TECHNOLOGY REPORT

Laser Technology Inc.

Laser Shearography Inspection of Helicopter Rotor Blades

A helicopter is an aircraft that has a main lifting rotor. Main rotor blades come in a variety of configurations. They can be a hollow composite beam, aerodynamically shaped with a spar and covered with a metal skin, fiberglass or composite material skin. Some will incorporate honeycomb core, metal spars, foam filled or laminate composite. There are bonded areas along the erosion strip leading edge and along it beam.

Considering the amount of load placed upon the main rotor blades, the inspection at manufacturing and or in-service is critical to ensure flight worthiness. Laser Shearography is an NDI method that offers solutions to the quick and effective inspection method for qualifying the integrity of a main rotor blade.

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Laser Shearography

Laser interferometric imaging NDT techniques such as holography and shearography have seen dramatic performance improvements in the last decade and wide acceptance in industry as a means for high-speed, cost effective inspection and manufacturing process control. These performance gains have been made possible by the development of the personal computer, high resolution CCD and digital video cameras, high performance solid-state lasers and the development of phase stepping algorithms. System output images show qualitatively pictures of structural features and surface and subsurface anomalies as well as quantitative data such as defect size, area, depth, material deformation vs. load change and material properties. Both holography and shearography have been implemented in important aerospace programs providing cost effective, high-speed defect detection.

Shearography NDT systems use a common path interferometer to image the first derivative of the out-of-plane deformation of the test part surface in response to a change in load. This important distinction is responsible to two key phenomena. First, shearography is less sensitive to the image degrading effect of environmental vibration. Shearography systems may be built as portable units or into gantry systems, similar to UT C-Scan systems, for scanning large structures. Second, the changes in the applied load required to reveal subsurface anomalies frequently induce gross deformation or rotation of the test part. With holography, several important test part-stressing techniques, such as thermal and vacuum stress, create gross part deformation. Defect indications may be completed obscured by these translation fringe lines. Shearography on the other hand is sensitive only to the deformation derivatives and tend to show only the local deformation on the target surface due to the presence of a surface or subsurface flaw.

Shearography, in particular offers unique and proven defect detection capabilities in aerospace composites manufacturing. Shearography images show changes in surface slope, in response to a change in applied load. Shearography whole field, real-time imaging of the out-of-plane deformation derivatives is sensitive to subsurface disbonds, delaminations, core damage, core splice joint separations as well as surface damage. Secondary aircraft structures have long used composite materials. The drive for better vehicle performance, lower fuel consumption and maintainability are pushing the application of composites and sandwich designs for primary structures as well. Faster and less expensive inspection tools are necessary to reduce manufacturing costs and ensure consistent quality

The concept of using a common path interferometer to image test part deformation derivatives to overcome the effects of environment vibration and loss of the defect signal due to gross part deformation , as seen with thermal stress holography, was first introduced by Butters *et al (1971)* and reduced to practice by Nakadate *et al(1985).*

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Shearography cameras generally use a Michelson type interferometer with two essential modifications. First, one mirror may be precisely tilted to induce an offset, or sheared image, of the test part with respect to a second image of the part. The sheared amount is a vector with an angle and a displacement amount. The shear vector, among other factors, determines the sensitivity of the interferometer to surface displacement derivatives, Fig 1.

The two laser speckle images of the test part, offset by the shear vector, interfere at every paired point over the surface in the field of view. The single frequency laser light from the two sheared images of the part is focused onto the CCD camera array of photosensitive pixels. Light from pairs of points in each sheared image interfere. Each video frame, comprised of the complex addition of these two sheared images can be subtracted from a stored reference image. The absolute difference yields a fringe pattern observed on the monitor. The second mirror in the Michelson interferometer may be phase stepped using a piezoelectric device and the images combined to create a phase map. Further processing using any number of unwrapping algorithms may be used to generate fringe free images of local surface deformation derivates, Fig 2.

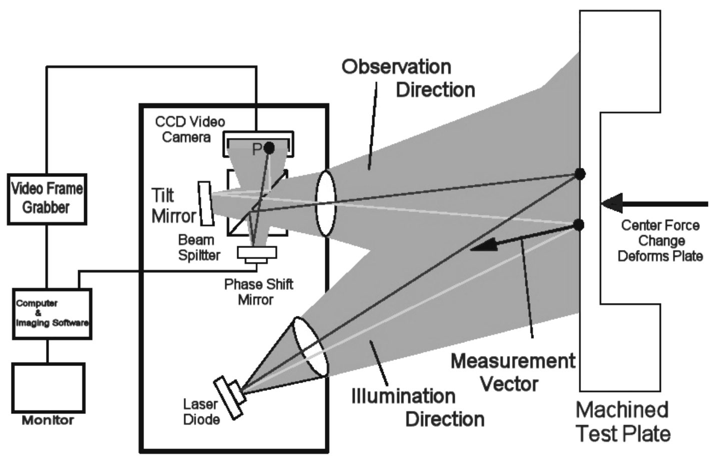

Fig. 1 Schematic diagram of a Michelson Type shearography interferometer observing a flat metal plate with a 4-inch diameter machined flat-bottomed hole. A center load change on the plate provides a variable deformation, observed on the computer monitor in real-time.

