Global Damping Validation and a New Modal Contribution Feature for Squeak&Rattle Simulation

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KEYWORDS

Squeak&Rattle simulation, modal contribution, E-line, relative displacement, correlation in time domain, modal transient

ABSTRACT

Squeak&Rattle simulation is based on calculating the relative displacement by running an analysis in time domain (modal transient). The simulation method is described in the SAE paper 2012-01-1553. The results of this type of analysis are very sensitive to the damping value. This paper presents a correlation approach in time domain which allows the validation of a global damping value. In the first part the theory behind this approach is shown more in detail.
In the second part a new modal contribution feature is presented which can be used to perform an engineering assessment on the relative displacement. This feature can be applied on three levels, a single peak, a “time average value” and a “topology average value”. The modal contribution feature was applied on the results of a correlation work on both an exterior and an interior assembly. For the correlation in time domain a 3D Laser Vibrometer (Polytec) has been used. The application of the modal contribution feature on the test results confirms also the validation of the global damping value of the first part on the one hand, and on the other hand it shows the benefit when using the feature as an engineering assessment tool.
Moreover it is shown that the modal contribution feature can be used to identify whether the response of the modal transient analysis is quasi static or dynamic.

TECHNICAL PAPER

1. BACKGROUND

The E-line method is focusing on calculating and evaluating the relative displacement between two parts, which is the main cause for Squeak & Rattle. The core features of the method are shown in Figure 1. The evaluation is always performed in time domain (modal transient analysis) and in a local coordinate system in order to capture the displacement in the rattle direction and in the squeak plane. To enable an efficient evaluation of the relative displacement, node pairs are defined along a 3D curve, which is located between the two parts. By using a script in ANSA each node pair gets its own local coordinate system in order to capture the local gap geometry.
The load is defined in time domain and can come from e.g. a PSD definition or a recorded time domain data. The resulting displacements along all the E-lines are calculated in the local coordinate system belonging to each node pair. The displacements are the input to a script in mETA, where the evaluation can be performed on a global level, line level and point level [5].
Since the result is a response in time domain (modal transient analysis) a statistical approach is needed to include the time aspect in the evaluation. The amplitudes are ranked and a certain percentage of the highest values is chosen. Finally, the mean value of these amplitudes is calculated [5]. In this way, the whole time history of the relative displacements can be condensed into one single value, which can be compared to a tolerance value for squeak or rattle assessment.

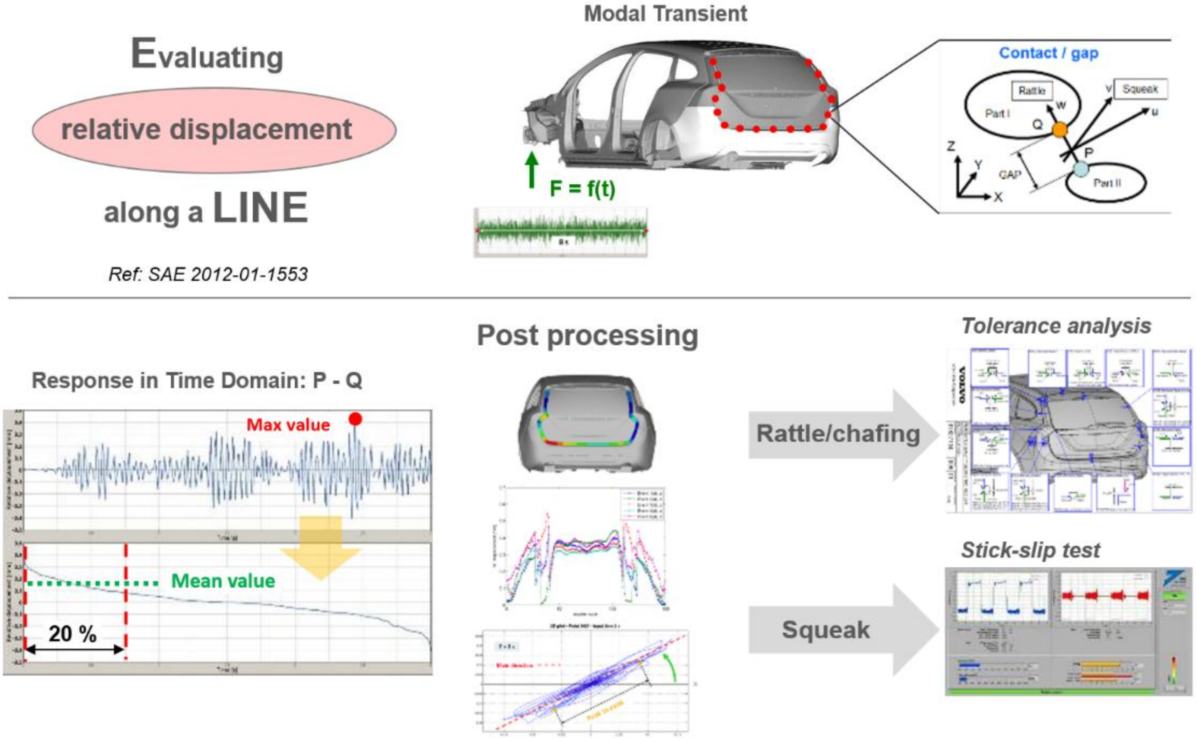

Figure 1 – E-line method

The E-line method is integrated in a simulation process for a complete vehicle, see Figure 2. This process starts with the load definition in Adams. The time history of all forces between chassis and body are calculated for a specific test track. The forces are applied on a trimmed body model in order to run a modal transient analysis. Finally, the results are post processed according to the E-line method on both exterior and interior parts.

