CETRA 2014

3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

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CETRA[2014]
3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

TITLE
Road and Rail Infrastructure III, Proceedings of the Conference CETRA 2014

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
"Tiskara Zelina", April 2014

COPIES
400

Zagreb, April 2014.

Proceedings of the
3rd International Conference on Road and Rail Infrastructures – CETRA 2014
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CETRA[2014] 28–30 April 2014, Split, Croatia
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MEASUREMENT AND ANALYSIS OF THE DYNAMIC EFFECTS ON THE CROSSINGS

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Abstract

The turnouts are one of the key points of the railway routes. In particular, turnouts in the main tracks are passed relatively high speed. This paper is focused on measurement and analysis of dynamic effects on railway turnouts. The main rail turnouts which are passed in speed of 160 km/h^{-1} and with different wear condition were selected. Attention was focused mainly on the crossing panel of the turnout, where the highest dynamic impacts occur. The turnout was measured twice: before and after frog repair by welding. The point of the paper is comparison of the crossing part of turnout in term of dynamic behaviour and assessment of influence of the transition geometry (wearing depth) on dynamic effects. Because dynamic impact from the wheel sets during the transition from the wing rail to the nose of the crossing depending on the quality of the transition geometry and also on the overall stiffness of the rail superstructure, the appropriate methodology of the measurement was designed. The methodology is designed for in situ measurement in condition of full operation and consists of two parts. Measuring of vibration and measuring of shifts of the bearers in the crossing panel. Piezoelectric vibration acceleration sensors (the accelerometers) were attached to plastic handles and glued to the cleaned surface of the measured structure. Three-axis accelerometer B&K 4524 B001 was placed at the foot of the wing rail, five accelerometers B&K 4507 B001 were placed at the bearer and one accelerometer B&K 4507 B004 was placed at the measuring bar embedded in the ballast. Shifts of the bearers ware measured by inductive displacement sensors HBM WA-10 T which were attached through magnetic holders to special frames. Frames are made of two steel bars embedded in the structural layers of subgrade and steel cross members connecting the two poles. This method created referential zero-point shift. For evaluation of measured data were used time analysis, frequency analysis using the amplitude spectrum and time-frequency analysis.

Keywords: turnout, crossing panel, vibration measurement, measuring of shifts, frequency analysis, time-frequency analysis

1 Introduction

The switches and crossings are the main parts of railway lines. Although the length of tracks with switches and crossings is relatively short, the maintenance of switches and crossings are approximately same expensive as maintenance of rest of the plain line. It is due to complicated force action when a train is passing the crossing and as well due to the maintenance of many different parts which crossing is built of. Except that the maintenance of the crossings carries expensive direct costs, it also carries non direct costs when repaired, for example: delay of trains, costs for alternative transport and so on. It's very important to plan the regular

maintenance of these parts very carefully. If regular maintenance is not done in time, the price for immediate repair is increasing very fast.
There is no complex methodics for measuring and evaluation of the dynamic effects on railway crossing in Czech Republic so far. Authors have been continuously working on solving this issue. They study development of the measuring methods and analysis of the dynamic effects as well, so it would be possible to plan repairs and the maintenance of crossings on time and with minimum costs. In this paper we are concerned with comparison of the dynamic behaviour of the railway crossing before and after repair of the frog by welding.

2 Description of the problem

Continuous demand on the bearing capacity leads to higher rigidity of construction layers and subgrade. The concrete sleepers are mainly used nowadays. Compare to wood sleepers their bending stiffness is much higher but on the other hand they are less plastic. All these aspects lead to higher stresses in the ballast, which change its shape under increased load and thus change geometric parameters of the track. Uneven support of the sleeper is then created and dynamic effects are increased which leads to faster degradation of the ballast. In the crossings, mentioned problems are combined with change in stiffness of the track and dynamic action when the wheels are passing from the wing rail to the crossing nose or vice versa.
Combination of these factors cause the fact that the most stressed point of crossing construction is the frog part where the wheel is crossing from the wing rail to the crossing nose. On this place the dynamic impact occurs and its magnitude is influenced by quality of the transition geometry (from the wing rail to the crossing nose). This impact is carried through the sleeper to the ballast, which is for this reason extremely stressed. This extensive load causes abrasion between gravel and sleeper. Whole process results in degradation of shape of the ballast under the sleeper, which leads to insufficient support of the crossing. If the crossing is not properly supported it collapses transition geometry and degradation process speeds up.

