(2)

AD-A263 170

AD

US ARMY
LABORATORY COMMAND
MATERIALS TECHNOLOGY LABORATORY

MTL TR 92-60

ENHANCED NONCONTACTING LASER EXTENSOMETER FOR BIAXIAL STRAIN MEASUREMENTS

September 1992

JAMES J. CONNOLLY, JAMES R. ENGEL, and
ANDREW T. LINTZ
Optra, Inc.
66 Cherry Hill Drive
Beverly, MA 01915

FINAL REPORT

Contract DAAL04-92-C-0005

Approved for public release; distribution unlimited.

Prepared for

U.S. ARMY MATERIALS TECHNOLOGY LABORATORY
Watertown, Massachusetts 02172-0001

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER MTL TR 92-60	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ENHANCED NONCONTACTING LASER EXTENSOMETER FOR BIAXIAL STRAIN MEASUREMENTS		5. TYPE OF REPORT & PERIOD COVERED Final Report - January 1992 - August 1992
		6. PERFORMING ORG. REPORT NUMBER OPT/261
7. AUTHOR(s) James J. Connolly, James R. Engel, and Andrew T. Lintz		8. CONTRACT OR GRANT NUMBER(s) DAAL04-92-C-0005
9. PERFORMING ORGANIZATION NAME AND ADDRESS Optra, Inc., 66 Cherry Hill Drive Beverly, Massachusetts 01915		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Materials Technology Laboratory Watertown, Massachusetts 02172-0001 ATTN: SLCMT-PR		12. REPORT DATE September 1992
		13. NUMBER OF PAGES 36
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

J. Mead (COR)

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Strain measurements	Poisson's ratio
Noncontact measurements	Laser extensometer
Mechanical testing	Biaxial strain

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

(SEE REVERSE SIDE)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Block No. 20

ABSTRACT

In the proposed program, OPTRA will develop and commercialize a non-contact biaxial extensometer for the material testing market. The optical technology, based on an existing OPTRA single axis product, allows the accurate measurement of surface strains on any test specimen without contact and without material preparation. The non-contact measurement is ideal for high temperature testing, single fiber testing, high humidity/liquid immersed testing, high strain elastomer testing and many other applications that are unsuitable for bonded gages. The incorporation of two axes of strain measurement in a single instrument allows users to measure shear strain, Poisson's ratio, and other biaxial strain conditions. The ability to reorient the measurement axes relative to the test specimen in real time with small cyclic loading allows the user to rapidly identify the maximum and minimum normal strain axes and thereby fully define an unknown state of plane strain. The product development will be focussed on meeting a wide range of material test requirements and on keeping production costs low to insure that a commercially viable product is produced.

CONTENTS

FIGURES

1.0 INTRODUCTION

The purpose of this program was to demonstrate the ability to monitor biaxial strain deformation of materials subjected to uniaxial or multiaxial loading conditions utilizing OPTRA's noncontact, single axis, laser extensometer.

Conventional means for gathering biaxial strain data include knife-edge extensometers, strain gages, and some full-field optical imaging systems. Biaxial contacting extensometer devices must physically contact the specimen surface and this disturbs the specimens behavior by inducing loading conditions, material contamination, etc. Strain gages can incorporate several measurement axes and have impressive resolution but must also be physically bonded to the surface. Full field optical imaging devices do not provide the measurement resolution or accuracy of the other methods and are thus not well suited for gathering accurate data. In testing of materials such as elastomers and rubber, conventional contacting methods cannot be used because of limited strain range.

Other types of extensometers require the use of flags to define the boundaries (gage length) of their measurement. System repeatability is dependent upon identical sample preparation and installation procedures. Flags and other such material preparation devices also can deform as the specimen is stressed. In deforming or shifting the orientation of an attachment, the boundaries of the measurement are changed without the chance to recalibrate or even become aware that this condition has occurred. The use of specimen attachments is especially detrimental in high temperature conditions where deformation, orientation changes, and slippage can lead to unknown errors. Another vulnerability of a boundary dependent extensometer is the possibility of dirt or other foreign particles on the chamber window. This type of extensometer would interpret such an interruption as a boundary condition and produce erroneous extension measurements.

A similar error source is also seen in strain gages that are required to be attached to the specimen. These gages must either be physically adhering the specimen or epoxied to the specimen surface. They suffer from the same error sources of slip-page, deformation, and orientation changes as boundary condition extensometers. Epoxied strain gages can leave the user to wonder if the measured strain is that of the specimen, the epoxy that attaches the gage to the specimen, or a combination of both. Under high temperature testing, both epoxy melting and slippage along with epoxy strain can result in a convolution of error sources.

The approach taken for this program was to utilize two of our commercially available, single axis, Laser Extensometer 3000's mounted in the necessary geometry to make the required biaxial measurement.

The Laser Extensometer 3000 measures extension by monitoring the single axis displacement of a test specimen at two locations a fixed distance apart. The difference between these two displacement measurements is the extension. Strain is the ratio of the extension to the fixed distance (gage length) between the two observation points. The measurement of extension is made without any surface preparation, indents, flag attachments, or moving parts.

OPTRA has successfully demonstrated the ability to make biaxial strain measurements in tensile testing to determine Poisson's ratio, shear testing and shear testing using a Iosipescu fixture.

2.0 LASER EXTENSOMETER 3000

2.1 History

The original concept for the Laser Extensometer 3000 (LE-3000) was developed from a Phase I SBIR program in 1984 under Department of Energy funding, to monitor fatigue and expansion in pipes. The Phase II program, in 1985, was used to develop and test a prototype noncontact, axial laser extensometry system. This LE-3000 system was first demonstrated at Oak Ridge National Laboratory in early 1987. Since that time, OPTRA has made steady advances in the field of noncontact, single axis laser extensometry. In late 1987, the first commercial LE-3000 system was built for NASA Lewis Research Center and there are now approximately thirty working units worldwide.

2.2 Theory of Operation

The Laser Extensometer 3000 measures extension by monitoring the single axis displacement of a test specimen at two locations a fixed distance apart. The difference between these two displacement measurements is the extension.

The laser technique applied here allows highly precise noncontact monitoring of axial motion. Consider the arrangement shown in Figure 1, in which two light beams from the same laser intersect in the vicinity of the surface whose axial motion is being monitored. Because the laser light is monochromatic, a pattern of interference fringes (alternate bright and dark zones) is formed in the region where the two overlap and is separated by a distance $d = \lambda/2\sin\Theta$ where λ is the wavelength of light and Θ is the angle between the two intersecting beams. A scattering particle moving through the interference fringes will scatter light that is modulated in intensity, due to the particles passage through light and dark planes. The intensity of the light which scatters will be modulated at a frequency, f, where

$$f = V/d \qquad (1)$$

and V is the particle's velocity component in a direction normal to the interference fringe planes. This description is based on a particle moving through a spatially modulated radiation field. An alternate description, based on Doppler shifts, can also be used and is described here for completeness. Referring again to Figure 1, the particle has velocity components $\pm V \sin\Theta$ along the propagation directions for the two beams, and has a zero velocity component along the line of sight to the detector. Light scattered from beam 1 towards the detector is thus Doppler shifted by an amount $-V\sin\Theta\ (\nu/c)$, while light scattered from beam 2 is Doppler shifted by $+V \sin\Theta\ (\nu/c)$, where ν is the frequency (Hz) of the light and c is the speed of light. At the detectors, two Doppler shifted scattered fields interfere to produce an intensity modulation at the difference frequency f:

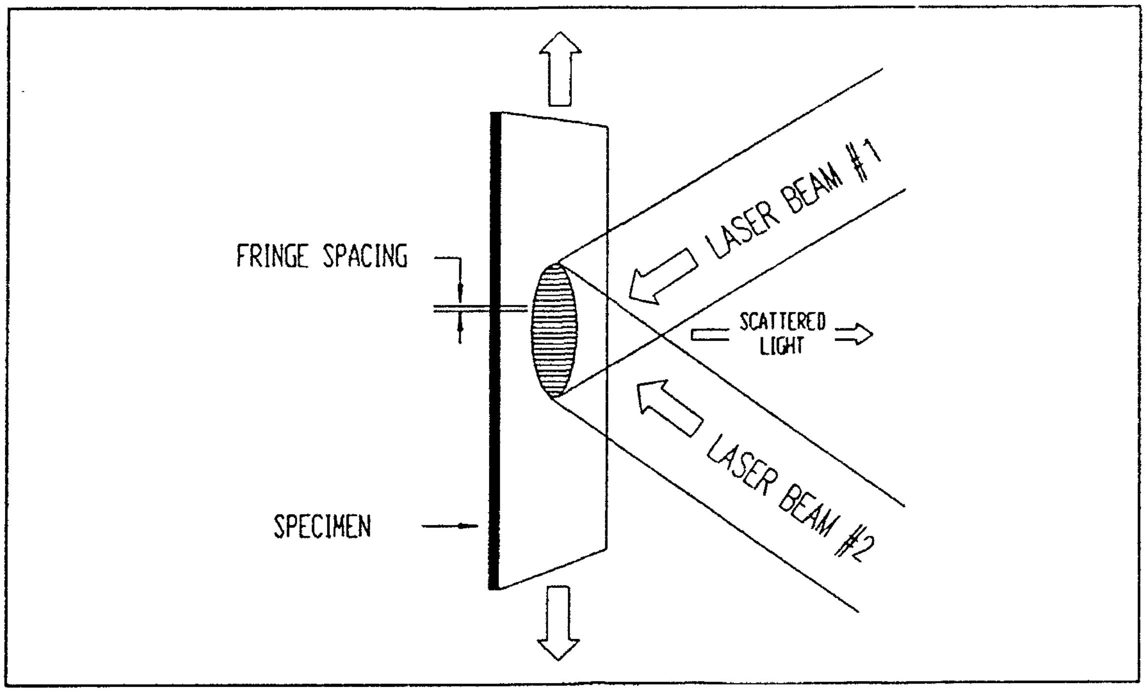

Figure 1 Interference Fringe Pattern on Specimen Surface

$$f = (+V\nu \sin\Theta/c) - (-V\nu \sin\Theta/c) = 2V\sin\Theta/\lambda, \qquad (2)$$

where $c \equiv \nu\lambda$.

Since a real scattering surface can be thought of as having many randomly located scattering particles within the illuminated area, the actual signal will be the randomly phased superposition of the number of signals. It remains however, a modulated signal having a well defined amplitude and phase.

The process of monitoring axial displacement is actually one of counting cycles and fractions of a cycle of modulation. This becomes increasingly more difficult, in a practical sense, as the surface velocity approaches zero. For example, an electronic system built to monitor the phase of the modulation signal is unable to distinguish between signal changes due to surface motion and those due to either electrical noise or low frequency fluctuations in power of the reflected laser beam. Moreover, the modulated signal does not indicate the direction of the motion.

For these reasons it is convenient to offset the modulation frequency by a fixed amount. Therefore, instead of using the same optical frequency, ν, in both beams in Figure 1, different frequencies, ν_1 and ν_2, are used. The resulting interference fringe pattern will not be stationary but will move at a velocity, v

$$v = (\nu_1 - \nu_2)/d. \quad (3)$$

The fringes will move past a fixed point at a rate, f, of

$$f = \nu_1 - \nu_2. \quad (4)$$

Ideally, the light at the two frequencies ν_1 and ν_2 would be temporally coherent; that is to say, their instantaneous phase difference at a time t would depend only on their initial phase difference, and their frequency difference. One would like the difference frequency to be high enough to avoid all low-frequency electrical noise sources and to unambiguously sense the direction of relatively high velocities ($V_{max} \leq fd$), but low enough for low-noise detection of the signals and to allow real-time detection and electronic data processing. OPTRA manufacturers a 2-Frequency HeNe laser which operates at a stabilized difference frequency of 250 kHz. In this case, when the particle is stationary, the scattered light is modulated at the difference frequency f. If the particle moves, it will pass through fringes at a greater or lesser rate depending on whether the particle moves against or with the fringe motion. If the particle velocity is V (V being positive when it opposes the direction of fringe motion), then the scattered light will be modulated at a frequency where,

$$f' = f + V/d = f + (2V/\lambda)\sin\Theta. \quad (5)$$

For a fringe spacing d = 10 microns ($\Theta = 1.8°$) and a velocity of ± 10 cm/sec, the modulation frequency would be 250 kHz ± 10 kHz. Given this type of velocity measurement, position can be easily calculated as the time integral of velocity. The output from a 2-frequency laser is comprised of two co-linear, orthogonally polarized components which differ in frequency by 250 kHz. The output from this laser goes to a beamsplitter which transmits one beam, and reflects the other. In this manner the two frequency components are separated on the basis of their orthogonal polarizations. The transmitted beam is made parallel to the reflected beam by a mirror, and its polarization vector is rotated 90° by a 1/2 waveplate so that it can interfere with the other beam. Both beams then pass through a lens which brings them to a point of intersection where the moving interference fringe pattern is formed. Light scattered by a particle within their fringe pattern is sensed by a detector.

