IMPROVED METHODOLOGY FOR SQUEAK & RATTLE ANALYSIS WITH ABAQUS AND CORRELATION WITH TEST RESULTS

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Abstract: : In recent years car manufacturers have been working intensively on new ways to improve the quality of the interior trim since it is extremely important to the customer's perception of quality and can be a source of after-sale complaints. Consequently, the study of squeak and rattle (S&R) has become one of the main concerns for car manufacturers. Simulation of S&R phenomena is a complicated issue to reproduce virtually, because they are difficult to study using methods based on eigenmodes due to the impossibility of using contacts in this type of FE model; since modal theory is based on the hypothesis of linearity. Software providers and automotive engineering companies have been working hard to provide tools and methodologies in order to be able to analyse these phenomena in the initial development phases. In this context, in 2009 IDIADA developed a simulation protocol that took advantage of software already existing on the market (Abaqus) by combining its capabilities to set up a methodology for detecting and analyzing potential S&R problems. This paper presents the latest improvements and correlation of the methodology of S&R detection. The improved methodology was applied to a complex structure (an instrument panel) and the results were compared with measurements.

Keywords: NVH, Squeak, Rattle, Connectors, Postprocessing, Automotive Structures, Instrument panel, Trimmings Development

1. Introduction

In recent years, with the improvement of the acoustic quality of vehicles and engines, other types of noises that normally were hidden by the usual noise of the engine and the rolling noise are now perceived by the occupants. Some of the most annoying ones are the small noises coming from the squeak and rattle of the interior trimmings, which in general have become an indicator of the quality and durability of the product.

Squeak phenomenon is caused by the relative movement between two components that slip and stick alternatively. The elastic deformation of the surfaces in contact accumulates energy and this is released when the static friction overcomes the kinetic friction producing then an audible noise. The generation of this type of noise occurs at low frequencies (under 200 Hz) they are normally induced by energy inputs coming from the suspension system; however the release of the elastic energy produces the vibration of the adjacent surfaces causing contact audible noises in the range of 200 to 10000 Hz (Kavarana, 1999).

Rattle noise is induced by impacts between parts; it is generated by the perpendicular relative movement between two parts, and is usually due to erroneous assembly tolerances or to lack of stiffness. The impacts will only generate noise if the adjacent surfaces to the impact point are capable of radiating audible sound-power levels (Kavarana, 1999).

Traditionally, automotive industry has been using physical testing to detect this kind of defects, but lately some efforts have been put in developing software and methodologies to simulate these phenomena. In 2008 a relatively simple methodology was developed based in ABAQUS for the simulation of the rattle event. This methodology was based mainly in the use of the Connector element of ABAQUS which was used as virtual sensor for the detection of the contact.

In that methodology the Connectors were created automatically in all the areas that can experiment contact events by defining a sphere of influence or a radius suitable for the model in relationship to the clearances of the structure.

During the simulation all basic and required information for the Squeak & Rattle analysis are stored in the Connector element. The connector section is defined as BUSHING and in that way, a connection between two nodes is created such as it allows independent behaviour in three local Cartesian directions that follow the system at both nodes a and b. Three amplitudes expressed in three local Cartesian directions can be obtained:

- Displacement amplitudes expressed in local directions 1 and 2, which are tangential to the connector.
- Displacement amplitude expressed in local direction 3, which is coincident with the axis of the connector itself.

With the normal NVH model plus the virtual sensors any type of vibratory simulation can be launched (direct response, modal superposition,…). In the time domain the virtual sensors wouldn’t be necessary because it is possible to define contacts between pieces, but in the frequency domain, they are the only way to detect where a contact will probably arise. The connectors allow tracking the steady-state amplitude of the movement relative to the two parts which the sensor is connected for each value of frequency in the range of study. In other words, it will be possible to study the resulting penetration between parts for each frequency. This value of penetration is the key to evaluate the chance of squeak or rattle.

The last step is the post processing. As mentioned before, the virtual sensors provide the amplitude of movement between two parts. Nevertheless, this value by itself alone has no valuable information for the final objective. The chance of squeak or rattle is not determined by the value of amplitude alone. The value of penetration must be calculated to do so.

