Influence of Temperature on Vibration Reduction Performances of Elastic Track Materials

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Elastic rubber materials such as rail pads are used on railway tracks in order to absorb vibrations and impact forces generated by passing trains. For example, rail pads reduce vibrations transmitted through the rails to structural track components such as rail fasteners and track slabs. The performance of rubber materials changes with temperature. Thus, there is a concern that the vibration reduction performance of elastic track materials may decrease at low temperatures because of the higher resulting stiffness. Field tests were conducted at the same point on a concrete viaduct in summer and winter to evaluate the influence of ambient temperature on the vibration and noise reduction performance of elastic track materials. The results showed that vibrations in some structural components under the rail pad increased at low temperature, which agrees with the track theory of the track vibration.

Keywords: elastic track materials, rail pad, vibration, railway noise, concrete viaduct

1. Introduction

Elastic track materials made of rubber, such as rail pads and slab mats are used to reduce vibrations, noise and impact forces generated by passing trains. In general, the physical performance of rubber materials changes with ambient temperature, unlike metal and concrete materials which are hardly affected by temperature. There are concerns that the vibration reduction performance of elastic track materials may fall at low temperatures due to the increase of stiffness of rubber materials. However, there are not many studies which have sought to quantify this phenomenon. It is not clear either whether characteristics of vibration and noise generated from running trains are affected by ambient temperature. A study was conducted therefore where vibrations and noise were measuring at the same point on a slab track of a conventional line in both summer and winter [1, 2]. This paper evaluates the influence of ambient temperature on the characteristics of vibrations and noise associated with elastic track materials.

2. Temperature dependence of rubber on physical performance

Figure 1 shows the storage elastic modulus and tangent loss $\tan\delta$ of a elastic track material, as an example of the temperature dependency of rubber's physical characteristics. In general, rubber material has both elastic and viscous properties. The storage elastic modulus shows the elastic factor and the loss elastic modulus shows the viscous factor. The ratio of the loss elastic modulus to the storage elastic modulus is $\tan\delta$. As indicated in Fig. 1, the storage elastic modulus and $\tan\delta$ vary according to tem-

Fig. 1 Storage elastic modulus and $\tan\delta$ of elastic track material

perature variation. The storage elastic modulus increases steadily as temperature falls. The $\tan\delta$ indicates the peak value at around -50°C at which the storage elastic modulus changes drastically. The temperature at the peak of $\tan\delta$ is called the glass transition temperature, around which the molecular state changes significantly.

3. Influence of temperature on the vibration reduction performance of elastic track materials

This chapter considers the influence of temperature on the vibration reduction performance of elastic track ma-

materials. The two main physical performances shown below are thought to be affected by the temperature:

- 1) Reduction in vibrations transmitted to the track substructure
- 2) Wheel load dispersion

In the case of description 1), Fig. 2 (a) indicates a mass spring model to represent the simplified physical structure of the elastic track material. In this model, a mass, a spring and viscous element, and a structure correspond to the rail, the rail pad, and the structural components respectively, which represent a single section around a rail fastener.

Vibration transmissibility τ is given by the following equation when harmonic force $F_0 e^{i\omega t}$ is applied to the mass as the external force,

$$\tau = \frac{1 + \left(2\zeta \frac{f}{f_0}\right)^2}{\sqrt{\left\{1 - \left(\frac{f}{f_0}\right)^2\right\}^2 + \left(2\zeta \frac{f}{f_0}\right)^2}} \quad (1)$$

$$f_0 = \frac{1}{2\pi} \sqrt{\frac{k}{m}}, \quad \zeta = \frac{c}{2\sqrt{mk}} \quad (2)$$

where m is the mass (kg), k is the spring constant (N/m), c is the attenuation coefficient (N · s/m), f is the frequency of excitation (Hz), f_0 is the natural frequency (Hz), and ζ is the viscous damping coefficient.

The frequency of excitation f is not influenced by the temperature because it is determined by the conditions of the running train and is generally given within the ff_0 range of 1 or more. However, f_0 is determined by the constant value of the mass and the spring constant and is thought to change with temperature variation. The vibration transmissibility τ of elastic track material is calculated by (1) and given as shown in Fig. 2 (b). The spring constant of elastic material increases with lower temperature, which means that f_0 increases, causing ff_0 to decrease in turn. Thus, τ increases as temperatures fall and it is assumed that the vibrations transmitted to the substructure will rise.

