Possibilities of Precise Determining of Deformation and Vertical Deflection of Structures Using Ground Radar Interferometry

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SUMMARY

The paper describes possibilities of the relative new technics – ground based radar interferometry for precise determining of deformation of structures. Special focus on the vertical deflection of bridge structures is also presented.

The technology of ground based radar interferometry can be used in practice to the contactless determination of deformations of structures with accuracy up to 0.01 mm in real time. It is also possible in real time to capture oscillations of the object with a frequency up to 50 Hz. Deformations can be determine simultaneously in multiple places of the object, for example a bridge structure at points distributed on the bridge deck at intervals of one or more meters. This allows to obtain both overall and detailed information about the behavior of the structure during the dynamic load and monitoring the impact of movements either individual vehicles or groups.

In addition to the necessary theory are given basic principles of using radar interferometry for determining of deformation of structures. Practical examples of determining deformation of bridge structures, water towers and wind power plants are also given.

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1. INTRODUCTION

By looking for methods of some contactless observation of deformations and vertical deflections of the structures, also we need to define other requirements for these methods. One of these requirements might be the ability to observe deformations and deflections in real time for both, short and long time span. For example, in the case of bridges they are passing of the vehicles or stress tests, in the case of high buildings they are wind gusts. As well dynamically observe and measure frequencies and amplitudes of observed object's oscillation in range for example of 100 Hz. Ability to determine the size of deflections with accuracy in 0.01 mm, because the size of the deflections is usually in range from 0.1 mm to 10 mm. Ability to simultaneously determine deflections on multiple points of the observed object, so that is possible to get both, detail and whole information about deformations of the structure during dynamic stress.

To all of these requirements fits the method of measurement based on principles of ground-based radar interferometry. The big capability of this method is the simultaneously measurement of multiple deflections on multiple points on one observed object with range resolution at least of 0.75 m. For example, on bridge with length of 100 m, we can simultaneously observe and measure roughly 100 points. To show the possibilities of the radar interferometry technology, this article will focus to determining of deformations and deflections of few different object types. It will be measurement of vertical deflections of concrete bridges and horizontal movements of water towers. The measurements are done by interferometry radar IBIS-S (IBIS-FS) of IDS – Ingegneria Dei Sistemi company.

2. PRINCIPLES OF USING RADAR INTERFEROMETRY

Basic principles of radar interferometry with IBIS-S are described in detail in [1]. This article describes only the most important policies of using of radar interferometry which are necessary.

- Ground interferometry radar is sensor measuring only relative movements in its line of sight (LOS).
- Radar is not able to discern movement perpendicular to its line of sight.
- There is a maximum movement between two subsequent acquisitions that is possible to correctly determine. This value corresponds to phase difference $\Delta\varphi = 2\pi$. For example for IBIS-S this maximum movement is ±4.38 mm (for $\Delta R = 0.75$ m). If this value is exceeded the resulting movement is incorrect. This error cannot be detected. The frequency of

acquisition can be up to 200 Hz, so it is possible to observe movements with speed up to 0.876 ms^{-1}.

- It allows monitoring area of interest from distance up to 1km without the need to install additional sensors or optical targets in case of good reflection. In the other case is necessary to install additional corner reflectors.
- It is possible to simultaneously observe multiple points on the object. So it is possible to get both, detail and whole information about behavior of the object.
- The movements are measured directly and in real time.
- Observations are possible during both day and night and almost regardless of climatic conditions.
- The standard deviation of the movements determining is about 0.01 mm and mostly depends on the quality of reflected signal, i.e. size of the corner reflectors and the distance from radar. The basic verification of precision was done through comparison of two independent methods (IBIS-S and total station SOKKIA NET1AX). The results are in [1]. It was recognized that this technology could be used to determining of movements with precision in the range from 0.01 mm to 0.1 mm.

All movements are measured in line of sight. If the radar's line of sight is not parallel with expected movement direction the real movements have to be computed from LOS movement using the following formula $d=d_R/sin(\alpha)$, where $sin(\alpha)=h/R$ and so $d=d_R \cdot R/h$, see Fig. 1. The situation of measurement is usually as in the Fig. 1. The distance R is measured by the radar, the height difference h is necessary to determine with additional geodetic measurement.

