Radiation Noise Simulation of a Rolling Tire Excited by Tread Pattern

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Abstract: The radiation noise simulation of a rolling tire is presented. Here we consider only radiation noise caused by structural vibration excited by tread pattern. The simulation consists of three parts, i.e. quasi-static rolling simulation using a tire model having tread pattern, frequency response analysis of a rolling tire model having longitudinal grooves and acoustic simulation surrounding the second tire model. Each part is conducted sequentially using Abaqus/Standard. The objective of the first simulation is to obtain variation of contact forces between tread pattern of a tire and road surface. The variation of contact forces on tread surface is mapped onto the surface of a tire model which has only longitudinal grooves for the next simulation. At the second part frequency response analysis under excitation forces caused by tread pattern is conducted after steady-state transport analysis. The last part is acoustic simulation of air around a tire to get sound pressure level. Numerical examples are illustrated, and predicted results by the simulation are compared with experimental measurements. The calculated sound pressure level around a tire is reasonably close to the experimental result.

Keywords: Tires, Radiation Noise, Steady-State Rolling, Frequency Response, Acoustics

1. Introduction

Fuel saving is important issue from the viewpoint of CO2 reduction and natural resource saving. The development of environment conscious technology is high priority not only for car manufactures but also for tire manufactures. Although the reduction of rolling resistance is the main priority for tire manufacturers, tire noise originating from rolling tire-road contact is a key issue from an environmental and regulatory (EU) perspective. So, some studies on numerical simulation of sound radiation of tires are reported (Nakajima, 1993; Saguchi, 2006; Biermann, 2007). Tire noise is originated by the excitation due to tread pattern and road asperity. Pipe resonance inside grooves is also origin of the radiation noise. In this study, tread pattern induced noise is focused and simulation procedure using Abaqus/Standard is presented with numerical experiments.

2. Simulation procedure of radiation noise of a rolling tire

Since the simulation of the real phenomenon of tire radiation noise is vary difficult, we decompose it into three aspects, i.e. reaction force variation due to tread pattern, vibration of a rolling tire, and sound radiation from a tire. The simulation procedure is shown in figure 1. The objective of step-1 is to obtain contact force variation due to contact between tread pattern and a road surface. At the step-2 frequency response analysis of a steady-state rolling tire is conducted to obtain vibration of a tire considering the influence of deformable wheel, acoustics inside cavity and gyro-effect. At the final step, sound pressure level in the acoustic domain surrounding a tire is calculated. Simulation at each step is conducted by Abaqus/Standard. Some in-house codes are developed for the bridging between those steps.

