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Use of the active thermography for the detection of cracks in metal structures of nuclear power plants

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Abstract— **The continuous operation of nuclear power generation plants can accelerate the fatigue phenomena of their metal structures and reveals the cracks. The Nondestructive control and preventive maintenance are highly demanded in these central to avoid nuclear accidents that have very serious consequences on the environment. In the present work we are interested in detecting by active infrared thermography the vertical cracks that are frequently encountered in the metal structures of nuclear power plants. We used the finite element method to simulate the controlled structures of nuclear plants The obtained results are in the form of thermal image. From these images, we have developed a numerical model to estimate the depth of the vertical cracks located at different depths.**

Key-word: Infrared thermography, Nondestructive control, environnement,* the finite element method, *nuclear plants

I. INTRODUCTION

Early detection of surface defects by non-destructive thermal control allows a relevant preventive maintenance of nuclear facilities to avoid accidents that can have serious consequences on the environment and human lives, so specialists can repair or replace the prematurely suspicious components in service.

The use of nuclear energy in modern industry is very important in industrialized countries that need a lot of energy. The fatigue phenomenon is inherent to metal structures, it is a major concern of nuclear energy industrialists.

The active infrared thermography is a method of non-destructive inspection; it is used in the detection of cracks on the surface or inside of the metal **[10]**. It is fast, contactless and allows the inspection of large surface. In its application, the active thermography compares favorably with conventional inspection technologies in terms of sensitivity and speed **[2]**. The quantitative characterization of the structures and materials by this technique enables the detection of defects and the extraction of their depths, sizes and also their thermal properties **[3-4].**

As part of preventive nondestructive testing of metal structures of nuclear power plants. We will use the method of 3D finite elements to simulate the presence of perpendicular cracks in the inspected surface .We will consider three samples of different metals. Each sample is infected with a subcutaneous crack located at shallow depths. We will propose a model to estimate the depth of this defect type in the metals from the value of the relative filtered thermal contrast.

II. DESCRIPTION OF CONTROLLED STRUCTURE

The control system is carried out on metal structures, for the demanding nuclear industry in quality assurance. These metal structures contain vertical cracks that are difficult to detect **[6],** because they are oriented parallel to the direction of propagation of the thermal front in the material to be inspected.

In the studied structure (figure 1), the crack has the thermal effusivity e_1 and is located in the depth L_{def} from the control surface. The structure is heated by a heat flow Q during a small time interval; its lateral faces are thermally insulated.

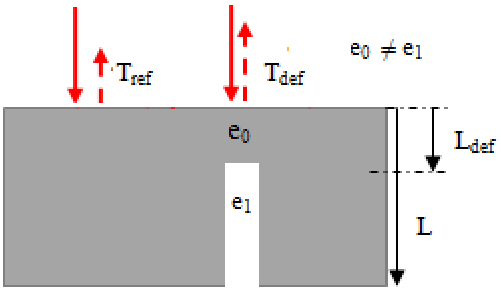


Figure 1: Diagram of an infected structure of a vertical crack

In our configuration we will use the concept of thermal effusivity to reveal the presence of cracks. The thermal effusivity of a material characterizes its ability to exchange thermal energy with its environment. It is given and defined as: [**9**]:

$$e_i = \sqrt{k_i.\rho_i.c_i} \qquad \textbf{(1)}$$

Where k is the thermal conductivity, ρ is the density and c is the specific heat of the material. The heat flow through the interface between two media is influenced by the ratio of their effusivity.

For a material with effusivity e_0, which contains an effusivity defect with e_1 we will use the reflection coefficient Γ which is defined by, [**9**]:

$$\Gamma = \frac{e_0 - e_1}{e_1 + e_0} \qquad \textbf{(2)}$$

- Γ is approximately 1 if the materiel has a thermal effusivity e_1 much lower than that of the defect.

- Γ is about -1 if the materiel has a thermal effusivity e_1 much higher than that of the defect.

- Γ is 0 to two layers of a same thermal effusivity.

Moreover, if the defect effusivity is less than the materiel effusivity, the temperature on defective surface T_{def} (t) is higher than the defect free zone temperature T_{ref} (t). This is the case for a crack (the presence of air) (Fig 1). Thus, by calculating the temperature distribution of the surface of a controlled structure, thermal footprint will reveal the presence of defects.

