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# Detection of poor filling in prestressed beams specimen by inductive thermography and transfer function analysis

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## Abstract

The sounding of the tendon ducts and rebars remains difficult due to their non accessibility and the important thickness of the cover concrete layer. This paper presents an active method to evaluate the poor filling of tendon ducts by way of active infrared thermography. This experiment is performed on two laboratory specimens. The experimental set-up depicts the non contacting heating technique based on the induction. A new systemic approach based on the transfer functions analysis of the thermograms is presented. This kind of data process illustrates the interest of magnitude and dephasing images.

## Résumé

L'auscultation des gaines de précontrainte et des aciers passifs reste difficile à cause de leur non accessibilité et de l'épaisseur importante du béton de recouvrement. Cet article présente une méthode d'auscultation active par thermographie infrarouge afin de détecter le faible remplissage des gaines de précontrainte. L'expérimentation est effectuée sur deux corps d'épreuve de laboratoire. Le dispositif expérimental décrit la méthode de chauffage sans contact basée sur l'induction. Une nouvelle approche systémique basée sur l'analyse des fonctions de transfert est présentée. Ce mode de traitement des données montre l'intérêt des images d'amplitude et de déphasage.

## Keywords

concrete, civil engineering, phase, infrared, thermogram

## 1 Introduction

Many prestressed concrete construction works, such as bridges, were built during the 50's to the 70's. Nowadays, most of them require to be surveyed or need to be repaired. Many detailed inspections lead to the conclusion that the problem is the poor filling of the post-tensioned ducts and tendon corrosion due to water and potential infiltration of corrosive agents [1].

Among the non-destructive testing methods, there is no reliable technique which is able to actually replace the gammagraphy. However, that technique remains expensive and sometimes difficult to implement. Futhermore, this technique required to have a two side access of the wall under test [2].

Many studies have been conducted in order to evaluate classical NDT methods in the field of structure. Many methods are based on the propagation of mechanical or electromagnetic waves. First attempts realized with thermography method in order to evaluate the location of the prestressed tendons and reinforcement bars were performed by De Halleux and Maldague during 1998 [3]. More recent works were carried out at the BAM [4] on a concrete test specimen containing voids with different sizes at various depth.

Within the framework of the ACTENA project, the main aims are to contribute to the localization of prestressed tendon ducts or rebars and also to the detection of poor filling defects. This study has been conducted in order to evaluate the applicability of the active thermography NDT.

The principle of the method developed in this work consists in generating a dissipation of heat by the bar and in observing the thermal diffusion effect on the surface of the beam. This approach has already been used by Ostrowki [5] where Joule effect had been adopted to ensure the heat generation. Nevertheless this heating technique associated with an electric generator occasioned difficulties. Windows in concrete have to be performed because tendons would need to be accessed to realize electrical connexions. Low electrical contact resistances at these points remain hard to ensure and lead to high temperature increasement which must be avoided with concrete.

In order to avoid these drawbacks, a heating method based on the electromagnetic induction technique is proposed [6]. The defects in the beam disturb the flow of the induced current and modify the temperature distribution.

## 2 Experimental set up

A schematic drawing of the experimental setup is shown in Fig. 1.

Specimens are placed on the arms of a heating system based on a electromagnetic inductor. The camera is facing the beam and is linked with a laptop computer. The thermograms sequence is recorded by a CEDIP Silver 220 camera equipped with a 320x240 pixels InSb detector. The camera positioned at a distance of 2 meters far from the system, provides a field of view of the heated area. The thermograms are recorded during the warming-up and the cooling down processes during and after heating with the inductor.

Internal temperatures of the bar are monitored with a data acquisition system interfaced with a computer.

