

Application of the Hybrid FE-SEA Method to Predict Sound Transmission Through Complex Sealing Systems

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ABSTRACT

Currently, the use of numerical and analytical tools during a vehicle development is extensive in the automotive industry. This assures that the required performance levels can be achieved from the early stages of development. However, there are some aspects of the vibro-acoustic performance of a vehicle that are rarely assessed through numerical or analytical analysis. An example is the modeling of sound transmission through vehicle sealing systems. In this case, most of the investigations have been done experimentally, and the analytical models available are not sufficiently accurate. In this paper, the modeling of the sound transmission through a vehicle door seal is presented. The study is an extension of a previous work in which the applicability of the Hybrid FE-SEA method was demonstrated for predicting the TL of sealing elements. A numerical validation of simplified Hybrid FE-SEA model is performed, which is followed by the application of the method to the TL of a car door seal. A full non-linear deformation/contact analysis is used to estimate the deformed geometry of the door seal in real conditions. The geometry is then used in a vibro-acoustic analysis to predict the in-situ transmission loss of the seal using a local Hybrid FE-SEA model. The channel between the door and the car structure where the seal is located is also included in the analysis. Results for the transmission loss are compared with experimental data, showing a good correlation.

INTRODUCTION

The last decades have seen intense research in noise control treatments applied to vehicles, which have resulted in a significant reduction in interior noise of new cars, trucks and buses. Such reduction was achieved by treating the main noise sources and transmission paths to the vehicle interior, such as the engine vibration and the airborne transmission through body panels (dash panel, windshield, doors, etc). With the reduction of the noise transmitted through these paths, other paths once though as secondary start to have a significant contribution to the interior noise levels. The sound transmission through sealing elements is an example of a secondary path that is now gaining importance. Assuming that the seal is properly installed (no aspiration noise), the sound transmission through the seal is a result of the radiated sound by the seal wall vibration, which in turn is due to the acoustic field inside the channel (cavity between the door and the vehicle frame, see Fig. 1) [1]. The acoustic performance of the seal can be an important factor to the interior noise of a vehicle in mid and high frequencies. As a consequence, there is an interest in optimizing the seal to reduce noise transmission. In order to reduce costs and time, such optimization must be done through the vibro-acoustic simulation of the sealing system.

Previous studies have relied on a 2D numerical model of the seal in order to investigate the sound transmission through sealing systems [1,2,3,4]. Typically, the sound transmission

was calculated by representing the seal deformed geometry using the Finite Element (FE) method and applying an acoustic excitation directly to the seal wall. In general, the studies have displayed different agreements with experimental results, varying from less than 5 dB [2] to around 10 dB discrepancies [1,3].

More recently, two aspects of the vibro-acoustic modeling of sealing systems were numerically investigated [5]: (i) the errors associated with a 2D model of seal and acoustic field, and (ii) the influence of the channel on the transmission loss of the seal. The Hybrid FE-SEA method [6,7,8,9] was used in the analysis. It was shown that the use of a 3D representation of the acoustic field can be important to capture some of features of the systems, and that the use of a 2D diffuse acoustic field can over estimate the transmission loss of the seal. It was also observed that the inclusion of the channel (not considered in previous studies) in the model has a significant impact over the transmission loss of the seal, reducing the transmission loss of the system by around 10 dB.

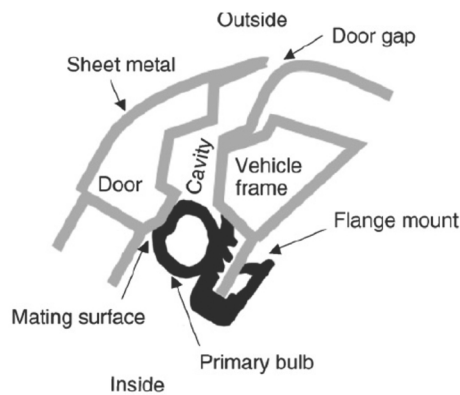


Figure 1. Cross-section of a typical car door seal installation [1].

The main aim of the present paper is to numerically and experimentally validate the Hybrid FE-SEA models of the sound transmission of sealing systems. In what follows, a review of the numerical approach used in [5] is presented, and the development of Hybrid FE-SEA models of the channel and the seal system is discussed. Numerical results for the TL of a slit and a simplified seal are presented and compared with BEM results. The method is then used to model the TL of a car door sealing system. The experimental procedures used to characterize the seal material and measure the sound transmission loss of the system are described. Finally, numerical and experimental results are compared, and some conclusions of the study are presented.

SOUND TRANSMISSION LOSS OF SEALING SYSTEMS

The problem related to the diffuse-field sound transmission through a sealing system is represented in Fig. 2. The seal is located inside the door channel (gap between the door and the car frame), with varying width w , channel depth b and length L (dimension perpendicular to the plane shown in Fig. 2 and much larger than w and b). A diffuse acoustic field (DAF) is assumed at the source side, and the aim is to estimate the transmitted power W_t to the receiver side. Given the incident power W_i , the transmission loss of the system can be calculate as

$$TL = 10 \log \left(\frac{1}{\tau} \right), \quad (1)$$

where

$$\tau = \frac{W_t}{W_i}, \quad (2)$$

while the incident power in a DAF can be calculated as

$$W_i = \frac{\langle p^2 \rangle}{4\rho c} \quad (3)$$

with $\langle p^2 \rangle$ been the far-field time-averaged square pressure, ρ is the fluid density and c is the speed of sound in the fluid. The objective of any numerical model is to predict the transmitted power to the receiver side and to estimate the TL of the system.

