NUMERICAL COMPUTATION OF TYRE RADIATION NOISE: A COMPARATIVE STUDY OF DIFFERENT TECHNIQUES

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SUMMARY

Increasingly stringent noise regulations concerning automotive vehicles particularly in Europe are forcing Tyre manufacturers as well as the automotive manufacturers to reduce radiated noise. With the future moving towards electric/hybrid vehicles, the ever present tyre noise will become more dominant. Even in the case of automotive engines running on fossil fuels, tyre noise dominates above speeds of 40 Km/h. Understanding the causes of tyre noise is the first step towards finding engineering solutions to reduce it. Numerical modelling can help the tyre engineer in understanding the causes of tyre-road noise with a design tool.

In the present work, the noise radiated by the tyre surface is computed numerically using three different computational techniques. Both the time domain approach and the frequency domain approaches are used and the results are compared. The input structural vibrations are computed in ABAQUS (Ref. 1) and the results are then imported to LMSVirtual.Lab (Ref. 2) for further acoustic computations. As the main focus of this work is on the acoustic computations, only a brief description of the process involved in the structural vibration calculations is provided. In the present work, the "Horn effect" is inherently captured in the acoustic simulations. Two model tyres, viz., with tread pattern and with circumferential grooves is evaluated. The presence of tread leads to the phenomenon of stick slip and stick snap mechanisms contributing to the overall tyre noise. In addition, the motion of air through the grooves causes air pumping noise.

It is to be noted that the structural vibration computations were performed on a rotating tyre that translated on a stationary road. In other words, the tyre underwent rotational as well as translational displacement. The acoustic computations are however performed on a stationary tyre model. One of the challenges addressed in the present work is the conversion of transient vibration results on a stationary acoustic mesh. The surface accelerations, required as boundary conditions, are converted to the frequency domain by the Fast Fourier Transformation for the Harmonic computations. The details of the

structural models as well as the acoustic models and a short description of the techniques used in the computations of the radiated noise are described in the next section.

1: Numerical Modelling Methodology

A numerical computation technique has been developed to compute the acoustic performance of tyres, based on virtual proto-types. The acoustic computations have been performed using three different techniques viz., Harmonic BEM method, Harmonic FEM method and Transient FEM method.

The process map showing the different steps involved in the simulations starting from the transient structural computations to the radiated noise is shown in figure 1.

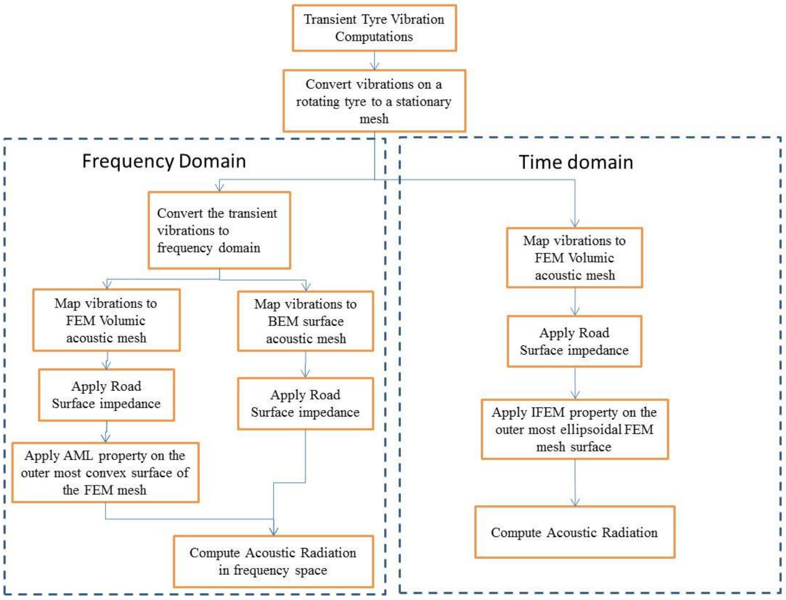

Figure 1: Flowchart showing the different process steps involved in the acoustic computations using different techniques.

Transient dynamic analysis is done in Abaqus by moving the tyre forward with a prescribed velocity and the vehicle load applied to the rim reference node. The tyre is allowed to rotate freely about the axle. All other degrees of freedom at the road and rim reference nodes are held fixed. The road is modelled as a rigid surface and the tyre translational speed is maintained at 90 KMPH. In the present work, only a simple material model is used which does not include material damping and hence the results are expected to be over predicted in comparison to measurements. It is seen that the time domain technique offers quick turnaround times for the final results. The frequency domain techniques will however enable the user to determine the dominant frequency of excitation and also gives the user more control over the range of frequencies for which computations are performed. In terms of meshing, the BEM approach has the simplest requirement.

