BMW Simulates the Durability Impact of Door Slam Sequences

ENGINEERING INNOVATION

LMS International, working in conjunction with BMW, FH Aachen and MAKROSS, has developed an analytical process that allows predicting the durability performance of vehicle doors. The scope of this project comprises the use of virtual simulation to predict the ability of components to withstand door slams. It combines explicit Finite-Element (FE) analyses using modal superposition techniques, and durability simulations to convert the obtained local stress histories into fatigue-life predictions. When further elaborated and optimized, this approach has the capacity to provide reliable insights in the durability performance of body and door components, before physical prototypes become available. In the future, this way of working may potentially replace or complement BMW's current approach, which includes performing physical tests on vehicle prototypes.

Tight vehicle crash regulations and high quality and comfort standards continuously raise the bar in vehicle-body and door design. The inclusion of additional crash safety structures as well as the usage of softer rubber elements increase the loading of components when doors are being closed. Also changes made to trim packages for increased passenger comfort, such as integrating new acoustic isolation materials, potentially impact the durability of doors and associated body components. When these components are not properly designed for durability, intensive use of the doors may cause obstructions when they are opened or closed. Such occurrences may generate undesired noise and rust, and may even lead to malfunctioning of the door lock mechanism. In order to avoid these problems and maintain reputation for extremely high quality, BMW performs tests on physical prototypes to guarantee that the durability performance of door and body components is sufficient. This test approach delivers reliable results, although a number of disadvantages are associated with it. Expensive prototypes are required to perform the verification tests, and the evaluation of numerous door slam events consumes a considerable amount of time. And when discovering durability problems, the design needs to be adapted, prototypes modified, and tests rerun, adding both time and cost to the vehicle development process.

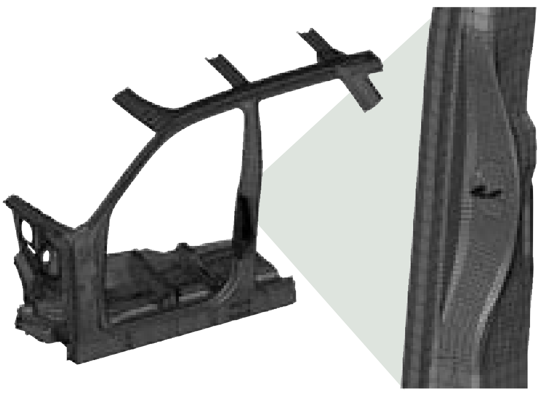
When the door hits the closing hook ...

BMW's goal was to explore the possibility to evaluate the durability of door and body components in relation to door slam events by means of virtual durability simulation. The durability test that was simulated consists of repeated door slam events with a predefined mixture of three different door-closing velocities. The simulations and physical tests involved were carried out on two different designs. The first design exhibited early failures in the metal sheets close to the reinforcement spot welds. In the second design, the reinforcement was revisited to obtain a more satisfactory load distribution.

When studying a door slam sequence in greater detail, three phases can be distinguished. First, the door contacts the rubber grommet on the body, which undergoes large deformations. The kinetic energy absorbed by the rubber is converted into heat and elastic energy. Then, the door hits the closing hook and is completely stopped. In the final phase, the previously stored elastic energy tries to swing back the door, but is stopped by the hook. The precise capturing of the time-dependent contact conditions between the different components of the closing mechanism is essential in simulating the load transfer between the door and the frame. The body-door contact sequence brings about a variable deformation of the rubber grommet, due to the curbed movement of the door and the resulting modal oscillations of the door itself.

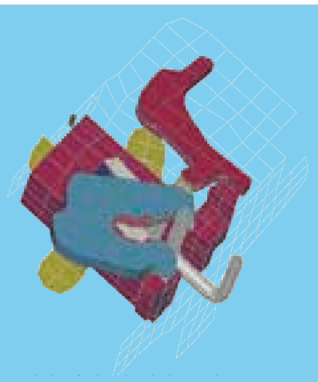
Starting from advanced FE modeling and analysis

The FE model that was used to simulate the door slam sequences consists of the door, body frame, grommet and lock. The basic FE mesh of the body frame components was taken from an existing full-vehicle model that was previously used for stiffness calculations. The engineers cut out the area around the front-left front door to reduce the number of elements, and refined the mesh density in the critical area around the lock hook.

