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A Interferometric Strain Rosette

presented by

Henry J. Wede

has been accepted towards fulfillment
of the requirements for

Master's degree in Mechanics

John F. Martin
Major professor

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AN INTERFEROMETRIC STRAIN ROSETTE

By

Henry John Wede

A THESIS

Submitted to
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for the degree of

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ABSTRACT

AN INTERFEROMETRIC STRAIN ROSETTE

By

Henry John Wede

While basic interferometry is the origin of most optical methods of strain measurement, it has rarely been used for its own sake. Some researchers have found methods to produce interference patterns from reflective specimens and have used these interference patterns for strain measurement. However, most of these methods have only provided systems to measure uniaxial strain or, at best, strain in two orthogonal directions. This paper describes a method which makes the interferometric strain rosette a potentially viable tool for the experimentalist. By using a circular indentation, interference patterns are produced which allow strain measurement in any direction or directions. Different methods of computer interfacing which further extend the capability of this technique are also discussed.

To my parents

ACKNOWLEDGEMENTS

I would like to thank Dr. John Martin for giving me the opportunity to do this work and the freedom to monopolize his laboratory. I would also like to thank my committee, Dr. Gary Cloud and Dr. Dashin Liu, for their patience towards my seemingly endless revisions. Also, Kurt Niemeyer and Leonard Eisele provided me with a great deal of help in working out the electronic and mechanical problems. Their help was greatly appreciated.

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INTRODUCTION

Interferometric strain measurement has been used sparingly by experimentalists for the past twenty years. The apprehension towards this technique is primarily due to the difficulties in the setup and certain limitations in measurements. This paper addresses both of these problems.

First, this paper will serve as a guide to constructing an interferometric strain gage. Many problems were encountered while setting up this system, and many different schemes were tried with varying degrees of success. This paper will prove to be a useful guide which is free from the space limitations of published papers.

Second, the limitation of uniaxial or orthogonal measurement has been eliminated. A circular indentation is introduced which allows strain measurement in any convenient direction or directions. This raises the idea of an interferometric strain rosette from the drawing board into the laboratory.

Young's Experiment and displacement equations

Many modern interferometric techniques are siblings of Young's two slit experiment[1]. Figure 1 shows schematically this experiment. Monochromatic and coherent light shines through two small slits in a thin sheet. Because of the small size of the slit, the light emitting from each one can be considered a point source of light. The close spacing of the light sources produces interference patterns, parallel bands of light. Two sets of interference patterns are produced; and the position of these interference patterns may be correlated to the spacing and the displacements of the slits[2].

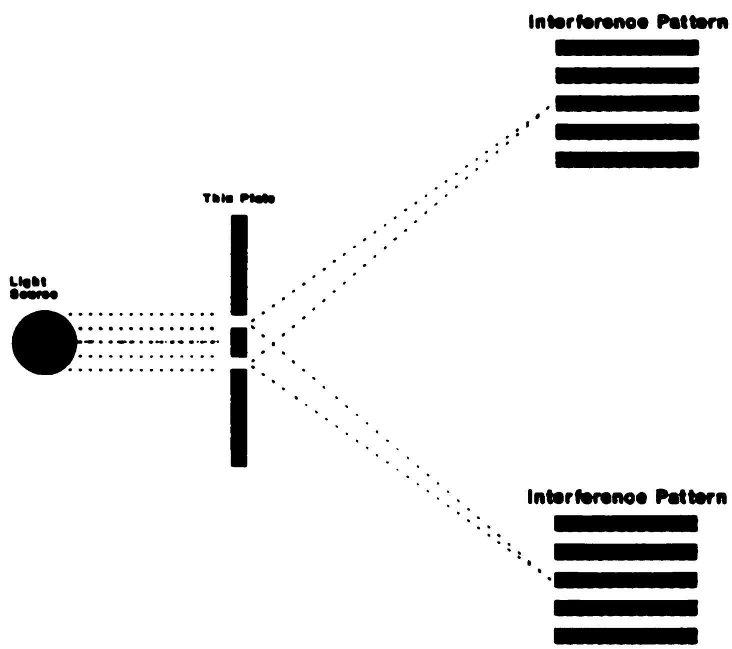

Figure 1. Young's two slit experiment

If the slits are separated by a distance *d* (see figure 2) the following relation can be made;

$$\sin\alpha = \frac{n\lambda}{d} \tag{1}$$

where *n* is an integer and λ is the wavelength of the light. If *d* changes the interference patterns will translate. Rearranging the above equation yields

$$\delta d = \frac{\lambda}{\sin\alpha} \times \delta m \tag{2}$$

where δd is the change in *d* and δm is the fractional percent that the bands translate.

