Discuss on the Noise Metrics for High-Speed Train Noise Assessment

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ABSTRACT

The high-speed train with a maximum speed of 350 km/h introduced noise with different characteristics both in time and frequency domain from those of conventional train, and led to new annoyance problems. A study of the noise characteristics and subjective response of the high-speed train noise was carried out in this paper, the result showed that the noise assessment L_{Aeq} used in the train noise directive could not reflect its noise subjective annoyance properly, the "shock-effects" caused by the sudden noise level increase and the frequency spectrum of the aerodynamic effects led to higher degree of noise annoyance, the onset rate of sound, as L_{Aeq}, got a strong correlation with the subjective evaluation effects.

Keywords: High-Speed Train, Noise Assessment , Noise-Metrics
I-INCE Classification of Subjects Number(s): 68.3

1. INTRODUCTION

Following German, France and Japan, lots of high-speed railway with the speed of more than 250 km/h have been constructed in China, which bring us not only convenience but also serious noise problems. For the unique features, such as the higher sound pressure level, the low frequency character and the sudden noise increase, the high-speed train noise introduces more serious annoyance. Fastl, Gottschling[1], Neugebauer, Ortscheid[2] and Vos[3] have analyzed both the conventional train noise and the magnetic levitation train. But it seemed that there is no agreed conclusion, Fastl found that there's no difference between the annoyance caused by the two kind of train noise[1], while Vos insisted the the high-speed magnetic train noise sounded much more annoying than the conventional slow-speed train noise[3]. And there is scarcely any research on the noise properties of the high-speed train constructed in China.

In the current standards of the aforementioned countries, besides the equivalent A-weighted sound pressure, there is no specific noise metric for the high speed train noise (except slow-mode $L_{AS\max}$ for Japan). The onset rate of sound and the $L_{A\max}$ will be discussed in the following sections of this paper, and analysis of correlative degree between the new metrics and the subjective annoyance will also be illustrated.

2. PROPERTY OF THE HIGH-SPEED TRAIN NOISE

2.1 Train Noise

Noise of the train can be decomposed into 4 individual parts: noise of the power system, noise of the wheel/rail friction, the secondary structural noise and the aerodynamic noise. The train noise can make people feeling annoy even ill, Moehler found that LAeq is much more accurate than the peak

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sound level $L_{A\max}$ and the frequency sound level L_{Af} to respect the subjective evaluation of the conventional low-speed train noise[4].

According to the UIC(international Union of Railways), trains with the speed exceed 200km/h can be called high train noise. The TGV team in France revealed that, the peak sound level can reach 90 dB(A) with the train speed of 400km/h and 25m away from the middle of the rail, while 97dB(A) with 500km/h, significantly higher than the that of the conventional train. Not only the sound level, there are also other noise characteristic difference as follows:

1) The peak noise level higher than the conventional train.
2) The main noise source is the aerodynamic noise while the power system noise for conventional train.
3) The area of influence is bigger than that of the conventional train, for the elevated railway line decreasing the blocking effect.
4) The noise contains much more low frequency component than the conventional train, which will be illustrated in section 2.2.
5) "Shock-effects" has arisen, caused by the sudden noise level increase, and it will be illustrated in section 2.2

2.2 Property of the High-Speed Train Noise

2.2.1 Low-Frequency Character

As shown in Fig.1, the high-speed train noise contains more low frequency components, range from 31.25Hz to 250Hz, than the conventional low-speed train noise. The noise samples were recorded from the observed point 30m away from the viaduct railway, with the speed of 300km/h and 120km/h, respectively. Please note that the two curves just explain the trends rather than representing the real A-weight SPL value.

