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ANALYSIS OF DYNAMIC EFFECTS ACTING ON RAILWAY CROSSINGS

Daniela Vukušičová

Institute of Railway Structures and Constructions, Faculty of Civil Engineering, Brno University of Technology, Brno, Czech Republic

correspondence: vukusicova.d@fce.vutbr.cz

Abstract. The paper is focused on measurement and analysis of dynamic effects on railway turnouts. Two same-type turnouts with different fastening elasticity were chosen. Attention was focused mainly on the crossing part of the turnout, where the highest dynamic impacts occur. The point of the paper is the assessment of influence of soft rail pads on spread of dynamic energy through the construction.

Keywords: turnout, crossing part, dynamic effects, vibrations.

1. Introduction

Switches and crossings are the key part of a railway track. In terms of dynamic effects they belong to the most loaded constructions on the railway infrastructure especially crossing part with common crossing. They are not only the places where wheel moves from wing rail to frog (or vice versa), but also places where the stiffness changes. However the length of track with switches and crossings constitutes just a small part of the railway network, maintenance of the crossings generates relatively high cost. [1] It is primarily caused by complex forces action which is induced by passage of the train through the crossing and also by the need of maintenance of many turnout components. The study of dynamic effects will help us to clarify some regularities which may be used for future optimisation of the construction and it should lead to its service life extension.

2. AIMS

The main aim is a comparison of dynamic behaviour of two constructions which different fastening system elasticity. The comparison is based on evaluation of transmission of vibration through these constructions. It is required to repeat measurements several times in reasonable time periods to compare the constructions in terms of increasing dynamic effects in time, as well. One of important things to do is also a choice of suitable mathematic apparatus for evaluation of dynamic effects in time, frequency and time-frequency domain.

3. Stress of a crossing part

The most important place of a crossing part in terms of dynamic effects is the area of transition from a wing rail to crossing nose, where the dynamic impact occurs. This impact is transmitted through the bearers to ballast which is then extremely stressed and it leads to abrasion of gravel particles on contact with a bearer. Due to this stress, degradation of ballast shape under the bearer happens and it causes inadequate support of the turnout. If a turnout is not supported appropriately, the geometry of transmission forms a wing rail to crossing nose collapses and the whole degradation process accelerates. The crossing part is stressed more and more which can cause damage of a frog.

4. Mechanism of wheel transition from the wing rail to the crossing nose

Mechanism of wheel transition from the wing rail to the crossing nose is a very complex spatial problem. The wheel passes three phases during the transition of the frog. At first, it goes on the wing rail, then it goes through a transition zone on both wing rail and crossing nose and at last it goes on crossing nose and related rail. This mechanism is shown in Fig. 1 In ideal case of geometry of transition a wheel passes from the wing rail to a crossing nose continuously without dynamic impacts.

This complex problem is often simplified. The simplification consists in the fact that a wheel runs on the wing rail, which deviates from the axis of the track to create a space for a crossing nose. Due to the geometry of the wheel and the wing rail the wheel often descends slightly at an angle α_1. After impact on the crossing nose a wheel rises again at an angle of a crossing nose α_2, as long as it does not reach the starting position at the end of the transition zone. This could be seen on the simplified model of the wheel movement through the crossing part shown in Fig. 2.

From Fig. 2 it is evident, that the total angle, at which wheels impact the crossing nose is $\alpha = \alpha_1 + \alpha_2$, in this angle the influence of transition geometry on dynamic effects is simplified described.

