APPLICATION OF INTERFEROMETRIC RADAR TO EXAMINATION OF ENGINEERING OBJECTS VIBRATION

Kuras P., Owerko T., Strach M.

Faculty of Mining Surveying and Environmental Engineering
AGH University of Science and Technology in Kraków

1. INTRODUCTION

The article concerns the basics of a ground-based interferometric radar, an innovative device, which can be used in studies of displacements and deformations of engineering objects. Structures of elongated shape, such as bridges or towers, are susceptible to vibrations. The interferometric radar described in the text, capable to measure the relative movement with 0.1 mm precision and 200 Hz frequency of data acquisition, enables detection of even slight vibration. The paper discusses procedures of data acquisition and processing. The results of two tests carried out on a bridge and a tower are also presented.

2. DESCRIPTION OF THE IBIS SYSTEM

In 2009 the Faculty of Mining Surveying and Environmental Engineering of the AGH University of Science and Technology in Kraków purchased the ground-based interferometric radar. It is the first unit of this device in Poland and sixteenth in the world.

The name IBIS comes from the acronym of Image by Interferometric Survey. The system was invented by the Italian company IDS (Ingegneria dei Sistemi). It is constantly developed and manufactured.

The main application of IBIS are measurements of slope and structure movements. Displacements of engineering objects may be monitored by the IBIS-S version of the system. Both static and dynamic tests may be carried out. The radar enables to characterize slow static deformation as well as fast variable movement.

Planning of any kind of displacement and deformations measurements demands to take several conditions into account. Applied technology must provide the required accuracy and the sufficient frequency of data acquisition. Moreover, to obtain a global representation of the entire structure deformation, a proper layout of observed points must be provided.

The main unit of the IBIS system is a ground-based interferometric radar (Fig. 1). Work of this device is based on two radar techniques: microwave interferometry (Skolnik, 1990) and stepped frequency continuous wave (van Genderen, 2003).

The phenomenon of microwave interference has fundamental importance in displacement measurements. Microwave interferometry facilitates the high accuracy of measurement. The displacement of selected point is computed basing on the difference between phases of the electromagnetic waves received at different times (Bernardini et al., 2008). Only the movement along the direction of wave propagation can be recorded. The displacement d is expressed as:

$$d = \frac{\lambda}{4\pi} \Delta\varphi$$

where λ is the radar wavelength and Δφ is the phase shift.

Fig. 1. The IBIS radar unit.

Obtaining a full image of the phenomenon using the classical methods requires the installation of many devices on the observed object. The stepped frequency continuous wave technique allows to avoid this difficulty. Processing of the output signal using the SFCW technique gives information on movements of several points of the structure. In fact, the points of object non-homogeneity scatter the radar beam. As a result, they become "virtual sensors" and their displacements may be investigated. Direct access to the object is not demanded. However, for observation of specific points, corner reflectors should be used.

An object observed by the IBIS radar is divided into parts according to the radar resolution in distance. The idea of resolution ΔR should be understood as the minimum distance between two points on the object which enables to detect them as different points. If the distance is less than ΔR, the points will be treated as one. The distance is taken along the direction of wave propagation.

3. THE IBIS SYSTEM PARAMETERS

The most important parameters of the IBIS-S radar are as follows:

- **0.1-millimetre displacement accuracy,**
- **frequency of sampling up to 100 Hz,**
- **operation range measurements up to 1 km.**

These values are sufficient for both slow movements in static mode and fast vibrations in dynamic monitoring.

IBIS-S operates on the K_u band of electromagnetic waves (frequency about 17 GHz). The bandwidth used comes to 300 MHz and allows to obtain 0.5 m ΔR resolution (Bernardini et al., 2008). This means the ability to monitor points of object separated by no less than 50 cm along the line of sight.

4. LIGHTING TOWER EXAMINATION

A lighting tower was among the objects, on which the usefulness of the described technology was tested (Fig. 2). It is located in the area of the Henryk Reyman municipal stadium in Cracow (Wisła Stadium).

