Frequency Analysis of Structure Deformation

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KEY WORDS: acceleration, displacement, dynamic deformation, frequency, FFT, periodogram

ABSTRACT:

Building structures are extremely sensitive at influence of outdoor conditions. Most often are these the influence of wind, sunshine temperature changes of the surrounding and at least the influence of the own or improper (other) loading. According resonance the structure with the surrounding is coming to vibration and oscillation in relative high frequency interval (0.1-100.0 Hz). These phenomena significant way affect the static and dynamic characteristics of structures, their safety and functionality.The paper bring example of monitoring these phenomena using geodetic methods at two different types of structures. The first is the industry object of cylindrical shape, which monitoring was made by total station with measuring frequency ca 2 Hz. The second is the Danube Bridge Apollo in Bratislava (Slovakia), which steel structure was measured by total station, GNSS and acceleration sensors with frequency up to 10 Hz.The central point of the paper is the analysis of dynamic behaviour of both structures using spectral analysis method. The usage of Fast Fourier Transform is described, own frequencies and amplitudes of structure oscillation are calculated.

1. INTRODUCTION

At the present time is more and more accentuates the need to monitor the dynamic deformation of civil engineering structure, which affects the stability and the safety of these structures. The dynamic deformation is general described by vibrations, inclination and other changes in relative short period, which are represented in frequency range by values from 0.1 Hz and higher. In this case is important to now not only the amplitudes of the structure movement but the frequency spectrum, also.

The Department of Surveying at the STU Bratislava (Slovakia) realises long time monitoring of dynamic effects at civil engineering structures different type and volume. The presented paper brings examples of usage various methods and technologies to determine dynamic deformation at two diametrically different types of structures.

In first case is measured the desorbing tower, which is a part of ammonia production line (technology). The aim of these measurements was the determination of the volume and the frequency of the tower inclination and the contribution of tower operation and the weather condition at this movement. Due to many limitations were the measurements realised by total station in fully automated mode with registration frequency ca 2 Hz.

The second example describes the measurement of bridge structure situated in Bratislava – the capitol of Slovakia. Analysis of the steel structure vibrations based on the accelerometer measurement was made whit 10 Hz frequency, which was sufficient for determination of the significant frequencies of the structure movement.

Spectral analysis was used to analyse the frequency spectrum of both structures. The estimation of spectral density of the measures time series was made by FFT.

2. DESORBING TOWER

The desorbing tower (No 54-2201-11) builds the part of the ammonia production line in chemical company Duslo, Ltd. in Šaľa (Slovakia). The tower has a cylinder shape, consists from two parts – bottom of 27.400 m high and 4300 mm diameter and the top with 34.380 m high and 4964 mm diameter (Fig. 1). These two parts are connected with conical shaped ring, which high is 1.770 m. The hall tower high is also 63.550 m and inside is divided to 5 blocks by filter gratings. The tower is based on reinforced concrete block and connected to this block by 20 screws of type M8 (Friedrich Uhde, 1970).

Figure 1. The desorbing tower

The dynamic loading due to the production, weather conditions (wind influence) are affects the tower base and the connection between the tower and the base. The structure is permanently

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inclined and the top of the tower is moved along the cyclic or elliptic way. Due to this permanent movement the connecting screws are affected by very high mechanical loading and the welding of more connected production lines is damaged. The aim of the measurement was to determine the trajectory of the tower top and the frequency of vibration.

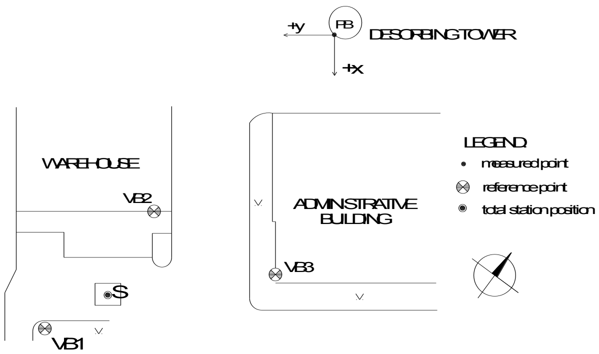


Figure 2. Reference and measured points

Due to large amplitude and inclination values was for trajectory determination the polar method chosen. The measurement was done by Leica TCRA 1101 total station, equipped by ATR function using Leica GPR1 prism positioned at the tower top in 63.000 m high (Fig. 2 and 3).