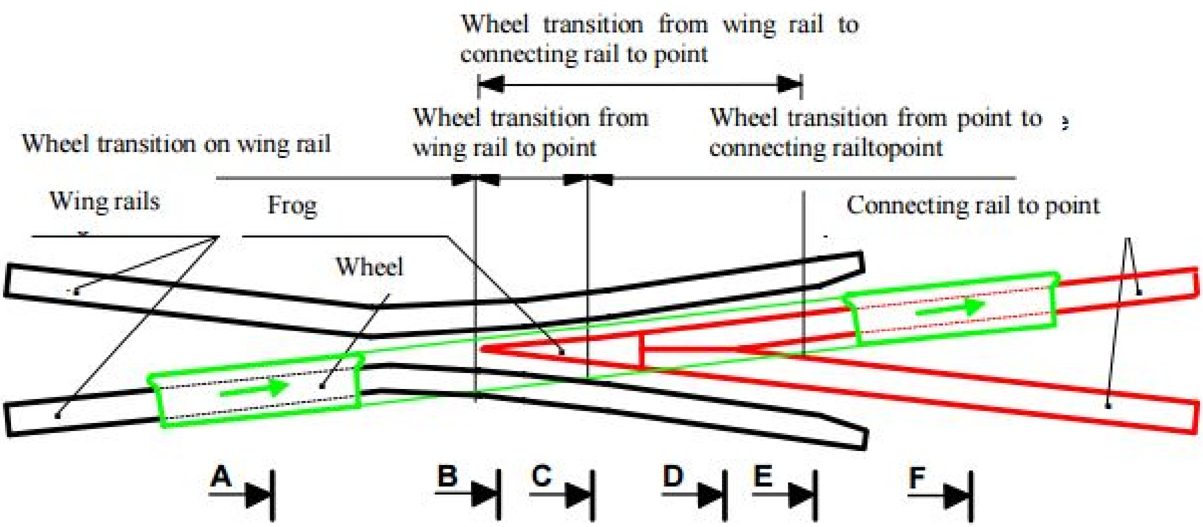

Figure 1. Schematic representation of the wheel set crossing over the frog – view from above [2].

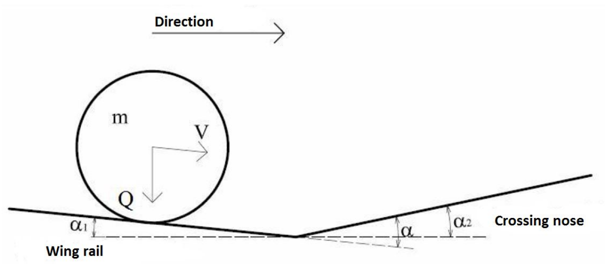

Figure 2. Simplified model of wheel movement through the crossing part [3].

Figure 3. Turnout no. 4 and single crossover with turnout no. 3.

5. Measuring location and description of measured turnouts

The measurements were carried out at the railway station Usti nad Orlici on main lines turnouts no. 3 and 4 (Fig. 3). Maximum speed on main line is 130 km.h^{-1} (160 km.h^{-1}) for tilting vehicles, such as Pendolino). Both chosen constructions are the same except elasticity of the fastening system. Description of the turnouts:

- Part of single crossover
- Rails profile UIC 60
- Fastening system (ribbed baseplate with Vossloh tension clamp Skl 24), turnout no. 3 has new ribbed baseplates with different rail pads – reduce overall stiffness of the track.
- Monoblock crossing from manganese steel
- Concrete sleepers
- Ballasted track
- Crossing angle 1:12 and radius 500 m
- Used almost exclusively in trailing direction

Three measuring campaigns were made on both above mentioned turnouts.

6. Methodology of the measurement

The certified methodology of the measurement was used [4]. Measurement methodology is designed for in-situ measurement in condition of full operation and was certified by the Ministry of Transport of the Czech Republic. The certified methodology consists of bearers displacements measurements, vibration acceleration measurements (on crossing, bearers and into the ballast), and pressure measurements (in two levels into railway substructure). For the purposes of this paper only small part of vibration acceleration measurement is described, only the part which is used below in evaluation part of the paper. The focus is on vibration transition from the crossing trough bearer to the ballast. The three-axis accelerometer was placed on flange of the wing rail (Fig. 4) and one-axis sensor was placed on bearer nearest to the crossing nose. Piezoelectric vibration acceleration sensors on wing rail and on bearer were attached to plastic handles and glued to the cleaned surface of the measured structure.

FIGURE 4. The three-axis accelerometer placed on flange of the wing rail.

For measurement into the ballast the measuring stone was developed. The three-axis accelerometer was inserted into the measuring stone which was placed into the ballast directly under the crossing nose.

7. Mathematical apparatus

When dynamic action from railway traffic is measured in-situ it is 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 it is possible to evaluate stochastic signal from three different perspectives. First perspective is time domain. The calculated value is area 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.

For detailed analysis of the dynamic actions above described method is not sufficient because frequency composition is unknown. For this reason it is useful to transform signal from time domain to frequency domain. For this transformation we use Fourier transformation method. In frequency domain it is possible to determine which parts of signal are the strongest ones. For detailed analysis it is useful to use third perspective, which evaluate signal from time-frequency domain [5]. With this perspective we can see not only frequency composition but also its occurrence in time.

8. 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 [6].

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

where

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

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

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

9. Short time fourier transform (STFT)

STFT provides compromise between time and frequency signal representation [7]. Its integral definition is

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

where g is window function, '*' complex conjunction, t' is time displacement of window, $x(t)$ its time representation of signal and $STFT_x^{(\omega)}(t', f)$ is its time-frequency representation [7].