2.1 Possible solution of the problem in practice

Planning of the maintenance and repairs of crossings in Czech Republic is mainly based on the visual control and basic geometric measurements directly in situ. Most of the time there is no defect prevention and later it's necessary to deal with damage which is more complicated and more expensive as well. Repair of damage is mostly done by frog welding, underlaying base plates and tamping of construction. Unfortunately these repairs have only short time effect and defects are detected again, sometimes developing even faster.
The aim of author's team is to complete present system of geometric observation and wear measurement for new element of monitoring which would be measurement of dynamic effects. Thanks to this new approach it would be possible to evaluate influence of repair works on dynamic effects. With long-term measurement of dynamic effects it would be possible to schedule regular maintenance better and prevent defects. This could not only save financial funds but also increase safety and fluency of the railway traffic.

3 Methodology of the measurement

The methodology of the measurement has two parts. The first part is focused on dynamic behaviour of construction and follows up transmission of the vibration from rail to sleeper and to ballast. The second part is designed to follow up construction movement under the load.

3.1 Vibration spreading in the crossings

Probably the most interesting thing from point of analysis and evaluation is following up the vibration acceleration transmission from the frog through the sleeper to the ballast when vibration is caused by the wheel sets. It's considered that small part of vibration is absorbed by the rail (frog) and rail pad, another part of the vibration is absorbed by the bearer and the rest of the vibration is transmitted to the ballast. Authors use piezoelectric vibration acceleration sensors (designation A) for measuring values of the dynamic effects.
The sensors are placed in such a manner that it's possible to follow up spread of vibration energy through the whole system. Three-axis accelerometer placed on flange of the wing rail is detecting magnitude of dynamic impact, which is placed on frog (A4Z, A5X, A6Y). Vertical dynamic impact posed on frog (A4Z) is detected in vertical direction, respectively the part which is transmitted to flange of the wing rail. The other sensors are one-axis sensors and are placed on such positions to best detect spreading of dynamic impact from the frog through the sleeper and into the ballast. Position of the sensors is as follow: A3Z – on bearer nearest to the crossing nose; A0Z – on the measure bar embedded to the ballast close to crossing nose. The vibration transmissions through the bearer under crossing nose: A1Z – on head in straight direction; A2Z – on line of the track in straight direction; A3Z – on bearer nearest to the crossing nose; A7Z – on line of the track in curve direction; A8Z – on head in curve direction. Thanks to the described methodology of the measurement it's possible to obtain complex information about how dynamic impacts are transfer in close proximity of the frog and into the ballast.

3.2 Measuring of moving behaviour of the construction

Moving behaviour in place of the frog is followed up by the induction sensors (designation S) which measure vertical displacement of the bearers.
The sensors S0, S1, S4, S7 are placed on single bearers along the crossing as close as possible to wing rail. Measurements from these sensors help us to imagine bending curve which occurs along the crossing. Maximum displacement is expected to be directly under the crossing nose.
Vertical displacements of the most loaded bearer (most likely under the crossing nose) are measured by following sensors: S2, S6 – placed on the head; S3 – placed in the line of the track in straight direction; S4 – placed nearest to the crossing nose; S5 – placed in the line of the track in curve direction.
The sensors of vertical displacements (S0, S1, S2, S3, S4, S5, S6, S7) are attached to steel beam with special magnetic holder. The frame consists of two steel rods with diameter 20 mm and length 70 cm. The rods are hammered to the ballast to depth of 65 cm. The axial distance from one another is 60 cm. The steel beam is attached to steel rods. The length of steel beam is 70 cm.
If trains are passing mostly through straight direction and curve direction is not that busy it could happen that bearers are lifting upward when a train is crossing. Thanks to position of the sensors these changes could be detected.

4 Mathematical apparatus

When dynamic action from railway traffic is measured in-situ it's necessary to describe and evaluate stochastic signal. This is rather difficult. In order to get necessary information and compare the dynamic action on each construction we can evaluate stochastic signal from three different perspectives. First perspective is time scale. We will calculate surface under the curve of moving RMS (RMS stands for Root Mean Square). Thanks to this time perspective it's possible to determine total dynamic action on construction. If we compare area under

curve of moving RMS with area under curve of moving maximum amplitude we get a value called Crest Factor. Crest Factor represents dynamics of the signals.
For detailed analysis of the dynamic actions above described method is not sufficient because frequency composition is not known. For this reason it’s useful to transform signal from time scale to frequency scale. For this transformation we use Fourier transformation method. In frequency scale it’s possible to determine which parts of signal are the strongest ones. For detailed analysis it’s useful to use third perspective, which evaluate signal from time-frequency scale [3]. With this perspective we can see not only frequency composition but also its occurrence in time.

