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Development of Experimental Procedure for Detecting and Evaluating Squeak and Rattle Noise Emission from the Instrument Panel in a Vehicle

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ABSTRACT

Among the various elements affecting a customer's evaluation of automobile quality, buzz, squeak, and rattle (BSR) are considered to be major factors. We propose an integrated experimental method that can be used to reduce BSR in an instrument panel module in a vehicle cabin, especially during the early design stage of vehicle development. We devised a vibration triggering system consisting of a fixture and an electromagnetic shaker to generate an input load reproducing the excitation signal from the road to the instrument panel without distortion. Potential source regions for BSR were localized using a near-field acoustic holography map obtained from near-acoustic field visualization equipment consisting of 48 intensity-type microphones, a data-acquisition system, and its analysis software. Finally, a sound quality evaluation of BSR from the detected potential source regions was performed using sound quality metrics. These experimental procedures were applied to characterize BSR from the instrument panel in a passenger vehicle. Based on our measurements and analysis, typical main source regions for BSR on the instrument panel were identified and quantitatively evaluated in terms of physical levels and sound quality metrics. These results revealed that the proposed experimental procedure can be used as a test procedure to identify BSR issues at an early stage in the vehicle development cycle, which could ultimately reduce production costs.

INTRODUCTION

Vehicle interior noise perceived in the passenger cabin of an automobile is one of the most important factors in a customer's determination of the durability and quality of the vehicle. Automotive interior noise is generated by various elements such as the engine, transmission, and climate-control system[1]. However, due to technological advancement in the sound and vibration engineering for vehicles, the overall noise level from vehicles has been continuously reduced, which has resulted in drawing the occupant's attention to intermittent noise such as buzz, squeak, and rattle (BSR) [2]. A market survey reported BSR as the third most important customer concern in cars after three months of ownership [3]. Therefore, BSR noise is increasingly perceived as a direct indicator of vehicle quality and reliability. Future electric vehicles will highlight even the most subtle BSR issues because of the generally low level of power train noise and the use of lightweight components inherent in their design. Usually the term of BSR denotes noise from structural vibrations in an assembly within the low frequency range. BSR is therefore categorized as structure-borne noise. The sound wave emanating from the vibrating structure alone is referred to as "buzz," "squeak" is noise originating from frictional movements between two parts, and "rattle" does noise due to the impact of one part on another [3]. The main causes of BSR noise can be categorized as structural deficiencies, incompatible material pairs, and poor geometrical alignment [3, 4]. The mechanism responsible for the generation of BSR noise is the relative motion of structural components exceeding a threshold value.

We developed a test procedure to systematically characterize BSR issues in the early stage of the vehicle development cycle. As previously described, most vehicle manufacturers detect and fix BSR problems with the road test as a result of various excitation sources, complex generation mechanisms, and subjective responses. To resolve these problems, the development procedure must 1) find and fix BSR problems for modules instead of a full vehicle to address the problems in the early stage; 2) design vibration exciters to perfectly reproduce input signals to the vehicle from the road; 3) develop techniques to automatically localize the source region of BSR in spite of various potential noise sources; and 4) to establish a sound quality evaluation system allowing for subjective responses to BSR. In this study, a BSR evaluation system and procedures were developed for automotive interior modules that consist of an excitation shaker and vibration jigs for the modules, acoustic-field visualization techniques, and the evaluation of sound quality.

SYSTEM AND METHOD FOR MEASUREMENT

The proposed system has three parts: an excitation jig devised to reproduce the input signal from roads without distortion; a near acoustic-field visualization technique for the detection of the potential source regions of the BSR; and subsequent analysis for ranking potential BSR source regions in terms of sound metrics. In this section, we describe the shaker and fixture for the IP, the acoustic-field visualization equipments and methods, and the sound quality metric.

