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NOISE CONTROL FOR A BETTER ENVIRONMENT

Investigation of High Frequency Interior Noise due to Tyre-Road Interaction using Experimental and Numerical Techniques

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ABSTRACT

Vehicle interior noise induced by tyre-road interaction is one among the major causes of the noise. The source is transferred to the cabin through structural and air borne paths depending upon its excitation frequency. Interior noise at higher frequency is affected by tyre noise radiation and tyre structural vibration due to low damping and limited symmetry of tyre wheel assembly. This work investigates the high frequency interior noise using Driving Point Mobility (DPM) technique. DPM is an indicator of noise radiated from tyre due to its vibration. The influence of tyre properties like stiffness, mass and tread pattern on noise is studied by numerical and experimental methods. The results indicate that increase in tyre belt stiffness and tread package mass lowers the DPM and in turn reduce the high frequency interior noise. Also, lowering the groove width of tread pattern reduces high frequency interior noise.

Keywords: Tyre NVH, High Frequency Interior Noise, Driving Point Mobility

I-INCE Classification of Subject Number: 10

1. INTRODUCTION

1.1 Background

Tyre NVH and its rolling resistance are twomost important and challenging targets for the today's tyre development Engineers. Nowadays, vehicles are made lighter in weight to meet the fuel economy target. Even thetyre weights are reduced and its inflation pressure is increased to lower the rolling resistance of the tyre. These low weight tyres have reduced damping to the structural vibrations compared to the conventionally designed tyres. This makes the structure borne interior noise extend to high frequency region.

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In the past, many researchers [2-9, 13] studied the high frequency interior noise using various experimental techniques and analytical tyre models. Andersson et al. developed both experimental frame work and mathematical model to study the dynamic behaviour of car tyre at high frequencies. They also discussed about the local contact area deformation of excitation point in both radial and tangential point mobility of tyre tread [10]. Iwao & Yamazaki in their experiment demonstrated that by adding an extra mass (rubber ring) along the centreline of the tread inside the tyre circumference reduces the tyre noise considerably [8].

According to Ejsmont & Sandberg and Kropp et al., an increase in belt stiffness decreases the radial driving point mobility of tyre [1,2] which in turn reduces the tyre noise radiation. This was observed in the condition in which both the bending stiffness and the mass of the belt were increased together. Kim et al. developed a method for determining the influence of tyre construction on the tyre induced air borne component of the interior noise [9]. In that study they have compared the contribution of tyre tread, sidewall and rim. Out of these, it was found that tyre tread contribute more to the air borne component of interior noise.

The tyre road interaction induces vibration of tread at the leading and trailing edge of the tyre contact patch, which generates noise radiation around the tyre. The peak amplitude occurs around 1 kHz in the tyre coast down noise spectrumfor any given tyre, even for non- tread pattern (slick) tyre. Hence, it is evident that the noise around 1 kHz is not only generated by tread pattern but also due to the vibration of tyre tread package. Doan et al., observed shoulder tread vibration is amajor source for tyre noise generation. They also suggested that the tyre tread vibration can be reduced by lowering the center contact pressure and / or by increasing the shoulder tread bending stiffness [7].

1.2 Vehicle Interior Noise Spectrum

Market requirements and customer demands impose stringent NVH performance targets for the new vehicles. The three major sources of vehicle interior noise are power train, tyre road interaction and aerodynamic drag of the vehicle. Among these, tyre road interaction makes most of the contribution compared to other sources. The tyre vibration induced interior noise is transmitted through two major paths: structure and airborne paths as shown in Figure 1. In general, the structure borne transmission is limited to below 400 Hz and above this frequency airborne path dominates. Road surface also plays a vital role in the interior noise generation. For instance, rough road excites low frequency range interior noise and smooth road excites high frequency range of interior noise spectrum [1].

