INCREASED ACCURACY IN SQUEAK & RATTLE SIMULATIONS BY ENHANCED MATERIAL PROPERTIES, DAMPING VALUES AND ALIGNED EVALUATION DIRECTIONS

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ABSTRACT
Squeak and rattle (S&R) are two undesired phenomena that can affect the quality perception of cars. The main reason of S&R is the relative displacement between parts [1]. One mean to identify the critical area for S&R at Volvo Cars during the virtual phase is the E-line method. This method, which was presented in a SAE paper [2] 2012, calculates the relative displacement along a line/gap. The application of the method at Volvo Cars was shown in a Beta paper 2013 [3].
Relative displacement calculation along a tailgate closure gap is sensitivity to damping value and sealing stiffness. Therefore, a correlation work in time domain has been performed to update the damping value and sealing stiffness. The test object is a body in white (BIW) including some assembly parts. The relative displacement along the closure gap of tailgate is measured and simulated in different setups which results in updating the unknown parameters. The updated sealing stiffness value takes into account all three directions and the damping value is only valid for the BIW.
Moreover, in order to increase the precision of the E-line method, a new principle to align measurement directions of the dynamic displacement with measurement directions of calculated geometrical variation has been developed. Geometrical variation or static displacement must be considered when assessing rattle because the minimum size of a gap is one of the essential parameters. Definition of measurement direction is based on a surface strip that is generated in the CAT (Computer Aided Tolerancing) tool RD&T. The combination of E-line with the surface strip shows a higher accuracy in the simulation method, which is presented in an industrial case-study.
These enhancements improve the capability of relative displacement simulation significantly.

1. INTRODUCTION

Squeak and rattle (S&R) occur in an assembled product when two components move relatively against each other where the motion caused by an external load. The relative displacement will result in squeak if the components are in contact and the relative displacement in the contact plane exceeds the squeak limit. Rattle occurs when the components have an initial distance between each other and the relative displacement causes continuous and repetitive contact between the components. The sound that is generated by the squeak and rattle phenomenon is usually audible for the user of the product and contributes to a low quality impression. Absence of unwanted sounds like S&R is a very important quality aspect in the automotive industry and especially within the premium segment.
Design for new car generations has encouraged the minimum gap size for a better customer's quality perception. Smaller gaps can lead to increase in risk for squeak and rattle and also require a more precise method of calculation. The occurrence of S&R is dependent on many different parameters such as dynamic relative displacement, friction between components, static relative displacement (geometrical variation over time), temperature, humidity, design concept etc. Consequently, this type of calculation involves different

simulation disciplines and is also very sensitive to input data and model parameters such as damping, sealing stiffness values, mesh quality and etc.

Scope of paper

This paper presents results from three studies that have been conducted in order to increase simulation accuracy when predicting S&R. Focused parameters are damping value, sealing stiffness and alignment of evaluation direction between dynamic and static relative displacement. The effect of increased accuracy is demonstrated in an industrial case.

Prediction of S&R using E-LINE method

At Volvo Cars, prediction of S&R is performed applying the E-line method [1-3]. The E-line method is used to calculate the relative displacement along a gap between two components. The E-line evaluation is performed in time domain and in local coordinate systems in order to capture the displacement in the rattle direction and in the squeak plane along a gap, see Figure 1.

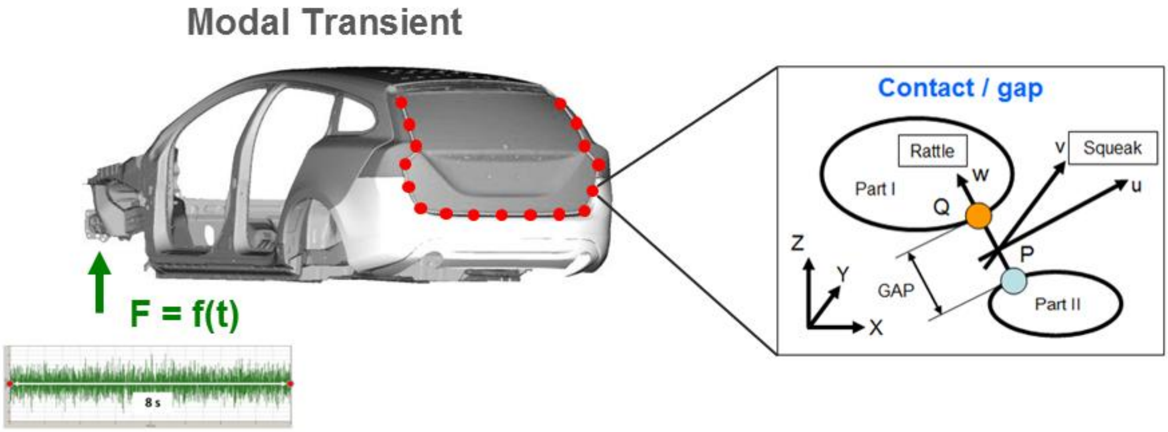

Figure 1 – E-line along tailgate gap [4].

To enable an efficient evaluation of the relative displacement, node pairs are defined along a 3D curve, which is located between the two parts. Each node pair has its own local coordinate system in order to capture the local gap geometry [4].
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. All pre-processing is conducted in ANSA [5]. In the post-processing phase, the displacements are input to an interface in mETA, where the evaluation can be performed on a global level, a line level and a point level.