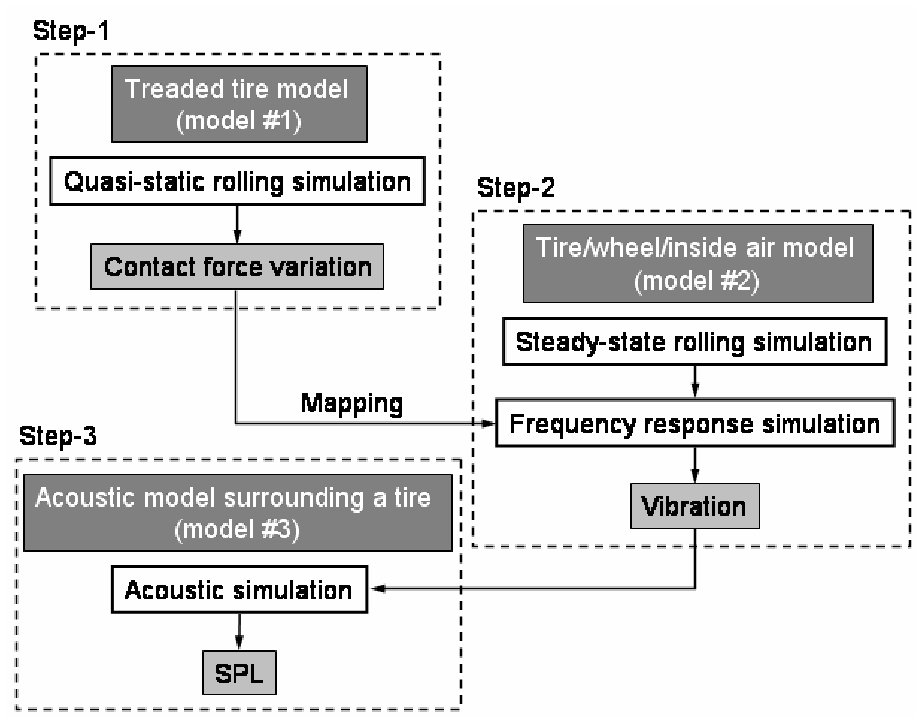

Figure 1. Flow chart of the radiation noise simulation of a rolling tire.

3. Validation and numerical experiment

In order to evaluate the effectiveness of proposed simulation, validation and numerical experiment are illustrated along the procedure. A tire having tread pattern formed grid by longitudinal grooves and lateral grooves as shown in figure 2 is considered here. Real tires have variable-pitch pattern, however, this tire model has non-variable pitch pattern (72 pitches). Tire size is 215/55R17.

According to the procedure, numerical simulation is carried out as followings;

1. Contact force variation using model #1 is calculated at step-1
2. Steady-state rolling simulation using model #2 is conducted at step-2

3. Contact force variation is transformed to prescribed displacement variation using in-house tool.
4. Frequency response analysis is conducted using model #2 subject to prescribed displacement variation.
5. The geometry of a deformed tire model resulting at the previous step is modeled by CATIA V5 and model #3 is prepared using Abaqus/CAE.
6. Vibration of outside surface of a tire is extracted from odb file resulting at step-2 and is applied to model #3 as boundary condition
7. Finally sound pressure level surrounding a tire is obtained by acoustic simulation using model #3.

3.1 Quasi-static rolling simulation (step-1)

The objective of step-1 is to obtain contact force variation due to contact between a treaded tire and a road surface. For the simulation of a rolling tire, two kinds of scheme can be chose. Explicit scheme for example using Abaqus/Explicit is used widely for dynamic rolling tire simulation including tread pattern. Implicit scheme using Abaqus/Standard is another choice. SST (Steady-State Transport) capability in Abaqus/Standard is useful for steady-state rolling tire simulation. Each scheme has advantage and disadvantage. In this study, quasi-static rolling simulation using Abaqus/Standard is chosen to consider the rolling contact of a treaded tire and to avoid vibration of a tire during rolling.

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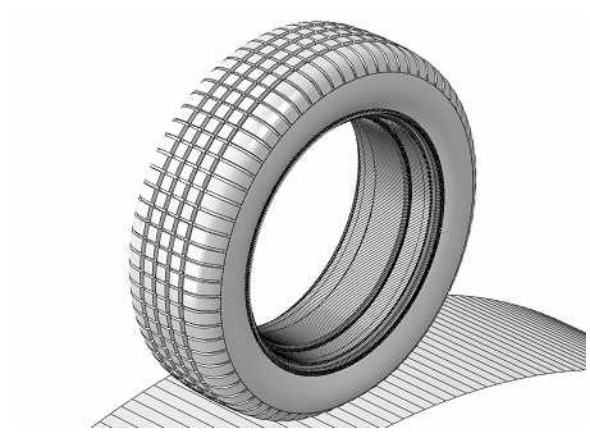


Figure 2. Tire FE model in step-1 (model #1).

Tire FE model in step-1, model #1 is shown in figure 2. The model consists of tire FE model having a grid pattern and a rigid wheel. The tire model is mounted to a rim, inflated and loaded on a drum to compare numerical results with indoor testing. In order to obtain contact force variation due to tread pattern the distance between a spindle and a drum surface remains constant during the simulation. Since the deflection of a rolling tire increases in comparison with that of a static tire, prescribed displacement which is consistent with deflection due to specified load (4.5 kN) in a rolling state is applied to tire spindle. Resulting force variation is shown in Figure 3. It is recognized that reaction force decrease with a rotation and it become steady-state.