10. Evaluation of vibration acceleration

Evaluation of vibration acceleration is divided to three sections: time domain, frequency domain and time-frequency domain. For time analysis comparable trains that passed over both turnouts were chosen. For detailed frequency analysis were chosen locomotive type 380 and two multiple units (LEO Express and Pendolino) because they passed over both turnouts the maximum line speed. The most interesting is transmission of vibration from wing rail (A4Z) through bearer (A3Z) to the ballast (A33Z). The evaluated signals are identified as follows: First letter A indicates vibration acceleration, number in the middle is a measuring channel number and the last letter indicates direction (Z is vertical direction).

11. Evaluation in time domain

From many graphs and tables I chose the one which best represents results of my analysis. Table 1 represents areas under the curve of moving RMS on both turnouts calculated from vibration signals measured from selected trains and their comparison in all measurements campaigns. Red colour typifies percentage loss of dynamic energy by transmission from rail to bearer and to ballast. Value of the area under the curve of moving RMS on rail (A4Z) is thought as 100% and it is calculated how many percent of this value is transmitted to bearer (A3Z) and to ballast (A33Z).

It is obvious that values on wing rail (A4Z) are increasing especially from third campaign on turnout no. 4. This fact is apparently caused by degradation of transition geometry, as the turnout no. 4 has bigger bearer displacement. On the bearer (A3Z) there are also increasing values from third measuring campaign, but the increase is not significant in either of turnouts. On the turnout no. 4 there is slight increase of the percentage of dynamic energy transfer to the bearer, while on turnout no. 3 not, which is interesting. Into the ballast both turnouts are comparable, but from overall point of view more dynamic energy is transferred from turnout no. 4. If we put into account all measurement campaigns on turnout no. 3, approximately 24% of dynamic energy is transmitted to the bearer, while on turnout no. 4 it is about 35%. Into the ballast almost 5% of dynamic energy is transmitted from turnout no. 3 and 6,6% from turnout no. 4. The positive contribution of new fastening system on turnout no. 3 is shown in these results.

12. Evaluation in frequency domain

Very important information can be obtained from frequency spectrum of the evaluated signal. For better comparison frequency curves were converted to numbers by calculating the areas under the curve. The area under frequency curve was divided into two frequency bands. First frequency band (150 – 600 Hz) is the band where high frequency contact impact force occurs. This high frequency impact cases especially plastic deformation on the crossing nose and that is the reason why these high frequencies are not transferred into the bearer. Second frequency band (0 – 150 Hz) is the band where low frequency bending process occurs. These low frequencies are responsible for bearer displacements and ballast bed bending. Based on the above mentioned on the wing rail both frequency bands were evaluated while on the bearer and in into the ballast only second frequency band (0 – 150 Hz) was evaluated [8]. Two multiple units (Pendolino and LEO Express) and locomotive type 380 were selected for comparison of the turnouts (Table 22).

It is obvious that between second and third measurement campaign all values except that into the ballast are increased. Lower values into the ballast can be explained by the fact that space between the bearer and ballast occurred. The bearer has worse support which resulted in bigger displacements. Bigger bearer displacements are on the turnout no. 4, this is reflected in the values from the bearer (A3Z). On the wing rail (A4Z) especially on the frequency band 150 – 600 Hz bigger values are on turnout no. 3, bud the difference between turnouts decreases. This fact can be caused by bigger wear of the turnout no. 3. Difference decreases because of displacement on turnout no. 4 bearers are more significant than on turnout no. 3. Based on above mentioned evaluation it is obvious that it is possible to valorise the wear of the crossing or bearer displacement only on the basis of vibration acceleration measurements. This is an important fact.

13. Evaluation in time-frequency domain

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 I present time-frequency graph calculated for signal detected on bearer when Pendolino train passed the crossing. As we can see on Figure 5 there is time on horizontal axis and frequency on vertical axis. Figure 5 shows the fact that the densest frequencies were detected in time when train wheel sets were passing the measuring point. Maximum frequency range is from 70 to 80 Hz and about 50 Hz.

14. Conclusion and recommendation

Within three measurement campaigns two turnouts with different fastening elasticity were compared. The comparison was based on measurement of dynamic effects in-situ. According to evaluation it is possible to declare that the new fastening system on turnout no. 3 appears to be perspective. It has a positive influence in reduction of dynamic effects on bearer and ballast.

I would like to recommend observation of both measured turnouts and realize more measurements on them with use of the certified methodology at least once a year. If the positive influence of new fastening system confirmed, I would recommend its installation on more turnouts.