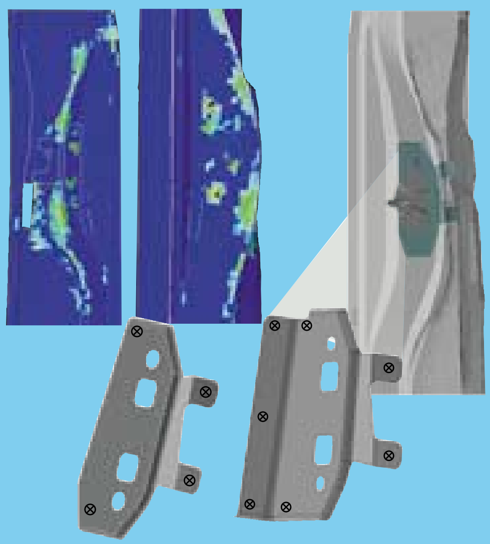


Cut-out and refined mesh in the critical area around the lock hook.

Detailed door model from previous side impact simulation.



Detailed model of the lock based on a mixture of solid and shell elements.



The modified design of the door frame re-inforcement component improved the total life by a factor exceeding 20.

From previous side-impact simulations, they retrieved a detailed model of the door. They realized the connection between the body frame and the door models by means of joint elements. Altogether, the resulting model consisted of approximately 60,000 elements and 65,000 nodes. The rubber grommet was modeled by a single row of solid elements with a skin of contact shells on top. To take into account the non-linear behavior of the rubber, a low-density foam material model was used for the solids. The material parameters of the rubber have been calibrated by comparing calculated and experimental data from a simple test setup.

The lock was modeled by using a mixture of solid and shell elements. The surfaces involved in the sliding contact were modeled in detail to avoid unrealistic peak loads when the contacting component is sliding over the mesh edges. The plastic buffers, coating and bump stops were modeled as low-density foam. Pre-stressed spring elements were included as well as a damper element to account for the friction of the locking mechanism.

Instead of using simple node-to-node beam connections, the beams were connected to the sheet elements by so-called rigid spiders. This modification simplifies the placement of the beams, especially when dissimilar meshes need to be connected. The application of rigid spiders also improves the overall stiffness behavior of the model. The engineers validated the FE model by comparing simulation and experimental results, and this showed an acceptable level of correlation. It became very clear that the force acting on the closing hook is a significant quantity. The validation showed a high sensitivity of the force histories with respect to the lateral positioning of the hook, the local stiffness around the lock mount, and the material properties of the rubber.

The transient FE simulations for a single door slam for three different closing velocities and two different designs have been performed using explicit ANSYS LS-DYNA FE analyses. In these simulations, the modal superposition technique is used to account for the rigid-body motion of the door, the extensive deformations of the rubber sealing, and the modal oscillations of the door. In the simulations performed, global as well as Rayleigh damping were used.

From local stresses to accurate durability predictions

The stress outputs from the FE analysis served as inputs for LMS FALANCS, which reliably converted the local-stress histories into fatigue-life predictions. As the loads generated by a door slam create mode shapes of the door, regular quasistatic superposition techniques cannot be applied. Therefore, durability analyses are performed following the modal superposition technique and with the transient analysis option activated. For the sheet metal, the strain-life approach is used, while for spot welds the engineers opted for a modified Rupp's approach. The primary input was the elastic-stress histories with elasto-plastic effects approximated with Neuber-type estimates. In the resulting elastic-plastic stress and strain histories, closed hysteresis loops were identified with the help of the rainflow-counting method. A damage value was assigned to each loop using material data and a suitable damage parameter. The force and moment histories at spot welds were extracted from the beam, and radial stress histories in both connected metal sheets were calculated using specific analytical formulas. These radial stress histories were then input into a stress-life analysis using a back-calculated Wöhler curve.

Dr. G. Tokar of Structural Analysis at BMW commented on the surplus value of the project, "Both the experimental and virtual results showed that the modified design improved the total life by a factor exceeding 20! The results predicted by the strain-life approach accorded better with physical test results than the results produced by Rupp's approach, which turned out to be too conservative. The use of rigid spiders instead of simple node-to-node connections caused the spot weld beams to transfer higher moments than those that occur in reality. This was partly adjusted by establishing a new back-calculated Wöhler curve for the modified spot-weld modeling. The project demonstrated that the combination of non-linear FE analysis and fatigue-life predictions is the right way to go. Once further elaborated and optimized, this virtual simulation approach has the potential to efficiently and reliably predict the fatigue life of body and door components, without having to wait for prototypes to be built and tested. When integrated in the mainstream development, this way of working potentially yields significant benefits in terms of development quality, duration and cost." ■

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