The stability of the total station during the measurement was controlled by observation to 3 control points signalized by Leica GPR1 prisms positioned on the buildings in the surrounding. The measurement was managed by Leica software DocWork and done with 1.66 Hz to 2.50 Hz frequency.

It was made 3 sets of measurement during the production (before and after reconstruction) and during the reconstruction works (without production).

Figure 3. Total station (left) and prism with meteorological station on the top of the tower (right)

3. THE APOLLO BRIDGE

The Apollo Bridge is one of the 5 bridges crossing the Danube in Bratislava (Fig. 4). These bridges build the part of the most important transportation corridors in Bratislava. The traffic load, water level changes in Danube and many other factors influence the basic function and safety of the bridge.

Figure 4. Apollo Bridge in Bratislava

The bridge structure consists from eight parts – the steel bridge with length of 517.5 m, concrete approach viaduct Petržalka with length of 236.0 m, concrete approach viaduct Bratislava with length of 195.0 m and five additional parts – three staircases and two cycling bridges. The main part of bridge is the arch steel structure with span length of 231.0 m and arch high of 36.0 m (Beňo et.al., 2006).

The main part is built by two steel timbers with orthotropic bridge floor (deck). The timbers are suspended on two central inclined steal arches. This part consists from 6 dilatation fields with spans of 52.5 m, 2 x 61.0 m, 63.0 m, 231.0 m and 49.0 m. The arch top is in 36.0 m high over the bridge deck. The pillar bases were builds by deck improved by injection or micro pilots. One of the pillars is positioned in the river. The main bridge field was mounted on the river bank and after this moved to the right position over the pillars and crossing the river (Kopáčik et al., 2011).

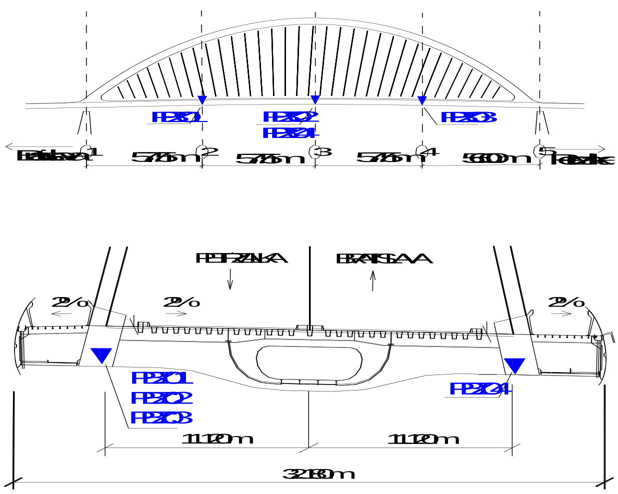


Figure 5. Longitudinal (up) and cross section (down) with localisation of the observed points

The measurement system consists of 4 four 1D accelerometers HBM B12/200 from HBM (Hottinger Baldwin Measurements) installed on the bridge deck (Fig. 5). These inductive sensors have the operating frequency of 0 Hz do 100 Hz and measuring range up to 200 m/s^2. The accuracy of the sensors is defined by relative error up to ± 2 %. Measured signal is digitized by A/D transducer Spider 8 and saved into computer.

Figure 6. Accelerometer HBM B12/200

Three accelerometers HBM B12/200 were situated at the left side of the bridge floor in the ¼, ½ a ¾ of the main bridge field (points PBZ01 to PBZ03) and the fourth accelerometers was situated on the right side in the ½ of the main bridge field (point PBZ04). The measurement axis of all accelerometers was vertical (Fig. 6).

