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Direction : DTA/CEREM
Département : DTM
Centre : SACLAY
Serv/Sect : STA
Référence : STA/LCME-93/76

Nature du document : Résumé ☐ Texte complet ☒

DL 608 IN. FR 9601569

Réf. DTM/Dir : 93/1349

Titre original du document : Crack detection by mobile photothermal probe

Titre français : Détection de fissures par sonde photothermique mobile

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COMMUNICATION ☒ { Nom : 12th International Conference & Exhibits on Nondestructive Evaluation in the Nuclear and Pressure Vessel Industries

à Conférence ou Congrès { Ville : Philadelphie Pays : Pennsylvanie

ou { Organisateur : The Materials Information Society

POSTER ☐ { Date début : 11/10/93 Date fin : 13/10/93

PERIODIQUE ☐ { Titre :

OUVRAGE ☐ { Editeur :

LIVRE ☐ { Collection :

THESE ☐ { Titre :

RAPPORT CEA ☐ { Université :

MEMOIRE DE STAGE ☐ { ou Etablissement d'enseignement :

COURS ☐ { Date début Date fin :

Langue : ☐ Français ☒ Anglais

Domaines scientifiques : 0315

Elément de programme : 52374

CONF-- 12336

ACCORDS	Dates Demandes	Dates Accords	Demandes sans objet	Observations
SPIn				
Coordonnateur filière CRE		30.7.93		
Partenaires				

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ACCORDS DTM	Sigle	Nom	Date	Visa	Observations
Chef Service	STA/DIR	JL. BOUTARD	26.6.93		
Chef du Département	DTM/Dir	P. PETREQUIN	3/8/93		

Copie à : INSTN/MIST/CIRST CE-S -

CRACK DETECTION BY MOBILE PHOTOTHERMAL PROBE

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Abstract

Within the frame of a previous study, encouraging results were obtained regarding the detection of microcracks by Photo Thermal Radiometry under sinusoidal excitation [5, 6]. However, the used method was too slow for an industrial application. It was therefore necessary to consider faster means of analysis. Such is the object of the present study.

We show that, by using a mobile photothermal probe displaced relatively to the sample, it is possible to rapidly detect opened or non opened cracks, of a few tens of micrometers wide, and a few hundred of micrometers deep.

The problem of crack detection has long been a center of interest for metallurgists and the sector of energy production (steam generators). It is possible to measure the importance of that industrial problem by the number of studies undertaken and the diversity of suggested techniques. Among those which are non destructive, control methods that use thermal waves, and particularly the photothermal radiometry, are developing [1 to 7].

Dring a previous study, carried out opened the use of photothermal radiometry under sinusoidal excitation, our team was able to obtain a certain number of encouraging results in that field [5, 6]. Simulations involving the numerical method of finite elements, first clearly highlighted the possibility, with that method, to detect opened cracks, either at the surface of the sample, or covered with a thin coating. These possibilities were later confirmed by experimental study. Opened microcracks (5 µm wide and 100 µm deep), either at the surface of the sample, or covered with a thin layer (16 µm) of polyurethane paint, have been so detected.

However, the used experimental procedure was not well adapted to industrial inspection. Indeed, requiring an interruption on each measurement point, it led, for the exploration of extended areas, to relatively long observation times. It was advisable, and such is the object of the present study, to develop a faster method.

Basing ourselves once again on theoretical simulations, we first chose a faster analysis mode. We then designed and developed a new photothermal device. The latter uses, for excitation, a laser beam submitted to a deflection and, for detection, an infrared thermographic camera, equipped with a thermomicroscope, and operating in line scanning mode.

Last, we estimated the performances of that device, by controlling samples that contained thin opened or non opened cracks, with a few tens of micrometers wide, and a few hundred of micrometers deep.

Comparison between sinusoidal, pulsed, and scanned excitation modes

As a general rule, in unstationary thermics one obtains, under pulsed excitation, a response which is generally faster and richer in information than under monofrequential sinusoidal excitation. This is the reason why we started out by simulating the case of a pulsed excitation, by keeping the same excitation advancing procedure as before : after each step, a luminous pulse is

sent onto the sample, then the surface temperature is observed until recovery to the initial thermal equilibrium.