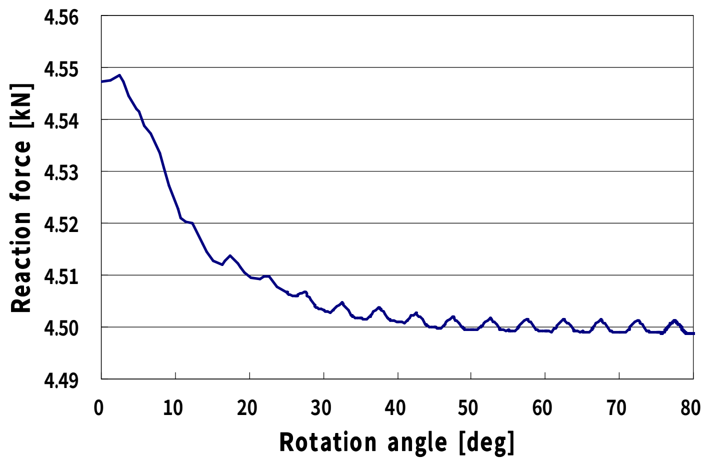


Figure 3. Reaction force variation.

3.2 Frequency response analysis (step-2)

Figure 4 shows FE model for the step-2. This is an assembled model among a tire, a deformable wheel and air inside the tire. The tire model which has only longitudinal grooves is used at step-2 Air inside a tire cavity is modeled by acoustic element.

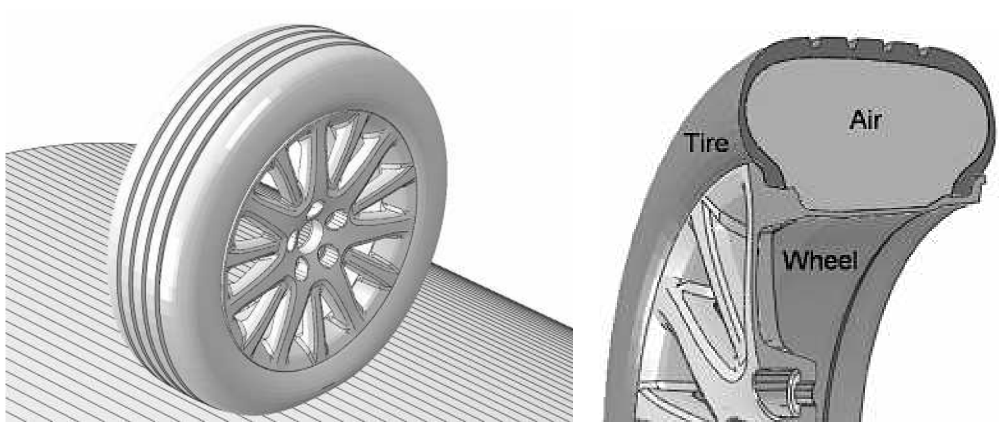


Figure 4. Tire, wheel and inside air FE model in step-2 (model #2).

Figure 5 shows frequency response function of model #2 subject to static contact with a flat surface comparing with measurement. Upper chart shows the response of tread surface under excitation to the same point and lower chart shows the response of spindle under excitation to tread surface of the top of a tire. FE results show good correlation with measurements including the peak of cavity resonance at 220 Hz. It is concluded that this FE model has enough accuracy.

