# THE DAMAGE DEPTH EVALUATION BASED ON THE ACTIVE IR THERMOGRAPHY

**Petra BAGAVAC[1], Lovre KRSTULOVIĆ-OPARA[1], Željko DOMAZET[1]**

[1] Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, R. Boškovića 32
21 000 Split, Croatia, E-mail: petra.bagavac@fesb.hr , opara@fesb.hr , domazet@fesb.hr

## 1. Introduction

Active infrared thermography is a NDT method capable of locating indications and damage in composites and metals. There are numerous approaches how to locate damage, but precise detection of depth was always an issue. A damage is fully described by its geometry and depth. Determination of damage geometry, based on thermal contrast between cooling curves of observed surface, is described in earlier work. Thermal contrast is the difference between the thermal properties of the observed material and the damage. Method of depth evaluation is demonstrated on an aluminum plate, where damage is simulated as Flat Bottom Holes (FBH) of different diameters, fig. 1.

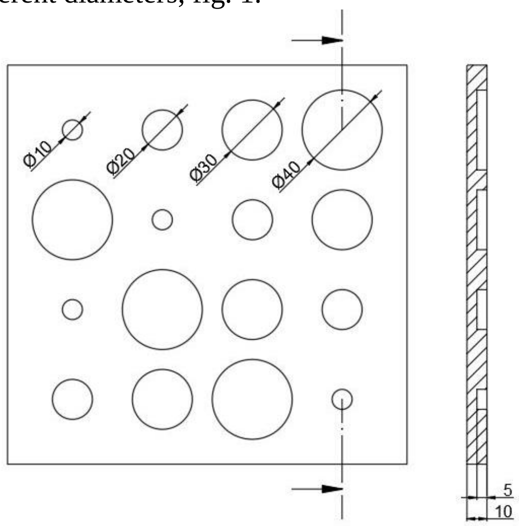


**Fig. 1.** Aluminum sample geometry

Aluminum, like all metals, is excellent heat conductor. IRNDT (InfraRed Nondestructive Testing) is possible on metal materials only with fast frame rate cameras and heat source with short and intensive heating period. Experimental setup included cooled middle wave InSb thermal camera and strong Xenon flesh lamp (releasing 6000J in 1/440 seconds), followed by signal postprocessing techniques.

## 2. Signal Reconstruction

To avoid reflections of surrounding objects and to reduce the signal to noise ratio of the camera FPA (Focal Plane Array) detector, postprocessing of the received signal (cooling curves) is needed [1, 2]. Fig. 2. shows the raw data of a single pixel cooling curve (blue line) and corresponding fitted curve (red line). Temperature cooling profiles for each pixel are fitted with the following logarithmic function:

$$\ln[T(t)] = \sum_{n=0}^{N} a_n [\ln(t)]^n \qquad (1)$$

$$T(t) = \exp\left(\sum_{n=0}^{N} a_n [\ln(t)]^n\right) \qquad (2)$$

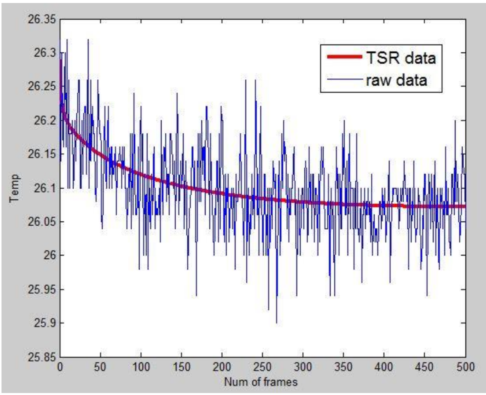


**Fig. 2.** Raw data and fitted data curve

Fitted data is processed by the Fast Fourier Transform (FFT) [3, 4], whereby the time domain is transferred to the frequency domain.

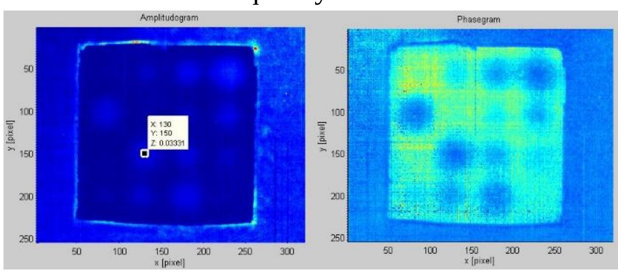


**Fig. 3** a) Amplitude image and b) phase image

Damage geometry is visible in the amplitude image (fig. 3.a) and the phase image (fig. 3.b) of the aluminum sample.