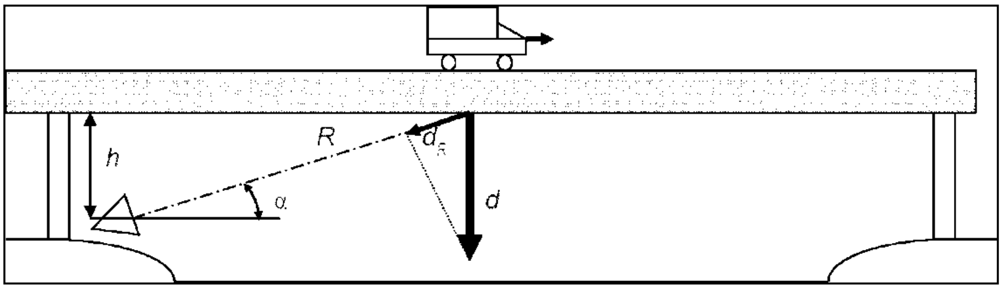

Fig.1 - Line of sight movement (d_R) and real movement (d) [source: IDS]

3. MONITORING VERTICAL DEFLECTIONS OF THE CONCRETE BRIDGE.

An example of monitoring vertical deflections of concrete bridge is shown on a road bridge near town Pelhřimov, Czech Republic [1, 2]. The monitoring was done during usual traffic.

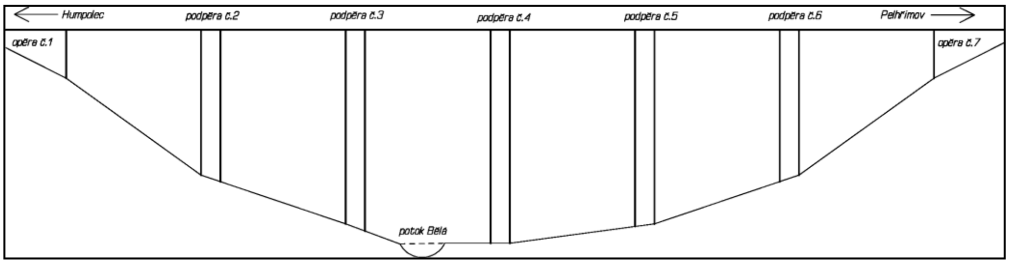

Fig.2 – Schema of the bridge

The way of measurement and placement of corner reflectors are obvious from Fig. 3. After evaluation of quality of measured data, it is possible to proceed whole measurement to get deflections of the bridge. The resulting vertical deflections of observed corner reflectors are shown in Figs. 4 and 5.

