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OPTICAL INSPECTION OF SPACE–PROPULSION COMPONENTS USING AN INJECTION SEEDED Nd:YAG LASER SYSTEM

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A dual–beam, injection–seeded, Nd:YAG laser has been demonstrated for detecting structural defects. This demonstration was part of an ongoing project[1] to use dual–reference–beam holographic interferometry to inspect space propulsion components for cracks, defects, structural failures, structural changes, and gas leaks. Potential subjects for inspection include welds, duct work, casings, turbopumps, blades, composites, and ceramics. The maximum dimension of an inspected area ranges from a few centimeters to a meter. The entire optical inspection system is now ready for a demonstration application

Dual–reference–beam holographic interferometry overcomes the most significant limitation of holographic interferometry: interpretation of the recorded fringe patterns. Measurement and analysis of the fringe pattern are fully computerized and automated. There is also a factor of 10 to 100 increase in sensitivity and dynamic range over other holographic methods. The electronic detection and computerized analysis of an interference fringe pattern can be accomplished by optical heterodyning, quasiheterodyning, or phase shifting. Optical heterodyning was selected as the most sensitive.

Pulsed lasers are needed for inspections in the field between tests and during tests of components or engines. The short pulse of the laser (7 nanoseconds) makes the hologram recording process insensitive to vibration and motion of the subject. A double exposure records the vibration or load–induced deflection of the subject. The deflection is encoded in the interference fringe pattern reconstructed from the hologram. The term "dual reference beam" means that geometrically distinct reference beams are used for each of the two exposures of the double–exposure hologram.

Both pulsed–laser and continuous–wave–laser holograms are interpreted by the same computerized, automated, readout facility. The recorded scene is reconstructed in that facility with duplicates of the two reference beams originally used to record the hologram. In optical heterodyning, an acoustooptic frequency shifter shifts the frequency of one duplicate relative to the other. A 125 kHz frequency shift is used in our facility. A lens forms an image of the fringe pattern and subject. The intensity of the fringe pattern varies sinusoidally at 125 kHz, and the phase of this signal contains the interference phase $\Delta\varphi$. The interference phase, in turn, depends upon the structural–deflection field $\delta(\mathbf{r})$ occurring between the two exposures. The signal is detected at each point of the fringe pattern by a photodetector positioned by a computer controlled, precision, XYZ, positioning system. The signal is sent to a phase sensitive detector which measures the interference phase $\Delta\varphi$ relative to a reference.

We note that the interference phase $\Delta\varphi$ in holographic interferometry is most sensitive to deflections along the optical axis or viewing direction. Therefore, we orient the surface of the subject as nearly perpendicular to the viewing direction as possible for an optical inspection. We also evaluate numerically one or more of the second derivatives of interference phase

$$\frac{\partial^2\Delta\varphi}{\partial x^2} \quad \frac{\partial^2\Delta\varphi}{\partial y^2} \quad \frac{\partial^2\Delta\varphi}{\partial x\,\partial y}$$

These quantities depend primarily on the deflection–induced change of curvature (bending) of the surface or on the spatial rate of twist (torsion) of the surface.

The bending distribution is sensitive to structural defects such as cracks. The use of heterodyne holographic interferometry to monitor the formation of a fatigue–induced crack in a blade of composite material has been reported.[1] We used the same kind of fatigue failure test to evaluate the performance of the pulsed laser system for recording dual–reference–beam holograms for heterodyne readout.

The pulsed laser system, intended for field inspections of propulsion components, contains two injection seeded, frequency doubled, Nd:YAG lasers. There is a 1–to–1000 microsecond adjustable delay between laser firings, so that double–exposure holograms with different time separations can be recorded. A single injection seeder assures that the Nd:YAG lasers operate in a single longitudinal mode. The laser system will produce two pulses of green light (532 nm) where each pulse has an energy equal to 500 mJ. The spectroscopic line–width of the pulses is 0.005 cm^{-1} . Consequently, good holograms can be recorded of subjects having a projected size up to about a meter and a surface relief (scene depth) of about half a meter.