A.Vibration Fixture

Instead of using a full vehicle, its components should be tested to shorten the development cycle, thereby reducing product costs. A vibration shaker and part fixture is generally used for this type of testing. However, a shaker-fixture environment often allows extraneous or masking effects that can distract from or diminish the audibility of a BSR event that may exist when evaluated in a vehicle. Furthermore, validation is needed to show that the excitation on a shaker fixture is truly representative of that seen in the vehicle. Especially, the resonance characteristics of the fixture mostly contribute to the laboratory background noise level, and distort the input signal from the shaker to the test specimen. Cabin input excitations due to road inputs usually occur at frequencies up to 40 Hz because the tires and suspension act as low-pass filters [3]. To minimize these masking effects and the distortion of the transferred signal, the first resonance frequency of the fixture should be greater than 40 Hz. In this respect, a fixture with lower mass and higher stiffness is indicated. To satisfy this criterion, the fixture is made of aluminum with holes, as shown in Fig. 1b. This fixture is supported with four air mounts to realize a free boundary condition. We measured the frequency response of the fixture subjected to an input excitation of a random signal, which is a typical signal transferred to a vehicle body moving on a rough road. The vibration system consisted of the electric type vibration shaker (B&K 4828), vibration signal controller (VR 8500) and accelerometer (B&K 4507B).

B.Noise Source Identification and Sound Quality

A near acoustic-field visualization technique was used to automatically detect the potential source regions of BSR on the IP module. The noise measurement system consisted of 48 microphone arrays (B&K 4951), a measurement and analysis system (B&K Pulse 3560D), and non-stationary spatial transformation of sound fields (STSFs) software (B&K 7712). This system was used to rank the magnitudes of the sources, and to precisely localize the source regions.

C. Sound Evaluation Metric

According to recent study [5], measured signals in BSR test in the automotive industry are typically analyzed with the A-weighted sound pressure level or stationary loudness using ISO532. However, due to the non-stationary nature of these signals, traditional metric often fail to fully describe the signals in question. In a real driving environment, the duration of a particular BSR is sometimes less than 10 ms while noise levels of BSR are generally high. In this work, therefore, various sound quality metrics such as loudness, sharpness, roughness, and fluctuating strength were used as evaluation metrics for BSR. To capture the non-stationary characteristics of BSR, Zwicker's percentile statistical measures (N10) were applied [6].

(a)

(b)

Figure 1. Test set-up for the BSR measurement of IP module with noise source measurement set-up(a), vibration system(b).

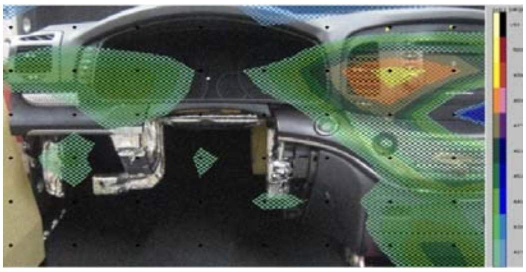

Figure 2. Visualized sound fields on the instrument panel(A)

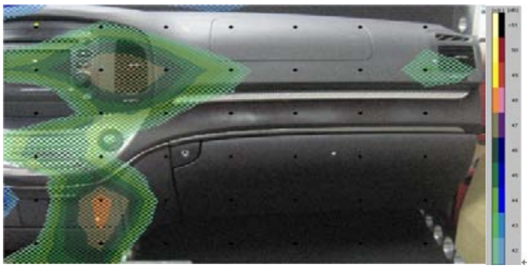

Figure 3. Visualized sound fields on the instrument panel(B)

MEASUREMENT RESULT AND ITS ANALYSIS

Various excitation profiles were imparted to the IP module with random signals of magnitude 5 m/s^2 in the frequency range from 10 Hz to 100 Hz, generated by a closed-loop signal generator than enabled the monitoring of the transferred signal in real time at a reference control point using four accelerometers (B&K 4507). During the experiment, background noise was retained below 22 dBA (0.19 sone) at the running condition of the vibration shaker. The temperature and humidity were kept at 23.6 ℃ and 48 %, which was reported to cause dimensional variation in the components, especially those containing elastomers [7].

A.Noise Source Identification

Figure 2 and 3 shows typical noise maps of the acoustic visualization on the IP module subject to the random excitation signal. From these maps, the components of the IP module that are potentially responsible for BSR noise can be identified, and their relative contributions are quantitatively evaluated. note that the noise levels of the components in the frequency range below 300 Hz are mainly due to the whole body motion of the IP module but not its parts. These facts reveal that the BSR in mainly due to the strcture borne noise within the low frequcny range. However, the distint mechanism responsible for the BSR noise at each point can be identified by analyzing the characteristics of the frequency components above 300 Hz.