Acoustic computations are performed by including the road surface impedance which is computed from the expression obtained from Reference 3 for a hot $Z = 1 + 0.0571 \left(\frac{f}{\sigma_e}\right)^{-0.754} + i\, 0.087 \left(\frac{f}{\sigma_e}\right)^{-0.732}$ rolled asphalt surface

Impedance,

with the flow resistivity that equals 10e6 Pa s/m^2. The impedance curve flattens out for the real part at high frequency. The application of road impedance in the time domain is quite complicated as a Fourier transform of the impedance in the frequency domain needs to be performed; besides, the acoustic software at present accepts only constant real valued impedance as input. Hence the road surface is modelled as a completely rigid surface in the time domain computations. Figure 2 shows the typical acoustic pressure distribution on a field point mesh. For the purposes of comparison of the results, the results at a reference listener point that is 200 mm*200 mm*100 mm from the tyre centre point on one side is selected. The sound pressure levels computed by the three techniques at the reference point are shown in fig. 3. It is seen that there is a very good match of the results for the different techniques. In order to plot the results obtained from the time domain FEM results a FFT was performed on the sound pressure levels.

2: Conclusion:

It has been shown in the present work that the acoustic pressure levels at a listener position is independent of the adopted computational technique and both time domain as well as frequency domain can be used to perform the computations. There is however a relative advantage in the use of frequency domain methods as the user has more flexibility in terms of selecting the range of frequencies over which computations will be performed. In terms of speed itself, the time domain technique is quite fast. The meshing needs are simpler in the case of BEM technique. The use of Automatic Matched Layer (AML) enables Harmonic FEM computations to be performed for exterior problems as seen in this case. The only requirement for using AML technology is in the creation of a convex surface that enclosing the road surface, in principle similar to IFEM mesh. However there is a vast difference in their performance in that AML is a lot faster than IFEM for the same level of accuracy. One of the possible explanations for the slight deviation in the results at the end of the comparison plot is due to the difference in the two techniques. In Transient FEM, the actual vibrational load at a particular time step is used to compute the sound pressure levels and then a FFT is performed on the end result. However, in the Harmonic FEM approach, the FFT is first performed on the vibrational loads. As the vibrational loads are computed at finite time intervals, and the vibrations itself have a broad band signature with a potential narrow band peak, there is a loss of information during the FFT conversion. This could lead to a slightly under predicted sound pressure levels for some frequencies in the harmonic computation.

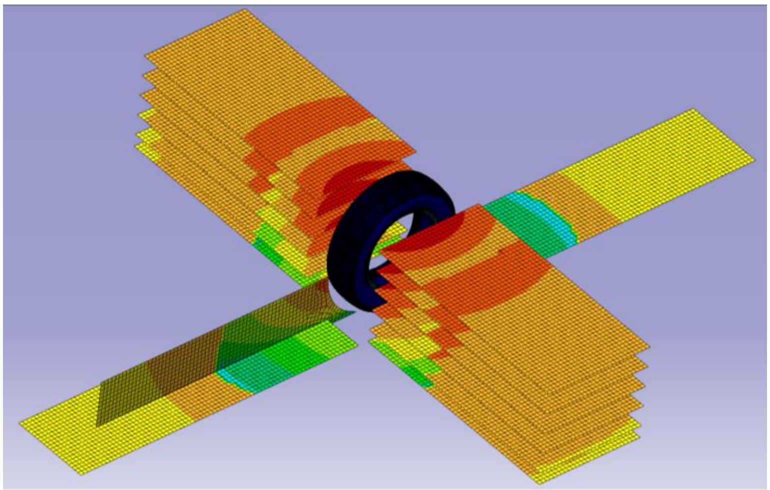

Figure 2: TDFEM Results at field points

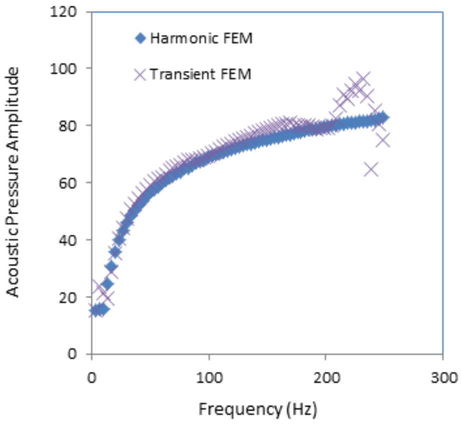

Figure 3: Harmonic FEM &Transient FEM sound pressure levels for a field point location near the tyre.

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