Unique Applications of Thermoelastic Stress Analysis

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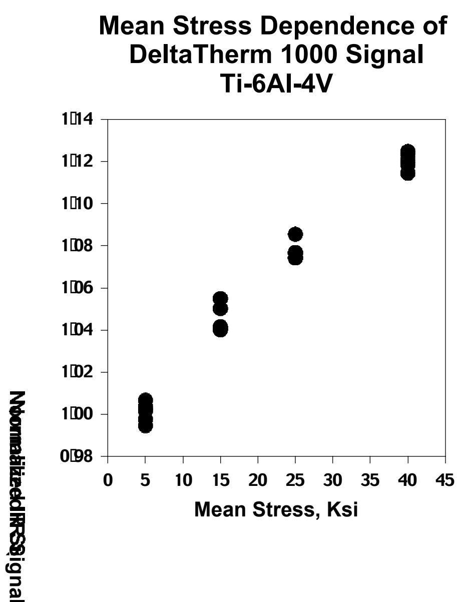
Introduction

Recent advances in instruments for collecting thermoelastic stress analysis (TSA) images have opened new application opportunities. Advanced image processing hardware and software combined with the latest in infrared detector arrays has drastically improved instrumentation used for TSA. As the new technology spreads into the hands of the engineering and research communities new and unique applications are being successfully completed.

The rapidity with which data images can be collected has lead to studies of variations caused by complicated influences. Analysis of composite material damage mechanisms, fracture mechanics, NDE, and many structural analysis applications have benefited.

Engineers and scientists from several countries and many interests have provided information for this paper about their uses of TSA. The contributors include students, practicing engineers, and professional research staff from academia, government, and private labs who are all successfully using new TSA technology in innovative ways. The authors thank these innovators for providing the foundation for this paper.



Example Applications

<u>Residual Stress Measurement.</u>

It has been known for some time (Wong, Mountain) that mean stress levels have an influence on the amplitude of thermal oscillation caused by an oscillating load. The effect is small and has been very difficult to measure with the first generation TSA equipment. The improved sensitivity of the array detector TSA instrument has brought new interest to practical use of the technique. Work at NASA-Lewis Research Center by Dr. Andrew Gyekenyesi has focused on quantifying residual stresses in several important components made of titanium alloy.

<u>Microstructural Load Transfer and Video Illustration</u>

A group lead by Dr. Eann Patterson at the University of Sheffield is investigating the load transfer between the grains of an aluminum alloy by using TSA measurements. The simple optics and low cross-talk between detectors of an array based TSA instrument enables spatial resolution capability far exceeding that of first generation equipment. A two-position zoom lens that maintains the center of the field-of-view and focus with a better than 25 micron per pixel resolution is a new tool for researchers using TSA.

The study of microstructural load paths has been aided by the collection of a series of images for assembly into short video style visualization. The collection and processing of the large amounts of data required to build an animation file would be incredibly tedious with the old style single detector TSA equipment.

<u>Contact Stresses</u>

The work in fretting fatigue by the engineering teams at University of Osaka and Purdue University illustrates well the advancement of TSA. In the work by Dr Farris and Dr. Sakagami infrared measurements are used to study contact stresses and fretting fatigue. The focal plane array makes the clever optical construction of their experiments possible. They use a transparent window to view a contact probe. By varying the hardness and size of window and probe they are able to confirm models of the contact stress and fretting problems. To illustrate the technique Dr. Sakagami has provided a view of embossed plastic type pressing against the window. He happened to choose the letters “SP”.

Figure 1. Contact stresses in embossed plastic letters. Darker colors indicate higher stress.

Fracture Mechanics

An exciting idea was put forward by Dr. Peter Stanley of the University of Manchester shortly after the introduction of the first commercial TSA equipment. He suggested, and then showed, that the equations describing linear elastic fracture mechanics stress fields, and hence stress intensity factors, can be rewritten in terms of the sum of the principle stresses. This lead to thermoelastic confirmation of calculated stress intensity factors. However, the quantity of the data that could be collected with first generation TSA equipment could not answer the interesting questions posed by the new measurements (Stanley). Shortly after the introduction of fast imaging TSA equipment this work was re-energized. High temperature effects, crack closure, and damage mechanisms have been some of the topics of the renewed interest by researchers. First to sponsor new work was the US Air Force (Lesniak). Currently there are efforts by teams at the University of Liverpool and the University of Sheffield to advance this important area.

