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INTERIOR STRUCTURE-BORNE SOUND CAUSED BY THE SLEEPER-PASSING FREQUENCY

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This study deals with the parametric excitation caused by the discrete sleeper support of the rail, the so-called sleeper-passing frequency. If the wheelbase is an integer multiple of the sleeper distance the vibration transmission to the body is believed to be increased. Tests were made on UIC 60 and SJ 50 tracks, with sleeper distance of 65 cm, for six speeds, from 130 to 250 km/h. A X2000 train set with one extra car were used. The extra car, X15-5, has bogies with a 2·7 m wheelbase whereas the ordinary cars have bogies with a 2·9 m wheelbase. The structure-borne sound caused by the sleeper-passing frequency can in some cases be the overall dominating noise source in a coach.

1. INTRODUCTION

The interior A-weighted sound pressure level (sound level) inside a railway coach consists of airborne and structure-borne sound. The airborne sound dominates for frequencies above 500 Hz and structure-borne sound has a major influence for frequencies below 250 Hz. The region where both sources contribute is highly dependent on the type of train. With a move towards lighter trains the influence from structure-borne sound will increase. The structure-borne sound has many sources but the dominating source is the wheel/rail contact. This source can in turn be divided in one broadband random vibration caused by the roughness on wheel and rail and one parametric excitation [1] caused by the discrete sleeper support of the rail, the so-called sleeper-passing frequency, f_s. The sleeper-passing frequency is speed dependant according to $f_s = v/d_s$, where f_s is the sleeper passing frequency, v is the train speed in m/s and d_s is the sleeper distance. With a normal sleeper distance of 0·65 m this gives a sleeper-passing frequency of 85 Hz at 200 km/h, which means that the sleeper-passing frequency will be in a frequency range in which several bogie resonances occur. The driving force in this parametric excitation is the variation of the vertical stiffness of the track, and both wheel axles in the bogie will be excited with a phase difference depending on the wheelbase. If the wheelbase is an integer multiple of the sleeper distance then the two axles will move completely in phase and the vibration transmission of the sleeper-passing frequency to the body is believed to be increased. In order to examine this hypothesis a test with two different types of bogies has been performed.

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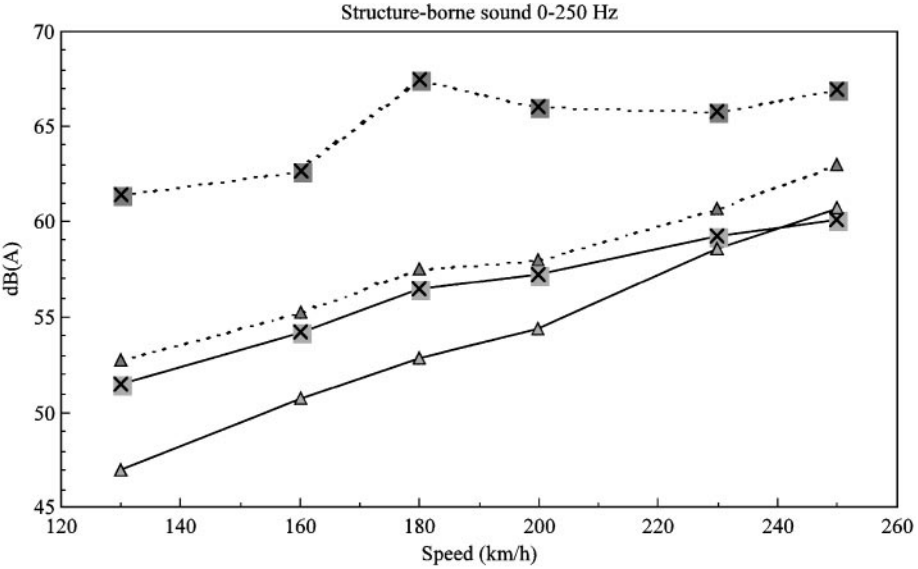

Figure 1. Interior structure-borne sound for two different bogies on soft (SJ 50) and stiff (UIC 60) rail for the speed interval 130–250 km/h. - -✖- X15-5 SJ50; —✖—X2000 SJ50; - -▲- X15-5 UIC60; —△—X2000 UIC60.