4. DATA PROCESSING AND ANALYSIS

In case of dynamic loading of structures is desirable to describe their deformation parallel to the trajectory (3D position) by frequency spectrum, also. General is calculated the own frequency or the frequency of forced vibration of the structure. In both cases, the tower and the bridge measurement, was the frequency spectrum of the structures described using spectral analysis method. The method is appropriate for estimation of the spectral density of measured time series and consequently using statistical test for determination of significant frequencies in the set of measured values. The first step of data processing was the estimation of trends and their elimination (extraction) from the data sets. In second step was applied the FFT methodology to determine the spectral density of the time series. To calculate the frequency characteristics of the time series, the discrete measured values should be transformed from time zone to the frequency zone, which is given by

$$f(\omega)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\gamma(k)e^{-i\omega k}d\omega, \qquad (1)$$

where $\gamma(k)$ is the auto-covariance function with time slip k (Kuo et. al., 2001).

For determination of significant frequencies from the discrete frequency spectrum was used the asymmetric statistical test of periodicity (Fisher test) (Cipra, 1986).

4.1 Processing the data of the tower measurement

The dynamic deformation of the tower was measured in three epochs during three different conditions. The first was done during the fully operation of the production line and before their reconstruction. The second measurement was done during the reconstruction of the tower, without operation loading and the last one was done after the tower reconstruction, to verify the correctness of these works.

The frequency analysis was made on various set of measurements of 60 minute length. According the registration frequency was the number of measurement epoch in sets different and varies from 5319 to 5530. The average frequency of time series was calculated and the interpolated data were calculated for the set. The tower movement is described by displacement (amplitude) and frequency in X and Y direction under all 3 different conditions. Fig. 7, 8 and 9 represents calculated values in chosen interval for X direction. In tables 1, 2 and 3 are shown significant frequencies determinated by Fisher test of periodicity.

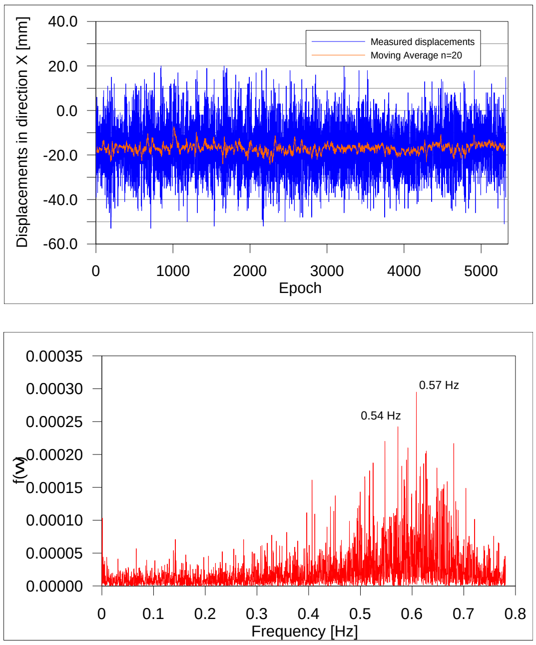


Figure 7. Measured displacements (up) and periodograms (down) - first measurement

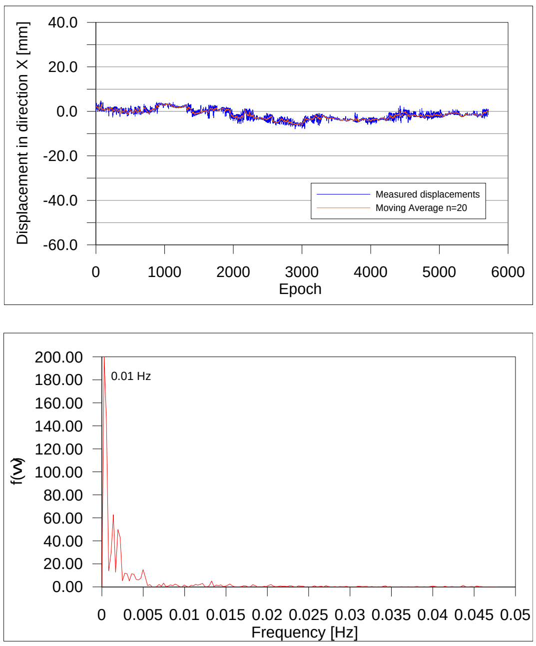


Figure 8. Measured displacements (up) and periodograms (down) - second measurement