In the methodology developed in 2008 the chance of rattle was related to the value of the calculated penetration. The chance of rattle, was automatically calculated using scripting and stored in a results file for its graphical post processing. Rattle was represented in the first version of the methodology as vectors being their magnitude the value of penetration between parts. This kind of visualization allows a rapid detection of problematic areas and an easy understanding of the phenomena by means of the analysis of the movements. For a better visualization it is possible to sweep the frequency within the whole range of study and follow the appearance of the rattle depending on the frequency. Another possibility is to analyze the most critical frequencies using a 2D plot. Using scripting an ASCII file is created with a sum up of the rattle issues that appear in the whole frequency range of study.

The script scans all connectors' responses and searches the frequency of the maximum penetration detected for all the connectors and saves the frequency of appearance and the value of amplitude. Such file can be visualized in a variety of spreadsheets in order to analyze the frequency ranges where the phenomenon appears.

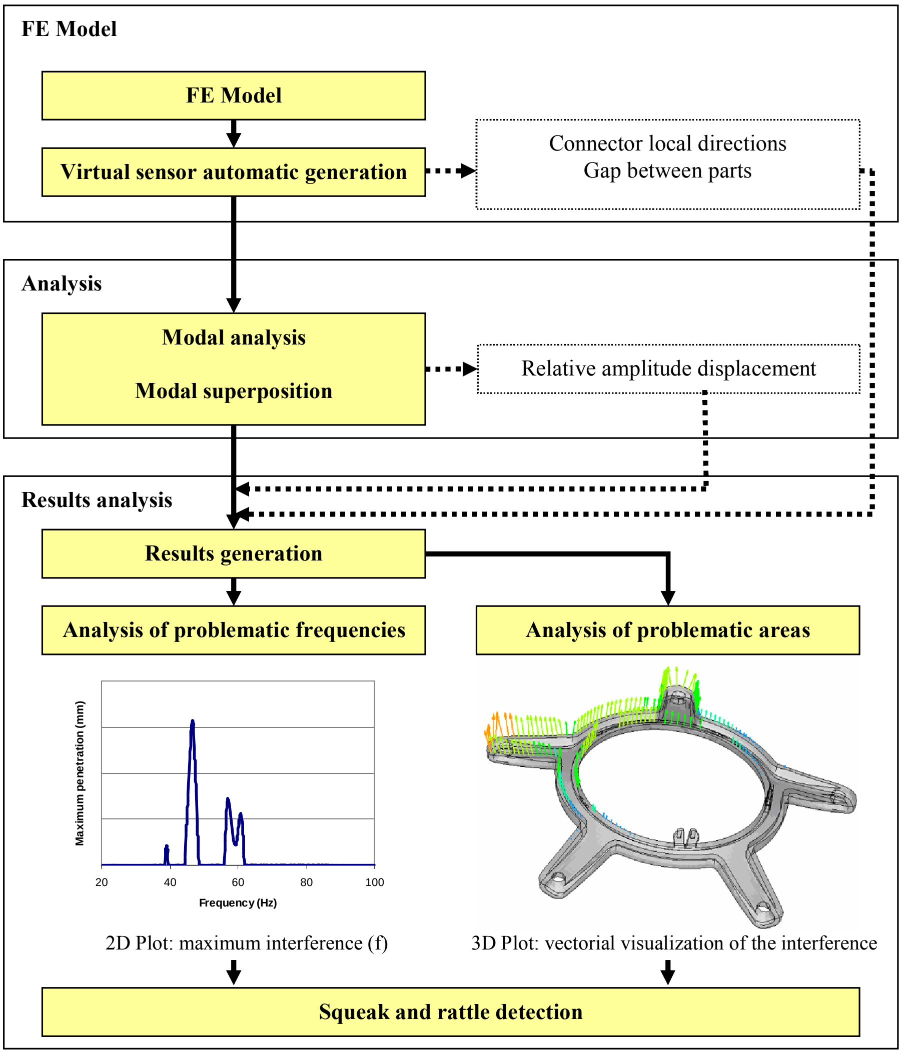


Figure 1. Workflow of the methodology

The main workflow of the methodology is shown in Figure 1.

