inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 6.3

BOOMING INDEX AS A MEASURE FOR EVALUATING BOOMING SENSATION

S. Hatano, T. Hashimoto

Seikei University, 3-3-1 Kichijoji Kitamachi, Musashino-shi, 180-8633, Tokyo, Japan

Tel.: +81(422)37-3721 / Fax: +81(422)3871 / Email: hatano@megw.me.seikei.ac.jp

Keywords:
SOUND QUALITY, VEHICLE INSIDE, BOOMING SENSATION, INDEX DEVELOPMENT

ABSTRACT
We have proposed the measure called booming level for evaluating booming sensation caused by car interior noise. In this measure, the scale was constructed by the arithmetic average of the weighted sound pressure level within specific frequency bands that contributed booming sensation. The weighting function was obtained by the subjective test using magnitude estimation. But this method had some difficulty to find out suitable frequency bands contributing booming sensation for calculation. In order to solve this problem, new method was introduced which based on the power summation of the weighted 1/3 octave band signals that was free from extracting specific frequency bands for calculation. This measure was named as Booming Index. As a result, good correlation was obtained between the subjective evaluation on booming sensation and Booming Index.

1 - INTRODUCTION

Due to the presence of low frequency noise, e.g., the firing order component of an engine, we feel strong booming sensation during acceleration and during cruising if the frequency of this noise is coincide with the resonance frequency of a cavity in a car compartment. And this sensation makes us feel unpleasant because of the pressurized feeling of our eardrums. In order to quantify this feeling we formerly proposed a measure named Booming Level. This measure related well with the subjective feeling of booming sensation but had some difficulties because we had to select frequency bands that contribute to booming sensation for the calculation of Booming Level. In order to solve this problem, we have proposed a new measure named Booming Index that based on the power summation of the weighted 1/3 octave band level of sound signals that was free from extracting specific frequency bands for calculation. By introducing this newly developed measure, we could obtain better correspondence between the subjective evaluation on booming sensation and the measure, i.e., Booming Index.
The formerly proposed Booming Level was defined in the following form [1].

$$BoomingLevel = 0.119 \times \left[\sum_{\substack{i \\ (B(Fc_i) - G(Fc_i)) > CUT_{dB}}} \{(B(Fc_i) - G(Fc_i)) \times W(Fc_i)\} / N \right] \times (0.0463 \times L_l + 0.397) \times (L_l / Loudness) \quad \text{(BL)} \tag{1}$$

where

- Fc_i: an ith center frequency of 1/3 octave bands from 25Hz to 10kHz
- $B(Fc_i)$: SPL of each 1/3 octave band

- $G\left(Fc_i\right) = B\left(pinkFc_i\right) - B\left(pink63\right)$ ($B(pinkFc_i)$ means SPL of each 1/3 octave band pink noise at 13 sone and $B(pink63)$ means SPL of 1/3 octave band pink noise with Fc=63 Hz at 13 sone)
- $CUT_{dB} = \{\max\{B\left(Fc_i\right) - G\left(Fc_i\right)\} - 12\} \geq 0$ (dB)
- $W(Fc)$: weighting function for Booming Level [2] obtained by dividing the ordinate value with the value at 63Hz shown in Fig. 1
- $W\left(Fc_i\right) = 2.13 \times \exp\left(-0.151 \times X\left(Fc_i\right)\right)$ ($Fc_i \geq$50 Hz), ($X(Fc_i)$ represents the order of center frequency of 1/3 octave band as $X(Fc)$=1 when Fc=25 Hz)
- W(25Hz)=1.05, W(31.5Hz)=1.10, W(40Hz)=1.18
- N: the number of chosen bands
- L_l: loudness of the band below 450Hz
- BL: unit representing Booming Level

