An investigation of the possibility to use axle box acceleration for condition monitoring of welds

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Abstract
Track short wave defects cause impact forces in the wheel-rail contact which leads to fast deterioration of the track. Early detection of such defects is very important for timely prevention measures. The present paper discusses a method for detection of track short wave defects by means of axle box acceleration (ABA). A validated finite element model was employed for numerical simulations of ABA. The dynamic responses of the vehicle-track system at a thermite weld were estimated.

1 Introduction

Condition monitoring of the railway track for early detection of track irregularities is very important for effective maintenance policy. On the one hand, worldwide many of the railway networks are regularly monitored with measuring trains for technical state in terms of long wave irregularities which can cause discomfort to passengers and damages to cargo. On the other hand, track short wave irregularities (less than about 3 m) are detrimental to the wheel-rail interface and the track infrastructure due to the impacting nature of the interaction. Therefore, track short wave irregularities are defects in the track system which can grow and cause damage in the railway track.

At present, ultrasonic measurements are conducted for monitoring of track short wave defects. However, this method is applicable for detection of rail defects with deep cracks, but it cannot find defects with shallow cracks or defects before crack initiation, such as light squats, and defects in the track infrastructure associated with rail fastening and damage of the ballast. It has been envisaged that axle box acceleration (ABA) can serve for detection of such defects, since it represents vibration of the structure due to the vehicle-track interaction. The main advantage of this method is the simplicity of the measuring system, mounted on standard in-service vehicles traveling at line speeds. Previous research has shown relation between ABA and track irregularities. In [1] the ABA has been proposed to control track short wave defects, and a study in [2] has shown correlation between ABA and corrugation level.

The present research is carried out to develop a method for detection of track short wave defects by means of ABA. Some initial results have been presented in [3]. It has been observed that the severe rail surface defects produce peaks in ABA; hence, they can be detected. Smaller surface defects and damages in the track infrastructure may be detected by analysis of both magnitude and frequency content of ABA. A validated finite element (FE) model was employed to find relation between parameters of the track system that are the most critical for damage occurrence and ABA characteristics such as magnitude and frequency content. Moreover, the contact forces at a defect may be estimated through numerical simulations and give a criterion for damage assessment. The FE model used for time domain simulations has been validated in previous work [4-7].

The approach discussed above may be applied for monitoring of welds. Welds of continuously welded rails are weak points in the track. Welds are susceptible to deformation due to material in-homogeneity in the heat affected zone. Figure 1 illustrates two squats initiated at a thermite weld. The surface of a weld is often irregular due to poor initial quality, which leads to increased vertical vibration of the wheel and rail, rolling noise emission, and amplification of dynamic contact forces, especially when the train travels at a high speed. High dynamic contact forces can cause damages in the track infrastructure and lead to fast deterioration of the track. This paper presents some initial results of numerical simulations of dynamic responses of the vehicle-track system at a weld.

Figure 1: Squats initiated at a thermite weld

2 Measurements

A number of thermite welds were registered for monitoring. Rail vertical geometries of these welds were obtained by a RAILPROF device which measures the vertical deviation of the rail surface within 1 meter.

Vertical ABA was measured at these welds to investigate the possibility of their detection. The reliability of data was ensured by repetition of the measurements. For analysis presented in this paper, three data sets of ABA were available. The position of the signals relative to the track was determined by GPS coordinates. The positioning error of GPS coordinates is 1 meter, which makes it possible to match the signals from different data sets.

Figure 2 shows an ABA signal for the section of track containing 2 welds. These two welds are characterized by large vertical deviation of the rail surface and can easily be found by ABA magnitude. The acceleration peaks excited at these welds are 70 and 75 m/s^2. In total 35 % of welds were recognized by magnitude in the measurements of ABA. For the rest of the welds, the magnitudes of ABA were comparatively small. The investigation of the frequency content of ABA is necessary for detection of such welds.

The vertical irregularities at welds usually have wavelengths from 0.1 to 1 m; hence, the frequencies excited at welds lie in the mid-frequency range (from 10 to 400 Hz) for operational speed of 40 m/s. However, quite often squats or corrugation initiate at welds, because of material in-homogeneity along the weld. These defects are characterized by shorter wavelength (see figure 1). Therefore, the frequency range should be extended and the high frequency components should also be considered.

