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Research Article

Simulation and Analysis of the bypass Influences on Tire Noise

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Abstract: It is a well-known scientific fact that circumferential groove exists great influence on tire noise. Increasing the void can help the rubber blocks to penetrate faster into the underlying water film and improve anti-skid performance, but which gives way to an increased air pumping noise. Therefore, the structure parameters of circumferential grooves play large influence on tire performance. The goal of this present study is using the bypass to change the grooves design and analysis the influence of bypass on tire noise and offer the tire designer a better approach to improve tire comfort ability. By virtual of numerical simulation method, the influence of bypass structure parameters, such as the width of junction pipe, the volume of resonance cavity, on tire noise were analyzed in this study. The result shows that the circumferential grooves with bypass not only bring down pipe resonance noise of circumferential grooves but also decrease far-field radiated noise of tire. Besides, with a certain resonant cavity, the width of junction pipeline between the circumferential grooves and the resonance cavity plays an important role in the improvement of tire noise. Simulation results are in reasonable agreement with experimental results.

Keywords: Bypass, number simulation, tire noise, tread pattern

INTRODUCTION

As the economy develops, the worldwide problems of resource shortage, environmental pollution and ecological degradation are getting worse due to the increasing disturbance of economic activity on natural system (Kazancioglu and Turkish State Railways, Ankara, 2012). In this context, the quality of urban life has become the focus of related scientific fields. With the increasing of population and growing importance of environmental protection, the reduction of traffic noise has become more highlighted than ever before. It is known that the tire noise dominates the traffic noise after the power unit noise has been considerably improved. Thus the performance of a tire is greatly respected and the legislative regulation of tire performance is continuously implemented in Japan and America. The European Union has worked out related rule of law for tire tags-EC1222/2009. Since November 1st, 2012, the passenger car, light truck, lorry and public bus sold in the EU must have been stuck with gags. Otherwise, it is forbidden for selling in the market. The focus of these regulations are tire fuel efficiency, external rolling noise and grate of wet snatching strength. As the direct component between tire and road, the tread pattern heavily determines the performance of tire grip, noise and anti-skid performance. Therefore, a reasonable structure of tread pattern is an effective way to improve tire comprehensive properties.

Tire noise generation mechanisms can be mainly divided into two parts: structure-borne and air-borne (Sandberg and Ejsmount, 2002). Owing to road surface texture impact, at the entrance the tread blocks impact against the road surface, while at the exit the tread blocks release from the road surface. Both of these actions make the tires generate significant impact force that lead to tread and carcass resonances and generate noise. Between 500 and 1000 Hertz, tread/sidewall is the main noise sources (Kindt *et al*., 2009). Aerodynamic noise is caused by air flow around tire surface due to the translation and rotation of a vehicle. Aerodynamic noise, which occurs between 1000 and 5000 Hertz, is mainly divided into air pumping and pipe resonances noise (Kim *et al*., 1997). Grooves in the tread that are substantially straight can act as organ pipes defined by the circumferential grooves and a contact surface of the road. The pipe resonance noise is generated by air resonance in these grooves, which is often measured at about 800 to 1200 Hertz. It is in accordance with the tire noise peak frequency (Sandberg and Ejsmount, 2002). Therefore, changing the structure of tire tread patterns and reducing pipe resonance noise can reduce tire noise dramatically.

By means of a hybrid technique and Computational Fluid Dynamics (CFD) technique, air-pumping noise

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from a transverse grooves was investigated and predicted by Sungtae *et al*. (2006). The comparison between predicted results showed that the nonlinearity of the air-pumping noise generation mechanism affects not only noise characteristics in frequency domain, but also in the directivity pattern. Through changing the parameters of transverse grooves, such as the length, breadth and depth, Yu *et al*. (2007) studied air-pumping noise mechanism and pointed out that air-pumping noise was generated from transverse grooves. With the application of computational fluid dynamics technique, the flow field of air in a transverse groove and air-pumping noise were studied by our research team (Wang *et al*., 2012). However, the previous studies only paid attention to transverse groove, while ignores the circumferential grooves.