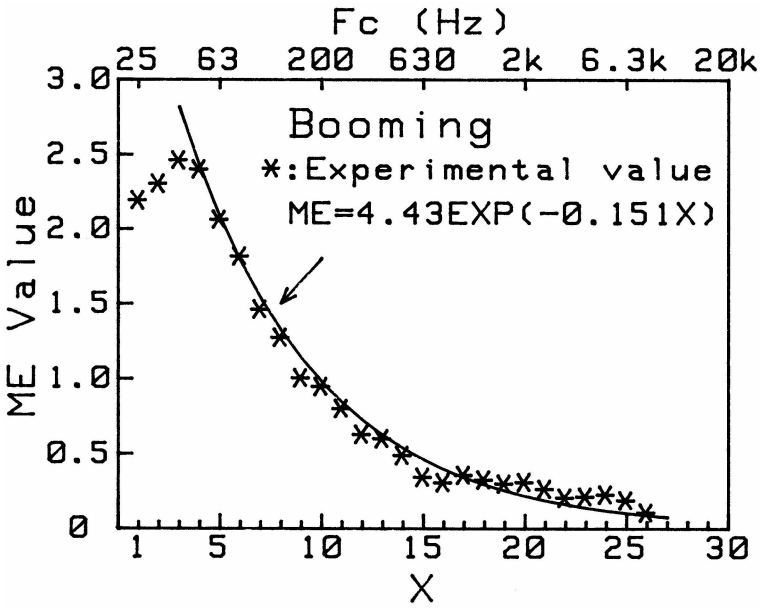

Figure 1: ME value on booming sensation.

The level of this measure is scaled to take 10 (BL) for the 1/3 octave band pink noise with its center frequency 63 Hz and its loudness for 13 sone.

2 - BOOMING INDEX

In calculation of Booming Level, only the selected 1/3 octave band levels of a sound with their ($B(Fc)$-$G(Fc)$) values exceeding CUT_{dB} are used. So if the ($B(Fc)$-$G(Fc)$) value is equal to CUT_{dB}, this band level is abandoned and excluded for calculation. For example sound A and sound B in Fig. 2 consist of two 1/3 octave bands and have the same band SPL at Fc=63Hz with each other.

According to the procedure for Booming Level, only one 1/3 octave band exceeds CUT_{dB} for sound A and two bands exceed for sound B. Booming Level of sound A is determined by only one 1/3 octave band level with Fc=63Hz. And that of sound B is determined by the two band levels with Fc=63Hz and Fc=80Hz, i.e., by taking average of two respective weighted band levels on booming sensation. Therefore Booming Level of sound A is higher than that of sound B against the fact that the two sounds have almost the same booming sensation. In order to solve this problem, a new psychometric parameter named Booming Index was proposed as follows:

$$BoomingIndex = Bandsum \times (L_l / Loudness) \tag{2}$$

where

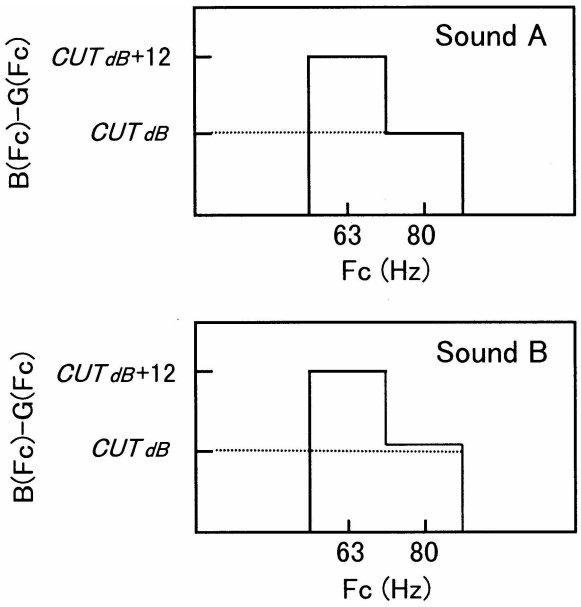

Figure 2: 1/3 octave band spectrum.

- $Bandsum = 10 \times \log \sum_i 10^{(I_i/10)}$
- $I_i = (B\,(Fc_i) - T\,(Fc_i)) \times W\,(Fc_i)$
- $T(Fc)$: threshold in quiet of 1/3 octave band with center frequency Fc [3]
- L_l: loudness of the band below 280Hz
- and other nomenclatures are the same as in eq. (1).