III. RELATIVE FILTRED TERMAL CONTRAST

The study initially focused on reducing the heterogeneity of Thermosignal by calculating the temperature distribution of a defect-free surface T_{ref} (t) (reference), and subtracting the surface temperature of the part to be inspected T_{def} (t). This treatment eliminates the heterogeneity of Thermosignal while preserving thermal prints defects. Indeed, we used a new type of thermal contrast RIFC (t), called "relative filtered thermal contrast ", this contrast is less sensitive to non-uniformity of the temperature distribution at the surface of the inspected material [**7-8**]. The relative filtered thermal contrast RIFC (t) is defined by [**9**]:

$$RIFC(t) = \frac{T_{def}(t) - T_{ref}(t)}{T_{ref}(t)} \qquad \textbf{(3)}$$

IV. SIMULATION OF STUDIED STRUCTURE

After defining the parameters required for non-destructive thermal control, we will simulate the presence of defects (cracks) in metal structures. The cracks are located at different depths. In figure 2 we reported the triangular mesh structure studied by the finite element method 3D

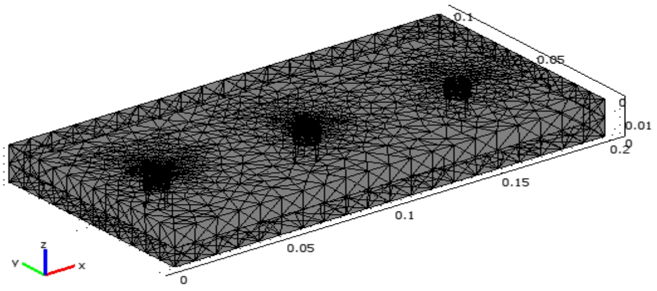


Figure 2: mesh structure studied by the finite element method 3D

We considered three samples of different metals (steel, aluminum and copper) which are often used in different parts of nuclear power plants: either in pipes or tanks. The Samples are with dimensions 200mm x 100mm x 20mm; each sample contains three round defects with a diameter of 5 mm. These defects are located at depths L_{def} = 1mm, L_{def} =2mm and L_{def} = 3 mm (Figure 2) .The thermal properties of the materials considered in this study as well as the reflection coefficient Γ for each metal are shown in Table 1.

TABLE 1: The thermal properties of the materials considered

Matériau	k (W/m.K)	ρ (kg/m^3)	c (J /Kg.K)	e (J/K.m^2.s$^{1/2}$)	Γ Métal-air
Acier	44.5	7850	475	12881.	0.9997
Aluminum	160	880	2800	19855	0.9998
Cuivre	380	8900	380	35849	0.9999
Air	0.002	1.184	1007	17436	-

The simulations were carried out with a flux density equal to 6000 W / m^2 for a period of 0.5s. For the studied samples, we reported on the figures below the variations of the filtered relative thermal contrast as a function of time for three considered depths L_{def} (Figures a, c and e). We also represented their thermal maps in Figures (b, d and f)