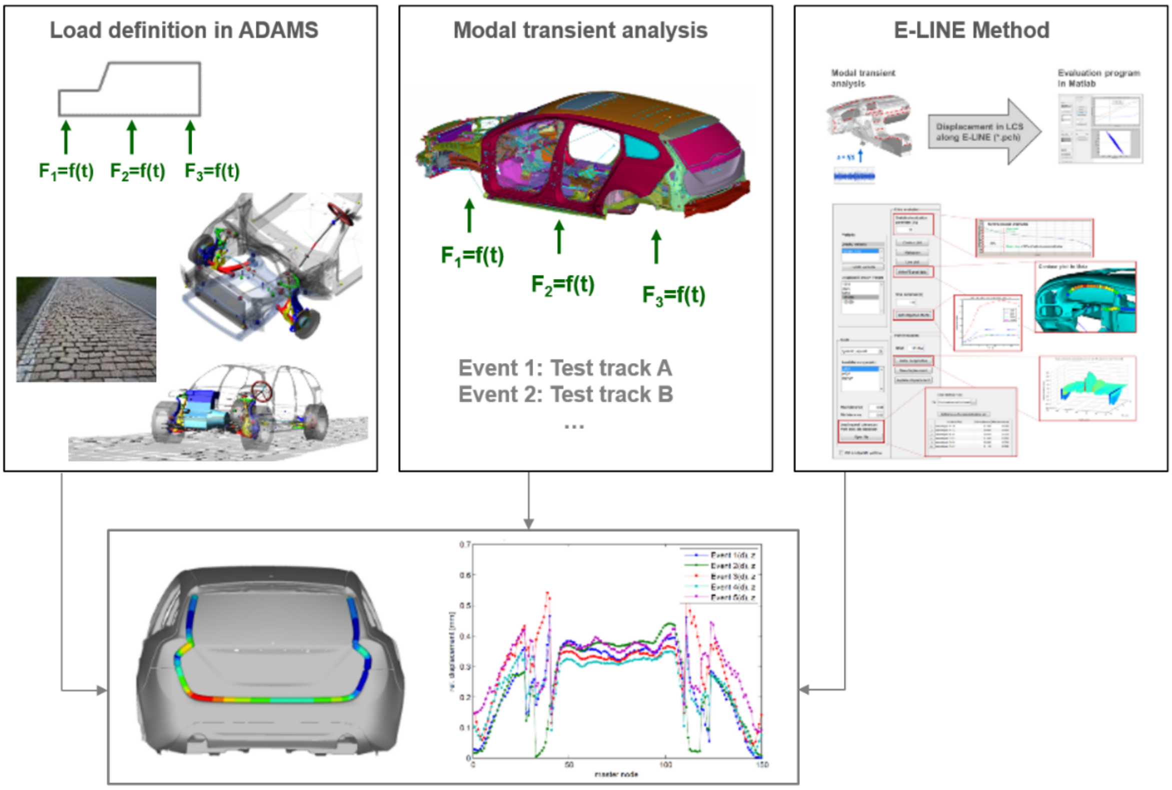

Figure 2 – Simulation process at VCC

Beside the established CAE disciplines such as Crash, NVH and Durability there is at Volvo Car Corporation (VCC) an area called Solidity, see Figure 3. While Durability is mainly focusing on evaluating stress in time domain and NVH on displacement in frequency domain, Solidity is somewhere in between. The E-line method is focusing on displacement in time domain.

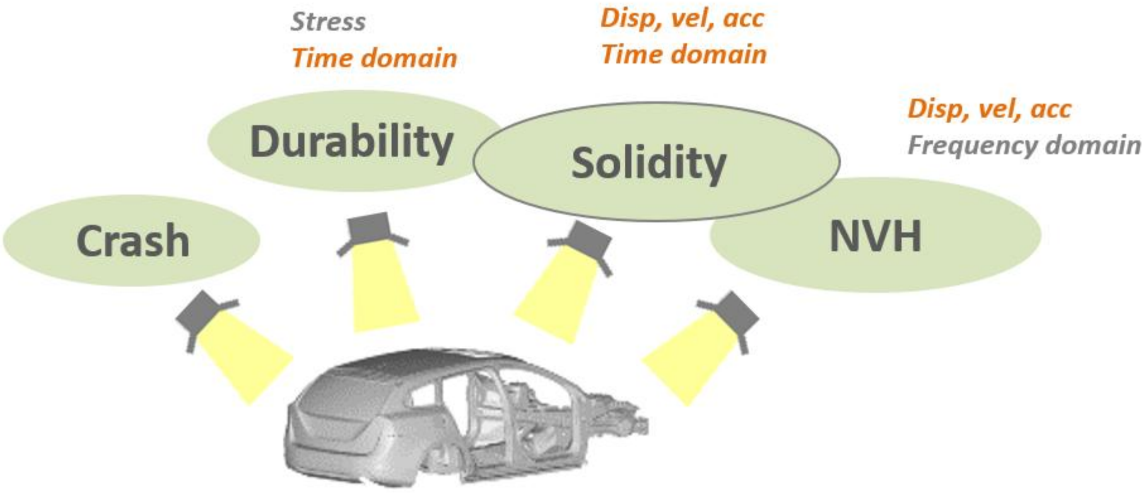

Figure 3 – CAE disciplines at VCC

The rattle assessment is based on the comparison between the simulated relative displacement and the results of the tolerance analysis. The squeak assessments uses the results from the stick-slip test. Hence it is important to increase the accuracy of the simulation. The damping value used in the modal transient analysis has a major impact on the results. In order to improve this value, a validation through a correlation in time domain has been performed.

2. CORRELATION IN TIME DOMAIN

Most correlations are performed in frequency domain. There are much fewer references for correlation in time domain.

The overall procedure for the correlation in time domain is shown in Figure 4 [1,3]. On the test side, the structure is excited by a pseudo random force signal. The displacement on both sides of the closure gap is measured with a 3D Laser Vibrometer (Polytec). The measurement points are defined according to the E-line definition (node pairs). In order to calculate the relative displacement for each point pair, it is necessary to trigger the excitation signal. Through this exactly the same excitation signal is applied for each point. The test data is saved in time domain.

On the simulation side, the excitation signal from the test is used and the relative displacement is calculated.

Before comparing test and simulation results, the test data has to be filtered and converted from global coordinate system to local coordinate system for each point pair. By using the statistical approach from the E-line method, the tested and simulated relative displacement along the closure gap can be correlated. This correlation enables then the validation of the damping value.