4.1 The Welch method

The Welch method is certain modification of the Fast Fourier Transformation. Digital signal x[n] (n=0,1,2,..., N-1) is divided into K segments each of them with length M (xi[m], i=0,1,..., k-1, m=0,1,...,M-1). Segments are either placed in row one by one then N=K·M or they overlap. Each segment is weight by function w[m]. After transformation and following calculations periodograms components Sj[k] are created. These components put together represent approximate spectral density S[k]. This estimation is described by following formulas. Component of periodograms is determined by formula [1].

$$S_j[k]=\frac{1}{U\cdot M}\cdot\left|\sum_{m=0}^{M-1}x[m+i\cdot M]\cdot w[m]\cdot e^{\left(\frac{-j2\pi mk}{M}\right)}\right|^2 \tag{1}$$

where:

$$U=\frac{1}{M}\cdot\sum_{m=0}^{M-1}w^2[m] \tag{2}$$

is vector’s standard of window function, w[m] is window function. Resultant estimation is done by averaged component periodogram.

$$\hat{S}=\frac{1}{K}\cdot\sum_{i=0}^{K-1}S_j[k] \tag{3}$$

4.2 Short Time Furier Transform (STFT)

STFT provides compromise between time and frequency signal representation [2]. Its integral definition is:

$$\mathrm{STFT}_x^{(\omega)}(t',f)=\int_{-\infty}^{\infty}\left[x(t)\cdot g^*(t-t')\right]\cdot e^{-i2\pi f(t-t')}\cdot dt \tag{4}$$

where:

g	window function;
‘*’	complex conjunction;
t’	time displacement of window;
x(t)	time representation of signal;
$\mathrm{STFT}_x^{(\omega)}(t',f)$	time-frequency representation [2].

5 Description of measuring location and measured crossing

The chosen crossing was the fix common crossing of turnout number 59 in station head of the railway station Chocen. The turnout track system: rails 60E1 on concrete bearers, fastening system Vossloh SKL 24 and ballast. Trains run in trailing direction. Turnout crossing angle is 1:14 and radius 760 m. The crossing of the turnout was measured twice: the first time before repair and the second time after repair of frog by welding, half a year later with previously mentioned methodics. The following measurements have been completed in full operation: construction moving behaviour, acceleration of vibration, geometry of transition by very accurate levelling and measuring with laser device for the measurement of cross sections of frogs.

6 Evaluation of measured data

Due to scope of our paper we are only interested in transmission of vibration from wing rail (A4Z) through bearer (A3Z) to the ballast (A0Z) and moving behaviour of bearers along the frog. Equally 20 trains were measured before and after repair of frog. From many graphs and tables we choose those which best represent results of our analysis.

6.1 Evaluation of vertical displacement of sleepers

From each train maximal vertical displacements were measured. Maximal vertical displacements were used to create bending curves along frog. Then, from all measured trains the envelope curve of maximal and minimal vertical displacements was created and finally the average displacement curve was created as well. This analysis was done before and after repair. Sensor S0 was placed two bearers in front of the crossing nose of the frog, sensor S1 was placed one bearer in front of the crossing nose, sensor S4 under crossing nose and sensor S7 one bearer behind the crossing nose. The figure 1 shows the fact that vertical displacements after repair are greater than displacement before repair. It’s obvious that the repair doesn’t stop the development of the vertical displacements. Dash line on figure 1 represent displacement before repair and full line represent displacement after repair. It’s interesting that the maximal displacement is not under crossing nose of the frog as it was in previous analyses we have conducted on other crossings. It’s actually shifted to the next bearer.

6.2 Evaluation of transmission of vibrations in construction

The evaluation of acceleration of the vibration is divided into three different perspectives. First perspective is time area, where we represent evaluation with Crest Factor, which is ratio between maximal amplitude and RMS. This factor is calculated as an area under curve of moving maximum amplitude and moving RMS which are compared. The table 1 represents the measurements from selected trains and their comparison before and after repair. The table 1 shows the fact that dynamics of the signals after repair are smaller than before repair. In other words we can see positive influence of repair on dynamic effects.

The second perspective is frequency area. Welch Method was used for all trains going over 120 km/h. All graph results were put together and one average graph for each sensor was created. For each sensor we get average graph before and after repair. Figure 2 shows that from frequency point of view repaired crossing is slightly worse than unrepaired one. Decline in vibration was detected only for 50 Hz frequency; the other frequencies show worse or equal results after repair. Significantly worse values after repair were measured for frequencies 75 – 150 Hz on bearer (A3Z) and for 150 – 700 Hz on wing rail (A4Z). In figure 2, dashed line is used for frequency measured after repair and solid line is used for non-repaired crossing.