Since the result is a response in time domain (transient) 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 will be chosen. Finally, the mean value of these amplitudes is calculated. In this way, the whole time history of the relative displacements can be condensed into one single value, which can be compared to a squeak limit value for squeak assessment or a geometrical tolerance value for rattle assessment [4].

2. INCREASING SIMULATION CONFIDENCE

To increase the accuracy of simulation, all input data such as material properties and sealing stiffness must be accurate. Furthermore, model properties such as mesh quality, boundary conditions and evaluation directions also influence the result. In this section, three studies are presented that have been conducted in order to increase the accuracy of damping value for BIW, sealing stiffness of tailgate and finally to align evaluation direction between dynamic and static relative displacement.

Damping value

A correlation work was performed [4] to determine the global damping for the BIW and sealing stiffness. The relative displacements in the closure gap of tailgate from test and from simulation are compared. The test object is a BIW of a Volvo V60 with tailgate, bumper and rear side lamps, see Figure 2-A. In the test, a 3D Laser Vibrometer is placed behind the object to measure the response of the visible rear end due to an input force from shaker. An 8 s pseudorandom signal (PSD 0-200 Hz) is used for the measurement. The modal shaker applies the signal through its stinger perpendicular to the front-left side of BIW, see Figure 2-B.

In the simulation, the same force is applied to the structure via a modal transient analysis. In both test and simulation the E-line method is used to calculate the relative displacement. Eventually, relative displacement results for all three directions are compared with each other [4].

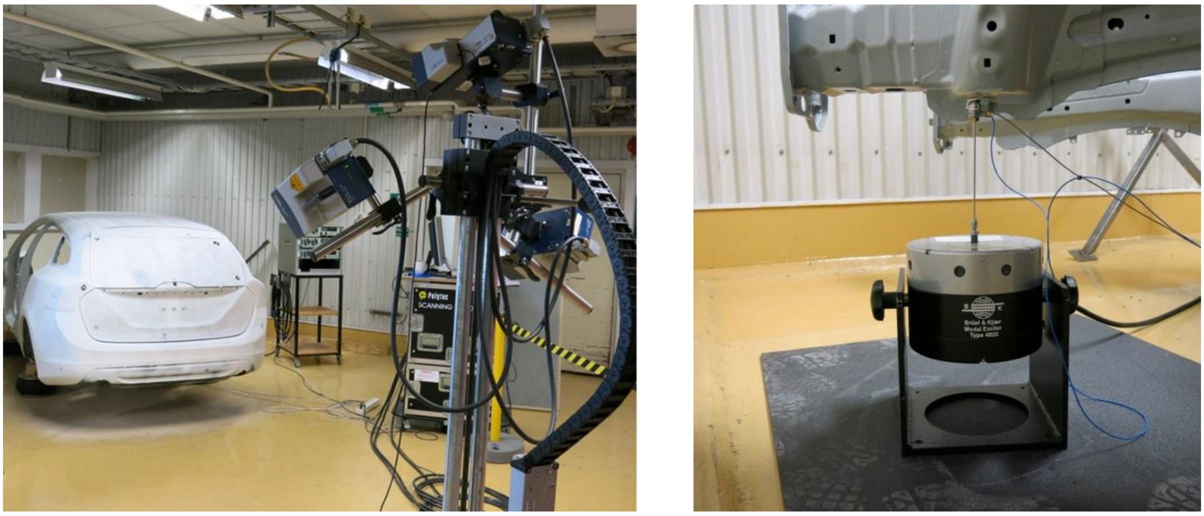

Figure 2 – 3D laser cameras pointing to the rear end (A), shaker location in the front end (B) [4].

Test and simulation are performed in time domain because evaluation of the relative displacement is meaningful only in time domain. The advantage of using a correlation in time domain is the fact that it includes both amplitude and the phase.

Figure 3 illustrates all defined measurement points on the test object. Two measurement runs, one in frequency domain and one in time domain were executed. The results from the frequency domain measurement are used to extract the mode shapes in order to validate the material properties. For the frequency domain run, the responses for all the points shown in Figure 3 were measured. In the time domain run, only the point pairs along the visible gap were evaluated which results in relative displacement along the visible gap. 70 point pairs along the tailgate gap are measured which results in calculation of the relative displacement between the tailgate and exterior parts. Eventually, the results from test and simulation are evaluated and compared using E-line interface in mETA.

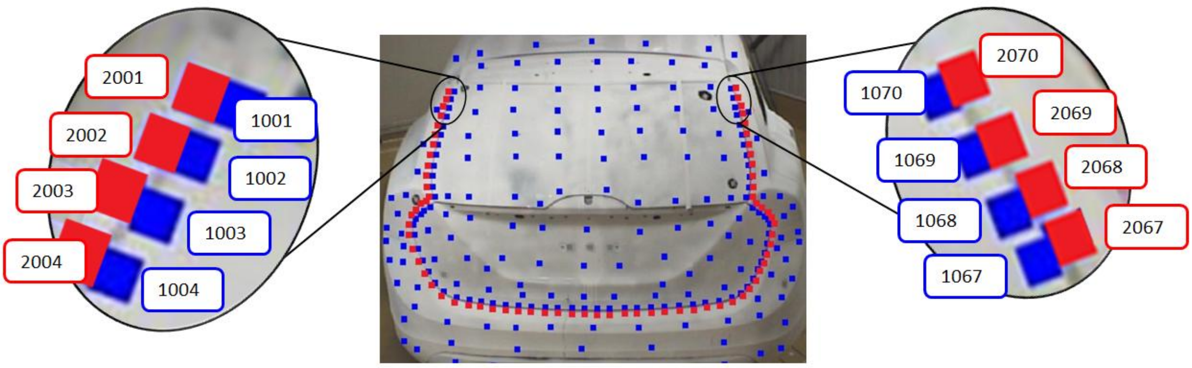

Figure 3 – Defined measurement points on the test object – point pairs along the gap [4].