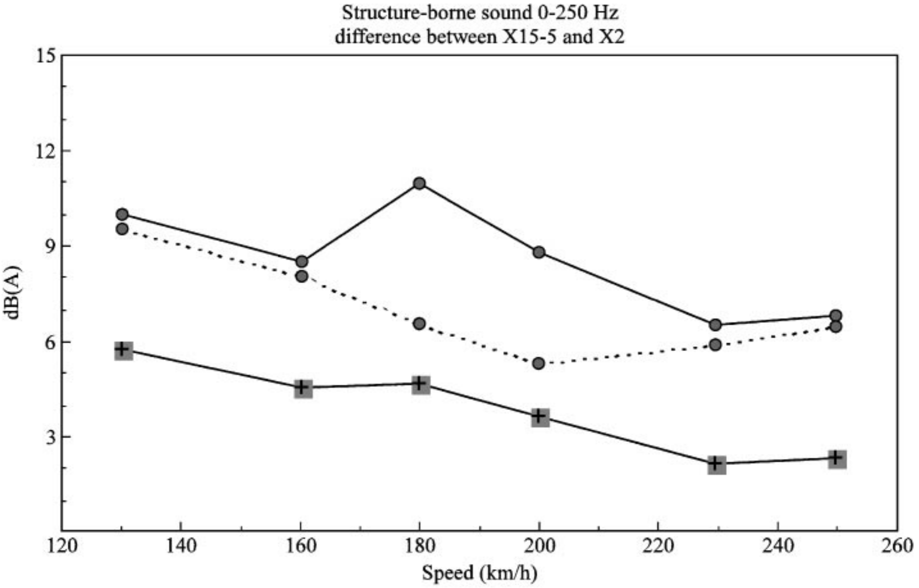

Figure 2. Difference between X15-5 and X2000 for: (i) SJ 50 rail, (ii) SJ 50 rail with the sleeper passing frequency, f_s, excluded and (iii) UIC 60 rail. —●—SJ 50; - -●- SJ 50 without f_s; —✚—UIC60.

2. METHODS

The present study is a part of a test series on a new type of bogie where one car in a train-set was equipped with new bogies and the rest of the cars were conventional X2000 cars. The test site is on the main line between Stockholm and Gothenburg where the south-going track comprises UIC 60 rail (60 kg/m) and the north-going track comprises older SJ 50 rail (50 kg/m). The track is straight and level. Tests were made on both tracks for six speeds; 130, 160, 180, 200, 230 and 250 km/h. Interior sound levels were measured at each speed.

The X2000 bogie is designed and built for Swedish track with a sleeper distance of 0·65 m. The wheelbase is 2·90 m, which is 4·46 times the sleeper distance, meaning that the two axles will move with a phase difference of 166° for the sleeper-passing frequency, f_s. The X2000 bogie is equipped with chevron rubber primary suspension. The new bogie, X15-5, is a prototype bogie with a wheel-base of 2·70 m, believed to be optimal for a sleeper distance of 0·6 m since this gives a ratio of 4·5 between wheelbase and sleeper distance. For a sleeper distance of 0·65 m this ratio will however be 4·15. The new bogie is equipped with helical steel springs for the primary suspension.

With this test set-up we have one bogie with a phase difference of 166° between the axles and one bogie with a phase difference of 55°. The measurements were made with one sound level meter in each coach placed directly above the bogie. The interiors in the two different coaches were similar.

