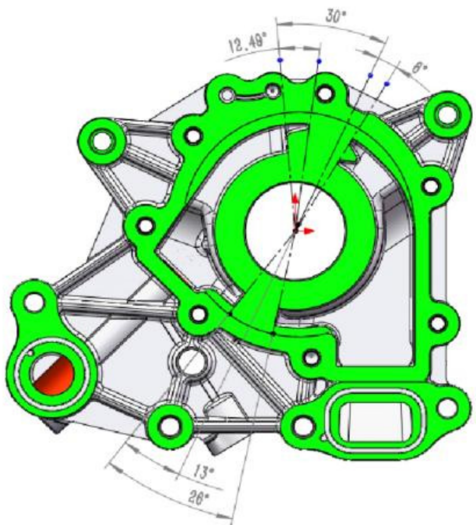

Figure 3. Schematic diagram of the structure of the oil pump in the first version (base)

3.2. Order Noise

Order is the amount of response to the vibration or noise generated by the rotation of structural components and the corresponding relationship between the rotational speed. Usually the frequency corresponding to the rotation of the drive shaft is called the fundamental frequency (1st order noise), and the order noise is N-order noise (multiples of the fundamental frequency noise).

Fundamental frequency

$$f = \frac{n.Z}{60} i \tag{6}$$

Formula: n represents the rotor speed in r/min; Z represents the number of teeth of the inner rotor; and i represents the order.

In this paper, the power of the oil pump comes from the crankshaft, with the crankshaft's power to drive the inner rotor rotation, and then through the meshing of the outer rotor to follow along with the movement. This structure makes the oil pump and the crankshaft ratio of 1:1, and the number of teeth of the inner and outer rotor are 10 and 11, so the crankshaft and the oil pump rotor teeth of the two-transmission ratio of 1:10. It can be seen that the engine front end of the 10th order and the multiples of the order of the 10th noise is generated by the oil pump.

3.3. Noise Source

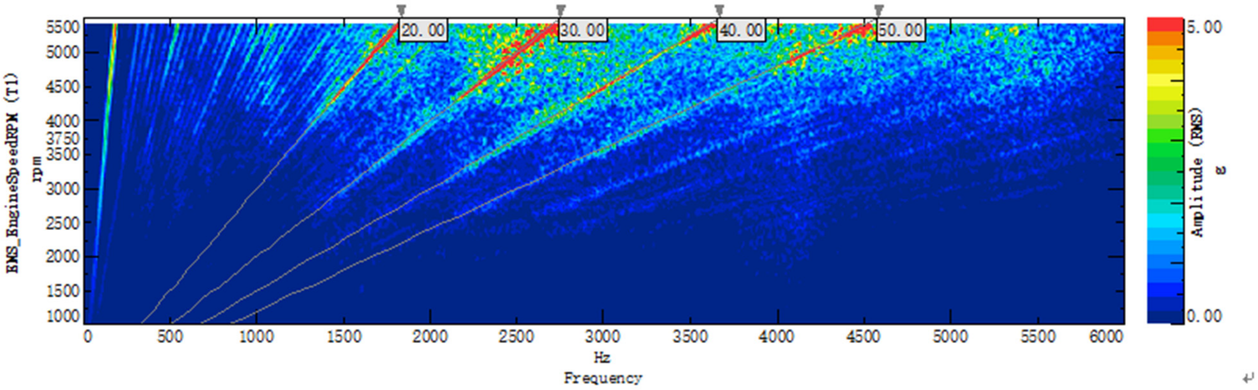

Figure 4. Frequency amplitude diagram of the oil sump at the front end of the engine

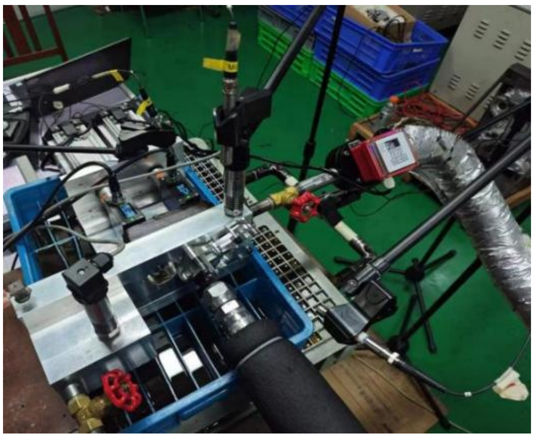

Figure 5. Oil pump NVH experiment

In the engine acceleration conditions, the engine appeared “buzzing” noise, after further investigation to confirm that the engine's front-end oil sump noise, so it can be inferred that the noise originates from the oil pump. As can be seen from the above, the 10th order and its multiples of the order of the noise for the oil pump order noise, according to the engine front end of the engine bench experiments resulting from the analysis of the engine front-end spectrogram Figure 4, the oil pump main order of the whistling characteristics of the engine front end of the rattles originating from the engine oil pump.