With the work done since 2008, some improvements have been introduced in the methodology in order to validate it for complex structures:

- the accuracy of the interference detection has been increased

- the automatic creation of the connectors has been sped up and their location is now more realistic

- the criterion of rattle detection has been also improved

Finally, as it will be explained in the following paragraphs, a complex automotive structure has been tested within the methodology in order to establish the modelization rules required for an acceptable degree of correlation of the rattle. In that process, the weak points of the methodology for its usage in normal development projects were also pointed out.

2. Improving the methodology

The basic methodology was developed in 2008 taking as sample a simple piece (a wheel trim), however in order to assure its robustness more complicated components were also tried. The instrument panel of the new SEAT Ibiza was taken as sample and was used for validating the methodology and correlating the rattle results.

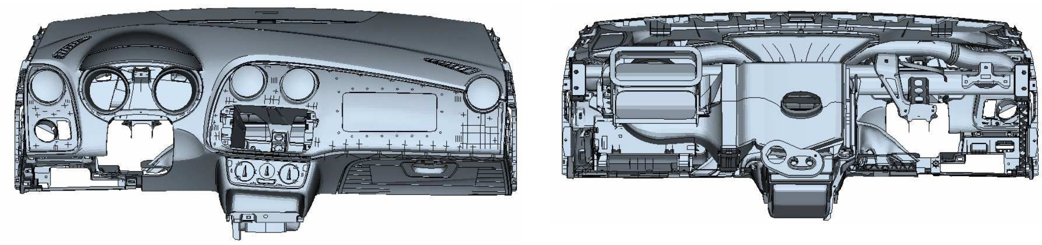


Figure 2. Instrument panel used for the study, courtesy of SEAT.

2.1 Rattle detection criteria

In the first version of the method it was assumed that the rattle ratio was equivalent to the interference measured by the Connectors, however the following aspects should be taken into account:
- at low frequencies the amplitude of movements is normally higher than at high frequencies and, therefore, the calculated interference will also be bigger. However, the low frequency movements have low associated velocities and, therefore, the kinetic energy in the impact can also be low (low dissipation of energy through the rattling event).
- at high frequencies the displacements are normally lower, but the velocity in the instant of the impact can be high.

For the previous reasons, it was considered that the evaluation of the kinetic energy at the impact time and its usage as scale factor for the interferences could offer a better approach as rattle criterion; therefore, the rattle ratio is calculated as the product of the interference detected and the kinetic energy at the impact time. All detected rattle ratios are afterwards scaled in reference to the highest rattle detected. It must be noticed that the rattle ratio is a relative value, it has no physical meaning; it shows only a bigger chance of having a rattle in one zone than in another according to the interference degree and the kinetic energy of the impact.

The *interference* in each connector is calculated as the difference between the longitudinal movement of the connector and the initial gap between the pieces. In point 2.2 it is explained why in the new version the gap is directly the elongation measured by the connector, and in that way the procedure has also been sped up.

2.2 Clearance analysis

In the previous version of the method, connector elements were created directly from mid-surfaces. This way of procedure implied that thicknesses of the different parts had to be taken into account in order to calculate the real gap between parts.

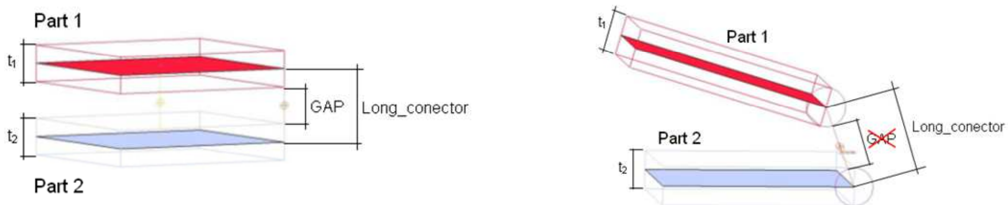


Figure 3. Evaluation of the gap in parallel elements or in elements with angle.