In the first time domain test setup, sealing is *not* mounted between the BIW and tailgate. This enables the determination of the damping value for the BIW.
In the second test setup, the sealing was mounted to the BIW to include its impact on the relative displacement. Having the damping value from the first test setup limits the second setup correlation to only the sealing stiffness in all three directions.

Sealing stiffness
Study [4] has shown that the stiffness value in all three directions can greatly influence the results of relative displacement for the tailgate gap. A simulation in time domain is performed by using the modal transient analysis (SOL 112) in Nastran [7]. The model contains the BIW, lamps, bumper and tailgate as in the test. The sealing is represented by spring elements, with stiffness in three directions following the sealing gap geometry, see Figure 4. For each sealing CBUSH the 'z' direction represents the closing direction, 'y' is the lateral and 'x' is the longitudinal direction. The spacing between the spring elements is 20 mm, which gives a length specific stiffness unit of N/mm/20mm for the sealing [4].

Figure 4 – Sealing represented by spring elements [4].

The correlation is done by comparing the relative displacement for test and simulation belonging to each node pair along the tailgate gap. An E-line was defined for the simulation model with local coordinates as shown in Figure 5. The 'z' coordinate (gap direction) follows the geometry of the components where 'y' is perpendicular to the plane and 'x' is along the defined E-line (gap).

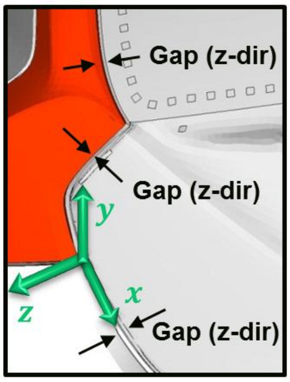

Figure 5 – E-line local directions, 'z' is the gap direction, 'y' is perpendicular and 'x' is along the line [4].

A statistical approach is used for the correlation work. The statistical approach as it was mentioned previously enables a robust evaluation of the transient response. In this correlation case the statistical evaluation parameter (SEP) was set to 30%.

Figure 6 shows the magnitude of the relative displacement for the first setup from test (solid) and from simulation (dash/dot). The first guess for the simulation is a global damping of D=1.0% (dot). Since the damping is the only unknown parameter in setup 1, simulation results from different damping values have been compared with the test curve. Finally, a best fit was achieved by decreasing the value to D=0.5% (dash).
The damping value equal to D=0.5% which gives the best correlation is also used for the second correlation work as the input for damping [4].

