Sound quality approach on vehicle interior and exterior noise :Quantification of frequency related attributes and impulsiveness

Takeo Hashimoto
Department of Mechanical Engineering,Faculty of Engineering,Seikei University , Tokyo,Japan

Introduction

According to our experience, the major factors relating to the perception of vehicle interior and exterior noise are power factor, pleasant-unpleasant factor and frequency factor. In case of vehicle interior noise, our major concern on the frequency factor is how to reduce booming sensation below 300Hz due to the firing order and its harmoincs of noise emitted from the engine. We call this sensation as booming sensation. We have tried to quantify this sensation while the vehile was in steady state in driven condition [1],[2],[3] and named the developed psychoacoustical measure as booming level. This measure correlated well with the booming sensation for a stable booming noise but the value of correlation coeffcient reduced in a case for the transient sound such as interior noise during acceleration. In order to overcome this defeciency, we have developed a new measure called booming index[4]. Away from the booming senation, one of the most annoying vehicle noise are impulsive exterior noise at idle and during acceration at low engine rpm condition emmitted from the diesel engine [5]. We have tried to quantify the subjective impression on impulsiveness of a sound [6], and the results are compared with the other metrics such as impulsiveness distiributed by Head Acoustics,GmbH.

Development of booming index

The booming sensation during acceleration is quantified by booming index. The acceleration noise under consideration is subdevided into ten equal time segments in the first place. For each time segment, weighted sensation level on boomig (WSL) which is equivalent with booming level is calculated utilizing the weighting function for booming sensation obtained from the subjective evaluation shown in Fig.1 by weighing the 1/3 octave band sensation level (the SPL at the thresold in quiet is extracted from the original 1/3octave band level) and this WSL is weighted by the loudness ratio (L-H)/(L+H) calculated from the partial loudness of the noise below 300Hz [L] and that above 300Hz[H] shown in Fig. 2. After calculating this value for the each subdivision, the booming index is obtained by the power average of this value at each time segment. The relation between the booming level and the subjective evaluation on booming for a vehicle interior noise during accleration in case of four cylinder engines is shown in Fig.3 and the similar result with booming index is shown in Fig.4. From these figures, it can be judged that booming index is a better metric for quantifying booming sensation when the vehicle under consideration is in acceleration.

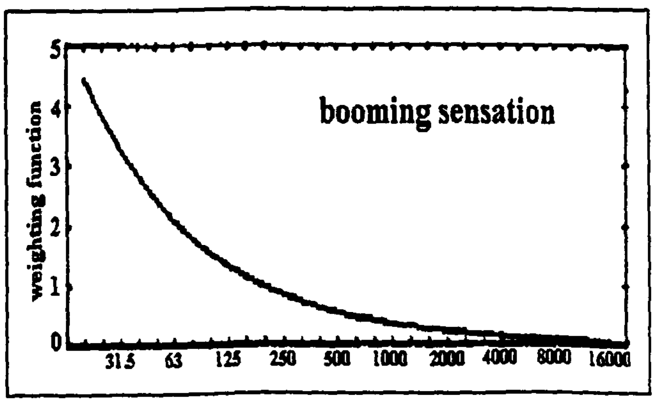

Fig. 1 weighting function for booming level
this curve was obtained obtained by the subjective evalutation on booming sensation by magnitude estimation obtainde by 21subjects with normal hearing ability aged between 22 and 46. stimmuli: 1 3 octave pink noise centered from 63Hz to 8000 Hz with their loudness fixed at 13sones.

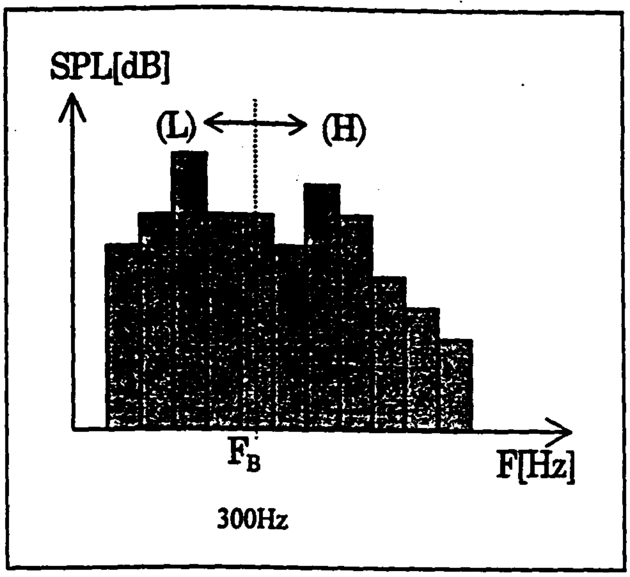

Fig.2 1/3octave band spectrum of the sound and the partial loudness below and above 300Hz. The reason why this 300Hz was selected as the dividing value for partial loudnesses below and above this value was based on the subjective tests on booming sensation and sensation of sharpness on the same stimuli of 1/3 octave band pink noise with their loudness 13sones. Booming sensation dominated below 300Hz and sharpness dominated above 300Hz according to this experiment done at author's laboratory.

