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Application of IBIS System to Measuring and Analysis of Displacement on the Example of Bridge**

1. Introduction

Bridges, as one of the most important civil engineering structure, are also one of most interesting structures as regards of their behavior under the influence of heavy. The key issue is the preparation of appropriate engineering control system. Survey engineer must be aware that forces influencing the structure, have variety of sources: self-weight of the bridge, traffic load and external loads. Their effect on the structure determinates the choice of appropriate measurement technology.

Very important parameter, which characterizes the structure behavior under load, is the displacement value. It is a direct result of applied force. To perform a comprehensive assessment of structural safety, it is necessary to compare values of designed frequency of the structure and the actual value of this frequency. The natural frequency reveals the object response of dynamic forcing [8].

Determining dynamic characteristics is the basis for implementation of structure diagnostics. This method of diagnosis contains of examining the response of structures such as bridges and viaducts. It also allows to estimate the dynamic excitation for bridges and viaducts [2, 6, 10, 13, 17] and the source of it (e.g. communications, seismic). What is more an information on the effect of vibration on the surrounding buildings and people is given [14, 15].

Monitoring systems consisting of a group of accelerometers are mainly used for the above-mentioned studies [6, 10]. The values of those parameters can also be obtained by using ground-based radar interferometer. The article describes the study of determining the usefulness of IBIS-S system for dynamic measurements of buildings.

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2. Ground-Based Radar Interferometric IBIS

2.1. General Characteristics of the System

IBIS system was launched in 2008 as a product of the Italian company IDS. Its name is an abbreviation for Image by Interferometric Survey [3]. There are two versions of this device that can be used for different purposes.

First – IBIS-S is suitable for measuring displacement of buildings of elongated shape [4], while the second, IBIS-L, has been designed for monitoring large areas of land (landslides, slopes, glaciers) and large structures (dams) [1].

Figure 1 shows the IBIS-S system at work. Total Station survey can be seen in the background. It is not part of the system, but is helpful during the measurements. Survey engineer determines the building's geometry using reflectorless distance measurement techniques. The localization of major structural components is crucially important. Based on that information the place in which measurement points are being set up is chosen. The observation of the location of these points is analyzed in detail in the further research process.

IBIS-S can work in two modes – static and dynamic. Each of the settings is characterized by varying frequency and measurement accuracy. In dynamic mode displacement measurement accuracy is 0.1 mm, and static – 0.01 mm [11]. Radar generates microwaves at Ku-band, in the range 17.1–17.3 GHz. The maximum sampling frequency of 200 Hz [4]. Measurement range reaches 1000 m [3], but is highly dependent on the intensity of the reflected signal, and other reflective elements found in the radars view.

Fig. 1. IBIS-S system during measurement

Figure 2 shows the characteristics of the horizontal antenna used in the IBIS system. Gain Directional Antenna IBIS-H23 is 23.5 dBi, while the antenna IBIS-H13 is equal to 13.5 dBi. The value given dBi is the ratio of the radiated power density in a given direction of the average power density. In other words, it is the gain in that direction compared to the theoretical isotropic antenna [16].

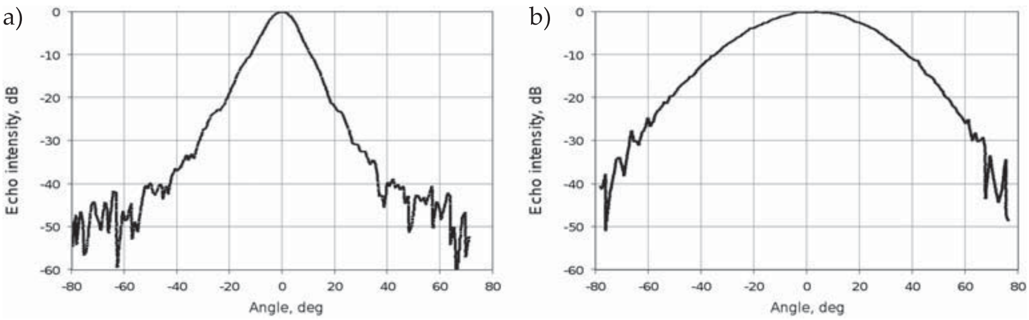

Fig. 2. Horizontal plane patterns of IBIS-H23 (a) and IBIS-H13 (b) antennas

Source: [7]

The graphs show that loss of half-power signal generated (–3 dB) holds for the horizontal angle of 11(aperture antennas in the case of IBIS-H23 and for an angle of 38° to the antenna IBIS-H13. These properties allow the different use of antennas for observation points located in a narrow or wide angle.