The pulsed laser was compared with a continuous wave laser (argon–ion) for detecting fatigue cracking in a blade of composite material 8 cm long and 2 cm wide. The blade was vibrated at a large amplitude in a shaker to induce cracking. Periodically, this destruction was interrupted and optical inspections performed. The pulsed–laser optical inspections were performed by recording double–exposure holograms of the blade as it vibrated in its first bending mode at a small amplitude. The laser firing was synchronized with an accelerometer attached to the blade. The two laser beams were each divided, routed into two separate reference–beam channels, and combined carefully in a single object–beam channel. The argon–ion inspections were performed by accurately displacing the blade tip between exposures of the double–exposure hologram.

The Nd:YAG laser and argon–ion laser performed equally well for detecting cracking in the blade using the procedures above. Both lasers were used with a small angle between reference beams (about 0.015 degree). The small angle makes it easy to form detectable fringes from holograms recorded in the field.

Optical inspections of the bending induced by a carefully excited vibrational mode, with the laser accurately synchronized with the phase of an accelerometer output, have the advantage of being repeatable. Hence changes in complex structures should be easier to recognize. This method is suitable between runs of a component or for acceptance testing. It may be desirable to inspect a component during a run or other test. The Nd:YAG laser is able to record up to 10 double–exposure holograms per second of such a time varying component. Using film to record the holograms, one could conceive of performing 100 optical inspections of a time varying and changing component from holograms recorded during a 10 second run.

The conclusion is that the combination of automated, computerized fringe measurement system and injection seeded Nd:YAG laser is both suitable and ready for a field demonstration of an optical inspection of a propulsion component based on dual–reference–beam holographic interferometry. The detailed inspection procedure will depend on the component and conditions.

1 Decker, A.J.; Krasowski, M.J.; and Kr[illegible]gulec, M.A.: Optical Inspection of Propulsion System Components Using Heterodyne Holographic Interferometry. in Advanced Earth–To–Orbit Propulsion Technology 1988, vol. II, NASA Conference Publication 3012.

TALK AND PROGRAM OBJECTIVES

- DISCUSS PROGRESS IN USING NEW Nd:YAG LASER FOR OPTICAL INSPECTION OF SPACE PROPULSION COMPONENTS
- INSPECT FOR CRACKS, DEFECTS, STRUCTURAL FAILURES, STRUCTURAL CHANGES, GAS LEAKS
- INSPECT WELDS, DUCT WORK, CASINGS, TURBOPUMPS, BLADES, COMPOSITES, CERAMICS
- INSPECT STRUCTURES WITH MAXIMUM PROJECTED DIMENSIONS PER INSPECTION FROM A FEW CENTIMETERS TO A METER

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METHOD OF INSPECTION

- DUAL–REFERENCE–BEAM HOLOGRAPHIC INTERFEROMETRY
- AUTOMATED FRINGE MEASUREMENTS USING OPTICAL HETERODYNING
- CW LASER IMPLEMENTATION DISCUSSED AT EARTH–TO–ORBIT PROPULSION TECHNOLOGY CONFERENCE, MARSHALL, MAY, 1988
- PULSED LASERS NEEDED FOR INSPECTIONS IN FIELD BETWEEN TESTS AND DURING TESTS OF COMPONENTS OR ENGINES