From the past studies, it has been observed that the difference in sound pressure level (SPL) is higher for different vehicles than compared to the SPL difference for tyres with different tread pattern and construction. Also, there is no exact correlation between the interior and exterior noise spectrum of the vehicle. But for a particular frequency ranges, the interior and the exterior noises can be compared [5].

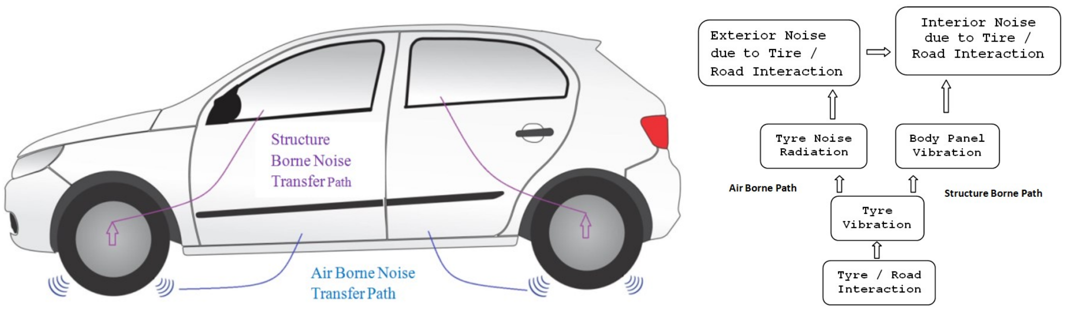

Figure 1 Tyre / road noise transmission routes

Figure 2 illustrates the typical tyre road interaction induced interior noise phenomena and its frequency ranges. These noise phenomena depend on road surface, speed, vehicle body and suspension. Booming, tyre cavity and rumble are low frequency noise phenomena and they are observed on the rough roads. Whereas, the high frequency (above 500 Hz) pattern noise is measured on the smooth road [6]. It is also observed that the high frequency interior noise due to rear tyres is higher than the front tyres [5]. This might be due to the load on the rear tyres are lesser than the front tyres of the front wheel driven car.

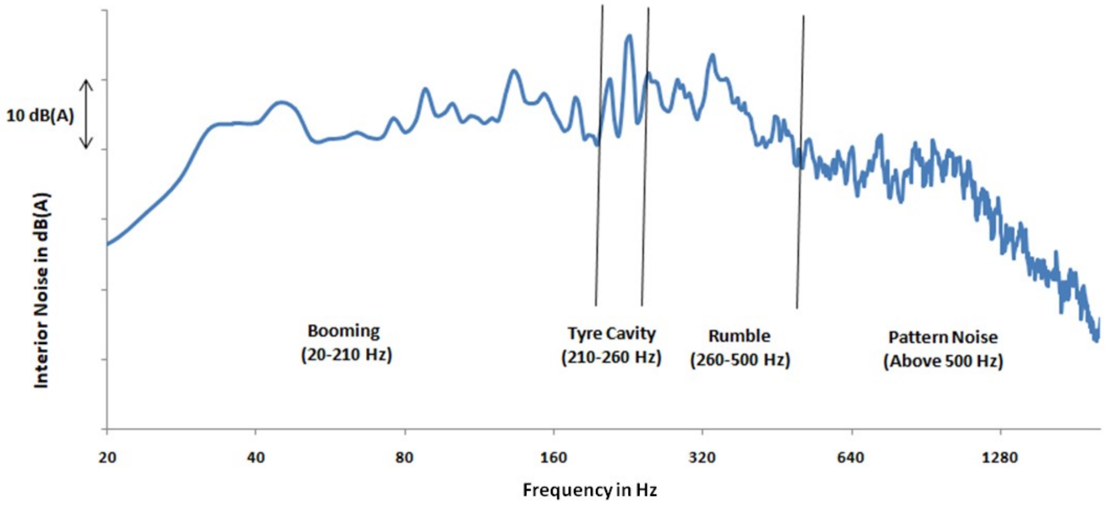

Figure 2 Interior Noise Spectrum with tyre road noise phenomena and its frequency range at 80 kmph speed on smooth road