If instead of a single particle, there is an array of randomly positioned particles, then the situation is changed. Consider an array of N randomly positioned identical particles. Each particle would individually produce a modulated signal with the same amplitude, but its phase would be a random variable which depended on its position relative to the fringe pattern at $t = 0$. The amplitude and phase of the net signal from the N particles are each random variables whose probability distributions can be calculated. This problem is the well known two dimensional random walk problem. If each particle independently produces a scattered irradiance

$$I = (1 + \cos[f't + \phi_1]) \tag{6}$$

at the detector where ϕ_1 is a random phase, then the net irradiant due to N particles is given by:

$$I_N = Na + aR_N\cos(f't + \phi_N) \tag{7}$$

where ϕ_N is a uniformly distributed random phase and R_N is a random amplitude whose probability distribution and rms value are given by:

$$P_N(R)dR = (2R/N)\exp(-R^2/N)dR \quad \text{and}$$
$$R_{RMS} = (N)^{1/2} \tag{8}$$

From the expression for $P_N(R)$ it can be shown that there is only a 1% probability that the random amplitude will have a value of less than 10% of its rms value. The consequence of this analysis is that although in the case of a large number of randomly distributed particles, and the net modulation amplitude is a random process, there is nevertheless a high probability that this signal can be detected and put to use.

In this discussion above we have considered first scattering by a single particle, and then scattering by N particles. If we wish to consider scattering by a diffusely reflecting surface we need a somewhat more sophisticated approach. Consider that a laser beam illuminates a spot of diameter D on a diffusely reflecting surface, and an aperture of diameter D_O, at a distance R, receives the scattered light (this aperture could either be the sensitive area of the detector itself, or the aperture of a collection lens). The question is, how many statistically independent contributions are there to the detected scattered light? We can address the question either in terms of the number of speckles falling within the detector aperture, or in terms of the number of spatially resolvable areas lying within the illuminated spot. The diffraction limited minimum resolvable dimension within the illuminated area on the surface is $X_{min} \approx R\lambda/D_O$. Thus the total number of independently resolvable elements of area within the illuminated spot is given by:

$$N \approx (D/X_{min})^2 = D^2 D_O^2/(\lambda^2 R^2). \tag{9}$$

It is straightforward to show that this same expression also gives the number of speckles (due to scattering of spatially coherent light by a diffuse surface) falling on the detector aperture. In those instances when either the spot on the surface or the detector aperture are not round, D and/or D_O should be regarded as the geometric mean of the corresponding x and y dimensions.

In an ideal system there would be no randomness associated with the surface (e.g. the surface could be a grating whose spacing matched the fringe spacing), and any noise would be negligible compared to the signals. With such a system, the lateral displacement of the surface by amount x would produce a detected phase change $\phi = x/d$ (cycles) relative to a stationary reference. An extensometer would be comprised of two such measurements made at locations separated by the gage length L_O. If the two phase measurements were ϕ_1 and ϕ_2, then the extension would be:

$$E \equiv \text{Extension} = (X_1 - X_2) = (\phi_1 - \phi_2)d, \tag{10}$$

where ϕ is measured in cycles. Since it is the difference in the phases which provides the measure of the extension, their difference can be measured directly (without need for a reference phase). All of the significant errors in the extension measurement are related to errors in the determination of the phases ϕ_1 and ϕ_2. Because the proposed extensometer technique involves observations at two fixed points separated by a fixed gage length (versus observations at points that move with the surface), the extension given by the equation above is different from the so called engineering extension resulting from a measurement with an electronic strain gage, and is often called true extension. If E_1 is the true extension and E_2 is the engineering extension, then it is straightforward to show that they are related by:

$$E_2 = \ln (1 + [E_1/L_O])/L_O. \tag{11}$$

2.3 Optical Configuration

The LE-3000 consists of two pieces of equipment: the sensor head and the electronic processing unit (see Figure 2). The sensor head is typically attached to the test frame or some rigid structure in close proximity to the specimen under test.

The LE-3000 utilizes a two frequency, Zeeman-split laser that is designed and manufactured by OPTRA. The laser output consists of two modes of circularly polarized light. The difference frequency between the two modes is 250 kHz. This difference frequency is stabilized by monitoring a small portion of the output and, with a servo loop, maintaining the proper length of the laser cavity.

The output from the laser is directed through a calcite crystal to spatially separate the orthogonally polarized modes (see Figure 3). A half waveplate rotates the polarization of one mode so that both will have identical axis of polarizations and can interfere efficiently. A combination of beamsplitters and mirrors direct the two modes through a pair of focusing lenses.

Collimated laser light is projected out of the sensor head. The four laser beams are brought to a focus as they approach the specimen to create two illuminated spots on the specimen surface. The specimen surface causes light to be scattered off of the surface, back to the sensor head. The scattered light, which contains the displacement information, is collected by optical detectors in the sensor head and transmitted with shielded cables to the electronic processing unit. The electronic processing unit collects the electrical information and calculates extension.

Both pieces of the LE-3000 contain no moving parts that would require any maintenance or calibration. The sensor head is an independent unit containing both projection and collection optics in a single package.

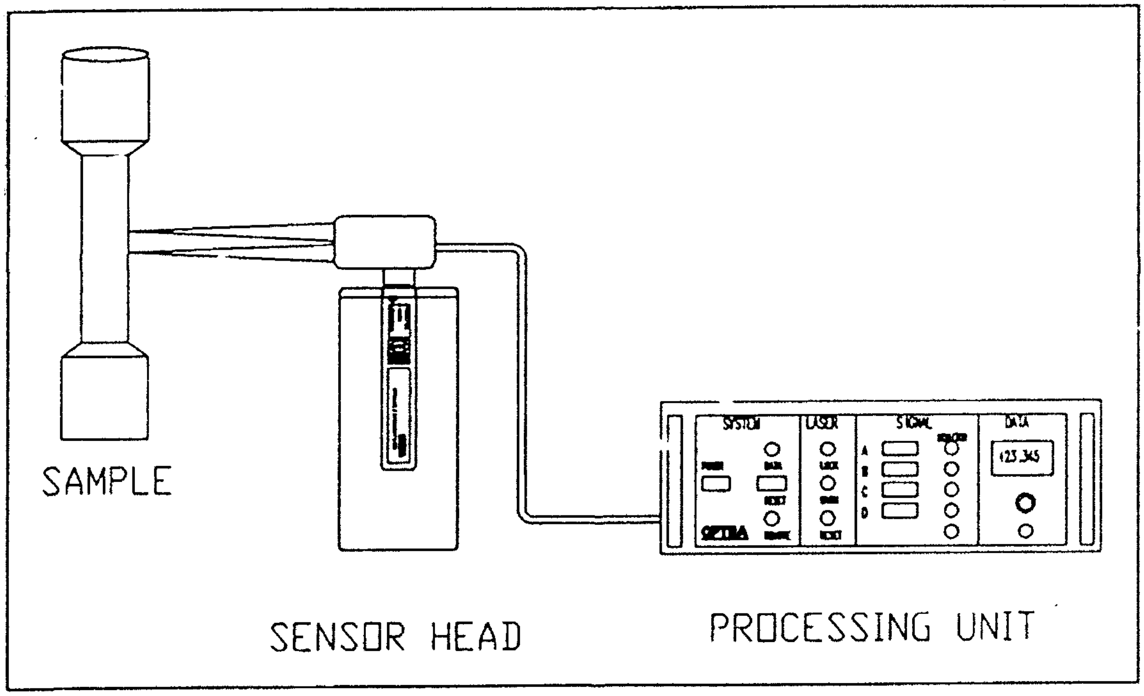

Figure 2 Laser Extensometer 3000 Configuration

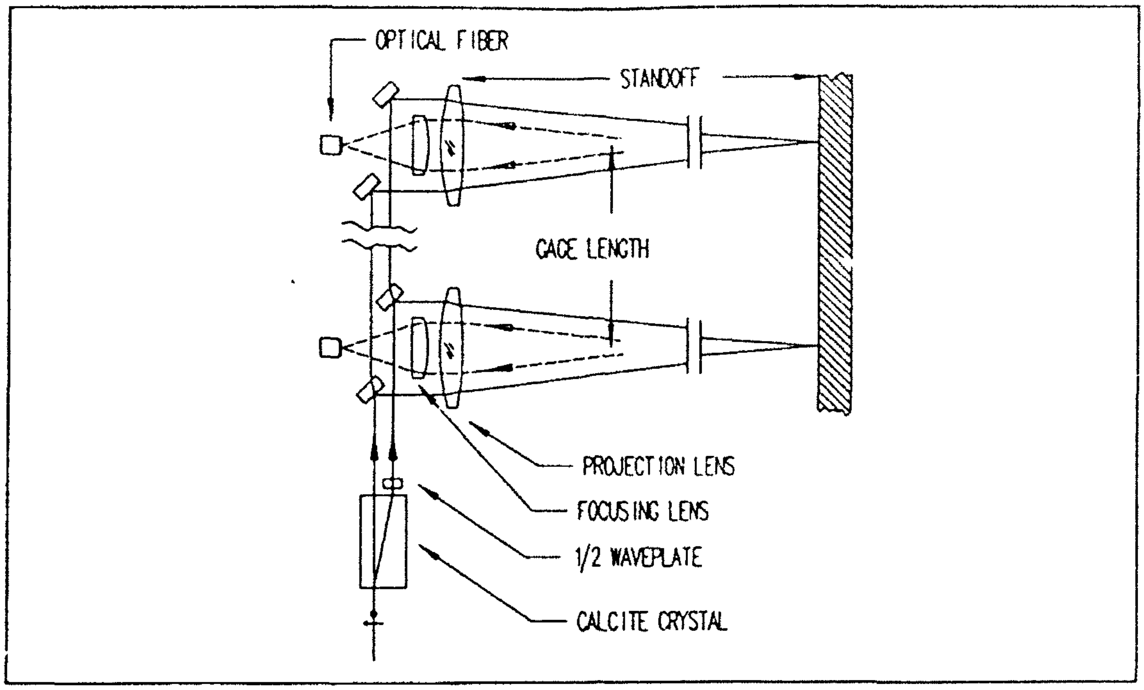

Figure 3 Optical Layout for the Laser Extensometer 3000

2.4 Electronic Processing

The existing commercially available LE-3000's signal processing uses four detectors in the optical head to collect scattered light from the specimen. The signals pass through a channel selection circuit and a tracking filter. After an amplification stage they are squared and brought into a phasemeter circuit. The phasemeter circuit calculates the relative phase between the squared laser reference signal and the signal from the specimen surface. A change in relative phase between these two signals corresponds to a displacement on the specimen surface equivalent to the fringe spacing. The phasemeter monitors the relative phase by timing the period between respective edges of the two square waves. In addition to resolving complete cycles of phase the circuit is also capable of discerning phase changes down to 0.01 of a cycle. The current laser extensometer design has a fringe spacing of 500 microinches and a resolution of 5 microinches.

OPTRA has developed, and for this program implemented, a signal processing scheme which is referred to as multiphase detection. This approach allows for improved resolution by subdividing a phase cycle into 1500 parts. Furthermore, the electronics are more robust in the presence of low return signals or those with a low signal/noise ratio.

2.5 Data Communication

The electronic processing unit provides extension output through several interfaces. A visual display provides extension readings with a resolution of 4.5 microinches. The analog output produces a $\pm$ 10 Volt signal corresponding to $\pm$ 100,000 microinches of extension ($\pm$ 5% strain) in our standard system. With the Analog Accessory Unit selectance strain ranges of ± 20%, ± 40%, ± 80% and 160% can be chosen for analog output. A 20 bit parallel interface is also available for collecting digital data and controlling the LE-3000 remotely. Strains of up to 192% can be read directly from this digital output. Other easily implemented interface options are the RS232C and the IEEE-488 interfaces.

2.6 Mounting Configuration

The LE-3000 is either mounted to the test frame that applies the load to the specimen or is supported by an independent tripod mount assembly. Mounting brackets have been designed for a wide variety of test frames and can be reconfigured for different frames by interchanging several components. The tripod mount assembly allows the LE-3000 sensor head to be positioned in front of many different test frames.