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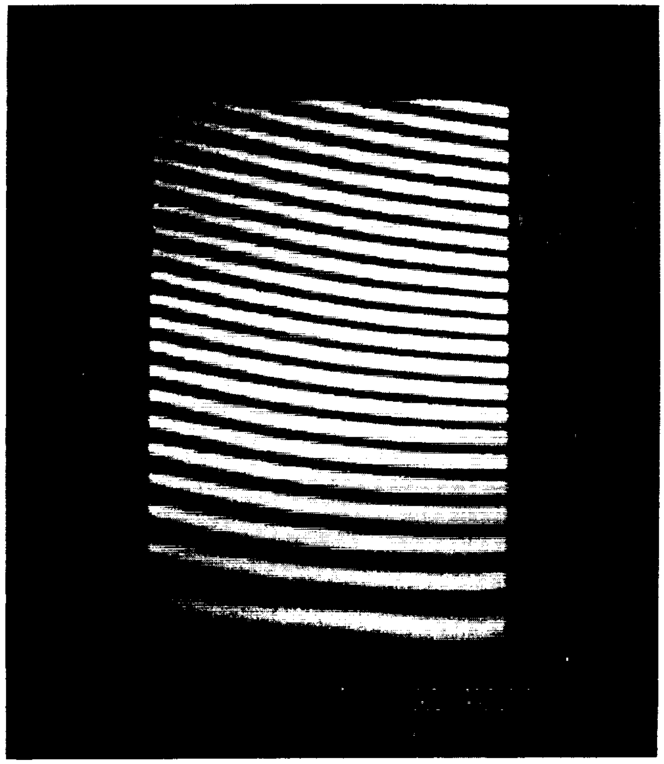
COSINE INTERFERENCE-FRINGE PATTERN BETWEEN BENT AND UNBENT STATES OF CANTILEVER



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PHASE CHANGE FOR DEFLECTION OF STRUCTURE

$$\Delta\Phi(\vec{r}) = \frac{4\pi}{\lambda} \frac{\left(\vec{K}_i - \vec{K}_r\right)}{2} \cdot \vec{\delta}(\vec{r})$$

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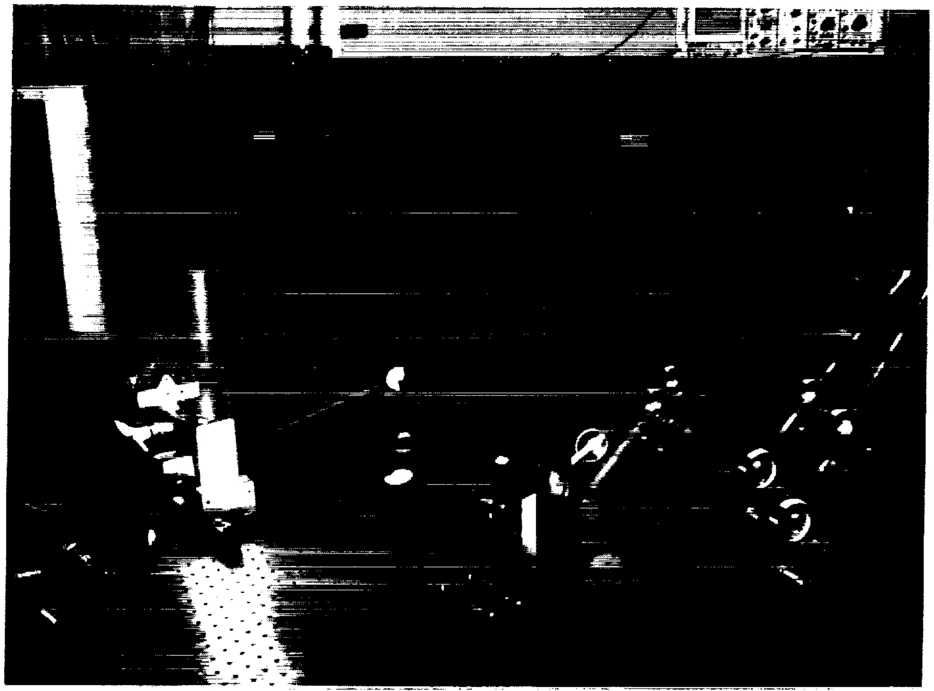
Nd:YAG LASER LAYOUT



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HETERODYNE HOLOGRAPHY

$$I = Io + I_1 \, Cos \, [\Delta\Phi \pm \omega t]$$

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STRUCTURAL PROPERTIES FROM HOLOGRAPHY

STRAIN

$$\varepsilon_{xx} = \frac{\partial \delta_x}{\partial x} \quad \varepsilon_{xy} = \frac{1}{2}\left(\frac{\partial \delta_x}{\partial y} + \frac{\partial \delta_y}{\partial x}\right)$$

$$\varepsilon_{yx} = \frac{1}{2}\left(\frac{\partial \delta_y}{\partial x} + \frac{\partial \delta_x}{\partial y}\right) \quad \varepsilon_{yy} = \frac{\partial \delta_y}{\partial y}$$

