ADVANCED PASSENGER SAFETY BY STRUCTURE BORN-SOUND DETECTION

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The structure-born sound sensing technology is a new advanced technique in the live saving field of passive safety. As an enhancement of the actual technology of deceleration measurement, structure-born sound sensing evaluates the high frequency oscillations caused from the deformation process of the car in crash. To prepare the series introduction of this crash sensing system it is necessary to investigate, measure and simulate the relevant effects and translate this specific know-how into the discrimination-algorithms.

1 Introduction

1.1. *History of passive safety*

The important job which arises from economical and social view is to form the traffic as safely as possible. The accident statistics nationwide and internationally show a steady decrease of accident victims despite a rising number of vehicles (Appel *et. al.*, 2002) since 1970.

Till 1970 the death rates grew continuously to its maximum value. In this year the number of killed drivers turned. Since then the traffic amount has tripled but the number of the killed road users has already been halved.

This development on one hand is based on the invention of passive safety systems like the seat belt or the airbag. On the other hand introduction of punishments has raised the attention of the drivers.

Today the safety technology is divided into two parts: active and passive safety. Besides, active safety stands for the systems which support the driver during the driving, for example ESP (electronic stability programme), ABS (anti-lock brake programme) as well as assistance functions count. Active security system should prevent the excess of physical stability borders and avoid accidents. Passive systems are based on the reduction of the injury gravity if the accident is not avoidable and the vehicle is in the crash phase. In the passive area the seat belt and the airbag are the best known.

1.2. *Basic idea of structure-born sound detection*

Todays airbag systems are based on the analysis of the rigid body movement. Moreover the low-frequency acceleration is measured in all actual crash detection systems. A modelling by a spring-mass-system can describe the speed reduction so that the force on the passenger can be computed and the system can react accordingly. If the speed reduction is too high, the vehicle will deform critically.

The innovation which is developed with Continental Regensburg and the Institute of applied Sciences Ingolstadt has just got into series production. It is based on the extension of the frequency band of structure oscillations in the range up to 20 kHz (Oestreicher & Luegmair, 2007). Thereby the analysis is working on the structure-born sound technique which is generated from the deformation of the vehicle during a fatal accident. The information propagates with structure sound wave speed through the vehicle body, so that important information about the crash is available at an early crash phase (Luegmair & Spannaus, 2007).

Besides, is to be pointed out to the fact that an airbag ignition will never take place on a single measurement signal out of one sensor. The sensors have to work with different sensor concepts on different physical values. The sensors will compare with each other for plausibility. With the structure-borne sound based crash detection the rigid body delay is enriched with additional information.

2 Technology of structure-born sound detection

2.1 Decomposition of the car structure into areas with similar characteristics

For a specific investigation of existing effects which dominate the sound emission and the transmission during the crash and also the detection process it is necessary to separate the structure of the car. With these areas of similar characteristics it is possible to investigate the effects with special theories, experiments and also simulation techniques.

As shown by Luegmair (2008) it is possible to decompose the car structure into two areas of different interest during the important time space of 30ms.

The first area, the structure-born sound emission area, is in the front of the car. This area includes the crash management system consisting of the cross bar and the crash boxes. Here occurs the deformation of the car structure and so nonlinear effects such as large deformations, plastically material behavior and deformation-rate depending material parameters and also the varying force on the structure results into another nonlinearity. Based on the time varying value of the force, the stress and the deformation, there is a strong dependency on time. Of course the normal frequency dependency of mechanical systems is also important. All these effects must be thrown into attention in an investigation of emission effects in crash detection.

The second area of interest is the so called structure-born sound transmission area. This area includes the whole structure from the emission area to the sensing point at the passenger compartment. It was shown that in this area no large deformations or plastically material behavior and so no deformation-rate dependency material parameters do occur. So the only nonlinearity is the force dependency of the transmission. This can also be seen as a time dependent transmission function, because of the time varying force value. This means, that with exclusion of the force dependency the transmission area has a linear behavior and can be investigated with linear methods.

2.2 Effects and theory in the emission

Structure-born sound is initiated in general by a force in a structure. Important factor for the characterisation of this structural-stimulating force is the dimension of the underlying effect and the temporal sequence of the force application.

The order of magnitude of the body sound sources is defined within the scope of the crash detection investigation to microscopic, macroscopic and global body sound sources. Microscopic effects are mechanisms of the material mechanics. It is shown by extensive investigations that the emission of body sound of the deformation depends linear on speed. Nevertheless, the measurable amplitude is smaller than the noise of measurement technology for vehicle. Breaks and failure of structures are macroscopic effects. Moreover fissure origin and crack propagation count. On this occasion, the high energy emission rates which become clearly visible in the structure-born sound signal are achieved (Spannaus, 2008).