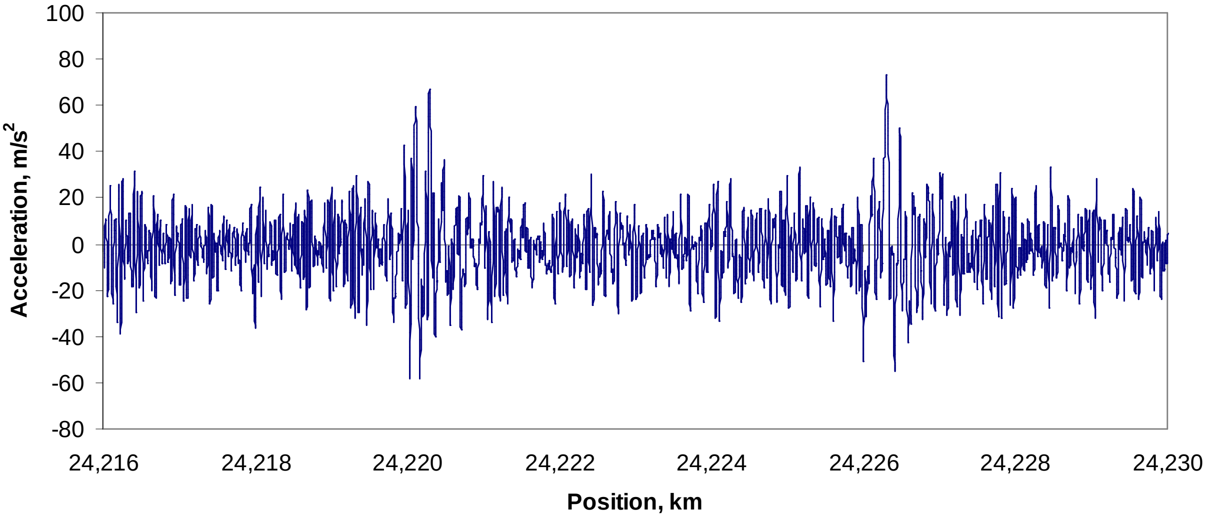
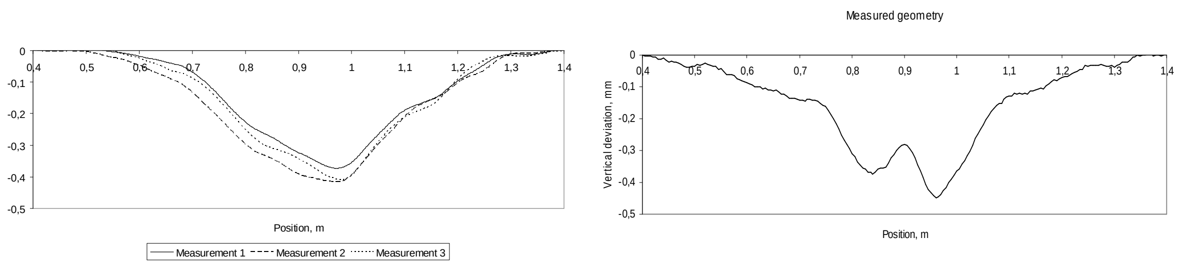


Figure 2: ABA measured at welds

Another approach for detection of welds is double integration of ABA signal, which may provide an indication of weld's dip. Figure 3 shows the double integration of three ABA signals at a weld and the measured geometry of the same weld obtained by RAILPROF. Double integration gives an assessment of the weld depth (0.4 mm for this weld), but it does not completely reproduce the shape of the weld.

The contact force is the main cause of the damage in the track. Therefore, the estimation of the contact force is necessary for assessment of the rate of track deterioration. As there is no direct relation between ABA and contact force, the FE model was applied for estimation of the contact force at a weld. The FE model is discussed in the next chapter.



(a) (b)

Figure 3: (a) -Double integration of ABA; (b) – measured geometry of the weld

3 FE model

A three-dimensional FE model was build up for numerical simulations of axle box acceleration and contact forces generated at welds. To simplify the model and reduce the calculation time, only a half of the vehicle-track system was modeled. Since this investigation was focused on dynamic responses of the system in the mid- and high-frequency ranges, sprung masses of the car body and bogie were lumped into one rigid body which was supported by primary suspension modeled with springs and dampers. The scheme of the model is shown in figure 4. The half of the wheel set, the rail and concrete sleepers were modeled with three-dimensional solid elements, representing their real geometry. The wheel geometry was adopted from a passenger car wheel with a radius of 0.46 m. The rail was UIC54 with 1:40 inclination. The length of the rail was 10 meters. The rail pads and ballast were modeled as springs and dampers. The material on the contact surfaces was bilinear elastic-plastic with kinematic hardening. The vehicle and track parameters as well as material properties of the wheel and rail were the same as in [3].