2.7 Specifications

The commercially advertised specifications of the LE-3000 are shown in Figure 4. The accuracy achieved by the system is limited by its two major error sources. These primary sources of error in the proposed extensometer concept are: (1) a dead reckoning error or DRE (so called because it is a function of the line integral of the surface motion past the point of observation) due to the random nature of the diffusely reflecting surface, and (2) phase errors associated with the finite signal-to-noise ratio in the detected signal. The dead reckoning error can be understood as follows: each time the surface moves past the point of observation by a distance equal to the spot diameter, D_x, in the corresponding direction, there is a complete loss in phase correlation. This results in a random phase error between ± 1/2 cycle. The rms value of this error is $\Delta\phi = [1/(2\sqrt{3})]$ cycles. For each cycle of phase error, there is a lateral displacement measurement error of d (the fringe spacing). Thus, for a displacement just equal to the spot diameter there is an rms displacement measurement error of $d/(2\sqrt{3})$. For a displacement equal to N spot diameters, the problem can be viewed in terms of a 2-dimensional random walk with N steps, each of length $d/(2\sqrt{3})$, in random directions. The rms displacement error is thus given by:

$$DRE = N^{1/2}d/(2\sqrt{3}) = (X/D_X)^{1/2}d/(2\sqrt{3}), \qquad (12)$$

Gage Length	1 inch[1]
Measurement Resolution	5 microstrain
Measurement Precision	± 10 microstrain
Measurement Accuracy	< 50 microinches for strain of 0% to 0.1%
	< 5% of the reading for strains of 0.1% to 2.5%
	≤1% of the reading for strains greater than 2.5%
Strain Range	Unlimited
Sample Velocity	Static to 2.0 inch/inch/second
Maximum Sample Frequency	> 50 kHz.
Update Rate Analog	125 kHz.
Update Rate Parallel	125 kHz.
Update Rate Display	2.5 kHz.
Update Rate Serial (Optional)	≤ 9600 BAUD.
Sample Temperature	-100° C to >2500° C
Test Environment	Open air or vacuum
Sensor Standoff Distance	7.5 inches ±0.125 inches
Data Interface	Display in microstrain
	Analog ± 10 Volts scaled
	Parallel BCD (16 or 20 Bit selectable)
	Serial RS232c (optional)
	Parallel IEEE-488 (optional)
Warm-up Time	< 5 minutes
Laser Source	He/Ne, 2-Frequency stabilized, Zeeman-split.
	Class IIIa laser product
Laser Wavelength	632.8 nanometers
Laser Output Power	≤ 1 milliwatt (continuous wave)
Working Environment	Temp 0-40° C (32° - 105° F)
	Rel. Hum. 0-95% (non-condensing)
Power Requirements	110 VAC, 60 Hz. (100 Watts maximum)[2]

Figure 4 Specifications for Single Axis LE-3000

where X is the line integral of the x-component of the path of the surface past the point of observation. Figure 5 shows the predicted DRE as a function of extension. This plot assumes that motion between the sensor head and the specimen is kept to a minimum. The trace labeled "percent" shows the DRE as a percentage of the extension. Dead reckoning errors can be minimized by reducing the motion between the sensor head and the specimen surface. Keeping one spot close to the fixed grip of the load frame minimizes rigid body motion and its subsequent dead reckoning errors.

The second major source of error is noise. In general, noise with an rms value N is added to a vector signal S, with a random phase difference between the two. The resultant error $\Delta\phi$ in the phase of the signal has an rms value $(\sqrt{2}[S/N])^{-1}$. The corresponding error in the measurement of extension is given by:

$$\Delta X_{S/N} = (d\Delta\phi)/(2\pi) = d/(2\pi[S/N]). \qquad (13)$$

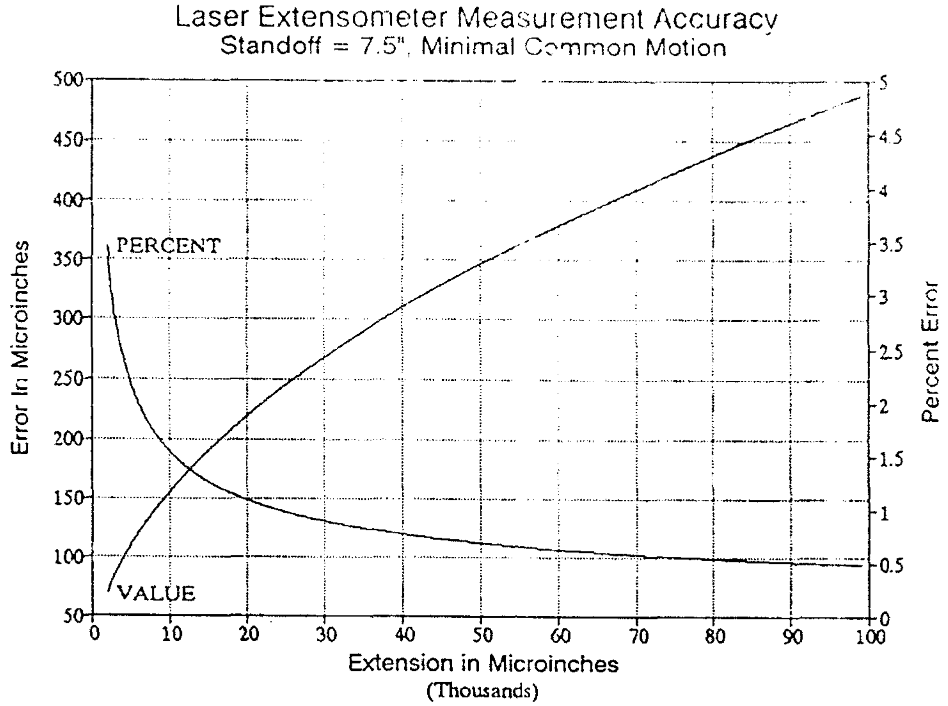

Figure 5 Predicted Dead Reckoning Error as a Function of Extension

The two primary sources of noise in the photocurrent from the detector are (1) electrical noise in the detector/preamp combination, which can be characterized by a Noise Equivalent Power, (NEP) and (2) shot noise in the photocurrent (due to shot noise in the photon flux). It is clear that the radiative power falling on the detector is comprised of a large DC component and a smaller AC component which is modulated at the laser beat frequency. From the definition of the surface reflectance r, the DC power at the detector is given by $P_d = r\Omega P_O$. Thus the rms AC power at the detector (comprising the information carrying signal), and the ratio of this signal to the electrical noise, are given by:

$$P_S = P_d/\sqrt{N} = r\lambda P_O\sqrt{\Omega}/D, \text{ and}$$

$$(S/N)_{ELEC} = (r\lambda P_O\sqrt{\Omega})/([NEP]D\sqrt{\Delta f}), \quad (14)$$

where Ω is the solid angle subtended by the detector collection optics. Photon shot noise represents a fundamental noise limit. The shot noise is carried primarily on the large DC light level, and leads to an rms noise and signal-to-noise ratio given by:

$$N_{RMS}(\text{shot}) = P_d \Delta f E/Q)^{1/2}, \text{ and}$$

$$(S/N)_{SHOT} \equiv P_S/N_{RMS} = (\lambda/D)(rQP_O/\Delta f E)^{1/2}. \qquad (15)$$

Because of the large number of parameters involved, this type of sensor cannot be characterized by a single optimum design. The relevant equations can be built into a spreadsheet for predicting extensometer performance and design parameters. In designing an extensometer for a specific application, the values for the required standoff distance, depth-of-field (tolerance on the standoff distance), surface reflectance, and accuracy, provide a useful starting point. The fringe spacing d, and spot diameter D, determine the depth-of-field; together with the anticipated total displacement they also define the rms dead reckoning error. Generally, the spot size is made as large as necessary to keep the dead reckoning error within bounds, and the detector solid angle is made small enough to keep the signal-to-crosstalk at a safe level. If the detector aperture is made too small, however, the electrical noise may become a problem.

Figure 6 is a typical single axis stress/strain plot obtained with a standard LE-3000 (1 inch gage) for an aluminum specimen. The curve represents several load/unload cycles and clearly indicates the precision or repeatability to be about 20 microinches. Analysis of this data reveals the average slope of the curve to be 1.08×10^7 psi, compared to a reference value for Young's modulus of 1.00×10^7 psi, or within a 8.0% accuracy.

3.0 PHASE I RESULTS

The following are the originally proposed Phase I technical objectives, followed by a discussion relating actual performance to those objectives.

3.1 Define Performance Requirements for Biaxial Strain Measurements

The purpose of this task was to choose specific tests that would be important in providing sufficient information to show that biaxial measurements can be made by adapting single axis laser extensometry to biaxial measurements. By providing accurate data for biaxial tensile and torsion shear testing, along with shear generated in an Iosipescu fixture, a variety of loading conditions, using varying gage lengths, was provided. It was during initial contact with the program technical monitor that the interest and need for strain measurements using an Iosipescu fixture was discovered.

These tests were considered to be a good crossection of types that represent general materials testing research. If biaxial strain measurement could be shown feasible with LE-3000 extensometry, then need for product development could be shown.

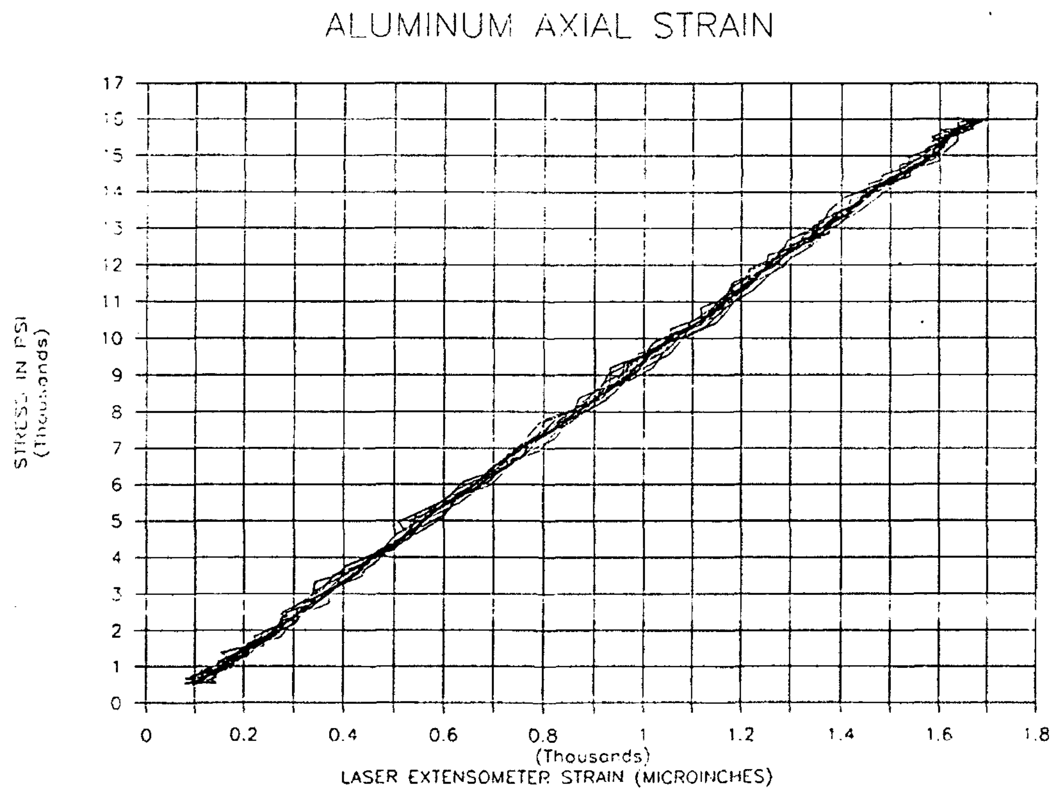

Figure 6 Typical Single Axis LE-3000 Test Data

3.2 Design and Develop Optical Enhancements for Biaxial Strain Measurements

Original thinking suggested optical adaptations to the standard LE-3000 to provide a spot orientation that would yield biaxial measurements. The need for optical adaptators was eliminated by the design of mechanical fixtures that provided equivalent capabilities without the need for custom optics. For example, by having two LE-3000's mounted 90° to each other it would be possible to measure the Poisson ratio of a specimen because strain is being monitored in both the axial and transverse directions.

This method would allow us to show the feasibility of biaxial measurements using noncontact extensometry and spend more time on testing. The original proposal would have caused us to spend a majority of time on optical designs that would be obsolete after this Phase I program.

3.2.1 Poisson Ratio Test

By measuring strain in both the axial and transverse directions of a sample that is loaded with uniaxial tension, the Poisson ratio can be determined. For this application it was necessary to mount two LE-3000's at 90° to each other on the same side of the specimen.

The experimental set-up for this test is shown in Figure 7. From these photos it can be seen that one LE-3000 is mounted vertically to monitor axial extension and the other orthogonally to monitor the transverse contraction during extension. The data for this test is shown in Figure 8. The sample used in this test was aluminum. By loading this sample from 125 psi to 350 psi at a rate of 16 lbs/sec, strain was measured in both the axial and transverse directions. Data was read simultaneously from the analog output of the control display unit (CDU) of each LE-3000 (one gathering axial data and the other transverse) into a data acquisition PC.

