Simulation of the radiation of a gearbox

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Abstract

With the emergence of electric powertrain, the radiation of noise due to the main engine has been highly reduced. New sources previously less present are becoming dominant (gearbox, HVAC systems, electric pumps…). The example is the gearbox which will be analyzed here.
The evaluation of the gears forces is done using a flexible body analysis simulation in order to obtain the detailed force spectra at the bearing of the gearbox housing and detect the critical frequencies for each RPM. The housing of the gearbox is modelled as finite elements and the radiation will be computed using the BEM method in order to predict the detailed noise radiated field. The simulation results for a run-up simulation will be presented.

Introduction

The gearbox in an automotive is becoming one of the main sources of noise due to the electrification of the vehicles. This paper will present a simulation method to predict the gearbox noise radiation, from the prediction of the efforts generated by the gears at the bearing using a detailed FEM simulation to the radiation of the housing of the gearbox using a fully coupled FEM/BEM model. ESI Group have developed coherent suite VPS / VA One [1][2]to address this kind of problematic from the source generation of noise to the radiation as described on Figure 1.

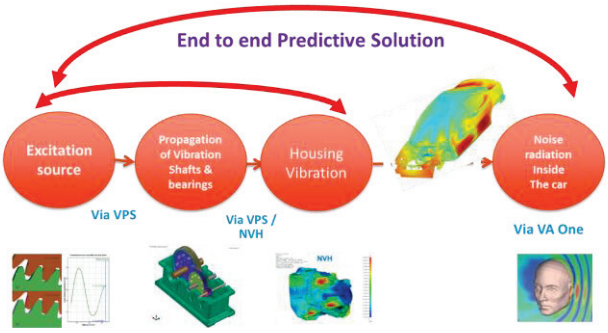

Figure 1: Overview of the simulation process proposed

Prediction of the gear dynamics

In this paper, a detailed method has been chosen to investigate the dynamics of the gears. Other methods like the multiple body simulation (MBS) can also be used. They are faster but does not give the possibility to model explicitly the complexity of the gears geometry and cinematic details. This method will ensure more detailed results. In the model, all the parts are modelled explicitly using a solid element mesh. The contact regions between the teeth have a refined mesh. This is done to improve the description of the contact between the teeth and better predict the generated forces transmitted to the housing through the bearings. Figure 2 shows the model used for the gears simulation and a detail of the teeth.

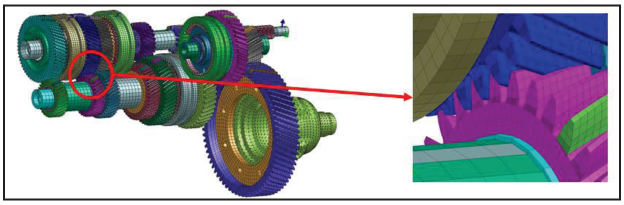

Figure 2: Details of the gear mesh

The bearings are modelled with spherical kinematic joints. The stiffness of the joints is set to 3kN/mm. To make the gearbox system in action, a resistant torque is applied on the differential gears (Figure 3). For the simulation, the 2nd gear is set with a nominal rotational velocity of the primary shaft of 3000RPM. The contact between the teeth is represented in this example as dry.

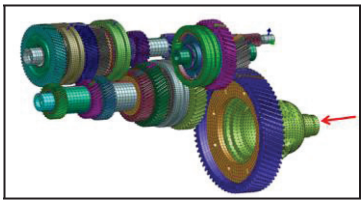

Figure 3: Torque excitation to the gearbox

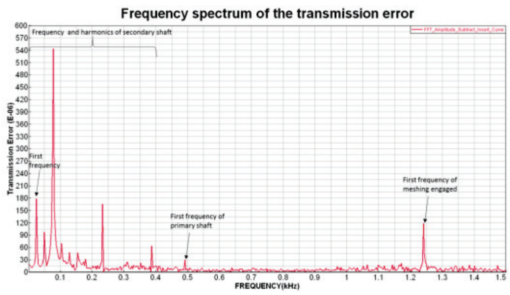

Figure 5: frequency spectrum of the transmission error

Figure 4 shows an example of transmission error obtained from the model. Before 100ms of run, the response is transient. Only the signal after 100ms of run will be used later to do the Fourier Transform. Figure 5 shows the frequency spectrum of the transmission error.