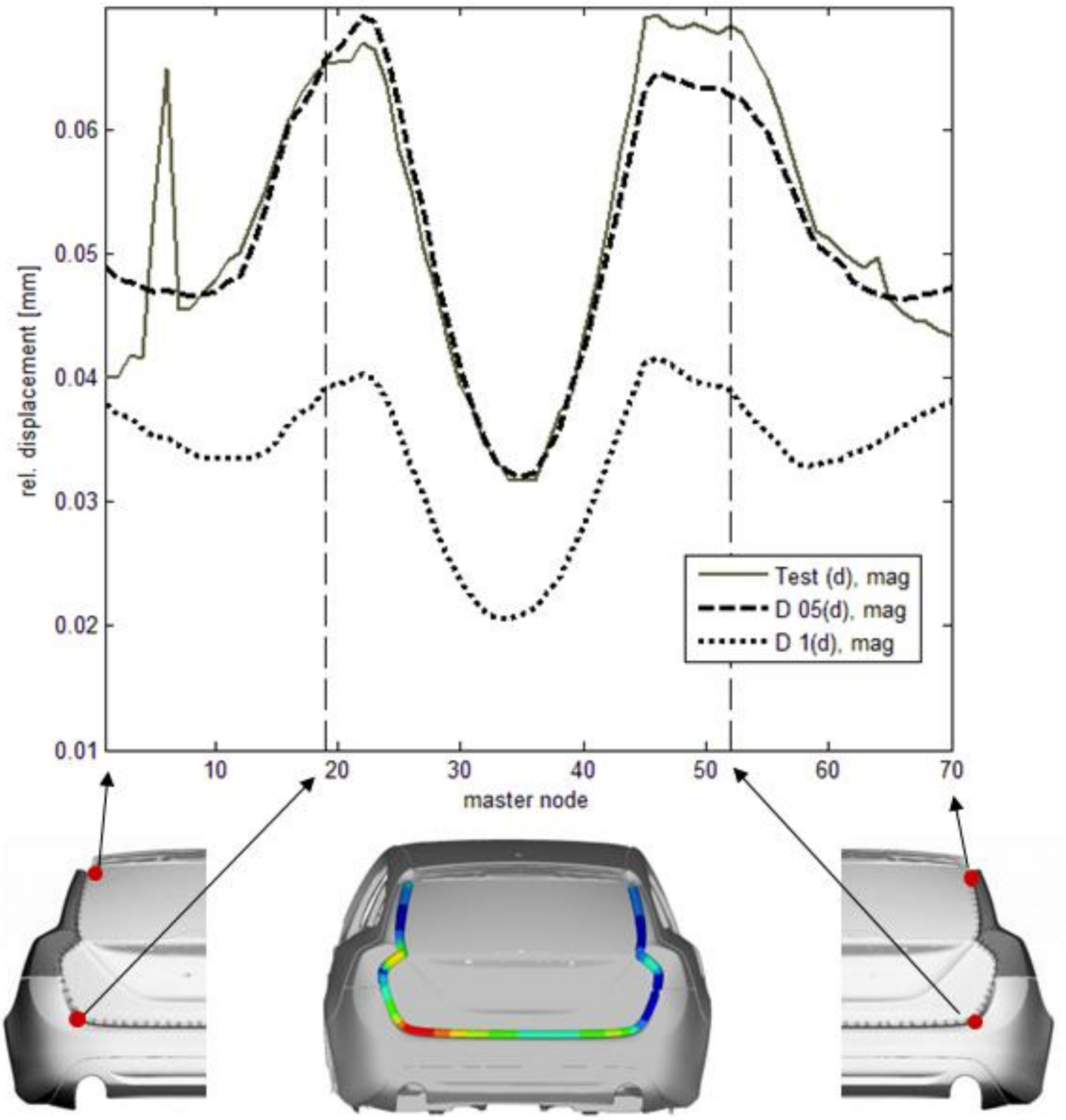

Figure 6 – Comparing relative displacement between test and simulation. The relative displacement plot starts at the upper left corner and ends at the upper right [4].

The relative displacement for the local z direction (rattle direction) is also evaluated, see Figure 7. The dash curve is the response for the simulation and the solid is the relative displacement plot for the test. Both the shape of the curves and values show a good correlation in the local z axis, which is the gap direction.

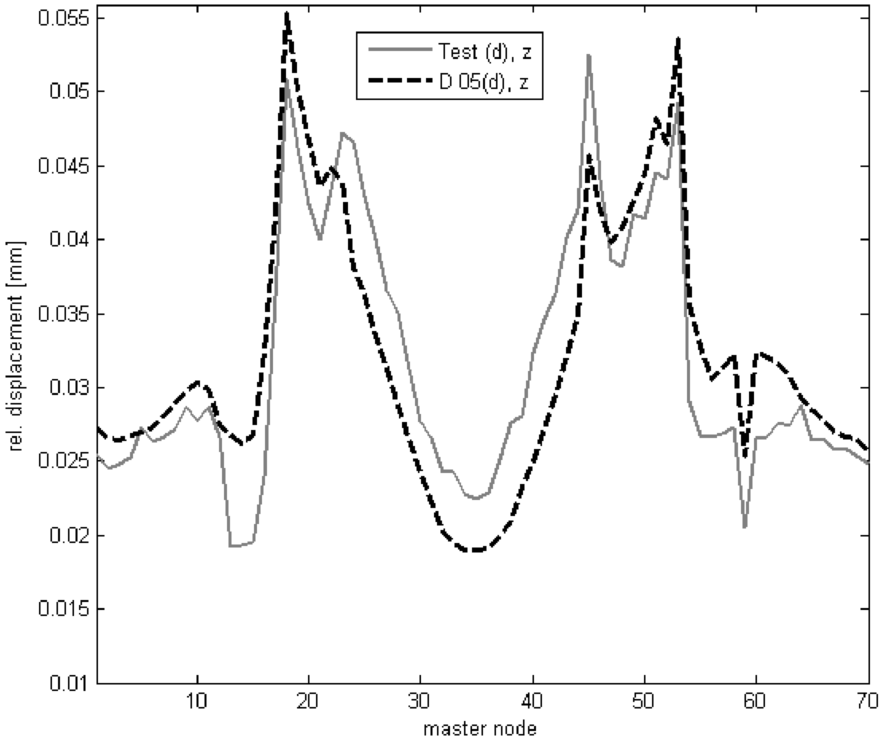

Figure 7 – Relative displacement in local z direction for test and simulation (setup 1) [4].

In the second setup, the three unknown parameters are sealing stiffness in all three directions kx, ky and kz. Each parameter can be varied independently in the simulation. When varying a single stiffness value, the eigenmode and eigenfrequency are changed. This leads to a change in amplitude and phase during the modal transient analysis and makes a prediction by extrapolation difficult. Based on that, several stiffness combinations can be found which give a good correlation for setup 2. To validate the results for the second simulation an engineering assessment on the sealing has been performed which results to the following stiffness relation; kx>kz>ky. Moreover, a third setup was done where the BIW was stiffen up by adding a cross beam. Third test setup was performed in order to provide a further confirmation for the second test setup. Hence, the sealing stiffness combination which gives a good correlation for both second and third setup is the following stiffness values: kx= 5, ky= 0, kz = 3 N/mm/20mm. The stiffness in lateral direction has no significant impact on the relative displacement [4].

Alignment of evaluation direction between E-line and variation simulation

When assessing rattle, variation over time needs to be considered because the nominal gap between components will have dissimilar dimensions between different manufactured units. This means that the smallest gap that can occur needs to be calculated. Consequently, rattle assessment can be formulated according to equation (1).