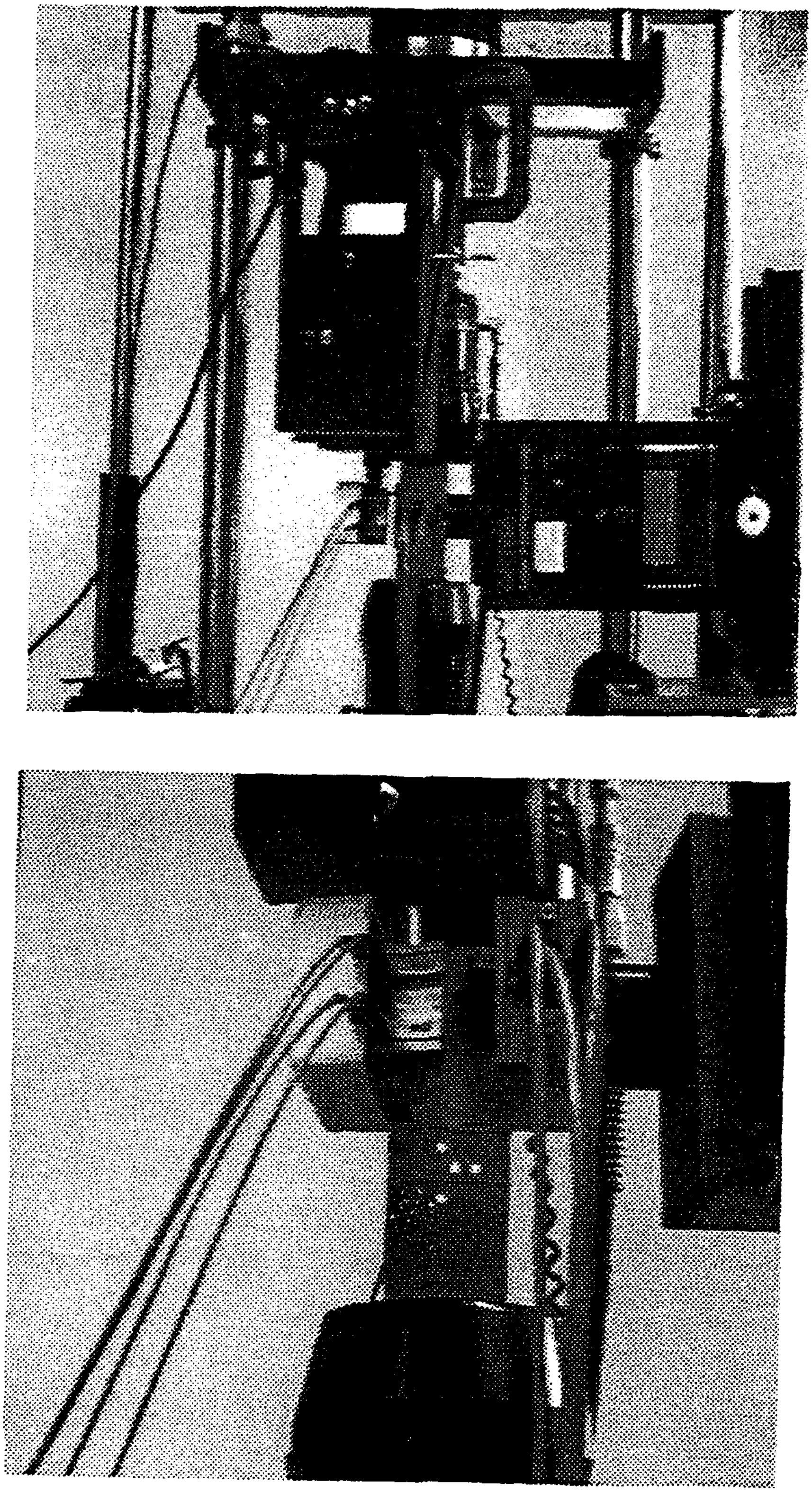

Figure 7 Biaxial Tensile Test Mounting Geometry

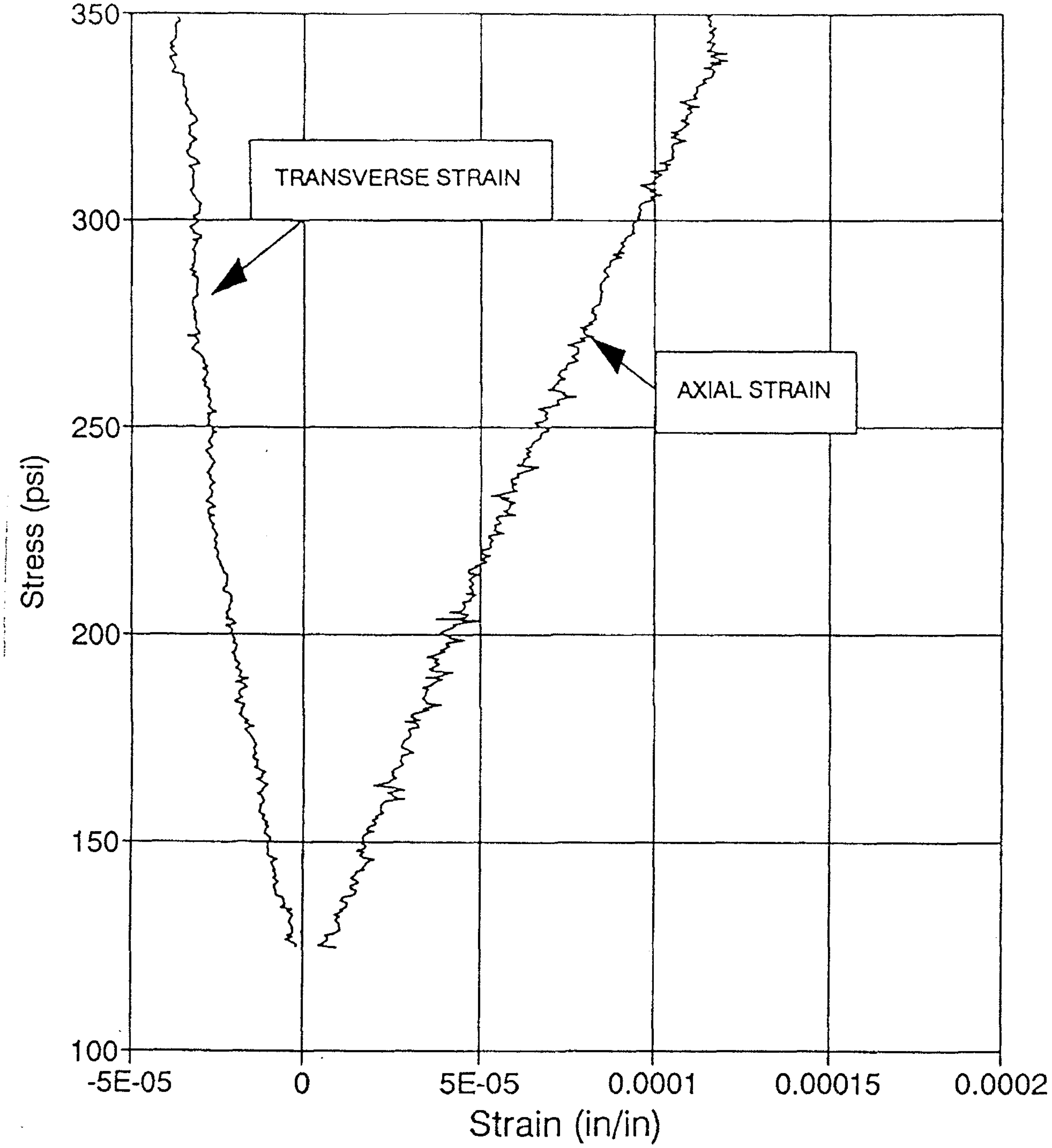

Figure 8 Biaxial Tensile Test Results

This allowed us to view the two slopes (stress versus strain) that were compared yielding a resultant slope (equal to the Poisson ratio) is 0.31. This compares favorably to an expected Poisson value for aluminum of 0.33.

3.2.2 Torsion Test

The measurement of twist in a sample, and can be used to determine the torsional or shear modulus of a material. In order to measure this we must place two LE-3000 spots on the surface with both fringe patterns in vertical directions. This allows for a surface displacement measurement at two points that can be used to detect the twist angle for an applied torque.

The experiment consisted of applying torque to an aluminum rod of 0.25 inch diameter with one end fixed in position. The applied torque was 50 in-lbs. As there was no torque load frame available, the load was applied with a torque wrench. As the LE-3000's sensitive axis is orthogonal to the fringe direction, a single LE-3000 will not work. Therefore two LE-3000's both mounted in horizontal but opposite in directions, as shown in Figure 9, was the method utilized. Figure 10 shows a diagram of the sample and the spots as they monitor surface displacement due to twist.

Figure 9 Torsion Test Set-Up

Spots ΔX_1 and ΔX_2 are from one LE-3000, and spots ΔY_1 and ΔY_2 are from another. The relative displacement between ΔX_1 and ΔY_1 is the measurement of interest. The first LE-3000 has spot ΔX_1 placed on the cylinder surface. Spot ΔX_2 is projected onto a fixed surface with zero motion. The second LE-3000 has spot ΔY_1 placed on the cylinder's surface, one inch below spot ΔX_1. Spot ΔY_2 is projected onto a fixed surface with zero motion. The expected angle of twist, Θ, for a given applied torque is

$$\Theta_{exp} = (TL)/(GJ) \tag{16}$$

where
- T = applied torque (50 in-lbs)
- L = gage length (1.0 inch)
- G = shear modulus (3.7×10^6 psi)
- J = polar moment of inertia = $\pi D^4/32$ (3.8×10^{-4} in^4)

TORSION TEST SETUP

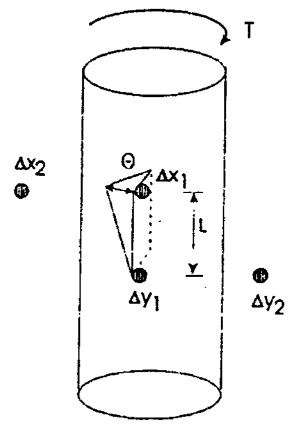

Figure 10 Torsion Test Surface Displacement Measurement

The angle of twist is measured by sensing the surface displacement of the two spots ΔX_1 and ΔY_1. The measured angle of twist Θ_M is

$$\Theta_M = (2\Delta X)/D \tag{17}$$

where D is the diameter of the cylinder and $\Delta X = \Delta X_1 - \Delta Y_1$ is the surface displacement due to twist (see Figure 10).

Spots ΔX_2 and ΔY_2 play no significant role in this measurement. The CDU of the LE-3000 #1 computes the relative displacement difference from $\Delta X_1 - \Delta X_2$. But since ΔX_2 is fixed in position, the motion seen is only that of ΔX_1. The same is true for LE-3000 #2 and the ΔY spots. The analog outputs from CDU #1 and CDU #2 are input to a PC and subtracted to give the resultant value of $\Delta X_1 - \Delta Y_1$ or ΔX.

Figure 11 shows an increasing twist angle as torque is applied by hand with a torque wrench. When 50 in-lbs is applied the torque is released. The measured peak twist of about 0.088 radian corresponds to a measured shear modulus of 4.3×10^6 psi, within about 14% of the expected value.

No detailed error analysis of this measurement was made. Error sources noted include possible bending moments applied to rod and the accuracy of the torque wrench. It is felt that the error experienced is consistent with these error sources (most especially the accuracy of the torque wrench) and that the experiment clearly demonstrates the ability of the technique to successfully make the measurement.

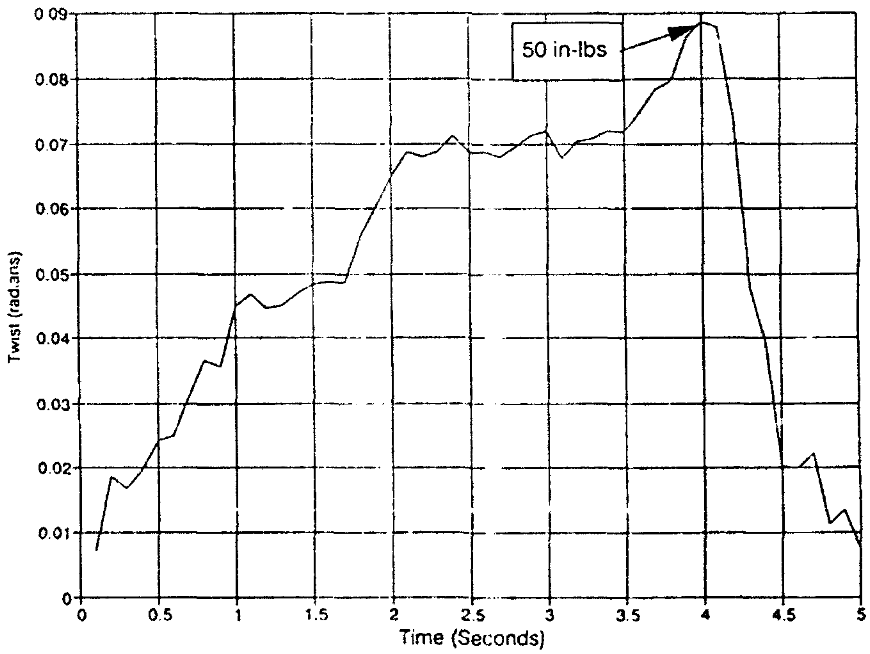

Figure 11 Torsion Test Results

3.2.3 Iosipescu Shear Test

The Iosipescu test fixture was developed to produce a test in which a specimen is subjected to pure shear. Although other test methods exist which produce the same results (e.g. large diameter, thin walled long cylindrical samples in torsion) the Iosipescu system minimizes the amount of sample material required. Using contact strain gages, the relationship between fixture, sample and strain gage is shown in Figure 12. Typically, one would measure the normal strain in the sample along the two orthogonal principal strain axes (i.e. σ_1 and σ_2) and then compute shear strain.