Figure 3 shows the interior noise spectrum of the vehicle rear seat microphone at 80 kmph speed on a smooth road with two different tyre sets. At the frequency of around 1000 Hz, the noise level of Tyre A is higher than Tyre B by a magnitude of 2 dB(A). Hence, there is a need to meet the tyre NVH requirements without compromising the other tyre performance criteria. Usually, the tyre tread pattern design parameters are varied to reduce the tyre induced interior noise in the high frequency region [1]. In order to do this, the mould has to be redesigned which is time consuming and costly. Alternatively, by playing with tyre construction nearly 2 dB(A) of high frequency interior noise can be reduced without affecting the other performance criteria of the tyre.

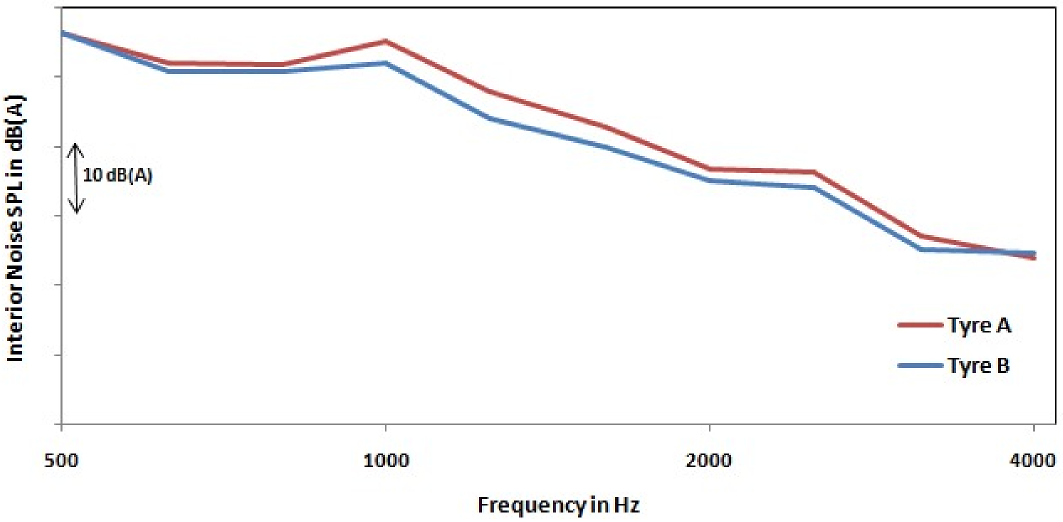

Figure 3 High frequency interior noise spectrum of rear seat microphone at 80 kmph speed on smooth road

1.3 Tyre Radial Driving Point Mobility

The driving point mobility (DPM) is a response acceleration for a given unit excitation force at every frequency. It is an indicator of the vibration characteristics of the tyre road interaction. Since tyre vibration generates the noise radiation, increase in the driving point mobility increases the noise radiation from the tyre. The sound pressure at the tyre contact patch is directly proportional to the radiation velocity of the tread blocks due to its vibration. In orderto achieve the low noise tyre performance without compromising much on other criteria, an optimized tread pattern design must be used with optimized tyre construction.The tyre tread vibration in the high frequency region is controlled by damping of the tyre.

The typical radial driving point mobility of a tyre is shown in figure 4. The low frequency region below 300 Hz exposes tyre circumferential modes and rigid body modes. In this region, tyre can be considered as a ring under tension.Tyre damping is low in this region due to less participation of belt bending motion. Between 200 to 400 Hz, tyre acts as a beam instead of a ring, lateral modes of the tyre appear in this frequency range. At frequency above 500 Hz, tyre behaves like a plate with higher modal density and increased damping [10].