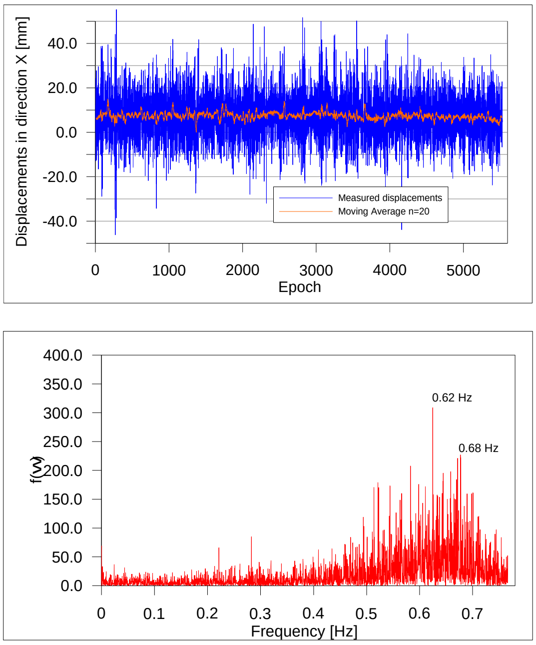


Figure 9. Measured displacements (up) and periodograms (down) - third measurement

Number of measurem.	Test statistic $\hat{W}$	Critical value F_{crit}	Frequency [Hz]
5319	0.00498812	0.0040841	0.57
	0.00411661	0.0040855	0.54

Table 1. Significant frequencies – first measurement

Number of measurem.	Test statistic $\hat{W}$	Critical value F_{crit}	Frequency [Hz]
5361	0.65327400	0.0040564	0.01

Table 2. Significant frequencies – second measurement

Number of measurements	Test statistic $\hat{W}$	Critical value F_{crit}	Frequency [Hz]
5530	0.00562410	0.0039431	0.62
	0.00415860	0.0039444	0.68

Table 3. Significant frequencies – third measurement

According the results could be concluded, the production has crucial influence on the dynamic loading and deformation of the tower, which result to the oscillations of the tower with amplitude up to 100 mm. Based on the estimation of spectral density was determined the frequency range of the tower motion 0.5-0.7 Hz, which represents the periods from 1.4 sec to 2.0 sec. According the results of the second measurement could be concluded the minimal influence of the weather condition (wind loading, etc.) on the tower movement or deformation – amplitudes are smaller as 10 mm. There are high frequencies not present in this time series, the frequency at level 0.01 Hz describes the slow and long term inclination of the tower, which could be generated by small wind, sun shine and own loading of the structure. This type of movement is not dangerous and do not affect the stability of the structure.

4.1.1 Processing of the Apollo bridge data

The measured data (acceleration) was registered by 10 Hz sample rate and transformed to vertical displacements by double integration. Frequency analysis was done at data sets with 18000 epochs, which represent the time range of 30 minutes. The maximum deformation achieve values up to 1 mm. Dynamic deformation of the structure is maximal affected by the transportation (traffic) and weather loading together. For illustration were chosen intervals with and without traffic from measurements realized at the points PBZ01 (Fig. 10 and 11) and PBZ02 (Fig. 12 and 13). Tables 4, 5, 6 are shown significant frequencies determinated by Fisher test of periodicity.