BENDING

$$\Delta K_\alpha = \frac{\partial^2 \delta_z}{\partial x^2}\cos^2\alpha + 2\,\frac{\partial^2 \delta_z}{\partial x \partial y}\cos\alpha \sin\alpha + \frac{\partial^2 \delta_z}{\partial y^2}\sin^2\alpha$$

TORSION

$$\frac{d\Omega}{dS} = \frac{\partial^2 \delta_z}{\partial x \partial y}\cos^2\alpha + \frac{1}{2}\left(\frac{\partial^2 \delta_z}{\partial y^2} - \frac{\partial^2 \delta_z}{\partial x^2}\right)\sin^2\alpha$$

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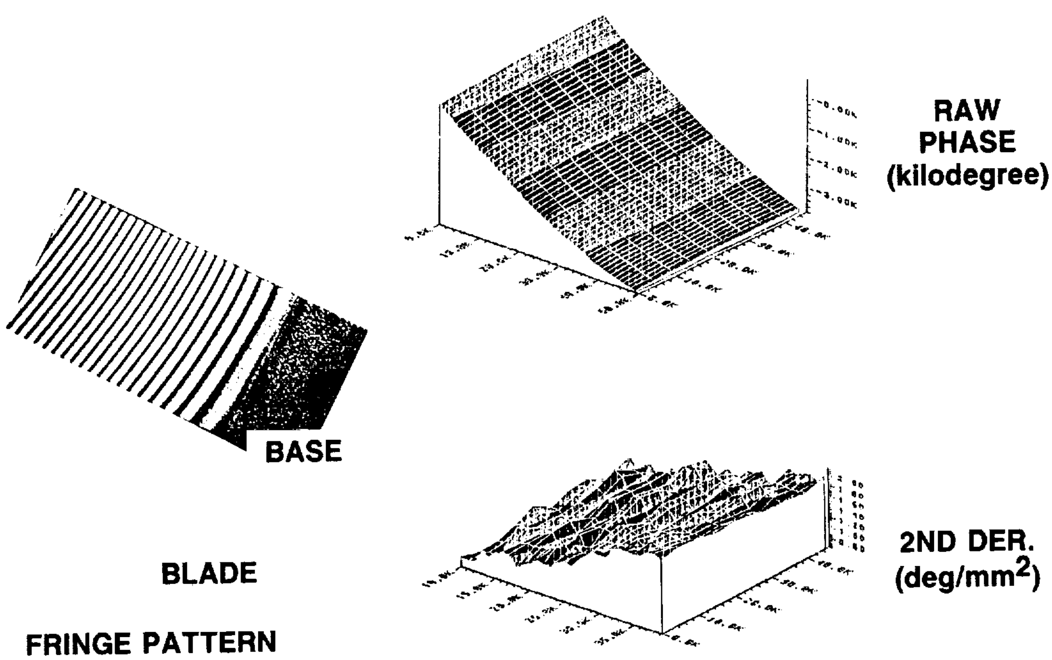

