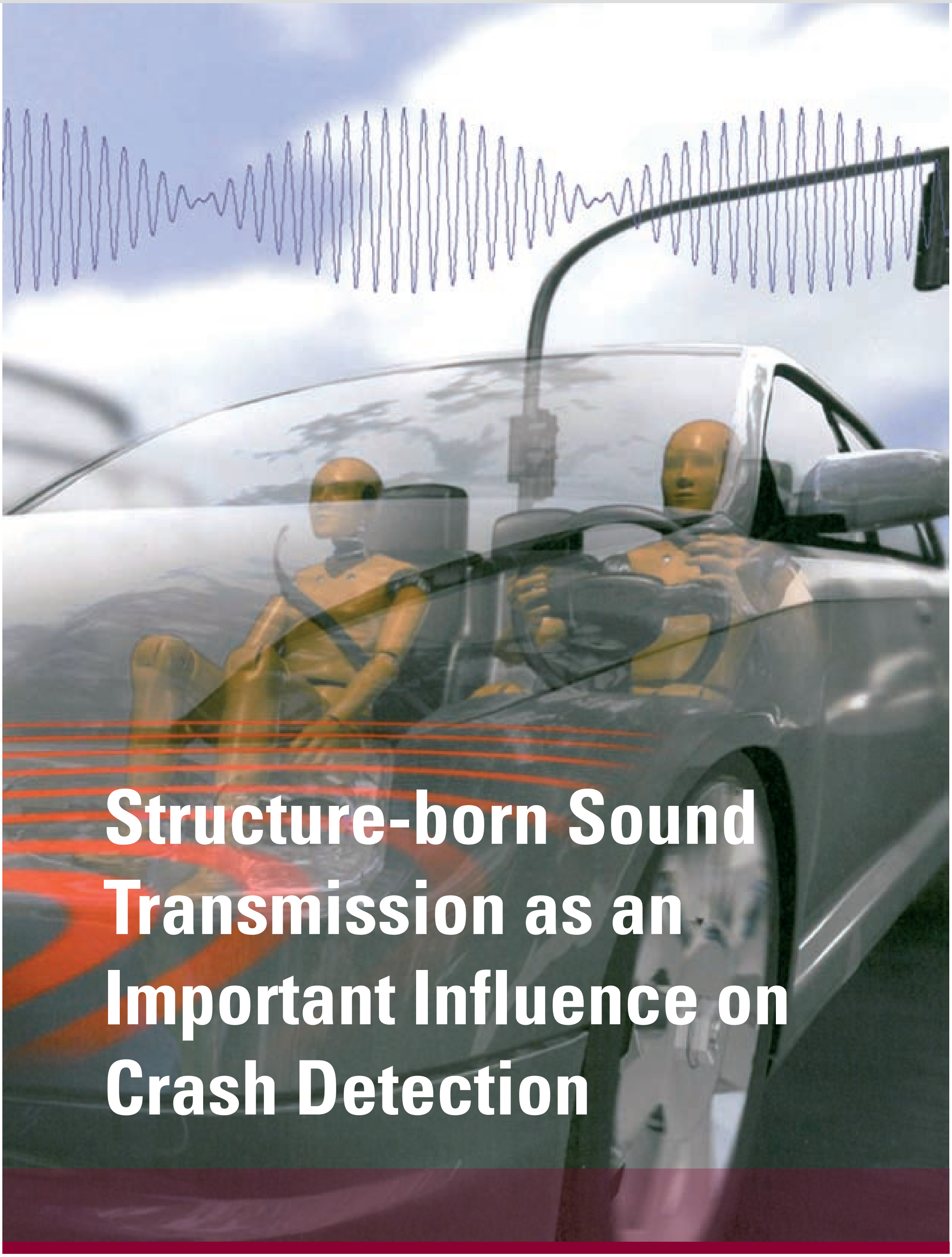

Structure-born Sound Transmission as an Important Influence on Crash Detection

"Hearing" sensors, which measure structure-born sounds, caused from deformation of a car during crash in order to advance crash detection performance, will go into series production soon. For this reason and to bring the next generation on the way there are many research activities in the field of structure-born sound transmission on the Institute of Applied Research at University of Applied Sciences Ingolstadt, which are done in cooperation with Audi AG and Continental AG.