In practice each step in creating a shearogram is performed automatically using image-processing macros constructed by combining each processing function in a sequence. Shearography system operators perform a test with a single keystroke.

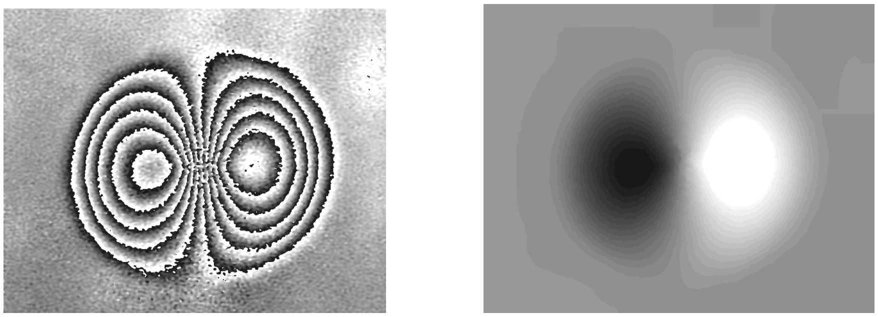

Fig. 2 A phase map shearogram with horizontal shear vector yields a fringe pattern showing the first derivative of the out-of-plane deformation, $\partial w/\partial x$. Using an unwrapping algorithm, the image at right shows the positive (white) and negative (black) slope change. The metal plate with a 4.0-inch diameter flat-bottomed hole was deformed by 7.0 microns.

Shearography imaging the first derivative of the out-of-plane deformation of the test part surface occurs as a response to a change in load. The applied load required to reveal subsurface anomalies can be in the form of thermal, vacuum, pressure and vibration stress. The following is a list of shearography stress methods and the type of defects typically detected.

- **Thermal Stress with 1-40°C Differential**

Defect: Impact Damage, Delamination, Disbonds

- **Vacuum Stress**

Defect: Disbond in Honeycomb, Core Damage, Disbond Core Splice

- **Vibration Stress**

Defect: Disbonds, Delamination in solid laminate or Metal Core Honeycomb

- **Pressure**

Defect: Impact Damage, Delamination in filament Wound Pressure Vessels

Laser Shearography inspection of helicopter blades would require a variety of stress excitation to the blade, depending on the type of discontinuity and helicopter blade structure. See chart below with examples of some blade inspection applications:

Application		**Shearography Excitation Technique**
Honeycomb Skin-to-Core	>	Vacuum Shearography
Composite Bond Areas	>	Thermal Shearography
FOD in Laminates	>	Thermal Shearography
Composite Delaminations	>	Thermal Shearography
Composite Spar	>	Thermal Shearography
Leading Edge Erosion Strip	>	Thermal Shearography

Fig. 3, X, Y Gantry Inspection System with Helicopter Blade

Fixed Production Shearography Systems

First introduced on the USAF B-2 production program, gantry mounted shearography systems share many operational features with UT C-scan systems. These include: teach/learn part scan programming, electronic image of the entire part, image analysis and defect measurement tools, automated operation. Shearography system however operate at throughputs typically in the range of 100 to 500 sq. feet/hour compared to a typical throughput of 10 sq. ft./ hour for UT C-Scan systems. In addition, gantries are considerable less expensive since precision part contour following is unnecessary.

Both metal and composite helicopter blades are easily tested in production with either thermal or vacuum shearography methods. Fig 3 shows a production shearography system with a gantry on the test chamber. The pressure reduction during inspection cycles between ambient and 0.3 psi. below ambient. The helicopter blade may be scanned in less than 15 minutes. The gantry can also be adapted with thermal excitations attachments like halogen lamps or forced hot air.

Images produced with a gantry will display, at the end of the scan sequence, a stitched image, which is the pasting of all collected images to display a complete single image of the tested area.

Gantry systems can also be provided separate from a vacuum chamber. Custom vacuum windows can supplied to adapt to specific helicopter rotor blades. In addition, gantries can be supplied with dual cameras positioned on the opposite sides of the blade to speed up the inspection time.

