CETRA^{2010} 17–18 May 2010, Opatija, Croatia
First International Conference on Road and Rail Infrastructure

ANALYSIS OF THE DYNAMIC AFFECTS ON TURNOUT USING VIBRATION MEASUREMENT

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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. Dynamic effects significantly increase with speed. The highest dynamics effects on turnouts are mainly on fixed crossings where dynamic impacts occur. Experience have shown that in case of speeds above $200\,\text{km}\cdot\text{h}^{-1}$ advantageous to use turnouts with movable point. The paper is focused on dynamic effects measurement on turnouts in condition of full operation (in situ). The aim was compared various turnouts. Both types (fixed crossings and crossings with movable point) were measured. Measurement evaluation is provided by modern mathematician methods in time, frequency and time-frequency area. Based on experience it was designed and tested complex methodology of measurement.

1 Introduction

The vibration of the railway track system is mainly influenced by its quality, by the operational technical conditions, climatic phenomena and above all by the dynamic load by the pair of wheels of the rail vehicles. Simultaneously, the dynamic parameters also depend on the speed of rail vehicles, on the arrangement of axles, their spring mounting and on the spring mounting of the body casing or on the weight acting on the axle, and last but not least, also on the quality of the running surface of the wheel tyre. The dynamic effects of sets of wagons are transferred through the rails to the rail pads below the base of the rails, then to the sleepers or bearers and fastening, then to the ballast bed and also to the subgrade. This fact applies especially for turnout structures which represent one of the key places of the railway traffic route. Text bellow deals with the analysis of the dynamic parameters of the turnouts where the wheels pass from wing rail to nose of the crossing.

2 Descripton of the proplem

Turnout structures represent one of the key points of the railway transport. Therefore it is necessary to pay a special attention to these structures. The turnout structure consists of a number of structural components of different properties which in summary must fulfil the required functions. Among the most important properties is especially their reliability and safety within the framework of the railway operation.

When running over the crossing nose of the turnout structure the railway wheel causes a smaller or bigger dynamic impact during the transition from the wing rail to the nose of the crossing depending on the technical condition of the whole structure (i.e. subgrade, ballast bed, bearers, fastening) [5]. This impact is also transferred to the railway bed where it causes a repeated stress of the contact edges and surfaces of the aggregate. During the multiple stress repetition, sharp edges are abraded. At an extremely high stress caused by impacts the grains become more rounded, their cohesion is reduced and the rail bed changes its shape. This results in the undesirable change of parameters of the rail bed leading to the deterioration of the quality of the rail geometrical parameters. Moreover, at high speeds, the crossing of the turnout is disproportionately loaded by the impacts from wheels. This is a complex spatial problem of the transmission of load and the action of the force.

The transition geometry is especially affected by the following parameters:

- By the quality of the turnout structure material (the profile of the rails heads and the steel quality)
- By the quality of the rolling stock (spring mounting, weight on the axle, the quality of the running surface of the wheel tyre)
- By the quality of the rail geometry in the turnout structure (gauge, track twist, cant, rail inclination)
- By the quality of supporting and rail rigidity (fastening, sleepers, rail pads, ballast bed, substructure)

The above described actions may also proceed in a standard rail. It is particularly a case when the sleeper substructure is not in order [3]. However, the degradation processes in the standard rail proceed at a much slower pace. These also do not constitute such a risk as in case of the turnout structure.

From mentioned above is obvious that it is proper to measure dynamic impacts on turnouts. Especially on main rails turnouts which are passed in high speed. Therefore the authors proposed and verified methodology of the measurement to provide the range and danger of the dynamic impact.

3 Implementation of the experiment

For experiment main rail turnouts which are passed in speed of 160 km·h^{-1} were selected. Particularly it regards turnouts in stations Vranovice, Moravany and Poricany. Let us add that this refers to turnouts 1:12 – 500 (in Poricany station is 1:26.5 – 2,500) of the system of the track system UIC 60 installed on concrete sleepers. The rails are fixed by the elastic fastening Vossloh skl.12 to grooved baseplates S 4pl. Four of the turnouts are equipped with common crossing (Vra 3, Mor 21, Vra 23, Vra 25) and two with movable point (Por 3, Vra 5).

