Time and frequency analysis of bogie-railway dynamics

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Abstract – The paper discusses the application of the electronic measurement system based on MEMS inertial sensors and GPS receiver which is capable to measure and record the dynamic parameters of the interaction of the bogie-railway system. The inertial data are combined with the GPS receiver and SD card to record all data which may be processed later to find the places with highest linear and angular accelerations.

Keywords – **MEMS, inertial sensor, bogie-railway dynamic**

I. Introduction

The safety and comfort motion of the urban trams is defined by the condition of the tramway and the dynamic interaction between the rails and vehicle. The tram operations influence over the rail parameters, so the rail deviation is increased from their initial position. The rail faults which depend from the geometry may be defined as periodic, non-periodic or custom ones. The rail faults also conduct to the vibration generation jointly with the tram wheels. The measurement of the railway current condition may be accomplished with specialized motor cars [1] and the railway geometry may be analyzed according to the measurements. This procedure requires expensive motor cars and often the railway condition is evaluated according to the manual railway measurements. The correlation between the obtained valuation and the generated forces is inadequate, but the passenger comfort depends from the dynamic forces. This is the reason to develop and evaluate the measurement systems, which are capable to measure the dynamic reactions between the railway and the tram. The main parameter of the dynamic reaction is the movement noise. The measurement of the generated noise is based on the microphone dynamics and this method is often used to determinate the wave wear of the rails [2]. The European standard EN3095 [3] defines the permissible levels of the generated noise from the railway roughness.

The measurement of the dynamic forces is accomplished by the strain gauges, which are stick on the wheel [4] or translation sensors and tensometers on the rails [5]. The force amplitude calculation is described in the European standard EN14363 [6]. Their amplitude is used as a criterion for valuation of the railway safety and its loading capacity.

Another main parameter is defined as vertical and horizontal accelerations and tram angular rate. The acceleration amplitudes are used as an index to control the rail failures. The acceleration measurements are accomplished by linear or angular rate accelerometers, which are installed on the tram or on the rails [7]. This method gives the valuation of the combined roughness of the rails and the wheels. In these systems [8] the roll value is also measured to obtain the accelerations which are caused by the varied rail level.

The paper discusses the time and the frequency analysis of the linear and angular accelerations of the bogie-railway dynamics.

II. System description

The MEMS based inertial system is built to measure the linear accelerations and to calculate the dynamic characteristics especially the rotation angle of the bogie. The system is recognized as 9DoF (Degrees of Freedom) and it is based on 3D linear accelerometer, 3D digital gyroscope and 3D digital magnetometer. The localization of the vehicle is obtained by build-in GPS receiver with a refresh rate up to 10Hz. The refresh rate of the navigation data is set to 4Hz.

The data acquisition system is based on the MEMS three axes digital output linear accelerometer and magnetometer LSM303DLHC and 3D ultra-stable MEMS angular rate accelerometer L3G4200D, both produced by *ST*. These sensors include a sensingelement and an IC interface able to take the information from the sensing element and to provide the measured acceleration signals to the external world through an I^2C serial interface.

The system reads the inertial and magnetic data 40 times per second and stores the navigation and inertial data in the internal FLASH memory (SD card) with a capacity up to 4GB. The navigation data are transmitted also to the remote server via GPRS connection. The block diagram of the system and the installation place are shown at Figure 1.

The measurement system is installed on the terminal clam and is firmly fixed to ensure proper transfer function between the rails and the system. The integrated GSM module transmits the GPS data to the server to realize real-time monitoring of the tram position. The acceleration data are not transmitted via GSM network due to their high volume but they could be analyzed directly in the device to detect the critical points. The detection of the critical point may be transferred to the server to point the railway fault positions.