AC and DC Thermography for Structural Analysis

Interesting work on composite materials and structures benefit from the integration of a combination of analysis techniques. The powerful features of the advanced DeltaTherm system were used by Sandia National Labs in Albuquerque, New Mexico to combine a wealth of data in analyzing a wind turbine blade. Three figures show the response of the structure to a resonant loading. The experimental analysis, which included dye penetrant work, were combined with finite elements to get a more complete understanding of the performance of the structure. Several vibration modes were analyzed in this way. The amount of data used in this analysis would not have been practical to collect with earlier generation TSA instruments. The blade was imaged in sections and a complete image of the blade was assembled from adjacent data sets.

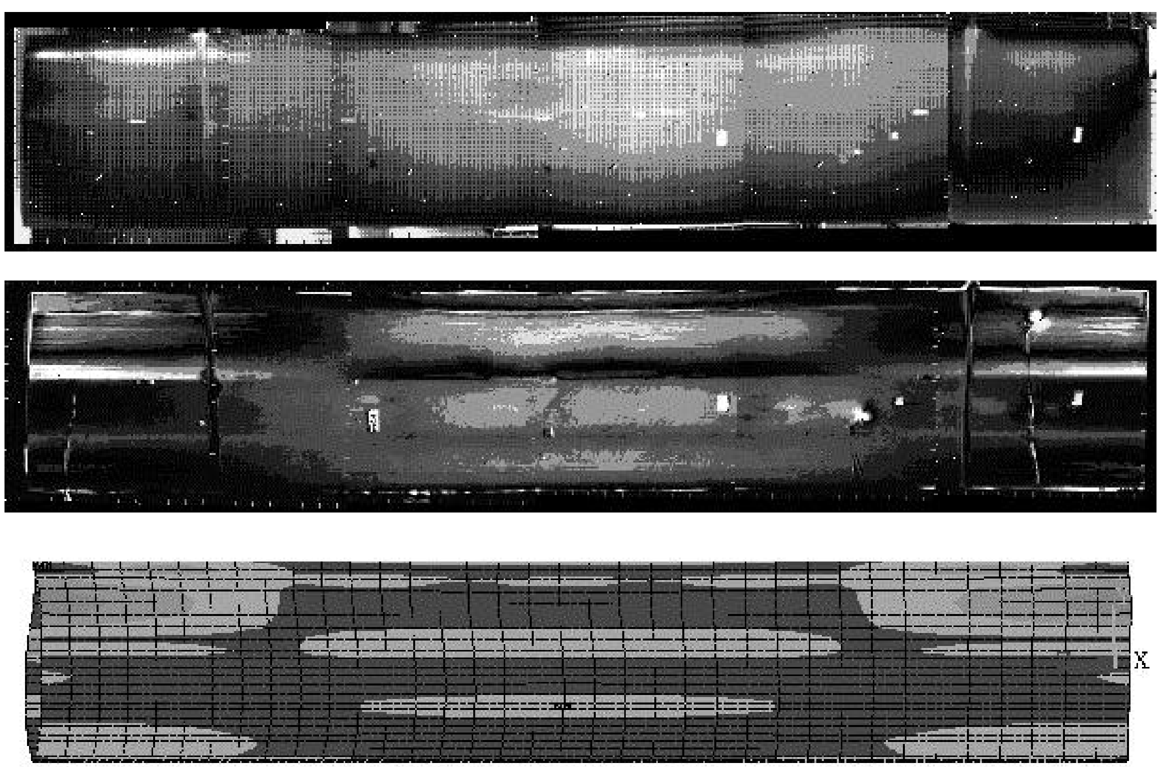


Figure 2. From top to bottom, DC and AC thermography images with FEA stress model of wind turbine blade resonating at a 38 Hz mode. In the DC image lighter colors indicate higher temperature. In the AC images lighter colors indicate higher stress. In the FEA image darker areas are higher stress.