1 Technology of Front Crash Detection

Today State-of-the-Art front crash sensing technology is mainly based on deceleration of the car during the crash. This low frequency acceleration is measured with sensors which have a frequency band below 1kHz, at one ore more positions in the vehicle.

1.1 Difficult Testing Scenarios

With actual sensing technology there are two different test types which are often hard to discriminate in the needed time gap [1]. The first one is the AZT-test (Allianz Centre of Technique) where the car crashes with 15 kph against a rigid 10 degree angle barrier. This test is the basis of the insurance classification. The second one is the ODB-Test (Offset Deformable Barrier), with EuroNCAP-Test as best known one. Here crashes the car with 40 to 64 kph against a deformable barrier witch covers the car by 40% and imitates another car, **Figure 1**.

The existing similarity in deceleration wouldn't be a problem if at the AZT case the airbag was not minded to open and in ODB case the opening of airbag was not essential to life.

1.2 Potential of Structure-borne Sound Sensing

To discriminate these two scenarios fast and safe enough more information about the crash is needed. One possibility to get further information is to measure high frequency structure-born sounds caused from the deformation of car structures in the crash, **Figure 2**. This signal is transmitted through the car body and measured in the airbag control unit [2].

2 Benefits of Investigations Concerning Structure Born Sound Transmission

Today's medium-sized and luxury class automobiles feature additional acceleration sensors in the front of the car to improve crash detection. These sensors permit to get information regarding the crash progress immediately after the collision. A so called airbag electronic control unit (ecu) evaluates the sensors signals, using specific criteria from different crash situations. The car deceleration for example arises faster impinging a wall compared to a "soft" object like a car. A crash algorithms works always on all sensors and incorporates a multitude of criteria.

Provided that the criteria are based on physical events the fire decision will be stable towards variability of tests and real life accidents. This assures, that an airbag system, which is configured from scenarios defined by laws or rating agencies, delivers highest safety in ordinary crash situations too. Information from the front sensors is transmitted via wires to the airbag ecu. Structure born sound will be used for crash detection in an analogous manner. A great difference is that the information is not transmitted by wire, but the car structure itself. The propagation of vibration through a car is not comparable to carrying electric signals by wire. Transmitting by wire you have to keep in mind the possibility of a breakaway of the cables, guarantee electromagnetic compatibility and search a proper position, where to place the sensors. All these topics are no more a technological challenge. Passing a wanted signal consisting of mechanical vibration over a car structure is in contrast a totally new field.

2.1 Basic Conditions in Cars

Using the bodywork of a car like a medium to transfer information requires a qualification of the same for this purpose. This means: The car has to be considered completely like an medium of transmission. Firstly all influences and situations are relevant whichever could occur in a car life cycle or any driving situation. It is desirable to reduce the complexity, to implement the qualification process efficiently.

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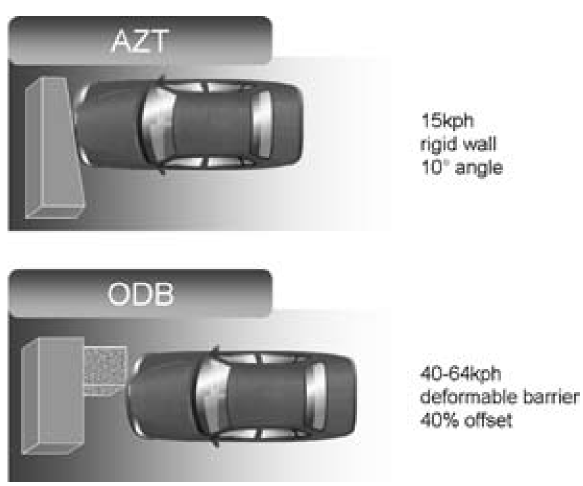

Figure 1: Sketch of both test cases witch are hard to discriminate

Effects on structure born sound generation have to be separated from those which take influence on structure born sound propagation. Modern methods of artificial deterioration can be used to simulate weather, environmental influences and extreme usage of a car. Specific driving situations can be investigated separately. Many influences can be excluded or evaluated theoretically. The robustness takes advantage from using a broad frequency band. In this case it is above distinct eigenfrequencies of parts. Therefore the change of such eigenfrequencies, caused by limited fabrication accuracy [3], does not play a decisive role. Another milestone is the identification of transmission paths through the bodywork. This helps to reduce the amount of parts to analyze.