This method still remains slow, given the duration of unstationary regimes. So we examined another, pseudo-pulsed, mode of excitation. For the latter, the sample is being displaced relatively to the source of excitation, which is, as for itself, continuous. The source of excitation then shifts at each step onto the next surface element, without waiting for thermal equilibrium (for calculation needs, but also for experimental reasons, we keep a discrete displacement of the sample). The advance velocity is then determined by the operator and is no more conditioned by the cooling down kinetics of the sample. It can therefore be relatively rapid.

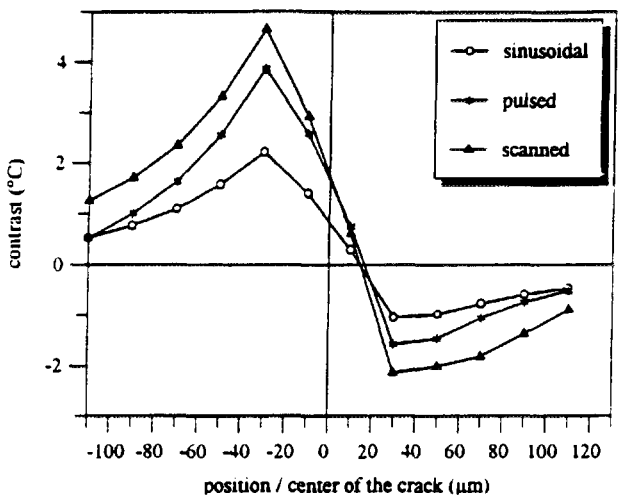

Fig. 1 : Profile of absolute thermal contrasts, obtained in all three modes of excitation, plotted along a straight line perpendicular to the crack

All three methods were compared in analogous experimental situations. The temperatures were calculated on the same types of samples. One of those samples is healthy, the other one presents a opened crack, perpendicular to the surface, with 20 µm wide and 100 µm deep. The limit conditions applied in each case are identical (except, of course, for what concerns the energy deposit mode). For an easier comparison of all three methods, we have plotted on figure 1, the profiles of absolute temperature contrasts (defined as being equal to the difference between the profiles obtained on cracked and healthy samples), at the representative moment when the excitation zone is on the edge of the crack. On that figure, we observe that the contrast profile is similar for all three types of excitation. It results from a "thermal barrier" effect due to the crack. The latter having a lower thermal conductivity, it tends to oppose itself to the diffusion of the heat flux, which results in an increase (relatively to the signal obtained when there is no crack) of the temperature on the excited side, and by a decrease on the opposite side. The pseudo-pulsed case being the fastest experimental mode, it is the one we chose to implement.

Design and development of the "mobile" photothermal probe device

After having highlighted the interest of a control mode through a continuous displacement of the photothermal probe relatively to the sample, it was necessary to design and then develop the instrumentation enabling to implement it.

Concerning the detection means, we chose to use an infrared thermographic camera (the 880 "long wave" AGEMA Thermovision, sensitive between 8 and 14 µm), which was a priori interesting from several points of view. First of all, such a system allows an analysis which is rapid and rich in information. Moreover, it is easy to implement and to operate, given the various optical accessories and data systems available (AGEMA optics, SAFIR system).

Concerning the choice of the infrared radiation collection optics, we selected the 880 AGEMA thermomicroscope. The latter, with an observation field of 1.6 mm, and a resolution of 12.5 µm per pixel, allows a good description of the observed photothermal signatures whose width, for the dimensions of studied cracks, is typically of a few hundred micrometers.

A prior theoretical study made it possible to show that, for the displacement velocity of the photothermal probe considered here (62.5 mm / sec), the thermal contrast of a point located in the immediate vicinity of the crack returned to zero in a few milliseconds. To obtain a temporal resolution sufficient for the analysis of thermograms, it is thus advisable to use the line scanning mode (period of 200 µs instead of 40 ms for complete images) for thermogram acquisition. In that case the obtained thermogram will no more represent, as in the standard operating mode of the camera, a "photograph" at a given time of the thermal scene. But it will represent the evolution throughout time (successive lines on the screen), of photothermal signals coming from the same spatial line.