Figure 4: Time simulation of the transmission error

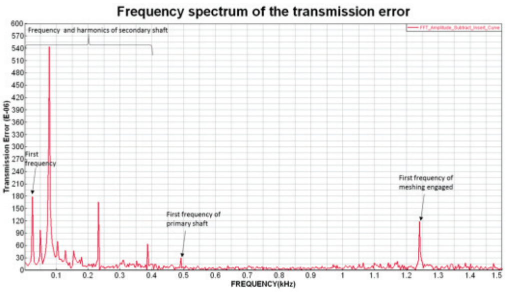

Figure 5: frequency spectrum of the transmission error

The transmission error spectrum shows the main frequency of the meshing engaged at 1241.5Hz.

For the further vibro-acoustic simulation, the forces are evaluated at the 8 bearings in the 3 directions. A FFT is made to convert the time domain data to frequency domain.

A run-up simulation will be also presented in the paper.

Vibro-acoustic simulation of the gearbox

A fully coupled FEM/BEM vibro-acoustic model of the gearbox has been built in order to predict its noise radiation. In this paper, the analysis will be run up to 2.5kHz. Simplified methods are also sometime used to predict the noise radiated by the gearbox like the Equivalent Radiated Power (ERP). However, the ERP method is limited in its validity due to the assumption of a radiation efficiency equal to 1. This is only valid at high frequency. A fully coupled FEM/BEM model will provide more realistic results.

Structural model

Only the housing of the gearbox is included in the model. The gears are included within the excitation generated by the flexible body simulation. The model is made of solid quadratic tetra elements representing the housing of the gearbox. The material used is steel. The mesh is valid up to 3.5kHz with 6 elements per wavelength. Coupling elements are representing the bolts connecting the different parts together. Figure 6 shows an overview of the housing of the gearbox.

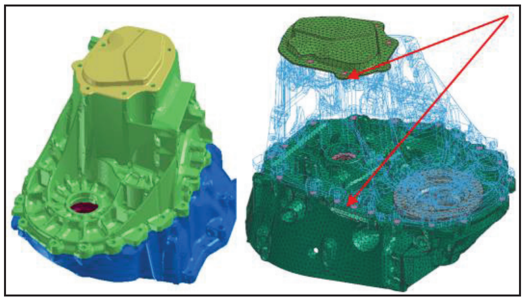

Figure 6: Left side, overview of the structural FEM model, right side, overview of the connection points

Rigid elements are used to simulate the bearings. The forces calculated using the flexible body model are applied on the center of the rigid element simulating the bearings in the 3 directions (x,y,z). Figure 7 shows the location of the forces on the housing model.

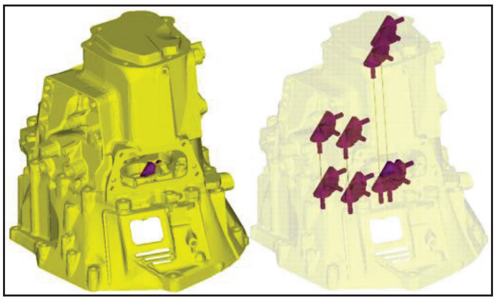

Figure 7: Force location at the bearings

The modes of the house were computed up to 3300Hz, 25 modes have been identified. The list of the first 8 modes is displayed in Table 1.

Table 1: First 8 modes eigen frequencies of the housing in Hz

Mode	Frequency	Mode	Frequency
1	837	5	1567
2	988	6	1668
3	1203	7	1765
4	1463	8	1855

BEM model

The coupling between the structure and the acoustic is represented by BEM elements. The BEM mesh is morphed to the shape of the structure (**Figure 8**). The BEM coupling surface is meshed with 6 elements per wavelength of the air for a validity up to 2.5kHz. The BEM mesh does not need to be coincident with the FEM structural mesh of the housing. Microphones are located around the gearbox in order to recover the pressure at 1m from it (**Figure 9**). A data recovery face is created to visualize the sound pressure level and the intensity. This surface will help to identify where the critical points are located.