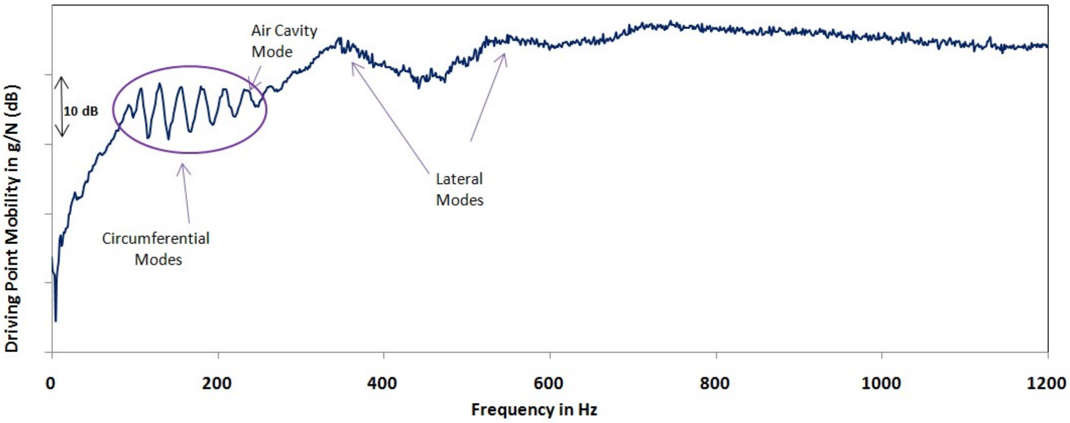

Figure 4 Radial driving point mobility of the tyre excited at the center rib [10]

In this work, high frequency interior noise due to tyre road interaction is investigated using tyre radial driving point mobility (DPM). The effect of tyre construction and tread pattern changes on high frequency interior noise > 500Hz is evaluated in terms of dynamic behaviour of tyre tread package. Later, using the numerical tyre model the driving point mobility is predicted for regular and construction changed tyres. Finally, the correlation of the radial driving point mobility is established for the experimental and the predicted numerical tyre model.

