Optimization and improvement of tread pattern pitch arrangement

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ABSTRACT: Tire noise is one of the main sources of car noise. In order to research on the tire noise, analysis method based on wavelet transform was proposed. Compared with traditional analysis methods, wavelet transform can effectively and intuitively find the effect of tire pattern arrangement on measurement noise. The simulation results show that tire noise is reduced by improving the pattern arrangement.
KEYWORD: tire pattern; wavelet transform; tire noise; pitch arrangement

1 INTRODUCTION

The traditional signal processing method such as FFT (Fast Fourier Transform) is often used to study on tire noise. When use this method to analyze the tire noise, it needs to assume that the tire noise is a stationary signal. But it's inappropriate if the noise is analyzed for finding the relation between the tire sounds and the tread patterns. Because pattern pitches will actually change during tire rotation, the tire noise is non-stationary signal in a rotating cycle. The frequency spectrum of the tire noise is synchronized with the tread pattern pitch in the time axis. Therefore, time-frequency analysis method is needed. In this paper, wavelet transform is used for the analysis of tire noise.

2 TEST METHOD

In order to use the wavelet transform to analyze the signal of tire noise, the tire noise needs to be recorded. Recording place is a dedicated tire noise test room, and the testing laboratory is a semi-anechoic chamber, which purpose is to minimize all kinds of interference noise. The test conditions are as follows:
• Tire pressure: 240 kPa;
• Test loads : 630 kgf;
• Test speeds: 50, 70 km / h;
• The position of the microphone measuring points as shown in Fig. 1;
• Sampling frequency: 32.4kHz;
• Tire Model: 205/60R16, circumference of tread approximately: 2048.5mm;
• When speed is 50 km/h and 70 km/h, the one rotation needs 0.148s and 0.105s.

The tire tread pattern is shown in Fig. 2. Tire treads are consists of three types of pitch sizes, which are denoted as S, M and L. The three pitch lengths are 24.996mm, 30.405mm and 37.485mm respectively. Black part on the figure stands for the pattern blocks, while the white part represents the pattern grooves. The whole tread pattern is composed of 66 pitches, including 22 S, 23 M and 21 L.
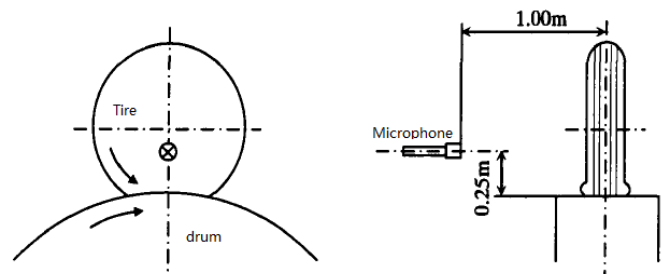

Fig. 1 Microphone measuring points layout

Fig. 2 Test tire tread pattern

3 NOISE ANALYSIS

3.1 *Choice of wavelet function*

One of the main causes of tire noise is block hitting ground (Cesbron, J et al. 2009) (Chen Lijun et al, 2001). Because each block to strike the ground is similar to striking the ground with a hammer, its vibration waveform in the time domain should be similar to the attenuation waves of impact vibration. Therefore, complex Morlet wavelet is selected, which has similar characteristics to attenuate waves.

Complex Morlet wavelet is one of the most commonly used complex wavelet, which have a good locality in the time-frequency domains. The mathematical expression is

$$\psi\left(t\right)=\frac{1}{\sqrt{\pi\cdot f_b}}e^{j2\pi f_c t}e^{-\frac{t^2}{f_b}} \tag{1}$$

Where f_b is the bandwidth parameters; f_c is the wavelet center frequency.

The corresponding Fourier transform is:

$$\psi\left(f\right)=e^{-\pi^2 f_b(f-f_c)^2} \tag{2}$$

If the characteristics of the signal on the time axis need to be analyze, f_c value can be smaller. On the contrary, a larger f_b values can be selected to analyze the frequency characteristics of the signal.