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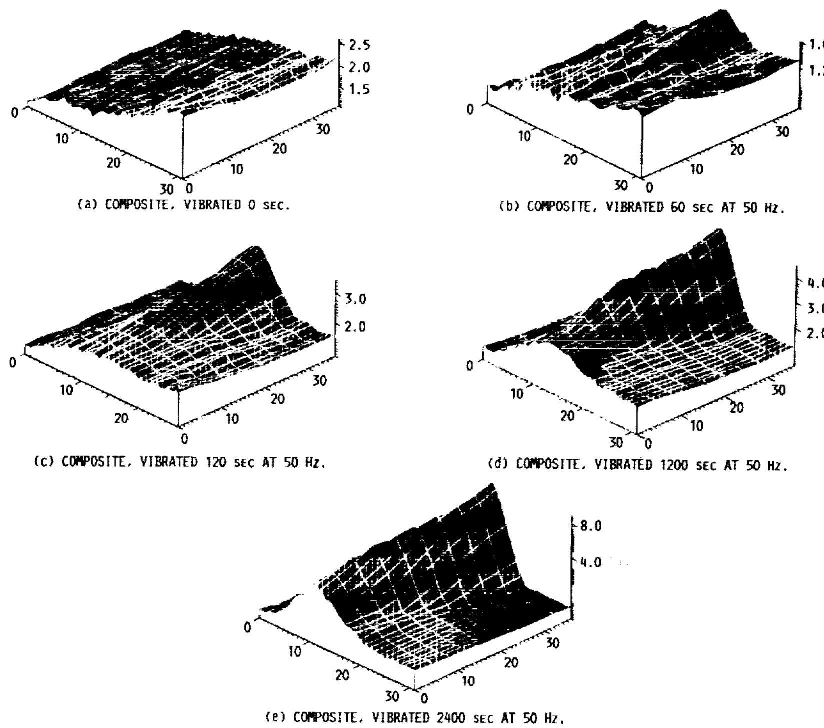
OPTICAL INSPECTIONS OF COMPOSITE BLADE



(a) COMPOSITE, VIBRATED 0 SEC.

(b) COMPOSITE, VIBRATED 60 SEC AT 50 Hz.

(c) COMPOSITE, VIBRATED 120 SEC AT 50 Hz.

(d) COMPOSITE, VIBRATED 1200 SEC AT 50 Hz.

(e) COMPOSITE, VIBRATED 2400 SEC AT 50 Hz.

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TESTS IN THE FIELD

- NEED DOUBLE–PULSE, PULSED–LASER SYSTEM (INJECTION–SEEDED Nd:YAG)
- CAN USE EXISTING AUTOMATED FRINGE MEASUREMENT SYSTEM USED FOR CW LASER APPLICATIONS
- NEED WAY TO CREATE INTEREXPOSURE DISPLACEMENT FIELD (VIBRATION)
- NEED PROCEDURES FOR INSURING REPEATABILITY OF TEST CONDITIONS

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INJECTION SEEDED Nd:YAG LASER SYSTEM

- TWO INDEPENDENT, Q–SWITCHED, Nd:YAG, OSCILLATOR, AMPLIFIER, FREQUENCY DOUBLER COMBINATIONS (QUANTEL YG 580 SERIES LASERS)
- ONE INJECTION SEEDER
- 500 mJ PER LASER OF 532 nm LIGHT
- 0.005 cm^{-1} LINE–WIDTH (2 m COHERENCE LENGTH)
- 1 TO 1000 MICROSECONDS BETWEEN PULSES FOR DOUBLE EXPOSURE
- 10 PULSE PAIRS PER SECOND

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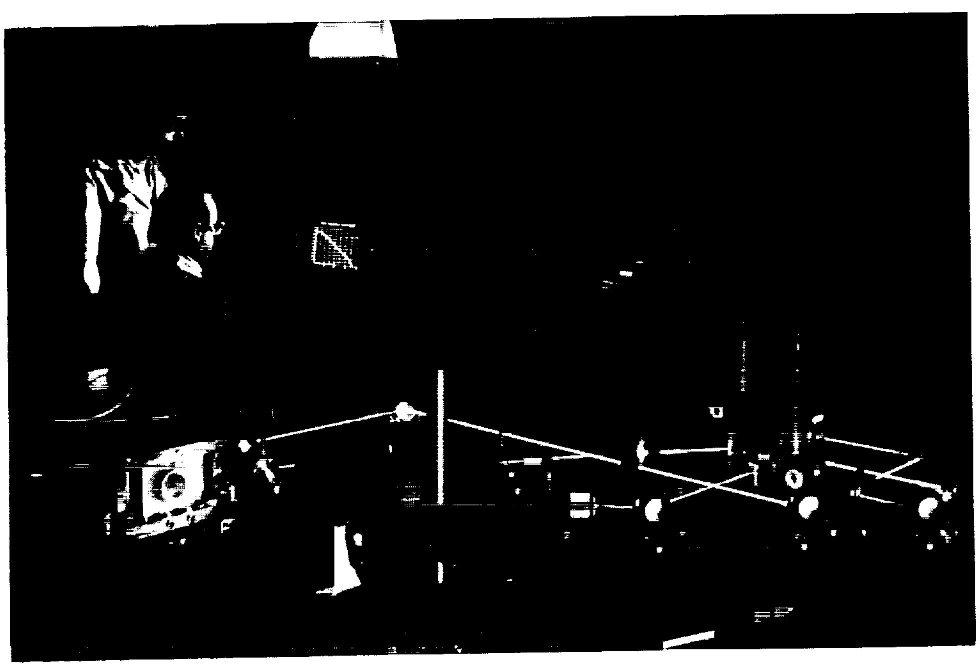
SAMPLE LAYOUT
DUEL REFERENCE-BEAM HOLOGRAPHIC INTERFEROMETRY