2 EXPERIMENTAL INVESTIGATIONS

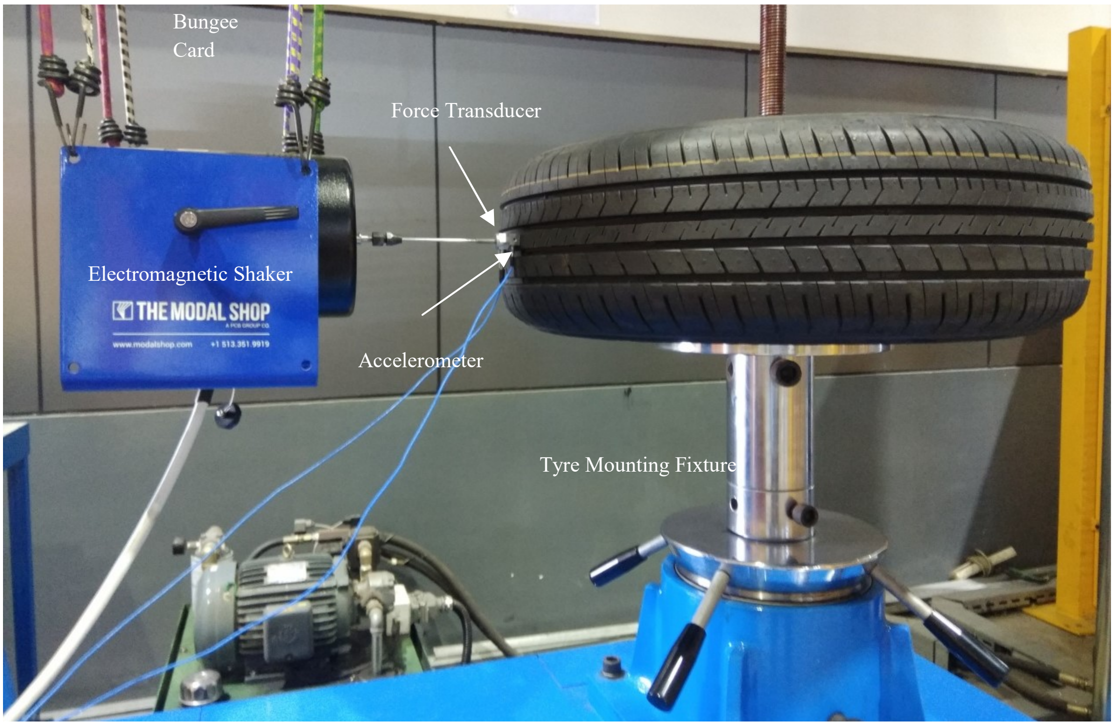

Figure 5 Tyre driving point mobility (DPM) measurement setup

The test setup for the driving point mobility measurement is shown in figure 5. In this setup, the inflated tyre rim assembly is mounted on a fixture. The excitation force at the center rib of the tyre is given by the electromagnetic shaker hung through a bungee cord. Near to the excitation point the radial response acceleration of tread is measured using accelerometer. The frequency response function (FRF) of driving point mobility is processed using data acquisition system. The good coherence of the driving point mobility is ensured for the accuracy of the FRF.

Four R15 size tyres, regular, two construction changed i.e., belt angle increased (from 24 to 27 degrees), under tread thickness increased (from 1.5 mm to 2.5 mm) and circumferential groove width reduced (from 9.5 mm to 7 mm) taken for the experimental investigation. All these tyre modifications were chosen carefully so that very little compromise is made on the other target criteria like rolling resistance and handling performance.

The measured radial driving point mobility of these tyres is shown in figure 6. It is evident from the results that the increased under-tread (UT) tyre has the lowest radial driving point mobility compared to all other tyres in high frequency region. This is because of the increase in tread damping due to its increased mass. It is also clear that the increased belt angle and reduced groove width lowers the radial driving point mobility of the tyre. Later, all these tyres werefitted on the vehicle and the interior noise were measured and a similar trend is observed.