After determining the noise from the oil pump, the oil pump NVH test experiments found that the rotor oil pump did not open the unloading slot when the noise effect is smaller than the base version of the unloading slot opened the noise; theoretical case to increase the structure of the unloading slot, the maximum pressure in the oil trap is significantly reduced, so that the oil trap pressure fluctuations are significantly reduced to reduce case vibration and rotor meshing noise. However, the real working condition is different from the theoretical effect that opening the unloading groove can reduce the noise of rotor oil pump. So, we adjusted the position of the unloading groove of the handmade sample, and found that the noise of the oil pump is also related to the position of the unloading groove when conducting NVH experiments.

4. Oil Pump Assembly Noise Optimization

4.1. Optimization Target

According to the preliminary analysis of the structure of this rotor oil pump and the noise factors, the reduction of the oil pump noise level as the optimization goal. According to the oil pump NVH experiment, the noise of the oil pump and the oil pump body unloading groove position related, so to adjust the unloading groove position as the basic program to optimize the noise of the oil pump.

4.2. Optimization Scheme

In the oil pump NVH experiment, found that the unloading groove position adjustment to the center position “hum” noise almost disappeared, so the following two better optimization scheme.

4.2.1. Optimization Plan 1

In view of the noise problem of the base version, and in the real working condition experiment, it is found that the noise is obviously improved when the position of the unloading groove is adjusted to the center, so in the optimization, first of all, without changing the size of the upper and lower sealing islands, the unloading groove is adjusted to the center position, and the unloading groove is adjusted to the length of the circular arc of 12 degrees, so that it is just able to release the pressure in advance at this length; as the unloading groove is adjusted to the center position, it will release the pressure earlier compared with the base version. base version will be earlier pressure relief, so adjust the eccentricity angle, so that its eccentricity clockwise rotation of 2 degrees, can increase its upper sealing island oil suction time, making the oil suction more fully, to avoid the situation of insufficient oil suction time.

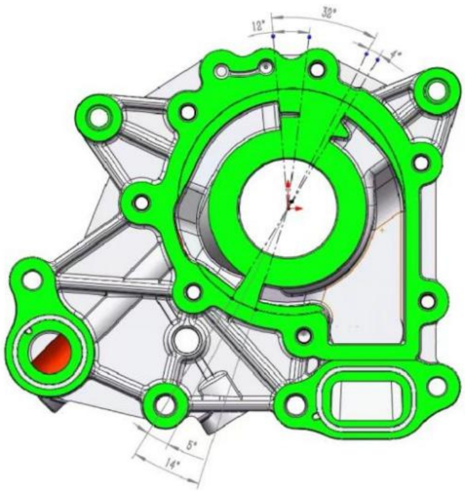

Figure 6. Optimization Scenario 1

4.2.2. Optimization Plan 2

Optimization scheme 2 compared to 1, in order to satisfy the case of early pressure relief, we adjusted the length of the unloading slot to a circular arc of 14 degrees, and its purpose is to study the effect of the length of the unloading slot on the noise of the oil pump.

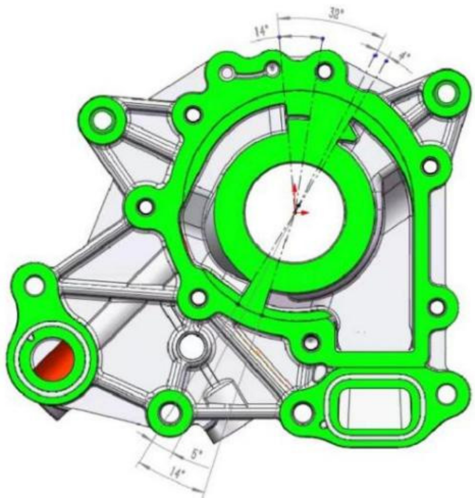

Figure 7. Optimization scenario 2

4.3. Noise Optimization Results

According to the oil pump front end sump noise spectrum and acceleration vibration order slice comparison analysis shows that in the acceleration condition, compared with the base state, the optimization scheme of the engine front end sump bottom amplitude level is significantly reduced, and the sump order slice energy in the various orders are significantly reduced, which indicates that the oil pump vibration energy has a substantial reduction, so change the unloading slot position can significantly reduce the order noise generated by the oil pump. . Optimization scheme 1 and 2 compared to the length of the unloading slot can be seen on the oil pump noise has little effect, both compared to the unloading slot 14 degrees of optimization scheme 2 noise reduction effect is slightly obvious.