Last, in order to perform, with the chosen detection system which remains steady, a relative displacement of the photothermal probe (excitation / detection couple), relatively to the sample, we had to realize a deflection of the exciting laser beam. For that purpose, we chose to

use a linear motor (designed from a loudspeaker), over-topped with a reflection mirror, enabling a relatively precise and fast displacement of the excitating spot.

The experimental device is schematically represented on figure 2.

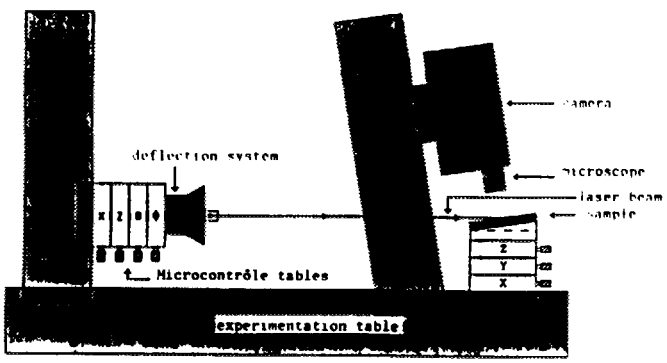

Fig. 2 : the experimental device

The experimental procedure that was applied consists in causing the exciting light spot to advance step by step, and by 12.5 µm gaps, along a line which is perpendicular to the crack of the sample (which itself is steady). At each step, synchronized with each line scanning start of the camera (every 200 µs), a thermogram line is acquired.

Such a procedure makes it possible to obtain, as we shall see, a thermogram which is very rich in information. At the initial moment, the exciting light spot is brought onto the first surface element of the line to control (on the left of the line observed by the camera) ; at the same moment, the camera seizes the thermal signal produced by the various surface elements of the controlled line, and creates the first line of the synthetical thermogram : the first pixel of that line then represents the photothermal signal coming from the surface element of the line to control located under the excitation center. At the next time step, the excitation advances by 12.5 µm and the camera creates the second line of the synthetical thermogram ; the photothermal response of the new excited surface element appears on the second pixel.
This is how, time step after time step, the global thermogram is created, and the instant photothermal responses of successively excited surface elements describe the whole main diagonal (figure 3).

On the same way, secondary diagonals, below and above the main diagonal, respectively represent the photothermal response of successive surface elements of the sample, one time step before or after they have been excited by the mobile light spot. It is then possible to extrapolate these conclusions to all the secondary diagonals of the image. We here note how complete the information provided by such a device can be. It actually enables to have access simultaneously to the results that would be produced by different experimental configurations which could be considered for the excitation / detection couple.

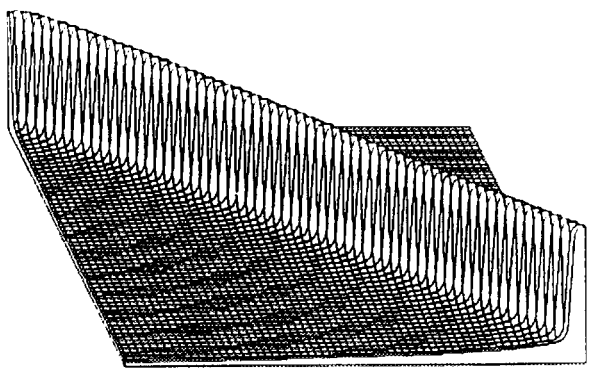

Fig 3 : Theoretical thermogram obtained during the study of a healthy sample

Theoretical and experimental results

During various operation tests, we were first able to test the main characteristics of our device : dimensions of the exciting light spot, advancement velocity, scan amplitude.