2.2 Identification of Transmission Paths

Identifying transmission paths serves to reduce the complexity of the qualification process. Furthermore this kind of analysis is important to determine the delay along the propagation path. Electric signals in cables reach a velocity up to 50 % speed of light [4]. Structure born sound propagates with up to 5000 m/s. Actual the delay depends on a lot of factors like the predominating wave type, the material or the form of the assemblies.

The alteration of the wanted signal, which is an effect of running to the measuring point has to be quantified. In contrast to electric transport it is not possible to get the same information at any position on the path, if you use propagation of vibrations. Knowledge about the structure on which a vibration signal was measured is necessary to evaluate the mentioned signal. Mostly this is a topic of structure dynamics or modal analysis. Concerning the technical constraints bandwidth and high frequency range some methods have to be adapted or advanced.

The classical method of transmission path analysis can be used for the determination of main propagation paths [5]. It is essentially based on correlation and coherence analysis. Investigating the delay time various signal criteria like first slope or maximum amplitude were useful. Damping and attenuation must not be disregarded, because of the multitude of interconnections between the parts. A lot of acoustic engineers, working on such themes try to guarantee highest comfort for the car passengers. In the case of car acoustics lower frequency range is mostly of interest.

The above mentioned knowledge about vibration behaviour of the parts helps similarly to find adequate measurement positions.

2.3 The Evaluation of Different Measurement Positions

For the usage in series vehicles structure born sound measurement system should be integrated in the airbag ecu. For any type of test or study (e.g. transmission path analysis) further measurement points are applied. Comparing signals from different positions the local dynamical stiffness has to be known. Then it is possible to separate propagation effects from local effects at a certain measurement position. At the same time this information helps to find a position as quite appropriate, e.g. linear over a wide frequency band. So the measurement quality can be optimized within the constraints of a total car development cycle.

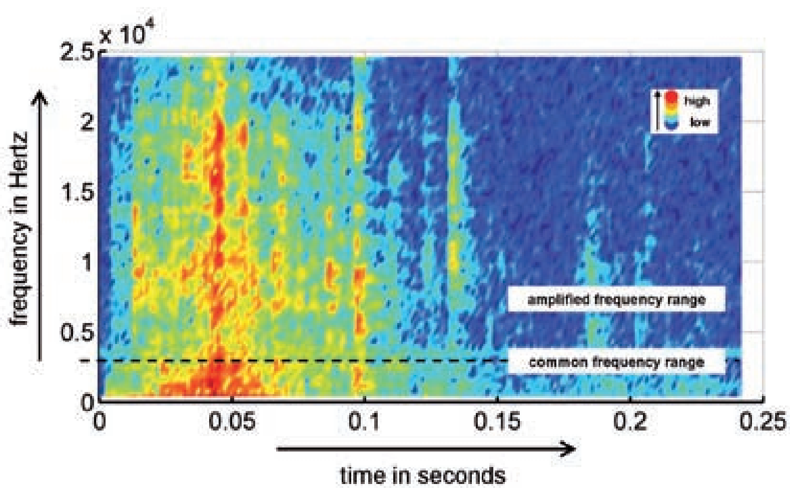

Figure 2: Expansion of the frequency range (spectrogram of an car crash)

2.4 Influences of the Crash

One fact has not been mentioned yet. During a car crash the car will be destroyed and the transmission medium selected too. Until today you had to guarantee that front sensors could send sufficiently long signals to the airbag ecu to facilitate a airbag fire decision. Adequate sensor positions, crash secure running of cables and protective cases for the sensors class among those arrangements. In the case of crash impact sound sensing the time until a fire decision can be calculated is decisive. During this time, in which sensors should be able to provide information to get an optimum deployment of the airbags, main transmission paths should be mainly intact to assure the predetermined characteristics. If any car collapses in the few milliseconds to an airbag fire decision, the transfer of information will be time varying. Internal studies of the project partners showed the stability of the main transmission paths. Moreover time variance could be considered within a crash algorithm. However it is not recommended to make a system more complex than necessary.

2.5 Advance in Performance

Observing an advance in performance using optimized sensors you have to question, what does one system to deploy airbags make better compared with another? Is the quality determined by the number of stars from the EuroNCAP? That is not the only truth of course. Standard test procedures represent a high number of relevant crash types, but cannot cover the spread of real accidents. It is not possible to check or simulate all thinkable variations.