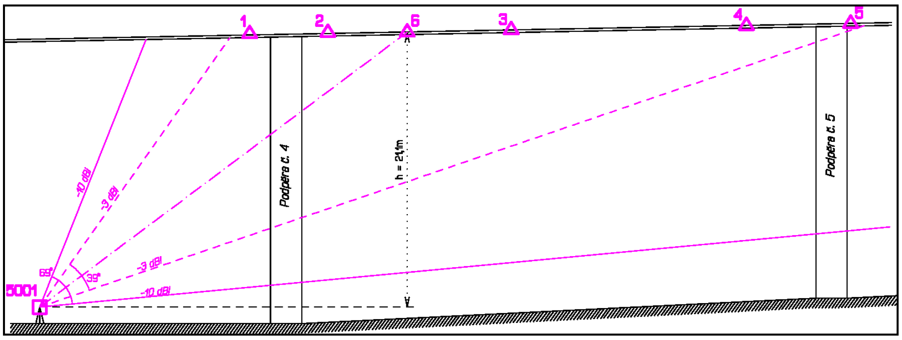

Fig.3 – Placement and orientation of radar and corner reflectors

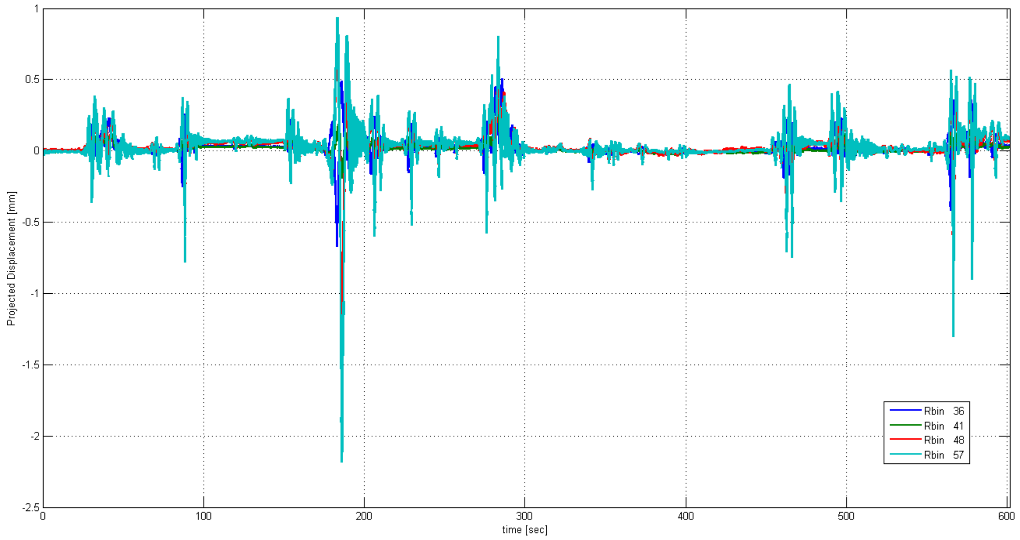

Fig.4 – Vertical deflections of corner reflectors No. 1, 2, 6 and 3

The vertical deflections of the bridge during vehicle passage are shown in the Fig. 4. The biggest deflections are caused by fully loaded lorries passing in northern lane, where the corner reflectors are attached. The lower deflections are caused by lighter vehicles or vehicles passing the other lane. The detail evaluation covering the biggest deflection in time span between 170 s and 200 s is shown in the Fig. 5.

Detailed analysis of the results of the deflections of reflectors with their mutual contexts is done in [1].

The basic frequency of the bridge deflections during vehicle passage is shown in the periodogram of the frequencies. In our case 2.671 Hz (cca 5 vibrations per 2s).

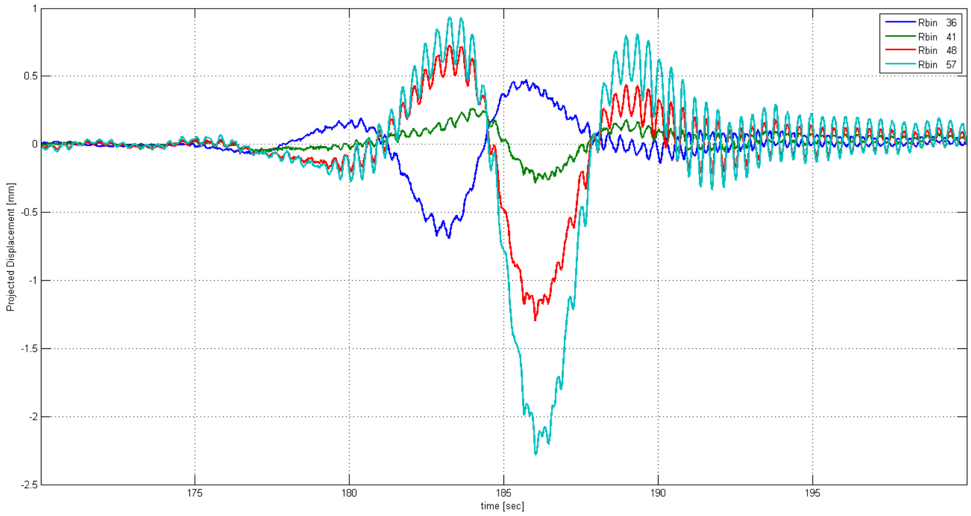

Fig.5 – Vertical deflections of corner reflectors No. 1, 2, 6 and 3 in time span between 170s and 200s

4. MONITORING VERTICAL DEFLECTIONS OF THE WATER TOWER

As the example of monitoring vertical deflections of the water tower, was chosen water tower in the Klecany town near Prague, Czech Republic. Water tower is composed by carrying the cylindrical pylon and spherical tank. The carrying pylon is composed by three sections, each section is composed by a few annuli. All the section joints are raised which makes them natural reflectors of the radar signal. The annuli joints are much softer, but there is still no need to install corner reflectors.