At the same time it is assumed that rail vibrations will fall with temperature, because track structural components

above and below the rail pad are built on a compound vibration system. In other words, an increase in vibrations transmitting to the substructure below the elastic materials reduces vibrations in the structure above them.

In description 2), soft elastic materials provide elastic support to a rigid rail, and wheel loads act not only on the elastic material under the wheel but also on adjacent elastic materials. In fact wheel loads are distributed over multiple elastic materials. It is thought that the softer the elastic material is the higher the load-dispersing effect is, and inversely, the more rigid the elastic material is the smaller that effect is. Thus, it is estimated that the vibration reduction performance and the wheel load dispersing performance of the elastic track material will fall with temperature. As a result, railway track and structural vibrations may increase.

4. Field test for evaluating the influence of ambient temperature

4.1 Test field

Field tests were performed to evaluate the influence of ambient temperature on the vibration and noise reduction performance of the elastic track material. Figure 3 shows a view of the test field. The specifications of the track and structure were as follows;

- 1) 60kg rail with the pandrol clip fastenings on the slab directly fastening the track to a concrete viaduct which is almost flat and straight;
- 2) The rail pad is a blend of natural rubber (NR) and

Fig. 3 View of the test field

(a) A mass spring model

(b) Calculation result of vibration transmission rate

Fig. 2 A mass spring model to represent the simplified physical structure of the elastic track material

styrene-butadiene rubber (SBR) with stud structure and the nominal spring constant is 30 MN/m;

- 3) The slab mat is installed between the slab track and the roadbed concrete.

4.2 Date of tests

The field tests were conducted on following dates:

- 3, Sep. 2013 in summer, 10:30-12:00, cloudy, rain later
- 4, Sep. 2013 in summer, 9:30-16:00, fine, occasionally cloudy
- 18, Feb. 2014 in winter, 6:00-12:00, cloudy

4.3 Measuring points

During the field tests measurements were taken as follows: 9 points for vibration, 3 points for noise and 5 points for temperature. This paper however only presents selected representative points as shown below and Fig. 4;

- 1) vibration; at the bottom of the rail (VR1), on the rail fastening system (VT), on the slab track (VS), on the floor slab (VC1), and on the ground just under the trussed girder (VG1);
- 2) Noise; at the point near the rail (SR), above the ground just under the trussed girder (SG1), and at the point 12.5 m away from the track center (SG2);
- 3) Temperature; of the rail (TR), of the rail fastening system (TT), of the slab mat (TS), inside the track (TA1), and near the measuring base under the adjacent track (TA2).

All these measuring points were on the same cross section without rail joints. Hereafter, only the vertical vibration of all measuring points is described.

Symbols for measuring points

(a) Cross section view of the measuring points

(b) Top view of the measuring points

Fig. 4 The outline of the measuring points

4.4 Measuring method

Vibration acceleration was measured with piezoelectric type acceleration sensors PV-94 and PV-84, the vibration level was measured with a vibration level gauge VM-52, while the noise level was measured with a sound level meter NL-21, made by RION Co., Ltd. VR1 and VT were measured with PV-94, VS and VC1 were measured with PV-84. VG was measured with VM-52 in accordance with the respective vibration characteristics of the measured frequency [3].

Vibration and noise measurements for all points except VG1, SG1 and SG2, were characterized as “Fast” for the time constant. The inherent characteristic of VM-52 was used for VG1, whereas “slow” was used for SG1 and SG2. Vibrations at VG1 were measured on a vibration acceleration level. And vibrations at other points were measured with F-weighting for frequency weighting characteristics and noise at all points was measured with A-weighting for frequency weighting characteristics.

All data were analyzed with SA-01, the RION Co., Ltd. frequency analyzer, to extract the peak level of vibration and noise. When the peak or approximate peak values of vibration and noise were measured for one of the main commuter trains whose running speed was 82-107 km/h, a one-third-octave band analysis was conducted and the average power value was calculated. The analysis was conducted for 3-5 data sets from summer and winter. The frequency range for frequency analysis was from 20 Hz to 10 kHz for PV-94 data, from 1 Hz to 2.5 kHz for PV-84 data, and from 1Hz to 80 Hz for VM-52 data. Temperature was measured every 5 minutes with a K-type thermocouple thermometer.