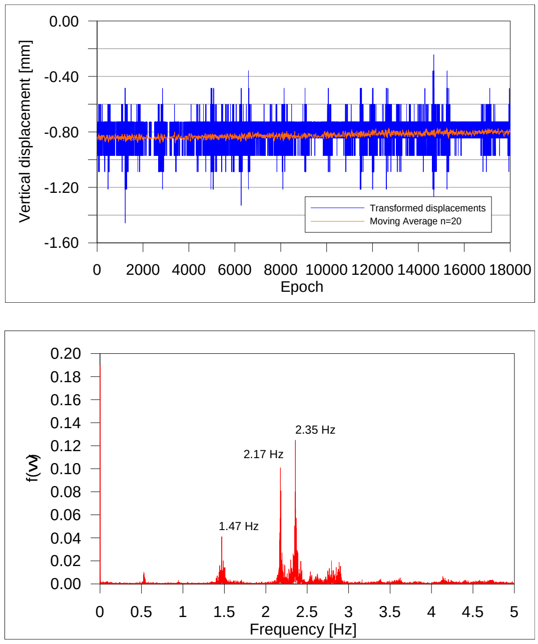
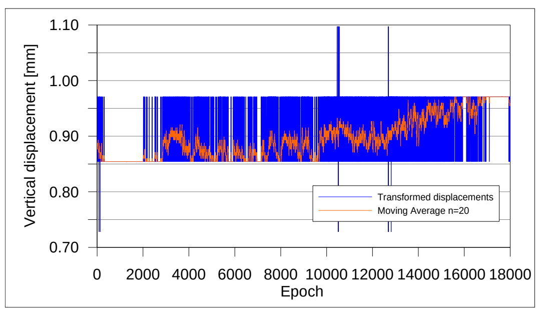


Figure 10. Transformed displacements (up) and periodograms (down) at the PBZ01 from 04:30 p.m. to 05:00 p.m.



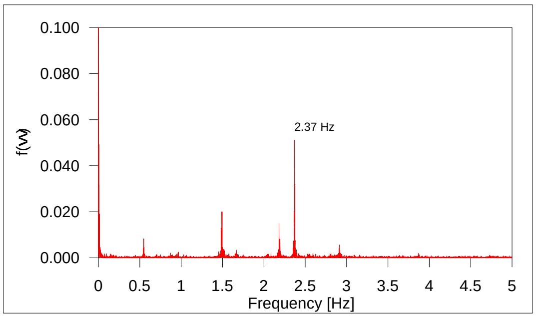


Figure 11. Transformed displacements (up) and periodograms (down) at the PBZ01 from 00:00 a.m. to 00:30 a.m.

Number of measurements	Test statistic $\hat{W}$	Critical value F_{crit}	Frequency [Hz]
18 000	0.0036728	0.0014521	1.47
	0.0096181	0.0013440	2.17
	0.0120872	0.0013439	2.35

Table 4. Significant frequencies at the PBZ01 from 04:30 p.m. to 05:00 p.m.

Number of measurements	Test statistic $\hat{W}$	Critical value F_{crit}	Frequency [Hz]
18 000	0.00142347	0.0013437	2.37

Table 5. Significant frequencies at the PBZ01 from 00:00 p.m. to 00:30 p.m.

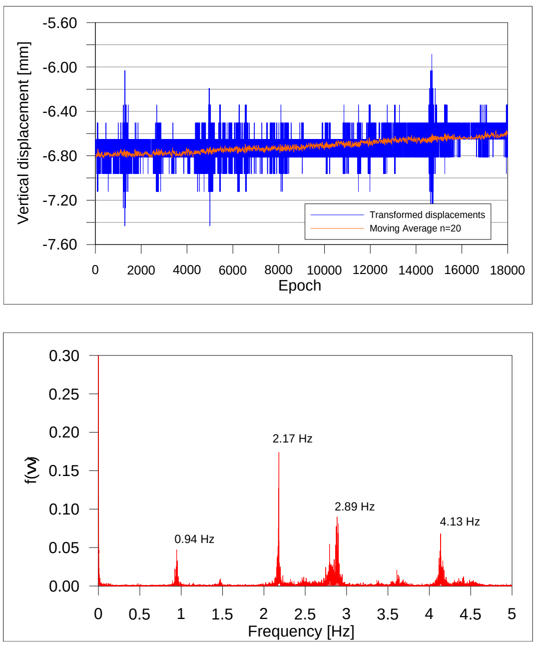


Figure 12. Transformed displacements (up) and periodograms (down) at the PBZ02 from 04:30 p.m. to 05:00 p.m.