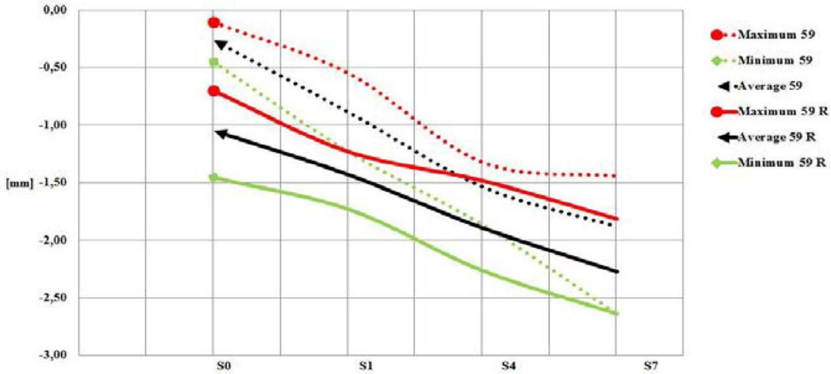

Figure 1 Vertical displacement curves along the crossing

Table 1 Evaluation with the Crest Factor

Train	Crossing 59				Crossing 59 repaired			
	Speed [km/h]	AOZ	A3Z	A4Z	Speed [km/h]	AOZ	A3Z	A4Z
Leo Express	157	4,38	2,78	2,81	156	4,64	3,31	3,09
163	49	4,34	3,52	8,48	51	2,53	2,09	3,07
RegioJet 363	137	5,57	3,67	4,21	139	5,09	3,09	3,10
Taurus	141	4,28	2,92	2,95	140	5,28	3,14	3,20
Pendolino 680	155	4,61	2,90	2,95	163	5,24	3,51	3,12
471 City Elefant	75	3,31	2,11	2,76	72	2,50	2,03	3,00
151	125	3,65	2,70	2,87	120	4,57	2,79	3,12

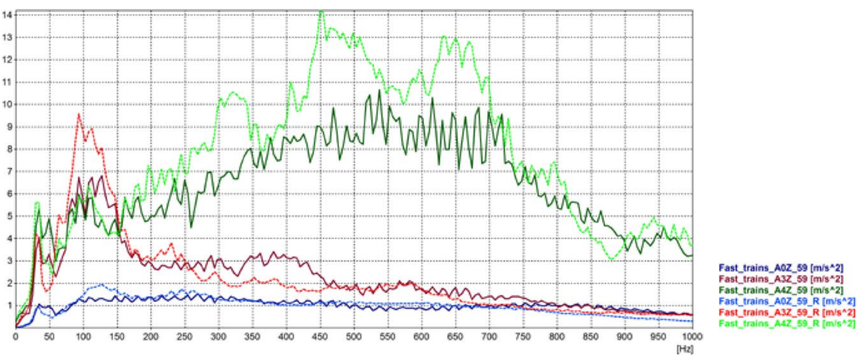

Figure 2 The Welch method analysis

Time-frequency method can be used for confirmation of conclusions from frequency and time analysis. The advantage of this method is that it can display time and value of frequency action in one chart. As an example we present time-frequency graph calculated for signal detected on wing rail when Pendolino train passed the crossing. As we can see on figure 3 on horizontal axis is time and on vertical axis is frequency. The figure 3 shows the fact that the densest frequencies were detected in time when train wheel sets were passing measuring point. Maximum frequency range is from 400 – 550 Hz and 600 – 750 Hz, which correspond to the frequency analysis.

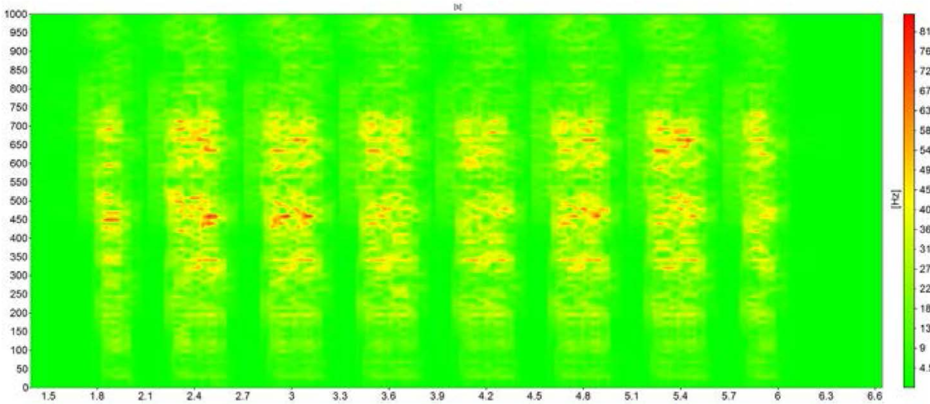

Figure 3 Time-frequency analysis with method STFT

7 Conclusion and recommendation

From conducted measurements is obvious that it's not efficient to repair the frog only by welding because dynamic actions are increasing even after repair. Detected signal magnitude degrees after repair (which is visible on Crest Factor) but overall dynamic actions are increasing even after repair. This conclusion is supported by practical experience as well, where repair effect doesn't last for a long time and defects are detected again. In this particular case it could be problem with track bed because vertical displacements under bearers are increasing. Ideal solution would be stabilization of track bed with combination of the ballast tamping and frog welding.

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