Tire provides traction, cornering force, brake force and so on, which is fundamental for vehicles stability control and safety. The tread pattern grooves mainly maintains drainage performance and the structure parameter of which determines anti-skid performance. Increasing width and numbers of tread pattern grooves can bring up tire's load-ocean comparison and be beneficial to drainage performance. But the more tread pattern total void, the higher contact pressure and the more serious tread pattern deformed, so that the air-pumping noise is higher and the performance of tire noise is worsen. Besides, rolling resistance and uneven wear will be more serious. Tire comprehensive properties are conflict, for example, rolling resistance, grip performance and anti-skid are called Devil-triangle. 1% improvement in hydroplaning long realized by increase grooves void will lead to 0.6% reduction in handing, 0.4% increase in rolling resistance, 2.3% decrease in rolling noise and so on (Wies *et al*., 2009). It is clear that enhance anti-skid performance by virtual of increasing tread pattern average void is at the cost of other property of tire.

Bypass is one kind of Helmholtz resonators, whose one end is connected to the main pipe and the other end is closed. The mechanism of noise reduction is that acoustic interference counteracts the primary pressure wave in main pipe and reduces acoustic energy. The bypass concept is a developed method for reducing noise. It is universally used in exhausting noise of internal combustion engines, turbofan engines and air conditioning compressor (Fahy, 2001). Inspired by the noise reduction mechanism of the bypass and with the help of numerical simulation method, tire noise performance of circumferential grooves with bypass was analyzed in this study. The influence of bypass structure and its parameters on the pipe resonance noise were analyzed. The results showed that bypass not only reduces pipe resonance noise of circumferential grooves but also decreases radiated noise of tire. The width of junction pipeline between circumferential grooves and resonance cavity plays an important role in the improvement of tire noise.

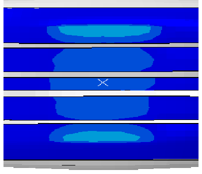

Fig. 1: Schematic of tire contact patch

TREAD PATTERN PIPE RESONANCE NOISE MODEL

Pipe resonance noise: Circumferential grooves serve as water drainage to ensure operational stability and safety of the vehicle on the wet pavement. However, on a dry pavement, a pipe opened at both ends is defined by the circumferential groove and pavement surface, which will radiate noise. Especially when a closed space is formed, radiated noise will be higher. The typical footprint of tread pattern circumferential grooves was shown in Fig. 1.

The pipe resonant frequency generated by the tread pattern circumferential grooves is:

$$f = \frac{nc}{2L} \tag{1}$$

where, c, L are, respectively, the speed of sound and the length of the contact patch. Pipe resonance noise energy is concentrated in the main resonance (n = 1) frequency. The contact patch length of a passenger car is typically from 100mm to 150 mm, whose pipe resonance noise energy is mainly between 800 and 1200 Hertz. Figure 2 shows the relationship between contact patch length and fundamental natural frequency (Sandberg and Ejsmount, 2002). It is noted that pipe resonant noise plays a dominant role in tire noise. Eq. (1) indicates resonance frequency is independent of travel speed and just relates to the contact patch length. Reducing the number of circumferential tread pattern and changing pattern groove volume can be adopted to reduce pipe resonance noise. However, for tread pattern circumferential grooves, these measures maybe decrease anti-skid performance. The mechanism of bypass is using acoustic interference to distract acoustic energy, thus reducing radiated noise. The characteristic of noise reduction depends largely on the impedance of resonant cavity volume. Without changing the premise structure of the original circumferential grooves, one rational design of bypass structure to achieve the purpose of reducing tire noise is shown in Fig. 3a. It shows the side-branch-type subresonator formed with the tube of uniform section area, which resonance frequency is given:

$$f = \frac{c}{4L_r} \tag{2}$$

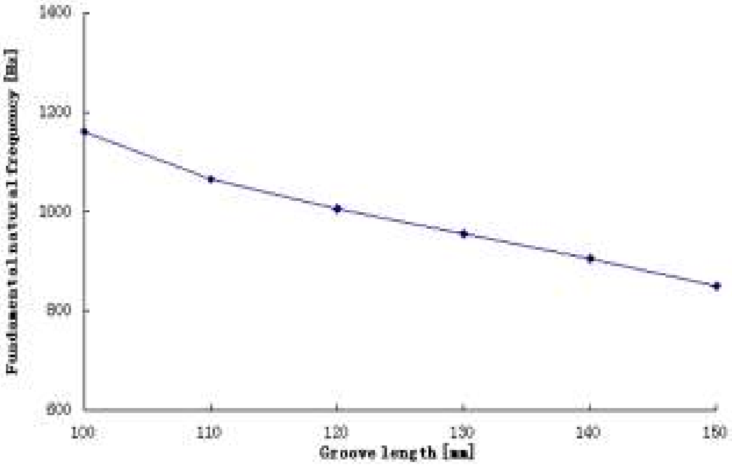

Fig. 2: Relation between contact patch length and fundamental natural frequency

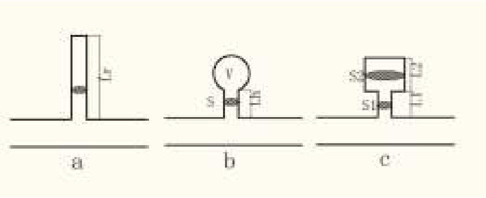

Fig. 3: Typical shapes of bypass structure

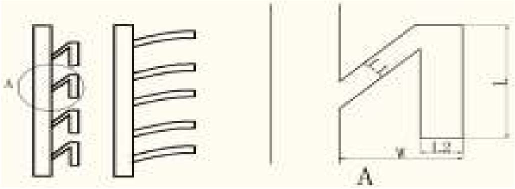

Fig. 4: Schematic of bypass structure and partial inset

Table 1: Structural parameters of bypass (mm)

	L1	L2	L	W	N
Origin structure	0	0	0	0	0
Scheme 1	1.5	8	21	18	4
Scheme 2	2.5	8	21	18	4
Scheme 3	4.5	7.5	48	17.5	2
Scheme 4	4.5	7.5	21	17.5	4

where, L_r is the length of the tube; Fig. 3b shows the Helmholtz-type subresonator with a narrow neck and cavity, this type yields:

$$f = \frac{c}{2\pi}\sqrt{\frac{S}{L_h V}} \tag{3}$$

where,

S = The cross-sectional area
L_r = The length of the neck

To be specific, the resonant frequency of the sub resonator formed with two-step tubes as shown in Fig. 3c is given by the following equation:

Fig. 5: Finite element pattern model with bypass structure

$$\tan(\frac{2\pi f}{c}L1)\tan\left(\frac{2\pi f}{c}L2\right) - \frac{S_2}{S_1} = 0 \tag{4}$$

where, L_i (i = 1 and 2) is the length of component tube and S_i is the cross-section area.

Tire 205/50R16 was chosen for the present study. By means of finite element analysis, the length of contact patch under the condition that the tire was mounted on a regular rim and inflated to at a normal internal pressure and loaded with a normal load, was 135 mm and the fundamental frequency of pipe resonance was about 1200 Hertz. To research the impact of bypass structure on pipe resonance, four kinds of bypass structure (Fig. 3c) were designed, as Fig. 4 shows. The structural parameters of these bypasses were shown in Table 1 and the resonance frequency was in 800 to 1300 Hertz, where N represented the number of resonant cavity in the contact area.

Numerical simulation: Generally speaking, the resonance frequency calculation Eq. (4) is statically indeterminate so that it is difficult to find exact values by means of analytical method, thus numerical calculation is used to determine their frequency ranges so as to reduce noise. In this study, the effects of different bypass structural parameters on pipe resonance noise were predicted by Virtual Lab Acoustic

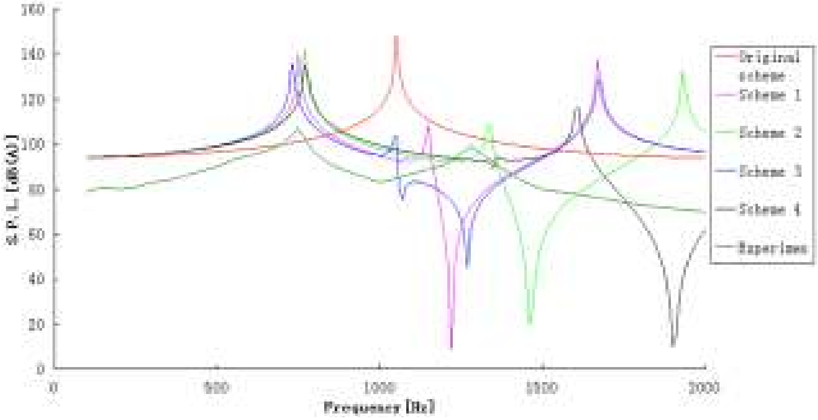

Fig. 6: Comparison of the SPL with different circumferential grooves

analysis software. Because of symmetry of tire treat pattern, a half of tire acoustics finite element model in contact region was shown in Fig. 5. The maximum grid size was 2 mm as to meet the requirement of six units in a wavelength in acoustic analysis. According to reference, tire noise sources mainly lie in the leading and trailing of the footprint, monopole source can be used to represent the characteristic of tire noise. Therefore, four sources of unit sound pressure were imposed in both ends of contact patch as the excitation source; the sound pressure measurement point was defined at the centre of circumferential grooves.