Fig. 2. IBIS-S during field test at the H. Reyman municipal stadium in Cracow.

Figure 2 shows the location of the radar with respect to the examined object. On the photo it is possible to notice, that the examined tower was hidden from view by the north grandstand of the stadium and its roof to the height of about 35 metres. Position both of the device and the observing objects, able to strongly scatter the radar wave, were surveyed with classical geodetic technology, using the Leica TCRP1200 tachymeter. It allowed, at the stage of data processing, to rule out points which did not belong to the examined object like the grandstand and the roof.

Selection of points subjected to further analysis was carried out on the radar profile of the scene (Fig. 3). The vertical axis shows the ratio of the returning signal strength to the noise (SNR, signal to noise ratio). On the horizontal axis it is possible to read out the distance of measured objects from the radar. On the profile (Fig. 3) for the first 35 metres, there is a strong reflexive signal. However it pertains to the grandstand and the roof. The next section illustrates the profile of the examined object. On it three points, representing the lighting tower, were marked with the sign of the cross. For them, further analysis was carried out. Several factors decide on the choice of points for analyses. Among others they are:

appropriate representatives of the examined object,

high power of signal to noise ratio (SNR),

unequivocal identification of points,

ability to measure the distance to the points with classical geodetic techniques,

independence from the influence of different factors not being an object of the examination.

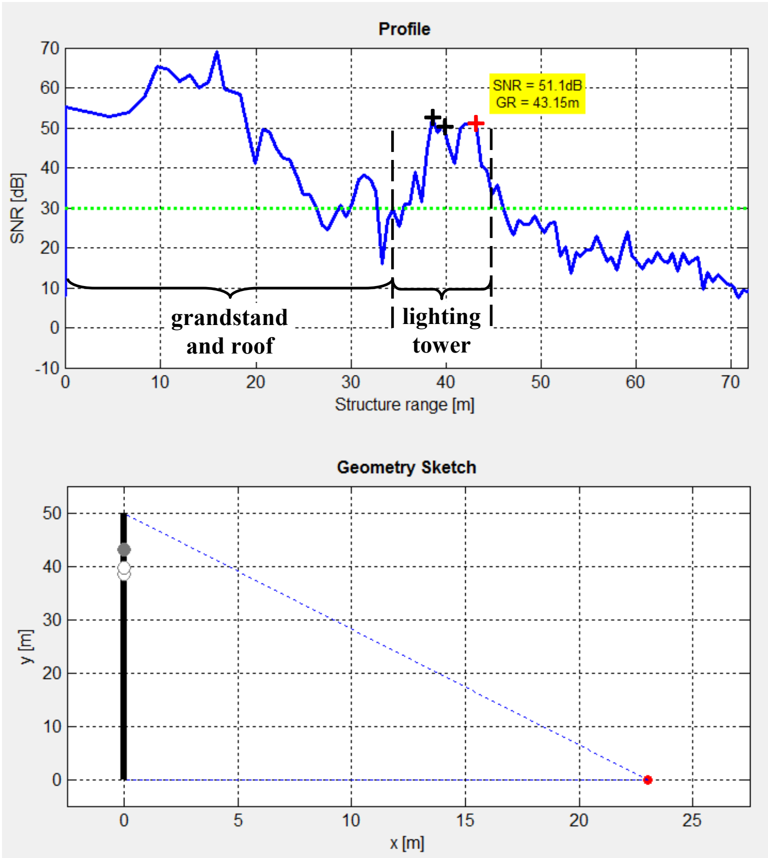

Fig. 3. Rangebin selection – way of qualification of points for analysis.