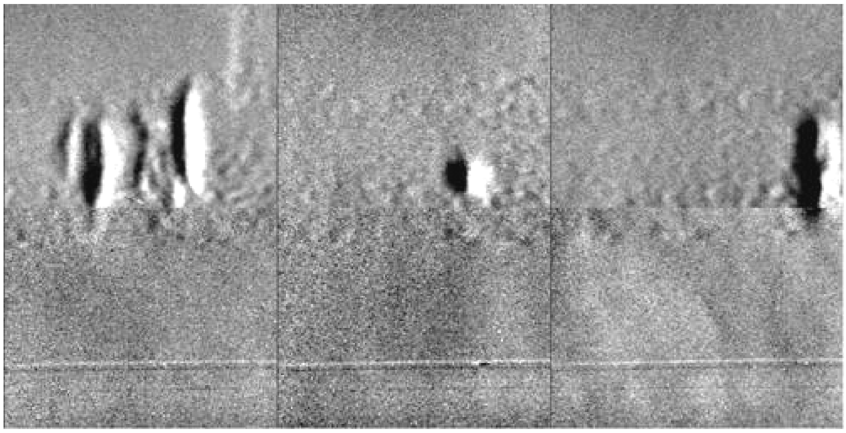

Fig. 4 Shearography indications of disbonds in this 24 inch section view of a helicopter blade. Defects such as crushed core, disbonds and sheared core are easily detected and measured. Fig. 4 is a stitched Image.

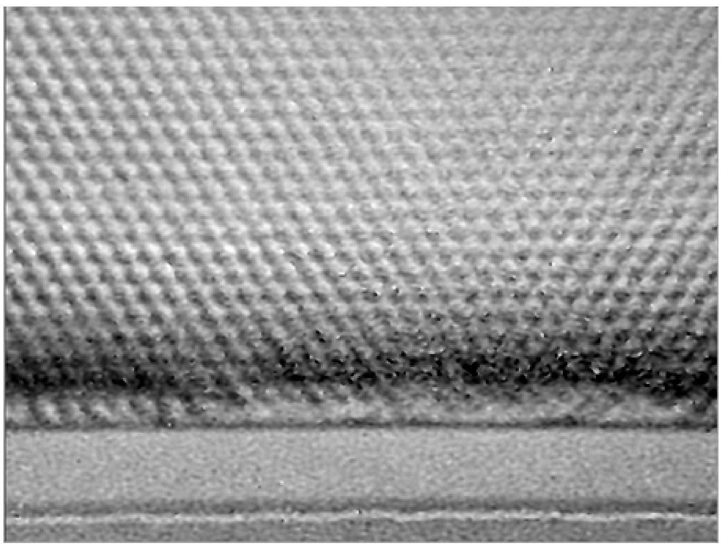

Fig. 5 Shearography image showing defect free honeycomb and trailing edge are on helicopter blade.

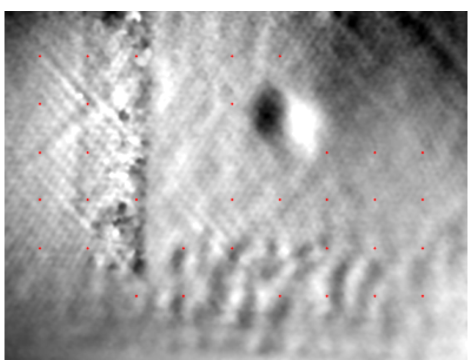

Fig. 6 Shearography image of a helicopter blade honeycomb disbond.

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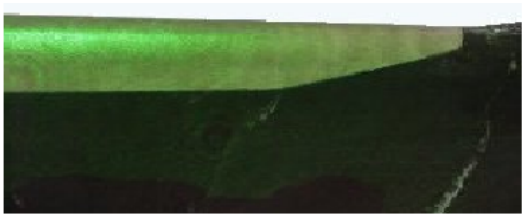

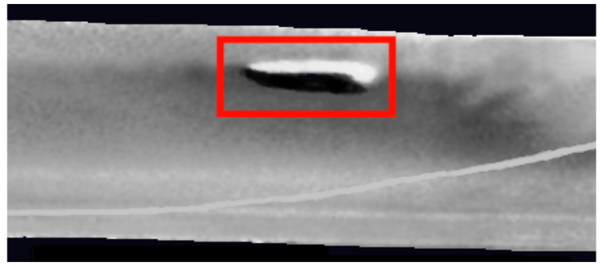

Fig. 7 Photo of a Helicopter Erosion Strip **Shearography Image of a Disbond of a Erosion Strip**

Laser Technology, Inc provides application assistance to evaluate company specific designs that present their own unique inspection requirements. LTI provides the capability to perform application feasibility studies, assist in establishing and write an inspection procedure, as it would apply to your production inspection req1uirement. Custom system configurations can be incorporated to meet the production through put.

Portable and semi-portable systems are available for flight line inspection incorporating the necessary shearography stress excitation needed to achieve an effective inspection.

All LTI systems are computer based with Windows™ operating systems.

LTI provides equipment training as well as Laser Shearography technology certification training as outlined in the ASNT SNT-TC-1A certification guideline.

For more information contact John W. Newman, President of LTI or Manny Butera, Sales Manager of LTI at Phone: 610-631-5043
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The Shearography techniques described in this document is protected under US and Foreign patents and additional patents pending.