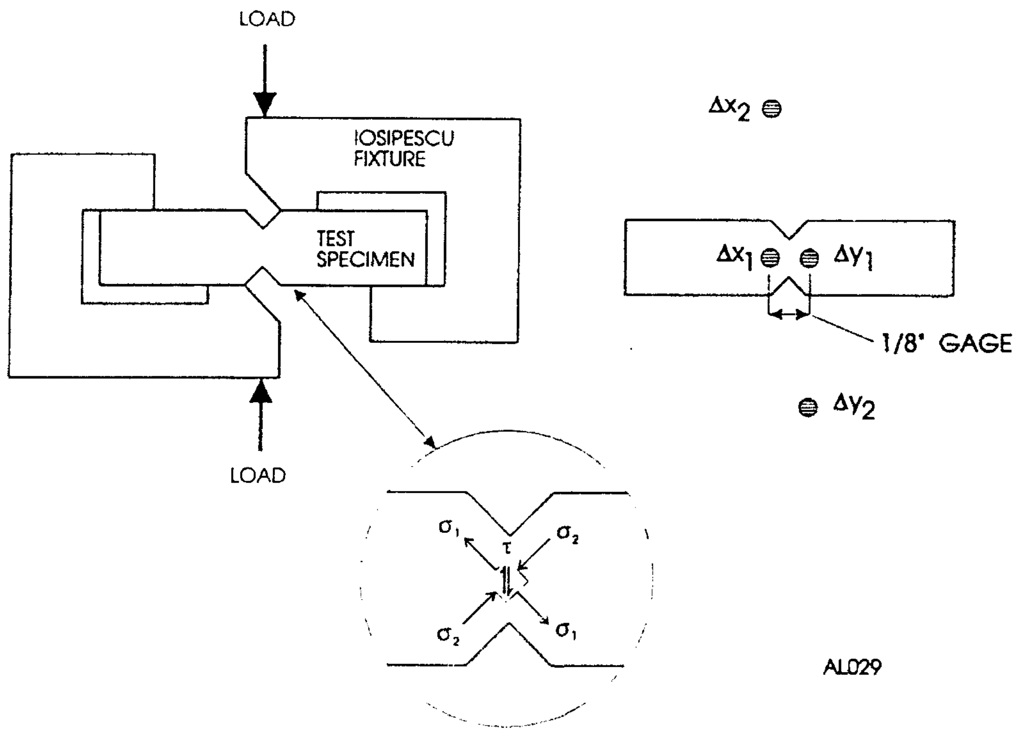

Figure 12 Iosipescu Test Fixture

While not a biaxial measurement, OPTRA has clearly demonstrated the ability to make a noncontact measurement of strain in the confined area. Furthermore, OPTRA attempted to measure the strain-produced material rotation directly by measuring displacements at two adjacent points straddling the shear plane. Although this technique can work in principal, rigid body rotations of the entire test specimen can contaminate the results. In retrospect it would have been more useful to measure the two principal normal strains (and compute the shear strain) using an identical configuration to Poisson ratio test setup described in Section 3.2.1.

An Iosipescu test fixture was provided by the Army Materials Technology Laboratory and mounted in the OPTRA load frame. Test samples were fabricated from .375 inches thick aluminum. Two LE-3000's were mounted side by side in opposite vertical directions as shown in Figure 13. Figure 12 is a diagram that displays the spot orientation relative to the specimen. Spots ΔX_1 and ΔX_2 are from one LE-3000 and ΔY_1 and ΔY_2 and the other LE-3000. Spots ΔX_2 and ΔY_2 are directed at rigidly fixed targets (not the test sample). The displacement measurement is made at ΔX_1 and ΔY_1 which are separated horizontally by 0.125 inches (gage length).

Figure 14 is a stress versus strain curve obtained during a load-to-failure test of the sample. The sharp jump in the curve at about 18 kpsi may be indicative of crack initiation. The sample failed at an applied shear stress of approximately 22,500 psi, somewhat lower than expected.

Although the quantitative analysis of the results of the OPTRA Iosipescu test were inconclusive, the test did indicate the ability to work with the Iosipescu fixture and achieve the small gage lengths needed for the Phase II system. If the spots shown in Figure 12 were rotated 45° and a second axis recorded simultaneously (the Phase II prototype will have this capability) we would have measured the shear stress in the sample. We believe we measured sample rotation in the configuration we used. We are confident that the optical configuration proven in the Poisson ratio test could be utilized with small gage lengths to provide accurate data in Iosipescu shear test fixtures.

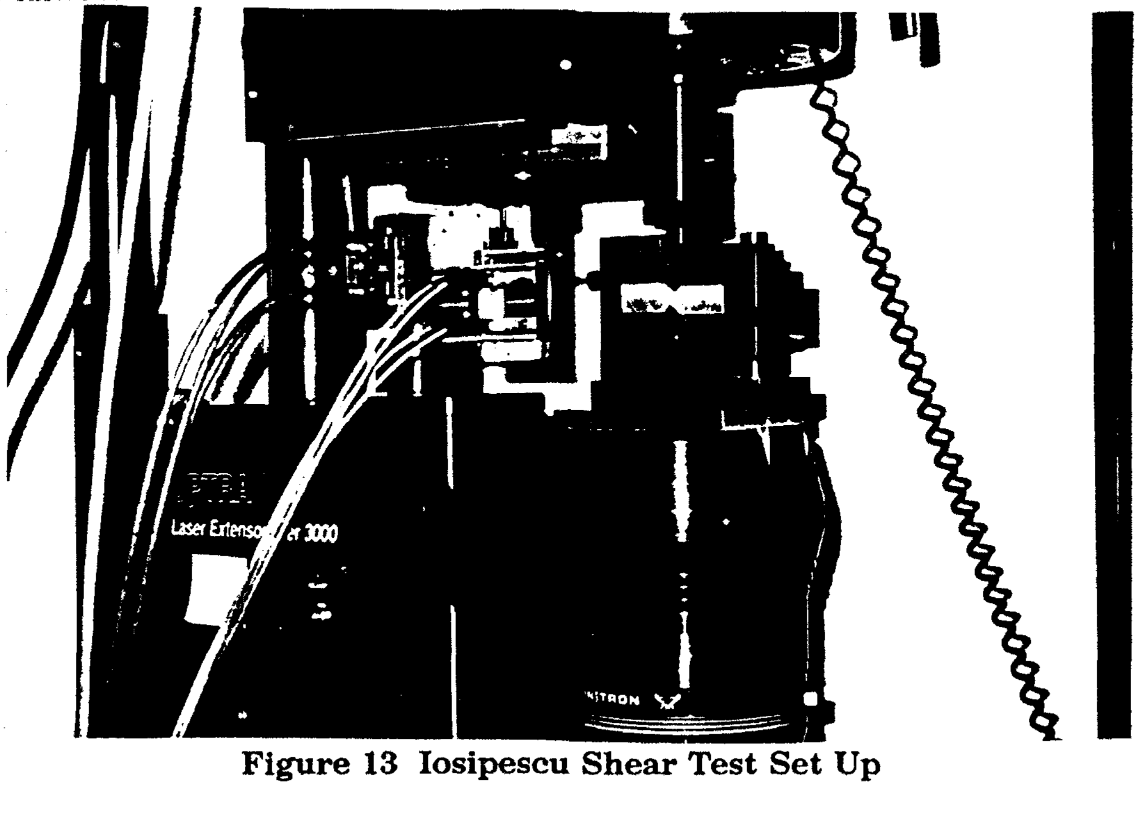

Figure 13 Iosipescu Shear Test Set Up

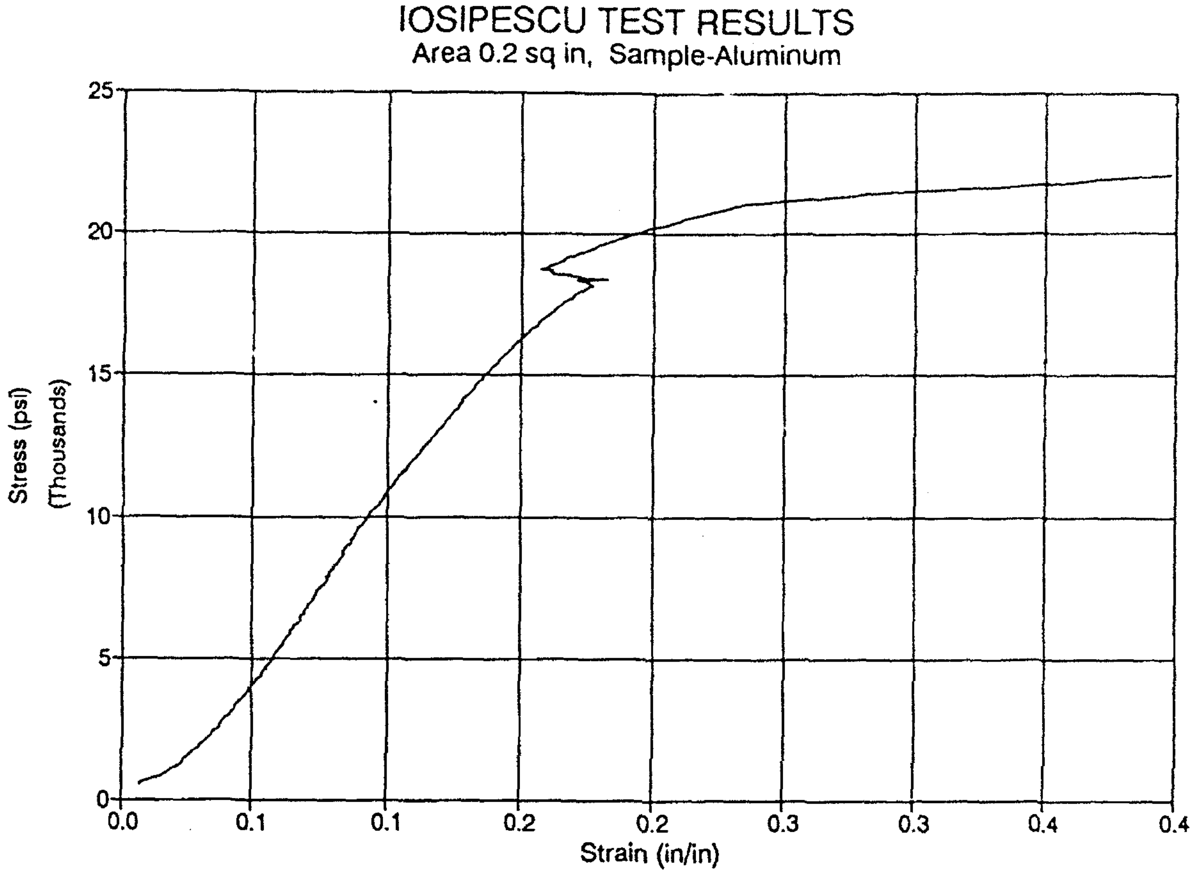

Figure 14

3.3 Electronic Signal Processing Enhancements

Scattered light from each of the four spots on the specimen is collected and converted by photodiodes into four electrical analog signals each with a nominal 250 kHz modulation and a certain phase relative to the laser reference. The phase of these signals is the information used to calculate extension. These return signals from the sensor head at any given point in time can be expressed with the following equation:

$$I(t) = I_1 + I_2\cos(f't + \Theta(x))$$

where

$$\Theta(x) = x/d, \qquad (18)$$

where I_1 and I_2 are dc and ac signal intensities respectively, x is the surface displacement and d is the fringe spacing. There is one directly measured quantity per signal, I, and three unknowns: I_1, I_2, and Θ. Since the signal is always modulated at f' = 250 kHz, simply ac coupling the signal will eliminate the variable I_1.

The phase measurement of the remaining ac signal can be readily made independent of amplitude by threshold detecting at (or near) zero volts to generate a square wave with the same phase relationship as the original analog signal. A phase measurement is then made by comparing the received signal to the 250 kHz reference signal from the laser to yield a phase result proportional to Θ or x.