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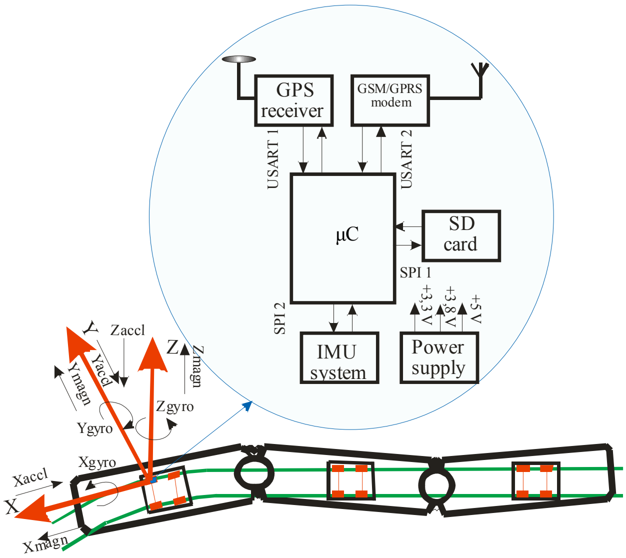

Fig. 1. The measurement system and its orientation relative to the vehicle axes

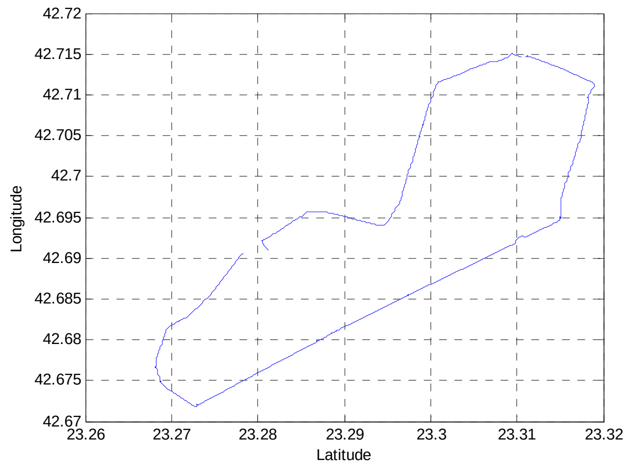

Fig.2. Geographic coordinates of the experimental track

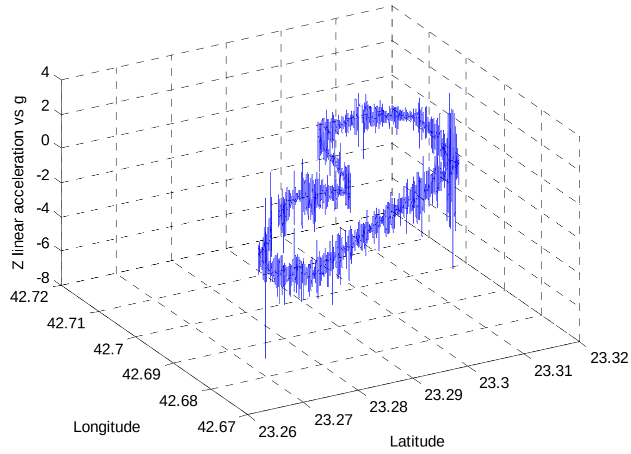

Fig.3. 3D Time analysis of Z linear acceleration

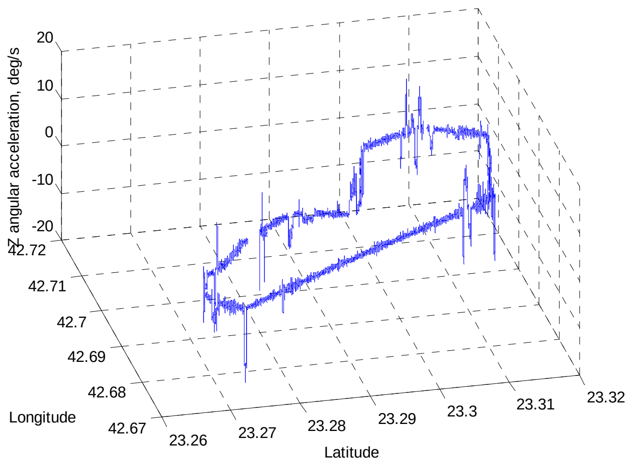

Fig.4. 3D Time analysis of Z angular acceleration

III. Data analysis basics

The navigation and the inertial data are recorded in a binary format on SD card and analyzed later by MATLAB routine. The spectrum analysis is realized on the basis of a Short Fast Fourier Transform. STFTs as well as standard Fourier transforms are frequently used to locate the frequencies of specific vibrations (especially when used with greater frequency resolution) or to find frequencies which may be more or less resonant in the space where the signal was recorded.