(1) Dynamic relative displacement + Static relative displacement < nominal gap

The dynamic relative displacement is gained from the modal transient analysis and the static relative displacement is derived from a Monte Carlo based variation simulation using the Computer Aided Tolerancing (CAT) tool RD&T [7]. The final geometrical variation in an assembled product can be controlled by: 1) the geometrical variation in all parts, stemming from the individual manufacturing processes used and 2) the geometrical robustness of the product and production concept, i.e. its ability to withstand the manufacturing and assembly variation. Each input tolerance is specified as a standard distribution or based on measurement data from manufacturing process. In each simulation step, tolerances are assigned according to distributions in all locating points (constrains between components) of the assembly and as part tolerances. Final variation is measured in defined local coordinate

systems between components during each simulation step and is represented as output distributions [8, 9]. Variation simulation can be performed with rigid or non-rigid components depending on how components are constrained. [10-12].
In order to allow superposition of dynamic and static relative displacement without adding an error, the direction of the local coordinate systems in ANSA and RD&T must be aligned. Since the local coordinate systems are mesh based in ANSA, the mesh quality impacts the direction, see Figure 8. The black lines in the section represent the geometry of the bumper and the tailgate while the red lines represent a mid-surf mesh of the same geometry. When defining the evaluation direction based on the mesh, both red arrows can be selected. As seen in the Figure 8, none of the red arrows on the mesh represent correctly the shortest distance whereas the black arrow illustrates the correct evaluation direction. Furthermore, dynamic and static relative displacement belongs to two different simulation disciplines that are conducted by different CAE departments.

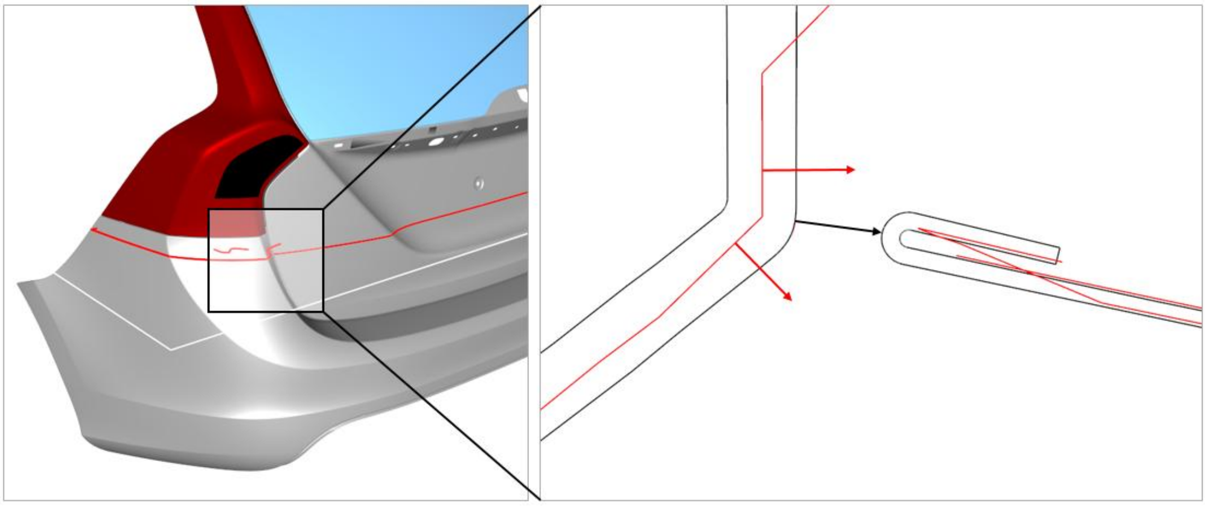

Figure 8 – Different possible evaluation directions due to different mesh qualities.

This fact also complicates a common definition of evaluation direction. In order to align evaluation directions, a new method has been developed and implemented in RD&T and ANSA. Since variation simulation is conducted earlier than E-line simulations in the development process and the fact that variation simulation models are defined using JT or VRML data it is appropriate to define a common evaluation direction in RD&T. It is also important that the common evaluation direction represents the shortest distance in the gap between the two components. A new type of measurement function has been defined in RD&T that is called *Seam* in the program. With the seam function, it is possible to calculate the shortest distance between two parts along a gap and to create a surface strip that represents the normal direction at the shortest distance. In Figure 9-A, the interface for seam creation is shown. The procedure to create the seam is simple. Two parts are selected, one master and one slave. Starting point for the relation is picked and a support line is created along a series of face edges, see Figure 9-B.
For each line segment, a section is created normal to the line. In each section, the shortest distance between the components is calculated and a surface strip that is normal to the shortest direction is created and placed tangent to the master component. The section that is displayed in the interface also represents the search boundary when calculating shortest distance. Accordingly, any geometry outside window will not be included in the search.