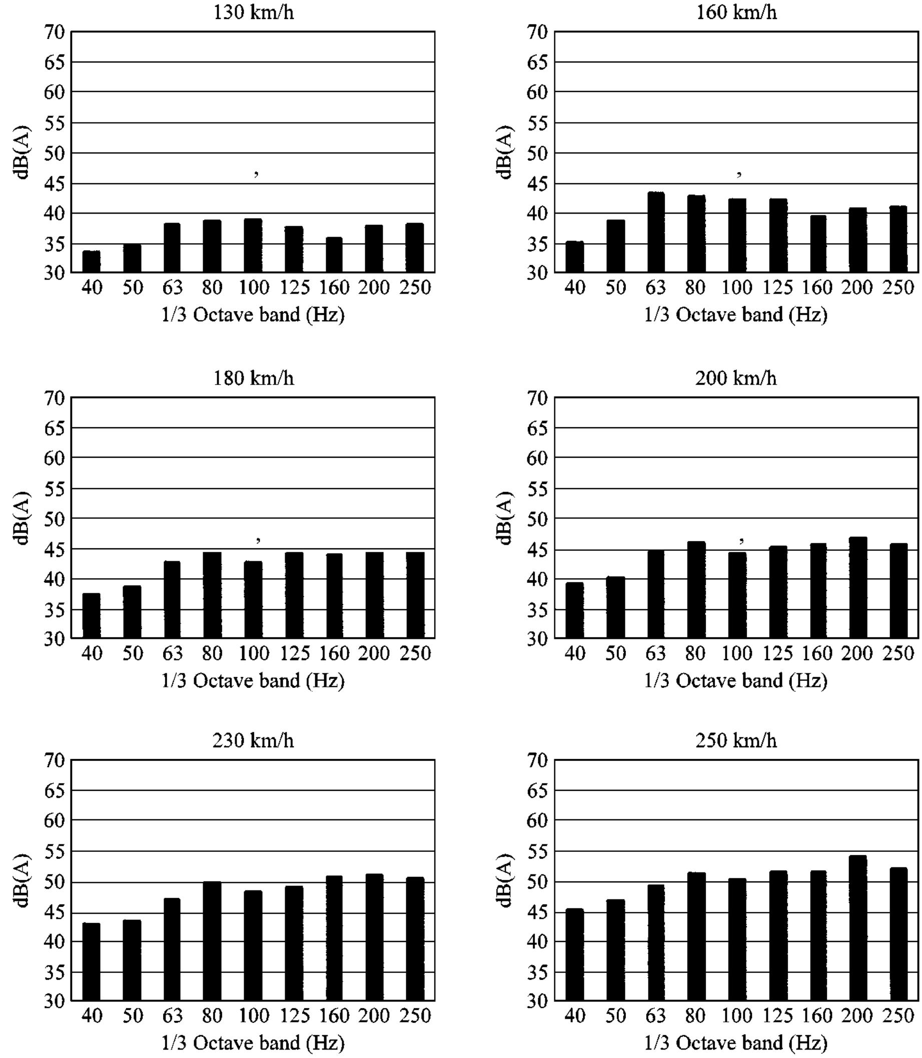

Figure 3. Structure-borne sound in X2000 for UIC 60 rail.