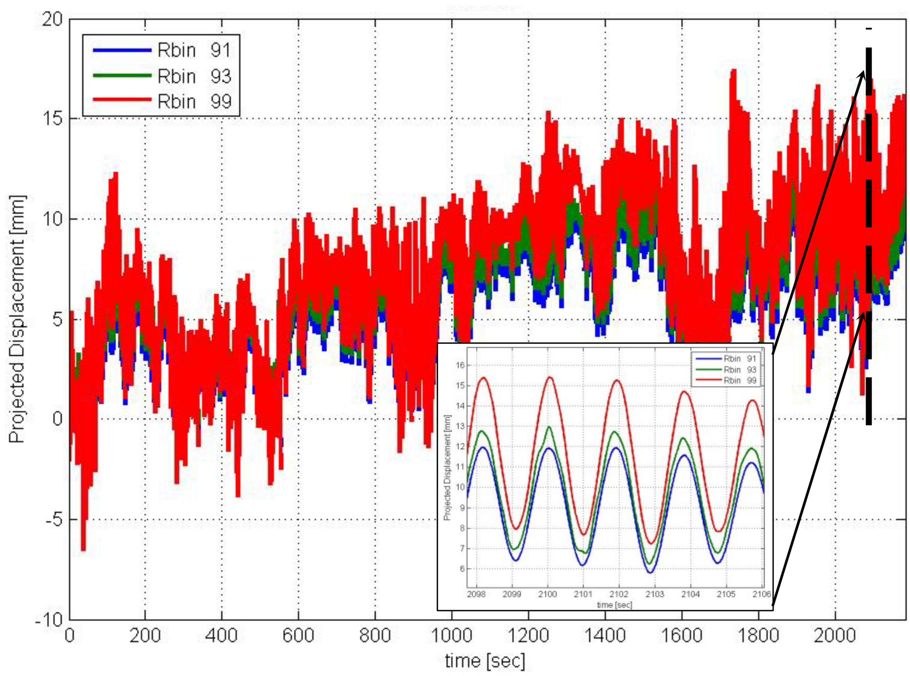

Fig. 4. Displacements of three points of the lighting tower.

The measuring session for the described object lasted for about 36 minutes. Figure 4 shows the amplitude of movements of points representing the top of the lighting tower. The figure also contains a few seconds' enlarged fragment of the graph close to the

second 2100. During this session, the selected measurement points, counting from the lowest upwards, moved in the range: -1.92 mm ÷ 6.77 mm (8.69 mm), -1.90 mm ÷ 7.15 mm (9.05 mm), -3.08 mm ÷ 8.22 mm (11.30 mm). In Figure 5 a histogram and chosen statistical parameters are presented for displacements of the highest point of the lighting tower.

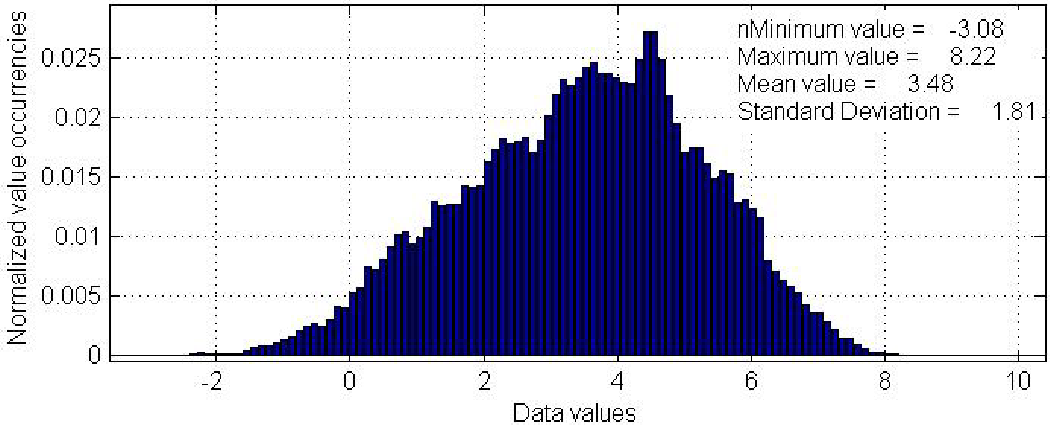

Fig. 5. The histogram and chosen statistical parameters for displacements of the highest point of the lighting tower.