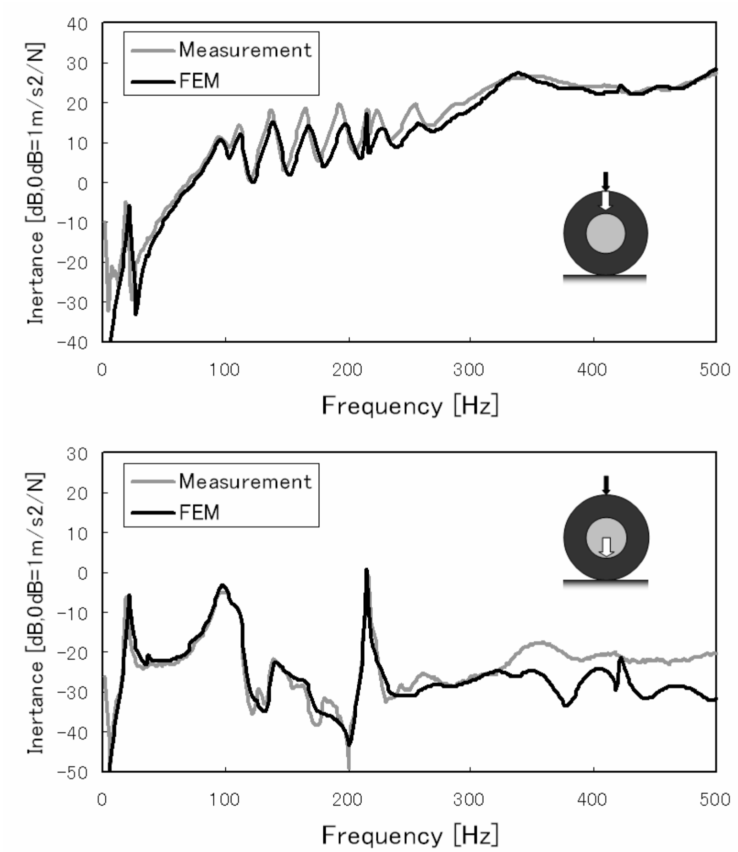


Figure 5. Comparison of inertances between FEM and measurement when the tread surface of a top is excited (upper figure: response at driving point. lower figure: response at spindle).

The step-2 consists of steady-state rolling simulation and frequency response analysis to extract vibration of a rolling tire due to contact force variation. Steady-state rolling simulation is carried out to consider the effect of centrifugal force and Coriolis force. Contact force variation obtained previously by quasi-static rolling simulation of a treaded tire is mapped onto contact patch of model #2. Contact normal force distribution of treaded tire obtained by quasi-static rolling simulation and mapped normal force distribution onto the model #2 are shown in figure 6 respectively. To satisfy the consistency of boundary condition near contact patch, contact force variation is transformed to prescribed displacement variation using the reduced stiffness matrix of a rolling tire using in-house tool. Guyan reduction is applicable to compute the stiffness matrix of a reduced substructure in which DOF of contact patch is retained. The transformation is conducted by developed in-house code.

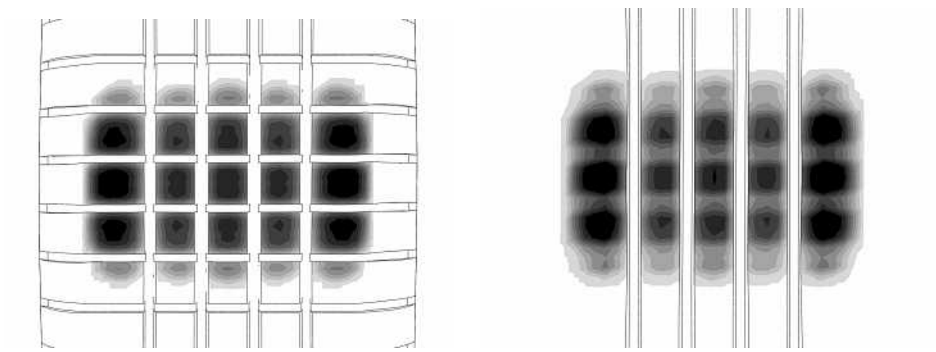


Figure 6. Contact normal forces on model #1 (left figure) and mapped them onto model #2 (right figure).

