



Automated characterisation of subsurface defects by active IR thermographic testing – Discussion of step heating duration and defect depth determination



S. Grys^{a,*}, W. Minkina^{a,*}, L. Vokorokos^b

^a Faculty of Electrical Engineering, Czestochowa University of Technology, Poland

^b Faculty of Electrical Engineering and Informatics, Technical University of Košice, Slovakia

HIGHLIGHTS

- We examine temperature rise in time on the surface of material with subsurface defect heated externally.
- The 1D analytical model of temperature rising of the material surface is useful for setting the time of data recording.
- The defect depth can be determined by the use of 1D analytical model of temperature rising of the material surface.

ARTICLE INFO

Article history:

Received 28 July 2014

Available online 20 November 2014

Keywords:

Infrared active thermography

Step heating

Material testing

Thermogram processing

3D modelling

ABSTRACT

The paper deals with two aspects of the automatic processing of thermograms visualising the front surface of object with internal defects. The material examination is done with active thermography. To assess the duration of step heating of the material tested and estimate the defect depth the 1D analytical model of temperature rising of the material surface was involved. Its applicability was examined by comparing temperature rises in time with those obtained for a 3D numerical model of material with hidden subsurface defect. Furthermore, method was validated with real measuring data. The conclusions are limited to the case of step heating.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

For assessing the condition of a material or a product's quality, the most vital issue is detecting non-homogeneities [1–3]. Faulty operating machines, weak electrical connections, damaged material components, e.g. delamination, inclusion, crack, etc., can cause abnormal temperature distribution. In the thermovision method, the properties of the object examined are assessed indirectly on the basis of the temperature map over an object surface [4]. Detecting temperature anomalies, not accountable for by the object structure or construction, provides an argument to treat the object as defective. Sometimes, additional examination of defects is carried out, to obtain information on their shape, size, location, and thermal resistance [5]. Such information may be useful in finding the causes of defects and estimating the remaining time of object exploitation. Obtaining details that are important for a precise defect description usually requires additional sophisticated data processing [6–8].

This paper discusses the chosen aspects of previously proposed method of automatic data processing in active thermographic non-destructive testing particularly suited for step heating. The novelty of the method is the fusion of two- and three-dimensional (single thermogram and time sequence of thermograms) measuring data sets, one-dimensional analytical model of thermal behaviour on material surface and processing techniques used for defect detection and identification of its selected properties [9,10]. The duration of step heating and method of defect depth determination have been thoroughly studied in this paper. Before it will be discussed an overview of commonly used techniques of image processing applied to thermograms is presented in the next section. It is done to show the audience that these issues have been not sufficiently investigated by scientists and examined by engineers yet.

2. Image processing for automated defect detection with IR thermography – a brief overview

Application of image processing techniques will lead to intelligent analysis ability of the software tools if needed in automated

* Corresponding authors.

E-mail address: grys@el.pcz.czest.pl (S. Grys).

Nomenclature

a	thermal diffusivity, m^2/s	λ	specific thermal conductivity, $\text{W}/(\text{m K})$
c_p	specific heat, $\text{J}/(\text{kg K})$	ρ	density, kg/m^3
F	thermal mismatch factor	ε	emissivity,
L	thickness, depth, m	e	thermal effusivity, $\text{J}/(\text{m}^2 \text{K s}^{1/2})$
$RIFC$	relative incremental filtered contrast		
t	time, s	Subscripts	
T	temperature, K	<i>def</i>	over defect, material of defect
ΔT	difference in temperatures, K	<i>mat</i>	tested material