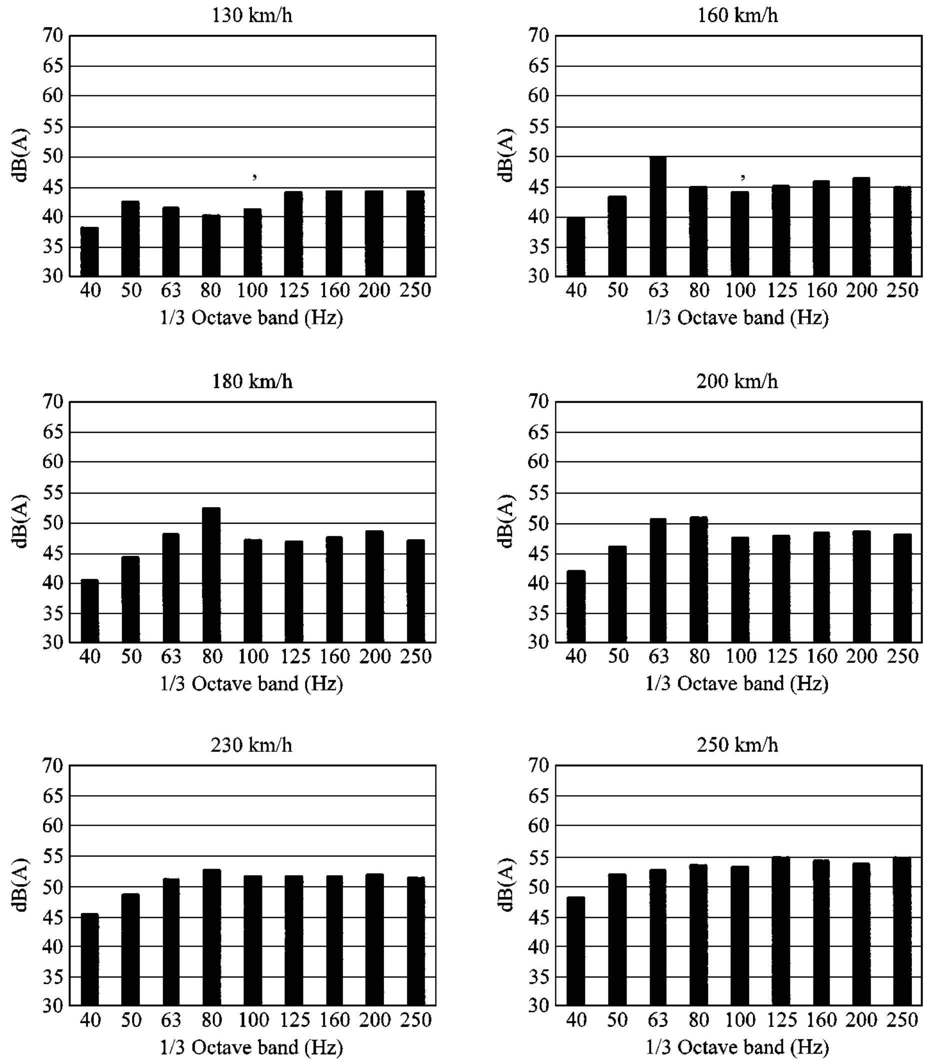

Figure 4. Structure-borne sound in X15-5 for UIC 60 rail.

3. RESULTS AND DISCUSSION

The structure-borne sound was assumed to be dominant up to at least 250 Hz and therefore the results for interior structure-borne sound levels described below include only the contribution from frequencies from 0 to 250 Hz. Figure 1 shows the measured interior structure-borne sound for the two different bogies. The dashed lines show the levels for X15-5 running on soft (SJ 50) and stiff (UIC 60) rail whereas the solid line shows the levels for X2000. The speed dependence is lowest for X15-5 on SJ 50 rail (17 log (v)) and highest for X2000 on UIC 60 (46 log v). Softer rail has a positve effect on the roughness excitation for frequencies above approximately 100 Hz; this might explain the lower speed dependence for the SJ 50. The difference in speed dependence between the two bogie types is believed to come from different proportions of sound caused by the sleeper-passing frequency, transmission of which to the car body decreases drastically for higher speeds. From