For the Phase I testing, two complete LE-3000 systems were used, with each set of optical information processed in its own control display unit (CDU). The analog output from each CDU was input to an IBM PC, via A/D converters, and processed in spreadsheet form.

This preceding description represents the signal processing technique currently used in the LE-3000. Evaluation of an alternative signal processing approach was proposed to improve the performance of the existing electronics. In this alternative scheme the ac coupled modulated signal was demodulated by sampling the signal with three separate sample and hold circuits each clocked with a signal derived from the laser reference. Fixed phase offsets of 120° and 240° were added to two of the clocks so that three analog signals (R, S, T) were produced of the form:

$$R = I_2 \cos(\Theta)$$
$$S = I_2 \cos(\Theta + 2\pi/3)$$
$$T = I_2 \cos(\Theta + 4\pi/3) \qquad (19)$$

There are several techniques that can then be used to determine the unknown Θ from the above signals, including lookup tables or pythagorean processors, such as the TRW TMC2330. The fixed clock offsets could be adjusted to produce different phase offsets so that two or more signals in quadrature could be generated (with 90° offsets).

OPTRA has previously developed multiphase detection circuitry that is designed to determine the unknown phase from three signals of the form given above for R, S and T (see Figure 15). The technique uses a combination of analog and digital signal processing, and produces a 27 bit digital word proportional to the instantaneous phase with a resolution of 1/1500 cycles and a dynamic range of 65,000 cycles (or the equivalent displacement resolution of about 0.3 μinch and range of 32 inches). The word is computed in real time at an update rate of 250 kHz. This processing configuration was successfully tested on the LE-3000 and resulted in improved performance with low return signal levels compared to the existing electronics.

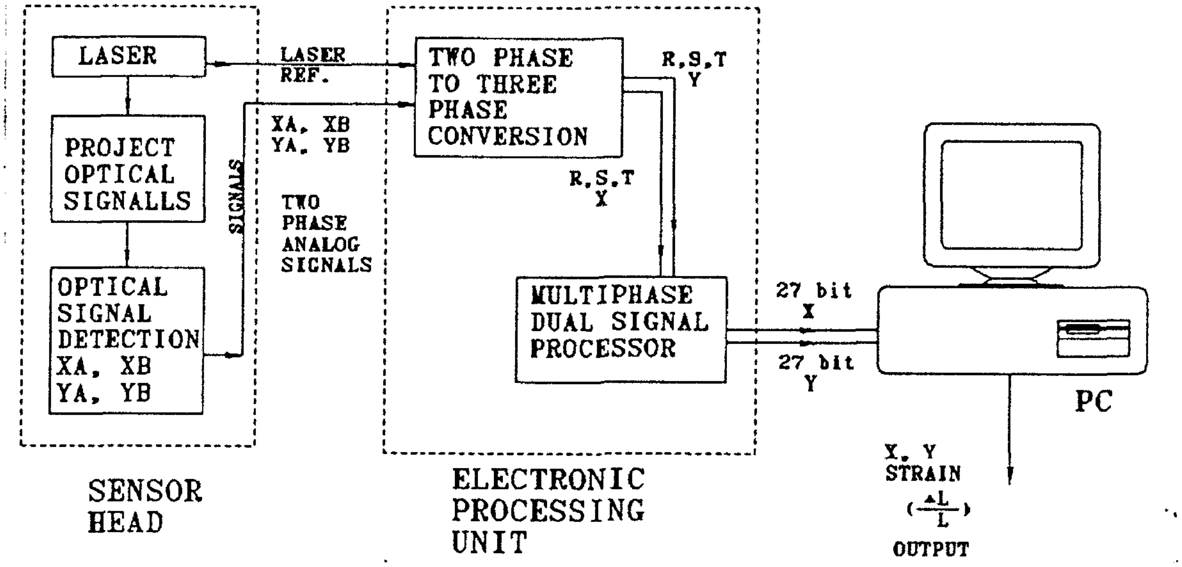

Figure 15 Electronic Processing Block Diagram

The objective of this part of the program was achieved.

3.4 Test Breadboard System on the Load Frame

All tests done in this program were done on an Instron Load Frame device. This allowed for controlled axial loading forces.

Each test specimen was designed for its specific test. Specimen material was chosen for ease of use to allow for concentration on the specific measurement.

4.0 PHASE II OBJECTIVE

In Phase II, OPTRA will propose a prototype optical, noncontacting biaxial laser extensometer, that will be a viable **commercial product**.

The objective of this program is to develop a commercially viable noncontact biaxial extensometer that can replace existing bonded strain gages in a variety of materials testing applications. The noncontact technique, which requires no sample preparation at all, allows shear strain measurements and Poisson's ratio measurements in environments unsuitable for traditional contacting techniques. The instrument will be suitable for high temperature testing, high strain elastomer testing, high humidity and liquid immersed testing, and many other difficult environmen s. In all materials testing laboratories, the proposed instrument will enable testing personnel to eliminate the meticulous sample preparation steps required for bonded strain gages and improve testing efficiency.

The target specifications for the proposed noncontact biaxial extensometer are presented in Figure 4. These target specifications were derived by combining inputs from a small market survey of potential customers to identify primary operational features with a realistic assessment of the capabilities of the OPTRA technology and costs.

Although the instrument to be developed will have two measurement axes similar to conventional biaxial strain gages, the rotatable gage orientation enables the sensor to be used in many situations that traditionally required triaxial rosette strain gages. In general, three quantities are required to fully define the state of plane strain on a surface. A single strain measurement is sufficient only for uniaxial loadings (pure tension or compression). Two strain measurements are sufficient for biaxial loadings **only if** the orientation of the principal strains is known (as is the case for pure shear-the principal axes are at 45 degrees to the shear axis). Three element rosette strain gages are required when the state of strain is completely unknown. The rotatable orientation feature of the OPTRA biaxial extensometer allows the user to find the orientation of maximum (principal) strain by lightly cycling the test specimen while observing a real time display of strain and manually adjusting the gage orientation to produce a maximum strain signal. This orientation is then the principal strain axis and the state of strain is fully defined. Conventional bonded biaxial strain gages require a priori knowledge of the principal strain axes during installation of the gage.

OPTRA proposes to construct a measurement system, the Laser Extensometer 3002, to measure transverse strain consisting of two pieces of equipment: an optical sensor head for projection and collection of optical signals and electronic processing unit to calculate strain measurements (Figure 16). Lotus spreadsheet software will be provided for the analysis of the two orthogonal strain measurements to calculate shear measurements, such as shear Iosipescu and shear on a torsicn loaded cylinder. Biaxial strain measurements can be made with repetitive design additions and enhancements to the technology previously proven in the design of the commercially available product, the Laser Extensometer 3000, which is designed and manufactured at OPTRA. The Laser Extensometer 3000 measures uniaxial strain by monitoring single axis displacement of a test specimen at two locations a fixed distance apart. The difference between these two displacement measurements is the extension. Strain is the result of the ratio of the extension and the fixed distance (gage length) between the two observation points. Biaxial strain measurements can be made with the existing Laser Extensometer 3000 theory of strain measurements while incorporating an additional axis of measurement with rotation. The electronic processing can easily be modified with repetitive strain processing circuitry. Two analog voltage signals corresponding to microinches of extension per voltage can be collected for data processing with software provided by OPTRA via data acquisition. The software can be used for analysis of poison's ratio and shear measurements such as shear produced on a tension loaded cylinder or in an Iosipescu fixture.

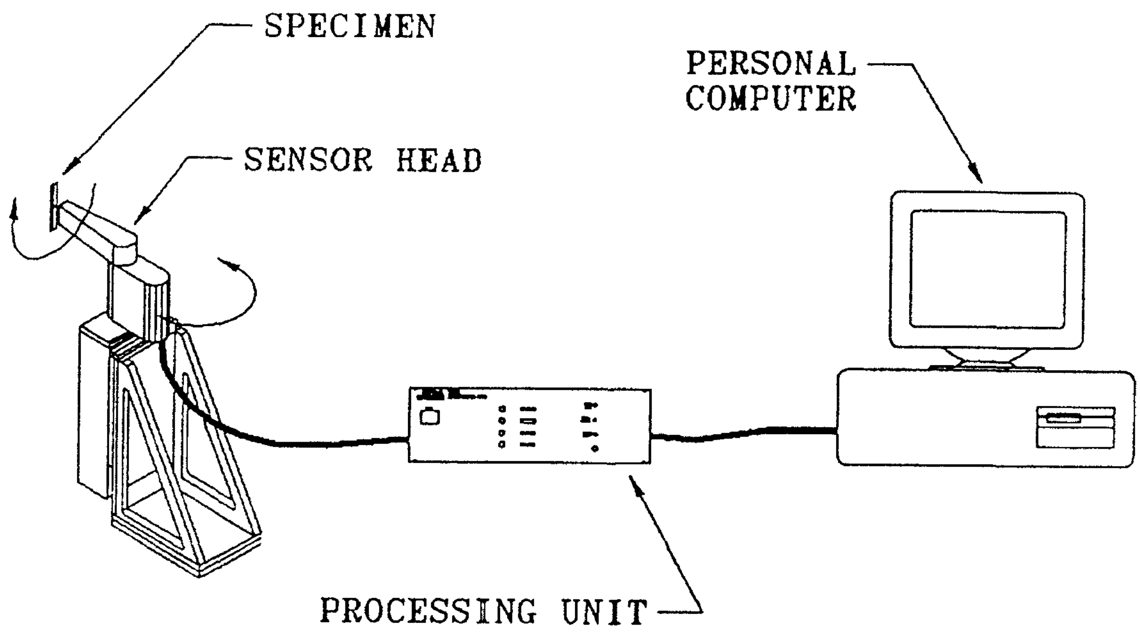

Figure 16 System Configuration

The Laser Extensometer 3002 will be provided with an optical sensor head for projection and collection of optical signals and an electronic processing unit for calculating strain measurements. The Laser Extensometer 3000 and the proposed 3002 utilize a two frequency, stabilized Zeeman-split laser that is designed and manufactured by OPTRA. The laser output is a common path beam with two modes of circularly polarized light modulated at 250 kHz. A rotating sensor head is attached to the laser to allow rotation of the biaxial measurement axes. Passing the output of the laser through a quarter wave plate in the sensor head creates an emission of a common path beam consisting of two orthogonally polarized modes. The common path beam is split to provide two common path beams consisting of two orthogonally polarized modes of equal intensity. These two common path beams begin to define the two axis of measurement (see Figure 17). Two calcite crystals are oriented with orthogonal fast axes relative to one another. Passing a common path beam through each calcite provides two orthogonal beams pairs spatially separated by polarization. The two beams pairs are brought together symmetrically in one plane through the use of fold mirrors and beamsplitters. The polarizations of the two pairs of beams are oriented with half wave plates so that both laser modes will have identical axes of polarization and can interfere efficiently. A standard gage length of .125 inches for the LE-3002 is set and permanently fixed at OPTRA during manufacturing. Additional gage length adaptors will be provided to allow use of the LE-3002 for gage lengths of .250, .500, and 1.00 inches. Beam displacers provided by OPTRA placed in designated positions after the calcite crystal displace the beams from one another to allow for this option. A dual axis grating having four pitches , which correspond to the four available gage lengths, angularly split the four beams into four pairs of unipolarized beams projecting from the grating at an angle, Θ, referred to as the interference angle. A folding mirror independent of sensor head rotation oriented at 45° diverts the beams towards the specimen. A focussing lens, also insensitive to sensor head rotation, focuses the four pairs of beams on the specimen surface.