2.2. The Radar Techniques used in IBIS-S System

An active radar is the basis for ground-based radar interferometer IBIS system. It generates the measuring signal, then using the transmitter-receiver antenna illuminates the entire area with microwaves, and then receives the reflected signal returning.

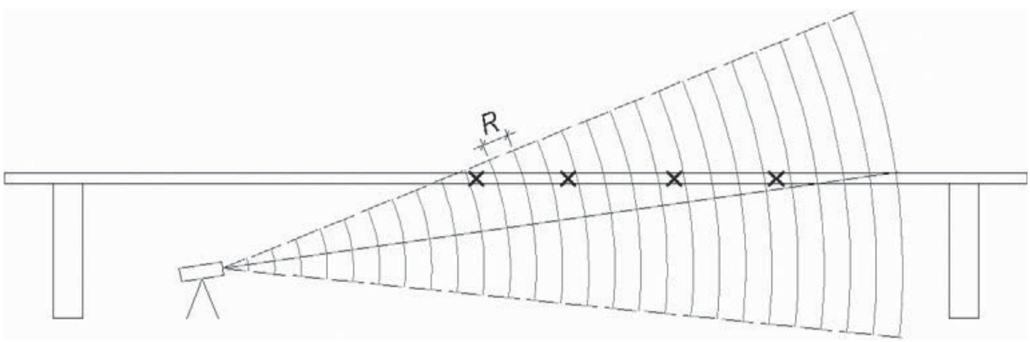

Fig. 3. Diagram of surveying using the microwave interferometer

Figure 3 shows radar during illuminating the object of measurement. Its first task is to detect elements of the object, and then determine their distance from the radar. The size of R is the resolution, the smallest distance interval in which one can distinguish a single observed point. For this scheme the maximum resolution is 0.5 m. The IBIS system uses technique of interferometry to determine the movements (Fig. 4).

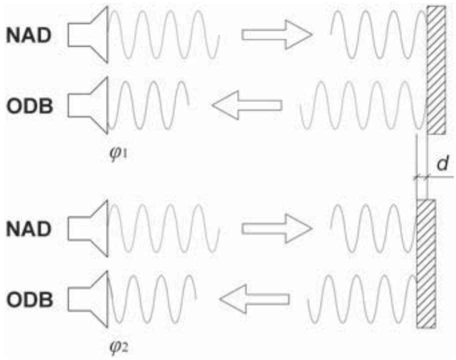

Fig. 4. Phase shift $\phi_2 - \phi_1$ as a result of movement d

Source: [12]

An important technique used in the system is swept frequency modulation continuous wave. It is used in order to achieve linear resolution [9]. The result of the object illumination is radar profile (Fig. 5), which reflects the intensity of the reflected signal in the field of distance from the radar. The values of intensities are determined for discrete arguments whose number depends on the resolution. Only points that strongly reflect radar beam can be observed.