Elevated Temperature Stress Analysis

Engine manufactures have been continually challenged by the difficult design decisions that must be made each time a new exhaust system is required. Prior to the innovation of fast TSA imaging with focal plane arrays, visualization of stress patterns in exhaust systems with TSA was only a dream. By using a focal plane array camera, images of both the absolute temperature and oscillating temperature caused by the thermoelastic effect can be acquired simultaneously. Furthermore, variable amplitude loading analysis is not a problem for the digital signal processing now used, as opposed to the analog instruments of prior implementations of TSA instrumentation.

Conclusion

A high performance thermoelastic stress analysis instrument that combines a focal plane array detector and digital signal processing has enabled new applications of TSA. Features of the new instrument that have had a particularly positive impact are rapid and easy data collection, simple optics, combined TSA and standard infrared imaging capabilities, and advanced acquisition and data processing software.

Thermoelastic stress analysis has moved significantly toward maturity with the introduction of a high performance instrument system based on an advanced infrared focal plane array. In many ways TSA has rounded the corner from a technique under study, to an engineering tool.

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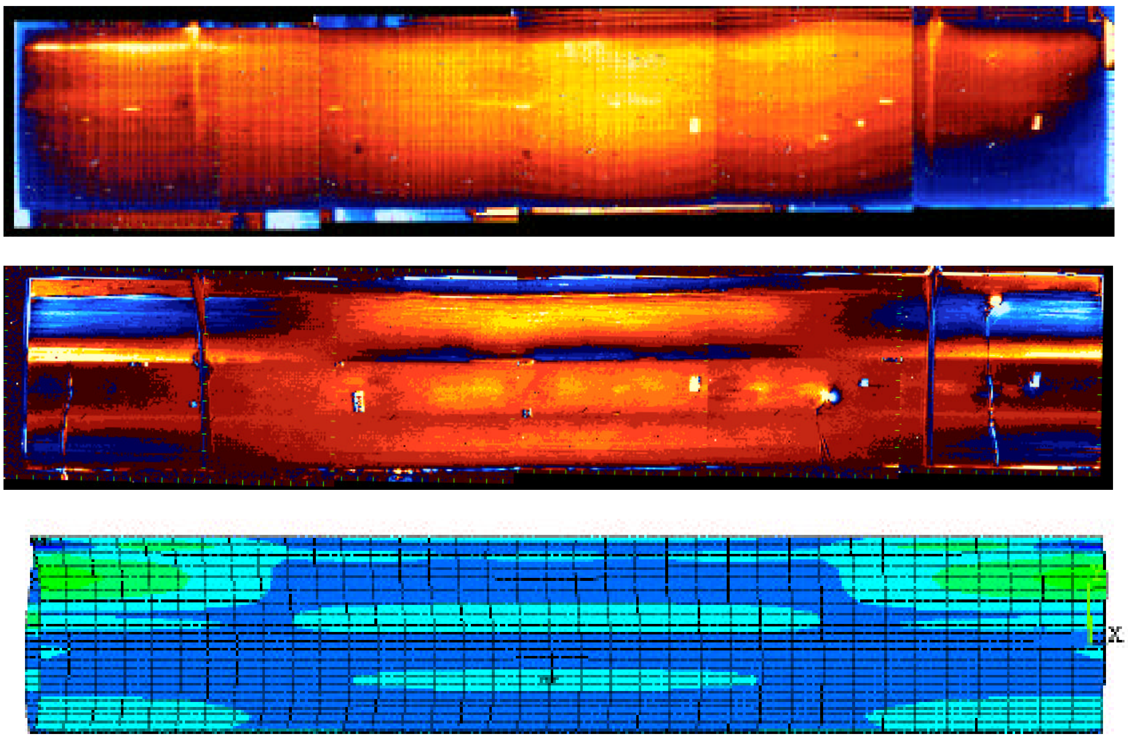

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