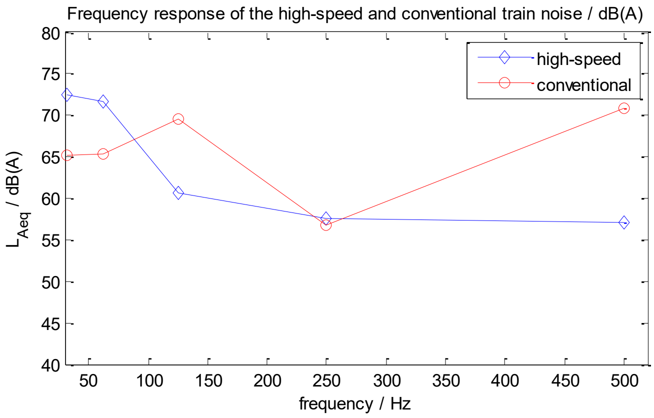

Fig.1 Frequency response of the high-speed and conventional train noise

2.2.2 Sudden Noise Level Increase Effect

The duration of a high-speed train, with 8 carriages at the speed of 350km/h, passing by the view point along the rail is 2s, while 14.4s for the conventional train with 16 carriages at the speed of 100km/h. So the high-speed train introduces a sudden noise level increase, shown in Fig.2, and makes people very annoyed around the rail line. The noise level increase is investigated by DL(Derivatives of the noise Level), and the DL is defined as follows:

$$DL = \frac{L_{A\max} - L_{A0}}{t_2 - t_1} \tag{1}$$

While $L_{A\max}$ is the peak noise level when the train passing by, $L_{A0} = L_{Abackground} + 3$ is the background noise level in a certain sense, and $t_2 - t_1$ is the duration of the noise level from L_{A0} to $L_{A\max}$. It can be seen for the high speed train, the value of DL range from 3dB/s to 20dB/s depending on the observation point, much bigger that that of the conventional train in the same condition.

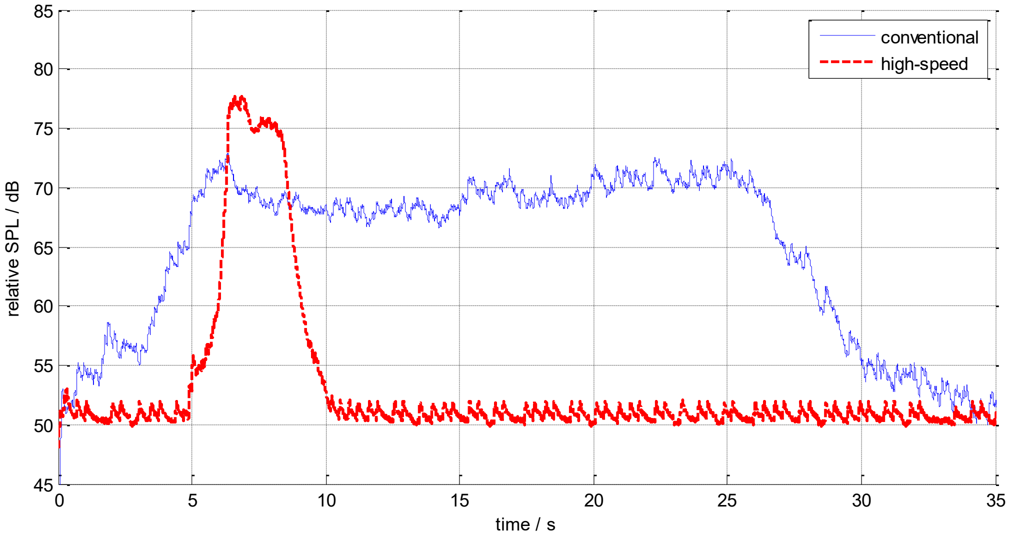

Fig.2 the noise level when the high-speed and conventional train passing by

3. EXPERIMENT and ANALYSIS

3.1 Framework of the Experiment

As shown in Fig.3, the whole experiment configuration can be divided into 5 parts: the noise sample recording, the noise signal processing, the noise sample replay, the subjective test and the correlation analysis of the subjective and objective evaluation.

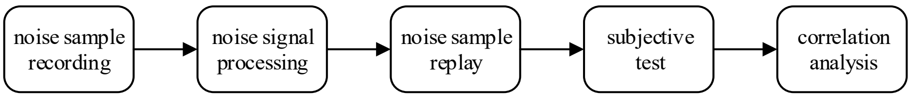

Fig.3 the diagram of the experiment configuration

3.2 Experiment setup

3.2.1 Recording Equipment Configuration and the Signal Processing

In this paper, train noise of the CRH series running on the viaduct railway was studied. The observed point were set to 7.5m, 25m, and 30m away from the middle of the rail when the train run at the speed of 350km/h and 160km/h, for the 25m point, the train also run at the speed of 250km/h and 300km/h. The muti-channel B&K PULSE 3050 was used as the data acquisition device, and B&K microphones type 4189 were used as sensors.