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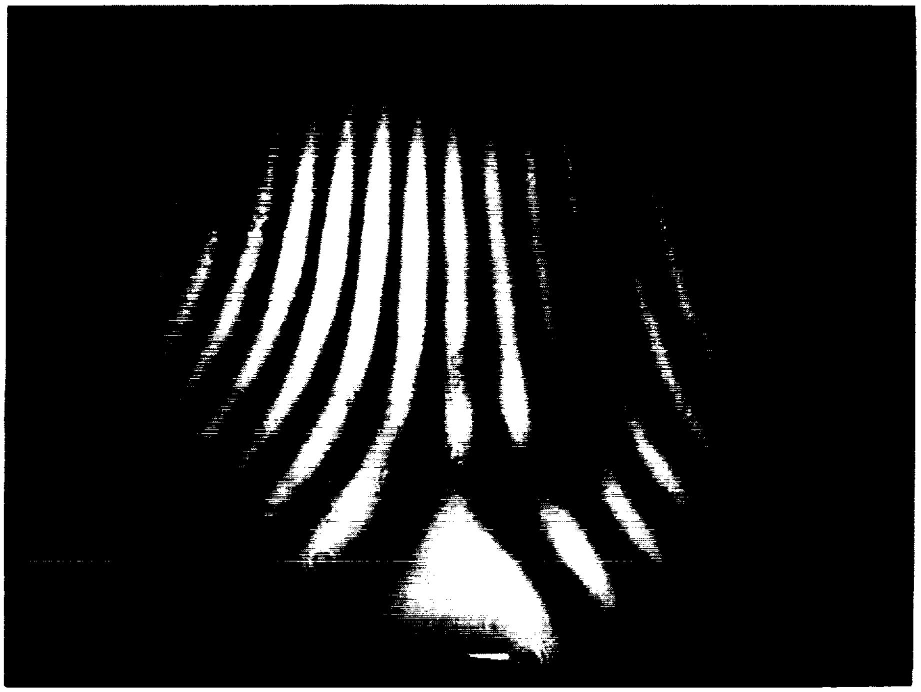
FRINGE PATTERN
SIZE ABOUT 1 m



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INTEREXPOSURE DISPLACEMENT

- SYNCHRONIZE LASER TO VIBRATIONAL MODE
- COMPONENT OR ENGINE INSPECTION BETWEEN RUNS: EXCITE VIBRATIONAL MODE NONDESTRUCTIVELY