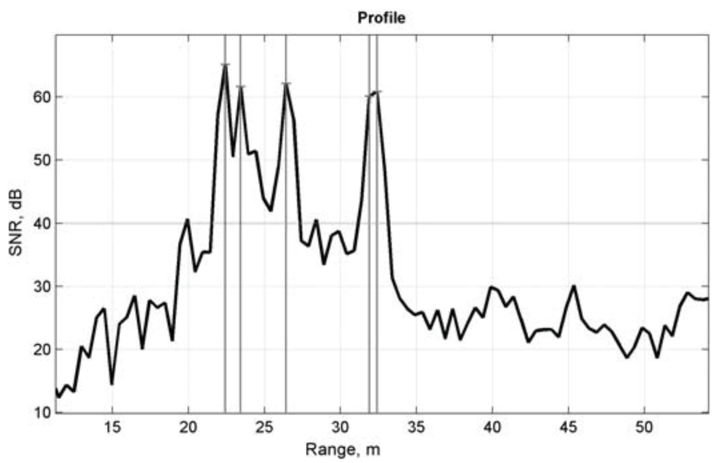

Fig. 5. Example of radar profile

2.3. The Principle of Selecting Sampling Points

Figure 5 presents an example of a radar profile, which is a plot from data obtained by measuring the reflection signal (SNR – Signal to Noise Ratio) of the target. A high SNR is the basis for selecting the observation points on the object. If identification of observation points is difficult due to various reflections from structural elements microwave reflectors are in use. They are also used if the object is made of material, which doesn't reflect microwaves. They help to identify specific points of building by strengthening the reflection of a radar beam. Figure 6 shows the reflector designed for tests using the IBIS system.

Fig. 6. Microwave reflector installed on an object

Radar profile can be divided into several peaks. Peaks are points of the object reflecting radar signal stronger than others. This way, we can find the places where the reflectors are installed. The possibility of using reflectors is often limited.

3. Displacement Measurement Bridge Structure under the Influence of Rail Transport

Railway bridge on the Vistula River in Kraków Zabłocie was a subject to displacement caused by trains (Fig. 7). This object is located on the railway line connecting two largest railway stations in the city: Kraków Płaszów and Kraków Central. It was built in the eighteen-fifties and since then has been repeatedly modernized. The last renovation, which consisted of replacing the spans, took place in 1988. Now the bridge consists of six 35.40 meters-long spans and has a steel structure separate for each path [18].

3.1. The Measurement of Vertical Displacements of the Bridge

The survey of fast-changing short-term movements of the bridge were made during the weekday with an average traffic volume. Interferometric radar IBIS-S recorded object displacement caused by loads of passing trains. Observation stations were located on the southern bank of the river at the height of the second span of the railway bridge (Fig. 7).

Fig. 7. View of the tested bridge with observed points marked

For the survey a receiving antenna IBIS-H13 (Fig. 2b) was used. It has 13.5 dBi of gain. There were no signal microwave reflectors installed on the structure. For the porpoise of the analysis only natural design elements ware used. Later on a survey of those points was made with the use of Leica TCRP1201 tachymeter.

The displacements of points located on the analysed structure were registered. Also the rail traffic on the bridge was monitored. The travel time of trains and their type was recorded in order to simplify the development of measurements results and further correct interpretation. These observations allowed to link distinctive movements of the bridge with the duration of the load caused by the passing trains. Figure 8 shows results of those studies.

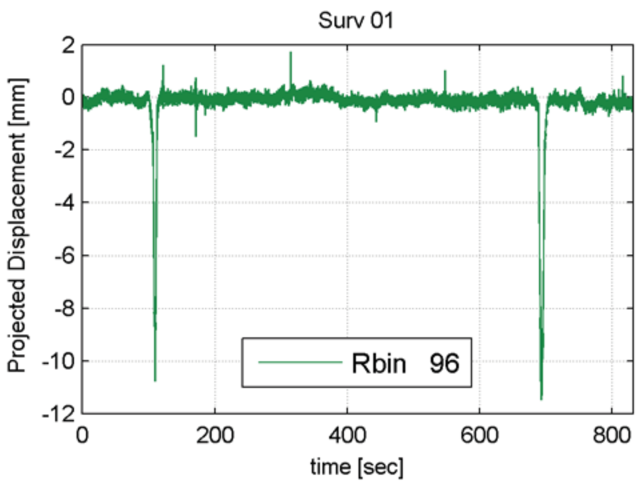

Fig. 8. Vertical displacements of the point located in the middle of the third bridge span

The time fluctuation of obtained values for individual points clearly show the sequence of deformation of the bridge spans and its connection with trains motion. Figure 9 shows the vertical displacements of points located on three successive spans (points 34, 96 and 138). The shown minimal peaks and there placements on the time axis is related to the distance between measured points and the speed of a passing train.