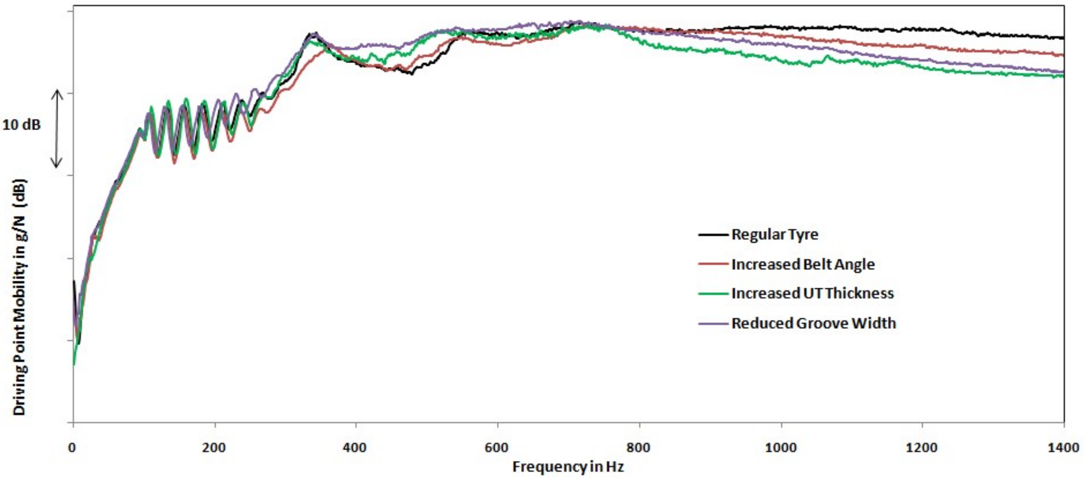

Figure 6 Radial driving point mobility of tyres

4 NUMERICAL PREDICTIONS

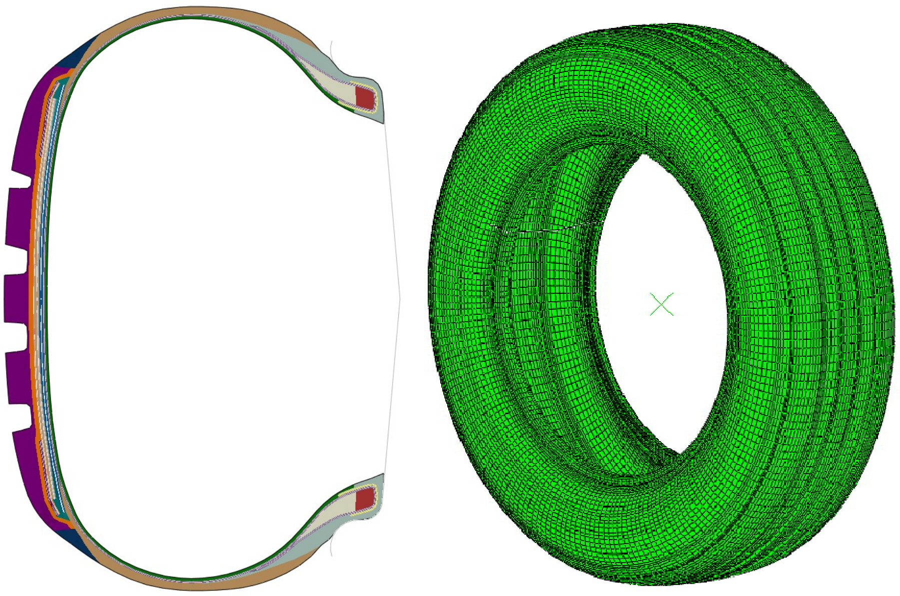

Figure 7 Finite element tyre modelling

Using numerical analysis in the early stages of tyre design, the high frequency interior noise can be indirectly predicted by radial driving point mobility of tyre with different tyre construction and tread pattern. FEM tyre model is capable of predicting driving point mobility for the entire frequency range, but the only limitation is the long calculation time and higher computational power requirements. To reduce the computational time and model complexity, circumferential groove tread pattern without any lateral grooves was considered.

Tyre cross section of axisymmetric FE model (figure 7) was prepared in the commercial available software. The tyre model consists of components like tread, plies, belts, apex, bead etc. After mounting the tyre on the rim, appropriate inflation pressure was given. By revolving the meshed cross section of axisymmetric tyre model, the 3D model of tyre was prepared. The free vibration tyre modes were extracted using Eigen value extraction analysis. Later, steady state dynamic (SSD) analysis was carried out to evaluate the tyre dynamic characteristics by applying an excitation force at the center rib of the tyre and calculating the radial acceleration near to the applied force.

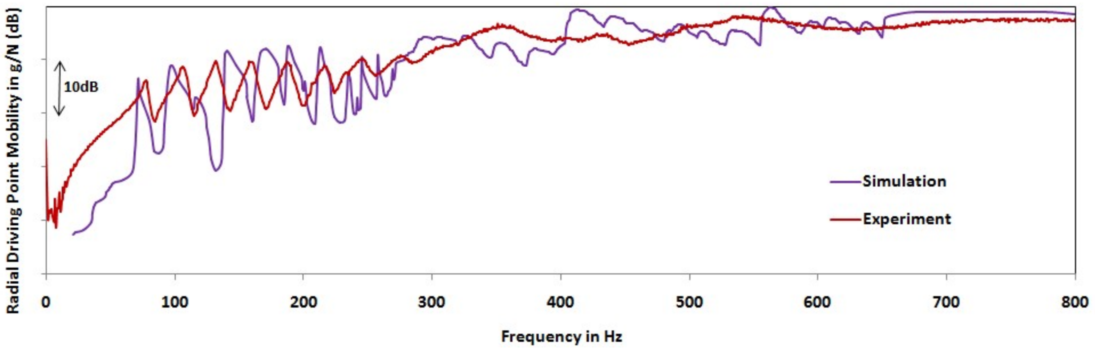

Figure 8 Comparison of Experimental and Predicted Radial DPM of tyre

The trends of the predicted radial driving point mobility of finite element tyre model shown in figure 8 are matching well with the experimental data. Accuracy of the prediction depends on amplitude of the excitation force and material properties of the model. It suggests that the material damping properties of the finite element tyre model is very less compared to an actual tyre. The prediction accuracy can be improved by assigning proper tyre material properties.

