An interferometric radar for displacement test and its application in bridges

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1. Introduction

Recent progress in radar techniques and systems has led to the development of a microwave interferometer, potentially suitable for non-contact displacement monitoring. This paper describes a new interferometric radar system, named IBIS-S, which is possible to measure the static or dynamic displacement at multiple points of structures simultaneously with high accuracy.

2. The radar-based measurement of displacement

The basic principle to measure displacements by using radar can be seen from the single degree of freedom system shown in Figure 1. Radar emits a simple sinusoidal wave. If the mass is vibrating, the received echoes obtained at different times exhibit phase differences, which are proportional to the displacement. Hence, the displacement d_r along the radar line of sight is simply computed from the phase shift as $d_r = -\lambda \cdot \Delta\varphi / 4\pi$, where λ is the wavelength of the electromagnetic signal. The main functions of the equipment are the simultaneous detection of the position and deflection of different targets placed at different distances from the sensor. This performance is obtained by using two well-known radar techniques, i.e., the stepped-frequency continuous wave (SFCW) technique[1] and the phase interferometry technique[2]. The details will not be described in this paper, which could be checked in the literatures[3].

The radar technology, based on the abovementioned technique, was implemented in the industrially engineered microwave interferometer (IDS, IBIS-S system) used in this paper. The radar equipment (Figure 2) consists of a sensor module, a control PC and a power supply unit. The equipment radiates at a central frequency of 17.175 GHz with a maximum bandwidth of 140 MHz. The main technical and operational characteristics of the IBIS-S sensor are summarized in Table 1. Since it can measure the distances of multiple points simultaneously the high accuracy and spatial resolution, it is expected to be widely utilized in the health monitoring of civil structures.

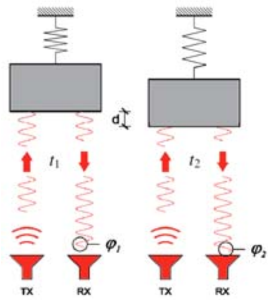

Figure1. Basic principles of radar[3]

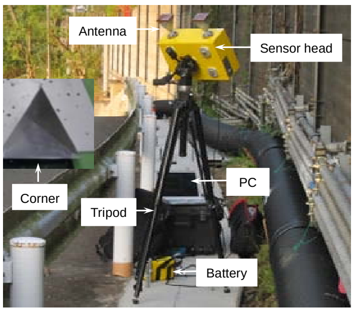

Figure 2. View of IBIS-S

Table 1. Specification of the IBIS-S

Parameter	Value
Measurement range of distance	1000 m for static, 500 m for dynamic
Range resolution	1.1 m
Maximum sampling frequency	200 Hz
Displacement accuracy	0.01 mm
Central frequency	17.175 GHz
frequency band	140 MHz
Power supply	12 VDC
Weight	14kg

3. Laboratory tests and results

Before using the radar sensor in the field on full-scale structures, various laboratory tests were carried out. The responses of sine-wave and random vibration excited by the shaking table are introduced. The test set-up was arranged by installing the corner reflector on the shaking table, in front of the radar sensor at a distance of 3.8 m. Figure 3 shows a photo of the test set-up. At the same time, a laser displacement sensor was utilized for comparison, measuring the displacement of the shaking table from about 10 cm away. First the sine-wave was applied to the shaking table. Figure 4 shows the results of

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radar and laser sensors excited using 1 Hz sine wave. The comparison clearly reveals the good agreements. To verify the performance of IBIS-S in frequency domain, random signal (white noise) was utilized to excite the shaking tables subsequently. Figure 4 shows one typical Power Spectral Density (PSD) result. In the range of [0 50] Hz, which is range of the natural frequencies of civil structures, IBIS has good performance to detect the vibration displacement. It suggests that, at least in a laboratory test, the displacement sensitivity of the sensor is close to the close-distance laser sensor.

Figure 3. Test in laboratory

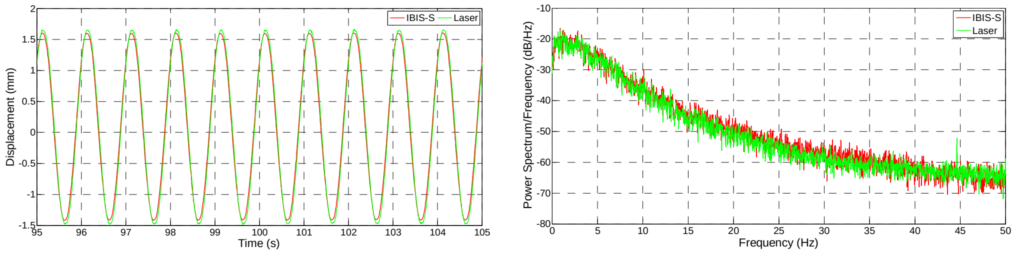

Figure 1. Comparison between the radar and laser sensor

4. Application to a cable-stayed bridge

The IBIS-S sensor was used on site during the deformation assessment of a cable-stayed bridge. Dynamic measurements on cables were carried out by simultaneously using accelerometers, Laser Doppler Velocimeter (LDV) and the radar system. The radar sensor was placed at the bridge deck and inclined 55° upward. The LDV sensor was placed nearby, shown as Figure 5. Accelerometer was attached on the cable where is close to the anchor part. It is observed that six well defined peaks clearly identify the position of cables. Simultaneously the vibration of six cables will be recorded.

Here the results of the third outermost cable are expressed. Figure 6 shows the PSD results associated to the ambient responses of this cable, obtained from measurements of abovementioned three sensors. Although the PSD results are associated to different mechanical quantities measured (displacement, velocity and acceleration), the spectral plots clearly highlight an excellent agreement in terms of local natural frequencies of the cable and are characterized by 4 equally spaced and well-defined peaks in the frequency range 0-10 Hz. The number of frequencies identified from radar was large enough to establish if the cables could be treated as a taut string, therefore accurate estimate of the cable tensions can be retrieved from the identified natural frequencies as well.

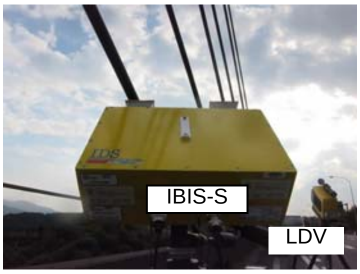

Figure 5. Radar and LDV sensor

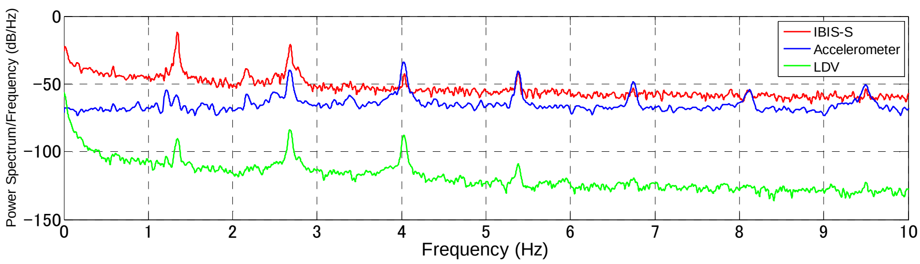

Figure 6. Comparison of power spectrum of measurement data

5. Concluding remarks

The new radar sensor exhibits excellent capability to measure the dynamic displacements of the structure. The nature of this sensor with non-contact, long-distance, multi-points simultaneous, high accurate characteristics will let it to become full of expectation in the field of structural health monitoring. Furthermore, there are also some potential obstructs existed in the practical usage, which will be challenging topics in the future.

Reference

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