B.The Sound Quality Level

There is no generally accepted standard for estimating the subjective loudness of non-stationary and transient acoustic event. However, a Deutsche Industry Normen (DIN) committee has agreed upon a definition of the behavior of such a model. The model uses a one-third octave band spectrum as an input and provides the non-stationary loudness in the form of the variation of its magnitude in the frequency-time domain [8]. Table 1 summarizes the sound quality metrics for potential noise source regions on the IP module that were computed using the data shown in Figs. 4 and 5.

Table 1. The sound quality value for each potential noise source regions

Point no.	Part name	SPL (dBA)	Louness (sone)	Sharness (acum)	Rougness (asper)
a	*Speed meter*	77.0	4.61	1.16	0.61
b	*A/V system*	80.5	5.66	1.10	0.66
c	*Dirver storage*	78.6	4.87	1.16	0.62
d	*Central airvent*	77.3	4.76	1.18	0.69

Source: (SHIN, 2010)

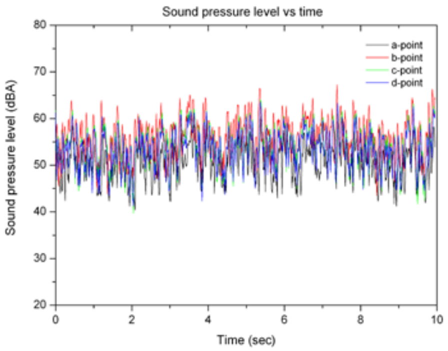

Figure 4. Sound pressure level with time variation at the noise source of IP module

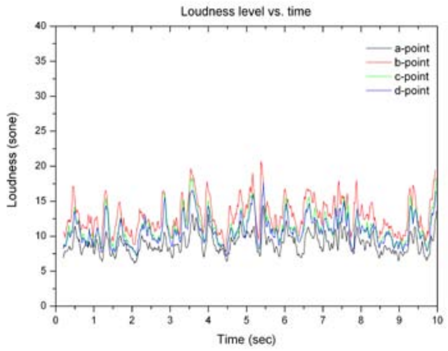

Figure 5. Loudness level with time variation at the noise source of IP module

The loudness level from the A/V system was much higher than the levels from the other regionss on the IP module, which closely follows the rankings of the source points using the magnitudes of the A-weighted SPLs. However, the other sound quality metrics show different results. The sharpness level of the acoustic wave from the central air vent is the highest. Considering the characteristics of the sensation of sharpness, although the BSR noise from the A/V system is the loudest, we inferred that the noise from the air vent may be the worst in terms of sensory pleasantness. The roughness from the central air-vent is also the greatest. Modulated sound induces two different kinds of hearing sensation: at low modulated frequencies up to about 20 Hz, the hearing sensation of fluctuating strength is produced, while at higher modulated frequencies the hearing sensation of roughness occurs. In these contexts, we infer that the noise generation mechanisms of the air-vent may involve the high frequency modulations, respectively.

CONCLUSION

Buzz, squeak and rattle from the instrument panel (IP) in a vehicle cabin were systematically evaluated using the integrated measurement method. Our approach used vibration-triggering system, acoustic field visualization equipment, and a subjective metric for sound quality evaluation. To reproduce the transferred signal from the road to the IP without distortion, a fixture was made from aluminum with holes for lower mass and higher stiffness effects. A near-acoustic-field visualization technique ws used to automatically detect the potential source regions of BSR on the IP module subject to random signal excitation. Based on the visual noise map on the IP, four potential source parts were identified. A frequency-time analysis for these potential source regions was used to analyze their detailed source generation mechanisms, which can provided insight toward the reduction of BSR. A subjective evaluation of the BSR from the selected dominant source points was made using the sound quality metric: loudness, sharpness, roughness, and fluctuating strength. Together with the sound pressure level, the loudness value from the speedometer was much higher than the other parts of the IP module. However, the other metrics rank the source points in a different way, by associating a specific source mechanism with its corresponding hearing sensation.

Our results show that the proposed test procedure can be used to systematically address BSR issues early in the vehicle development cycle, which can reduce production costs.

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