Experiment on Noise Source Identification Based on Acoustic Array

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Abstract. In order to effectively control the noise source, the experiments on sound source identification were conducted on the generator side, intake side, and exhaust side of the test bench of the 2VQS EFI Volkswagen engine under different working conditions using the acoustic array. And applying the beamforming algorithm, the main noise sources at frequency range of 1000~2000Hz were located at the three test surfaces. The result show that: In front of generator side, the source was mainly located at the generator, the crankshaft pulley and the intake manifold and the strongest sound pressure was focused on the generator; In front of intake side, the source was mainly located at the generator, the cylinder body, and the transmission case, and the strongest sound pressure was focused on the cylinder body; In front of exhaust side, the source was mainly located at the cylinder body, the three-way catalytic converter and the transmission case, and the strongest sound pressure was focused on the generator pulley and gear system. The strongest sound pressure of the three test surfaces increase with the rotational speed of engine, was nearly equal to 2500r/min, and changed smoothly more than 2500r/min. It provided a way for controlling engine noise.

Key words: Noise source; Acoustic array; Noise source identification; Beamforming.

1. Introduction

With the number of cars increasing, car noise become increasingly prominent, which seriously affects people's work, life and physical and mental health. According to statistics, traffic noise pollution accounts for 70% of urban environmental pollution, and has become the main noise source of noise pollution in modern cities. In recent years, car noise control has become an important research topic for scholars [1]. Engine noise is the most important noise source of the cars, and engine noise control is particularly important. Domestic and foreign scholars have done lots of research on engine noise. A. E. W. Auste and T. Priede [2] studied noise mechanism of diesel engines, and the engine noise was related to the pressure in the cylinder. Jose Scarpati and Adam Wikstrom [3] predicted the noise of a six-cylinder diesel engine using the cylinder pressure curve in the combustion chamber. Shi Chundi Chen Enli et al. [4] of the Shijiazhuang Railway Institute test the vehicle's external radiation noise used the principle of sound intensity, and identified the main noise source. Liu Yuehui and Hao Zhiyong [5] predicted acoustic
power of the surface components of the engine and located the main sound source of the engine using surface vibration. Chu Zhigang team of Chongqing University [6] collected acoustic data of the top side, exhaust side and intake side of an engine using BK acoustic array, and identified the sound source based on beamforming. The results showed that the middle of 1- and 2-cylinder head cover and the middle of 3 and 4 cylinders, the cylinder block, the exhaust bypass valve and the generator were the main noise sources. Jiachi Yao [8-9] of Wuhan University identified the diesel engine noise based on the variable mode decomposition and independent component analysis algorithm, separated and identified the diesel engine noise based on the binaural sound localization and the blind source separation, and proved it can identify the sound source accurately.

Approaching engine noise generation mechanism research for noise reduction, precisely locating sound sources is key. According to the related literature, noise source identification mainly was based on near-field acoustic holography [7-9], sound pressure [9-11] and beamforming [12-15]. The beamforming was widely used for noise source identification because of its fast measurement speed, high computational efficiency, suitable medium and long-distance measurement, high steady state transient and high positioning accuracy of moving sound source. In the paper, the sound signal was collected by the BK company's acoustic array at the three test surfaces of the generator side, the exhaust side and the intake side of the Volkswagen 2VQS EFI engine, and the main noise source were located based on the beamforming. An idea for controlling engine noise was provided.

2. Acoustic array principle
Spatial sound field was measured using an array of microphones arranged in different spaces in a certain manner. Sound source pulse signal collected by each microphone was processed for detailed sound source information. The processing algorithm of the microphone array signal is called beamforming. Beamforming is an array signal processing method based on microphone array, which can make the microphone array form directivity in a predetermined direction and realize directional reception. Acoustic signals is filtered in spatial, information of required signals is extracted, and the location and the spectral characteristics of the sound source are obtained.

Process the sound source signal based on beamforming, and obtained the spatial position or orientation of the acoustic signal through the delay and sum. thereby different sound source on the surface of the entire radiation sphere was located. The principle of beamforming based on acoustic array see figure 1. Suppose the space has a sound source \( p(x,r) \). The array is composed of a multi-sensor, and \( r_m \) represents the distance between the sound source and the m-th microphone (m=1, 2,...M). The time from sound source to the reference microphone is \( t = r/c \), where r is the distance from the microphone to the sound source, and c is the speed of sound. According to the principle of delay and sum, each microphone signal was compensated for Delay, Phase difference of the ith sensor collected acoustic signal \( \Delta t = |r_i - r|/c \). The delay is compensated for each microphone signal, summed and normalized to obtain the beamforming sound pressure output:

\[
B(x,t) = \frac{1}{M} \sum_{m=1}^{M} w_m p_m(x,t - \Delta t)
\]

Where \( w_m \) is the weighting factor of each microphone.

3. Experimental devices and Scheme
The tests on sound source identification were conducted on the generator side, intake side, and exhaust side of the test bench of the 2VQS EFI Volkswagen engine (shown in Figure 2a) under different working conditions using the acoustic array (shown in Figure 2b). And sound source were located applying the beamforming algorithm. The test arrangement is shown in Figure 3. The test was carried out at the automobile engine laboratory of Inner Mongolia University of Technology. Acoustic data was collected by BK microphone array. The microphone array was comprised of 60 class 4958 1/4 phase-matched array microphones, and the array diameter was approximately 0.78 m. The array was located 1m away from the engine generator side, intake side and exhaust side. Sound source signals under engine idle,
engine speed of 1500r/min, 2000r/min, 2500r/min, 3000r/min and full load were collected. The sound signals was received via the 60-channel Pulse 3560D data acquisition system and transmitted to the Array Noise Source Identification postprocessing software simultaneously for data processing. And get the maps of spectrum and sound source location.

