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Steel detection in reinforced concrete wall by microwave infrared thermography

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ABSTRACT

This paper presents a NDT by infrared thermography with a microwave excitation system. The advantages of such stimulation lie in the volumetric absorption of incoming waves which lead to a greater sounded depth. The device generating the microwaves was made of a commercial magnetron 800 W at 2.45 GHz associated with a pyramidal horn antenna. This method was applied to detect the steel reinforcements (deformed bar 12 mm of diameter placing at every 10 cm) in a concrete specimen (1 m $\times$ 1 m $\times$ 6.5 cm) with a concrete cover of 3.8 cm. The specimen was heated with an average power of 600 W for 5 min. An infrared camera was placed on the same side as the stimulated surface and thermograms were recorded at regular intervals. The whole assembly was placed in a protective enclosure against high frequency electromagnetic fields. The method based on a contrast algorithm was used to analyze the thermogram series. The result shows a higher temperature rise in front of the steel reinforcement areas. The effect of microwave caused an increase in moderate temperature does not lead to alteration of inspected concrete.

1. Introduction

Many diagnostic methods have been developed in the field of civil engineering. They are intended to evaluate the conditions of different kinds of structures such as bridges, roads and buildings [1–8] by providing information about the internal structures or materials' conditions. Techniques based on infrared thermography are promising as they have high performance and result in the observation of thermal images that seem more accessible. Non-destructive infrared thermography has been the subject of numerous studies. The developed methods are based on the temperature output of a structure's surface correlated with a controlled heating source [9]. Many signal processing techniques have been used to extract information of thermograms [10]. The advantages of the infrared thermography methods lie on the speed of the test, faster than Cover meter that needs to scan the detected elements linearly, and Radar [11] that needs to reconstruct the images after determining the reflection and transmission coefficients. Moreover, it is simpler to get a whole image (thermogram) immediately.

With the appearance on the market of measuring equipments more robust, flexible to use and suitable for outdoor use [12], researchers are trying to transpose the existing thermography methods to civil engineering. The transition to this applications' field is done with different constraints mainly related to the size of the detected structures and the nature of the encountered materials. The Implementation of appropriate thermal stimulations remains a problem.

In this work, a microwave excitation system is used allowing to stimulate the samples in a larger surface area. It responds to the structures' size in civil engineering field. This system provides a direct microwave transmission onto the samples by diffusion with a pyramidal horn antenna, which does not require putting them in the oven cavity as the existing method [13–15]. It is also an economical solution. This new method is applied to detect the presence of steel reinforcements in a wall made of concrete, a common material used in civil engineering. At this step, our method needs a reference sample (without steel reinforcement) for calibration.

2. Microwave excitation system

Electromagnetic waves generation was carried out using a commercial magnetron at the power of 800 W and the frequency of 2.45 GHz. The generator was adapted to a horn antenna with an opening of 40° which serves to guide the microwave beam onto the tested samples. The controls' section was kept to adjust

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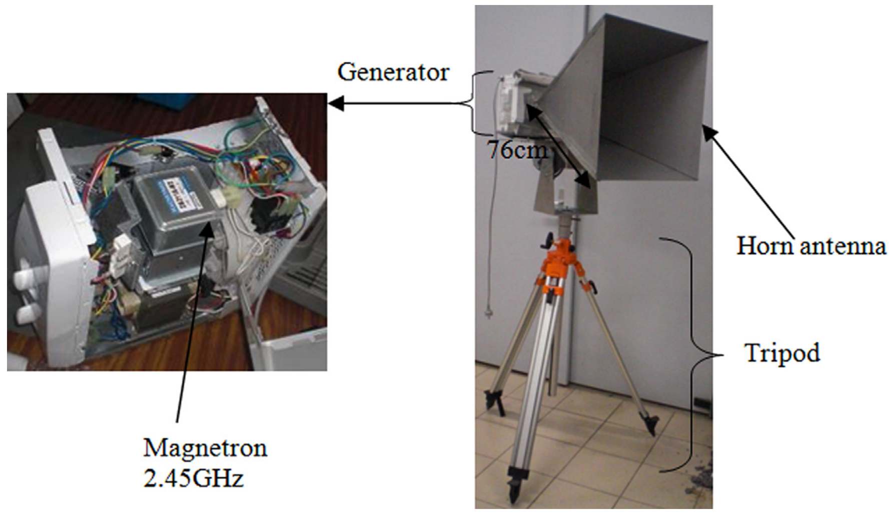

Fig. 1. Microwave excitation system.