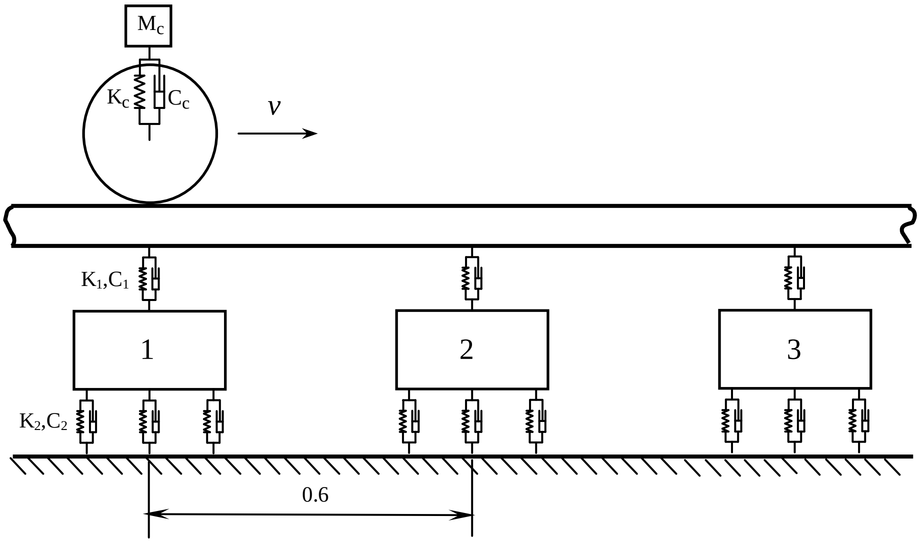


Figure 4: The scheme of the FE model

The starting position of the wheel was at the center of the sleeper 1 (figure 4). After finding the static equilibrium position, time domain simulations were performed with an explicit integration method. During the dynamic simulations the wheel runs over the rail with a speed of 110 km/h, which correspond to the speed of the measuring train.

The real weld was simulated in this paper (figure 5). The geometry of this weld, obtained by RAILPROF, is shown in figure 3b. The weld was modeled as vertical deviation of the rail surface. The center of the weld coincided with the center of the sleeper span between sleepers 2 and 3 (see figure 4). To avoid noise in simulated signals the weld geometry data was smoothed with application of moving average algorithm (figure 6). The simulations were performed for both smoothed and original weld geometries.

Figure 5: The simulated weld

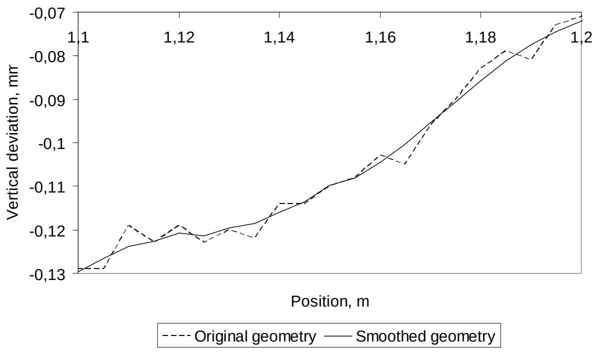


Figure 6: Smoothing of the measured weld geometry

4 Results

4.1 Acceleration in time and frequency domain

Three ABA signals measured at the weld are shown in figure 7. The signals are quite variable in shape, but the positions of excited peaks coincide. However, peaks B and D do not appear in each measurement. Figure 8 illustrates accelerations calculated at original and smoothed welds. The signal calculated at original geometry of the weld is noisy, as expected. The signal calculated at the smoothed geometry of the weld has good agreement with the measurements. The peaks appear in the same positions as in the measurements. However, the shape of calculated signal before peak B is quite different from the measurements. The reason should be that the vibrations forced by the weld are less pronounced before the peak B, as the geometry of the weld changes gradually. The maximum value of calculated acceleration is 93 m/s^2. The maximum values of measured accelerations are 73, 106 and 99 m/s^2 (peak C of each measurement), which is in average 93 m/s^2 as well.