In the first place, Booming Level and Booming Index were calculated with the test results [1] for booming sensation by magnitude estimation (ME method) for 47 kinds of sounds i.e., artificial sounds, car interior noise and machine noise. Figs. 3 and 4 show the relations between ME value and Booming Level, and ME value and Booming Index respectively. ME value has better correlation with Booming Index than with Booming Level.

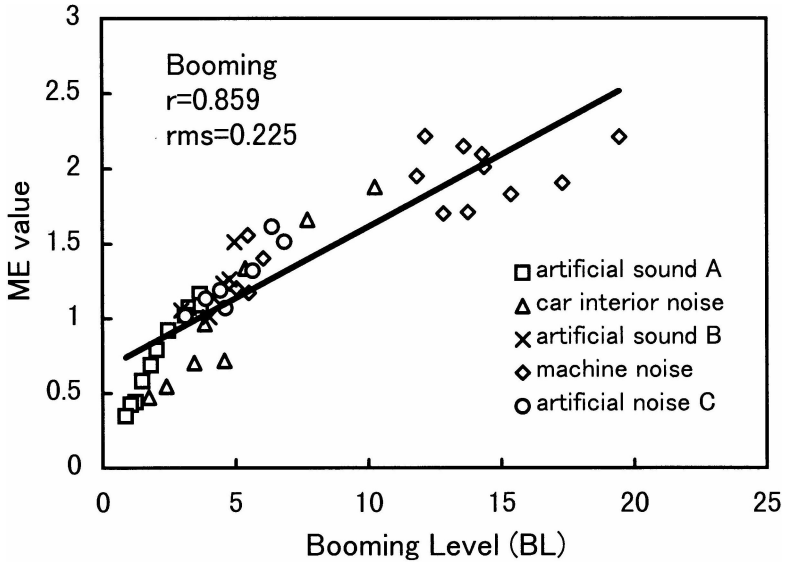

Figure 3: Relation between Booming Level and ME value for booming sensation.

Then in the next, in order to test the validity of Booming Index with the subjective rating on booming sensation, Booming Index was applied to the sounds including prominent low frequency components.

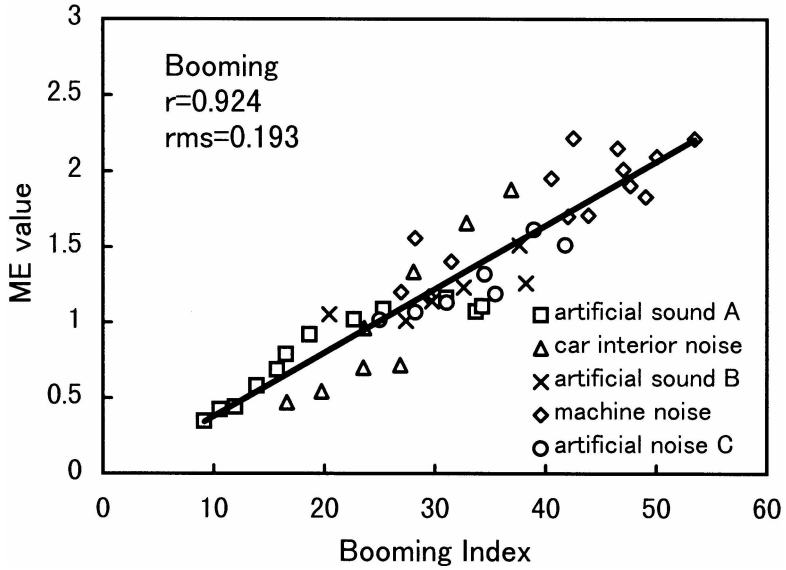

Figure 4: Relation between Booming Index and ME value for booming sensation.

An experiment for rating 48 kinds of car interior noise and artificial noise for booming sensation by ME method was carried out. Figs. 5 and 6 show the relation between Booming Level, Booming index and ME value obtained from this experiment. Booming Index is in good correspondence with ME value to confirm the validity of this measure.