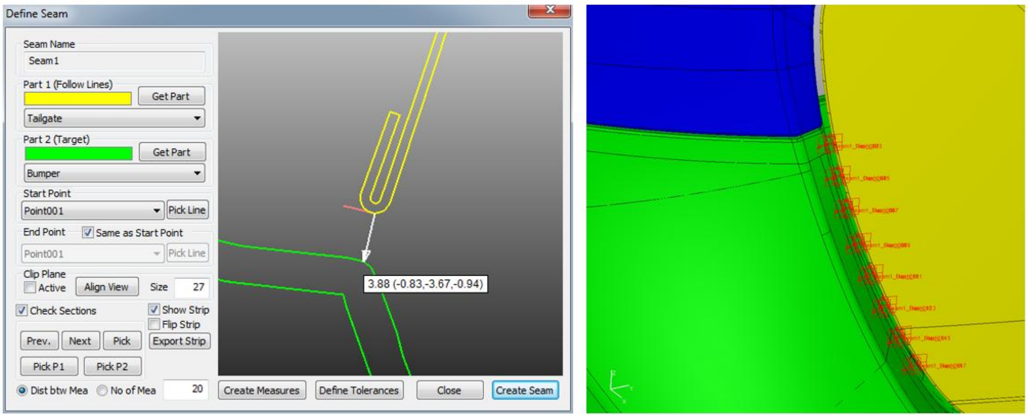

Figure 9 – (A) Seam creation interface. (B) Defined measurements along the seam.

The choice of support line is not important for the result but to orient and locate search area. In Figure 10-A and 10-B, two support lines for creation of surface stripe for same relation are shown. The first line is based on the tailgate and the second on the bumper.

The section in Figure 10-C shows the geometry of the tailgate and bumper together with the two surface stripes. It can be seen that they are exactly parallel although different support lines has been used.

When the seam has been created, it can be checked and adjusted manually if it is necessary. The exact nominal gap is also illustrated in the graphical area of the interface for each section. The surface strip is also included in the section and can be seen in Figure 9-A, above the white arrow. Finally, measurements are created along the seam that can be used in the variation simulation in RD&T, see Figure 9-B. The surface stripe is exported from RD&T as a .vrml or .imp file and can be then imported to ANSA and used in the E-line creation.

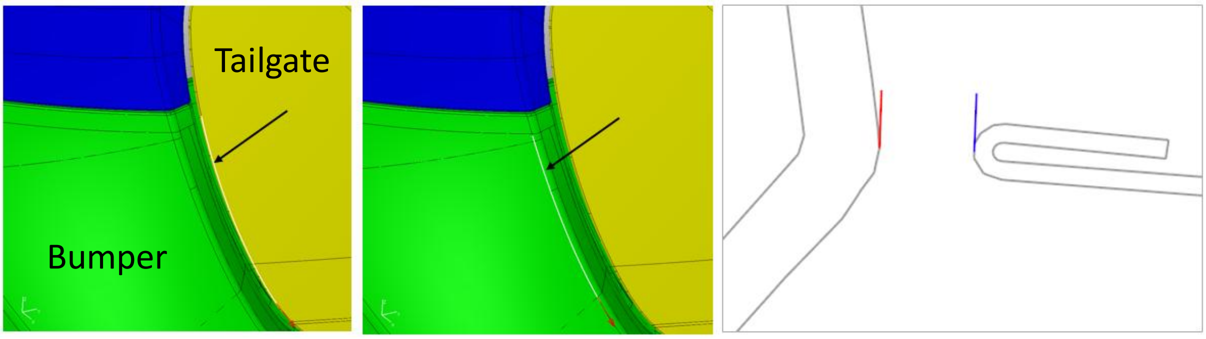

Figure 10 – (A) Surface stripes based on tailgate support line. (B) Surface stripes based on bumper support line (C) Section with the two parallell surface stipes.

3. INDUSTRIAL CASE

The mesh based E-line and surface stripe based E-line are evaluated in an industrial case study. Figure 11 shows the imported surface stripe from RD&T into ANSA. As it is shown in the Figure the surface stripe is taken from the lamp and bumper components.

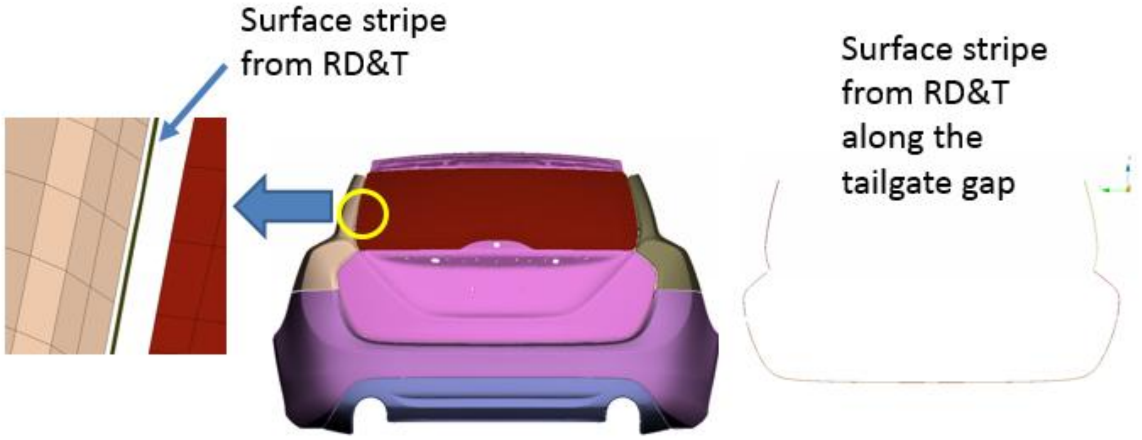

Figure 11 – Importing the surface stripe in ANSA for the E-line calculation.

A new feature has been developed in ANSA to allow the creation of E-line using the surface stripe. This feature implements the surface stripe for creation of the CBUSH coordinate systems. Hence, all the CBUSH elements, created for the E-line are pointing to the shortest distance of the gap regardless of mesh quality. Therefore, this feature results in a more precise and reliable calculation of relative displacement. The difference between CBUSH orientation when creating the mesh and surface stripe E-lines can be seen in Figure 12.