The power spectral densities (PSD) for measured and calculated signals are shown in figures 9a and 9b. The measured accelerations have four frequency components in mid-frequency range, which may be related to the weld. The powers of these frequency components differ from one measurement to another. The PSD of calculated acceleration contains only three of these components (see table 1). Therefore, it is necessary to make improvement in the model. The frequency components above 500 Hz appear in the measured signals and in the signal calculated at original geometry of the weld, but they are not found in calculated signal for smoothed geometry of the weld (figure 9). Hence, they appear due to the noise in the signals and are irrelevant. The frequency component of 900 Hz, which is found in all of the signals, should be one of the eigen frequencies of the system.

	Frequency, Hz			
Measurement 1	60	200	320	425
Measurement 2	60	190	330	440
Measurement 3	60	205	320	425
Average of measurements	60	198	323	430
Simulation	50	220	335	-

Table 1: Frequency characteristics of the weld

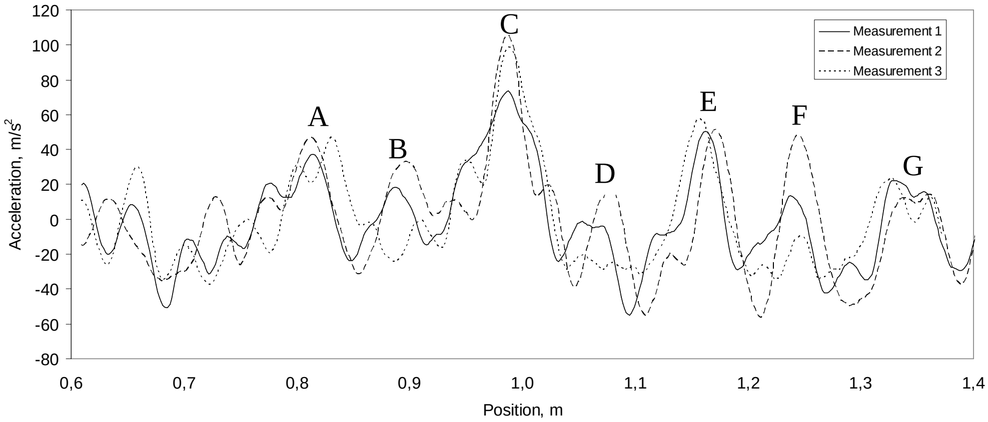


Figure 7: Axle box accelerations measured at a thermite weld

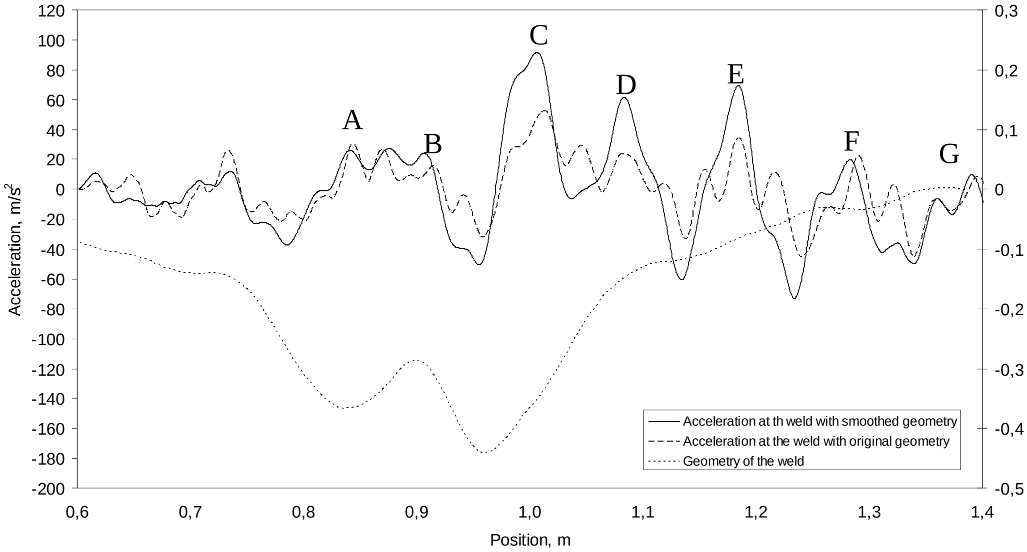
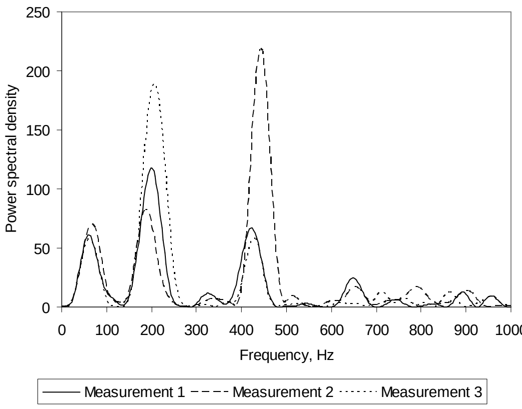
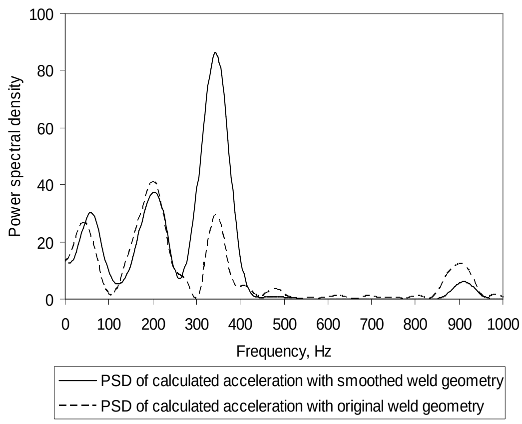