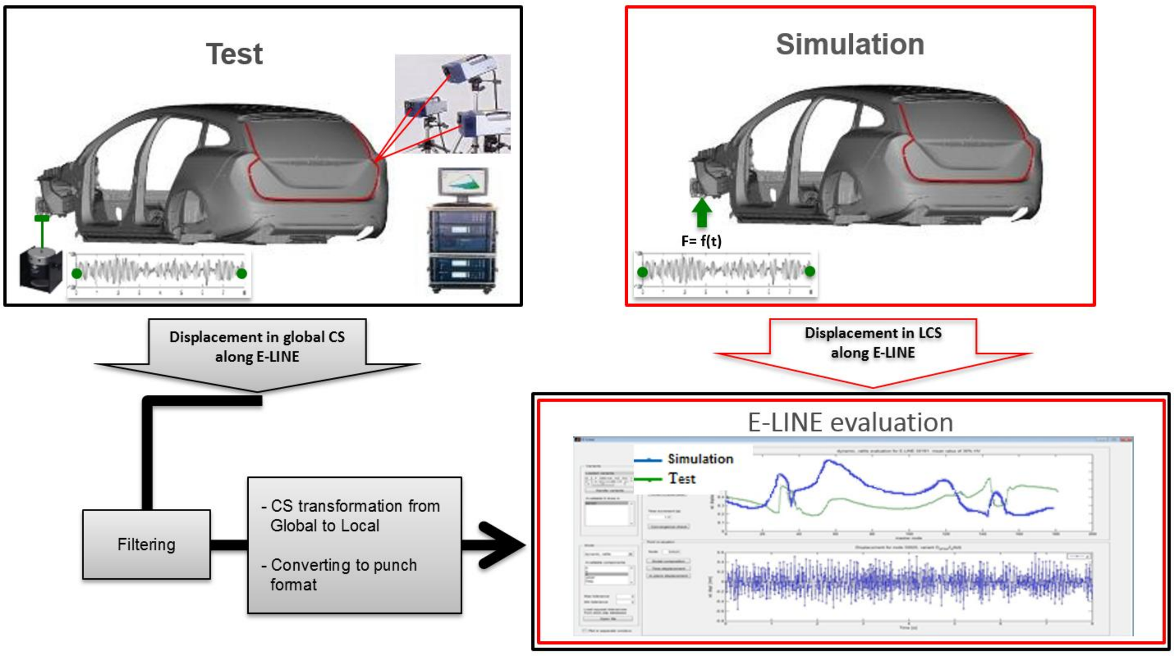

Figure 4 – Correlation procedure

3. GLOBAL DAMPING VALIDATION

A common approach to validate a global damping value (viscous damping) in frequency domain is to find a best fit for the FRF's for both simulation and test, see Figure 5. This can result in either one damping value for the complete frequency range or in different values for specific frequency ranges. (a*n alternative is using structural damping, which only works in frequency domain, but not in time domain*)

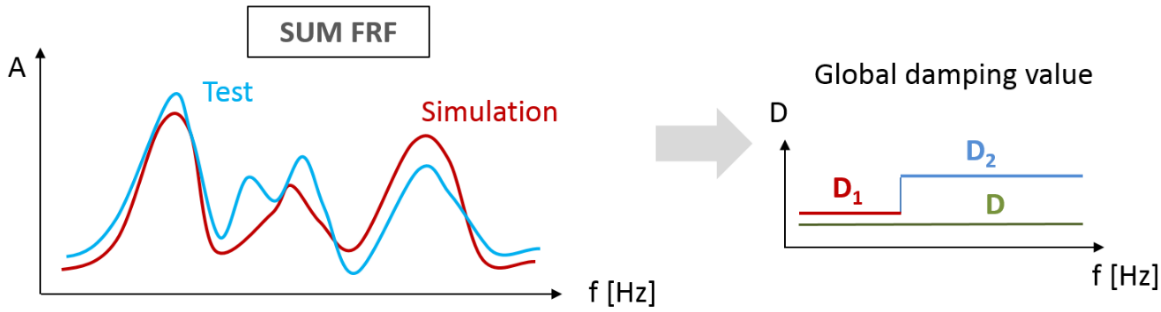

Figure 5 – Damping validation in frequency domain

When performing a correlation in time domain the time history of the displacement for both test and simulation is compared. For the modal transient analysis the *modal damping* (viscous) enables an efficient solution [9].
The response A(t) of a modal transient analysis is the sum of all modal contributions c_i, see Figure 6. The modal contribution is the product of the eigenvector v_i by the participation factor Ψ_i. A modal damping value D_i can be assigned to each modal contribution, because the participation factor is a function of modal damping. These modal damping values can be determined e.g. through a modal correlation for a defined test setup.
When simulating a complete trimmed vehicle it is not possible to identify all modal damping values due to a large number of modes. A common approach within the simulation is to use a single damping value instead, a so called *global damping*.

The correlation in time domain is performed by comparing the test response to the simulated response using the statistical approach from the E-line method.
The aim is to determine the value of global damping by minimizing the difference between test and simulation responses.

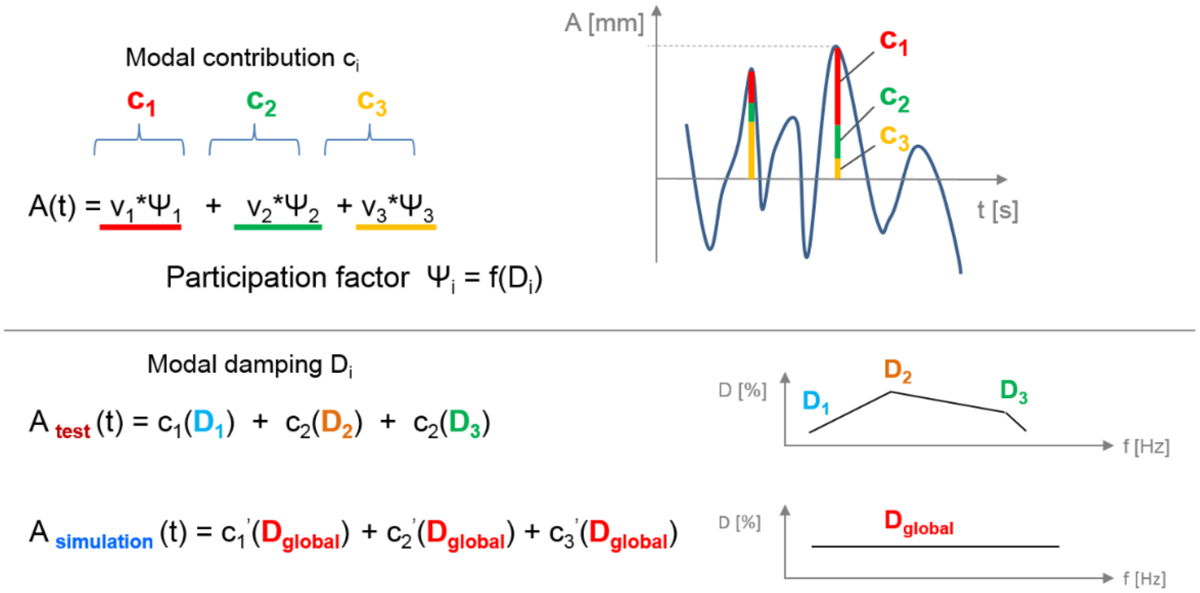

Figure 6 – Damping validation in time domain

When comparing the time history of test and simulation by using a certain percentage value of the highest peaks (statistical approach of the E-line method), it becomes obvious that the participation factors are acting as weight factors [2]. This means, if there is a mode with a dominant contribution, the global damping value will be close to the modal damping value of this dominant mode.
Similar to the relation between a modal damping value for a specific mode and the global damping, a relation can be described between the modal contribution and a response value (relative displacement). Based on that a modal contribution feature has been developed for engineering assessment.

4. MODAL CONTRIBUTION

A new feature for engineering assessment was implemented on the E-Line Matlab graphical user interface, see Figure 7 below.