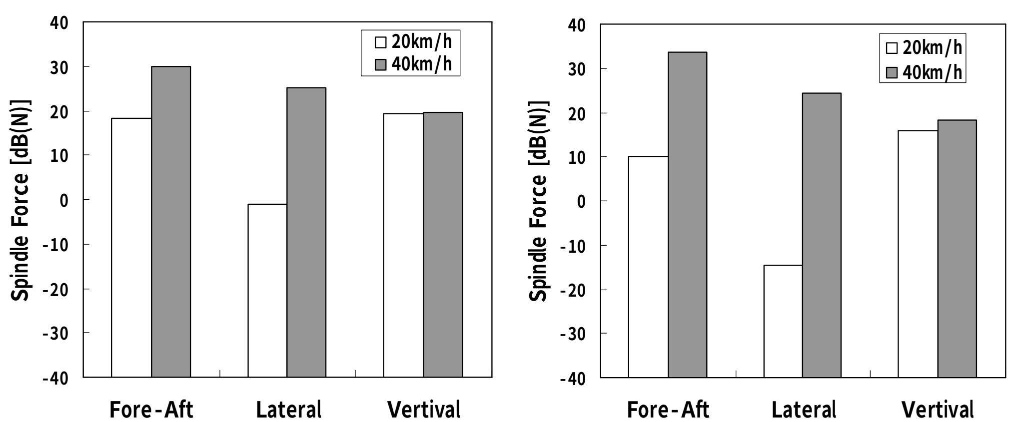
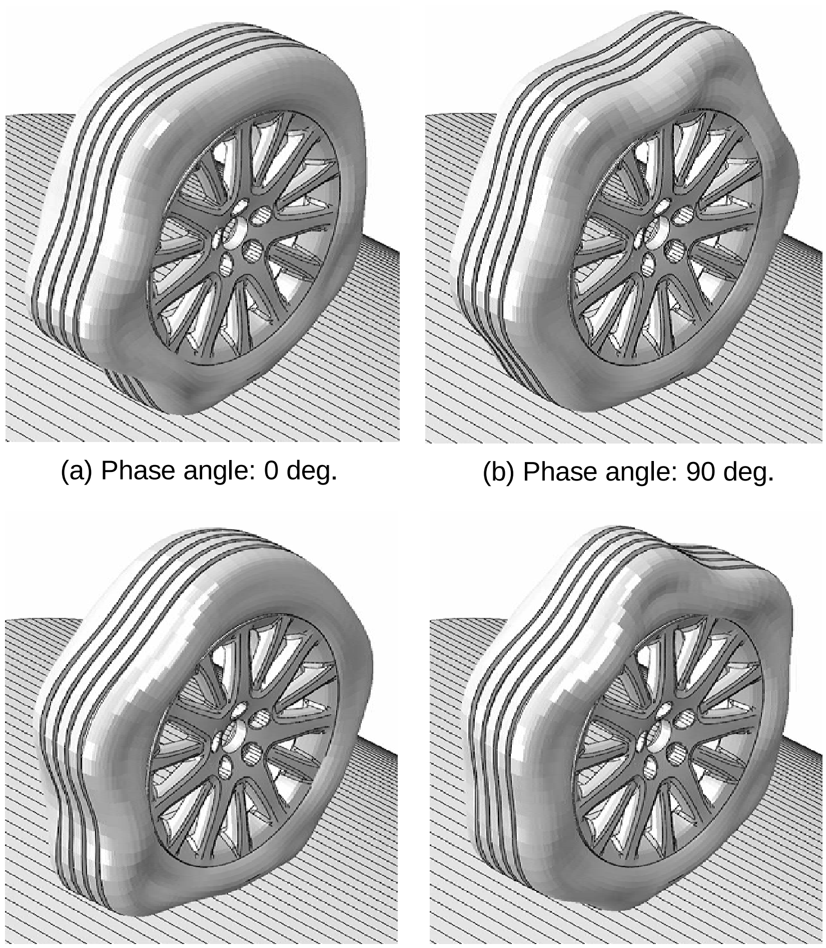


Figure 7. Comparison with measured spindle force (left figure) and calculated spindle force by FEM (right figure).

