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Identification and localization of surface and buried heat sources through curve fitting of the temperature-time profile for vibrothermography

by Stephen D. Holland*

**Department of Aerospace Engineering and Center For Nondestructive Evaluation, Iowa State University, Ames, IA USA 50011, sdh4@iastate.edu*

Extended abstract

Finding cracks in vibrothermography requires identifying and localizing pulsed surface and subsurface heat sources from a time-series of infrared images. We present an algorithm that uses curve fits of the temperature-time profile to simultaneously compress the time-series into a single image, improve sensitivity to faint indications, and estimate the source depth or distance. In addition, the algorithm improves rejection of false background indications.

Each pixel in the infrared time-series provides the temperature-time profile of a single point on the specimen surface. A pulsed heat source is assumed to turns on at time t_1 and off at t_2. An example profile is shown in Fig. 1, where the point starts at ambient temperature until t_1=0.2 s, when the heat source turns on and temperature begins to rise. The rate of temperature increase slows with time, and then begins to drop towards ambient after the heat source turns off at t_2 =1.2 s. The exact profile depends on the distance and spatial extent of the heat source. Basis functions for curve fitting the temperature profile can be readily found from theory, and appropriate combinations of these basis functions can provide accurate fits with a minimum of free parameters. Such a curve fit is shown as the dashed line in Fig. 1.

A number of parameters can be extracted from the curve fits, and these parameters can be used to identify and classify heat sources and thermal indications. Since the basis functions are calculated from the theory for pulsed heat sources that turn on at t_1 and off at t_2, they are only capable of representing heat sources which follow that pattern. Therefore, the quality of the fit (relative residual error) provides a metric for classifying an indication as either a real source or a false background indication, as well as a means to filter out camera noise. The overall amplitude of the fit provides a metric for the amount of crack heating, and the shape of the curve can be used to estimate distance and dimensionality of propagation.

Since close heat sources provide very rapid temperature rises and falls, whereas distant heat sources provide slow temperature rises and falls, the fitting process provides an estimate of the source distance. Source distance can be used as another discriminator of real indications, since they show a characteristic 'bulls eye' pattern of small distance at the center (on top of the defect) surrounded by radially increasing distance. Source distance also provides a means to distinguish between surface cracks and subsurface cracks.

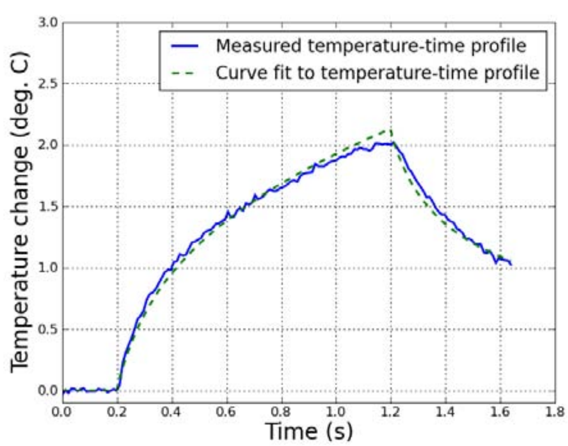

Fig. 1. *Measured and fitted temperature-time profiles for a single pixel.*

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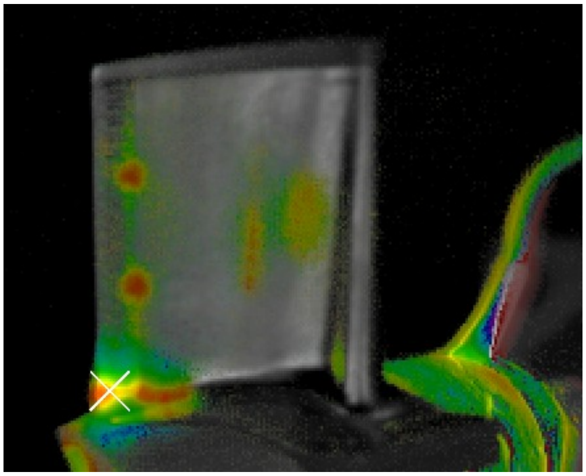

Fig. 2. *Rendering of curve fits to the vibrothermographic response of a turbine blade as a single false color image*

The critical parameters of fit quality, heating amplitude, and distance are combined into a single hybrid false-color image such as that shown in Fig. 2. Heating amplitude maps to intensity, distance maps to color, and fit quality maps to opacity of the colored indications over the raw grayscale background. The combination of data visible in a single image allows rapid identification and analysis of vibrothermographic indications. In this case a significant crack at the trailing edge, marked with a white 'x', gives a very large amplitude, while fainter indications near the trailing cooling holes share the characteristic bullseye pattern of a near-surface indication. Deeper indications closer to the leading edge are also clearly visible.

Curve fit-based image processing of the temperature-time profile of vibrothermographic crack heating can simultaneously compress the time-series into a single image, improve sensitivity to faint indications, and provide an estimate of the source distance. This algorithm provides a means to transform the complicated sequence of images from a vibrothermography experiment directly into a single, easy to interpret summary.