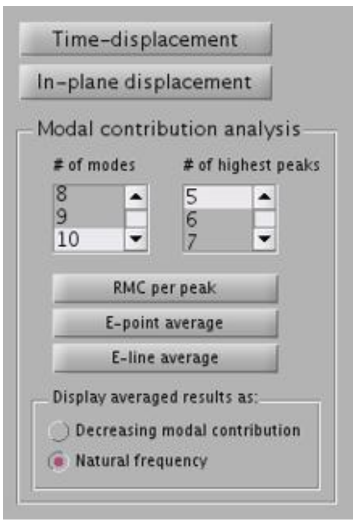

Figure 7 – New modal contribution feature implemented on Matlab interface

This feature shows the modes which are contributing the most to the relative displacement and can be applied on three different levels:

1. Relative Modal Contribution (RMC) per peak
2. E-Point Average
3. E-Line Average

Each functionality is presented more in details in the next section, starting with the RMC per peak.

5. RMC PER PEAK

The RMC per peak is a functionality whose aim is to represent the modal composition of the highest peaks for the response of a given node pair in terms of relative modal contributions.
To explain the theory behind this functionality, a simple example is described in Figure 8. The response in time domain of a given node pair is shown in Figure 8-A. This response is decomposed into modal contributions, more precisely into the modal contributions of M1 (red), M2 (green) and M3 (yellow).
In this example only the two highest peaks P1 and P2 are considered.
In Figure 8-B the corresponding RMC per peak is plotted. This column chart is composed of two sets of bars which are related to a peak. Since the peaks are ranked according to their amplitude and the amplitude of P2 is higher than P1, the first set of bars is related to P2 and the second one to P1.
We note respectively cij and RMCij the contribution and the RMC of a mode i for a peak j. According to the formula shown in Figure 8, RMC_{12} describes the contribution of M1 relatively to the other contributions for P2. There are two main advantages to use this definition of RMC. The first one is that the sign information is preserved; indeed a contribution could be negative, cf. example in Figure 8. The second advantage is that the RMC results in an understandable percentage value between -100 % and +100 %.

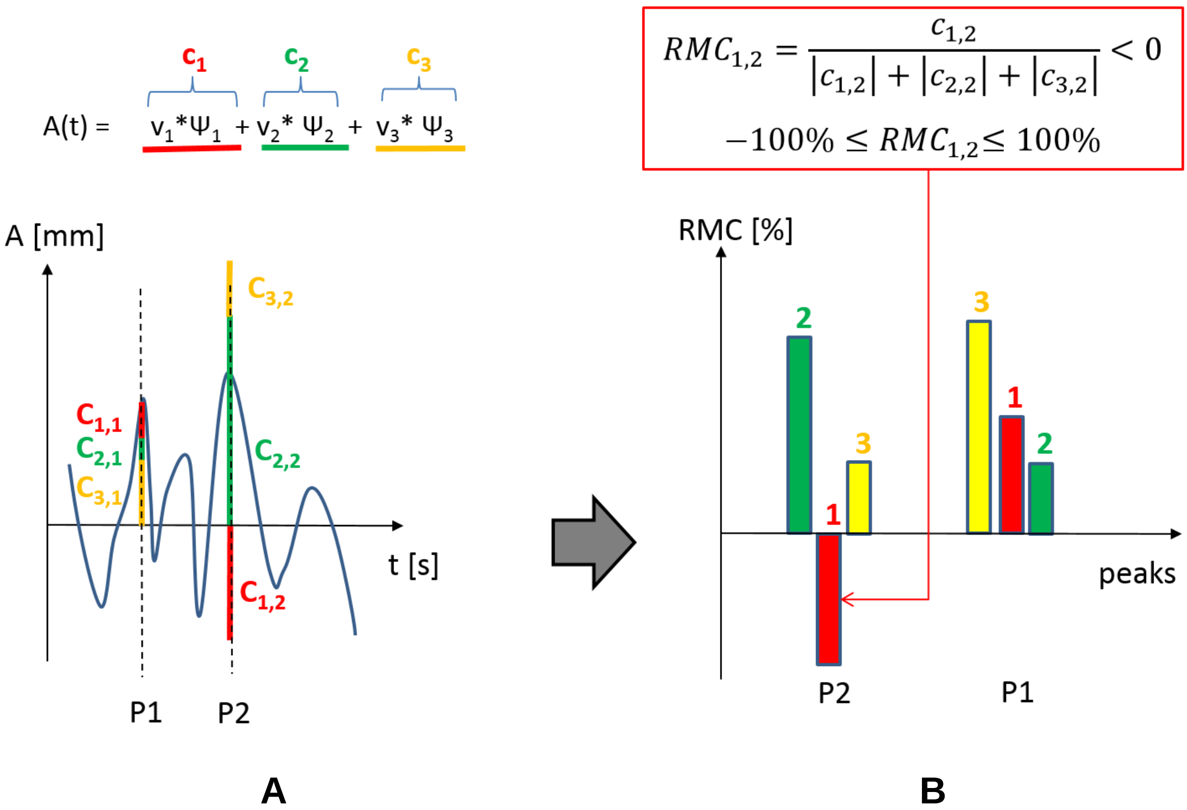

Figure 8 – Time response (A) and corresponding RMC per peak (B)

With the RMC per peak a user defined number of the most contributing modes are plotted per single peak. When applying the statistical approach on these peaks with a given Statistical Evaluation Parameter (SEP), a single value (MHV) is obtained, see Figure 1. The aim for the next feature is to show the modal contributions for this single value in the same way as it was described for the single peaks.

6. TIME AVERAGE

The *Time Average (or E-Point Average)* is a functionality whose aim is to represent the modal composition of the response of a given node based on the mean value of a certain percentage value (SEP) of the highest peaks. A simple example is described in Figure 9. Only the two highest peaks P1 and P2 are considered, see Figure 9-A.
In Figure 9-B the corresponding E-Point average is plotted. This column chart is composed of three bars, which are related to a mode. These bars are ranked according to their associated values.
We note c_{ij} the contribution at mode i for a peak j, and RMC_i the RMC with SEP of mode i.