The duration of the train passing by the observed point is no more than 40s for both the high-speed and the conventional train, so the noise sample when the train passing by is set to 60s. For subjective test, 6 recorded noise samples were combined into a test sample with the length of 15min. 5 test samples were prepared in total, and those 5 samples were modulated into 50, 55, 60, 65, 70dB(A) for both the high-speed train and the conventional train.

3.2.2 Auditory Subjective Test Configuration

The test room was a silent rectangular office room with the background noise below 45 dB(A). The Lenovo X230 notebook was used as the sound reproducing equipment, the adobe audition version 3.0 as the player, the Beyerdynamic A1 as the power amplifier, and the Sennheiser headset HD600 as the speaker.

3.2.3 Subjective Test Configuration

The 0-100 score method[5] was used in the auditory subjective test, while 0 represent with no annoyance and 100 represent extremely annoyed.The subjects for the study were 12 adults from a company, 6 male and 6 female, ages from 24 to 43 years old. Every subject listened to the test samples, and made a decision according to the 0-100 scare method after each noise sample.

3.3 Analysis and Discussion of the Experimental Results

The result of the auditory subjective test is shown in talbe 1.It can be found that the closer to the rail way, the more annoying felt for both the two kind of trains. And with the same L_{Aeq}, the noise of the high-speed train caused much more annoyance than that of the conventional train, partially as a result of the difference of the DL value.

Table 1 – the result of the subjective test

type of train	7.5m	30m
high-speed	94.2	69.4
conventional	88.9	58.7

The analysis of the L_{Aeq} and the subjective score are illustrated in Fig. 4. The linear relationship between L_{Aeq} and the subjective score was confirmed again, but it's also shown that simply using L_{Aeq} to represent subjective annoyance is not suitable, for the different "score" of the two kind of train noise. We can find that there's also strong correlation between the DL and subjective annoyance score with the correlation coefficient of 0.84, and it should be a good idea to combine both of them to form a new noise evaluation metrics $f(L_{Aeq}, DL)$.

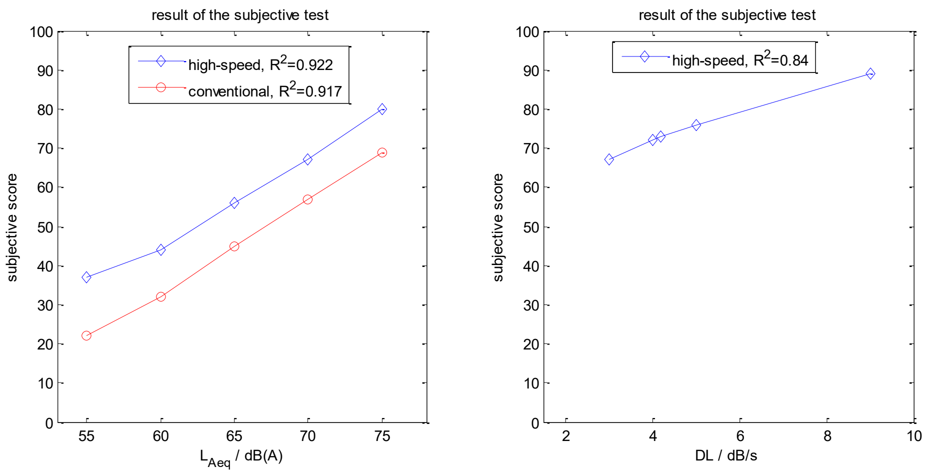

Fig.4 result of the subjective reslust

4. CONCLUSIONS

A study of the noise characteristics and subjective response of the high-speed train noise was carried out. The result shows that the high-speed train noise cause much more annoyance than that of conventional train with the same sound level. L_{Aeq} has linear relationship with the subjective test results, but could not be simply implied to evaluate the high-speed noise, and it's suggested that $f(L_{Aeq}, DL)$ should be studied to evaluate the noise annoyance more precisely.

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