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Area under curve of moving [m/s]								
Measurement	Train	A4Z on crossing no.		A3Z on crossing no.		A33Z on crossing no.	
		3	4	3	4	3	4
1	loko 380	49	43	12 24	13 31	3 6	3 6
2	loko 380	45	34	8 18	10 29	3 7	3 10
3	loko 380	64	40	11 17	14 35	4 6	3 8
1	LEO Express	123	93	31 26	34 36	4 3	4 5
2	LEO Express	121	89	27 22	30 33	5 4	6 6
3	LEO Express	152	105	32 21	37 35	4 3	4 4
1	Pendolino	217	308	74 34	116 38	11 5	13 4
2	Pendolino	264	229	74 28	76 33	15 6	14 6
3	Pendolino	312	239	85 27	104 44	16 5	23 10
Average		**149,7**	**131,1**	**39,4** **24,1**	**48,1** **34,8**	**7,1** **4,9**	**8,1** **6,6**

Table 1. Area under curve of moving RMS and the percentage transfer of dynamic energy from rail to sleeper and to ballast.

Area under curve of frequency spectrum Hz * m/s^2									
Measurement	Train	A4Z on crossing no.				A3Z on crossing no.		A33Z on crossing no.	
		3		4		3	4	3	4
		0-150Hz	150-600Hz	0-150Hz	150-600Hz	0-150Hz	0-150Hz	0-150Hz	0-150Hz
1	loko 380	1735	6413	1340	4555	988	986	328	344
2	loko 380	1206	5854	1438	4688	621	855	314	391
3	loko 380	1620	6428	1747	4635	864	1311	199	153
1	LEO Express	675	3461	500	2463	502	448	72	75
2	LEO Express	449	2402	489	1932	293	379	66	90
3	LEO Express	604	3463	616	2750	421	604	47	32
1	Pendolino	1018	3731	737	2718	634	816	96	135
2	Pendolino	1000	3615	853	3074	642	626	132	126
3	Pendolino	1085	3985	991	4008	794	1175	83	72
Average		**1044**	**4372**	**968**	**3425**	**640**	**800**	**149**	**158**

Table 2. Area under frequency curve divided in to two frequency bands.

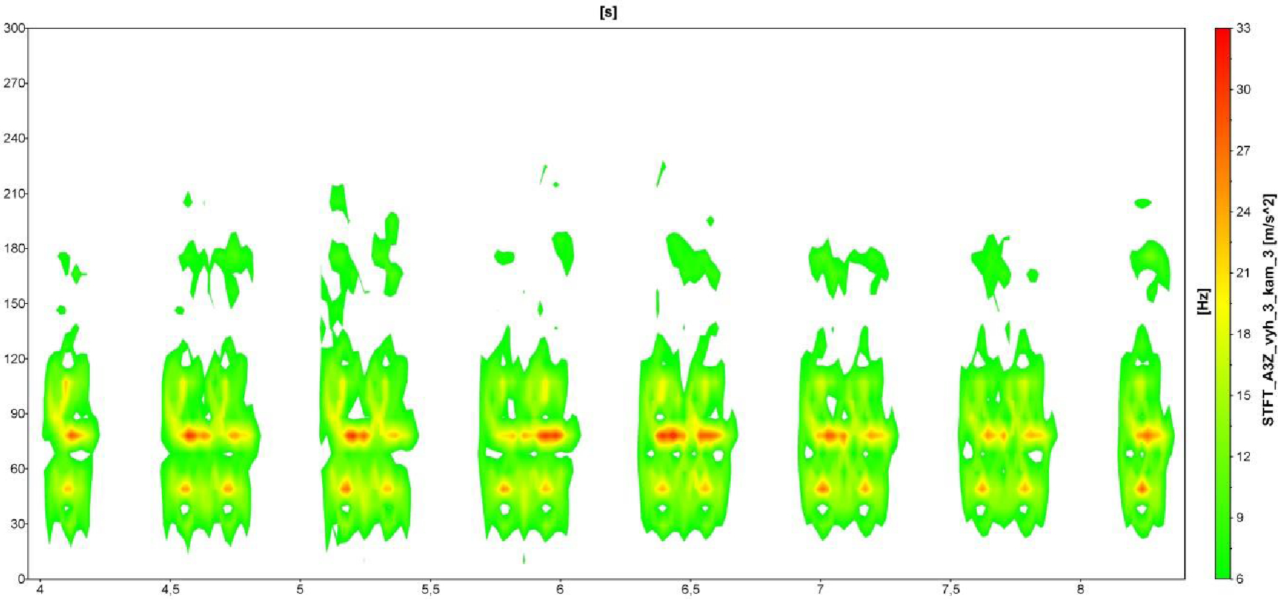

FIGURE 5. Time-frequency spectrogram calculated by STFT method, turnout no. 3, Pendolino train, third measurement campaign.

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