$$\overline{RMC}_1 = \frac{|c_{1,1}| + |c_{1,2}|}{|c_{1,1}| + |c_{1,2}| + |c_{2,1}| + |c_{2,2}| + |c_{3,1}| + |c_{3,2}|}$$

$$0\% \leq \overline{RMC}_1 \leq 100\%$$

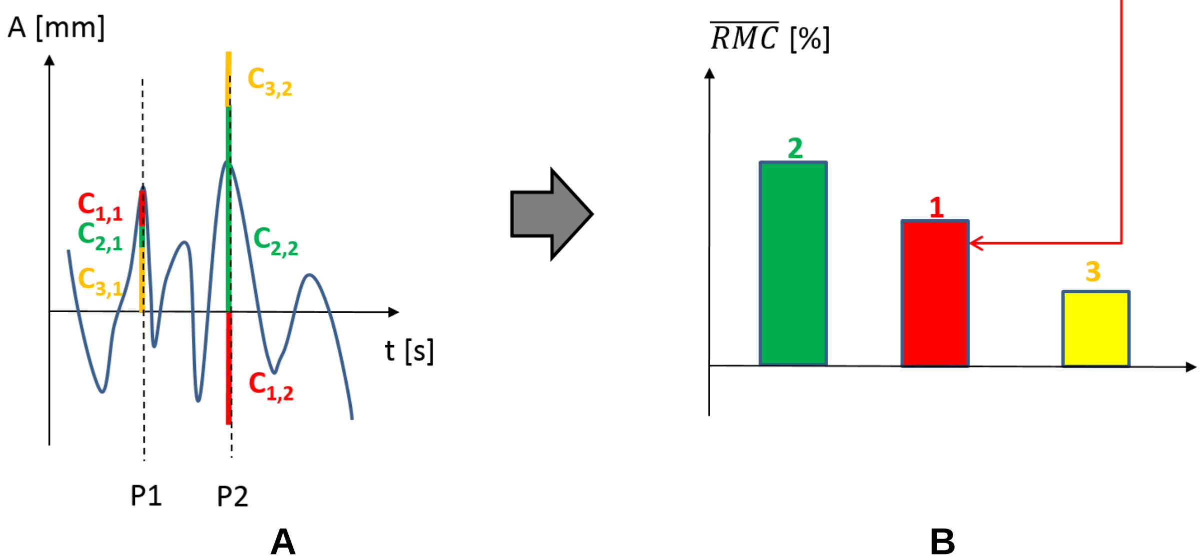

Figure 9 – Time response (A) and corresponding E-Point average (B)

For instance let the total number of peaks be 4 and set the SEP to 50 %. Therefore the corresponding E-Point average (time average) is based on the two highest peaks, which are P1 and P2 in this case. According to the formula shown in Figure 9, RMC_1 describes the contribution of M1 relatively to the other contributions for 50 % of the highest peaks. Since a random excitation requires the statistical evaluation (SEP), the modal contribution of this result (MHV) is of interest and can be obtained with this feature. However as an average was performed, the sign information of the modal contribution will be ignored.

So far the functionalities described previously were applied on the response of a given E-Point. The next step is to perform a topology average by calculating an RMC for an entire E-Line.

7. TOPOLOGY AVERAGE

The *E-Line Average (or Topology Average)* represents the modal composition of the response of all the E-Points belonging to a given E-Line, based on the mean value of a certain percentage value (SEP) of the highest peaks. In the example shown in Figure 10-A, the E-Line is composed of two master nodes noted Node 10 and Node 20. These nodes representing the topology are included by using a third index for the modal contributions. In Figure 10-A the relative displacement of both E-Points are plotted, the corresponding E-Line average is represented for a given SEP, see Figure 10-B.

$$\overline{RMC}_1 = \frac{|c_{1,1,10}|+|c_{1,2,10}|+|c_{1,1,20}|+|c_{1,2,20}|}{|c_{1,1,10}|+|c_{1,2,10}|+|c_{1,1,20}|+|c_{1,2,20}|+|c_{2,1,10}|+|c_{2,2,10}|+|c_{2,1,20}|+|c_{2,2,20}|+|c_{3,1,10}|+|c_{3,2,10}|+|c_{3,1,20}|+|c_{3,2,20}|}$$

$$0\% \le \overline{RMC}_1 \le 100\%$$

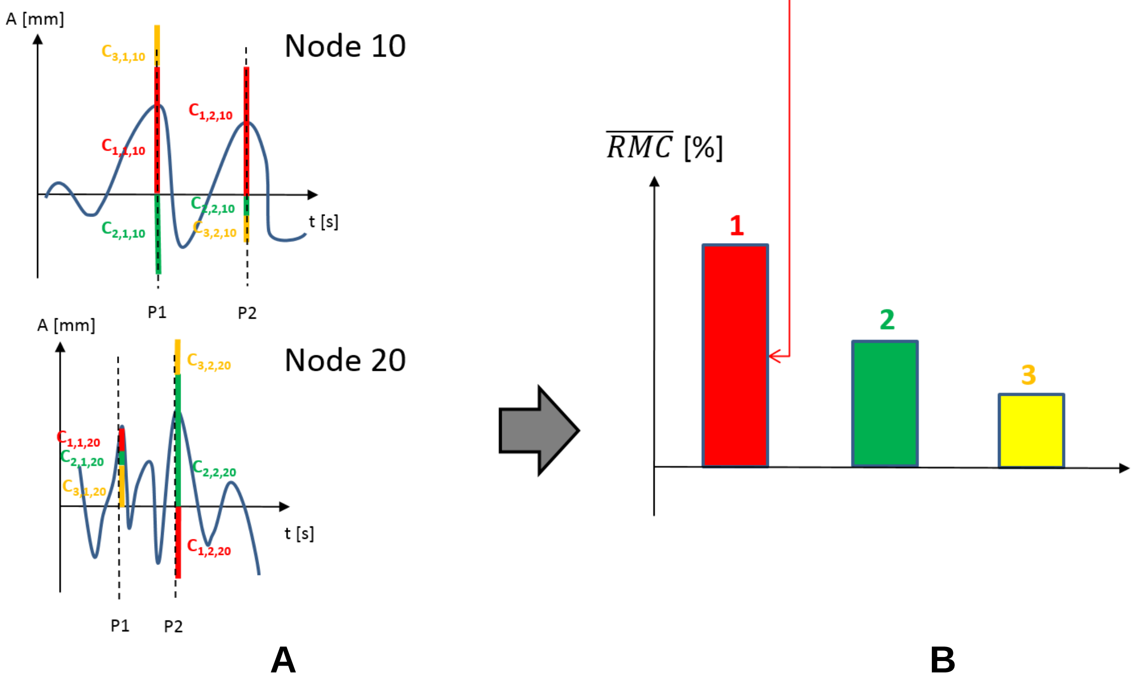

Figure 10 – Time response for two E-Points (A) and corresponding E-Line average (B)

To conclude: From the *RMC per peak* of the response of a given E-Point, a time average is performed to calculate the *E-point average*. Finally the *E-line Average* is obtained using a topology average.

The RMC for both *E-point average* and *E-line average* can be sorted either according to the relative modal contribution or according to the frequency of the mode.

In Figure 11 the mETA interface of the modal contribution feature is shown.