Figure 7 shows computed spindle force variation of 1st pitch peak due to excitation by tread pattern. Since the input by the pattern is transmitted to a spindle through the vibration transmissibility of a tire, spindle force variation of the 1st pitch varies with travel velocity. The relation of each component at the different velocity obtained by FEM is reasonably close to experimental result. It guarantees the reliability of coupled simulation between step-1 and step-2.

Figure 8 shows tire variation mode with considering gyro-effect at 20km/h. It is recognized that the mode rotates with the change of phase angle.



(a) Phase angle: 0 deg.

(b) Phase angle: 90 deg.

(c) Phase angle: 180 deg.

(d) Phase angle: 270 deg.

Figure 8. Tire vibration mode at 20km/h.

3.3 Acoustic simulation (step-3)

The last step is acoustic simulation. Acoustic FE model surrounding a loaded tire on a drum is shown in figure 9. The surface of a drum is also modeled to compare the result with measurement of indoor test. Infinity element is used and ASI element is also used to input vibration of a tire obtained at previous step. To simplify the model, wheel is replaced by flat plates.

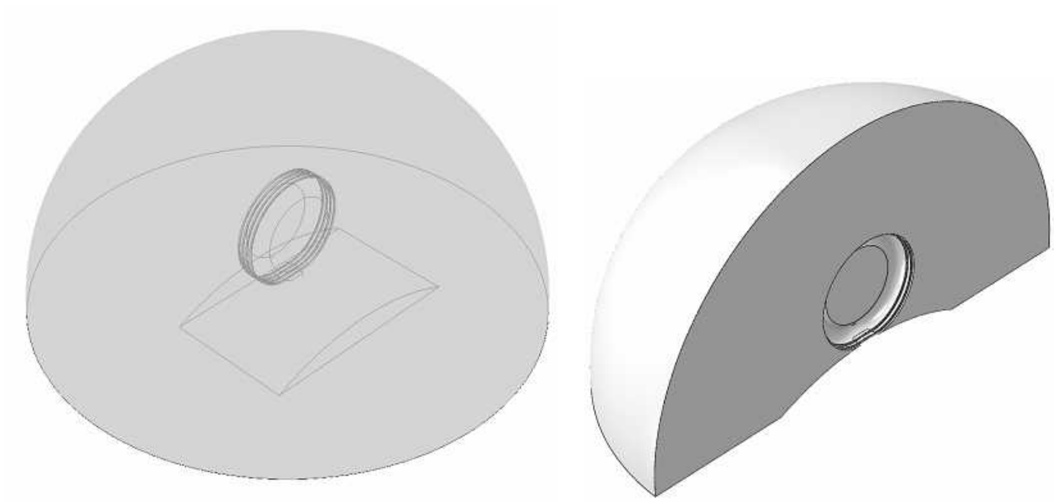


Figure 9. Acoustic FE model surrounding a tire in step-3 (model #3).

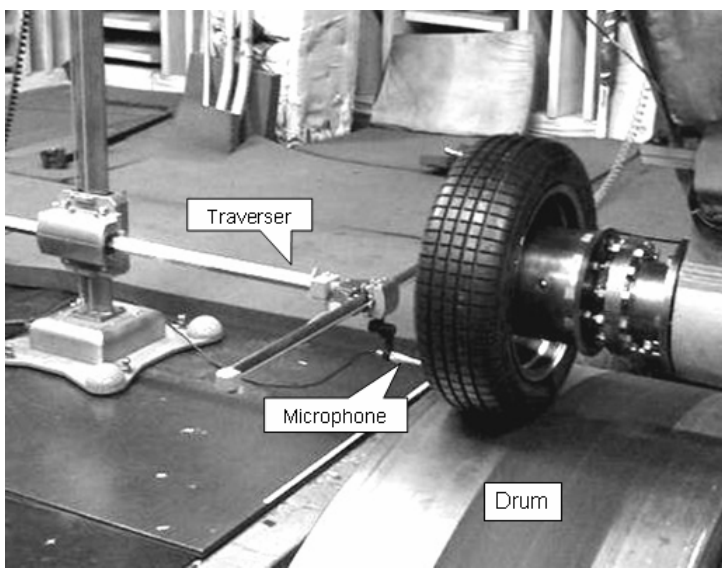


Figure 10. Experimental setting at a semi-anechoic room.

