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Experimental Stress Analysis

EXPERIMENTAL EVALUATION OF STRUCTURAL COMPONENTS VIBRATION IN RAILWAY TRACK

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Abstract: The concentrates on some results of in situ vibration measurements of the track components – the rails, the sleepers and the subgrade during operation conditions for track loading by passenger and fright trains at the straight line on the new built up railway corridor Bratislava – Žilina. Dynamic tests were carried out to evaluate the dynamic track behavior and the force effects between the track components during the passage the trains at variable speeds. Experimental approaches and analysis focused on the vertical vibration rails, sleepers and the ballast field in time and frequency domains are described.

1. Introduction

The dynamic interaction between moving vehicle and the rail can be investigated and described reasonably well in the vertical direction using suitable mathematical models, see Fig 1, or an suitable experimental analysis based on an experimental measurement in the vehicle and in the track, see Fig. 2. Problems arising from the vehicle track interaction may be simply expressed in frequency domain, see Tab.1. In [1] several mathematical models of varying complexity for calculation the vertical dynamic response of the track is examined.

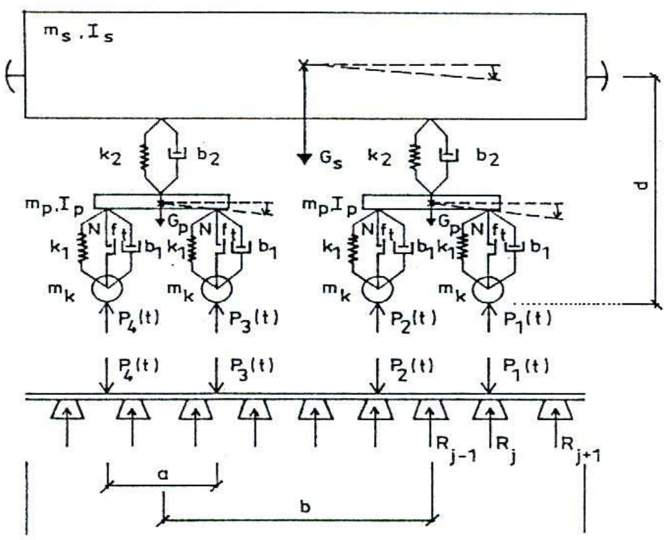

Figure 1: *Mathematical model for dynamic interaction between moving vehicle and the track*

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In order to verify these theoretical models and evaluated the dynamic interaction vehicle – track, full-scale experiments on the rail-vehicle and on the track structure were performed. Techniques employed to measure the wheel – rail dynamic response fall into two categories:

- The response measured at a specific location of the track, see Fig.2..
- The response measured at un-sprung wheelset of a rail-vehicle, see Fig. 3.

The second category of measurements may be used as a prediction tool or monitoring tool for the track deterioration. Deterioration in the track is manifested by increasing in vibration levels on the axle-boxes of train. This paper is focussed on in situ dynamic measurements on the track structure in the new Slovak railway corridor Bratislava – Košice, under traffic and briefly presents some experimental approaches in order to appreciate the dynamic behaviour of the track structure.

Table 1: *Problems of vehicle-track interaction*

Problems of vehicle – track interaction		
	Area of concern	Frequency range [Hz]
1	Vehicles	0 – 20
2	Bogie and un-sprung mass	0 – 500
3	Irregular running surfaces of Wheel and rail	0 – 1500
4	Track components	0 – 1500
5	Wheel – rail noise	0 – 5000
6	Structure – borne noise and vibration	0 – 500