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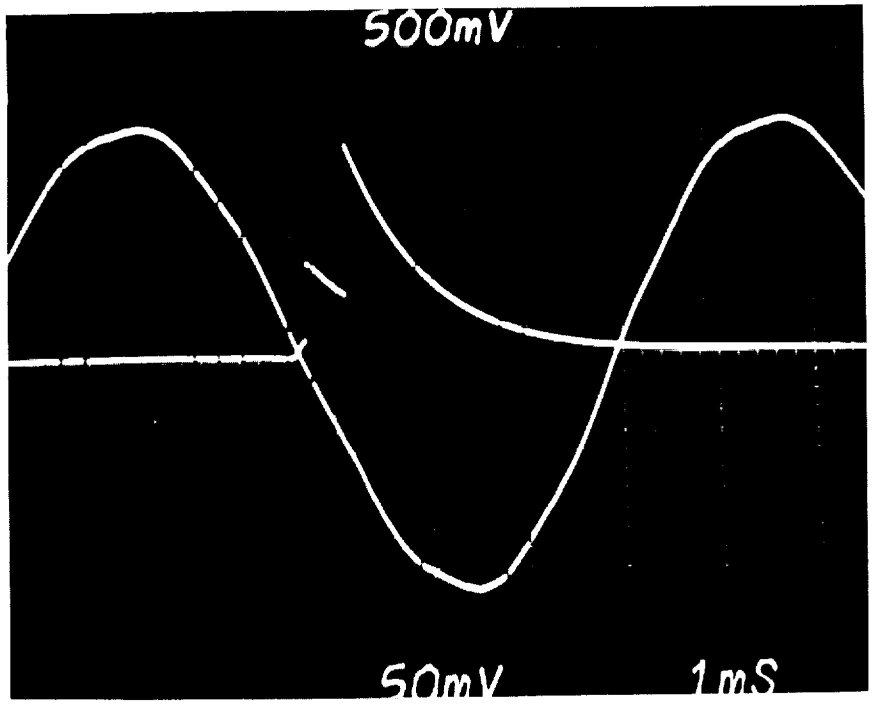
TWO LASER PULSES SYNCHRONIZED WITH ACCELEROMETER OUTPUT



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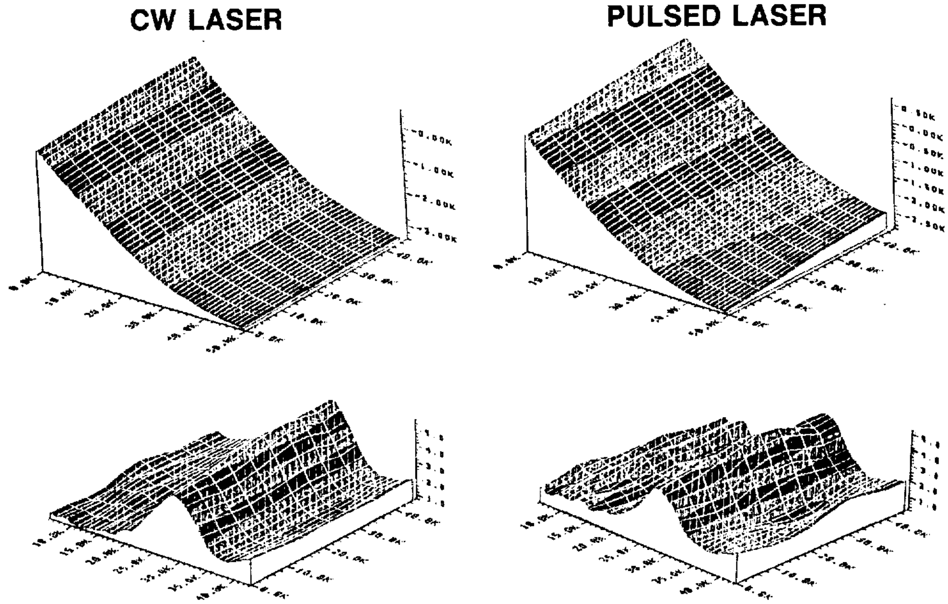
COMPOSITE AT 21 000 FATIGUE CYCLES



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STATUS

- INJECTION SEEDED Nd:YAG LASERS ARE SUITABLE FOR DUAL–REFERENCE–BEAM HOLOGRAPHIC INTERFEROMETRY

- SENSITIVITY OF CW AND PULSED LASER INSPECTIONS SIMILAR FOR THE SAME REFERENCE BEAM INTERANGLE

- 3 STANDARD DEVIATIONS:
  1/300 FRINGE, CW, LARGE ANGLE
  1/100—1/60 FRINGE, CW AND PULSED LASER, SMALL ANGLE

- CW AND PULSED LASER METHODS CAN NOW BE DELIVERED TO SPECIFIC PROJECTS

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