The dynamic effects on structures are best caught by the time behaviour of acceleration (or that of speed) [4]. Therefore a certain form of the vibration diagnostics was used, i.e. the measurement of quantities characterizing the dynamic effects by the acceleration indicators. Based on the above facts, it is evident that the proposed methodology of measurement had to be composed in a way to enable us to observe the range of dynamic impact. The following points for installing the indicators were chosen:

- Wing rail in the straight direction of the run
- Under the crossing nose
- Sleeper under the crossing nose
- Ballast bed close to the crossing nose

Two sensors of acceleration were placed on the base of the wing rail. One of the indicators of acceleration was placed so that it might take the vibrations in the cross direction and the other, with respect to the rail axis, in the vertical direction. The indicator in the vertical direction was used for taking the size of the dynamic impact. The reason for choosing the cross direction was to show how important the cross constituent of the dynamic impact is.

Another measuring point was chosen under the crossing nose of turnouts. The processes ongoing in a given place are very interesting from the analysis point of view. On the turnout with a crossing with movable point, the indicator was placed from below on the tip of the crossing nose.

An interesting behaviour of the vibration acceleration in all three directions was expected especially on the crossing with movable point. Therefore a three-axial indicator of acceleration was used in this place. The analysis of the vibration acceleration in this position may disclose how perfectly the movable point is held in a correct position during the passage of the set of carriages.

The reason why the measuring points were chosen on the bearer under the crossing nose was the analysis of the transmission of the dynamic impact from the rail to the bearer. On the bearer one indicator was placed in the vertical direction with respect to the rail axis. The indicator was placed in the centre of the sleeper in the rail axis in the straight branch of the turnout. Let us observe that in the turnout provided with the crossing with movable point, the so-called pot sleeper is directly under the crossing nose. Therefore it was necessary to install the indicator inside the pot sleeper in its centre.

The other measuring point offered the possibility of evaluating the influence of the crossing structure on the ballast bed. Probably, the best solution would be to put the indicator of acceleration to the ballast bed directly under the bearer below the crossing frog. This was not possible because of the intensity of traffic on this corridor line. Therefore to investigate the shock waves and the propagation of vibrations from the track skeleton to the ballast layer, the so-called measuring hemisphere was created. The hemisphere is fitted with pyramids of the base length of 1cm and of the same height. 21 pyramids are placed on the hemisphere. The diameter of the hemisphere was 12cm. The advantage of the hemisphere is that it is surrounded by the grains of the ballast chips from all sides, and thanks to the pyramids it is also well wedged in these. In the middle of the upper flat surface of the hemisphere a three-axial indicator of acceleration was placed. The hemisphere embedded in the ballast layer close to the crossing frog.

The used indicators of acceleration were inserted in plastic packing pieces which afterwards were glued on the observed places with instant glue. Altogether 5 accelerometers by the firm Bruel&Kjaer were used. So, 9 measuring channels were used in all.

4 Methodological and Conceptual Approaches

After an executed analysis of the problem, implemented check measurement both in the laboratory and in the field as well as calculation, the analysis of measurement data used the methods and parameters as follows:

1. Time display of the course of instantaneous value of the acceleration, further values Min, Max and RMS of the measurement signals
2. Frequency analysis utilising the course of amplitude spectrum (for transition from time domain to frequency domain the Fast Fourier transform was used)
3. Time frequency spectral analysis methods (transition from time domain to time frequency domain was used Born-Jordan transformation algorithm)

Overall information on the vibration level can be obtained by calculation of effective value or root-mean-square (RMS) according to equation

$$\mathbf{RMS} = \sqrt{\frac{\mathbf{1}}{\mathbf{T}} \int_0^T a^2 dt} \tag{1}$$

where *a* is instantaneous value of the acceleration and *T* is total action time of vibration.

Fourier transformation is a method, which is most frequently used to transform the time domain into a frequency one. For a continuous function, it is defined by the following integral equations. For the forward Fourier transform, we have

$$\mathbf{X}(\mathbf{f}) = \int_{-\infty}^{\infty} x(t) \cdot e^{-j2\pi ft} \cdot dt \tag{2}$$

where *f* is a frequency, *t* time, *x*(*t*) a signal in time domain and *X*(*f*) its representation in the frequency domain. If a discrete sequence is processed, the above integral equations have to be replaced by the following formulas. For the forward Fourier transform, we have

$$\mathbf{X_k} = \frac{1}{T} \cdot \sum_{n=0}^{N-1} x_n \cdot e^{-j\frac{2\pi k}{T} \cdot (n\Delta t)} \cdot \Delta t = \frac{1}{N} \cdot \sum_{n=0}^{N-1} x_n \cdot e^{-j\frac{2\pi kn}{N}} \tag{3}$$

where x_n is the value of the n-th term of a discrete sequence (time $t = n \cdot \Delta t$), X_k is the k-th frequency component of the signal, $\Delta t = \frac{T}{N}$, T is the realisation duration, N is the number of samples a j stands for the imaginary unit.