![Beamforming principle](image1)

**Figure 1.** Beamforming principle

![Experimental devices](image2)

(a)Engine test bench   (b)Acoustic array   (a)generator side   (b)Intake side   (c) Exhaust side

**Figure 2.** Experimental devices

![Experiment Overall Layout](image3)

**Figure 3.** Experiment Overall Layout

4. Results Discussion and Analysis

This paper mainly discussed the sound source position and sound energy at the frequency range of 1000~2000Hz based on the principle of beamforming technology and the spectrum of engine sound source.

4.1. Background noise spectrum analysis

To avoid the interference of the background noise on the sound source identification, We analyzed the background noise spectrum characteristics of the test environment. Acoustic array was located 1m away from the generator side, the intake side, and the exhaust side of the engine. And acoustic signals of the unstarted engine were respectively collected using the BK acoustic array. In this paper, sound energy at the frequency range of 1000~2000Hz was mainly analyzed. Therefore, the background noise at the frequency range of 1000~2000Hz was only considered. The sound power level spectrum of background noises in front of the generator side as shown in Fig.4. The background noise energy was lower 20dB than the energy of the sound source, and the background noise energy was negligible.

4.2. Sound source spectrum analysis

The spectrum of 1000-2000Hz under the different working conditions were analogous in front of the generator side, the intake side and the exhaust side. Take the spectrum of 1000-2000Hz at engine speed of 2000r/min as an example for analysis (see Fig.5). The noise energy of 1000~2000Hz was mainly concentrated on 1600~1800Hz. The sound pressure level of in front of the generator side and the intake side was larger. The sound source sound pressure level in front of the exhaust side was the smallest. The strongest energy sound pressure was 53.027dB in front of the generator side at engine speed of 2000r/min.
4.3. Sound source location identification analysis

The sound sources of the acoustic array located in front of the generator side were identified as shown in Fig 6. The sound source of 1200–1400Hz was mainly concentrated on the crankshaft pulley and the starter. The sound source of 1400–1500Hz was mainly concentrated in the intake manifold. The sound source of 1500–1600Hz was mainly concentrated on the crankshaft Pulley and starter. The sound source of 1600–1800Hz was mainly concentrated on generator. The strongest sound source energy was located at generator and pulley (as shown in Fig. 6d); The sound sources of the acoustic array located in front of the intake were identified as shown in Fig 7. The sound source of 1176–1228Hz was mainly concentrated on the generator. The sound source of 1300–1400Hz was mainly concentrated on the generator and the transmission case. The sound source of 1400–1500Hz was mainly concentrated on the intake manifold. The sound source of 1600–1800Hz was mainly concentrated on the cylinder and generator. The strongest sound source energy was located at the cylinder and crankshaft pulley (see Fig. 7d); The sound sources of the acoustic array located in front of the exhaust were identified as shown in Fig 8. The sound source of 1000–1200Hz was mainly concentrated on the cylinder block. The sound source of 1200–1300Hz was mainly concentrated on the transmission case, gear train and three-way catalytic converter. The sound source of 1300–1400Hz was mainly concentrated on the three-way catalytic converter. The sound source of 1400 ~ 1600Hz was mainly concentrated on the cylinder, three-way catalytic converter and gear train. The sound source of 1600 ~ 1800Hz was mainly concentrated on the generator and pulley. The strongest sound source energy was located at the generator pulley and gear train as shown in Fig.8d.

The strongest sound energy in front of the generator side, intake side and the exhaust side changed with the speed of engine as shown in Figure 9. At beginning, the strongest sound energy of the three test surfaces increased with the speed of engine. The sound pressure levels of the strongest sound energy were almost equal when the engine speed was up to 2500r/min, and the sound pressure level of the strongest sound energy of the three test surfaces changed smoothly more than 2500r/min.
Figure 6. Location of sound source with dynamic range of 3dB in front of the generator side

Figure 7. Location of sound source with dynamic range of 3dB in front of the intake side

Figure 8. Location of sound source with dynamic range of 3dB in front of the exhaust side

Figure 9. The Location of the strongest sound source increased with the engine speed

5. Conclusion
In this paper, the experiments on sound source identification were conducted on the generator side, intake side, and exhaust side of the test bench of the 2VQS EFI Volkswagen engine under different working conditions using the acoustic array. The sound sources of the three test surfaces were located based on beamforming algorithm. The main conclusions drawn from this work were:
1) Sound source identification: The sound pressure level on the generator side and the intake side was larger, and the sound pressure level on the exhaust side was the smallest. The main sound source of the generator side were located at the generator, the crankshaft pulley and the intake manifold. The strongest noise energy was located at the generator. The main sound source of the intake side were located the generator, the cylinder block, the transmission case, and the intake manifold. The strongest noise energy was located at the cylinder block. The main sound source of the exhaust side were the cylinder block, the three-way catalytic converter, the transmission housing and the gear train. The strongest noise energy was located at the generator pulley and the gear train.

2) The rule of the strongest sound pressure level changes with the rotating engine speed: The strongest sound pressure of the three test surfaces increased with the rotational speed of engine at first, was nearly equal to 2500r/min, and changed smoothly more than 2500r/min.

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