RESULTS AND DISCUSSION

Influence of structure parameters of bypass on pipe resonance noise: Figure 6 shows the comparison of predicted sound pressure generated from the five models, as Table 1 shows. The results indicate that the structure of bypass has a major influence on pipe resonance. The reason being is that bypass structure not only affects resonance frequency but also noise reduction characteristics. With a fixed resonance cavity volume through comparison of scheme 1 and scheme 2, the width of pipe which connects the main grooves and the resonance cavity mainly affects resonance noise frequency, particularly the main resonance frequency. The wider the junction pipe, the lower the resonance frequency and the smaller the scope of reducing noise. By analyzing scheme 3 and scheme 4, increasing the volume of resonance cavity can substantially reduce the pipe resonance noise and increase the range of noise reduction within the studied frequency range. In comparing scheme 1 and scheme 3, it is concluded that increasing the width of junction pipe and the volume of resonance cavity has little influence on the characters of noise reduction. In comparing scheme 2 and scheme 4 shows that the width of junction pipe directly affects the frequency range of reducing noise. Figure 6 shows that the centralized acoustic energy of tread pattern circumferential grooves with bypass can be effectively decomposed into several acoustic energy areas and caused a significant sound pressure reduction between 800 and 1500 Hertz. That is to say, the peak sound pressure at around 1000 Hertz is avoided. Multiple peak sound pressure is remarkably lower than the original single sound pressure peak around 1000 Hertz, which is in reasonable agreement with experimental results measured by Fujiwara *et al*. (2009).

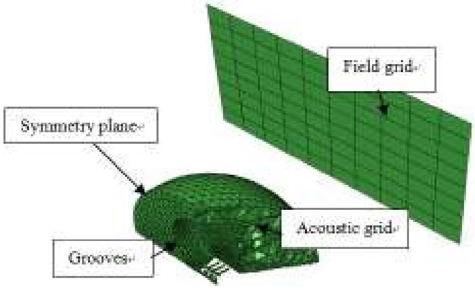

Fig. 7: FE modal of tire noise

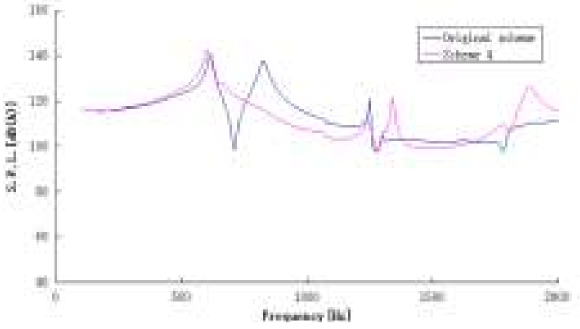

Fig. 8: Comparisons of SPL

Influence of bypass on radiated noise: In order to analyze the far-field acoustic radiation, one acoustic finite element model of circumferential grooves with bypass structure was shown in Fig. 7. Two monopole sources were located at the center of circumferential groove as the acoustic excitation. The radius of the sound hemisphere was 1.5 m, and the outer surface using acoustic infinite element is used to simulate sound propagation infinity and acoustic energy disappears. One acoustic field point grid was set 2 m away from the symmetry plane. By measuring the sound pressure of field point to determine whether the bypass reduce far-field acoustic radiation of tire noise or not.

Figure 8 shows the comparison of predicted sound pressure between two models at the same field point. It is obvious that circumferential groove with bypass reduce significantly the far-field sound pressure within 800 to 1500 Hertz. The frequency scope of far-field sound pressure reduction is in accordance with that of pipe resonance noise reduction. It is concluded that the tread pattern grooves with bypass not only reduces pipe resonance noise of circumferential groove but also decreases the far-field radiated noise.

CONCLUSION

The influence of bypass and its structure parameters, such as the width of junction pipe, the volume of resonance cavity, on tire noise reduction and antiskid performance were numerically investigated in this study. The conclusions that can be drawn from our teams' investigation are as follows:

- The existence of bypass structure can change tread pattern circumferential grooves pipe resonance noise, disperse noise energy and reduce tire noise.
- With a fixed volume of resonant cavity, the width of junction pipe between the main circumferential groove and resonance cavity affects the resonance frequency scope of pipe resonance and antiskid performance.

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