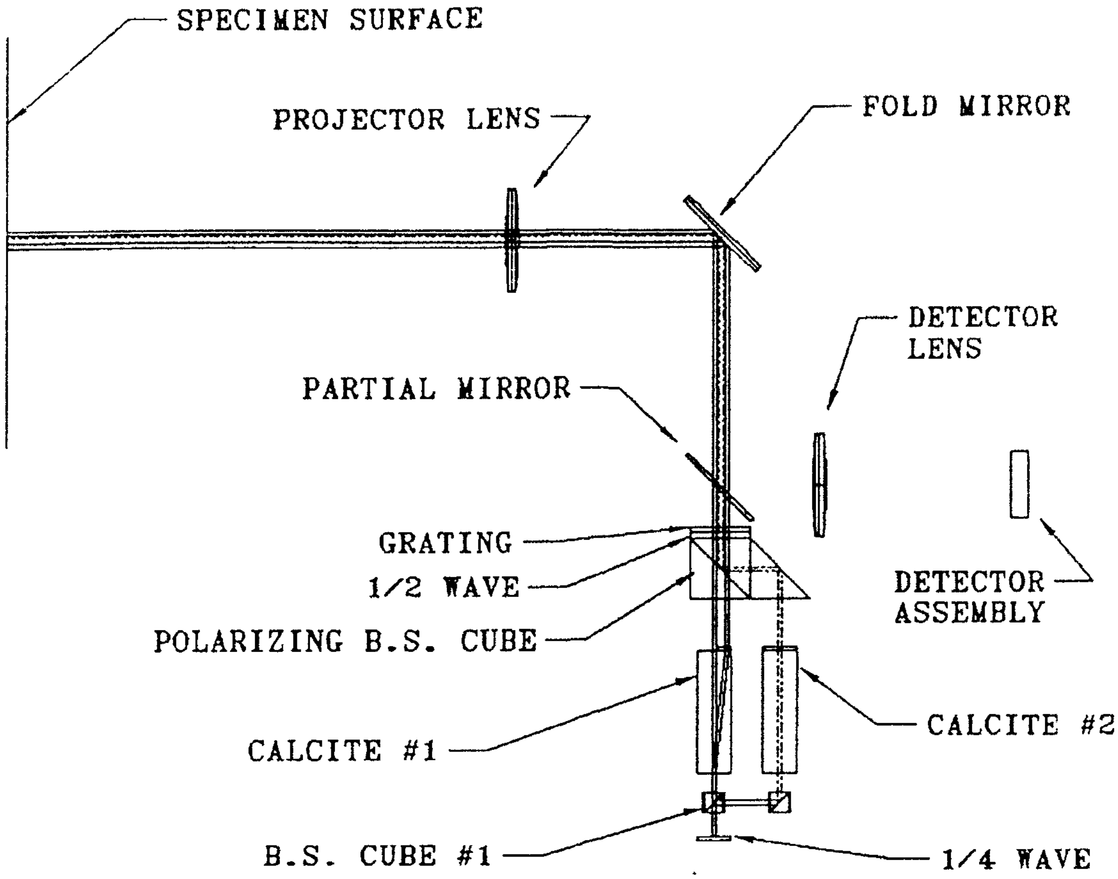

Figure 17 LE-3002 Optical Layout

Four interference fringe patterns are formed in the region where the four pairs of beams intersect (Figure 18). Each pair of focused beams contains fringes moving and oriented in the same direction. The two orthogonal orientation of the fringe patterns allows for measurement of extension in both axes. The difference frequency between the interfered beams causes the fringe pattern to move in one direction through the region at a rate equal to the difference frequency. As these moving fringes illuminate the specimen surface, particles within the specimen scatter light back to the sensor head. If the specimen and the particles that comprise its surface are not in motion, the scattered signal will be modulated at the laser difference frequency. When the surface begins to move, as in extension, compression, or shear, the scattered signal will be Doppler shifted in that axis of movement from the 250 kHz difference frequency. A comparison between the frequencies of the scattered light and the laser reference signal gives a resultant signal of specimen motion magnitude and direction, while a comparison between the phases of the scattered light and the laser reference gives a measure of specimen displacement in that axis of motion. The modulation of the fringes, and the Doppler shifted frequency associated with specimen movement, allow the LE-3002 to monitor simultaneous specimen motion in two orthogonal axes of extension and compression only. The LE-3002 is insensitive to all other axes of motion.

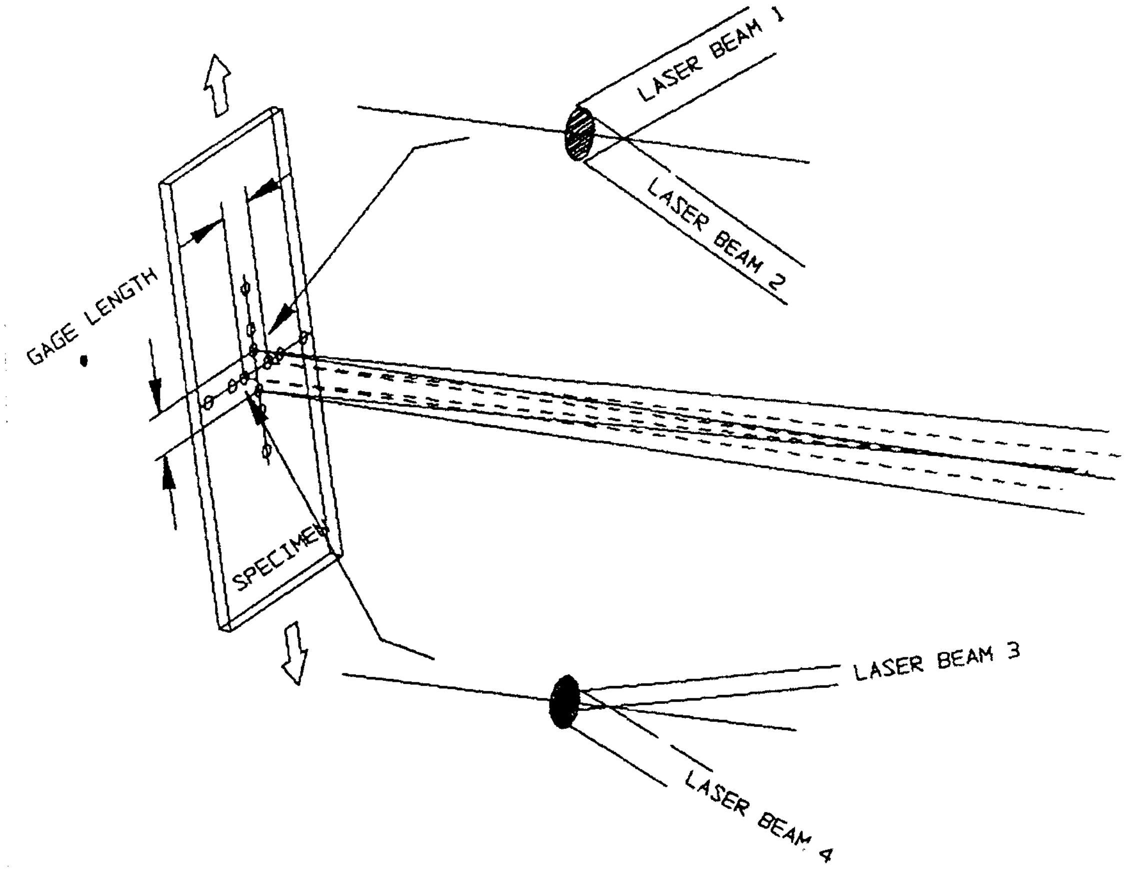

Figure 18 Measurement Surface

The Doppler shifted light scattered back to the sensor head is collected by the focusing lens and diverted into a collection lens that produces four beams input to four detectors which convert the optical signals into electrical signals. The electronic processing unit calculates simultaneous dual axis extension from the input signals from the sensor head using the multiphase signal processing technique outlined in

For specimen temperatures above 800°C an optical bandpass filter is inserted between the collected scattered light and the optical detectors in the sensor head. The optical bandpass filter exclusively transmits the light scattered off of the specimen, thereby protecting the electronic processing unit from detecting and erroneous signals associated with specimen heating. This technology has been proven in the LE-3000, which has been successfully used to monitor specimens heated to 2500°C and above.

The LE-3002 sensor head is assembled to an adjustable sensor head mount, currently used with the LE-3000 sensor head, that orients the projected beams appropriately for testing specimens while allowing angular adjustments for convenient sensor head alignment. The sensor head and mount are typically attached to the test frame or some rigid structure in close proximity to the specimen under test. The eight laser beams are brought to a focus as they approach the specimen to create four illuminated spots on the specimen surface. Rotation may be applied to the sensor head to simultaneously align the four focused beams in order to test poisson's ratio and shear measurements such as shear on a torque loaded cylinder and shear Iosipescu on a specimen. The specimen surface causes light to be scattered off of the surface, back to the sensor head. The scattered light, which contains the displacement information, is collected by optical detectors in the sensor head and transmitted with shielded cables to the electronic processing unit placed independently from the sensor head. The electronic processing unit collects the electrical information and calculates simultaneous dual axis extension.

Both pieces of the LE-3002 contain no moving parts that would require any maintenance such as calibration. The sensor head is an independent unit containing both projection and collection optics in a single package. This approach eliminates the possibility of relative motion errors associated with separate projection and collection systems. Software is provided by OPTRA to analyze the simultaneous biaxial strain measurements to solve for poison's ratio and shear measurements such as shear on a torque loaded cylinder and shear Iosipescu. The standard gage length for the LE-3002 is .125 inches. Gage length adaptors will be available for alternative measurements using gage lengths of .25, .50, and 1.00 inches. All gage length adaptors will be calibrated at OPTRA and will remain calibrated for the life of the unit. High temperature test can be performed with the use of an optical bandpass filter provided by OPTRA. Again, the calibration of the unit will stay in tact whether or not the user chooses to exploit this system accessory.

The electronic processing unit receives the electronic signals from the sensor head and simultaneously calculates extension in each of the two measurement axis. OPTRA has successfully developed and tested a signal processing scheme which is referred to as multiphase signal processing. This approach allows for improved resolution by subdividing a phase cycle into 1500 parts. The electronics show improved performance in the presence of low return signals and higher tolerance to low signal/noise ratios. This approach was utilized in Phase I and is described in Section 3.3.

5.0 CONCLUSION

OPTRA has successfully demonstrated the capability to make biaxial measurements subjected to multiaxial load conditions using two single axis LE-3000's.

Successful biaxial measurements, such as biaxial strain to measure Poisson ratio, torsional for measurement shear modulus and Iosipescu shear testing to demonstrate compatibility with the Iosipescu fixture, have been achieved.
The information gained in this Phase II program has provided insight for a Phase II biaxial prototype that will be of interest and need to both the sponsor and the commercial/research testing community.

APPENDIX A COMPARISON OF STRAIN AND EXTENSION MEASURING INSTRUMENTS

For the purposes of potential industry need, Appendix A contains a comparison of a variety of commercially available strain and extension measuring instruments. It indicateS that the performance of the proposed OPTRA biaxial extensometer is favorably positioned for noncontact applications.

Bonded strain gages provide the highest accuracy (5 μinch) but are not suitable for high temperature or high strain and require meticulous surface bonding techniques. Clip on strain gages, made by MTS and Instron are available for a wide range of special applications including biaxial and high temperature. They have limited strain range and the knife edges can cause stress concentrations on test specimens. A typical general purpose clip on has errors due to linearity and hysteresis of about 225 μinch, although some versions can do slightly better at reduced ranges. The errors associated with the two contact gage techniques is also plotted on Figure A1.

Noncontact extension measuring instruments are available from several manufacturers. Table A1 summarizes the salient features of these alternate technologies. OPTRA's interferometric technique is the only one that does not require some sort of sample preparation. Zygo and United utilize flying spot scanners in which a laser is scanned across the test specimen and the precise time when the beam spot hits two or more targets applied to the surface indicates the surface extension. The Zygo systems have good linearity and repeatability specifications, but require separately mounted transmitters and receivers, are limited to two inch target separation and are not able to measure shear at a point on a surface. Flying spot scanners produce significant errors when strain rates are above a few hundredths of an inch/inch/sec. Shenck makes a laser based extensometer that requires mirrors on the test sample and a linear position detector to track the beam translation. It is very fast (100 kHz), but not very precise and has limited range. Sintech has a video based system that tracks the distance between two targets applied to the specimen. The errors can be fairly low, with this system but bandwidth is limited, recalibration is required if the specimen or camera move, and targets must be high contrast and brightly lit.

While there are other noncontact instruments available, OPTRA's proposed device will have good accuracy with the unique ability to measure biaxial strains on any unprepared test sample with unlimited strain range.