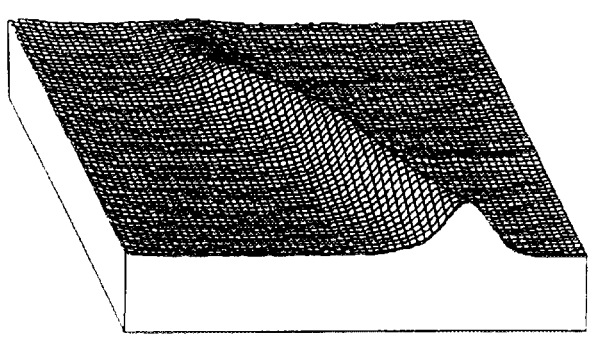

Fig. 4 : Experimental thermogram obtained during the study of a healthy sample

Figure 4 is a 3D representation of the synthetic thermogram obtained in the case of a healthy metallic sample, coated with a thin layer of black paint (in order to increase the photothermal signal). It is possible to observe on that diagram the instant photothermal responses produced by successively excited surface elements ; the maximum of each one, according to the exciting light spot, indeed describes a trajectory close to the main diagonal, as we have seen before.

The different theoretical and experimental results

obtained later on, with that experimental device, show that the method and the device enable rapid detection of opened or non opened cracks, a few tens of micrometers wide and a few hundred of micrometers deep. To give a good illustration of the aptitudes of both the method and the device, we present on figures 5 and 6, the theoretical and experimental diagrams, obtained during the study of a crack coated with a thin layer of paint (about 20 µm thick). This case is probably the one that involves the most complex thermal phenomena, as well as the one for which the defect detection is the least easy.

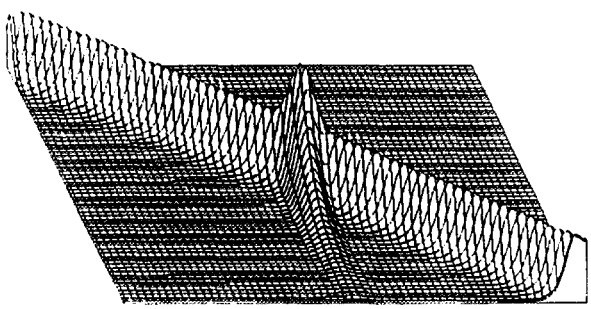

Fig. 5 : Theoritical thermogram obtained during the study of a sample containing a non opened crack 100 µm wide and 5 mm deep

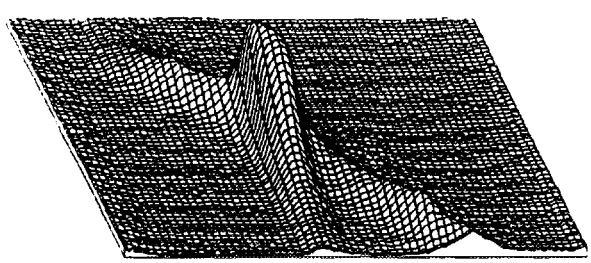

Fig. 6 : Experimental thermogram obtained during the study of a sample containing a non opened crack 100 µm wide and 5 mm deep

Both representations, theoretical and experimental, are remarkably similar. The latter produce two bands of thermosignals with higher values, one according to the diagonal of the image, and the other one according to a vertical trace crossing the first one and extending towards the bottom of the image. The first trace is due, as for figure 4, to the heating that comes along with the displacement of the light spot on the coating. The second trace is characteristic of the presence of a crack in the controlled sample. Due to its presence under the coating, the crack tends to slow down the heat flux coming from the near excitation (this one can be upstream, downstream, or straight on the crack). That causes a thermosignal peak at the level of the crack. Such a peak is very important when the light spot is right above the crack (at the intersection of both traces), it then decreases when it moves away from the crack after having passed it.

Conclusion

This study being over, a number of conclusions can be drawn from it.

First, the method and the device are able to allow the rapid detection of thin cracks, even in the most difficult case where they are coated with a dielectric layer.

Then, we may now consider, from the confrontation between theory and experience, whose we got an idea, to go further into the process of the dimensional characterization of cracks.

Last, from this laboratory device and the richness of information it is able to provide, it becomes possible to design and develop other devices, which will be intended for industrial applications, taking into account their own constraints.

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