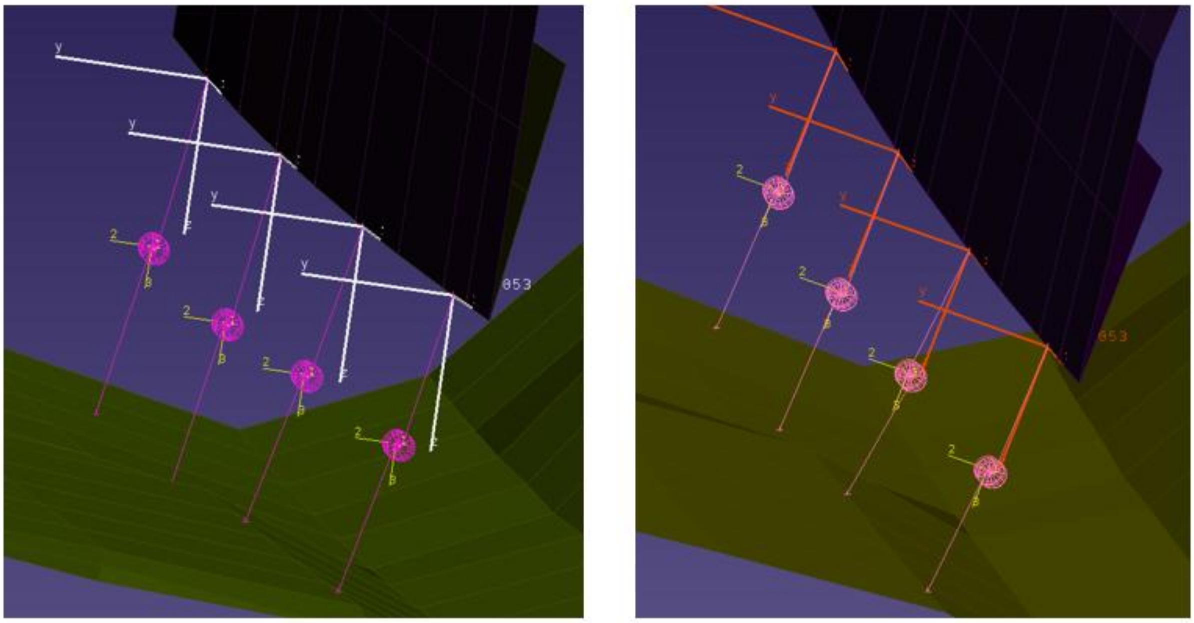

Figure 12 – CBUSH orientation due to mesh (A) and surface stripe (B) based E-line.

Figure 12 indicates how the coordinate for CBUSH element can be influenced by the mesh. The white coordinates on the Figure 12-A represent the local CBUSH coordinates for the corresponding CBUSH and as it can be seen they are following the mesh direction. In Figure 12-B, the surface stripe is guiding the direction which is pointing to the closest distance in the gap. Therefore the results for the relative displacement can vary due to the difference in the coordinate system for CBUSH elements.
The creation of the mid-surface from geometry is the reason why the mesh direction is not always reliable. Figure 13 shows how the mid-surface creation influences the results for the coordinate system