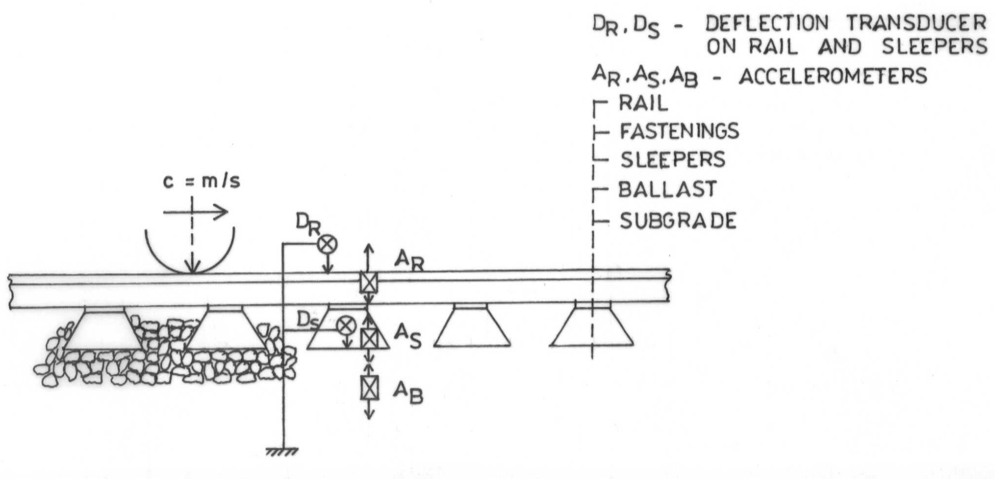

Figure 2: *The scheme for the vehicle-track interaction measurement in the track*

Experimental measurements presented in this paper correspond in situ measurements at the straight section of the main railway line Bratislava – Košice in the section Trnava – Cifer for the train speed 160 km/h and axle forces 225 kN.

2. Measurement in the track

The dynamic response of the track is experimentally measured for a typical arrangement of track structures, for some typical configuration of passage trains and for characteristic track sections:

- straight sections out of rail welds and near welds,
- in curve sections,
- in turnouts.

2.1 The track

Measurements have been performed on the conventional ballast track in the section of straight track. Continuously welded UIC 60 rails with a mass per unit length of m_r=60 kg/m and a moment of inertia I_r = 0,3038.10^{-4} m^4 are fixed on the concrete monoblock sleepers of the type BP 3 with a length l=2,42m, the width under the rail b=0,28 m, the high h=0,22 m, and a mass m_s=260 kg. The rails are fastened to the sleepers with using of the steel baseplates and clip bolts Vossloh. Flexible rail pads with thickness t=0,01m are placed under the rail.

2.2 The trains

The measured line was loaded in operational conditions by passenger trains and freight trains. The speed of passenger trains in the measured section has been varying between 90 km/h ÷ 120 km/h. The speed of the freight trains has been varying between 40 km/h ÷˙70 km/h. The locomotives of passenger trains (types L350, L162, L163, L150, L363) are supported by 2 bogies. The locomotives of freight trains are of the type 2x L131 (2x85 t), L182 (85 t) and L183 (85 t) and L121 (88 t), L363 (87 t).

The basic characteristic of locomotives and carriages for the coaching traffic – the carriage total length L_t, the distance between bogies L_b, the axle distance L_a, the total masse M_t, and axle masses M_{1a} are summarised in Table 2.

***Table 2**: The geometrical and the mass characteristics of vehicles (characteristic locomotives and of the coaching traffic) in ŽSR*

Locomotives	*Axles*	*Length [m]*			*Mass [t]*	
		L_t	L_b	L_a	M_t	M_{1a}
EL 162,163	4	16,80	5,10	3,20	85,0	10,625
EL 350	4	17,24	5,10	3,20	87,6	10,950
EL 362,363	4	16,80	5,10	3,20	87,0	10,875
EL 150	4	16,74	5,10	3,20	87,0	10,875
Carriages	Axles	L_t	L_b	L_a	M_t	M_{1a}
Bte	4	24,5	14,6	2,6	34,0÷44,0	4,25÷5,50
Bai	4	24,5	14,8	2,4	38,0÷46,0	4,75÷5,75
Ba	4	24,5	14,7	2,5	39,0÷47,0	4,80÷5,80

3. Measurement set up.

The measurement has been focussed to the identification of dynamic response of the track components under traffic:

1/ The vertical vibration of rails, sleepers and free ballast field between the sleepers. They were measured as the vertical displacement *w(t)*, the acceleration $\ddot{w}$(t) of these components. The B&K piezoelectric accelerometers of the type BK 4500 were glued to the rail and the sleeper. For the ballast response the BK 8306 seismic accelerometer were used. The vertical displacements *w(t)* of rails and sleepers were measured by the relative displacement transducers of the type Bosh mounted on the fixed reference datum, see Fig.1.