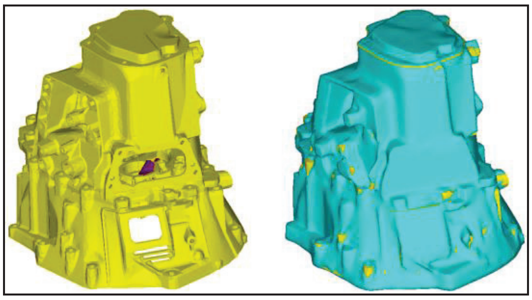

Figure 8: Comparison of the FEM structural and BEM acoustic shape meshes

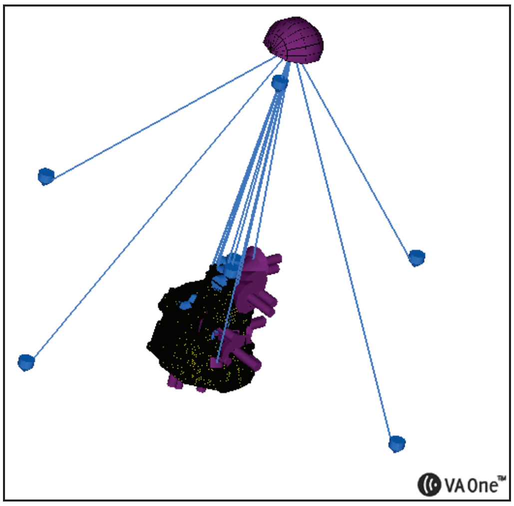

Figure 9: Representation of the BEM model with microphones

Results

The model has been computed from 500 to 2500Hz with a frequency step of 20Hz. The modes are computed using ESI Group software VPS an implicit solver [1]and the BEM intermediate results and coupled response using ESI Group software VA One [2].

The sound pressure levels microphones at the different microphones shows peaks at the different modes frequencies. At 1241Hz a peak can be observed. It is corresponding to the main whining frequency. However, it is not the highest peak present in the curve for the pressure and the power radiated (Figure 10, Figure 11). For this frequency, the mode shape, intensity maps are displayed on Figure 12. These maps can show where most of the energy is being radiated from the gearbox housing. It is a good indicator to help the design of updates in the structure or showing that the upper side of the gearbox where the shift lever is implemented is the most radiated zone. This allows us to notice where the high levels of energy are located. From this figure, some design changes can be decided and investigated. This was the topic of another article [3]. A mode has also been identified at 1203Hz (see Table 1). But the contribution of this mode despite its close location to the whining noise maximum is not significant. This mode is having an effect on the cover of the housing.