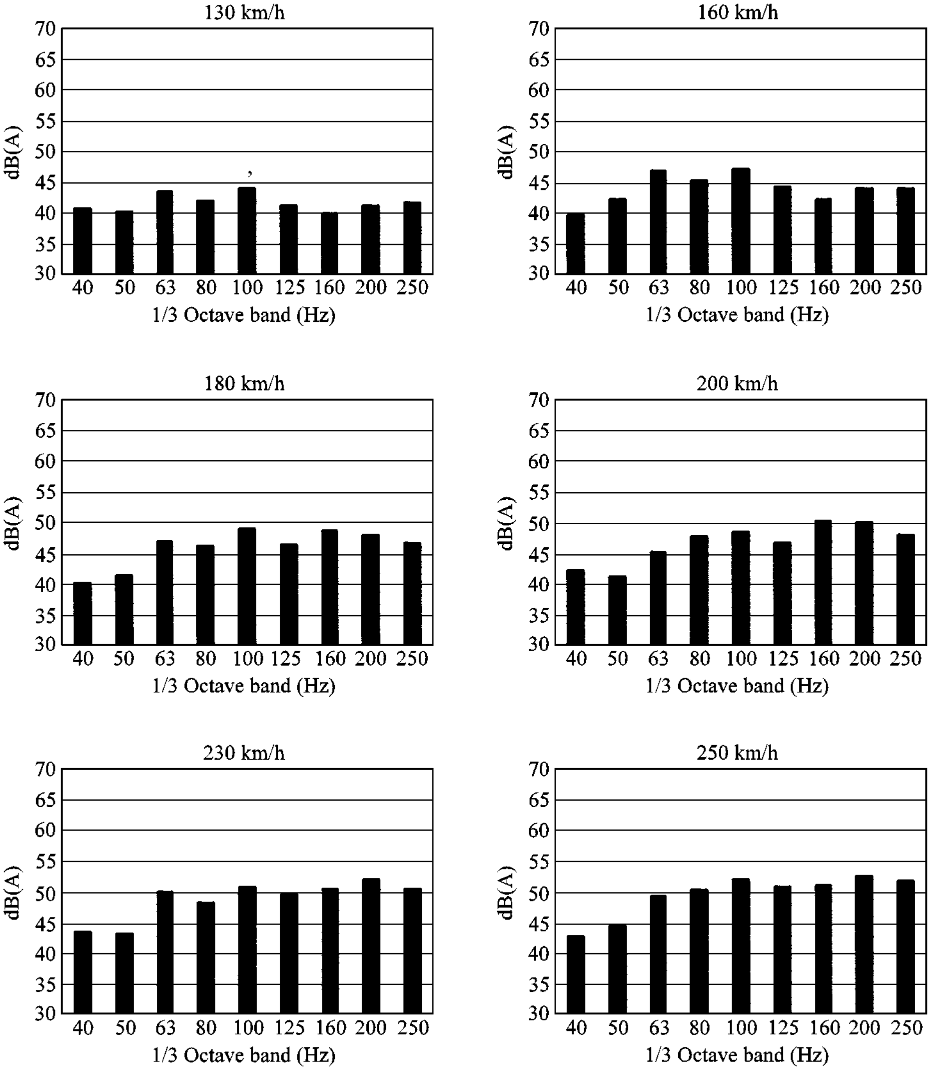

Figure 5. Structure-borne sound in X2000 for SJ 50 rail.

Figure 1 it is clear that the X15-5 bogie not only has higher transmission but is also much more sensitive to the increased sleeper excitation which occurs for a softer rail. The increase for the X15-5 bogie when changing from UIC 60 to SJ 50 rail is between 4 and 10 dB for the total structure-borne sound whereas for X2000 it is between − 1 and 5 dB. For the sleeper passing frequency the increase can be as high as 13 dB for the X15-5 bogie. The difference between X15-5 and X2000 on SJ 50 and UIC 60 rail is illustrated in Figure 2. The figure also indicates the difference with the contribution from the sleeper-passing frequency excluded. From these results it is clear that the sleeper-passing frequency can in some cases contribute as much as 4 dB to the structure-borne sound, when it becomes the overall dominant source. The difference between the two bogies is at maximum 11 dB(A). The two bogies differ in more aspects than the wheelbase only but the results in Figure 2 indicate that the ratio between the wheelbase and the sleeper distance has