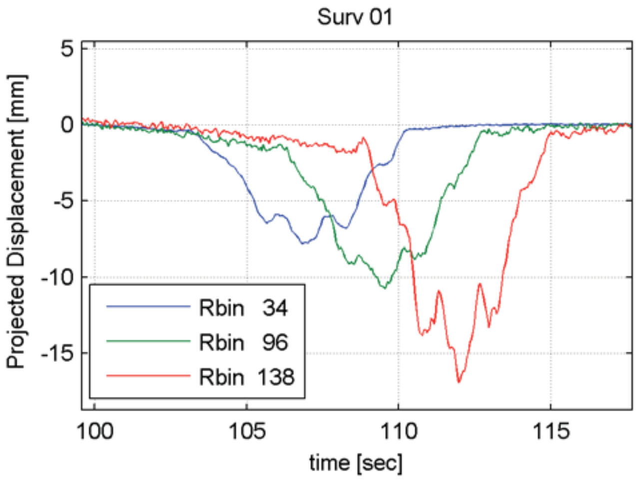

Fig. 9. Vertical displacements of three points located on three subsequent spans

Vertical displacements of the points located on the bridge span are connected with the occurrence of the load on this constructional element. However forces acting on adjacent spans do not affect the value of the observed parts because bridges structural elements are separated by expansion joints. The values of the displacements of points, which are located on one span, depend on the position of measured point on the span [5]. The highest deflections values were observed in the middle of the studied bridge spans while the values of subsidence decrease near bridge pillars (Fig. 10). The deflection in about 1/2 span (point 96) was 11 mm for the third bridge span, while the vertical displacement of points located near the pillars was –5 mm (points 49 and 113). The results are recurrent for all performed observations of the bridge displacements.

The change of the interferometric radar position made it possible to analyze the movements of the points located in the vertical plane perpendicular to the axis of the object, which were caused by the load of the bridge. The profile of points movements in this section (in 1/2 second span) is presented in Figure 11. The load of the span caused by the locomotive, got the deflection close to 15 mm, while the carriage-load effect was about 7–8 mm. The points returned to its original position after the release of the structure from the load.

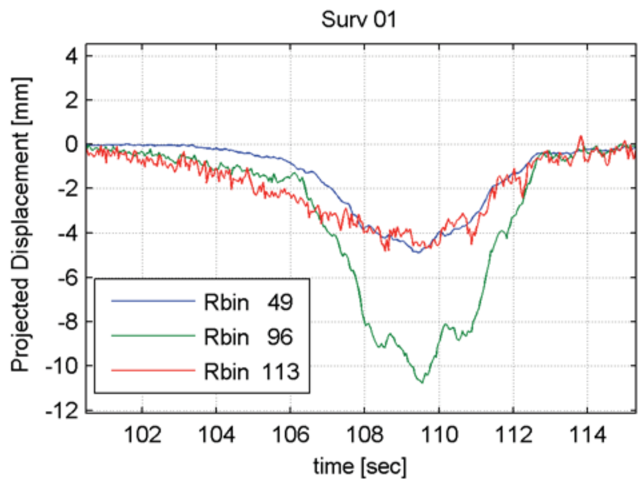

Fig. 10. Vertical displacements of the points located on one span

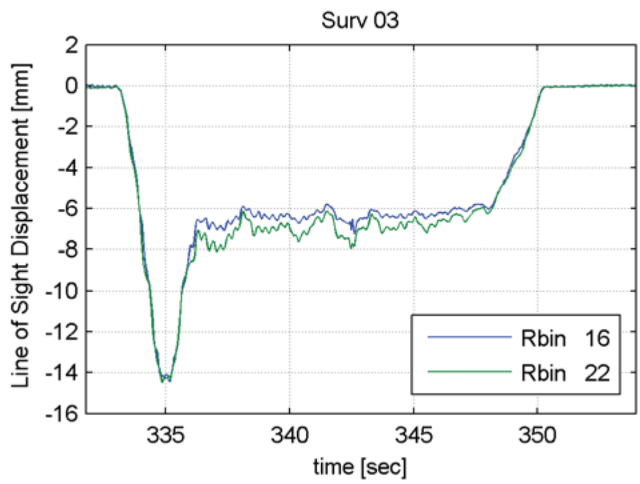

Fig. 11. Vertical displacements of the points located in the vertical cross-section

The test measurements also allowed to analyze the behavior of the bridge structure under the influence of different types of trains and different speeds.