Global body sound excitation occurs through the crash impulse. The vehicle stiffness and the firmness of the other vehicle, as well as the relative crash speed determine the pulse entry in the system which stimulates the structure to high frequency oscillations.

All structure-born sound effects can be described superior with the force time function. Accordingly to the Fourier transformation quick force changes are characterised by a high frequency spectrum.

2.3 Theoretical effects in the transmission process

In the very short time and the high frequency band there are both pure wave propagation and standing waves effects on the complex structure that is investigated, so it is necessary to look at the theoretical effects of both physical principle (Fahy & Walker, 2004).

At first there are different possible wave types in solids. The basic waves are the compression and the shear wave. On thin structures there are three more wave types: bending, torsion and the surface Rayleigh wave (Cremer & Heckl 1996).

There are also many possible wave propagation effects, such as interference, dispersion, polarization, reflection, refraction, diffraction, damping and absorption (Meschede, 2006). All effects have special attributes for each wave type, so it is very important to know which wave type dominates the wave scattering. With this specific know how for the car structure it is possible to investigate all relevant facts of the wave propagation.

Additionally there are standing wave effects, also known as vibrations. Vibrations of mechanical systems are dominated from eigenmodes and eigenfrequencies (White & Walker, 1982).

Based on the high amplitudes of the eigenmodes they are good detectable with accelerometers. But at high frequency the mode density and the mode overlap are so high that there are no dominant eigenmodes left and the frequency response function is rather smooth (Fahy & Walker, 2004).

All these effects must be investigated very well to understand the behavior of the car structure in crash.

2.4 Application of the theory on crash detection algorithm

The crash algorithm must be able to classify and interpret the accident situation based on the sensor information. On this occasion, a huge number of the test standards which are defined by car manufacturers, legislators or assurances are to be considered.

By theoretical investigations it can be shown that the low-frequency acceleration is connected to the high-frequency structure-born sound signal. If rupture events within the structure appear during the deformation, the body sound signal is corrupted. By means of adaptive filtering the plausibility is checked between acceleration and body sound.

The filter structure must be effective and robust because of the processor limitation of the airbag control unit (Lauerer *et. al.,* 2006).

3 Implementation of structure born sound into car

There are two major challenges in getting the system into a car.

On the one hand there is the design process where there are no prototypes available. In this early stage, it is only possible to investigate virtual models. So it is very important to have adequate simulation techniques for this special purpose.

On the second hand there is the later phase short before the introduction of the car into the field. In this phase prototypes are available and crash tests are made. Now it is possible to measure structure-born sound effects on real structures and verify the simulations of the earlier design process. With the real crash data it also is possible to get the optimal algorithm for the specific car.

3.1 Simulation techniques in the early design process

It is necessary to have specific simulation techniques in order to evaluate how adequate the structure in structure-born sound emission and transmission is. This is the only possibility for investigations without expensive prototypes.

By Luegmair (2008) it was shown that for the deformation area where the structure-born sound is generated the only possibility to simulate all relevant nonlinear effects is the finite element analysis (FEA). Here it also is possible to integrate the sound emission with special material models into the simulation.

The area where only the transmission proceeds is more simple and so it is possible to look after more efficient and faster linear simulation techniques as the statistical energy analysis (SEA) and the transmission line method (TLM). They have to be adapted to the specific request of the structure-born sound crash detection (Luegmair & Oestreicher 2008).

So there is further effort for deeply investigation of simulation techniques and bring them into the design process for tremendous results in the safety function of the sensing principle.

3.2 Introduction into field

For the introduction of the structure-born sound technology in vehicle crash detection extensive tests and specifications are to be fulfilled.

Based on these tests the theoretical know-how over structure-borne sound effects is transferred into the car and in the field application, so that the best performance of the passive safety system airbag is ensured.

4 Outlook

Nevertheless the system actually improve the safety of the vehicle occupant, there is space for further optimization and new functions.

One step is to investigate high performance simulation techniques for structure-born sound which accelerate the integration of the system into the car and also allow gaining the knowledge in the relevant parameters.

In the algorithm development there can be found new and faster algorithms for the crash detection.

But future of the vehicle safety is the integration of active and passive safety systems into a new general safety system. This makes possible for example that information from active safety systems such as electronic stability control (ESC) help the airbag system to discriminate different scenarios. Another point is the possibility that different features as distance control, seat belt fastener and others use the same sensors and know what is happening round the car and with the car (Spannaus & Ertlmeier, 2008).

All these investigations are made in order to reduce the number of injured and killed persons.

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