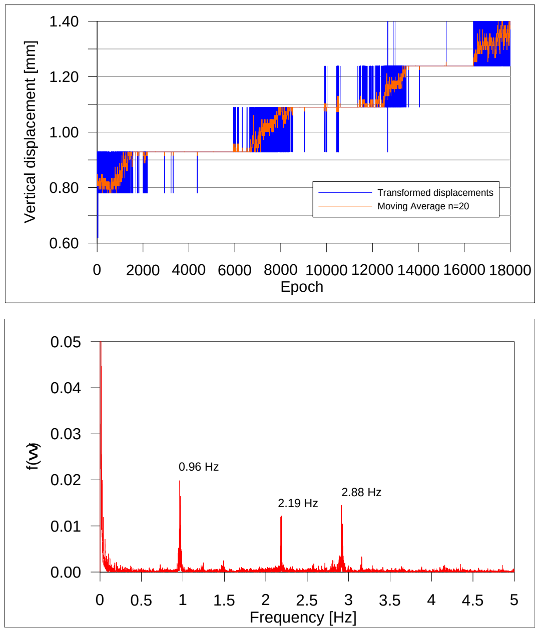


Figure 13. Transformed displacements (up) and periodograms (down) at the PBZ02 from 00:00 a.m. to 00:30 a.m.

Number of measurements	Test statistic $\hat{W}$	Critical value F_{crit}	Frequency [Hz]
18 000	0.00253242	0.0013505	0.94
	0.00642022	0.0013442	2.17
	0.00436679	0.0013467	2.89
	0.00402282	0.0013501	4.13

Table 6. Significant frequencies at the PBZ01 from 04:30 p.m. to 05:00 p.m.

Number of measurements	Test statistic $\hat{W}$	Critical value F_{crit}	Frequency [Hz]
18 000	0.00145228	0.0013563	0.96
	0.00139283	0.0013601	2.19
	0.00139452	0.0013589	2.88

Table 7. Significant frequencies at the PBZ02 from 00:00 p.m. to 00:30 p.m.

The results in the figures 10 and 11 are measured and processed at point PBZ01. In both time intervals there is frequency at the level around 2.36 Hz. Time series registered during traffic loading occurs next two significant frequencies at level 1.47 Hz and 2.17 Hz. The results in the figures 12 and 13 are measured and processed at the central point (midpoint PBZ02) of the structure. In both time series are present three frequencies at level 0.96 Hz, 2.18 Hz and 2.88 Hz which belong to the spectrum of calculated own frequencies of the structure. In the data set whit traffic loading are present next significant frequency at level 4.13 Hz. Frequencies which are occurred in time series from 4:30 p.m. to 4:35 p.m. represents the permanent influence of the traffic loading to the structure deformation at the both points.

5. CONCLUSIONS

Paper presents results of monitoring dynamic deformation of technological structure (Desorbing tower) and bridge structure (Apollo bridge). Characteristics of structure and some operation restrictions caused way of realization geodetic monitoring. Oscillation frequency determination of structures were realised by FFT methodology. In the case of desorbing tower could be concluded that dynamic deformation of structure characterized by deflection from vertical axis with frequency from 0.4 Hz to 0.7 Hz is caused mainly by operation load. It is confirmed by control measurements before, during and after the reconstruction works. Wind speed and direction affect only long periodic changes of inclination from vertical axis. Dynamic deformation represented by oscillation of Apollo bridge structure parts are induced by loading changes by traffic load at the structure with frequency from 0.9 Hz to 4.2 Hz. Results present important information about behaving of monitored structures in real time induced by operation load and atmospheric conditions.

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