Interferometric radar IBIS-S with a high sampling frequency allows the designation of the frequency of vibration of objects. Construction of the tower vibration analysis was performed using FDD (Frequency Domain Decomposition, Brincker et al., 2000). As shown in Figure 6, the dominating frequency of vibration of the structure is about 0.53 Hz. A strong wind which had an influence on the object in the day of the measurement is a probable reason of such characteristics of the tower.

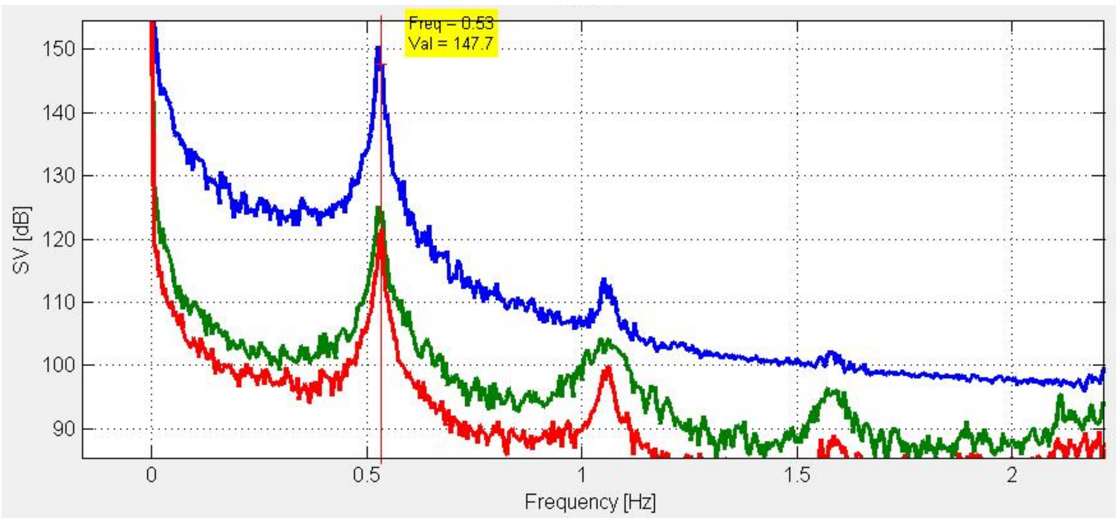

Fig. 6. FDD method result.

5. BRIDGE EXAMINATION

Another experiment was conducted on the prestressed concrete Grunwald Bridge in Cracow (Fig. 7). Observations were made during the day, with the aim to determine the impact of traffic on the construction. There are many points on the object which could scatter radar wave. Therefore three special reflectors amplifying the signal were installed. Reflectors were arranged in 1/2 and 1/4 of the length of the span and above the pillar (Fig. 7). Distances between the position of the radar and reflectors were measured with a reflectorless tachymeter.

Fig. 7. General view of the Grunwald Bridge and positions of the reflectors.

Selection of points was carried out on the radar profile of the scene (Fig. 8). Three points – reflectors represented the examined bridge. For them more further analysis was carried out. During the tests a few measuring sessions were made. Figure 9 shows the amplitude of displacements for three reflectors representing bridge span. The figure also contains a few seconds' enlarged fragment of the graph close to the second 400. During the measuring session chosen points moved not more than 1 mm. It can be concluded that in spite of the traffic the measured object remained stable.