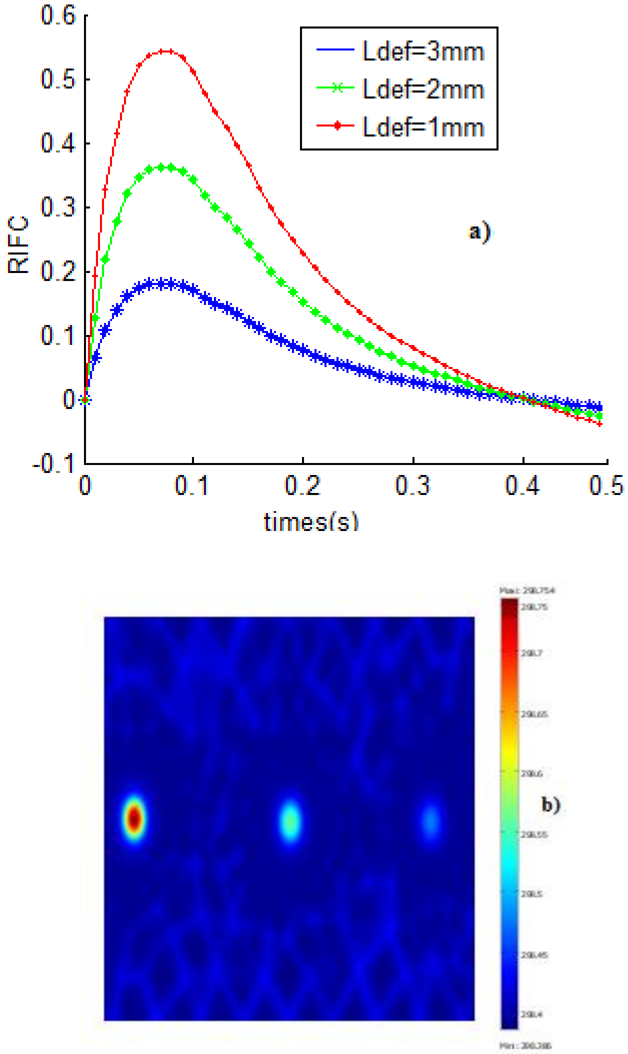
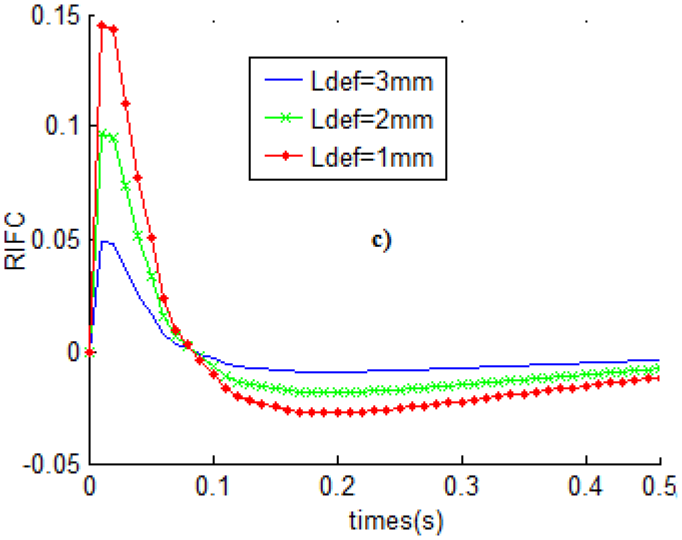


Figure 3: variations of the filtered relative Thermal contrast versus time for the steel sample; b) thermal image of the controlled face t = 0.5s



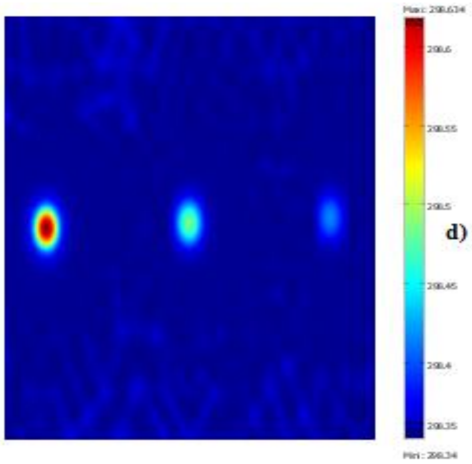


Figure 4: a) variations of the filtered relative Thermal contrast versus time for the aluminum sample; b) thermal image of the controlled face t = 0.5s