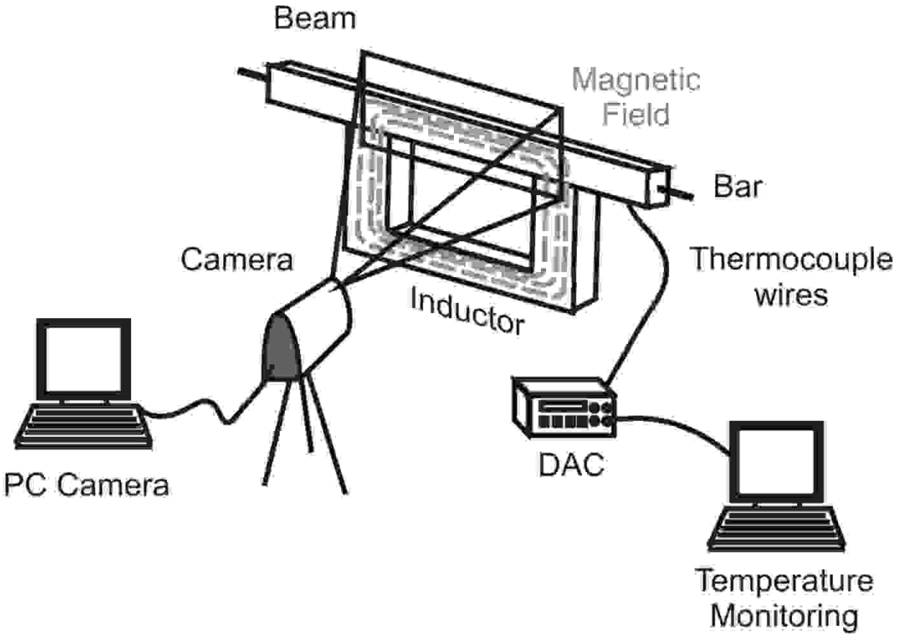


***Figure 1**. Experimental set-up*

### 2.1 Specimens

The longitudinal cross sections of the specimens used for the investigation are drawn in Fig. 2. These two beams are 1.5 metres long and have 0.1x 0.1m² sections and are made with concrete. Their formulation is identical for specimens A and B. They contain a metallic bar of 12mm diameter, coaxial in their longitudinal axis.

- The specimen A is the reference sample. It is completely filled with injection grout and not contains defects. The rebars is well stuck on the concrete on all its length.
- The specimen B contains a PCV duct of 25mm interior diameter. Only the half side of the duct is filled with grout. The other half is empty of grout to simulate a defect. Grout is made with a paste of water and cement (CEM 1).

Thermocouples was inserted on the bar every 10cm to know its temperature during the experiment.