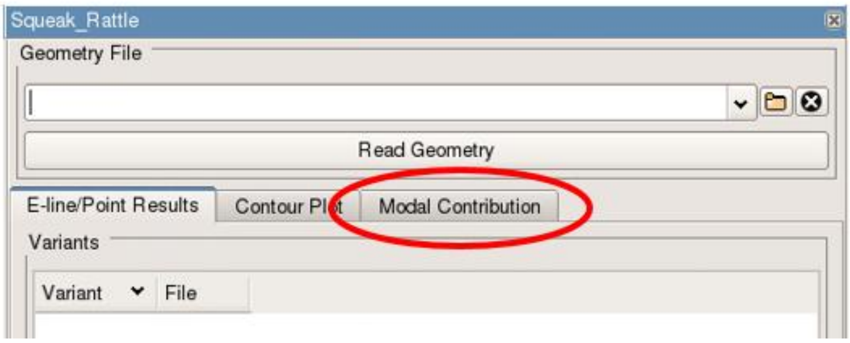

Figure 11 – Modal contribution in mETA

8. INTERIOR EXAMPLE

The interior assembly studied is an instrument panel (IP) from the Volvo S80. The IP is fully constrained in 3 locations, as depicted in Figure 12.

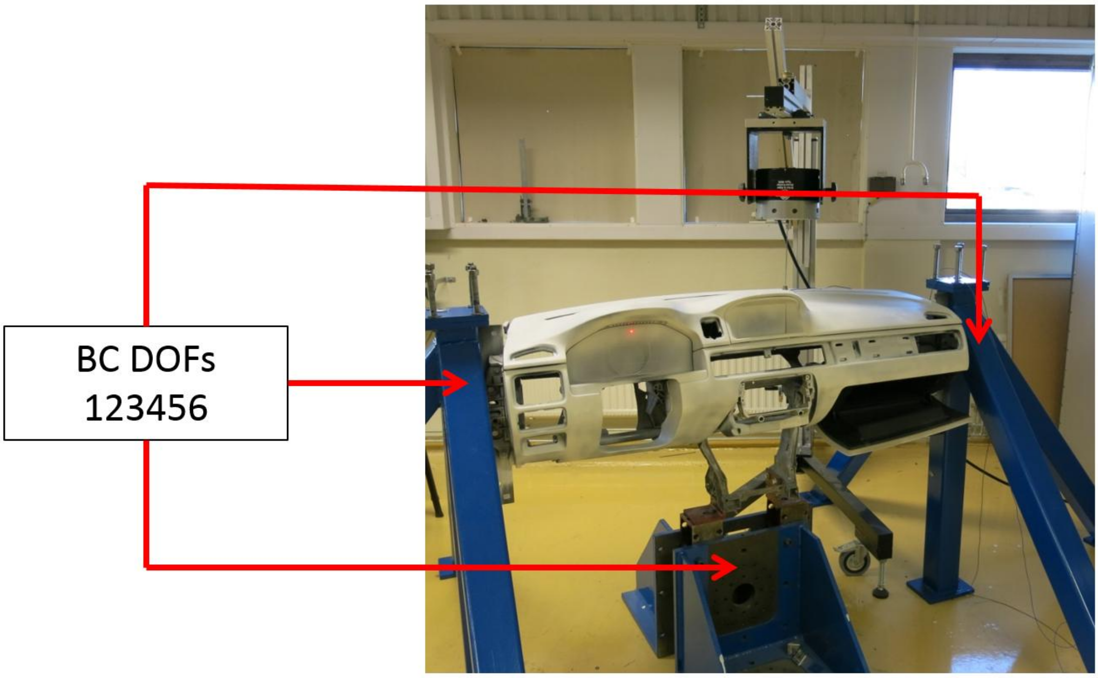

Figure 12 – Boundary conditions - Fully restrained

For the measurements an E-Line was defined along the glove box lid. This E-Line is composed of 30 node pairs. A local coordinate system is associated with each node pair, numbered from 1001 to 1030.
Figure 13 shows the test setup where a pseudo random load is applied on the top surface of the IP using a shaker. The 3D Laser Vibrometer measures the displacement along the glove box E-Line [2].

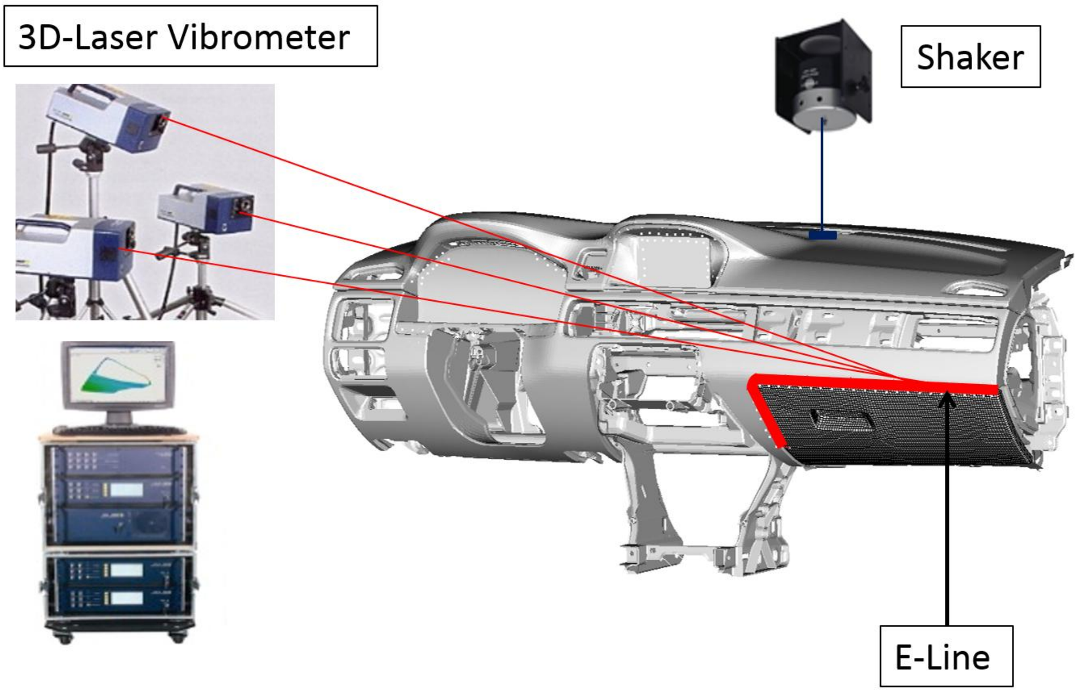

Figure 13 – Experiment setup - Test interior

By correlating the tested and the simulated relative displacement a global damping value of D_{global} = 2% is obtained, see also chapter 3. The *E-line average* is applied on the glove box E-Line as represented in Figure 14. One main contributing mode is identified, M2 (in phase mode). Based on a modal test a modal damping value of D= 2.16 % is calculated by Polymax (LMS) for mode number 2.
According to the conclusion of chapter 3, participation factors are acting as weight factors, and therefore D_{global} should be around the modal damping ratio of M2. Indeed that is confirmed by the modal contribution feature.