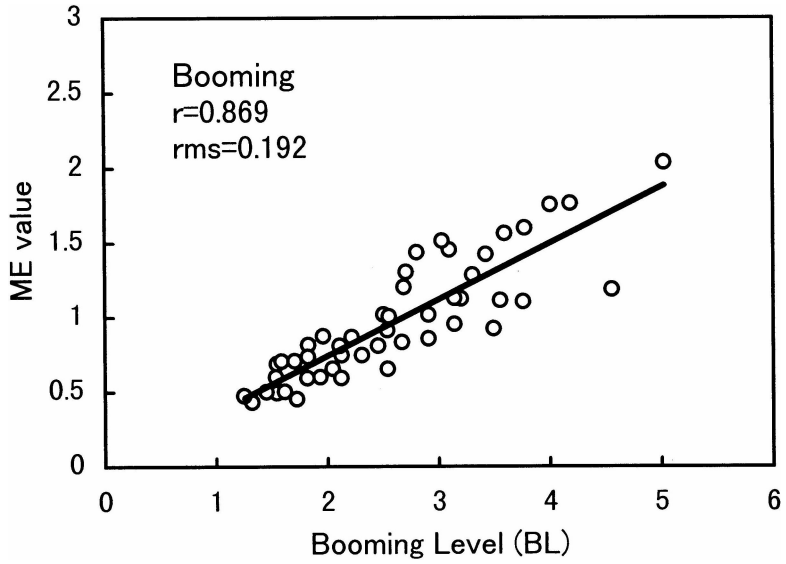

Figure 5: Relation between Booming Level and ME value for booming sensation.

3 - CONCLUSIONS

- A new measure named Booming Index is proposed and this measure solves the problem of mismatch with the subjective evaluation Booming Level has.
- Booming Index has good correlation with booming sensation for the sounds including prominent low frequency components to confirm its validity.

REFERENCES

1. **S.Hatano and T.Hashimoto**, Modification of Booming Level due to high frequency components for better correlation, In *Proc. INCE/J*, pp. 41-44, 1998

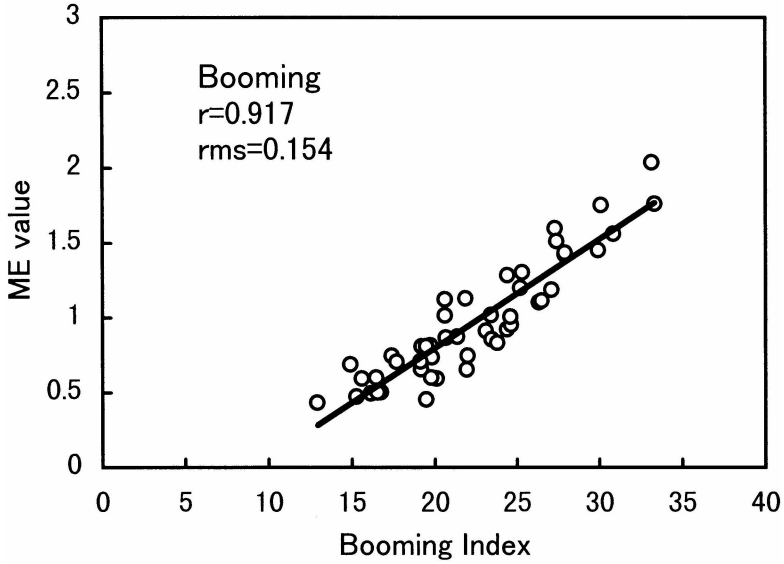

Figure 6: Relation between Booming Index and ME value for booming sensation.

2. **S.Hatano and T.Hashimoto**, Modification of Booming Level for higher correlation with booming sensation, *Trans. JSAE*, Vol. 29(4), pp. 107-110, 1998

3. **E.Zwicker and H.Fastl**, *Psychoacoustics, Facts and Models*, Springer-Verlag, pp. 16-19, 1990