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Sensors and Actuators A 118 (2005) 248–253
SENSORS AND ACTUATORS A PHYSICAL
www.elsevier.com/locate/sna

A low-cost thermographic device for the detection of concealed groove in metal plate

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Received 4 March 2004; received in revised form 5 August 2004; accepted 31 August 2004
Available online 5 October 2004

Abstract

A low-cost infrared temperature sensor module is developed for the detection of a concealed groove in an aluminum plate. The module, consisting of five infrared temperature sensors in a row, is used to scan the surface of the sample plate to measure the temperature variation while moving horizontally. A two-dimensional conduction equation is formulated and numerically solved to compare computational outcome with experimental results.

The measurement results demonstrate temperature decrease at the position of the groove, which is also shown from the numerical solution of temperature distribution. Though the temperature measurement with the proposed sensor module is not stable near to the top and bottom of the plate, a distinctive temperature variation at the concealed groove shows the application possibility of the module to the detection of defects in a metal plate.

Keywords: Thermography; IR Sensor; Defect detection; Nondestructive detection; Numerical analysis

1. Introduction

Defects concealed in metallic objects are difficult to find using common instruments. These are practically examined with the instruments utilizing radioactive material or X-ray in field applications. However, the instruments are expensive, and handling the hazardous material causes a variety of problems. The defect detection in process industries employing metallic equipment and structure is an important procedure of maintenance. In spite of the importance, the limitation of proper detection technique incurs restricted examination of the material in the industries. Recent development of thermographic defect detection helps to solve the problem. For instance, thermographic defect detection was applied to the inspection of composite materials [1–3], laminated wood [4] and thermal barrier coating [5]. In addition, the effect of defect size was theoretically investigated [6,7].

In many applications, the temperature of metallic equipment is high and the thermographic technique can be employed for in situ defect detection. For example, vessels and pipes in chemical processes are in high temperature, and therefore, the process operation need not be interrupted for the defect detection of the metallic vessel and pipe when the thermographic detection is applied. This procedure saves a lot of expenses and time in the industry.

However, the infrared (IR) cameras utilized in the technique are expensive and their limited imaging resolution keeps from detecting the defects of small size. Low-cost temperature measurement sensors, IR thermometers are useful replacement of the IR camera. Though their limited resolution and difficulty of dense arrangement of many sensors in a small area are obstacles, their cost benefit and ready availability are merits of the sensor application. In this study, the applicability of the IR sensors to the defect detection is examined by utilizing them in the detection of an artificial groove in an aluminum plate. The measurement results of temperature are compared with the temperature distribution of the

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0924-4247/$ – see front matter
doi:10.1016/j.sna.2004.08.024

Nomenclature

A	aspect ratio
T	temperature (°C)
x	horizontal coordinate (cm)
X	width of sample plate (cm)
y	vertical coordinate (cm)
Y	height of sample plate (cm)

plate surface computed from numerical analysis using a heat conduction equation.

2. Numerical analysis

A square aluminum plate of 10 mm thickness is used in this experiment, of which the detailed dimension is given in Fig. 1. In the middle of the plate, a rectangular hole of 15 mm width and 2.5 mm height is drilled and covered both sides with thin aluminum foil in order to conceal the groove. In order to provide a temperature distribution on the plate, a heater is placed on the top and a cooler is on the bottom as demonstrated in Fig. 2.

Considering the shape of the plate, heater and cooler, a two-dimensional rectangle is utilized in the development of a system equation. For the computation of temperature distribution, a conduction equation is formulated based on the following assumptions:

1. steady-state temperature profile;
2. negligible temperature difference in the direction of plate thickness;
3. constant temperatures at the top and bottom of the plate;
4. adiabatic at both sides and the concealed groove of the plate;
5. constant thermal conductivity throughout the plate.

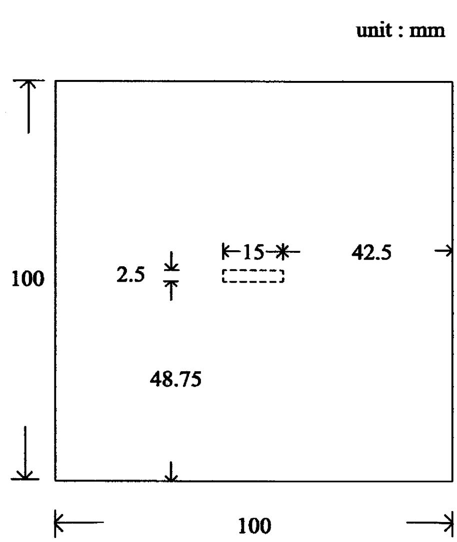

Fig. 1. Dimension of an aluminum plate and location of a groove.

The assumptions result in a two-dimensional conduction equation written in rectangular coordinate as

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = 0 \quad (1)$$

B.C. $\frac{\partial T}{\partial x} = 0$ at $x = 0$

$$\frac{\partial T}{\partial x} = 0 \quad \text{at } x = X$$

$$T = T_1 \quad \text{at } y = 0$$

$$T = T_2 \quad \text{at } y = Y \text{ for non-hole}$$

$$\frac{\partial T}{\partial y} = 0 \quad \text{at } y = Y \text{ for hole}$$

For the computational simplicity, the plate is separated into four sections by halving in both x and y directions. The boundary conditions are for the top section of left half of the plate, and the origin is the top left corner of the section. The first boundary condition is of the adiabatic side of the section, and the second denotes the symmetry of temperature distribution. The conditions in y-direction are the constant temperature assumptions except the groove being adiabatic.

For the simplicity of analysis, the equation is rewritten in dimensionless form.

$$A^2 \frac{\partial^2 T'}{\partial x'^2} + \frac{\partial^2 T'}{\partial y'^2} = 0 \quad (2)$$

where the primes indicate the dimensionless variables as below.

$$T' = \frac{T - T_2}{T_1 - T_2}, \quad x' = \frac{x}{X}, \quad y' = \frac{y}{Y}$$

and

$$A = \frac{Y}{X}$$

In the formulation of finite difference equation from Eq. (2), a two-dimensional rectangular grid is employed. The finite difference equation derived from Eq. (2) is

$$A^2 \frac{T'_{m+1,n} - 2T'_{m,n} + T'_{m-1,n}}{\Delta x'^2} + \frac{T'_{m,n+1} - 2T'_{m,n} + T'_{m,n-1}}{\Delta y'^2} = 0 \quad (3)$$

From the upper left corner of the two-dimensional rectangular grid, Eq. (3) is applied to compose a set of simultaneous equations, which is solved to find temperature distribution. A