The submodeling capability in Abaqus/Standard is ideal for sequentially coupled structural-acoustic simulations where the structural deformations caused by pre-loading are small. However, the tire footprint loading causes large deformations that cannot be handled directly by structural-acoustic submodeling. So, the geometry of outside a deformed tire resulting in step-2 is modeled by CATIA V5 and outside surface of a tire is modeled by ASI elements. Vibration of outside surface of a tire is extracted from odb file obtained at step-2 and is applied to ASI elements using in-house tool as boundary condition.

Numerical results are compared with experimental measurement at a semi-anechoic room shown in figure 10. Resulting sound pressure level distributions of the side neighborhood of the tire are showed in figure 11. Upper figure shows the results of FEA and lower figure shows those of measurement. High sound pressure level at leading edge and trailing edge is observed from both FEA and measurement. Numerical result is reasonably close to experimental result.

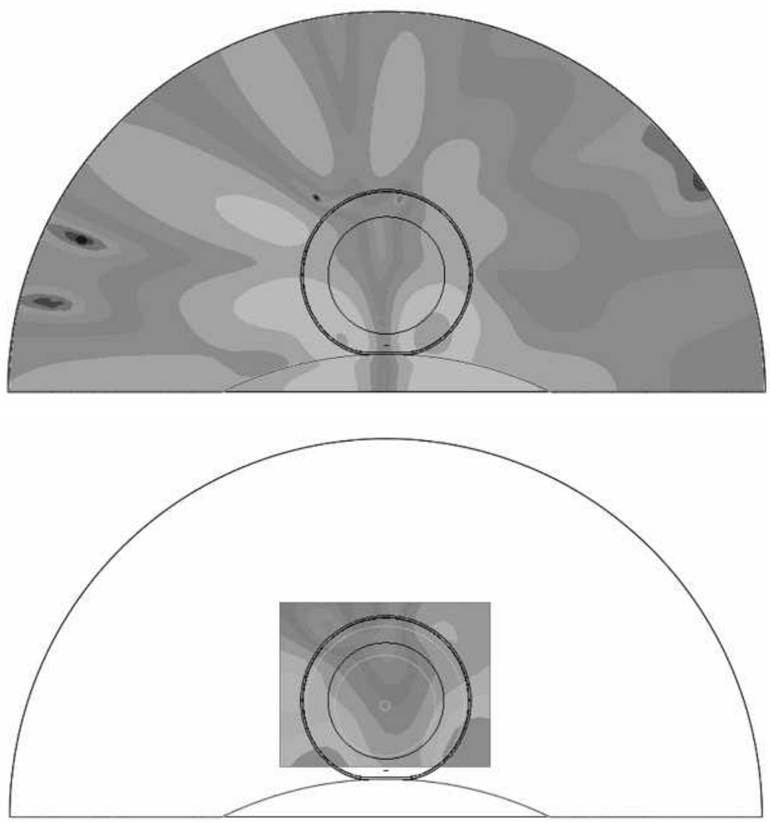


Figure 11. Sound pressure level distribution at 20km/h by FEM (upper figure) and measurement (lower figure).

4. Conclusions

- The procedure of sound radiation simulation of a rolling tire due to tread pattern excitation and numerical experiments are presented.
- Procedure is made up of three steps, i.e. quasi-static rolling simulation of a treaded tire, frequency response analysis of a steady-state rolling tire without lateral grooves, and acoustic simulation surrounding a tire
- Since the deflection of a rolling tire increases in comparison with that of a static tire prescribed displacement, which is consistent with deflection due to specified load in a rolling state, is applied to tire spindle.
- To keep consistency of the boundary condition of contact area, contact force variation is transformed to prescribed displacement variation using the reduced stiffness matrix of a rolling tire.
- Numerical results using Abaqus/Standard show reasonably close to experimental measurements.

5. References

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