There are two main parameters which have to be determined to obtain an optimal resolution. The first parameter is directed to the analyzed window size *N* and the second one – the number of the overlapped samples. Because the data are noisy, we have to choose between the better noise suppression windows and the higher spectral resolution windows. So we have to analyze the different windows and find the best one for the application. The proper selection of the ST-FFT window length and overlap processing produces excellent and accurate time-frequency resolution to show the frequency at any given time of the original waveform.

IV. Experimental results

The experimental data are collected using the described measurement system, which is installed on the 6-axes tram motor car T6M 400. Its suspension consists from three carts: power ones (I and III-rd) T65 and supporting one (II-nd cart) type T_{sp}65. The carts consist of two-stage spring suspension (cylindrical springs) and the H-shaped open type cart frame.

The time analysis of the experimental data is shown at Figure 2 (Geographic coordinates of the experimental track), Figure 3 (3D Time analysis of Z linear acceleration) and Figure 4(3D Time analysis of Z angular acceleration). Their amplitude is used as a criterion for valuation of the railway safety.

The frequency analysis is realized on the basis of a Short Time Fast Fourier Transform. The window has a rectangular shape with different size (from *N*=64 to *N*=256 samples) and 25% overlapped samples. The frequency bits may be calculated according to the equation f_i=i/N*Fs, where Fs = 40Hz – sampling frequency.

The results of the frequency analysis of the Z linear acceleration using 256, 512 and 1024 point window are shown at Figure 5.