2/ The direct dynamic interaction force the rail - the sleeper F_{R-S} (t) were measured by the Kistler piezoelectric load cell inserted between the rail and sleeper placed instead the removed baseplate, see Fig.2. The inserted load cell is prestressed to the selected value.

3/ The direct dynamic strain ε(t) of the rail was measured by the Kistler attached piezoelectric tensiometer mounted on the rail flange.

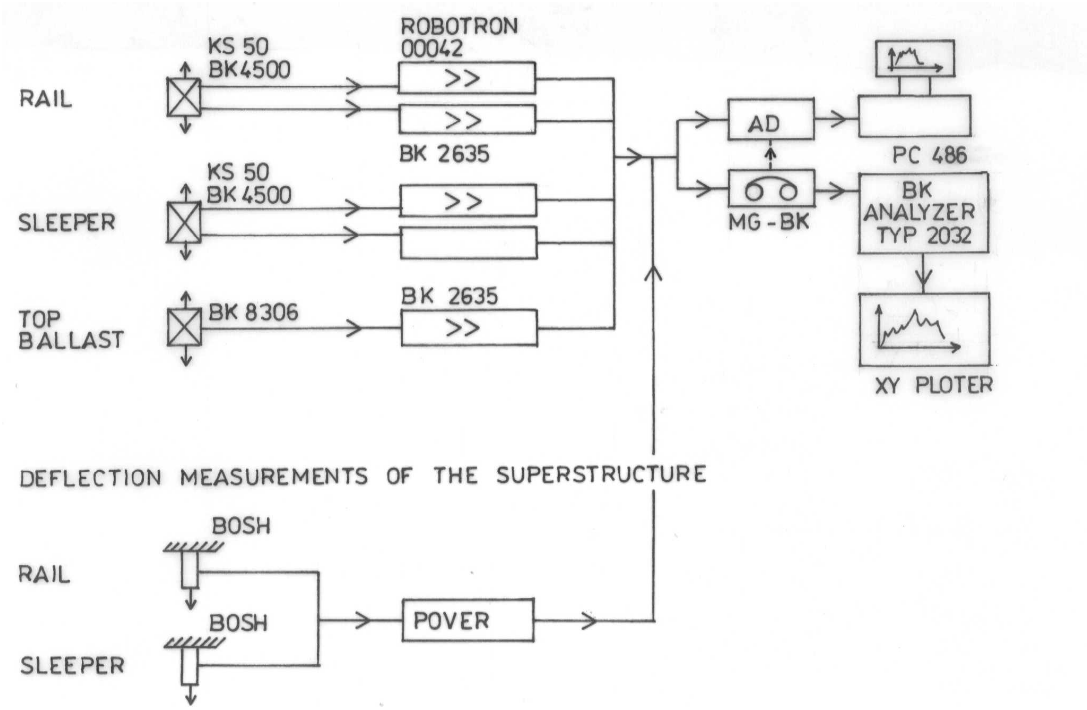

***Figure 3**: Scheme of the measurement set-up and positioning transducers in the track*

Measured quantities were recorded as electrical signals by means the analog–digital convector of the type 16-channel DAS 16, or the Disys 32 channel system for data acquisitions and they were parallel recorded with the BK 4-channel tape recorder of the type BK 7005. The actual train speed has been derived from continuous records of passage trains. The A/D device records signals with a chosen sampling frequency f_s directly into the computer memory. In track response measurements the sampling frequency plays the important role because speedy processes (impact processes). While the dominant frequency composition of wheel forces and deflection of rails and sleepers lie in the low frequency range, the frequency content of accelerations of these motions lies in the much wide frequency range. In our dynamic response measurements the sampling frequency f_s were selected for appreciation of the middle frequency response of the track: f_s=1000 Hz.

4. Measurement results

Measured signals of the track response recorded and stored on the disk in the DISYS measured and evaluated system. Signals are analysed in the time domain and next in the frequency domain. Generally, we can say that in service conditions each rail cross-section or each sleeper is loaded by a sequence of impacts or shocks from the passage wheels of the train. This dynamic load induces a dynamic displacements *w(t)*, stress $\sigma_z(t)$ and strain $\varepsilon(t)$ in rails, sleepers and subgrade and corresponding dynamic accelerations of these components having a characteristic shape in time domain, see Fig. 4 ÷ 5.