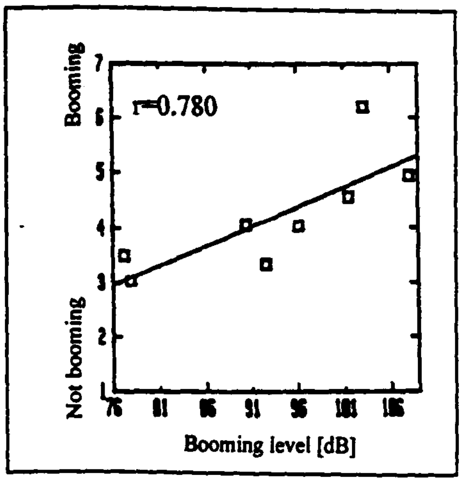

Fig.3 Evaluation on booming sensation and booming level

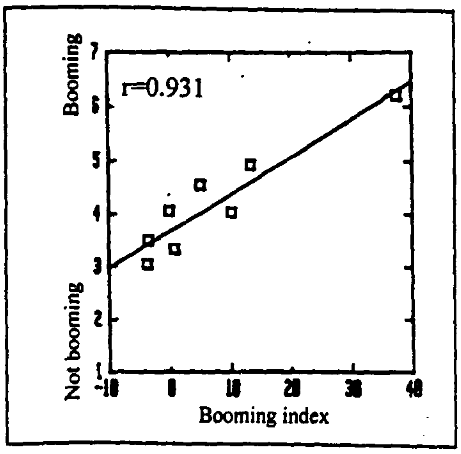

Fig.4 Evaluation on booming sensation and booming index

Development of IMPULSE as a metric of impulsiveness

In order to quantify the sensation caused by the impulsiveness of noise emitted from the diesel engine, we have developed a new metric named IMPULSE. This metric is calculated from the abosolute noise signal subdivided into short time segments of 200ms. In the first place, rms value of each time segment is calcutated. Then, fine time segments that excess the rms value of each 200ms time interval are chosen with their time length. After selecting these fine time segments, the time average value of the selected fine time segments that excess the rms value is calculated in each 200ms time interval. Finally, IMPULSE is calculated from the average value of the time averages that excess the rms in each 200ms time segment (Fig.5).

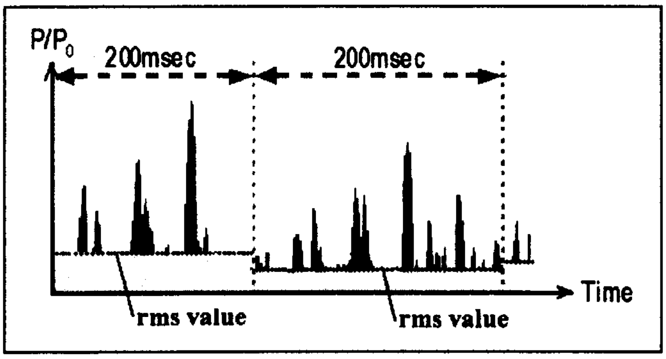

Fig.5 Absolute wave form of impulsive noise signal with 200ms fine time segments. The noise waves excessing the rms value are colored in thick color wherea the noise waves below the rms value are in thin color.

The relation between IMPULSE and the subjective evaluation on impulsiveness of the diesel engine noise at idle with varying the frequency contents from 800Hz to 4kHz that thought to be the cause of impulsiveness of the diesel noise in its level ±3dB, ±6dB, ±9dB are shown in Fig.6. The similar figure with the relation in impulsiveness provided by Head Acoustics, GmbH is shown in Fig.7. From Fig.6, a good correlation is found between the subjective evaluation on inpulsiveness and IMPULSE proposed by the author (r=0.974). Concerning the impulsiveness proposed by the Head Acoustics,GmbH, a good correlation is also found between this metric and the subjective evaluation (r=0.944) although there exists a little disagreement for one sound(No.4).