Fig.6 – Water tower, section and annuli joints, schema of measurement

During the measurement there was very weak northwest wind and radar was stationed in the direction of the wind to the water tower. Movements of three points corresponding with

section joints are shown in Fig. 7. High frequency and variable amplitude of the oscillation of the water tower pylon is clearly detectable.
The composite vibration is also shown in Fig. 7. It is probably caused by movement of the water mass in the water tank, independently on the pylon vibrations caused by wind.
The resulting vibration is the sum of two simple vibrations. In the periodogram of the horizontal movements are detectable three basic frequencies. The most one is 0.24 Hz which is approximately once per 4s. Other details are in [3].

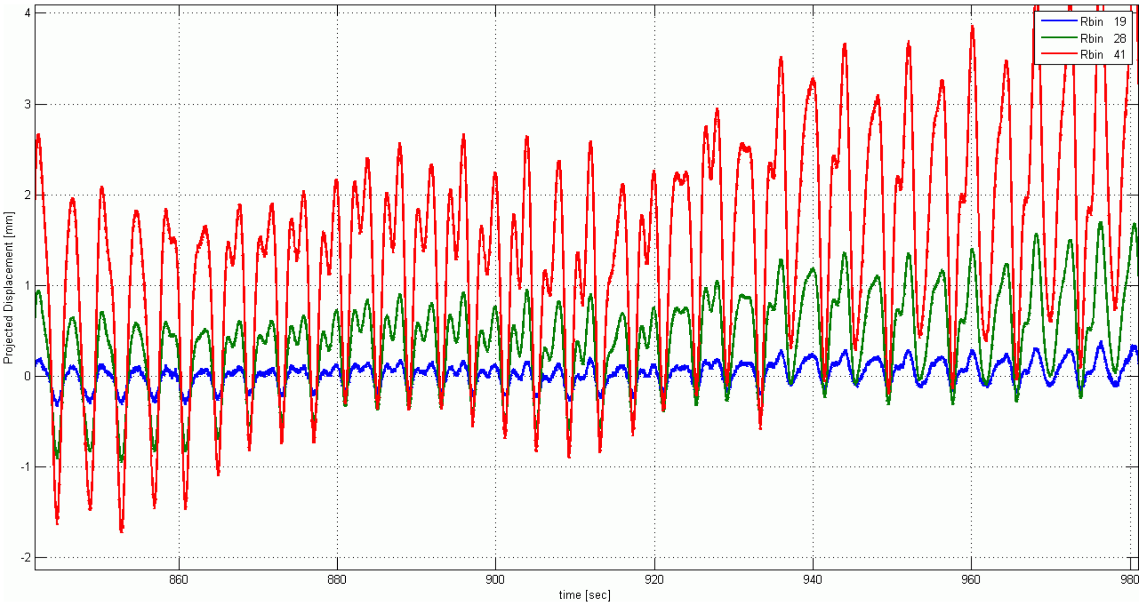

Fig.7 – The resulting vibration is the sum of two simple vibrations

5. CONCLUSION

Presented technology of ground-based radar interferometry provides determining of deformations and deflections/movements of many different objects. Only because of the need to reduce this article, the results of many other measured objects are not presented (e.g. horizontal transversal movements of flood-gate sides, horizontal movements of wind-power plant pylons, horizontal movements of brick factory chimneys). Technology provides determining of the deformations and deflections/movements of structures with high relative precision (up to 0.01mm) in real time simultaneously on multiple points of the observed object. From the results we can obtain new information about behavior of some structure types. It is recommended to repeat measurement with a certain interval to get information about observed object‘s behavior depending on its senescence, external conditions or the season.

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BIOGRAPHICAL NOTES

Milan Talich, Ph.D. (*1961) was graduated from the Czech Technical University in Prague, Faculty of Civil Engineering, Department of Geodesy and Cartography. Then he was engaged in the Research Institute of Geodesy, Topography and Cartography (VÚGTK), working since 1987 in the International Centre on Recent Crustal Movement (ICRCM) at geodetic networks processing and geodynamic problems, later in geoinformation technology. Since 2012 he work also in the Institute of Information Theory and Automation of the CAS (Czech Academy of Sciences) at using GB SAR technology for determining of deformation.

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