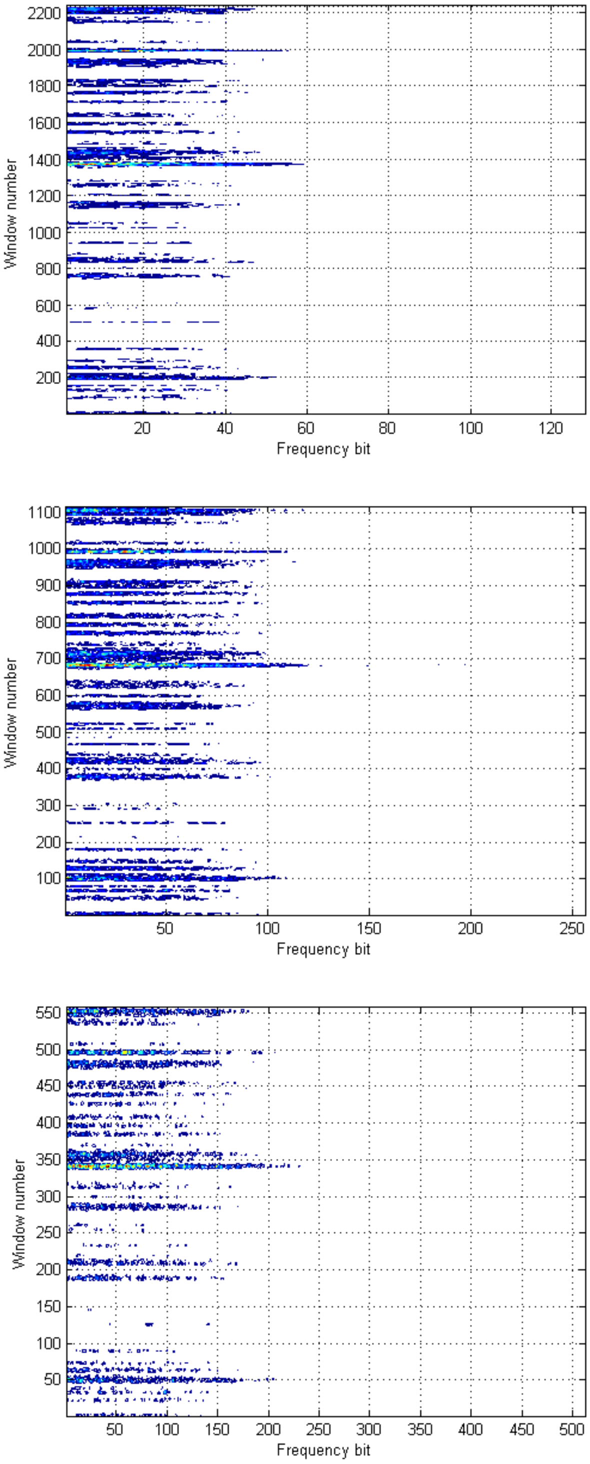

Fig.5. ST-FFT analysis of the Z linear acceleration using 256, 512 and 1024 point window respectively

signal to achieve the maximum value of the spectrum peak. The Figure 6 represents the zoomed picture of the spectrum peaks at the selected region of the time-frequency distribution.

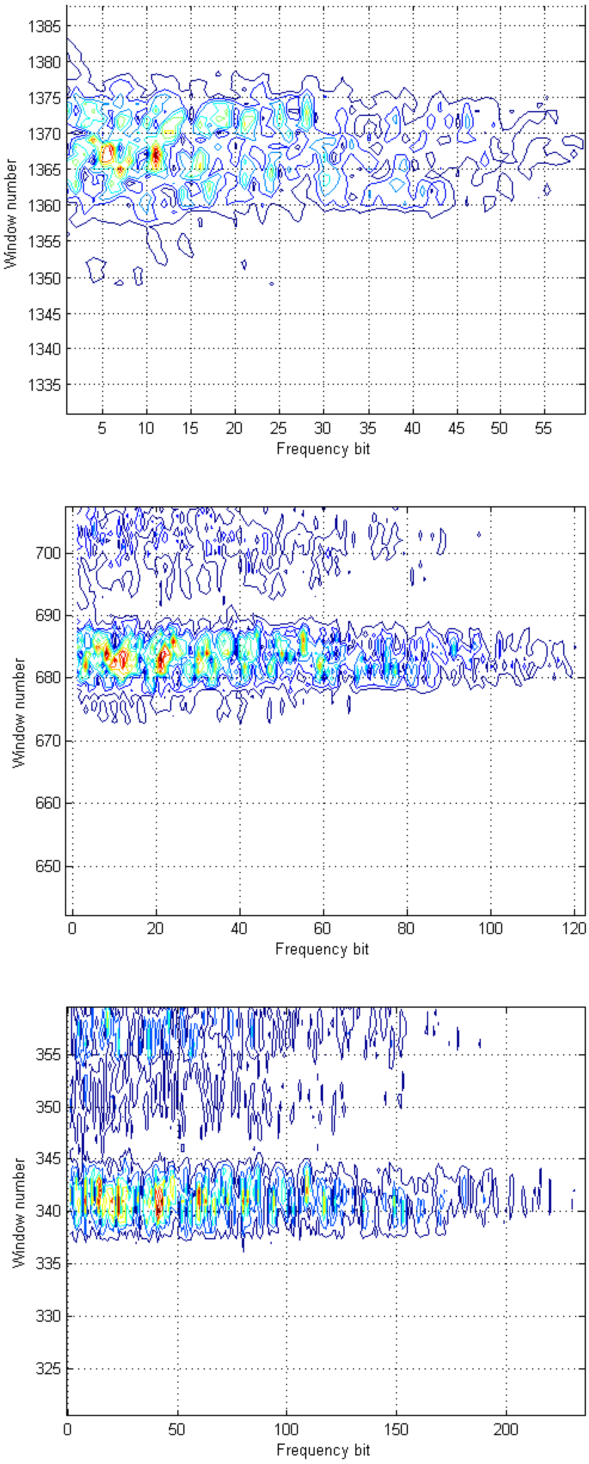

Fig.6. Zoomed picture of the spectrum peaks using 256, 512 and 1024 point window respectively

The results show that the maximum magnitude of the frequency peaks appears at the window number equal to approximately to 1370 when the window size is equal to 256 points. The right choice of the window size is determined from the circumstance to include the maximum points of the

It is clearly visible that the choice of the window size is essential to obtain the maximum value of the spectrum peaks. When the window size is equal to 512 point the maximum sampling points of the vibrations are included in the analyzed window. As the window size is higher than this optimum value the analyzed window includes not only all signal samples but also a lots of noise samples which blurred the spectrum peaks. If the window size is lower than the optimum value then the window includes a part of the signal samples and the spectrum peaks are not clearly defined.