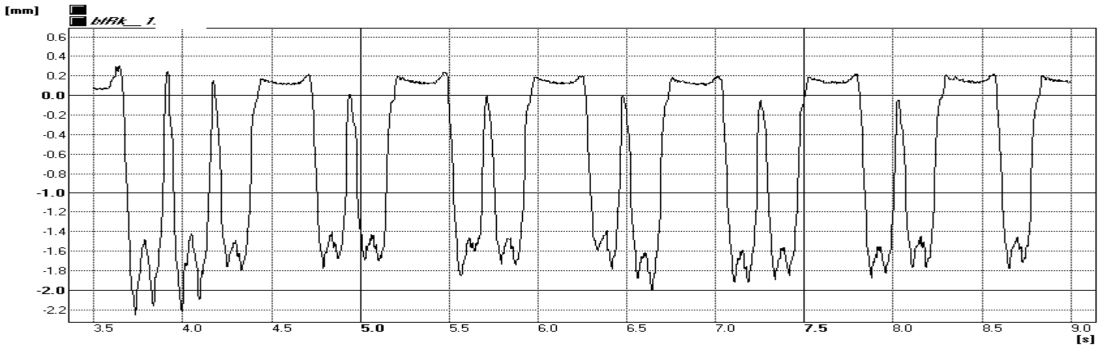

Figure 4: *The time history of the vertical displacement of the rail for the passenger train passage L 350 + 6 coaches, c=115 km/h. The sampling frequency* f_s*=1000 Hz.*

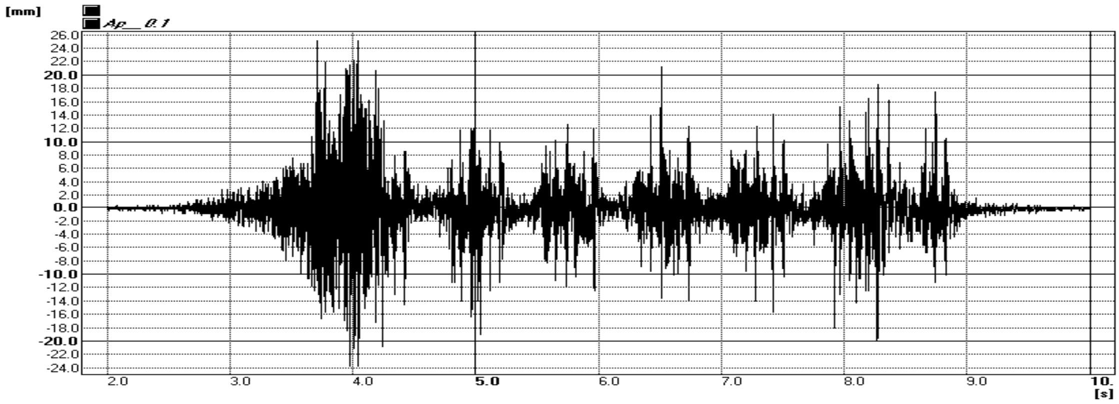

Figure 5*: The time history of the vertical acceleration of the rail* $\ddot{w}_R(t)$

As we can see from Fig.4 the time histories allow well detection passages of bogies and axles of vehicles and the corresponding detection peaks of the measured value. Amplitudes of the measured values give a good picture about dynamic effects of the wheel load on the track structure.

4.1 Frequency content of the vertical track response

Transformation of the measured signals to the frequency domain provides with comprehensive information about track vibration and gives a picture about concentration of the energy on frequency components. The analyser module of a applied system enable at the same time to process the additional information of the response, for example the frequency response function (FRF), the cross spectrum, etc. It can be expected that the low-frequency response range 1 Hz ÷100 Hz and the mid-frequency range between 100 Hz ÷ 500 Hz play an important role in the track dynamics. In these frequency ranges the track components – sleepers, pads, the ballast and subsoil have a strong influence on the track system behaviour. The frequency analysis corresponding to the rail, sleeper, and ballast acceleration for the passage the whole passenger train is shown in Fig. 6 ÷ 8.