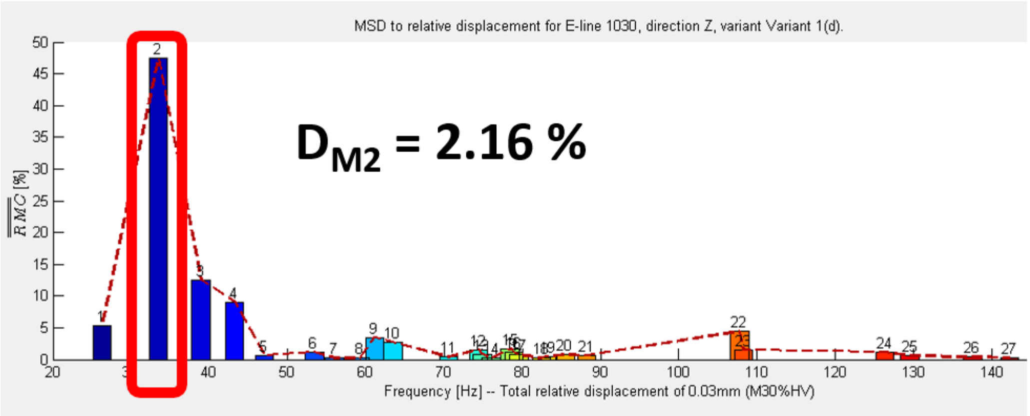

Figure 14 – E-Line Average applied on the glove box E-Line - Test interior

9. DYNAMIC VS QUASI STATIC

In this section the modal contribution feature is used to identify if a given response is either quasi static or dynamic.
As an example, 4 E-Lines are defined on a center console CAE model, as illustrated in Figure 15. Three prescribed forces are applied on a fully constrained structure.

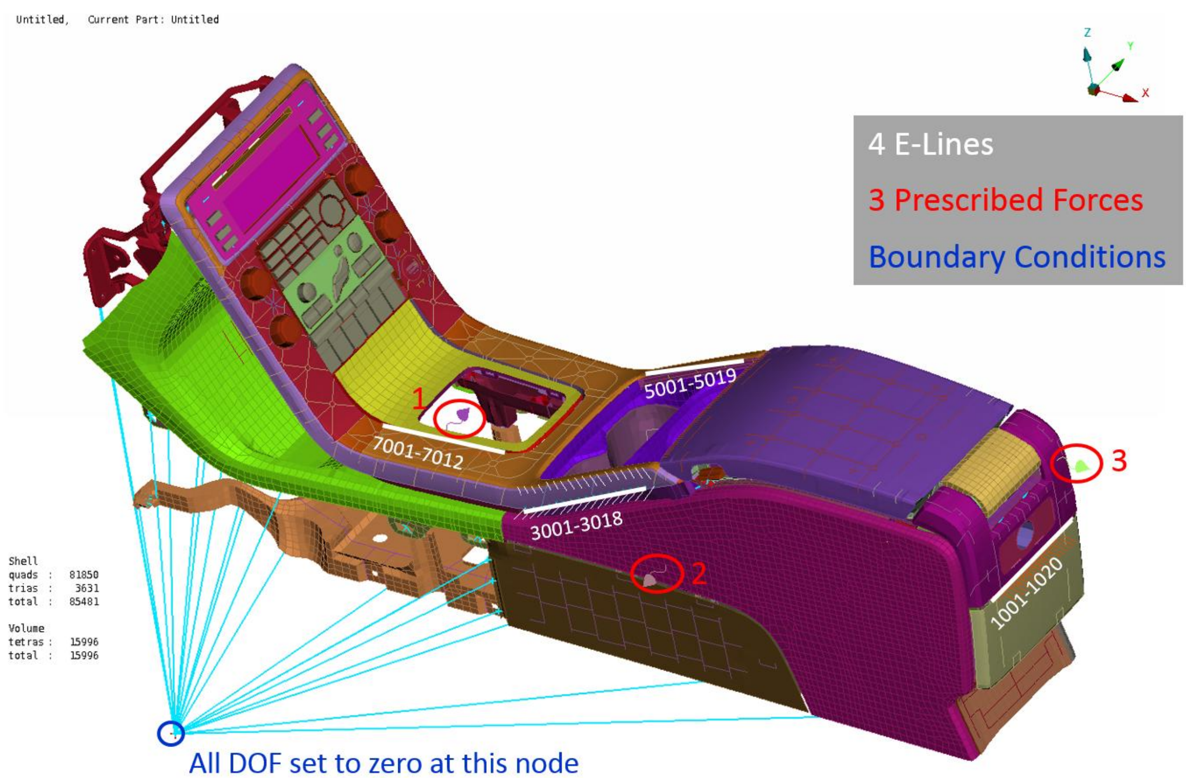

Figure 15 – Center console CAE model

Knowing that the first structural resonnance frequency is around 44Hz, two cases concerning the forces applied on the center console are studied:

- Case 1 : the PSD is defined as the indicator function $1_{[5;20]}$ which equals to 1 between 5 Hz and 20 Hz.
- Case 2 : the PSD is defined as the indicator function $1_{[5;150]}$ which equals to 1 between 5 Hz and 150 Hz.

For the next step one node pair per E-Line is randomly chosen, and the corresponding RMC per peak is plotted for each case. The composition of the first 5 highest peaks is illustrated in Figure 16 (Case 1) and Figure 17 (Case 2).
For Case 1, we can clearly notice that the modal composition is the same for the 5 highest peaks. Therefore, the response of the structure can be identified as quasi static.