Figure 8: Accelerations calculated at the weld with original and smoothed geometries and the geometry of the weld



(a) PSD of measured acceleration



(b) PSD of calculated acceleration

Figure 9: PSD of measured and calculated acceleration signals

4.2 Contact force

Figure 10 shows the vertical normal contact force along with geometry of the weld. The peak B_1 excited by the weld is 1.3 times of the static load, the peak C_1 is 1.7 times of the static load. These results agree with the maximum force presented in [4]. These high values of the contact force lead to plastic deformation of the wheel and the rail, and cause their damages. The wavelength of the wave patterns of the contact force after peak C_1 is 9.3 cm in average.

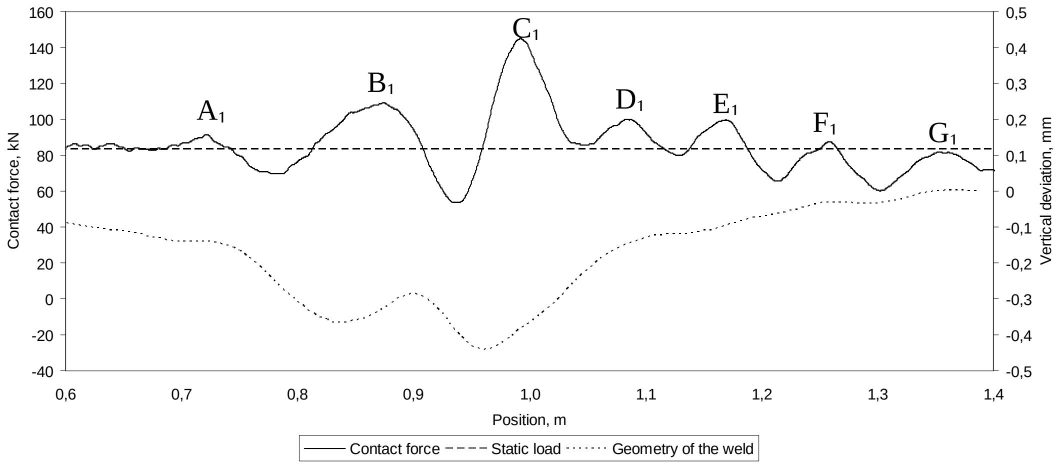


Figure 10: Contact force and geometry of the weld

5 Conclusions

The possibility of condition monitoring of welds by ABA was investigated in this paper. The dynamic responses of a vehicle-track system at a weld were estimated through numerical simulations. The results of numerical simulations have been compared to the measurements. The magnitude of ABA has good agreement with the measured one. The most of important frequency characteristics of ABA excited at the weld have been reproduced. The maximum contact force induced by the weld is 1.7 times of the static load. This high value of the contact force leads to plastic deformation and cause damages of the wheel and the rail. These results may be used in further investigation for development of a method for detection and assessment of welds.

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