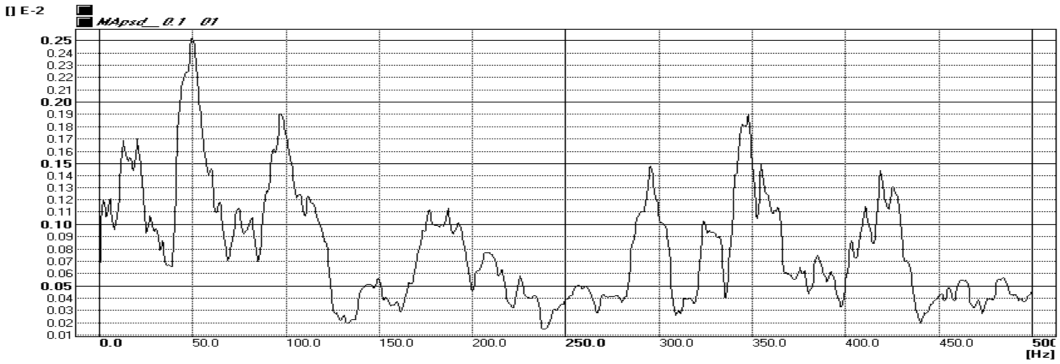

Figure 6: Averaged spectrum S_{wR}(f) of the vertical rail acceleration $\ddot{w}_R(t)$

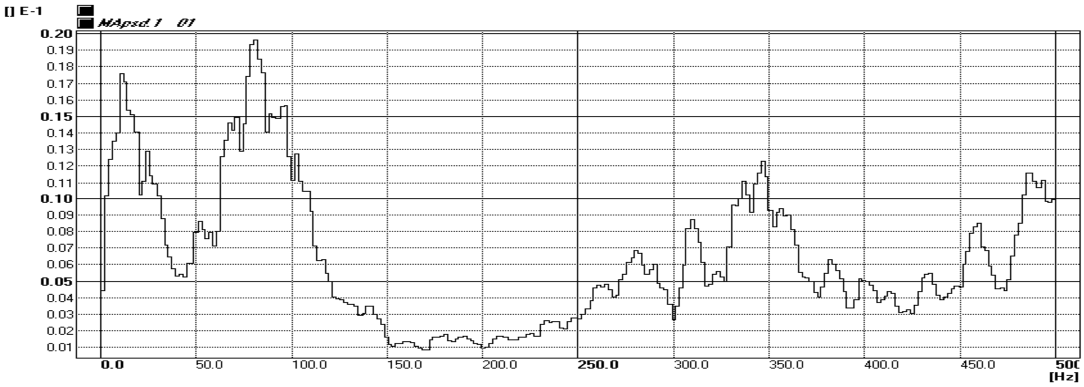

Figure 7: Averaged spectrum S_{ws}(f) of the vertical sleeper acceleration $\ddot{w}_S(t)$

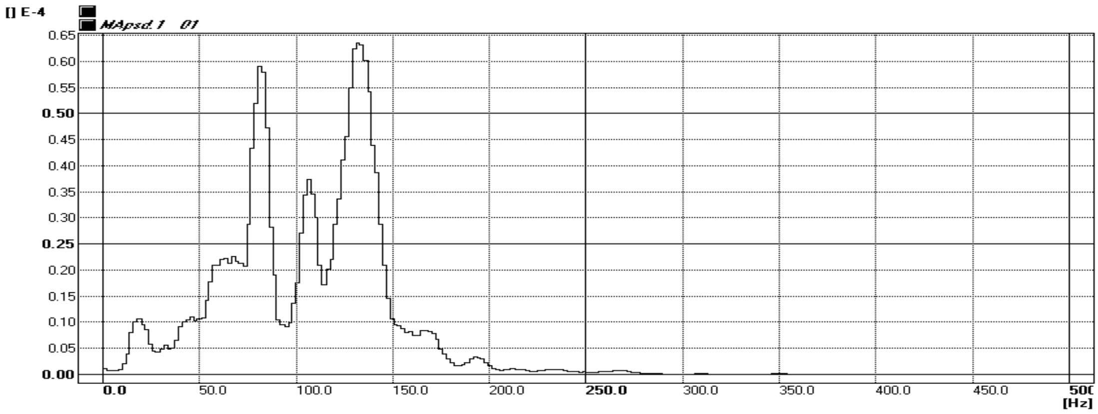

Figure 8: Average spectra S_{wB}(f) of the vertical ballast acceleration $\ddot{w}_B(t)$