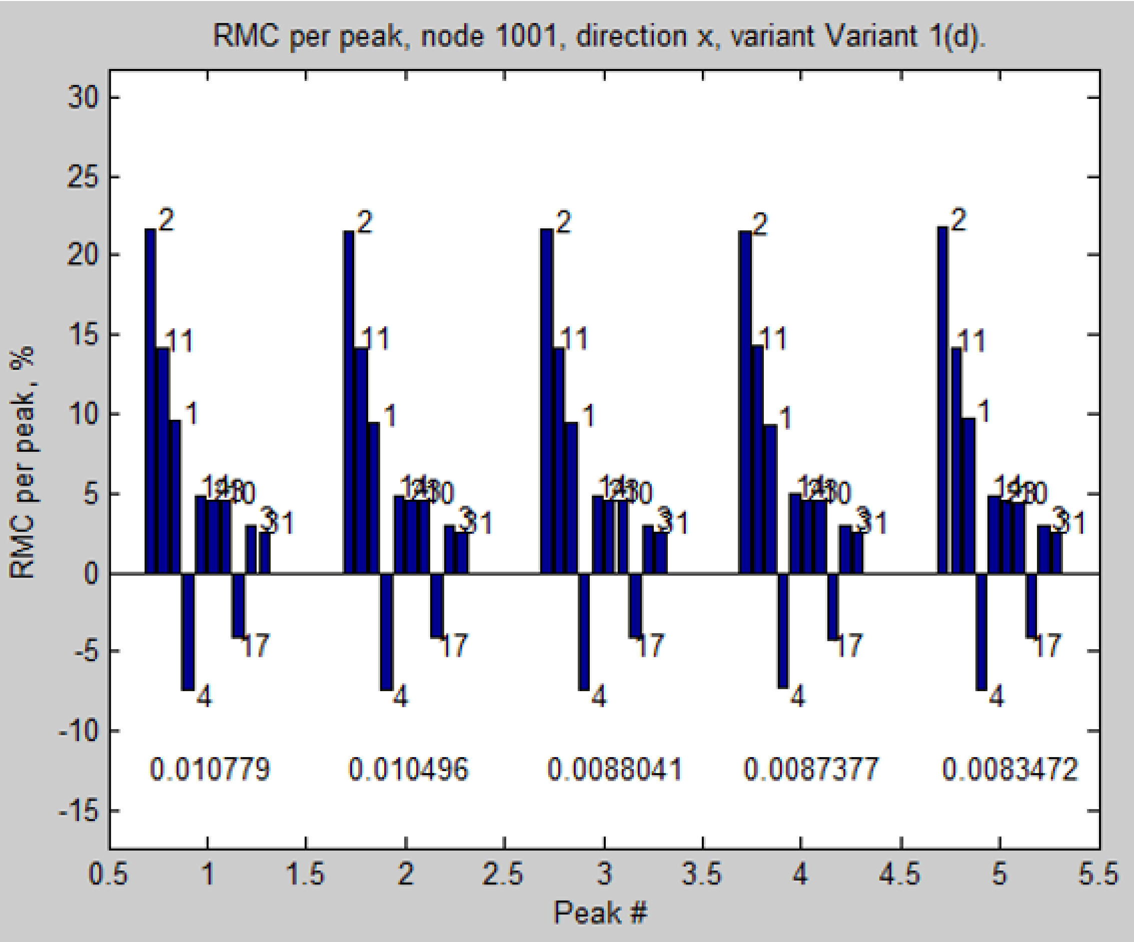

Figure 16 – RMC per peak for node pair 1001 – X direction – Case 1

However for Case 2, the modal compostion differs from peak to peak. For instance, the most dominating mode is mode M2 for all the peaks, except the third highest peak whose most dominating mode is M11. To conclude, the response of the structure can be identified as dynamic (see Figure 17).

Through this example, it is shown that the RMC per peak can be used to know if we have a quasi static or dynamic response, which can be important for the requirement settings.
However, such a study can be performed only if the different forces applied on the structure are proportional.

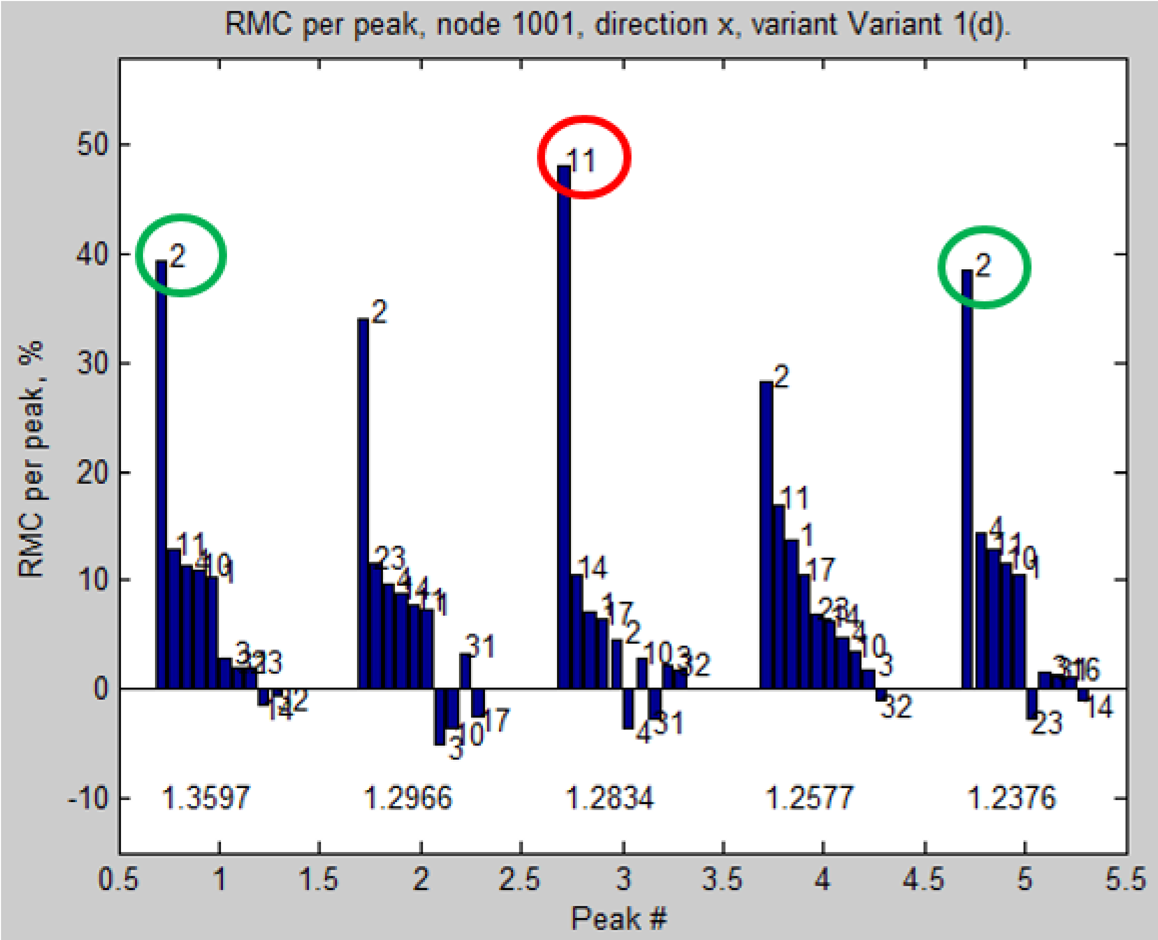

Figure 17 - RMC per peak for node pair 1001 – X direction – Case 2

10. CONCLUSIONS

A global damping value has been validated through a correlation in time domain. It is shown that the participation factors (modal contributions) behave like weight factors when validating global damping through such a procedure in time domain [2]. This conclusion led to the development of a new modal contribution feature, which can provide the modal composition of a time domain response on three different levels: RMC per peak, E-Point average (time average) and E-Line average (topology average).
The main application of this feature is to perform an engineering assessment when evaluating the relative displacement.
Another use of the new modal contribution feature is to identify whether the response of a structure is quasi static or dynamic. A possibility is also to use it in other engineering areas such as Durability, by replacing displacement with stresses.

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