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A Novel Pulsed Video Thermography Apparatus for the Quantitative Characterization of Material Flaws

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ABSTRACT

Pulsed Video Thermography (PVT) is an emerging nondestructive test method that offers inherent advantages over more conventional techniques. The PVT Laboratory of Southern Illinois University at Carbondale is one of the few research groups in the United States to have developed a novel PVT computer work station that utilizes simple off-the-shelf components with inexpensive liquid crystal technology. The system is user friendly, portable, and allows for automated thermal image capture. It represents a significant advancement toward the practical application of the method.

INTRODUCTION

Today's highly competitive global market has made the inexpensive, rapid, on-line non-destructive assessment of material integrity crucial to the economic survival of many companies. This is especially true of the composite materials industry where the prevention of catastrophic failure of aerospace or automotive structures is paramount to public safety. The traditional non-destructive testing (NDT) methods for the location and characterization of flaws and quality parameters are sometimes not physically or economically feasible. For example, X-ray NDT applied to carbon-carbon composites has the advantage of detecting internal flaws but buried delaminations are difficult to detect due to poor contrast between the fibers and matrix (Gardner, 1973) . Complex structures are difficult to test because access to two opposing surfaces is required. Cost is high and the method is safety intensive. Ultrasonic NDT yields good sensitivity and resolution of voids, cracks, and delaminations, but is time consuming and usually needs some type of surface coupling or liquid immersion (Vavilov, et al., 1993). Non-contact laser ultrasound is currently being developed. However, it is usually economically feasible only for high-priced products (Ashley, 1994).

The emerging method of Pulsed Video Thermography (PVT) can be used as a viable alternative or screening procedure for the traditional NDT methods. It can detect the same type of defects but does not require two sided access, typically has a fast area scan rate, and can be non-contact. A test specimen is **pulsed** with a powerful externally applied heat source to create a traveling steep temperature gradient within the test specimen. Flaws or irregularities alter the flow of heat, producing temperature contrasts at the surface that are **video** captured via computer. **Thermography** techniques can then be applied to the surface image to characterize the flaw and predict performance capability. Possible limitations of PVT include the requirement of uniform surface heating and the need for greater computational speed/memory when defects are multi-dimensional.

The development of a PVT computer work station using off-the-shelf components would have the benefits of low cost, ease of use, portability, and flexibility of application. A few research groups outside of America are currently pursuing this avenue (Hobbs, 1992) using relatively expensive infrared temperature imaging. The PVT Laboratory of Southern Illinois University at Carbondale is one of the few groups in the United States to have developed a quantitative apparatus using low cost liquid crystal technology for automated thermal image capture.

METHODS AND MATERIALS

A schematic of the apparatus is given in Fig. 1. The equipment/software are relatively low cost, off-the-shelf items that are readily portable and well suited for plant operations.

The experimental procedure begins with the specimen surface facing the flash lamps being coated with a layer of temperature sensivtive liquid crystals approximately 0.02 mm thick. A 286 control computer then administers a short intense pulse of heat via a bank of lamps while simultaneously initiating the video camera to capture board system of the 486 computer. It does this through the use of a programmable relay card that has access to the computer time clock. The control computer then continues to oversee the capture of a set amount of image frames at predetermined times until the test is finished.

Once the experimental image frames are captured the pixel information that they contain is accessed by an image processing software package. Each pixel consists of red, green, blue (RGB) color values of the light reflected by the liquid crystals on the test piece surface. These RGB values are correlated to the surface temperature through a newly developed calibration scheme validated by the authors. Thus, each image produces a matrix of transient temperatures representing each position which is used to quantify the flaw characteristics via thermography.

RESULTS AND DISCUSSION

Kulkarni and Brady (1995) have developed a simple expression for estimating the time for an applied heat pulse to reach a defect at a given depth within a test piece. Table 1 lists their results for several common materials. This information can be used along with the PVT system data to compare the thermal response between flawed and benchmark specimens. The time at which the surface temperature image of the defective specimen deviates from the standard can be directly related to flaw depth.

The previously described PVT apparatus has been successfully calibrated for the syncronization and control of the heat input and image capture. A new calibration technique has been used to correlate pixel RGB color data to temperature without the use of optical filters or observer judgement (Kulkarni and Brady, 1995).

Preliminary test results have demonstrated the predicted relationship between the thermal response of flawed specimens and defect depth. Fig. 2 compares the PVT acquired thermal response between defective and flawless plexiglas plates 152 mm x 152 mm x 6.35 mm in size. The defective plate had a 6.35 mm diameter hole drilled at its center to a depth of 1.8 mm below the viewed surface. A heat pulse lasting approximately 1.8 s was applied to both plates. From Fig. 2 it can be seen that the deviation between the thermal response of the two plates begins at about 2.5 s, which represents the time for the heat input to travel from the surface to the hole bottom. The analysis of Kulkarni and Brady (1995) given in Table 1 predicts a flaw depth of 1.7 mm when using a t_d time of 2.5 s. Hence, the novel PVT apparatus combined with numerical modeling leads to an error of only 6% in characterizing flaw depth. Detailed discussions of more comprehensive investigations will be the subject of future articles.