Given a time series, x(t), it can readily be seen how the “energy” of the signal is distributed in time. By performing a Fourier transform to obtain the spectrum, X(ω), it can also be seen how the “energy” of the signal is distributed in frequency. For a stationary signal, there is usually no need to go beyond the time or frequency domains. However, most real world signals have characteristics that change over time, and the individual domains of time and frequency do not provide a means for extracting this information. For determination of time localization of frequency components within non-stationary signals there is not possible to use classical proceedings of frequency analyses but it is necessary to apply some other transformation procedures and other calculation methods. One of the possible procedures is the application of so called chronological-frequency transformations. They can be divided according to calculating methods into two basic classes:

- Linear (including especially short-tome Fourier’s transformation, transformation Wavelet etc.)
- non-linear (including especially quadratic Cohen’s, affinity and hyperbolical transformations, eventually other special proceedings)

Non-linear methods are based upon estimating an instantaneous power spectrum using a bilinear operation on the signal *x*(*t*) itself. The class of all non-linear time-frequency distributions to time shifts and frequency-shift is called Cohen’s class. One of them Born-Jordan transformation is defined by [1, 2]

$$\mathbf{C_x}(t,f) = \iiint e^{-j \cdot 2\pi \cdot \theta \cdot t' - j \cdot 2\pi \cdot f \cdot \tau + j \cdot 2\pi \cdot \theta \cdot t} \cdot \psi(\theta,\tau) \cdot x\left(t' + \frac{\tau}{2}\right) \cdot x^*\left(t' - \frac{\tau}{2}\right) \cdot d\theta \cdot dt' \cdot d\tau \tag{4}$$

where x is the signal, t (t’) is the time, τ is the time location parameter, ω is angular frequency, θ is shift frequency parameter, ψ(θ, τ) is called the kernel of the time frequency distribution. Kernel function ψ(θ, τ) of the Born-Jordan transformation is defined by next equation

$$\psi(\theta,\tau) = \frac{\sin \frac{\theta \cdot t}{2}}{\frac{\theta \cdot t}{2}} \tag{5}$$

5 Evaluation

For purposes of presentation, the part of measured signal (section) relevant to influence of locomotive 350 type was chosen. The reason for this solution was that this type caused the highest dynamic impacts and passes given locality in speed of 160km·h^{-1}, which is the highest permitted speed in the Czech Republic. Figures 1 and 2 show amplitude spectrums calculated by Fourier transformation. For illustration, two signals were chosen which are vertical direction on wing rail and longitudinal direction on crossing nose. Each of turnouts has its particular colour. Amplitude spectrum is evaluated in the range of frequency 1 – 500 Hz. The frequencies that are smaller than 500 Hz are important for the stress of the structural components of the track system and for the subgrade. The region of high frequencies over 500 Hz is essential for the dynamic stress of rails and noise emission.

Figure shows comparison of measured turnouts by Fourier transformation in section of locomotive type 350. Figure 1 shows vertical direction on wing rail. It is obvious that the biggest dynamic impacts are on turnout no. 21 in station Moravany (turquoise colour). Especially within the area up to 200 Hz where dynamic impact is the most prominent. On this turnout was provided measurement of vertical displacement and displacements of bearer below the crossing nose up to 1cm were proved, which is rather high value and indicates non-efficient support of bearers. In the area of about 325 Hz the most prominent value was proved on turnout no. 23 in station Vranovice (dark violet colour), which might be caused by imperfections on rail head.

Figure 2 shows break up of the geometry transition from the wing rail to the nose of the crossing on turnout no. 21 in Moravany station (turquoise colour). It concerns longitudinal direction on crossing nose. Distribution of the dynamic impact after break up of the geometry transition from the wing rail to the nose of the crossing, when major part of energy is absorbed in longitudinal direction, is very prominent on this signal. Here, other turnouts achieve severalfold lower values. In a frequency area above 200 Hz, turnout no. 5 with movable point, is also prominent which might be caused by imperfections on running surface of the movable point.