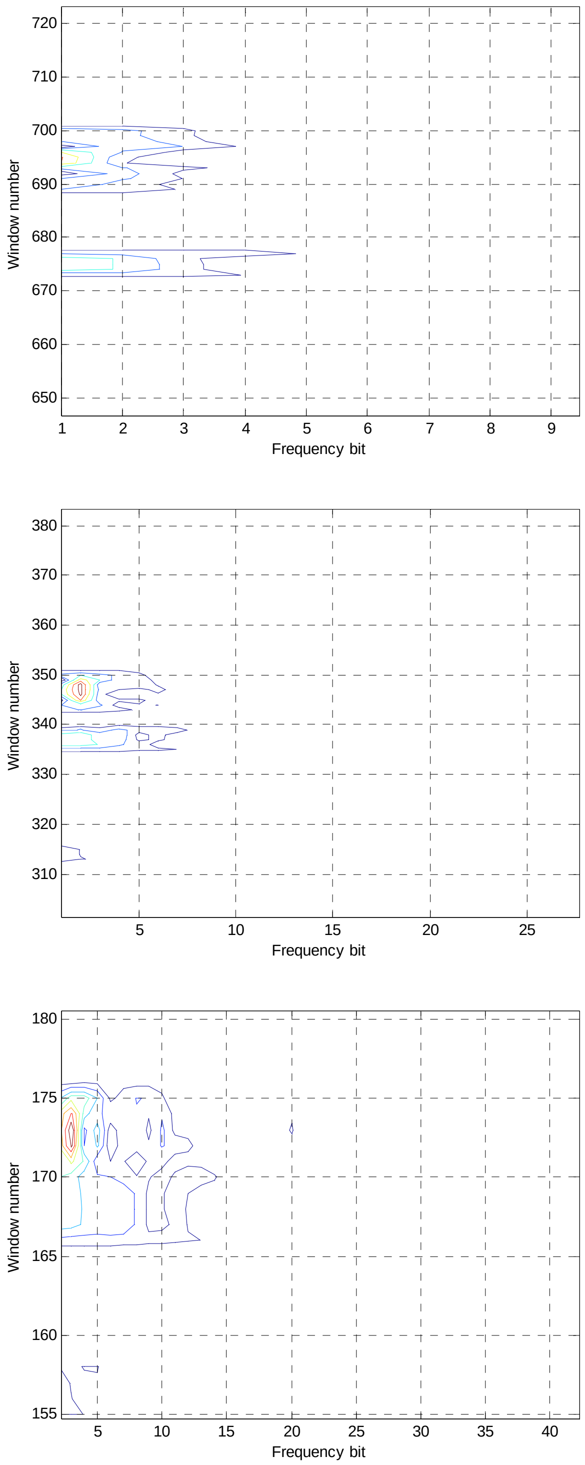

Fig.7. Zoomed picture of the Z angular acceleration spectrum peaks using 512, 1024 and 2048 point window respectively

The same situation appears when the Z angular acceleration is analyzed, but due to the fact that the spectrum peaks are situated at very low frequencies it is very important to obtain excellent frequency resolution by increasing of the window size. The results are shown at Figure 7.

V. CONCLUSION

The current paper represents the inertial measurement system based on MEMS inertial sensors which is capable to measure and analyze the linear and angular accelerations while their amplitude is used as a criterion for valuation of the railway safety. It is shown that the proper selection of the ST-FFT window length and overlap processing may produce excellent and accurate time-frequency resolution to show the frequency at any given time of the original waveform.

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