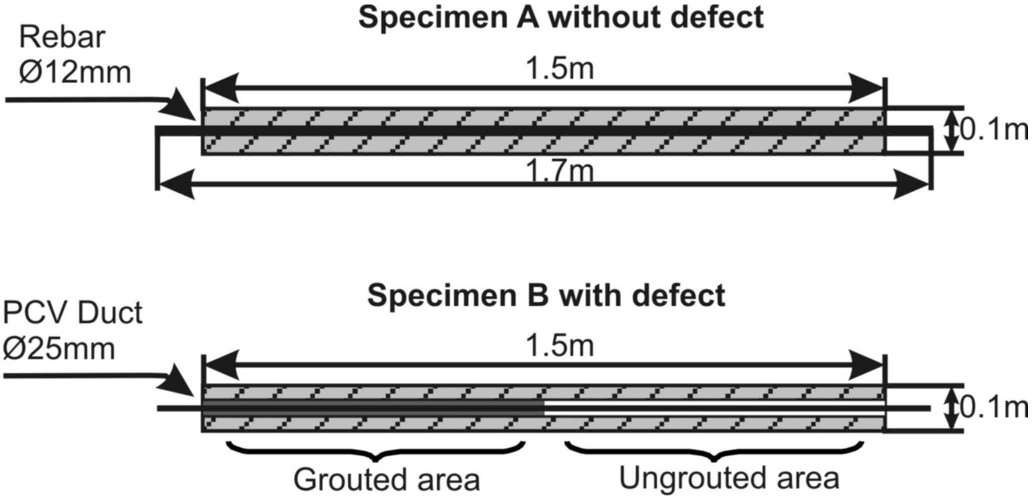


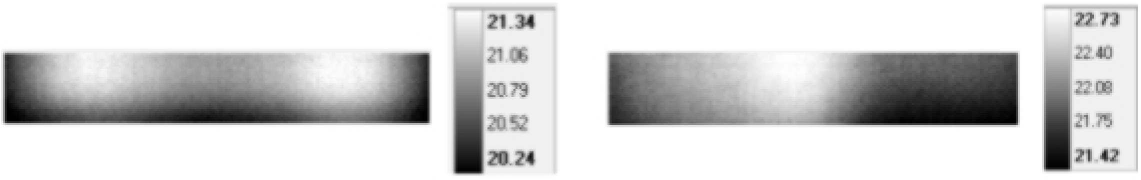
***Figure 2.*** *Specimens A et B*

### 2.2 Heating unit

The main advantages of the inductive heating are to be a non-contacting method. The metallic parts to be heated do not have to be connected with wires to an electric generator. The inductor has a U shape and is made with resonant LC circuit tuned at a 50 Hz frequency. The inductor coils generates a magnetic field which close by the metallic bar of the beam. This technique utilizes heating by electrical losses due to the eddy current. The defects in the beam disturb the heat flux and modify the temperature distribution.

## 3 Thermograms analyses

First attempts presented in Fig. 3 reveal that the inductor provides a non uniformity of the heating. This makes difficult to obtain information directly from the raw thermograms. The non uniformity of the thermal stimulation generates artefacts on the temperature field. The thermocouples have also recorded this non uniformity of the temperature profile along the metallic bar. Moreover, the FEM simulation of the magnetic behaviour of the inductor has proved that his shape yields to the non uniformity stimulation along the bar.



Specimen A
Beam without defect

Specimen B
Beam with defect

***Figure 3.*** *Raw Thermograms after 5 min heating*

The advantages of the spectral analysis have been demonstrated in infrared thermography. The works of [7-8] has proved the advantages given by the properties of amplitude and phase images in NDT's methods.

Regarding the experiment, the stimulation pulse of heat can be considered as an input signal noted x(t). The output signal can be considered as being the temporal evolution of the temperature of each pixel and is denoted $y_{i,j}(t)$. One pixel represents an elementary surface of the beam and is localized by his coordinates (i,j). The temporal functions x(t) and $y_{i,j}(t)$ denote their Fourier transforms by X(f) and $Y_{ij}(f)$ respectively.

For one pixel, corresponding to an elementary surface viewed by the detector, a transfer function $H_{ij}(f)$ can be evaluate as being the complex ratio of $Y_{ij}(f)$ / X(f). Thus, magnitude and phase images reconstruction can be performed by replacing the pixels thanks to their coordinates.

This transfer function based analysis is depicted in Fig. 4.