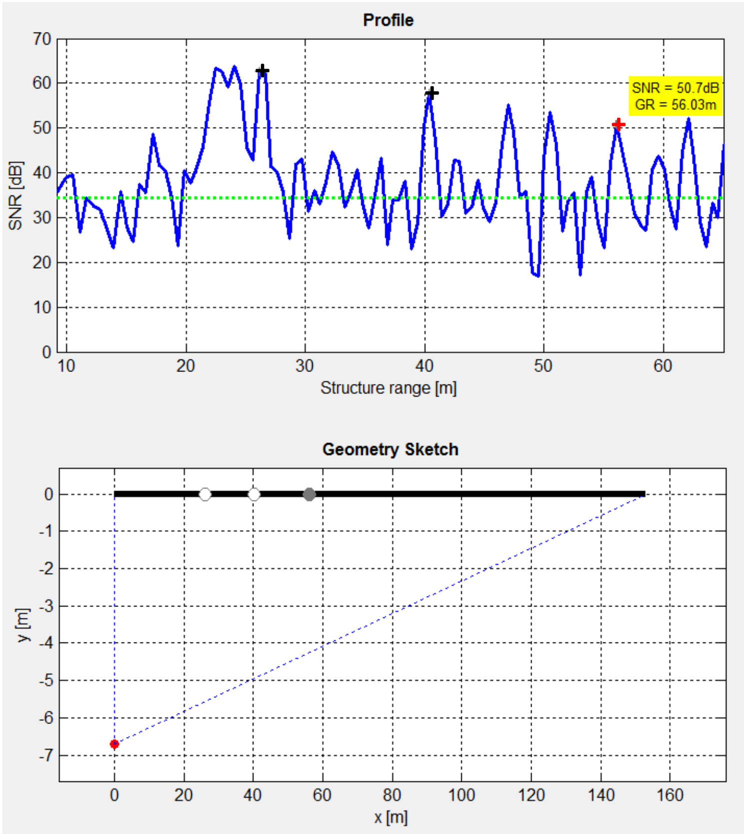

Fig. 8. Rangebin selection – way of qualifications of points for analysis.

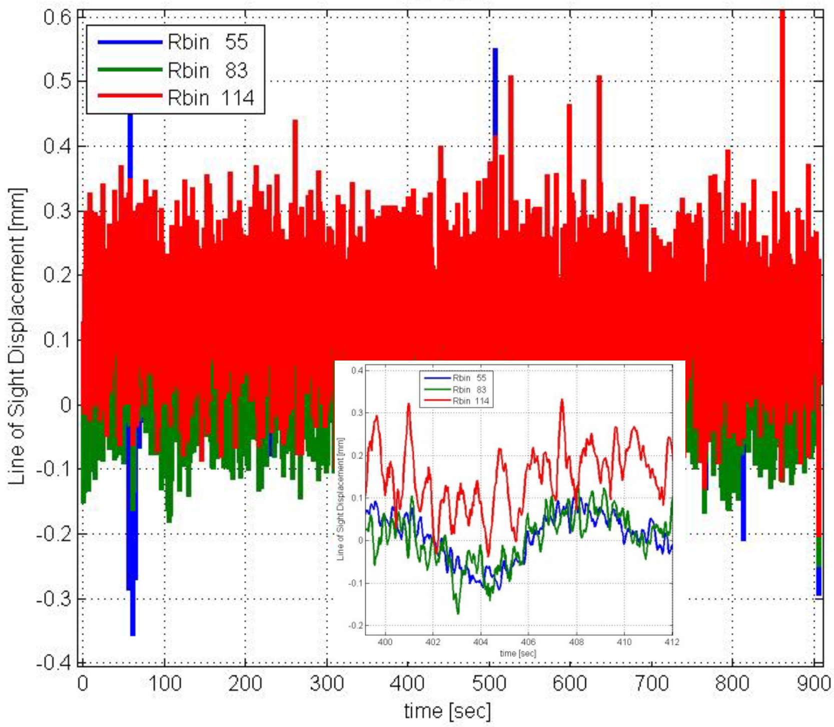

Fig. 9. Displacements of identified points.

6. CONCLUSIONS

Obtained test results confirm the applicability of the IBIS-S radar to vibration monitoring. It could be a powerful tool when applied to examination of such engineering objects as bridges, masts and towers.
There are real advantages for using the interferometric technology in studies of the engineering objects dynamic behaviour. Main of them are: long range, very high sampling rate and the simultaneous observation of the entire structure.

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