## 3. Depth Estimation

In the frequency domain, blind frequency is the frequency at which there is no phase contrast between the the damaged zone and surrounding sane material.

$$\Delta f = \frac{1}{N_{tot} * \frac{1}{f_s}} \quad (3)$$

$$f_b = N * \Delta f \quad (4)$$

where $N_{tot}$ is total number of thermal images in sequence, $f_s$ is acquisition frequency, $f_b$ is blind frequency and $N$ is the number of thermogram on the frequency axis at which there is no phase contrast.

The damage depth can be estimated from the blind frequency as [5]:

$$z_{estimated} = 1.81 \sqrt{\frac{\alpha_{diff}}{\pi * f_b}} \quad (5)$$

where $\alpha_{diff}$ is thermal diffusivity. This value describes how quickly a material reacts to the change in temperature. The thermal diffusivity was determined by the infrared thermography based on the Flash diffusivity method [6]. Experimentally obtained value was is in good correspondence to the tabular values, so this method is proposed for determination the heat diffusion coefficient for composites and other anisotropic materials.

## 4. Results and Conclusions

Blind frequency is determined as the intersection of the phase curve for damaged zone pixel (drilled hole) and neighboring sane zone pixel (wall), Fig. 4.

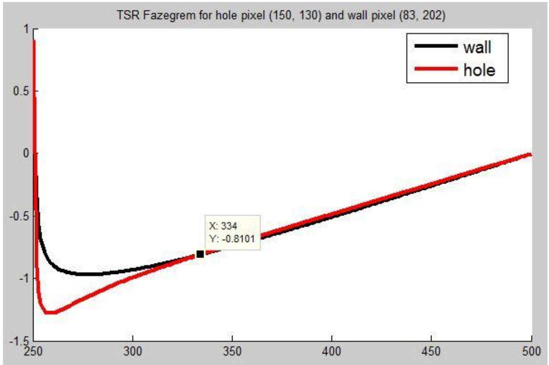


**Fig. 4.** FFT phase values for different frequencies

From such estimated blind frequencies and relations (3-5), depths of evaluated flat bottom holes are summarized in Table 1.

**Table 1.** Estimated depths of FBH defects

| Pixel (x, y) | $z_{true\_value}$ $[mm]$ | $N_{\Delta f}$ | $f_b$ $[Hz]$ | $z_{estimated}$ $[mm]$ |
|---|---|---|---|---|
| 1 (150, 130) | 5 | 84 | 4.2 | 4.8516 |
| 2 (230, 50) | 5 | 82 | 4.1 | 4.9104 |
| 3 (80, 100) | 5 | 85 | 4.25 | 4.8230 |

This method slightly underestimates the depth at which defects are found. The authors agree that this underestimation is result of the extremely rapid heat dissipation in the aluminum. We expect that the method will give more accurate results for defects in materials with lower thermal diffusion, such as composites.

## References

[1] Ibarra-Castanedo C., Tarpani J. R., Maldague X. P. V. *Nondestructive testing with thermography.* Eur. J. Phys, 2013, 34, 91-109.

[2] J.M. Roche, D. Balageas. *Common tools for quantitative pulse and step-heating thermography- Part II: experimental validation.* The 12th International Conference on Quantitative InfraRed Thermography (QIRT 2014), Jul 2014, BORDEAUX, France.

[3] Umar M. Z., Ahmad I., Vavilov V., Swiderski W., Hamzah A. R. Abdullah W. S. *Developing Methodology of Pulsed Thermal NDT of Materials: Step-by-step Analysis of Reference Samples.* Journal of Nondestructive Testing, 2008.

[4] Ibarra-Castanedo C., Gonzales D., Galmiche F., Maldaque X. P., Bendada A. *Discrete signal transforms as a tool for processing and analyzing pulsed thermographic data*. In *Thermosense XXVIII vol. 6205*, *Defense and Security Symposium*, Florida, United States, 2006; Miles J. J., Peacock G. R., Knettel K. M., Eds: Procedures of SPIE, 2006.

[5] Ibarra-Castanedo C., Maldaque X. P. *Defect Depth Retrieval from Pulsed Phase Thermographic Data on Plexiglas and Aluminum Samples.* In *Thermosense XXVI vol. 5405, Defense and Security Symposium*, Florida, United States, 2006; Burleigh D. D., Cramer K. E., Peacock G. R., Eds: Procedures of SPIE, 2004.

[6] Meola C., Carlomagno G. M., Squillace A., Prisco U., Morace R. E. *Analysis of Composites with Infrared Themography*. Macromol. Symp. 2005, 228, 273-286.