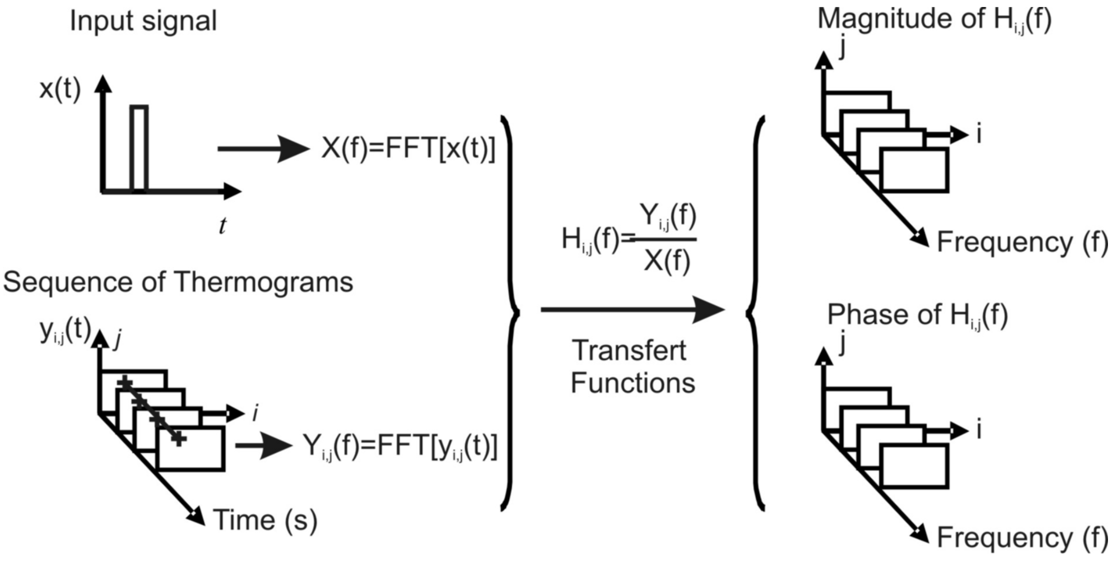
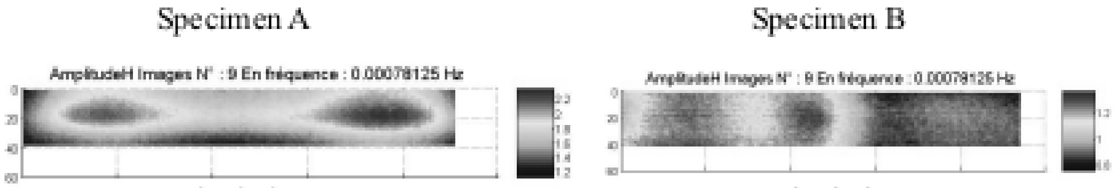


***Figure 4*** . *Transfer Function analysis of the thermograms*

## 4 Conclusion and results

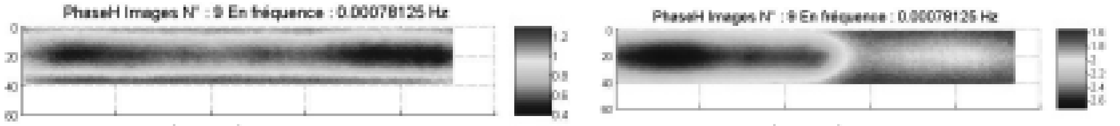
Experimental and calculus procedure applied on the two specimens lead to the results show in Fig. 5. The heating time was 5 minutes and the thermograms were recorded during 2 hours at a frame rate of 0.2 Hz in order to acquire the whole temperature evolution until the specimen returns in its initial thermal condition. This low frequency of 0.78 mHz is mostly of interest due to the short-pass band transmission characteristic of the concrete beam. Higher frequencies present a higher noise level. The upper magnitude images in fig.5 and the raw thermograms showed in Fig.3 are more affected by the non uniformity of heating than the lower phase images.

The phase image of the specimen A clearly highlights the thermal layout of the metallic rebar. The comparison of the specimen A and B phase images reveals a possible defect area on the right side of the specimen B. This suspected area is in agreement with the defect present in the beam.



Magnitude image
of the beam without defect
freq.=0.78 mHz

Magnitude image
of the beam with defect
freq.=0.78 mHz



Phase image
of the beam without defect
freq.=0.78 mHz

Phase image
of the beam with defect
freq.=0.78 mHz

***Figure 5.*** *Magnitude and phase images of specimen A and B*

Finally, this experimentation has demonstrated the applicability and the efficiency of the induction heating on a concrete beam reinforced with a metallic bar. The function transfer analysis leads to results in accordance with experimental setup. The phase images results are less sensitive to non uniformity of heating than raw thermograms and magnitude images. The major drawback remains the relative slowness of the procedure when dealing with materials of civil engineering. Further studies should focus on the design of the inductor and the heating time optimization.

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