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Structural oscillation modes identification by applying controlled loads and using microwave interferometry

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A B S T R A C T

Radar interferometry, capable of remote detection of displacements and deformations of a structure, has been successfully experimented in a number of case studies. Radar interferometry offers high-speed range imaging and range displacement measurement capability, but it lacks in the identification of the different kinds of modes usually excited in a dynamic test. In this paper an approach to the measurement capable of identifying bending and torsional oscillation modes is described. The basic idea rely on the application of suitable loads to the structure under test in order to cause controlled changes of its frequency response. The results of such a dynamic test, performed on a canopy, are reported.

1. Introduction

Architectural structures require static and dynamic tests to ensure their safety before going into service or for structural damage identification [1,2]. The simplest dynamic tests consist in applying a stimulus to the structure, measuring its response, finding its resonant frequencies and modal shapes and comparing them with the design specifications. These measurements are usually performed using consolidated techniques based on networks of accelerometers, installed at key points in contact with the monitored structure. GPS sensors too has been experimented in combination with accelerometers [3], also if their accuracy and sampling rate are again not fully satisfactory. Recently laser vibrometers has been successfully used for bridge load testing [4] and for bridge cable tension assessment [5]. These equipments are surely effective in a number of cases and have the unique capability to detect vibration without contact at a single point precisely identified, but they are rather sensitive to dust and their operating distance typically does not exceed 20–30 m. The latter is recognized to be the most significant limitation [4], furthermore distance affects considerably accuracy and acquisition speed.

A radar interferometer, capable of remote dynamic measurement of a structure, has been recently developed by the authors [6], and successfully applied in a number of case studies [7–9]. In these, uncontrolled natural or artificial stimuli have been used in order to excite structural oscillations. While radar interferometry offers the great advantage of remote dynamic measurement, allowing fast and inexpensive tests with accuracy comparable with that ensured by accelerometers [8], the radar technique is not able to completely identify the oscillation modes of a structure [9] in case of simultaneous bending and torsion modes excitation. Bending oscillation modes cause vertical deflections of the structure, while torsion modes cause rotational deflections along its longitudinal axis. In this paper, a measurement approach aimed to discriminate bending and torsional oscillation modes, is described. It is based on multiple acquisitions of a microwave interferometer in combination with a controlled alteration of the frequency response of different oscillation modes of the structure under test. The case study concerns a walkway canopy of the railway station of the town of Terni, Italy.

2. The interferometric technique

The measurement technique is based on a continuous wave stepped frequency (CWSF) radar. This performs a sampling of the field of view by transmitting of a set of N monochromatic waves, linearly spaced in frequency by a constant step of Δf, thus scanning a bandwidth

$$B = (N-1)\Delta f \quad (1)$$

and acquiring the amplitude and phase of the N received echoes signals [10]. The N monochromatic waves are transmitted consecutively, each of them with a time duration of Δt thus the

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sampling time of the field of view is

$$T = N\Delta t \tag{2}$$

The signal versus range (distance from the radar) is obtained by calculating the inverse FFT of the N samples, and achievable range resolution is given by

$$R_{res} = \frac{c}{2B} \tag{3}$$

with an unambiguous range of

$$R_{UN} = \frac{c}{2\Delta f} \tag{4}$$

A target is identified as an amplitude peak of the signal plotted versus distance. The phase difference $\Delta\varphi$ of the pixels identified as a target, between two subsequent acquisitions is proportional to range displacement Δr of the target

$$\Delta\varphi = \frac{4\pi f_C}{c}\Delta r \tag{5}$$

where f_C is the band center frequency.

Generally speaking, Eq. (5) is valid only if the target remain in the same resolution cell during the time interval between two subsequent acquisitions, but Doppler effect for CWSF modulation can give an apparent range shift of the targets related to their speed (V). Therefore the application of Eq. (4) is constrained by the following condition:

$$V < \frac{c}{2Tf_C} \tag{6}$$

The interferometric sensor is implemented as portable equipment held by a stable tripod, powered by a battery pack: thus, it can be installed easily in different positions with the respect of the structure under test. It is equipped with two horn transmitting and receiving antennas with half power beam width (HPBW) of about 13°.

As the radar merely provides range resolution along its line of sight, imaging of the whole structure requires its positioning in such a way that different points of the structure appear at different distances from the radar observation point. Furthermore, as the radar does not possess cross-range resolution, torsion oscillation modes cannot be easily discriminated. So, impressive images of the bending oscillation of great bridges have been obtained by illuminating the bottom of the bridge from one extremity pillar [6]; but these images do not give enough information about the possible torsional movements. In this paper, a discrimination of oscillation modes in a specific case study is attempted.

3. The case study

A bus shelter, a walkway canopy and new parking facilities have been recently built in front of the railway station of the town of Terni, Italy, (Fig. 1). The structure is suspended on four central pillars, and the bus shelter has two secondary points of support at its extremities. All the structure was built using metallic materials rigidly connected or suspended with stay rods. The canopy is composed of a metallic structure and a corrugated iron sheet; its width is 4.1 m and its length 11.3 m from the frontal edge to the center of the four pillars. The height is 6.4 m on the frontal edge and 5.5 m in the center of the four pillars.

The interferometric radar was used in the final test of the structure aimed to identification of the canopy main bending and torsion oscillation modes frequencies. Torsion modes should include also transversal deformations, which however are usually negligible for structures similar to that under test [11].

3.1. Acquisition procedure and stimuli application

The modal identification procedure was based on the selective modification of the frequency response of different oscillation modes randomly excited by natural stimuli (for example the wind or the vibrations caused by vehicular traffic around the structure). The oscillation frequency modification is achieved by using a 58 kg weight suspended at different points of the canopy by a cord

Fig. 1. The canopy under test.