Optimization scheme 2 compared to the base state, the oil with the rotor movement to the trapped oil zone, scheme 2 can be earlier in the trapped oil zone of the workpiece leakage to the pressure oil chamber. Although there is no significant difference in the maximum pressure level in the trapped oil zone between the two, and there is little difference in the level of pressure fluctuation, the impact of the trapped oil zone on the rotor is reduced in Option 2, which can effectively reduce the noise level.

4.4. Comparison of Trapped Oil Zone Pressure

According to Table 1, it can be seen that the rotor oil pump in the oil chamber after the opening of the unloading groove, the maximum pressure level in the oil trap area is significantly reduced. Comparison of the three states of the open unloading groove with each other shows that the position of the unloading groove has little effect on the maximum pressure in the oil trap, and the level of pressure fluctuation in the oil trap is basically unchanged.

Table 1. Detecting oil pressure in the trapped oil zone

Speed r/min	Maximum pressure in ungrooved trapped oil zone (KPa)	Base Trapped Oil Zone Maximum Pressure (KPa)	Unloading tank 12 degrees trapped oil zone maximum pressure (KPa)	Unloading tank 14 degrees trapped oil zone maximum pressure (KPa)
1000r/min	855	513	515	513
3000r/min	2653	689	687	685
5000r/min	3420	1205	1045	1206