When parts are parallel, the calculation of the gap value is straight forward; half of the thickness of each part is subtracted from the connector length. However, when parts are not parallel one to each other, the relative angle between parts plays an important roll in the gap value. This fact makes the calculation of the gap value more tedious.

It has been seen that the correct calculation of gap value is essential since the final value of rattle is directly dependant on it. If the gap value is incorrect, the results for the rattle will also be incorrect.

In this sense, after studying different proposals, it has been accepted that the best way to procedure is to volumize the mid-surface shells so that we work with a model which is more representative of the real geometry. Working this way, the connector lengths are directly the gap between parts since the relative angle is implicitly taken into account.

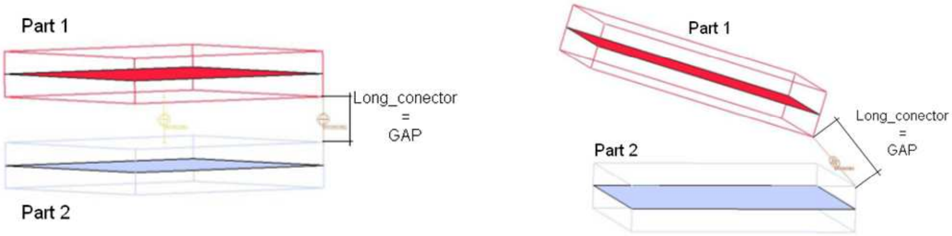


Figure 4. Effect of the volumize tool.

It is also interesting to note that with the new technique we make the routine more precise since more connectors are created. Besides, since the gap value is directly the connector length and there is no need to subtract any thickness from it, the time execution of the routines has been improved significantly.

The main disadvantage of generating the connectors using the volumized mid-surface shells is that more connectors than the ones strictly needed are created. For this reason, the routines have been adapted in order to delete those connectors that either have no physical meaning or give no additional information for squeak and rattle purposes.

3. Improving the correlation

The detection of the rattling event is based on an accurate simulation of the frequency response functions (FRFs) of the areas susceptible of having a contact event. For that reason, a big effort has been put in improving the correlation not only in terms of the eigenmodes but also in terms of frequency responses.

The improvement of the correlation has been carried out in two steps. In the first one the eigenmodes of the whole instrument panel as a global model and also by different areas were studied and compared with the experimental ones. Table 1 shows the Modal Assurance Criterion (MAC) values of different modal pairs. The MAC values have been calculated for the whole structure as well as for specific areas in an effort to localise the areas of higher discrepancies. All MAC value calculations have been performed on the same test and simulation data.

	Test Freq. (Hz)	Sim. Freq. (Hz)	Global MAC	MAC without HVAC	MAC without glovebox	MAC only outer panel	MAC only MQT
1	28.8	28.1	**0.77**	0.83	0.83	0.91	0.69
2	33.1	34.2	**0.51**	0.54	0.53	0.61	0.71
3	40.7	36.6	**0.70**	0.74	0.71	0.77	0.67
4	43.3	40.4	**0.57**	0.63	0.70	0.80	0.63
5	93.9	82.1	**0.53**	0.59	0.56	0.61	0.52