Figure 11 shows a graphic image of the vertical displacement of the points under the load, caused by a slowly passing freight train with many goods wagons. While Figure 12 visualizes the movement of the bridge caused by rapid passage of a lighter passenger train. The passenger train passing resulted in span deflection of less than 10 mm and the state of the bridge deformation lasted about 5 seconds. The strain caused by a freight train lasted about 17 seconds. Damped harmonic oscillation with a starting amplitude of about 0.7 mm has also been observed with the use of spectral analysis tools.

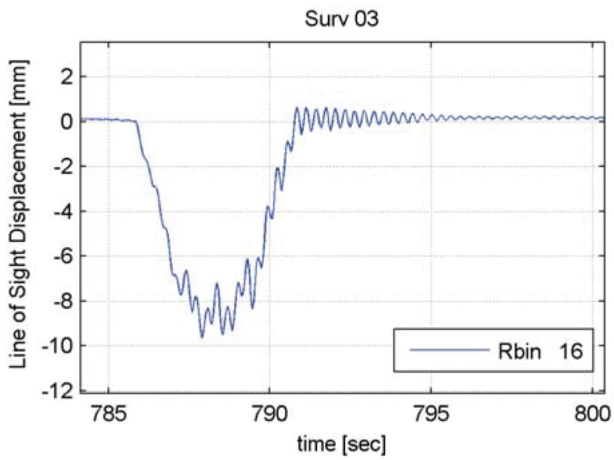

Fig. 12. Vertical displacements of the point caused by passing of a passenger train

3.2. Observation Analysis Capabilities

IBIS system software enables the calculation of the values, generate and acceleration. It also gives detailed acceleration graphs for all test points. High accuracy of the survey and its frequency allows to record direction and even smallest changes of acceleration.

The following acceleration graph (Fig. 13), shows the results of the observations analysis generated for points 16 and 22. The sufficiently long period of the registration allows to observe the gradual attenuation of the acceleration values. The enlarged portion of this graph (Fig. 14) shows that the accelerations of two points have very similar conduct. The resulted values caused by trains entrance are similar and reach a maximum of 0.4 m/s^2.