5. Test results

5.1 Characteristics of vibration and sound at the measuring points

This chapter first gives the analysis results of measured data shown in Fig.5 from summer, and then compares results from the two analyses based on winter and summer measurements.

- 1) The order of magnitude arranged according to the vibration acceleration level is as follows: the rail (VR1), the rail fastening system (VT), the slab track (VS), the floor slab (VC1), and the ground (VG1). Comparing the vibration level simply, the value of VG1 is smaller than that of VC1 by over 10dB.
- 2) There are no significant differences between the floor slab (VC1) and the rail fastening system (VT).
- 3) The order of the magnitude arranged according to sound level is as follows: near the rail (SR), at the point 12.5 m away from the track center (SG2), and above the ground just under the trussed girder (SG1).

Description 1) indicates that vibrations gradually fell as distance between structural components according to the increase in distance from the excitation source at the contact interface of wheel and rail, increased. This

(a) Vibration acceleration level

(b) Noise level

Fig. 5 Results of the vibration acceleration levels and noise levels in summer

is because the rail pad set between the rail and the rail fastening system contributes to a reduction in the vibrations transmitting to the rail fastening system and the slab track and that a slab mat set between the slab track and the floor slab also contributes to reducing vibration transmission to the floor slab.

Description 2) indicates that the rail fastening system and slab track are vibrating together as a result of their rigid connection.

Description 3) is a natural consequence of rolling noise and under-car-body noise being transmitted directly to the measured point near the rail. It is difficult to explain however the difference between the magnitude of the noise level at the point under the trussed girder and at the point 12.5 m away from the track center, based on the distance between each noise emission source and noise reception point alone. It is conceivable that one of the reasons for this is that the acoustic levels of rolling noise and under-car-body noise are higher than that of structure-borne noise, and therefore these noises affect the noise level at the 12.5 m point more than under the trussed girder point.

5.2 Temperature

Figure 6 shows the result of measured temperature. The temperature of the rail was from 20 °C to 40 °C in summer and 4 °C to 10 °C in winter. The atmospheric temperature in the railway track was from 20 °C to 30 °C in summer and from 4 °C to 10 °C in winter and the difference between them was within about 15 °C to 20 °C.

As mentioned in chapter 2, the glass transition point of the elastic track material is below -40 °C; therefore, it was more desirable that the field tests be carried out at a higher temperature in summer and at a lower temperature in winter than the actual observed temperatures. Significant insight was gained from these tests because the storage modulus changed according to temperature variation.

Having high thermal insulation, the elasticity of the slab mat hardly changes with temperature. Therefore, it was thought that slab mat track vibration and noise reduction would be insignificant even with changing temperature. For this reason, only the influence of changes in rail pad elasticity was evaluated thereafter.

(a) Temperature in summer

(b) Temperature in winter

Fig. 6 Measured temperatures

5.3 Vibration and sound characteristics in summer and winter

Figures 7 and 8 show the vibration acceleration level and Figs. 9 and 10 show the frequency characteristics of the vibration acceleration for summer and winter data, respectively. The following results were obtained:

- 1) At a speed of 100 km/h or more (referred to as high speed) the vibration acceleration level of the rail (VR1) is almost the same in summer and in winter, while the value in winter is slightly smaller than in summer at a speed of under 100 km/h (referred to as low speed).
- 2) Vibration acceleration level of the rail fastening system (VT), showed a higher value in winter than in summer for the whole speed range.
- 3) Vibration acceleration levels under the trussed girder (VG1), showed smaller values in winter than in summer for the whole speed range.
- 4) There was no clear difference in value between summer and winter for the spectrum of the vibration acceleration level of the rail (VR1).
- 5) Values in winter were slightly larger than in summer across the whole medium/high frequency range for the spectrum of rail fastening system (VT) vibration acceleration levels.
- 6) The spectrum of the vibration acceleration levels under the trussed girder (VG1), showed that the value found in winter around the peak value frequency was smaller than in summer.

In the case of description 2), it was confirmed that the vibration acceleration level of the slab track (VS) and the floor slab (VC1) in winter were also higher than in summer.