Here we mainly analysis the noise signal which the test speeds are 50km / h and 70km / h. The reason why these speeds are selected to study is that when the tire is running in low speed, block bounce noise is the main noise. While the tire is running in high speed, air-pumping noise is the main noise.
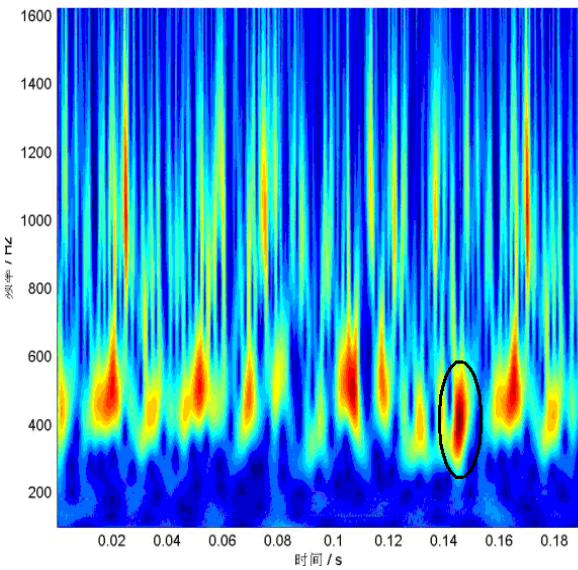

Fig. 3 Wavelet transform of tire noise in 50km/h
(Center frequency 0.3Hz bandwidth parameter 8)

When wavelet transform is used for the analysis of tire noise, appropriate bandwidth parameters and center frequency should be chosen. These parameters should meet the following conditions: firstly, the signal can be decomposed clearly after wavelet transform; secondly, it doesn't need the high order for scale transformation. Through several parameters adjustment, finally the center frequency is selected as 0.3Hz, the bandwidth parameter is selected as the 8, while the highest frequency limit is 1600Hz.In order to observe conveniently, length of time is slightly more than one cycle. The corresponding wavelet transform is shown in Fig. 3 and Fig. 4.
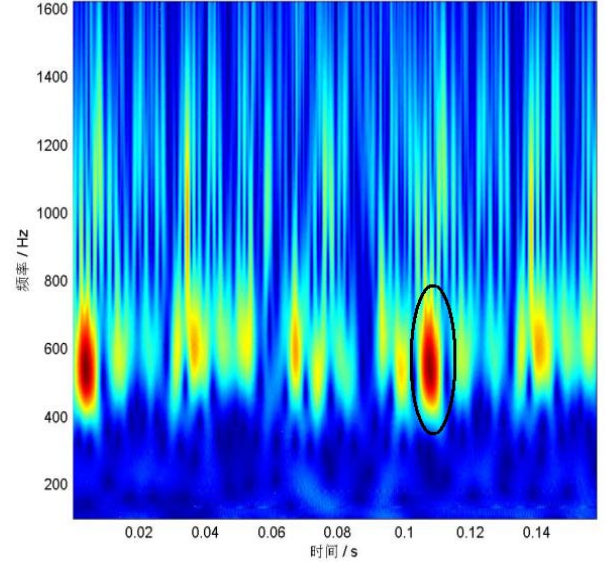

Fig. 4 Wavelet transform of tire noise in 70km/h
(Center frequency 0.3Hz bandwidth parameter 8)

3.2 *Analysis of the reasons*

As can be seen from the Fig. 3 and Fig. 4, the frequency of the noise signal, respectively, are concentrated in 400- 500Hz and 400-700Hz. The deepest color is just located in these frequency bands in one cycle, which represents the largest sound intensity during the time. The maximum sound pressure level has been marked with ellipse in the figures.

The hit is related to the distance of block and speed (Chen Lijun et al. 2000).

$$f_s = \frac{v}{L}\times n \tag{3}$$

f_s: Frequency of block hitting ground, Hz; v: Tire rotation speed, m/s; L: Tire circumference, m; n: Number of pitches

According to Equation (3), the frequency of the block hitting ground is about 458Hz when the speed is 50km/h. When the speed is 70 km/h, the frequency is about 650Hz. The frequency of block hitting ground corresponds with the frequency of the maximum sound pressure level in Fig.3 and Fig. 4. Therefore, the maximum sound pressure level is caused by block hitting ground.