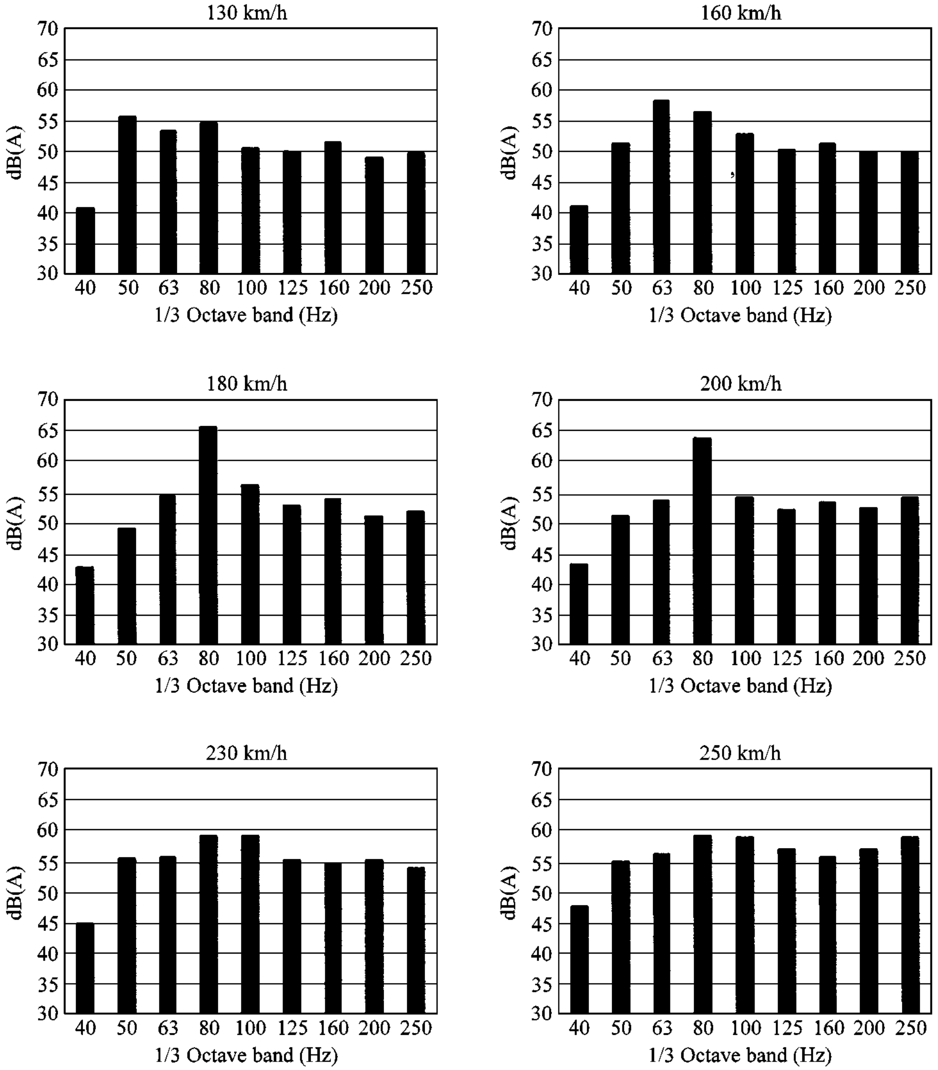

Figure 6. Structure-borne sound in X15-5 for SJ 50 rail.

a significant influence on the transmission of structure-borne sound caused by the sleeper passing frequency. In Figures 3–6 the structure-borne sound for the test bogies on both SJ50 and UIC 60 rail are shown with the contribution from each 1/3 octave. From these figures it is clear that the X2000 bogie is insensitive to sleeper excitation even though an indication can be seen for low speeds on SJ 50 rail in Figure 5. For the X15-5 bogie the situation is quite different. For UIC 60 rail there is clearly some sleeper excitation for speeds between 160 and 200 km/h, as can be seen in Figure 4. For SJ 50 rail the structure-borne sound is completely dominated by the sleeper-passing frequency for speeds up to 200 km/h, as shown in Figure 6. In both Figures 4 and 6 it can be seen that the influence from the sleeper-passing frequency almost vanishes for speeds above 200 km/h. This can also be seen in Figure 7 where the vibration transmission from the axle bearing to the car body coupling point is shown. The measured data have been taken from both

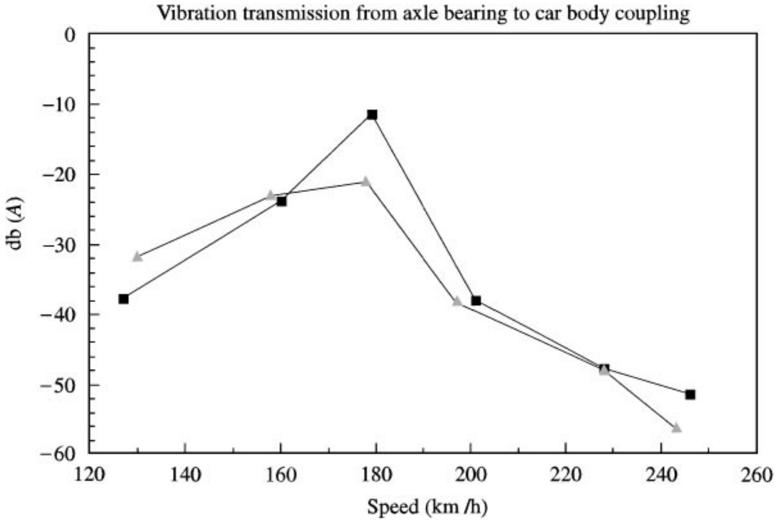

Figure 7. Vibration transmission from axle bearing to car body coupling on X15-5 for the sleeper passing frequency. ■ - UIC60; ▲ - SJ50.

types of track, SJ 50 and UIC 60, for the X15-5 bogie. Both curves show a decrease in transmission after approximately 180 km/h and low transmission is achieved at 200 km/h where the sleeper-passing frequency is around 85 Hz. At 200 km/h the sleeper-passing frequency has passed through many of the fundamental frequencies in the train/track system and the vibration isolation of the system starts to work efficiently. With shorter sleeper distance this occurs at lower speeds and the amplitude will also be lower due to smaller variation in track impedance.

4. CONCLUSIONS

This study shows that the structure-borne sound caused by the sleeper-passing frequency can in some cases be the dominant noise source in a coach. Removal of this source can give as much as 4 dB(A) reduction of the structure-borne sound. The sleeper-passing frequency is excited parametrically by the impedance variation of the track and it can be reduced by stiff rail, short sleeper distance, low ballast stiffness, wheel-base $(n + \frac{1}{2})$ times the sleeper distance. (e.g. 2·7 m for 0·6 m) and low transmission for pitch movements.

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