Performed analysis was complemented by jointed time frequency Born-Jordan transformation (Figures 3 and 4). The signals measured on wing rail – in vertical direction were plotted on graphs. Figure 3 and 4 represent the analysis during the passage of the Pendolino set of wagons by Born-Jordan transformation. There are three graphs in Figure 3 and Figure 4. The upper graphs show time history of acceleration and left ones show frequency spectrum. Last graph included time frequency distribution of spectrum computed by using Born-Jordan transformation. Note horizontal axis is time, vertical is frequency and color (or shade gray) mean spectra values.

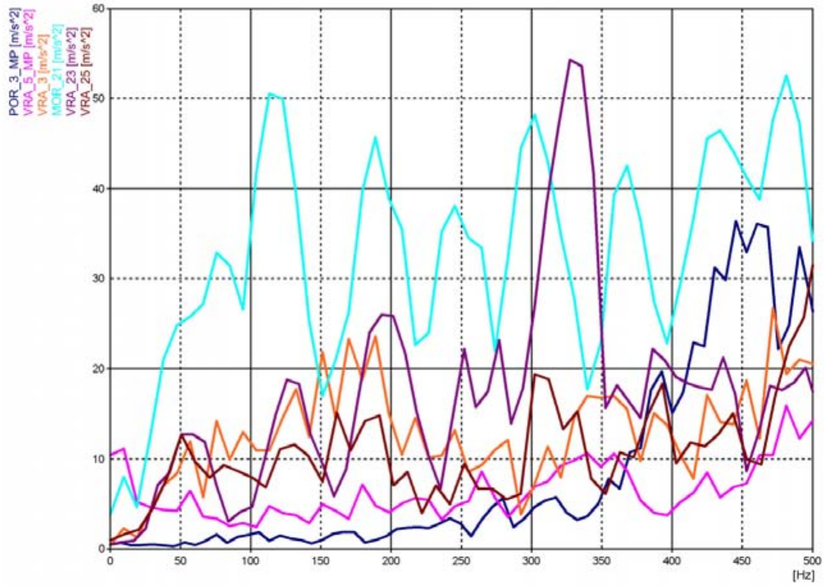

Figure 1 Comparison of turnouts by Fourier transformation - vertical direction on wing rail

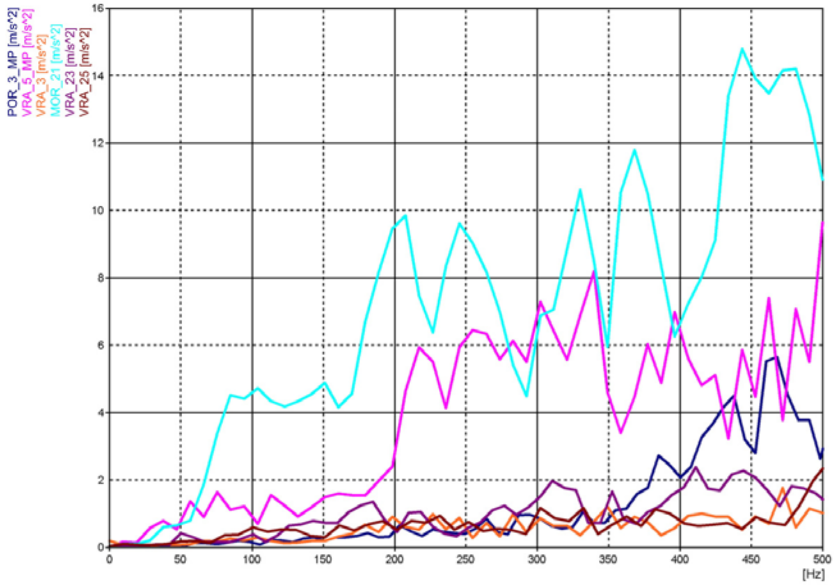

Figure 2 Comparison of turnouts by Fourier transformation - longitudinal direction on crossing nose