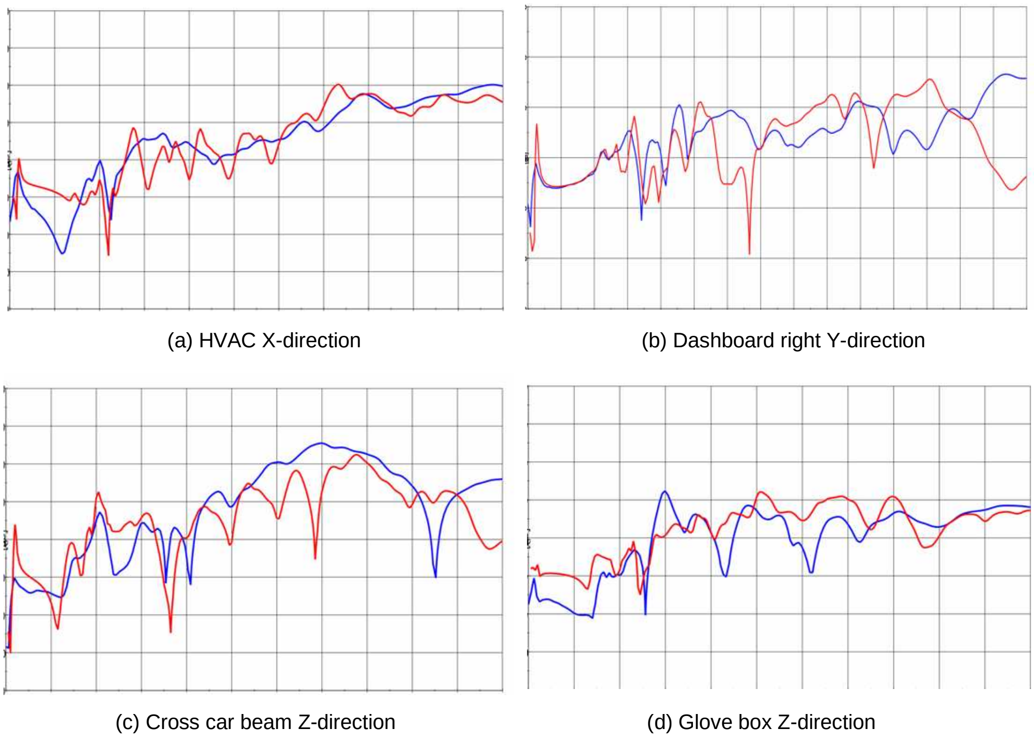
Table 1. Global and partial MAC values.

The correlation of a model with test results of a complex part, such as an instrument panel, possesses several challenges because of the complicated connections of different components. Several modifications were tested and implemented in order to improve the correlation of the instrument panel under study compared to previous published result (Lama, et. al., 2009). The main modifications are the addition of more geometrical details, including the masses of the radiators in the HVAC system, as well as the use of more appropriate values for the stiffness of different connection points.

Three connection points were found to influence the results the most and were studied more intensively. These points are the two connections of the HVAC ducts leading to the two side diffusers and the connection of the HVAC duct leading to the central diffuser. The values of the stiffness of these connection points were determined through an optimisation procedure which aimed to minimise the difference between measured and simulated FRFs for all the measured points.

In the following pictures some examples of the degree of correlation of the FRFs are shown. The modifications introduced in the model led to better results not only in the MAC values but also in the FRFs comparison.

Figure 5. Testing layout of the instrument panel.



(a) HVAC X-direction

(b) Dashboard right Y-direction

(c) Cross car beam Z-direction

(d) Glove box Z-direction

Figure 6. Comparison of measured FRF (in red) and simulated (in blue) for four different points

4. Rattle results

A listening test was performed on the real structure and the dominant areas of S&R generation were identified for different frequencies. A rattle simulation was also performed for the same excitation as in the listening test. The simulation was able to predict the rattle areas with a reasonable degree of correlation. Figure 7 shows However, there were more rattle areas detected by the simulation compared to listening test. Some of the reasons for this discrepancy, regarding the simulation procedure, could be small differences between the mesh of the FE model and the real structure, especially regarding clearances, the generation of some misplaced rattle sensors during the automatic generation procedure and the poor correlations at some part of the model.

