DETECTION OF OPEN CRACKS BY A PHOTOTHERMAL CAMERA

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INTRODUCTION

The number of methods which allows for non destructive testings of opening cracks is always increasing but, for industrial applications, the visual testings are still the most widely used especially during the processing steps and the maintenance operations. Among these visual techniques, penetrant testing is one of the most popular methods because its cost is very low and its versatility is large. Nevertheless, sometimes, this simple technique cannot be used. A few typical cases should be mentionned : unsecured human interventions, forbidden contact with the surface specimen, possibility of false alarms when the surface roughness is important, necessity of an automatised control.

The results obtained with the photothermal camera and presented in this paper aim to demonstrate that in such cases, this special infrared camera is a convenient industrial alternative to penetrant testings on metallic surfaces.

PRINCIPLE OF THE PHOTOTHERMAL CAMERA

It is well-known that quantitative infrared thermography consists in the measurement of the time evolution of the surface temperature of a specimen after having imposed a pulsed heating. In its classical version, this pulsed heating is achieved by a transient uniform illumination of the surface [1]. Since, in this case, the heating is uniform, the surface temperature evolution corresponding to heat diffusion normal to the surface, is only sensitive to defects mainly parallel to the surface, such as delaminations, and thus cannot reveal the cracks which are generally oriented normally to the surface.

With the photothermal camera, the surface heating of the surface is achieved by the absorption of the focused beam of a CW laser which scans the surface. By this way, the surface heating is transient (due to the scanning) and localised (due to the focused spot). This localisation of the heating allows for a three dimensional heat diffusion in the specimen which is sensitive to the defects perpendicular to the surface [2]. The infrared emission of the surface is monitored by an infrared sensor whose image scans also the sample surface at the same velocity as the laser spot and with an adjustable offset.

To simplify the explanations, let us assume that the image of the infrared sensor follows the laser spot during the surface scanning. Far from any crack, the temperature measured by the infrared detector is equal to a value that we will call the standard value. This value is depending upon experimental parameters, such as the scanning velocity, the power and the radius of the laser spot, the offset between the laser and the detected spots. When the laser spot approaches an opening crack from its left side, the surface temperature at the point where the infrared emission is detected (detected temperature) increases since the heat diffusion is strongly reduced in the direction of the crack. Just after this temperature increase, the crack passes between the laser spot and the detected spot. Then, the detected temperature decreases fastly since the crack prevents the heat deposited by the laser to reach the detected point. Finally, both the laser spot and the detected spot pass on the right side of the crack and the detected temperature recovers its standard value. This increase/decrease of the detected temperature from part to part of the standard temperature is called the thermal signature of the crack.

A complete model of this thermal signature has been established and its contrast can be optimised by adjusting the different experimental parameters previously mentionned. This model is especially important to define the laser power which is necessary on a given material, taking into account the thermal properties of the inspected metal and the velocity of inspection which is required by the industrial application.

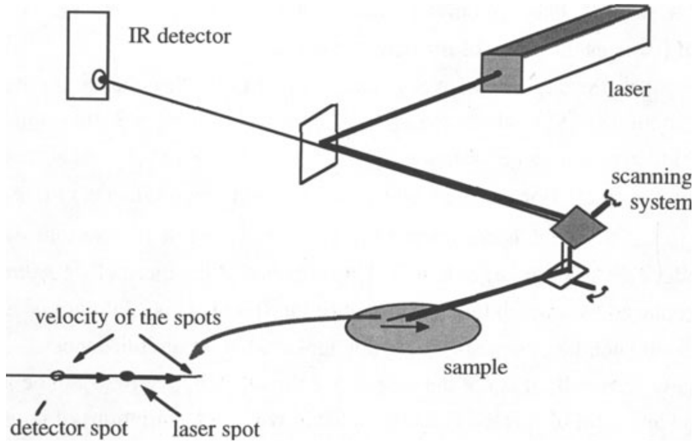

Figure 1. Principle of the photothermal camera also called flying spot.

THE BLACK BODY EFFECT

Actually the signal S(x) delivered by the photothermal camera is not the local temperature at the detected spot but the infrared emission of this point x. The crucial problem of all the thermal cameras is to recover the temperature from the infrared emission or, in other words, to know the local emissivity $\varepsilon(x)$ of the inspected surface.

Assuming for simplicity that the optical axis of the camera is parallel to the normal at the surface, the general expression of the signal S(x) can be written:

$$S(x) = \varepsilon(x)\left[\int_{\lambda_1}^{\lambda_2} L_\lambda^0(T)\, d\lambda\right] \delta S . \delta\Omega \tag{1}$$

where $L_\lambda^0(T)$ is the spectral illuminance of the black body at temperature T,
δS is the surface of the detected spot,
$\delta\Omega$ is the solid angle,
λ_1 and λ_2 are the limits of the wavelength bandpass of the camera.

The simplicity of this expression, only due to its writing, actually hides a rather complex problem : the temperature T depends on the energy deposited at times preceding the detection, i.e. depends on the values of the surface absorption at all the points scanned before point x. Of course, in this expression the weights of the points close to x are much larger than the ones of those which are far from x, nevertheless, it is clear that the surface state, not only at point x but also in a relatively large vicinity around it, influences the value of the detected signal.