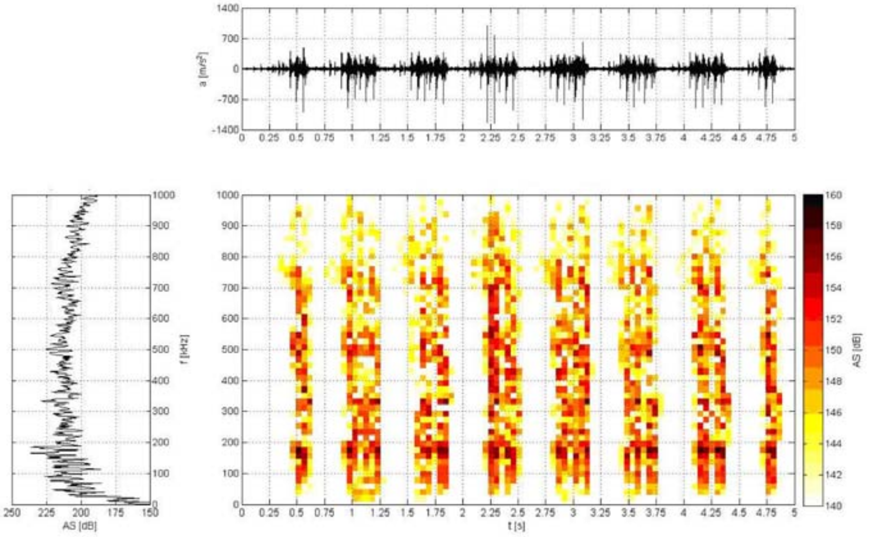

Figure 3 Born-Jordan transformation – common crossing – vertical direction on wing rail.

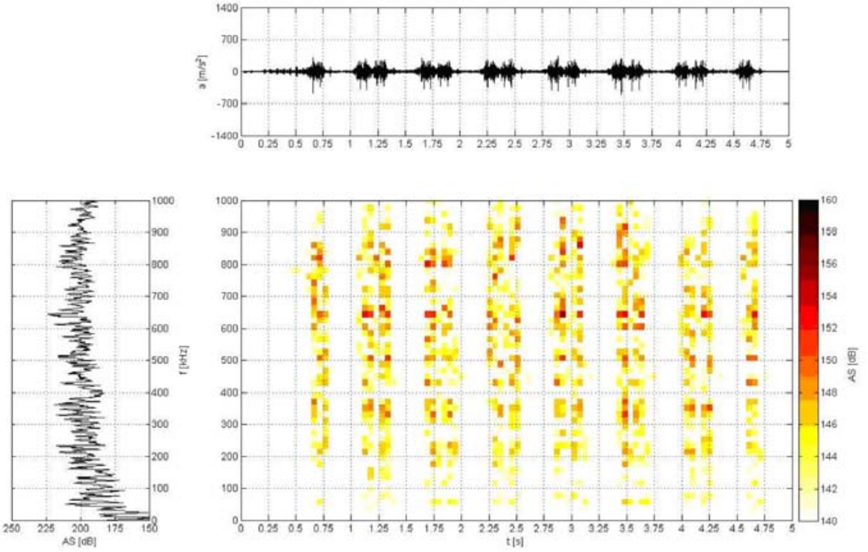

Figure 4 Born-Jordan transformation – crossing with movable point – vertical direction on wing rail.

6 Conclusion

Failures appearing in the crossing region of the turnout belong to the most frequent problems which occur in the turnout structures. These failures develop by a higher dynamic stress on the transition from the wing rail to the crossing nose and vice versa. This dynamic stress markedly rises together with speed. This may result in a gradual collapse of the transition geometry in some turnout structures and in some localities. Consequently, this effect retrospectively increases dynamic effects and accelerates the whole negative process. Therefore it is necessary to take measures leading to the longest possible maintaining of the transition geometry. The importance of the transition geometry is given by the mechanism of running of the wheel over the crossing frog.

The results of the comparison of turnout structures and the long-term research of the problems offer the following conclusions. The service life of turnout structure depends not only on the quality of the turnout itself but also on the quality of the rolling stock and the quality of the construction work preceding the installation of the turnout structure. The choice of the turnout structure is important as well.

The measurements taken proved that the advantage of turnouts provided with the crossing with movable point will be fully revealed at the speed higher than 160 km·h^{-1}. Up to this speed both structures (movable point and fixed crossing) are almost comparable. The turnouts with the crossing with movable point are more expensive than the turnouts with the fixed crossing. So, their application for the speed to 160km.h^{-1} is not indispensable if there is not any other reason.

In conclusion it is necessary to say that methodology of measurement and the selected analysis gives a good results and it is applicable for all types of turnout structures.

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