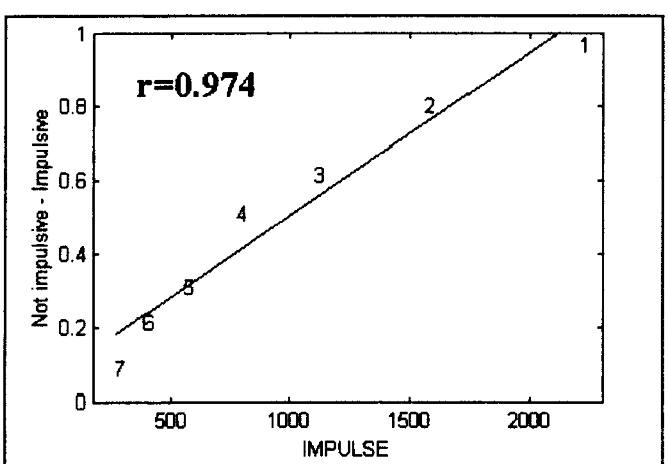

Fig.6 Relation between subjective impulsiveness and IMPULSE. Stimuli: original diesel exterior noise at idle and its variations in impulsiveness by varying the frequency band level ±3dB, ±6dB, ±9dB which is considered to be the cause of impulsiveness.

Conclusions

(1) The booming sensation for transient noise such as vehicle interior noise during acceleration can be well quantified by taking the time dependent loudness ratio calculated from the partial loudnesses below and above 300Hz as a multiplier with booming level.

(2) Subjective impression on Impulsiveness of the diesel engine noise is well quantified with the IMOULSE proposed by the author. This measure takes the time average value of the peaks that excess the rms value of the noise signal within 200ms fine time segment into account.

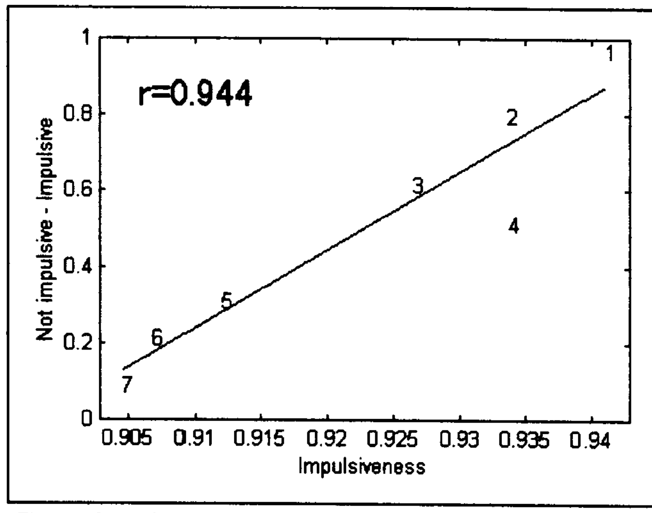

Fig.7 Relation between subjective impulsiveness and impulsiveness (Head Acoustics,GmbH). Stimuli: original diesel exterior noise at idle and its variations in impulsiveness by varying the frequency band level ±3dB, ±6dB, ±9dB which is considered to be the cause of impulsiveness.

Literature

[1] Hatano, S.,Hashimoto, T.,Evaluaion of booming factor of car interior noise under running condition:evaluation of artificial noise and the location of subjective impression of real car noise,transaction of the Society of Automobile Engineers of Japan, Vol.26, No.3,98-103 (1994) (in Japanese with English summary).

[2] Hatano, S.,Hashimoto, T.,Quantification of booming factor ,Transaction of the Society of Automobile Engineers of Japan, Vol.27, No.1,94-97 (1996)(in Japanese with English summary).

[3] Hatano, S.,Hashimoto, T.,Quantification of booming factor , modified measure taking the effects of specrum pattern and the loudness of the sound into consideration,Transaction of the Society of Automobile Engineers of Japan, Vol.27, No.2,85-89 (1997)(in Japanese with English summary).

[4] Takada, M.Hashimoto, T., Hatano, S., Wen, S. C.,Evaluation of Brightness and booming sensation of car interior noise during acceleration, Transaction of the Society of Automobile Engineers of Japan, Vol.30, No.2,87-91 (1999)(in Japanese with English summary).

[5] Hashimoto, T., Hatano, S.,Improvement of sound quality of exterior noise at idle of small diesel track, Transaction of the Society of Automobile Engineers of Japan, Vol.27, No.2,80-84 (1997)(in Japanese with English summary).

[6] Takada, M., Hashimoto, T., Hatano, S., Shibuya, G., A proposal of quantification measure on impulsiveness of diesel engine noise, Proceedings of the Society of Automobile Engineers of Japan,No.19-99,17-20(1999) (in Japanese with English summary).