4.5. Comparison of Trapped Oil Zone Pressure

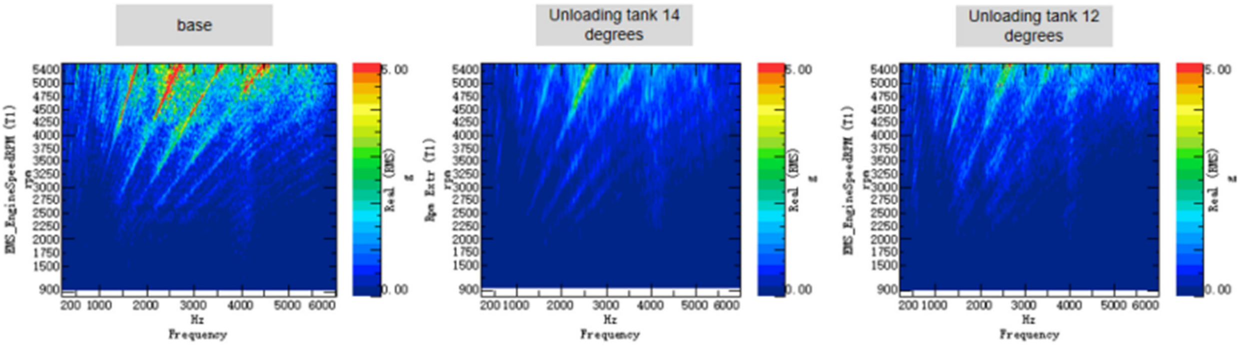

Figure 8. Spectrum of sump noise under accelerated condition

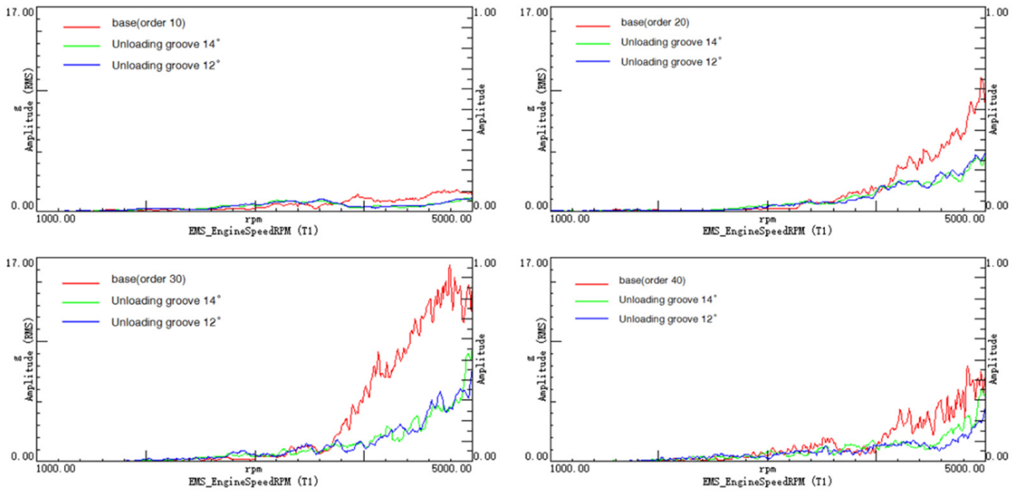

Figure 9. Comparison of accelerated vibration order slices

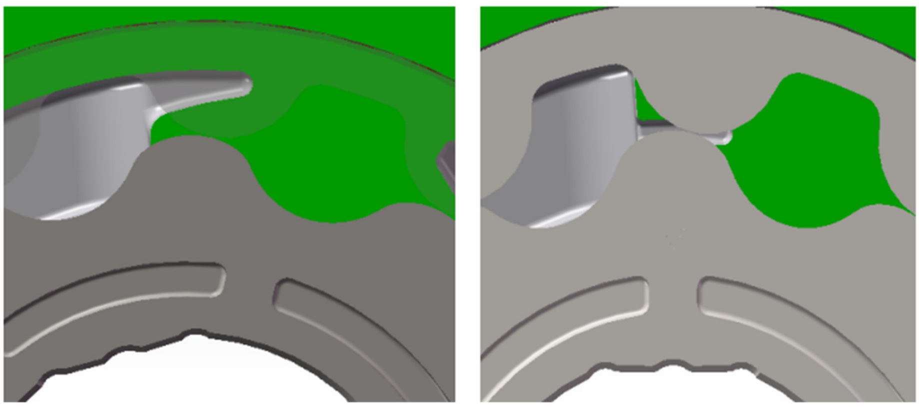

Figure 10. Schematic comparison of the 14 degree and BASE versions of the trapped oil zone in the unloading chute

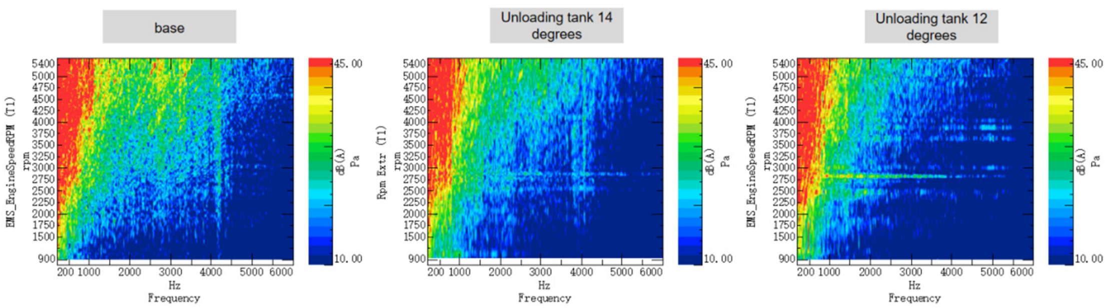

Figure 11. Intra-vehicle noise spectrum under accelerated condition

When the original oil pump is working, a clear whistling sound can be heard inside the cockpit. After optimization, the noise inside the cockpit is significantly reduced; after testing, the noise inside the car is reduced by about 18dB, which is consistent with the results shown on the noise spectrum of the car.

5. Conclusion

In this paper, a systematic study on the noise performance and optimization design of rotor oil pump assembly is carried out. Firstly, the noise mechanism of rotor oil pump is elaborated in detail, and then the noise characteristics are evaluated based on the spectrograms of engine bench noise experiments and the field results of NVH experiments of the oil pump, and two optimization schemes are put forward with the optimization objective of reducing the noise of the oil pump, and the following conclusions are obtained: 1) Based on the field experiment, it is learned that opening the unloading groove in the oil cavity to open the unloading groove is not necessarily able to reduce the noise of the oil pump, and the noise reduction effect is related to the location of the unloading groove. 2) Analysis of the spectrum graph of the sump noise experiment reveals that most of the oil pump rattling occurs between 1500-4500Hz, which has obvious main-order whistling characteristics and presents the characteristics of order noise. 3) From adjusting the location of the unloading groove as an optimization scheme, the optimized structure and the BASE version Compared with the maximum value of the pressure in the trapped oil area, there is no significant difference, but it can reduce the impact of the trapped oil area on the rotor so as to improve its acoustic performance significantly, and the noise reduction effect is significant, which also confirms the accuracy and practicability of the optimization scheme, and provides a technical and theoretical framework for the noise reduction of the rotor oil pump in order to improve the noise problem of the oil pump and the performance enhancement.

Acknowledgments

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