While traditional spectral analysis techniques based on FFT provide a good description of stationary and pseudo-stationary signals, non-stationary signals should be analysed with consideration of a spectral information in time. One of the techniques applied here use a window function to window out short sections of the overall signal which are near stationary or which contain isolated events.

Analysis for the passage of characteristic coach bogies – the two bogies of the coaches No. 3 and 4 of the passenger train is shown in Fig. 9÷11. The time history are shown in Fig. 9 - 10 and corresponding spectral density is in Fig. 11.

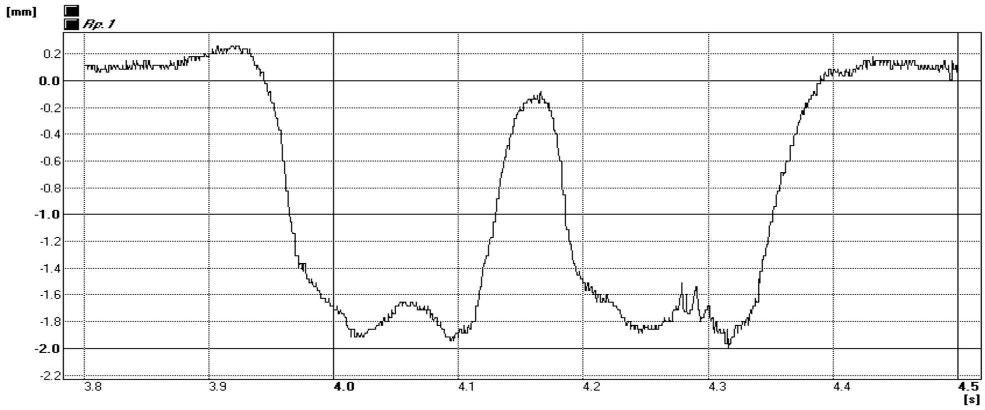

Figure 9: *The time history of the vertical displacement of the sleeper head for the two bogies of the coaches No. 3 and 4 of the passenger train, c=115 km/h,* f_s*=1000 Hz.*

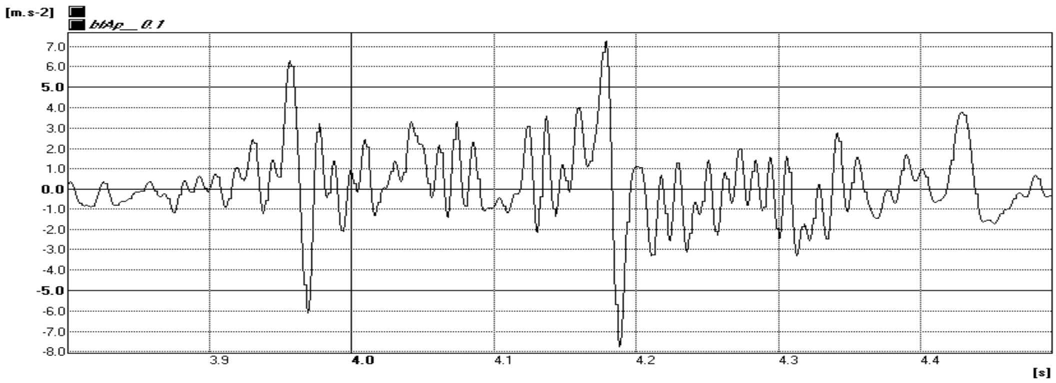

Figure 10: *The corresponding time history of the vertical acceleration of the sleeper* $\ddot{w}_S(t)$