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Table 1. Thermal velocity analysis of transient thermography.

$$t_d \approx \frac{l_d^2}{\alpha} \quad , \; t_{d,num} = C_0 \frac{l_d^2}{\alpha}$$

t_d = time for thermal front to reach defect

$t_{d,\ num}$ = numerical method t_d

l_d = surface depth of defect

α = thermal diffussivity

Material	α (m^2/s)	$C_0 = \frac{\bar{t}_{d,num}}{t_d}$
Aluminum	7×10^{-5}	0.136
Fiberglass	4×10^{-7}	0.114
Particle Board	1×10^{-7}	0.112
Plexiglas	1×10^{-7}	0.105

Fig. 1. Pulsed video thermography test apparatus.

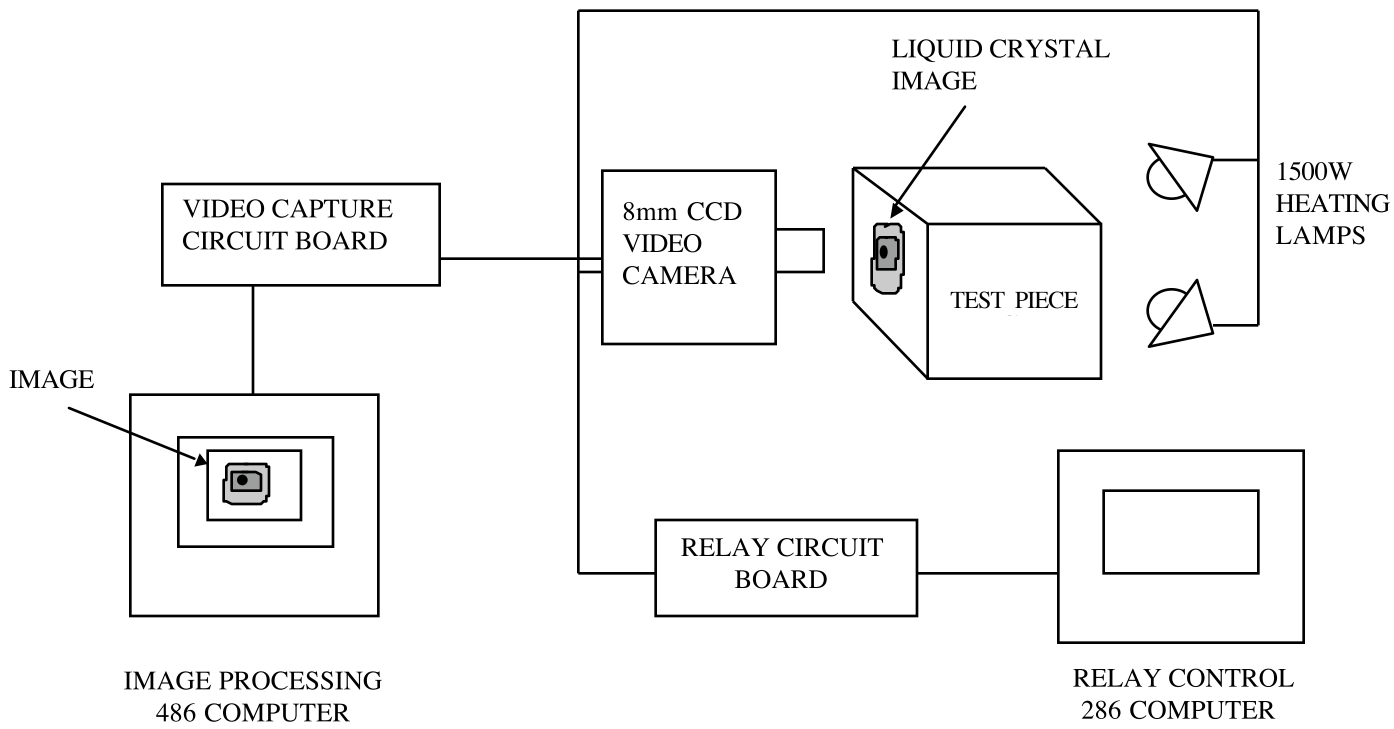

Fig. 2. The Effect of Time Upon Thermal Response
Defect-Free and Flawed Plexiglas Plates
Defect: 6.35 mm Dia. Hole 1.8 mm Below Viewed Surface

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