In order to analyze the influence of the maximum sound pressure level on the total sound pressure level, a noise signal is selected, as shown in Table 1:

Table 1.　Relationship between frequency and response

Band center frequency (Hz)	Measured sound pressure level (dB)
63	90
125	75
250	80
500	78
1000	60
2000	78
4000	70

The total sound pressure level can be expressed as

$$L_{PT} = 10\lg\left[\sum_{i=1}^{n} 10^{0.1 L_{Pi}}\right] \tag{4}$$

L_{Pi} : corresponding sound pressure level of each center frequency; L_{PT} : the total sound pressure level of the sound source

According to the formula (4), if sound pressure level of each frequency component is superimposed, the total sound pressure level is 91.03dB. It is found that the total sound pressure level is slightly bigger than the maximum sound pressure level (90dB), which is much larger than the second sound pressure level (80dB). The maximum sound pressure level is the most major factor affecting the total sound pressure level. Therefore, by reducing the maximum sound pressure level of Fig. 3 and Fig. 4, the total sound pressure level of the tire pattern can be reduced. If the reason why the maximum sound pressure level is large can be found, noise from tire tread patterns can be appropriately reduced after improvement.

The sounds of block hitting ground are directly proportional to the area of the block, and the sounds can be seen as a collection of many point sound sources (Chiu JT et al, 2015) (Larsson, K et al. 1999). By analyzing the patterns, it can be found that the area ratio of pattern block is 1.0000:1.2164:1.4996, that is to say big patterns are 1.5 times larger than small patterns. The 66 pitches are randomly arranged, and found that there is a section of the arrangement is LLLLMLLL. This arrangement resulted in the excessive concentration of large pitch sizes. According to the superposition principle, the total sound pressure level is larger than either after the superposition. The reason why the maximum sound pressure level performs too high is that pattern arrangement is unreasonable.

4 IMPROVEMENT AND SIMULATION VERIFICATION OF TREAD PATTERN

In order to avoid the excessive concentration of big patterns, the order of patterns need to be adjusted. The analysis software TNS/ODS (Lu Yinxiao et al. 2012) is used to simulate and optimize the tire noise. After adjustment, related parameters, such as graphic of the tread patterns, pitch arrangement and pitch ratio, should be input in the software. By calculation, A-weighted sound level of tire noise decreased from 76.723dB to 76.154dB, declined by nearly 0.6dB. The simulation spectrum diagram is shown in Fig. 5. As can be seen from the figure, the corresponding frequency of some peak values have changed, and the maximum sound pressure level also has decreased after the adjustment. Therefore, it is effective to reduce the tire noise by using the method of pitch modification, and it also shows the prediction which pattern arrangement is unreasonable is correct.
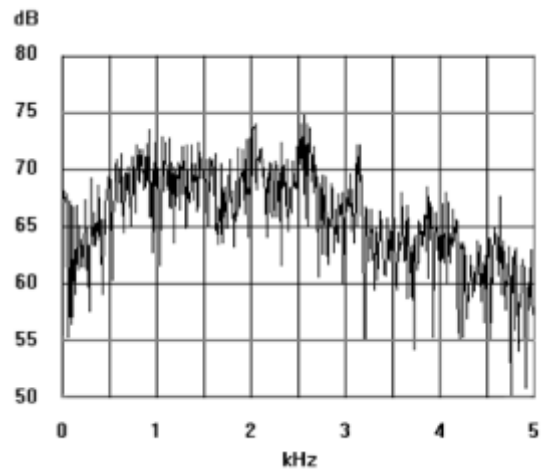
(a) simulation spectra of tire noise before pitch adjustment
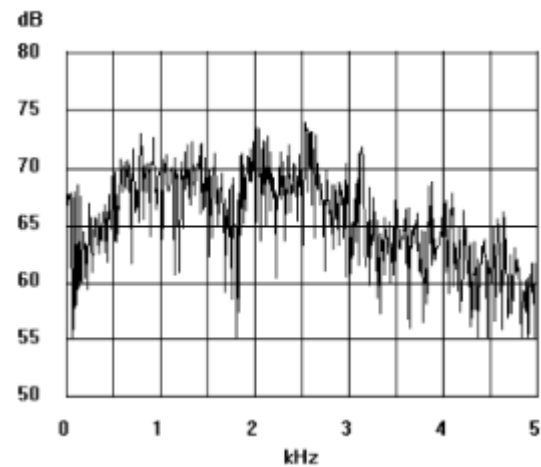
(b) simulation spectra of tire noise after pitch adjustment

Fig. 5 simulation spectra of tire noise

5 CONCLUSION

Wavelet analysis is a good method for processing non-stationary signal. By analyzing the frequency component of the tire noise, it can be found that the maximum sound pressure level is caused by block hitting ground. It is inferred that unreasonable pattern pitch arrangement is the reason for the tire noise too large. And the simulation results are used to verify this inference. Therefore, wavelet analysis is helpful to improve and get low noise tire patterns.

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