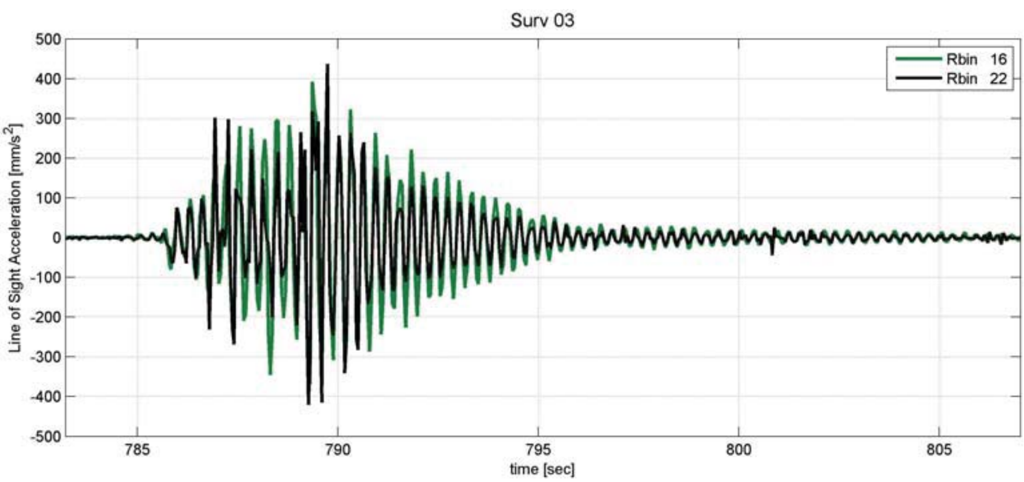

Fig. 13. Accelerations of the points located in the vertical cross-section

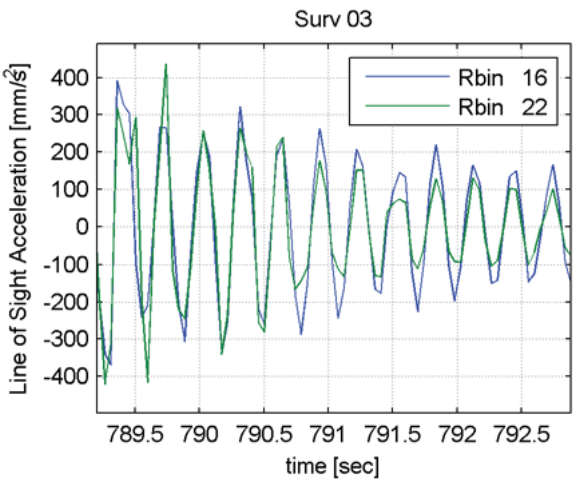

Fig. 14. Part of the acceleration plot

The important part of the survey is spectral analysis of the obtained values of displacement. It allows to set the oscillations frequency induced by a passing train. The values shown in the static displacement graph on Figure 12 suggest superposition of vibrations at certain frequencies. As the result a spectral analysis for the intervals [786 s, 795 s] is shown in the graph on Figure 15.

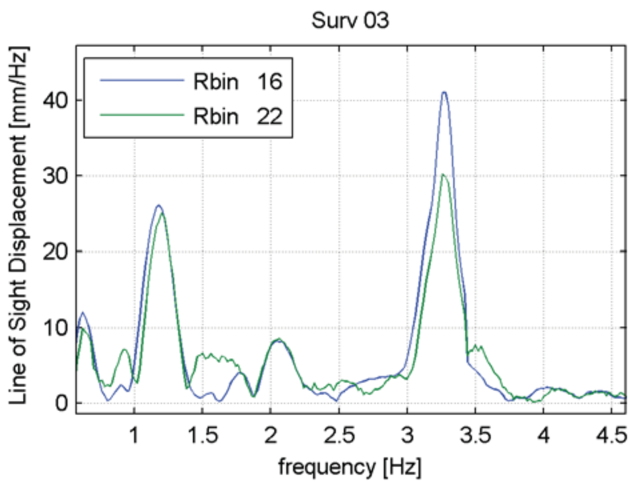

Fig. 15. Results of spectral analysis

Spectral analysis allowed to establish that dominant share of the vibration with frequency around 3.3 Hz in the course of acceleration. It corresponds with the vibration period of 0.30 s. This frequency is present in the whole analyzed period of time, also during vibration damping. The existence of 1.2 Hz vibration, which is equal to the period of 0.83 s, was also found.

4. Summary

IBIS system provides an alternative method for measuring the displacements of structures. The displacements are determined on the basis of the observation of the phase difference of microwaves generated and reflected from the object. Through further analysis it is possible to calculate the velocity and the acceleration of the structural vibration as well as to conduct spectral analysis. The high frequency of the survey allows reliable description of the objects movements. One of the devices advantage is the possibility of observing the entire object at once often without the need to install additional reflectors.

The results presented in Chapter 3 show how various informations are provided with the use of IBIS system. The accuracy obtained by this system and the frequency of displacement measurements permits to receive the results for objects profound dynamic analysis in the oscillation frequency up to 100 Hz. In addition, the use of microwave reflectors can increase the accuracy and the certainty of identification of the observed point.

They railroad bridge has been chosen as a testing object for this kind of survey. Further research will assess the accuracy of measurements by compare with results obtained by other methods.

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