In order that car airbags are not deployed only in the EuroNCAP tests, the physics of a crash should have an important role programming an airbag algorithm. For such an algorithm the information about the car, which is available during an accident, is fundamental. That shows the advantage of crash impact sound sensing. The additional measurement of structure born sound within a car crash is a growth of information (fig. 2) and therefore an enhancement of the basis of decision, on which the algorithm calculates the fire decision.

The analysis of structure born sound propagation in a car can contribute to improve the quality of the basis of decision furthermore. That contains all activities like searching appropriate measurement positions, taking into account local properties of a measurement position and determining and considering the characteristics of the transmission paths.

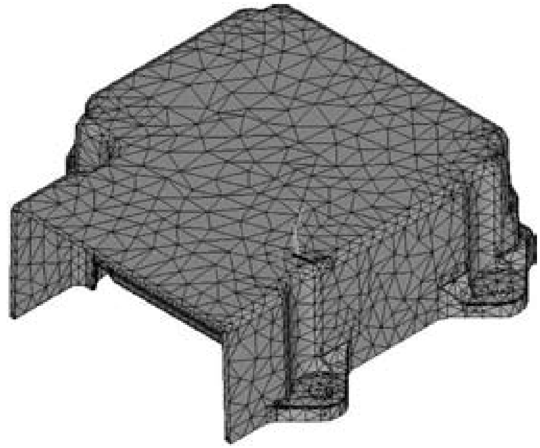

Figure 3: FEA of a car structure part

3 Need of Transmission Simulation

Experimental investigation can not be started until a physical prototype of car or parts of it are available. So an earlier evaluation of the design is only possible if special simulation techniques are used. Based on even shorter design cycles and a high money saving potential the FEA (Finite Element Analysis) is getting more and more important at the development process, **Figure 3**. Structure-born sound waves are stress waves, so FEA is theoretically perfect for the investigation of transmission phenomena in the virtual design step [6]. The high deformation rates and the non-linearity of materials in the crash can also be handled with this method.

3.1 Inadequacy of Actual Simulation Programs

Based on the high frequency band up to 20 kHz and more in the structure-born sound technique for crash sensing the simulation investments are getting very high. To get these high frequencies correct in simulation both - time step round about 1μs, and geometrical division of the structure, near 10mm - must be very short and for this reason the simulation time is very high. This use of time is inadmissible in the design process [7].

3.2 Development of Specific Simulation Methods

To keep the needed investments on a structure-born sound transmission simulation as low as possible, it is necessary to adapt existing techniques or to develop new simulation methods. Not only the replacement of the nearly exact FEA simulation is a point, but also making available methods with can evaluate transmission parameters before a complete CAD (Computer Aided Design) file is provided.

Through the high mode density in the investigated frequency area one suitable method is SEA (Statistical Energy Analysis). This well known technique in NVH (Noise and Vibration Harshness) doesn't regard the single wave but the average energy which is transmitted through the structure.

Another interesting method is TLM (Transmission Line Method) witch describes the structure through one-dimensional transmission blocks. Both methods reduce the time investment in the simulation process.

3.3 Virtual Parameter Variations

With these simulation methods which first have to be developed, or today already on single parts of car structures with FEA-method, it is possible to make virtual parameter investigations. This way it is possible to get a good design for the transmission without physical prototypes.

3.4 Evaluation of the Frequency Response Function

Besides the experiments a virtual investigation of the frequency response function is possible. So the simulation can optimize the transmissibility at the early design process to get the best transmission for the structure-born sound in the crash relevant frequency band of the sensor. This optimization leads to a perfect signal for the crash discrimination process.

4 Conclusion

The transmission of wanted signals using the car bodywork like a transmission medium is totally new. Researching the high frequency structure born sound propagation in car structures alleviates the qualification of the transmission path. The study of constraints and environmental factors guarantees the robustness of the technology under the assumption of common vehicle use. So additional information can be provided to future crash algorithms.

In the future the evaluation of the structure-born sound transmission through the car structure in the early design stage is only possible with specific simulation methods. For this reason it is important to check the existing simulation techniques and develop new methods.

Themes like driving assistance systems or technologies, which help to soften or prevent accidents, will attract the attention in the next years. But neither those systems, neither speed limits nor higher speeding fines won't eliminate, that accidents happen. The advance in performance in the field of passive safety can fortunately not be experienced by any customer. But if an accident passes the experience will be as much more intense.

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