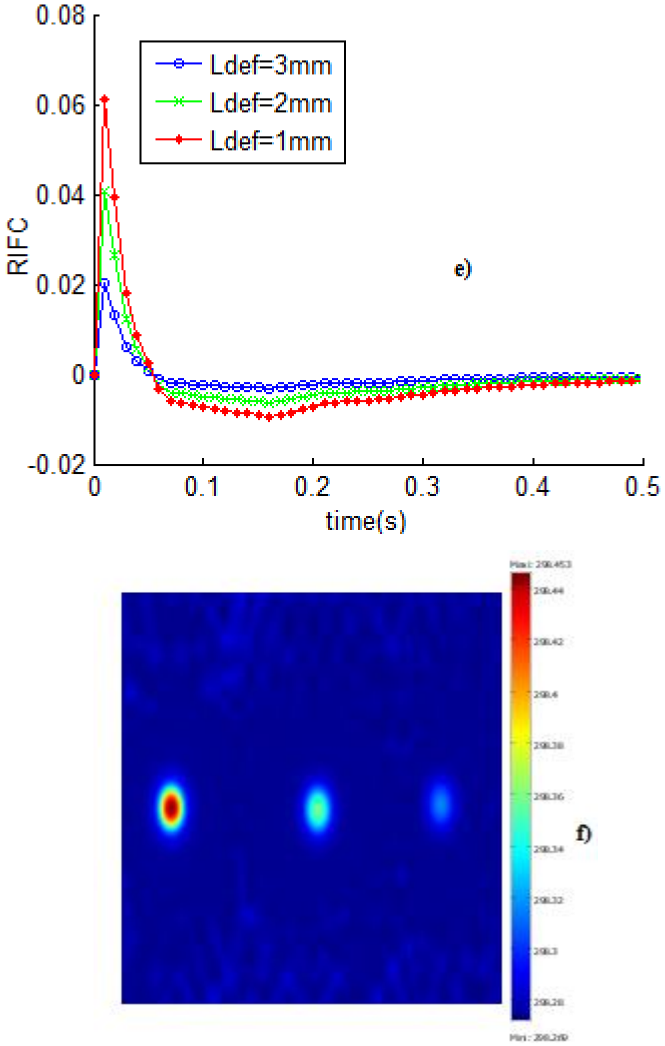


Figure 5: a) variations of the filtered relative Thermal contrast versus time for the copper sample; b) thermal image of the controlled face t = 0.5s

We notice firstly that for the three samples the relative filtered thermal contrast passes through a maximum for each depth of the crack. On the other hand, for the same depth the contrast changes depends on the type of metal. In general, a near surface crack is detected better than a deep crack in the structure.

The aim of our non-destructive testing is to estimate the depth of the defect from the thermal image provided by infrared cameras. Taking into account the variation of values of the filtered thermal contrast and values of the reflection coefficient for the three studied samples; we suggest a graphic model to estimate the depth of cracks L_{def} from the maximum value of the relative filtered thermal contrast $RIFC_m$:

$$L_{def} = A(R)\,RIFC_m + B(R) \qquad (4)$$

Avec:

- *L_{def}: The estimated value of the defect depth,*
- *$RIFC_m$: the maximum value of the filtered relative thermal contrast*

Where:

- The coefficients A(R) and B(R) are given by:

$$A(R) = [6.72.R^2 - 0.013.R].10^{10} \qquad (5)$$

$$B(R) = [- 4.1.R^2 +0.008.R].10^6 \qquad (6)$$

V. CONCLUSION

The control system introduced by active thermography can detect and quantify cracks inside metal structures of nuclear plants.. The technique consists of displaying by means of a thermal camera the reaction of the surface of the structure after a thermal stimulation.

In this article, we simulated the detection of vertical cracks often encountered in the metal structures of nuclear power plants, using a new contrast of the infrared thermography called filtered thermal contrast. We proposed a model to estimate the depth of a vertical crack located at a shallow depth within a metal structure from the filtered thermal contrast. This model that considers the thermal diffusivity allows preventive maintenance to avoid nuclear accidents.

REFERENCES

[1] Maldague Xavier PV. Theory and practice of infrared technology for non- destructive testing. John wiley & Sons; 2001

[2] Steven M. Shepard, Flash thermography of aerospace composites, in: IV Conferencia Panamericana de END Buenos Aires, Octubre 2007.

[3] D.P. Almond, S.K. Lau, Defect sizing by transient thermography I. An analytical treatment, J. Phys. D Appl. Phys. 27 (5) (1994) 1063–1069.

[4] J.G. Sun, Analysis of pulsed thermography methods for defect depth prediction, J. Heat Transfer 128 (4) (2006) 329.

[5] Maldague X. Nondestructive evaluation of materials by infrared thermogra- phy. New York: Springer; 1993.

[6] Chiwu Bu, Qingju Tang, Yuanlin Liu, Xiangyang Jin, Zhihui Sun, Zugen Yan, A Theoretical Study on Vertical Finite Cracks Detection Using Pulsed Laser ,Spot Thermography (PLST*), Infrared Physics & Technology,* 29 January 2015

[7] S. Grys, New thermal contrast definition for defect characterisation by active thermography, Measurement 45 (2012) 1885–1892

[8] . Grys, Filtered thermal contrast based technique for testing of material by infrared thermography, Opto-Electron. Rev. 19 (2) (2011)234–241

[9] S. Grys , W. Minkina L. Vokorokos Automated characterisation of subsurface defects by active IR thermographic testing – Discussion of step heating duration and defect depth determination *nfrared Physics & Technology,*

[10] A.Elhassnaoui , A Saifi, A.El Amiri[1], S Sahnoun[1],Pulsed thermography model for detecting the internal ferritic steel crack ,An International journal