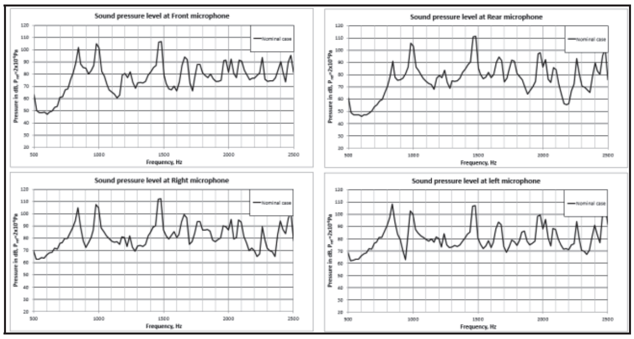

Figure 10: Sound pressure level at microphones

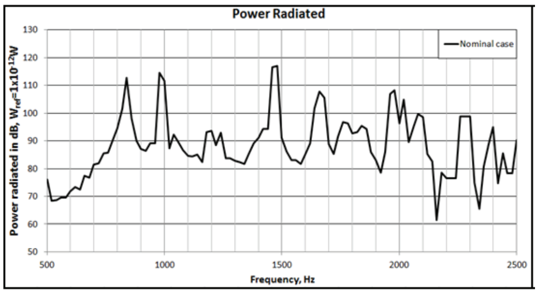

Figure 11: Power radiated by the housing of the gearbox

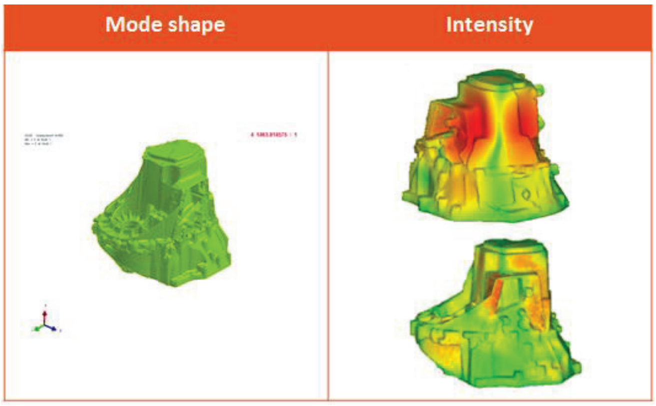

Figure 12: Mode shape and intensity map at 1460Hz

Run up simulation

A run-up simulation has been investigated using this process. The gear kinematic simulation was run from 500 to 4000 RPM with 50RPM steps. For each RPM, the forces at bearing have been extracted and applied to the FEM/BEM vibro-acoustic model. To visualize the results, Campbell diagram have been prepared. The Campbell diagram is displayed in Figure 13 On the diagram, the rays due to the different modes can be clearly identified. It is more difficult to identify the rays due to the engine orders. This is due to a low amplitude of the excitation. On this graph can be identified the highest pressure levels. In this case, it seems to be at around 1760Hz for RPM of 3300. The intensity map (Figure 14) at the surface of the gearbox housing can be analyzed and design changes proposed.

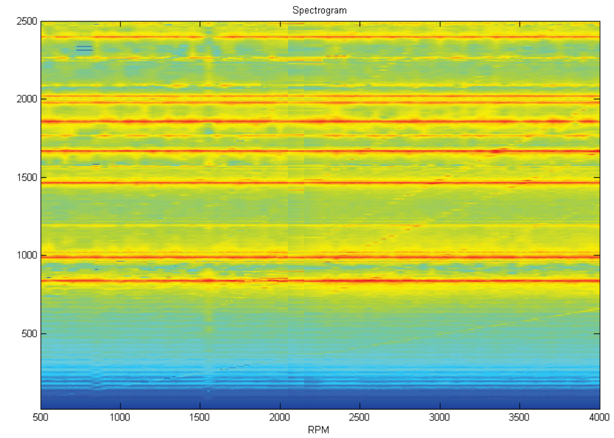

Figure 13: Sound pressure level as Campbell diagram

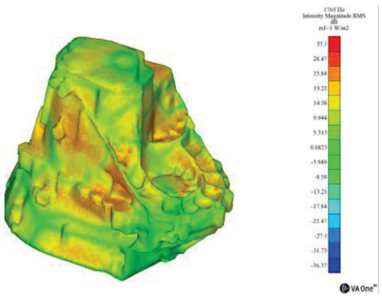

Figure 14: Intensity map at 1760Hz, 3000RPM

Conclusion and perspectives

With the electrification of the vehicles, the gearbox noise becomes a more dominant source within the different sources contributing to the sound pressure level perceived by passengers. It is important for the OEM to predict this noise using a predictive method. This paper has proposed using ESI software VPS and VA One a method to predict the noise radiated by a gearbox with details for a single RPM and also for a run-up case. In a previous paper was investigated the influence of design changes. The strength of the method presented is that for each steps, the user can assess the sensitivity of the model to modelling choices or design changes [3]. Further investigations are currently done to check the influence of modelling the housing of the gearbox within the gear simulation.

Literatur

[1] VPS user's manual 2015, ESI Group, www.esi-group.com

[2] VA One User's Guide 2016, ESI Group, www.esi-group.com

[3] Caillet A., Van Hal W., Gargouri Y., From gears dynamic to noise radiation, End to end simulation of a gear box, Akustik Aachener Kolloquium 2016