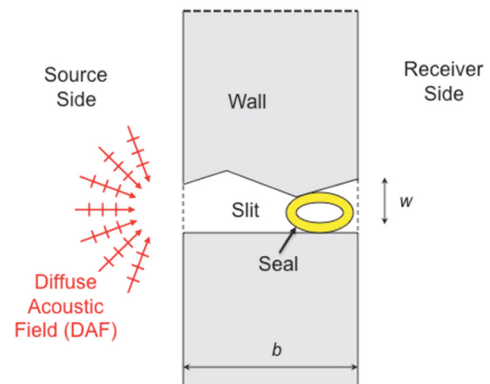


Figure 2. Schematic representation of the sound transmission through a sealing system.

HYBRID FE-SEA MODELS

The prediction of the sound transmission through openings has been the subject of many published studies, and an extensive review of the subject can be found in ref. [10]. In this paper, the procedure proposed in ref. [5], which is based in the Hybrid FE-SEA method, is used. The Hybrid FE-SEA method is a newly developed method that rigorously coupled FE and SEA methods [6,7,8,9]. The method allows rigid components with modal behavior to be modeled deterministically using FE while highly modal dense components can be described using SEA. The reduction of the number of Degrees of Freedom (DOF) by using a SEA representation of some components can considerably reduce the computational costs of solving the problem. In what follows, the commercial software VA One was used to create the Hybrid FE-SEA models [11].

The Hybrid FE-SEA model of a channel with varying width is represented in Fig. 3. Both the source and receiver sides of the slit are modeled as SEA fluids. The channel is represented by an FE acoustic subsystem, which is coupled to the SEA fluids by means of Hybrid Area Junctions. The model assumes a DAF applied to the channel and that the channel ends are baffled (located within an infinite rigid wall). More details about the numerical approach can be found in [5,6,7,8,9].

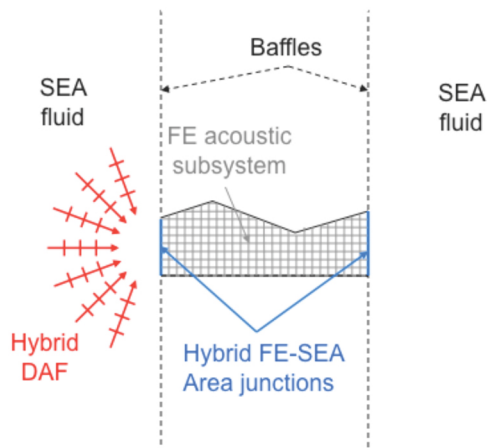


Figure 3. Schematic representation of the Hybrid FE-SEA model of the channel.

In the case of a sealing system as shown in Fig. 2, a FE structural subsystem representing the seal is positioned between two FE acoustic subsystems. Structural and acoustic FE subsystems are coupled through FE area junctions, which means a strong coupling. The source and receiver side are again represented as SEA fluids, which are coupled to the FE acoustical subsystem through Hybrid area junctions. A Hybrid DAF applied to one of the FE acoustic subsystems provided the excitation of the system. Pinned boundary conditions were applied to the nodes seal in contact with the

wall of the channel. In the next section, the approach is used to model a rectangular channel and a simplified sealing system with no channel.

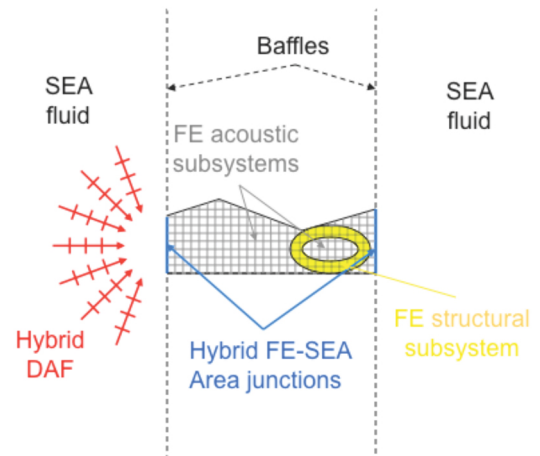


Figure 4. Schematic representation of channel and seal Hybrid FE-SEA model.

NUMERICAL VALIDATION

CHANNEL TRANSMISSION LOSS

A simplified channel of regular dimensions $w = 0.02$ m, $b = 0.06$ m and $L = 0.2$ m was initially considered, and the transmission loss was calculated for the frequency range of 100 to 4000 Hz. Both the FE acoustic mesh in the Hybrid FE-SEA model and the BEM mesh were created so that at least five elements were defined across the slit width. This also ensures a minimum of 6 elements per acoustic wavelength. The first step of the solution of the Hybrid FE-SEA model is the calculation of the modes for the FE acoustic subsystem. It is important that a minimum number of modes are included in the analysis to obtain convergence of the results. A total of 440 modes were obtained up to 20kHz and were considered in the model. Once the modes are available, the full solution was performed and the transmission loss calculated. The solution of the Hybrid model was around 50 times faster than the BEM model. The Hybrid FE-SEA model and the BEM model used for the analysis are shown in Fig. 5, while the calculated transmission loss is shown in Fig. 6. In general, a very good agreement between Hybrid and BEM results can be observed, with results within 1.5 dB. The hybrid model slightly over predicts the transmission loss at low frequencies where the limited length of the channel affects each model differently.

SEAL TRANSMISSION LOSS

The next step was to compare the numerical result for a simplified seal without the channel. The following dimensions for a rectangular seal were assumed: $w = 0.02$ m, $b = 0.018$ m, $L = 0.2$ m, and wall thickness of 2 mm. The