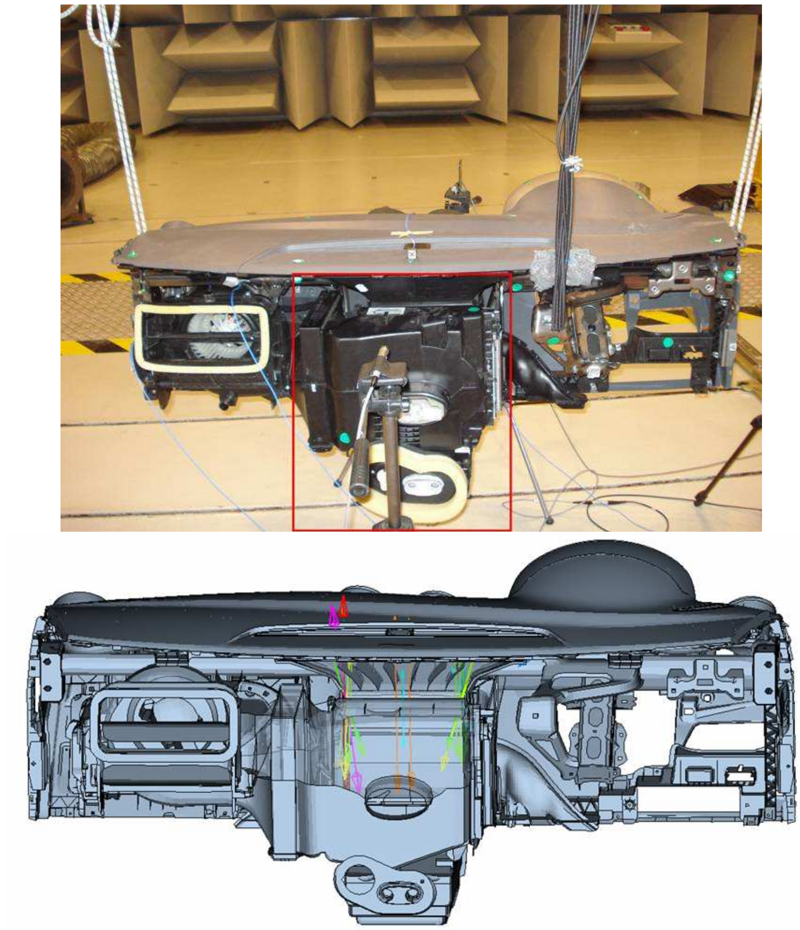


Figure 7. Rattle detected in the connections of HVAC tubes in the frequency range 41Hz-46Hz

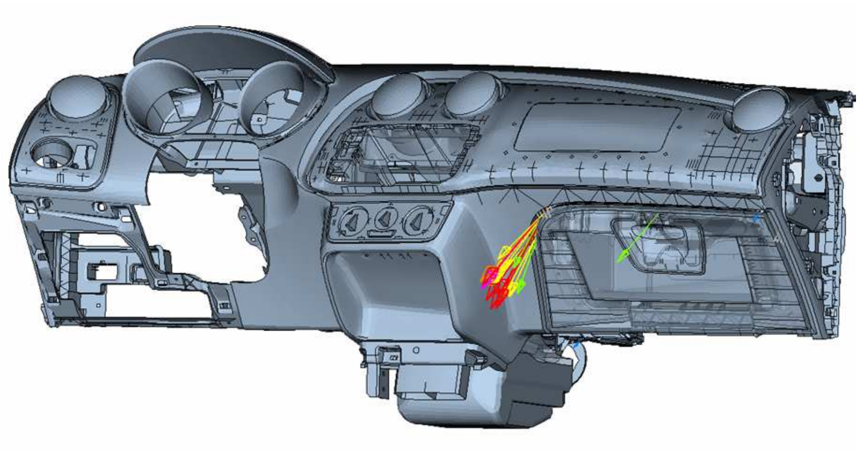


Figure 8. **Rattle detected in the glove box in the frequency range 71Hz-75Hz**

5. Conclusions and future work

In the present work an additional step has been done in the area of simulating S&R. Some improvements have been introduced in the methodology and also in the vibrational correlation in order to obtain better results. One of the main conclusions is that a more realistic representation of the geometry helps to improve the accuracy of the rattle responses. This leads to the conclusion that, when an S&R analysis is planned, accurate meshes should be obtained from the first stages of the project. This can be achieved by using advanced software capabilities (like continuum shells) and automatic meshing technics. An accurate mesh will avoid re-meshing work at a later stage of the project and will ensure correct clearance representation for a correct S&R analysis.

The simulation procedure for rattle detection presented here was able to predict some of the dominant areas where rattle generation was observed during a listening test. In the future, the aim is to use the rattle simulation in more applications in order to fine tune several aspects such as the automatic generation of rattle sensors and the impact detection calculation procedure. Moreover, a more precise procedure for rattle detection during testing is required to give useful feedback for the results obtained through simulation.

6. References

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