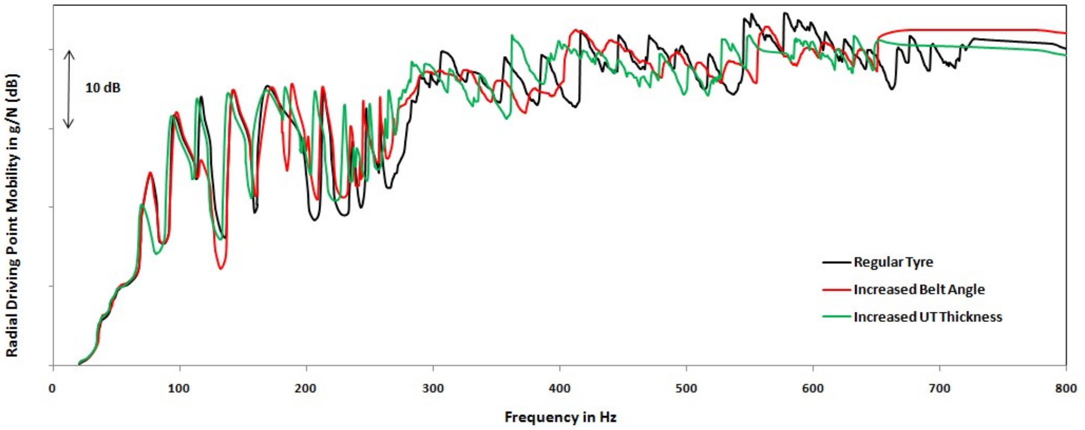

Figure 9 Predicted radial driving point mobility after filtering

Figure 9 shows the filtered predicted radial DPM of tyres with different constructions. In the high frequency region (above 500 Hz), the under-tread thickness and belt angle increased tyres are having lesser radial driving point mobility compared to the regular tyre. The noise radiated due to driving point mobility is proportional to the velocity of the vibrating tread surface. Figure 10 shows the velocity field of higher order radial mode of tyre at 600 Hz frequency. The velocity field magnitude indicates its sound radiation level. Low velocity field magnitude implies less noise radiation by tyre tread.