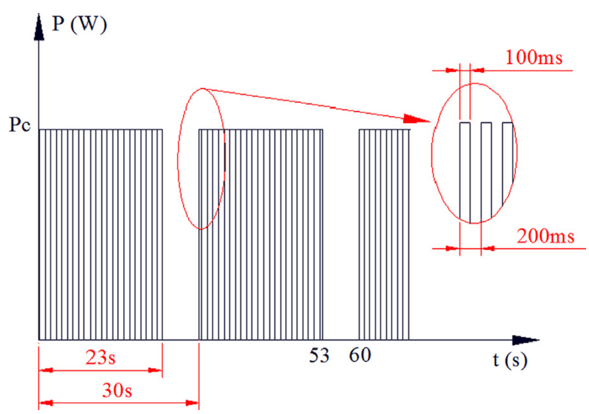

Fig. 2. Microwave signals at 600 W.

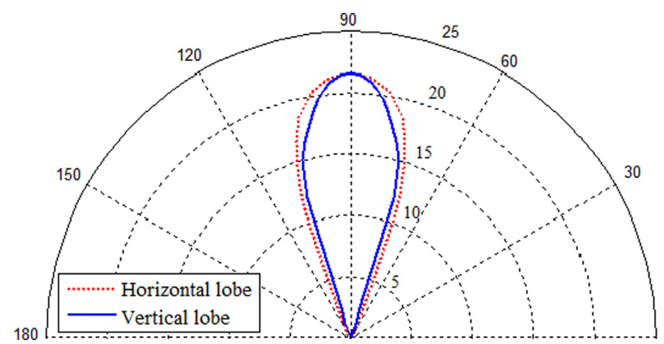

Fig. 3. Radiation pattern (principal lobes).

the emission's duration and power. The entire device was assembled on a tripod adjustable in elevation and azimuth (Fig. 1). The antenna has a gain of 21.67 dB in its main direction determined by the following relation [16,17]:

$$G_{dB} = 10 \times \mathrm{Log}_{10}[(4\pi/\lambda^2) \times \varepsilon_{ap} \times AB] \quad (1)$$

where λ wavelength (12 cm at 2.45 GHz), A, B aperture dimensions (A=59 cm, B=56 cm), ε_{ap} aperture efficiency (0.51 generally).

The control's signals from the magnetron were used as the reference to know the waveform of the power supplied to the samples. The waveform's envelope can be considered as a pulse train of variable width related to the transmitted power. Fig. 2 shows the output signal of the microwave detected by a sensor. At the average power of 600 W, it is the pulse train with a period of 30 s and pulse duration of 23 s. In each slot of the train, there is a modulation period of 200 ms and 100 ms of pulse duration.

Pc is the peak power, which can be determined by the relation in [17]: Pc=(200 ms/100 ms) · 600 W=1.2 kW.

Measurements of the microwaves' signal in the far field by a sensor (placed at 25 m from aperture) in the vertical and horizontal directions enable the radiation pattern of the antenna in a polar axis system (Fig. 3). In this figure, the horizontal lobe represents the main lobe of the microwave radiation in the magnetic field's plan (H-plan). The vertical lobe is the main lobe of the microwave radiation beam in the electric field's plan (E-plan). The heating by microwave energy concerns with the density of microwave power absorbed by dielectric material (Q) that can be determined by [18]:

$$Q = \omega\varepsilon_0\varepsilon_r''E^2 = 2p \times f \times \varepsilon_0 \times \varepsilon_r'(\tan\delta)E^2 \quad (2)$$

where E is electromagnetic field intensity; f is microwave frequency; ω is angular velocity of microwave; ε_r' is relative dielectric constant; ε_0 is dielectric constant of air; $\tan\delta$ is dielectric loss tangent coefficient.

3. Reinforced concrete samples

Two specimens were prepared; one was the concrete wall 1 m × 1 m × 6.5 cm and another one was the reinforced concrete wall of the same dimension (Fig. 4). The concrete walls were casted with water/cement/sand/coarse aggregate mixing ratio of 1:1.6:4.45:4.7 (by weight). High performance cement type I 52.5R, sand (0/4) and coarse aggregate (4/12) were used. The vertical steel reinforcements were the deformed bar 12 mm of diameter placing at the regular spacing of 10 cm (between the centers of the bars) as shown in Fig. 4(b). The concrete cover of 3.8 cm (on the tested side) was considered, which responds to the value obviously used in construction field (from 1 cm to 5 cm according to the exposure environment). The specimens were exposed to ambient room temperature and humidity for 1 month before subjected to the tests at the age of 2 months. The water ratio during the mixing step affects the dielectric constant of the concrete [18–20], thus on the penetration depth of the microwave