Analysis of Annoyance of Low-Frequency Beat inside a Vehicle

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Abstract: Because station wagons/estate cars have a greater volume than sedan/saloon vehicles, low-frequency acoustic problems very often occur in the frequency range between 30 and 50 Hz. The sound produced is described as humming. Not only is the acoustic effect unpleasant, but can lead to physiological changes in the driver, e.g. a feeling of being unwell, nausea and similar stress symptoms. These changes are due to specific properties of the acoustic signals. The mechanisms by which this low-frequency excitation arises in the interior of the car may be very varied. Excitation frequencies can be produced by the powertrain, exhaust system or wheel suspension. Transmission takes place via the points by which these components are attached to the car body. Resonance in this special frequency range may well be present along these transmission paths. The spectral components thus arriving at the structure are radiated into the car interior via various "loudspeakers", such as floor panels, roofs or doors. Moreover, some loudspeakers may show special resonance's for this frequency range. Finally, the volume of the vehicle interior results in amplification of the low-frequency spectral range. During field trials, all excitation mechanisms and transmission paths were investigated using various measurement and analysis procedures. The combination of Artificial Head and multichannel measurement technology allows subjective evaluation of various vehicle models. Playback of the Artificial Head signals, however, is not only via headphones, but via a special "sound car" which also creates low-frequency excitation of airborne and structure-borne noise. Multichannel measurement technology enables a connection to be made between the frequencies at the driver's ear giving cause for complaint and the various excitation points. Moreover, the use of a two-dimensional laser vibrometer enables a connection to be made between vibrating structures and the annoying sound components driver is hearing.

NOISE AND VIBRATION EXPOSURE IN VEHICLES

The vibrational situation in a passenger compartment can be divided into two main categories: Firstly, the vibrational excitation through operational devices (i.e. engine, transmission system, wheels and suspension system). A good example for this excitation is the second order of an 4-cylinder engine. Secondly, there is also a vibrational impact by 'comfort features', such as power windows, electric sunroof, power seats and electrical mirrors. The electrical devices used here cause low frequent noise shares ("booming") and vibrations. There exist various transfer paths from a sound (and vibration) source to the passenger. In general, the transfer is possible via source, car body and vehicle's interior to passengers body or ears. The sound quality of car and its components is judged based on the resulting vibro acoustical exposure. At present, there is no detailed research known that gives a sophisticated scientific background. Examinations have shown, that there exist a trade-off phenomena between sound and vibration when the vibration level is in the range of perception threshold: The loudness is judged higher when vibrations are present in this case. Our experience when dealing with complaints in vehicles have shown that normally the consideration of vibrations at passenger's seat and of the rotational vibrations at the steering wheel is sufficient for a first approach. The mentioned vibrations represent the major part of relevant influences for the judgement. For particular devices - for example power windows - the excitation of other points at the car body may be considered. Based on this, a suitable vibro-acoustical playback may consist of airborne sound via head phone(s), low frequent sound below 150 Hz via subwoofer(s) and vibrations at steering wheel and seat via excitation devices. The integration of an adequate analysis and signal manipulation software allows the individual editing of each measurement- and playback-channel. The set-up of such a system, is shown in Fig. 1. It includes the multichannel measurement and analysis system SQlab for the recording of sound and vibrations and the additional acquisition of rpm and speed. Via digital interface the input signal is fed to digital equalizers (PEQ). It is possible to implement in each equalizer the particular equalization curves for the individual devices. Additionally, for a correct playback of the airborne sound via headphones and subwoofer it is necessary to consider the time delay. The complete system (called "sound car") is mounted in a. The main advantages of the "sound car" are playback of a combined vibro acoustical situation in a realistic environment; comparison of several vibro-acoustical situations without time delays and without necessity to "switch" between various test vehicles and a fast and cost saving judgement that is more reliable. The complete proceeding for the work with such a system may consist of introductory multichannel measurements with acquisition of binaural signals and...
accelerations at the points of later excitation, multichannel playback and judgement of vibro-acoustical situation, digital signal synthesis (i.e. filtering) of particular signals, play-back of modified signals and comparison to basic version and optimization of vibro-acoustical situation using the possibility of time and/or synchronous comparison of samples.

Introductory research tests within the European research project OBELICS have shown that the use of sound car may lead to more reliable judgments of sound characteristics and sound quality. Further examinations have been carried-out within several projects. The corresponding results will be explained in the following chapter.

APPLICATION EXAMPLE

Humming: Humming is low-frequency vibration at approx. 39 Hz to 41 Hz as shown in Fig. 2. In this figure you may see a resonance band (horizontal band dark color) in the spectrogram around 40 Hz. Rising straight lines indicate tire orders. It is obvious, that the superposition of tire orders and resonances cause high levels that are annoying. It becomes clearly perceptible to the ear through temporal modulation, or rise and fall. The effect called humming is reinforced due to the fact that it occurs suddenly at only a few specific vehicle speeds regardless of the properties of the driving surface, and in particular on smooth road surfaces. In the vehicle under examination, the impression of humming is most apparent at speeds around 90 km/h, although it can also be heard at speeds of approximately 40 km/h, 60 km/h, and also 140 km/h. In this vehicle, the excitation due to room resonance is reinforced by structural resonance. Simultaneous occurrence of structural resonance and room resonance amplifies transient response in the spectral range around 40 Hz. Structural resonance is reproduced and amplified by a number of "loudspeakers" in vehicle's interior. During excitation of the vehicle on a roller test stand, the 3rd wheel order is always present to the same degree, if the front axle or rear axle are driven separately. If a shaker is used to excite a front wheel, an extremely sharp structural resonance is perceptible around 39 Hz. During the examination it was also shown that the front doors contribute significantly to the frequency range. Appropriate stiffening of the door panels made a significant reduction of this radiation possible. The vehicle objected to was completely modified on the basis of the results described. The result was a clear improvement of the vibro-acoustical impression at all speeds. This improvement was established both objectively, in terms of measurement technology, and subjectively through reproduction of sound and vibration in the sound car. The resulting acoustic improvement is shown in Fig. 3.

REFERENCES

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