Moreover, the expression of S(x) has an important consequence for the detection of cracks : though $L_{\lambda}^{0}(T)$ contains the thermal signature of the crack, this signature is generally hidden by the large variations of the local emissivity $\varepsilon(x)$ and absorption $\alpha(x)$ produced by the crack. For instance, on a polished metal the product $\varepsilon(x)\ \alpha(x)$ varies from 10^{-2} to 1 if the crack is considered as a black body, while the thermal signature cannot produce a variation larger than 2. That means that the thermal signature of cracks is always replaced by a much larger increase of the signal. This could not be a real inconvenient if such large signals would not appear in other circumstances. Unfortunately, generally it is not the case, since the black body effect can be also observed on any kind of surface defect associated with local variations of α or/and ε. This occurs, for instance, when scratches pass under the spots of the photothermal camera, i.e. when the surface is not perfectly polished which is always the case on industrial metallic surfaces. This result probably explains why, up to now, no industrial applications of the photothermal camera have been developed.

To recover the thermal signature, a special procedure is necessary. This procedure includes several steps :

- the use of several scannings with both different offsets between the spots and modifications of the pump distribution,
- a weighted combination of these different scannings.

This procedure is being patented. In the next section, we present a few experimental results which demonstrate its efficiency .

SPECIFICATIONS OF THE CAMERA AND EXPERIMENTAL RESULTS

The pump used to produce the temperature increase is a 1 kW CW YAG laser. The shape of the spot on the inspected surface is line of 10 mm X 100 μm. The distribution is not gaussian.

The infrared sensor is a short wavelength MCT focal plane 128 X 128 pixels, with dimensions of the pixel equal to 50 X 50 μm. The germanium optics components have large apertures and an autofocus allows to keep the focused spots on the surface during the scanning. The work distance between the last objective and the structure is about 50cm.

The scanning velocity can reach 2 cm/s which leads to a maximum velocity of inspection of 25 cm^2/s. The spatial resolution is about 100 μm.

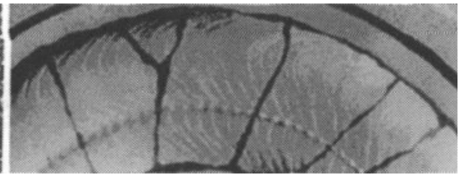

Figure 2. View of the inspected sample. Figure 3. Penetrant testing of the sample

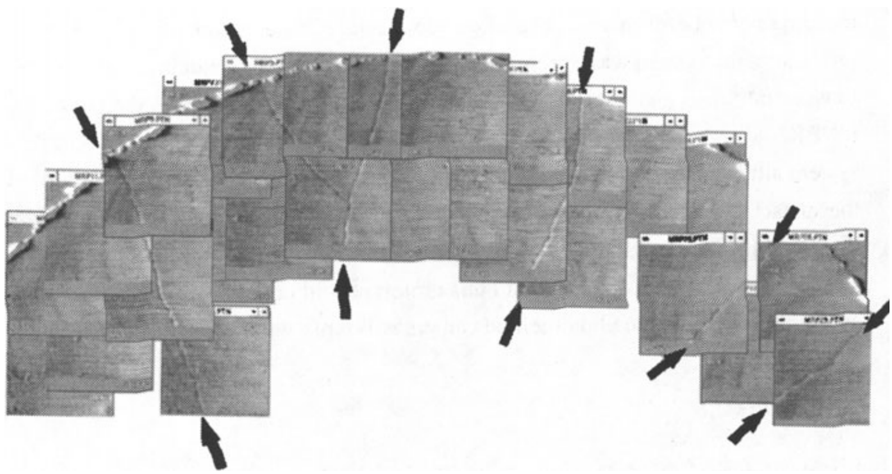

Figure 4. Photothermal image of the sample

The performances of this system are illustrated in figures 2,3 and 4. The inspected object is a piece of steel (XC38) plasma coated with an alloy containing iron and chromium in which cracks of openings ranging from 1 to 15 μm have been generated. It is interesting to note that the plasma coating surface presents an important roughness which is clearly visible in figure 2. Figure 3 is a photography which shows the results of penetrants inspection in the region of the plasma coating : five openings craks are detected without any ambiguity, the external diameter of the coating also produces a signal. Figure 4 is the result obtained with the photothermal camera : the five opening cracks are detected with the thermal signature which is represented in the grey scale used by the lines black/white posionned between the arrows in figure 3. The external diameter presents the same thermal signature which confirms the result obtained with the penetrants. Finally, no false alarms are produced by the roughness which is almost invisible in the photothermal image.

Several measurements on calibrated cracks (openings measured with a microscope) have shown that the limit of detection of this camera is probably better that the one of the penetrants. It is difficult to quantify this limit but openings smaller than 1 μm have been detected clearly.

CONCLUSION

The photothermal camera is a method known for more than thirty years but the technique did not reach an industrial development because, without any adapted procedure, the system was enable to discreminate craks from scratches, i.e. was enable to work on rough metallic surfaces. The procedure developed by FRAMATOME and ONERA allows to recover the thermal signature produced by cracks and makes the system almost unsensitive to optical effects (called here black body effect) produced by the surface defects. A prototype of this photothermal camera is now built and used in the FRAMATOME plant of St Marcel (France) for the inspection of large stainless steel structures. The results obtained with this prototype will define in a next future the conditions in which the photothermal camera will replace the use of penetrants.

REFERENCES

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