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APPLICATION OF THERMOGRAPHY MODEL-BASED INVERSION

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ABSTRACT

A new method for model-based inversion for pulse thermography of composites takes advantage of heat conduction physics to improve the interpretation of pulse thermography NDE data. The method is based on representing measured surface temperature as a linear combination of contributions from the original pulse plus reflections from delaminations and the back wall. Linear inversion is used to solve for the reflection intensities, providing a representation of the subsurface. We previously reported on the development of this technique and now report on its application to the inspection of a variety of composite specimens.

INTRODUCTION

Pulse thermography is the use of of a heat pulse applied to a surface to probe for material thickness and subsurface discontinuities such as delaminations in composite laminates. The heat pulse rapidly heats the surface, and the surface temperature is monitored with a thermal camera as the heat diffuses through the thickness. Thinner regions equilibriate more quickly and end up as bright spots, whereas thin regions equilibriate more slowly [1]. Unfortunately when geometry is more complicated, then lateral heat flows make the the flash thermography data much harder to interpret.

MODEL-BASED INVERSION

In model based inversion, a computational model of the NDE process is used to facilitate analysis of NDE data. In this case, the surface temperature is represented as originating from the original pulse plus a linear combination of a large number of possible reflectors at a very large array of possible depths and positions [3]. Each reflector is represented mathematically from of the well known thermal Green's function. A regularized linear inversion process is used to solve for the pulse and reflector intensities given the measured sequence of thermal images. An implementation of the model-based inversion is published online as open-source [3].

REGISTRATION

Since pulse thermography data is recorded as a series of thermal camera images, in order to perform the inversion it is necessary to correct for the perspective of the camera. This involves either as perspective correction for simple, flat geometries, or a ray tracing process to align the thermal images onto a parameterization of the specimen surface. A series of landmarks on the object surface are used to align the the specimen and CAD model so that the thermal images are projected onto the surface.

EXPERIMENTS

We have tested a series of specimens in order to explore the merits and limitations of this technique. One example of impact damage to a composite laminate is shown in Fig. 1. In this case, a poorly manufactured curved and stiffened composite laminate, subjected to impact damage, has a large delamination roughly 0.5 mm below the surface, seen as yellow in the top portion of

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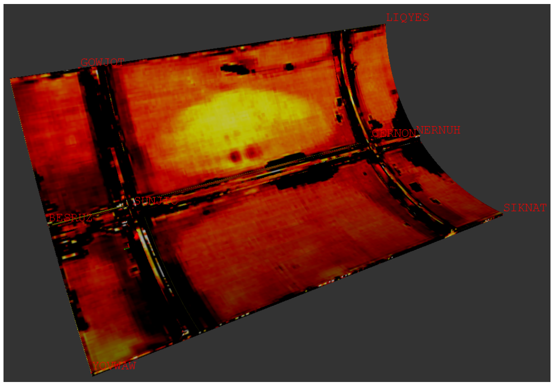

Figure 1. Example model-based inversion of a composite specimen subjected to impact damage

the projection. Interestingly, the damage to this curved and stiffened composite is quite different from the classical patterns of delamination impact damage often seen in flat plates.

DATA FUSION

On real geometry parts, it is often necessary to combine data from multiple camera angles. Data fusion can be performed in the domain of the surface parameterization of the 3D model. In our first attempts, we performed data fusion prior to model based inversion. Unfortunately, this meant that fusion artifacts interfered with the inversion process. We have since learned that it is better to perform the inversion separately based on the data from each camera angle, and then fuse the output of the inversion. The result can still have inversion artifacts but they are generally much less significant, much less noticable, and do not adversely impact the interpretation of the NDE data.

SUMMARY

Model-based inversion provides a more concrete way to interpret NDE data. In this presentation we will show data from multiple specimens illustrating the merits and limitations of model-based inversion. In comparison with more conventional approaches to analyzing pulse thermography data, the experimental process may be more complicated because of the need to project the data to a domain in which the spatial step sizes are known so that the correct Green's functions used in the model can be calculated. The benefit is a substantial increase in resolution and interpretability at only a minor cost in signal-to-noise ratio.

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