In the case of description 2), it was confirmed that the vibration acceleration level of the slab track (VS) and the floor slab (VC1) in winter were also higher than in summer.

The track and structures in descriptions 1), 2) and 5) indicated a tendency for relatively smaller rail vibrations, and higher track slab and the floor slab vibrations at lower winter temperatures. It is thought that this was caused by

the lower of vibration reduction performance mentioned in Chapter 3, which is due to an increase in the rail pad spring constant as the temperature drops. This can also be explained by a decrease in the vibration reduction performance and the load dispersing performance, although it is difficult to know from these test results the share of influence on this from each performance.

Descriptions 3) and 6), indicate that ground vibration characteristics (VG1) differ from track structure vibrations, such as those found in rail fasteners. While it is difficult to clarify which factors generate this difference, it is thought that one reason is that the ground structure begins to vibrate more easily when ground structure stiffness increases because of lower temperatures.

Figure 11 shows the noise level in summer and in winter, and the following results were obtained:

- 7) In the case of noise level near the rail (SR), the value in winter was smaller than in summer on the whole at low speed. As velocity increases, the differences converge, while both values are almost the same at high speed.
- 8) In the case of noise level under the trussed girder (SG1), the value in winter was smaller than in

Fig. 8 Comparison of vibration acceleration levels on the ground in summer and winter

(a) The rail (VR1)

(b) The rail fastener (VT)

Fig. 7 Comparison of vibration acceleration levels in structural components in summer and winter

(a) The rail (VR1)

(b) The rail fastener (VT)

Fig. 9 Comparison of vibration acceleration level spectra of structural components in summer and winter

Fig. 10 Comparison of vibration acceleration level spectra of the ground in summer and winter

summer on the whole at low speed. In addition, it was found that the values in winter depended on travelling speed and were slightly larger than those in summer at high speed.

Although the difference in sound level near the rail

between summer and winter was larger than that in the vibration acceleration level at low speed, description 7) is thought to be reasonably consistent with the results obtained for the vibration acceleration level of the rail.

In reference to description 8), a similar tendency was shown at the point 12.5 m away from the track center (SG2). In other words, changes in sound characteristics at high speed were consistent with changes in vibration characteristics of the track member structure under the rail pad, such as floor slabs, and the value in winter was larger than in summer while changes in characteristics were the other way round at low speed. It is thought that this is caused by the contribution of rolling noise and under-car-noise at the 12.5 m point and the influence of vibration characteristics of the floor slab and structural components under the floor slab. However, they are insufficient to explain the value differences between summer and winter being small at low speed. In addition, the under-car-noise may be different in summer and winter considering description 7). In addition it is difficult to explain the consequence of this specifically in this test, therefore work will be continued, to evaluate the influence of the ambient temperature on railway noise.

(a) Near the rail (SR)

(b) Under the trussed girder (SG1)

Fig. 11 Comparison of noise level in summer and winter

6. Conclusion

In order to evaluate the influences of the ambient temperature on the vibration and noise reduction performance of elastic track materials, field tests were conducted in summer and winter. Measurements of vibration acceleration levels on track structural members, the noise level near the rail and along the railway, and the temperature at the same point on the slab track on a concrete viaduct in a conventional line, produced the following results:

- 1) As far as the characteristics obtained in these field tests are concerned, vibrations gradually fell as interposition of the structural members increased based on the distance from the excitation source on the wheel/rail interface, and the rolling noise and under-car-noise contributing to trackside noise.
- 2) Rail vibrations in winter were smaller than in summer for almost all vehicle speeds, while vibrations were larger for track structure members, such as the rail fastening system and floor slabs, in winter than in summer. These results are thought to reflect the change in stiffness of the elastic track material.
- 3) Contrary to description 2), field tests showed that ground vibrations under the trussed girder were smaller in winter, while the reason for this is difficult to explain based on elastic track material characteristics alone.
- 4) The results of measured noise levels near the rail at low speed, and noise levels under the trussed girder and at 12.5 m from the track center at high speed agreed with the changes in performance of

elastic track material according to temperature, while some of the other noise data indicated different behavior.

This paper showed the influence of the ambient temperature on the vibration and noise reduction performance of elastic track materials, but some results differed from those expected in terms of change in elastic track material performance. Further studies are underway to clarify these remaining issues.

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