process monitoring and fault detection. The analysis of a single thermogram makes it possible to detect a defect by spotting non-homogeneity, and the analysis of the variation over time of the particular pixels provides information on physical and thermal properties of the object or on the non-homogeneity. Formally, a sequence of thermograms recorded over time can be treated as a three-dimensional map of the temperature field. Due to the similarity between thermograms and classical images from the visible spectrum, commonly used DSP techniques and algorithms are applied in the time and/or frequency domains. In general, infrared thermograms are noisy. Furthermore, in comparison to images from visible range, the object edges are blurred on the corresponding thermograms, which is characteristic for them. Hence, an enhancement of the acquired thermal images is needed. The basic goal of image enhancement is to present the visual information it contains with greater clarity. For image enhancement purposes various neighbourhood and statistically oriented algorithms like contrast stretching, histogram equalization and image filtering are used. Very effective tool is a fusion of visual and infrared thermography images. The output image incorporates temperature field with sharp and correctly identified object edges [11]. Thanks to Thermographic Signal Reconstruction TSR technique [12] and principal component analysis PCA material flaws of greater depths can be detected [13]. A sophisticated analysis based on segmentation with thresholding, edge detection has been found to be helpful in image classification and object shape determination [14,15]. Such techniques and tools like FFT, continuous wavelet analysis, artificial neural networks, 1D analytical model of the thermal behaviour, morphology, polynomial approximation, classifiers, S/N ratio, statistical moments (skewness, kurtosis) are often engaged [16–22]. It must be clearly stated here that some of them are rarely sold with the commercial cameras, as they are special techniques willingly used by scientists but not always by engineers. In couple of cases they are even patented and therefore these methods are only in special software packages available, e.g. TSR technique.

An overview of abilities of the commercially available software for thermogram visualisation was carried out on the basis of documentation of IR cameras. It indicates that commonly applied features are: palette selection, profile, plot, histogram, minimum, maximum, and average temperatures along the line, zooming, region of interest. Rare features are: basic arithmetic operations, square root, logarithm, trigonometric functions, averaging or median temperatures, image sharpening and edge extraction by means of the Prewitt, Sobel, Laplacian filtering, the Gaussian smoothing for noise suppression, morphology operations, alarms settings for sub areas (configuration for each sub areas allows to set up the infrared diagnostic system for continuously process monitoring; alarms are triggered if any of the zone average temperature value exceeds the temperature limits specified), pattern recognition, evaluation of a process. Most of the techniques mentioned above is aimed to object presentation and enhancement of its features. It is sometimes called “thermal imaging” [4].

3. Defect imaging and characterisation by active IR thermography – discussion of chosen aspects

Detection is understood as finding the occurrence of defects in the structure of material inspected, locating them, and specifying their number based on an analysis of a single thermal image of material surface. Estimation of selected parameters of defects, referred to commonly used term defect characterisation [23,24], involves finding the information on defect depth, size and thermal properties as compared to those of the material inspected. The characterisation relies on the analysis of a single thermogram to examine neighbouring pixels and of a sequence of thermograms to trace the variability of a single pixel in time. An example of sequence of thermograms (thermal images) in the time domain is shown in Fig. 1.

For defect characterisation it is necessary to analyse and solve a thermal inverse problem. It means that knowledge on the internal structure and properties of the material, including its non-uniformities treated as defects, is sought by analysing the variation of temperature distributions on one surface of the object. The information on the material tested is usually limited to the kind of material and its thermal diffusivity (assumed or measured). Furthermore, it is possible to collect a reference thermogram before thermal stimulation starts, to decide the duration time of material inspection and energy supplied to the material. Preliminary results of an inspection, i.e. defect features, should be available in a reasonably short time after, or, if required, during testing, as on-line monitoring in the course of the object operation. In this situation, employing complex three-dimensional models to solve the inverse problem is not practical [26,27]. Instead, in this paper, a simple one-dimensional analytical model of a system of two objects, defining the surface temperature rise in response to step heating, is applied. A drawback of this approach is neglecting lateral heat flow that can cause the significant errors if defect size is small comparing to its depth.

This paper is a continuation of the research in this field carried out and reported by authors and other researchers [5–7,9,10,28–31]. The model of thermal phenomena, properties and implementation of relative incremental filtered contrast *RIFC*, defect detection by global segmentation, counting and reporting of automated flaws and size determination of defect, experimental setup with chamber, all of them also validated by experiments on samples with artificially prepared defects, were explained in details in previously published papers [9,10,28,29]. The duration of step heating and the method of defect depth determination are studied in the next subsections.

3.1. Determining the duration of step heating

One of the parameters characterising a measuring procedure is the amount of time it consumes. In the active thermography method, in which step heating is applied as a thermal stimulation,

Download English Version:

<https://daneshyari.com/en/article/8146978>

Download Persian Version:

<https://daneshyari.com/article/8146978>

[Daneshyari.com](https://daneshyari.com)