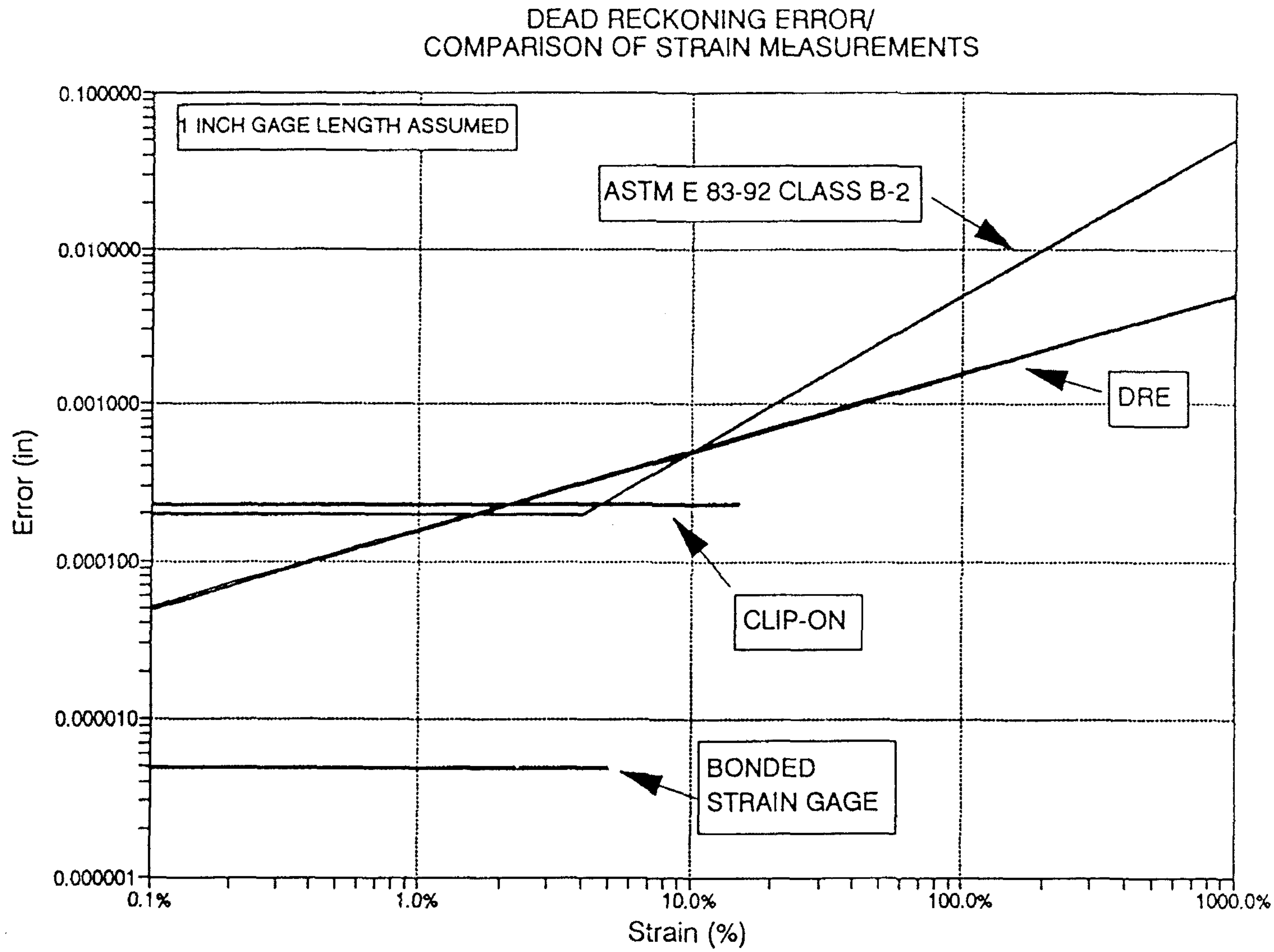

Figure A-1 Error Comparison for Strain Measurement Instruments

TYPE	MANUFACTURER	OPERATING PRINCIPLE	TYPICAL ERRORS	MAXIMUM RANGE	COMMENTS
Non-Contact	OPTRA LE 3000	Interferometer	See Figure A-1	Unlimited	Good accuracy - No sample prep
	Zygo 1100, 1200	Flying Spot Scanner	60 - 100 micro-inch	2 inch	Double Ended - Not suitable for shear
	United	Flying Spot Scanner	2000 micro-inch	1000% +	Low accuracy - Recalibration req'd
	Schenck	Linear Detector	6000 micro-inch	0.75 inch	Low resolution - Hi bandwidth - No shear
	Sintech	Video	300 - 3000 micro-inch	100% +	Low Bandwidth - Recalibration req'd
Contact	MTS	Clip-on	225 micro-inch	15%	Contact Req'd - Low range
	HBM	Bonded Strain Gage	5 micro-inch	5%	Surface bond req'd - High accuracy

Table A-1

DISTRIBUTION LIST

No. of Copies	To
1	Office of the Under Secretary of Defense for Research and Engineering, The Pentagon, Washington, DC 20301
	Commander, U.S. Army Laboratory Command, 2800 Powder Mill Road, Adelphi, MD 20783-1145
1	ATTN: AMSLC-IM-TL
1	AMSLC-CT
	Commander, Defense Technical Information Center, Cameron Station, Building 5, 5010 Duke Street, Alexandria, VA 22304-6145
2	ATTN: DTIC-FDAC
	Commander, Army Research Office, P.O. Box 12211, Research Triangle Park, NC 27709-2211
1	ATTN: Information Processing Office
	Commander, U.S. Army Materiel Command, 5001 Eisenhower Avenue, Alexandria, VA 22333
1	ATTN: AMCSCI
	Commander, U.S. Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, MD 21005
1	ATTN: AMXSY-MP, H. Cohen
	Commander, U.S. Army Missile Command, Redstone Scientific Information Center, Redstone Arsenal, AL 35898-5241
1	ATTN: AMSMI-RD-CS-R/Doc
	Commander, U.S. Army Natick Research, Development and Engineering Center, Natick, MA 01760-5010
1	ATTN: Technical Library
1	Janet E. Ward
1	Heidi Gibson
	Commander, U.S. Army Tank-Automotive Command, Warren, MI 48397-5000
1	ATTN: AMSTA-TSL, Technical Library
	Director, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD 21005
1	ATTN: SLCBR-TSB-S (STINFO)
	Commander, Harry Diamond Laboratories, 2800 Powder Mill Road, Adelphi, MD 20783
1	ATTN: Technical Information Office
	Naval Research Laboratory, Washington, DC 20375
1	ATTN: Code 5830
	Chief of Naval Research, Arlington, VA 22217
1	ATTN: Code 471
1	Dr. Alan Grasto, Wright Patterson AFB/VDRI, Non-Metallics Research Branch, Dayton, Oh 45433
1	Prof. John Mandell, Dept. of Chemical Engineering, Room 302, Cobliegh Hall, Bozeman, MT 59717
1	Dr. Les Lee, Penn State University, Engineering Science and Mechanics, 227 Hammond Bldg., University Park, PA 16802
1	Prof. Ken Bowen, MIT, Bldg. E-40, Room 435, 77 Massachusetts Avenue, Cambridge, MA 02139
1	Prof. Craig Douglas, University of Massachusetts - Lowell, Department of Mechanical Engineering, 1 University Avenue, Lowell, MA 01854
1	Prof. Don Adams, University of Wyoming, Department of Mechanical Engineering, Box 3295, University Station, Laramie, WY 82071
1	Instron Corporation, 100 Royal Street, Canton, MA 02021
1	MTS Systems Corporation, Box 24012, Minneapolis, MN 55424
	Director, U.S. Army Materials Technology Laboratory, Watertown, MA 02172-0001
2	ATTN: SLCMT TML
1	SLCMT-IMA-V
1	SLCMT-PR
21	SLCMT-MEC, J. Mead (COR)

U.S. Army Materials Technology Laboratory
Watertown, Massachusetts 02172-0001
ENHANCED NONCONTACTING LASER EXTENSOMETER FOR BIAXIAL STRAIN MEASUREMENTS
James J. Connolly, James R. Engel, and Andrew T. Lintz
OPTRA, Inc.
66 Cherry Hill Drive
Beverly, MA 01915
Technical Report MTL TR 92-60, September 1992
36 pp-illus.-tables, Contract DAAL04-92-C-0005
Final Report, January 1992 to August 1992

AD__________
UNCLASSIFIED
UNLIMITED DISTRIBUTION

Key Words

Strain Measurements
Noncontact Measurements
Mechanical Testing
Poisson's Ratio
Laser Extensometer
Biaxial Strain

In the proposed program, OPTRA will develop and commercialize a noncontact biaxial extensometer for the material testing market. The optical technology, based on an existing OPTRA single axis product, allows the accurate measurement of surface strains on any test specimen without contact and without material preparation. The noncontact measurement is ideal for high temperature testing, single fiber testing, high humidity/liquid immersed testing, high strain elastomer testing and many other applications that are unsuitable for bonded gages. The incorporation of two axes of strain measurement in a single instrument allows users to measure shear strain, Poisson's ratio, and other biaxial strain conditions. The ability to reorient the measurement axes relative to the test specimen in real time with small cyclic loading allows the user to rapidly identify the maximum and minimum normal strain axes and thereby fully define an unknown state of plane strain. The product development will be focussed on meeting a wide range of material rest requirements and on keeping production costs low to insure that a commercially viable product is produced.

U.S. Army Materials Technology Laboratory
Watertown, Massachusetts 02172-0001
ENHANCED NONCONTACTING LASER EXTENSOMETER FOR BIAXIAL STRAIN MEASUREMENTS
James J. Connolly, James R. Engel, and Andrew T. Lintz
OPTRA, Inc.
66 Cherry Hill Drive
Beverly, MA 01915
Technical Report MTL TR 92-60, September 1992
36 pp-illus.-tables, Contract DAAL04-92-C-0005
Final Report, January 1992 to August 1992

AD__________
UNCLASSIFIED
UNLIMITED DISTRIBUTION

Key Words

Strain Measurements
Noncontact Measurements
Mechanical Testing
Poisson's Ratio
Laser Extensometer
Biaxial Strain

In the proposed program, OPTRA will develop and commercialize a noncontact biaxial extensometer for the material testing market. The optical technology, based on an existing OPTRA single axis product, allows the accurate measurement of surface strains on any test specimen without contact and without material preparation. The noncontact measurement is ideal for high temperature testing, single fiber testing, high humidity/liquid immersed testing, high strain elastomer testing and many other applications that are unsuitable for bonded gages. The incorporation of two axes of strain measurement in a single instrument allows users to measure shear strain, Poisson's ratio, and other biaxial strain conditions. The ability to reorient the measurement axes relative to the test specimen in real time with small cyclic loading allows the user to rapidly identify the maximum and minimum normal strain axes and thereby fully define an unknown state of plane strain. The product development will be focussed on meeting a wide range of material rest requirements and on keeping production costs low to insure that a commercially viable product is produced.

U.S. Army Materials Technology Laboratory
Watertown, Massachusetts 02172-0001
ENHANCED NONCONTACTING LASER EXTENSOMETER FOR BIAXIAL STRAIN MEASUREMENTS
James J. Connolly, James R. Engel, and Andrew T. Lintz
OPTRA, Inc.
66 Cherry Hill Drive
Beverly, MA 01915
Technical Report MTL TR 92-60, September 1992
36 pp-illus.-tables, Contract DAAL04-92-C-0005
Final Report, January 1992 to August 1992

AD__________
UNCLASSIFIED
UNLIMITED DISTRIBUTION

Key Words

Strain Measurements
Noncontact Measurements
Mechanical Testing
Poisson's Ratio
Laser Extensometer
Biaxial Strain

In the proposed program, OPTRA will develop and commercialize a noncontact biaxial extensometer for the material testing market. The optical technology, based on an existing OPTRA single axis product, allows the accurate measurement of surface strains on any test specimen without contact and without material preparation. The noncontact measurement is ideal for high temperature testing, single fiber testing, high humidity/liquid immersed testing, high strain elastomer testing and many other applications that are unsuitable for bonded gages. The incorporation of two axes of strain measurement in a single instrument allows users to measure shear strain, Poisson's ratio, and other biaxial strain conditions. The ability to reorient the measurement axes relative to the test specimen in real time with small cyclic loading allows the user to rapidly identify the maximum and minimum normal strain axes and thereby fully define an unknown state of plane strain. The product development will be focussed on meeting a wide range of material rest requirements and on keeping production costs low to insure that a commercially viable product is produced.

U.S. Army Materials Technology Laboratory
Watertown, Massachusetts 02172-0001
ENHANCED NONCONTACTING LASER EXTENSOMETER FOR BIAXIAL STRAIN MEASUREMENTS
James J. Connolly, James R. Engel, and Andrew T. Lintz
OPTRA, Inc.
66 Cherry Hill Drive
Beverly, MA 01915
Technical Report MTL TR 92-60, September 1992
36 pp-illus.-tables, Contract DAAL04-92-C-0005
Final Report, January 1992 to August 1992

AD__________
UNCLASSIFIED
UNLIMITED DISTRIBUTION

Key Words

Strain Measurements
Noncontact Measurements
Mechanical Testing
Poisson's Ratio
Laser Extensometer
Biaxial Strain

In the proposed program, OPTRA will develop and commercialize a noncontact biaxial extensometer for the material testing market. The optical technology, based on an existing OPTRA single axis product, allows the accurate measurement of surface strains on any test specimen without contact and without material preparation. The noncontact measurement is ideal for high temperature testing, single fiber testing, high humidity/liquid immersed testing, high strain elastomer testing and many other applications that are unsuitable for bonded gages. The incorporation of two axes of strain measurement in a single instrument allows users to measure shear strain, Poisson's ratio, and other biaxial strain conditions. The ability to reorient the measurement axes relative to the test specimen in real time with small cyclic loading allows the user to rapidly identify the maximum and minimum normal strain axes and thereby fully define an unknown state of plane strain. The product development will be focussed on meeting a wide range of material rest requirements and on keeping production costs low to insure that a commercially viable product is produced.