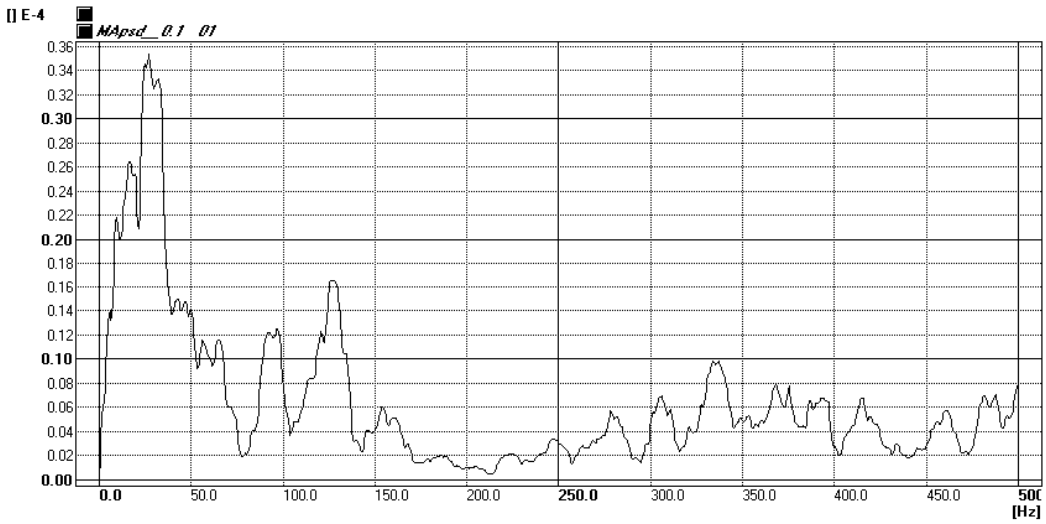

Figure 11: *Average spectra* $S_{ws}(f)$ *of the vertical sleeper acceleration* $\ddot{w}_S(t)$

5. Conclusion

The purpose of experimental measurements was to assess the dynamic behaviour of the rail, sleepers and the interaction force the rail – the sleeper under the passage of trains in operational conditions. In this paper are presented some results of the measurement and their analysis for the typical passenger train passage only.

- *Time histories of the vertical response of track components* – rails, sleepers and the interaction force the rail – the sleeper, that give the basic information about the effect dynamic load on behaviour of these components. They show a total effect of the locomotive and coaches on the dynamic response of these components. For the sampling frequency f_s*=1000Hz* and the train speed *c=100÷130 km/h* (passenger trains) peaks of the vertical response reach value:
  - Peaks of the vertical rail accelerations reach values $\ddot{w}_r \approx 150 - 350 m/s^2$,
  - Peaks of the vertical sleeper accelerations reach values $\ddot{w}_s \approx 50 - 90 m/s^2$,
  - Peaks of the vertical ballast accelerations reach values $\ddot{w}_b \approx 0{,}2 - 2 m/s^2$,

For the sampling frequency f_s*=100 Hz* and the train speed *c=100÷130 km/h* these peak values are reduced approximately 12 time.

- The displacements measured on rails and sleepers showed that individual axles and bogies of passage vehicles are clearly distinguished in displacement records and than they are proportional to the dynamic wheel load of passage vehicles.
- *The frequency analysis* of recorded signals gives comprehensive information about the track component vibration and gives a picture about concentration of the energy on frequency components. While the dominant frequency composition of interaction forces and deflection of rails and sleepers corresponds to low frequency range, say to $f \in \langle 1 - 20 Hz \rangle$, the frequency content of accelerations of these motions lies in the much wide frequency range. At the same time the mid-frequency range between 100 Hz ÷ 500 Hz play an important role in the track dynamics. In this frequency range the track components – sleepers, pads, ballast and subsoil have a strong influence on the track system behaviour.

Acknowledgement

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References

[1] Moravčík M., Moravčík M: Mechanika železničných tratí I, II. Teoretická analýza a simulácia úloh mechaniky železničných tratí. EDIS ŽU v Žiline 2002, 312 p. ISBN 80-00-984-9, (in Slovak).

[2] Moravčík M., Moravčík M: Mechanika železničných tratí III. Experimentálna analýza namáhania a pretvorenia konštrukcie trate. EDIS ŽU v Žiline 2002, 220 p. ISBN 80-00-984-9, (in Slovak).