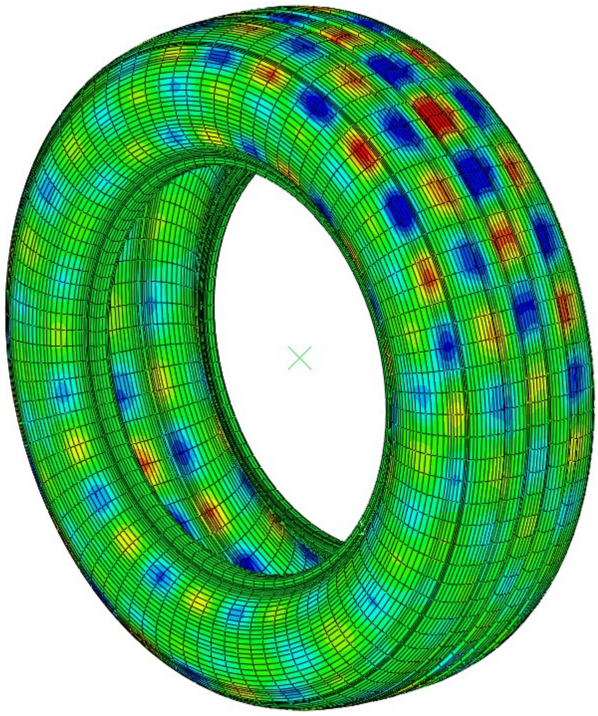

Figure 10 Velocity field of tyre radial driving point mobility at 600Hz

5. CONCLUSION

An indoor tyre testing methodology has been established to measure the high frequency vehicle interior noise. From this experimental study, it is observed that the lower driving point mobility (DPM) of tyre at high frequency will have lower interior noise at high frequency. This work investigated the influence of belt angle, tread mass and tread grooves on the high frequency interior noise of the vehicle. The high frequency interior noise of the vehicle is reduced by increasing the belt angle along with its mass, tread mass and also by reducing circumferential groove width of the tyre. The numerical prediction of driving point mobility is in well agreement with the experimental test results. But there are still room for fine tuning the numerical prediction. The damping properties of numerical tyre model needs to be improved especially at the high frequency region to accurately predict the high frequency interior noise at the design stage.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

1. Sandberg U, Ejsmont JA. Tyre/road noise reference book. Kisa, Sweden: Informex: 2002.
2. Kropp, W.; Larsson, K.; Barrelet, S.; The influence of belt and tread band stiffness on the tyre noise generation mechanisms, Proc. Of the International Congress on Acoustics (ICA) 1998, Seattle, WA, USA.
3. Yum, K., Hong, K., and Bolton, J., "Influence of Tire Size and Shape on Sound Radiation from a Tire in the Mid-Frequency Region," SAE Technical Paper 2007-01-2251, 2007, https://doi.org/10.4271/2007-01-2251.
4. Blom, R. (2004). Report on tyre/road noise: generation mechanisms, influence of tyre parameters and experiment on belt resonances. (DCT rapporten; Vol. 2004.020). Eindhoven: Technische Universiteit Eindhoven.
5. Koners, G. and Lehmann, R., "Investigation of Tire Road Noise with Special Consideration of Airborne Noise Transmission," SAE Technical Paper 2009-01-2109, 2009, https://doi.org/10.4271/2009-01-2109.
6. Koners, G. and Lehmann, R., "Investigation of Tire-Road Noise with Respect to Road Induced Wheel Forces and Radiated Airborne Noise," SAE Int. J. Passeng. Cars - Mech. Syst. 7(3):2014, doi: 10.4271/2014-01-2075.
7. V. Q. Doan, D. Brackin, S. Nishihata, and J. Sauerzapf (1995) Investigation into the Influence of Tire Construction on Coast-by Noise. Tire Science and Technology: April 1995, Vol. 23, No. 2, pp. 96-115.
8. Iwao, Keijiro; Yamazaki, Ichiro; (1996) A study on the mechanism of tyre road noise, JSAE Review 17 (1996) 139-144 Society of Automotive Engineers of Japan.
9. Kim, G.J., Holland, K.R. and Lalor, N. (1997) Identification of the airborne component of tyre-induced vehicle interior noise. *Applied Acoustics*, 51 (2), 141-156. (doi:10.1016/S0003-682X(96)00061-8).
10. Andersson, Patrik; Larsson, Krister; Wullens, Frédéric; Kropp, Wolfgang, High Frequency Dynamic Behaviour of Smooth and Patterned Passenger Car Tyres, ActaAcustica united with Acustica, Volume 90, Number 3, May/June 2004, pp. 445-456(12).
11. Xu Wang, "Vehicle Noise and Vibration Refinement," (CRC Press, 2010), P. No. 333, ISBN 978-1-84569-497-5.
12. Höstmad, Patrik& Larsson, Krister. (2005). Validation of a High Frequency Three-Dimensional Tyre Model. ActaAcustica united with Acustica. 91. 121-131.
13. Castellini, Paolo &Giovanucci, F & Nava Mambretti, G &Scalise, Lorenzo &Tomasini, Enrico. (1998). Vibration Analysis of Tire Treads: A In-plane Laser Vibrometry Approach. Proceedings of SPIE - The International Society for Optical Engineering.