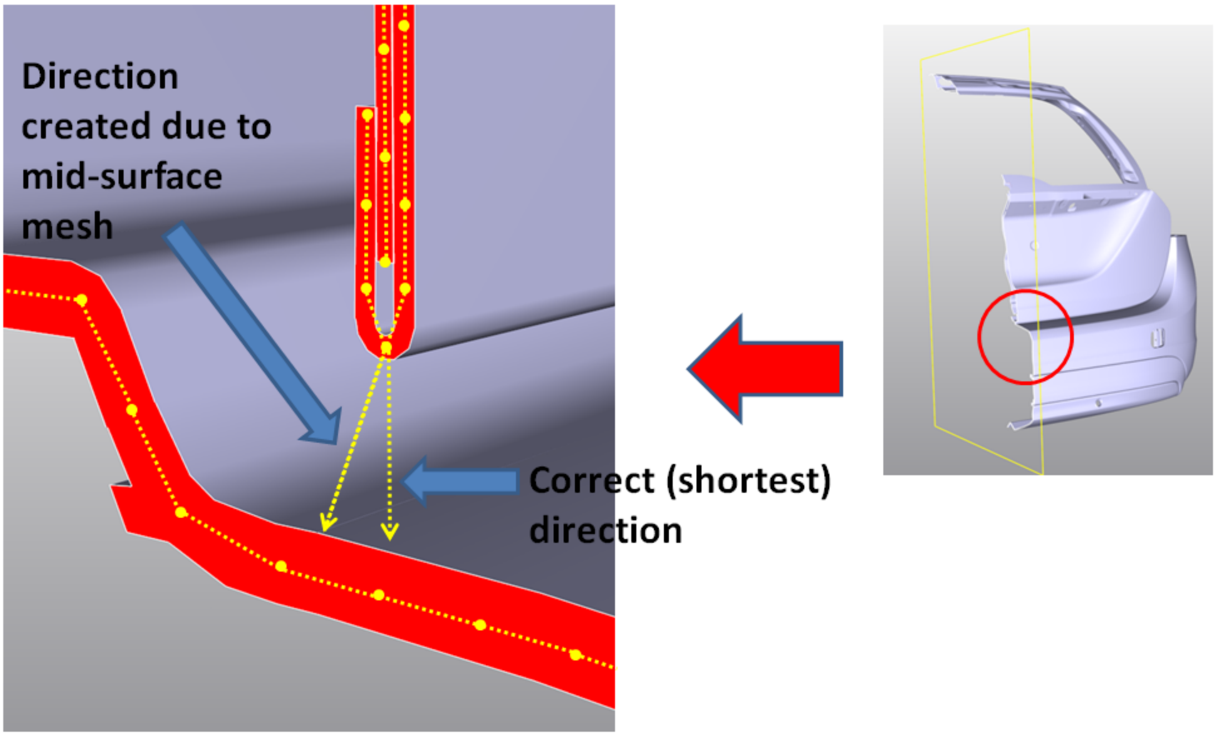

Figure 13 – CBUSH orientation due to mesh (A) and surface stripe (B) based E-line.

The yellow dotted lines, see Figure 13, represent the mid-surface which the mesh will be created on. The yellow dot which is pointed in the Figure is the reason of direction deviation. The difference in the results is presented in Figure 14.

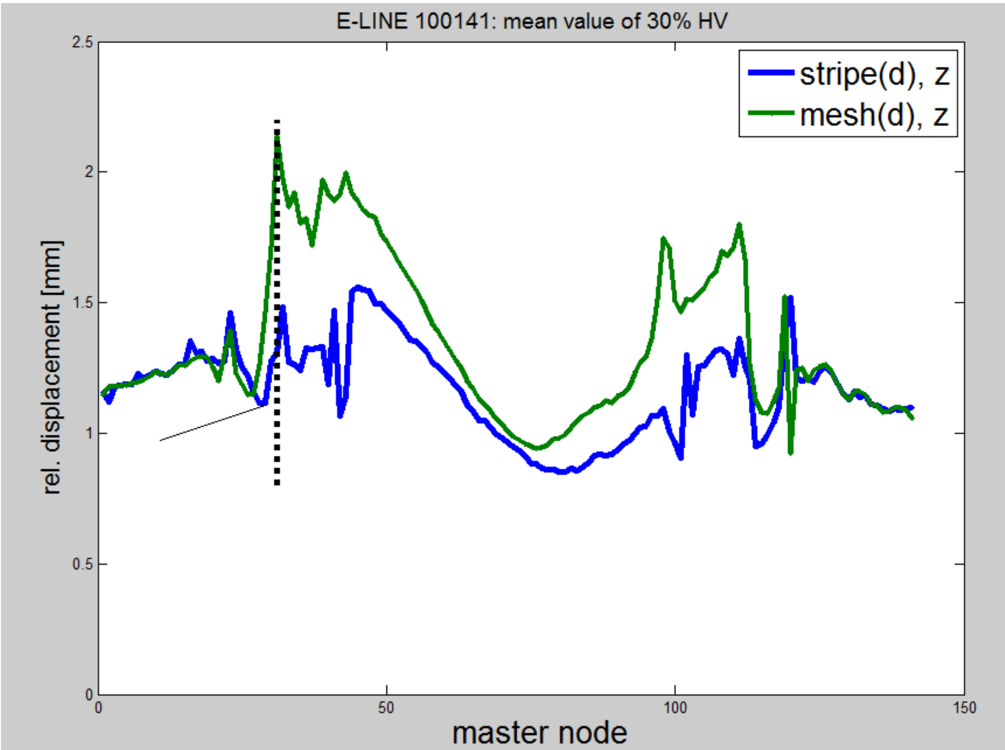

Figure 14 – Relative displacement in local z direction for Mesh based and surface stripe E-lines.

Figure 14 is achieved by simulating the relative displacement along the tailgate gap due to a time domain signal. The mesh based curve (green) has a difference of 24% in value from the surface stripe curve (blue) in the marked point (point 31-dotted line). This means that the accuracy of results can be radically increase by implementing the new feature in ANSA which uses the surface stripe from RD&T software.

4. DISCUSSION AND CONCLUSIONS

Prediction of S&R is a fairly new CAE area and it is not until last decades that true efforts have been made to efficiently use CAE tools in order to predict and avoid S&R during development phases. Due to this fact, substantial work still remains to be done regarding the accuracy of the input data and model properties. In addition to that, simulation tools need to be developed further on both pre- and post-processing side.

In this paper, three parameters; 1) BIW damping 2) sealing stiffness 3) alignment of evaluation direction between dynamic and static relative stiffness have been studied in order to increase the precision of S&R simulation. The updated damping value is valid for the BIW while the S&R simulation requires the whole trimmed body and this leads to the future work which is to perform the same correlation procedure on a complete vehicle in order to determine the global damping.

Information that is transferred between RD&T and ANSA will also be extended in order to increase the accuracy and concurrent engineering. A naming convention based on geometrical requirements that are defined for all visible split-lines on the vehicle will be included in the surface stripe. This means that all generated E-lines will follow the same name convention as for seams in RD&T. Furthermore, for each section that is created, the nominal gap values and calculated static relative displacement will also be included in order to be used in post-processing.

The case studies result shows that all three parameters contribute to the accuracy of simulation where only alignment of evaluation directions can up to 24% increase the precision of relative displacement calculation.

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