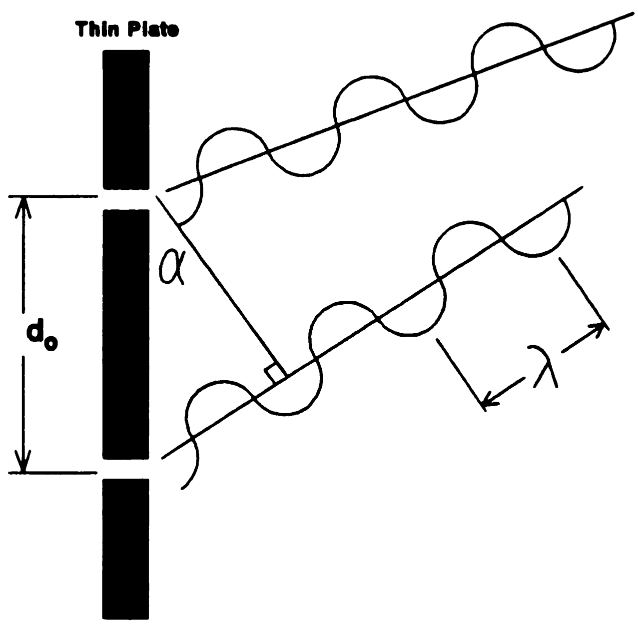

Figure 2. Derivation of displacement equations

However, the change indicated by δm reflects both the change in d and any rigid body displacement between the light sources and the observation point. To eliminate rigid body motion, two values of δm are recorded, one from each (top and bottom in figure 1) interference pattern. The average of the two values represents the change of d. If the original value of d, denoted as d_o, is known, then the above equation can be written in terms of strain.

$$\epsilon = \frac{\delta d}{d_0} = \frac{\lambda}{d_0 \sin\alpha} \times \frac{\delta m_1 + \delta m_2}{2} \tag{3}$$

where δm_1 and δm_2 are the two percentages of fringe translation measured from opposing interference patterns. The above equations will serve as the base for the techniques described in this paper.

History of interferometric strain measurement

The key to applying this idea to practical strain measurement is to generate interference patterns from two closely spaced points on a specimen - then record the translation of these patterns during specimen loading to determine the displacement of the points. This was first done by scribbing two *V* shaped groves on a round specimen and illuminating them with a laser[2]. The parallel faces of the groves produced two sets of interference patterns. Measuring the translation of these patterns during loading proved the above strain equations to be true.

Obtaining interference patterns from flat specimens required a bit more creativity. Interference patterns were obtained by pressing pyramidal indentations into the surface[3]. The pyramidal indentations were made with a Vicker's hardness indentor, see figure 3a. As with the circular specimen, the parallel faces of the indentations produce two interference patterns. These patterns only allowed for uniaxial strain measurements.

Biaxial measurements were achieved by arranging three pyramidal indentations as shown in figure 3b. This pattern produces two pairs of interference patterns.

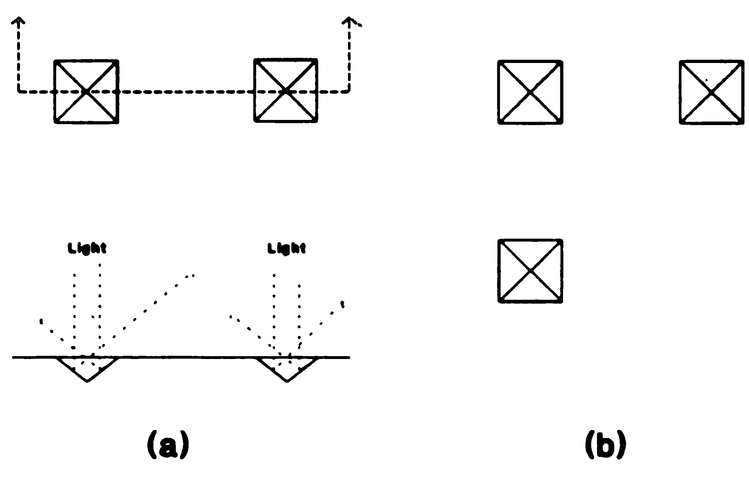

Figure 3. Patterns for pyramidal indentations

The next logical step was to produce interference patterns that would allow for measurement in three directions allowing complete plain strain information. An arrangement of several pyramidal indentation[4] and hexagonal indentations[5] were tried with varying success.

Expanding this method even further, this paper introduces a new type of indentation which allows strain measurement in any arbitrary direction - a circular indentation. This indentation produces concentric fringe patterns that contain average displacement information in any direction. Using this new idea the interferometric strain gage can continue to evolve into a valuable laboratory tool.

A DISCUSSION OF DIFFERENT INDENTATIONS

As with all methods of interferometry, this method starts with the interference of two coherent beams. When using this technique, the indentations are responsible for providing this interference. Proper indentations must be made on the specimen to produce adequate interference patterns. Applying the indentations, a seemingly easy task, proves to be one of the hardest parts. Not only do the indentations have to be located and oriented correctly but they have to produce fringe patterns that can be easily recorded.

A brief discussion of the different types of indentations will help show which is appropriate for specific testing. When choosing an indentation type a good balance between simplicity and utility must be maintained. Each type has certain advantages and restrictions.

Pyramidal Indentations

Pyramidal indentations have been used almost exclusivly with this technique. They have proven to be very versatile. The key to using pyramidal indentations is the arrangement of the indentations. They may be arranged to give interference patterns related for simple uniaxial measurement or measurement in several directions. Uniaxial and biaxial arrangements are shown in figures 3a and 3b. These arrangements are not too difficult to set up, although arrangements for multi-directional measurement are very time consuming.

When using a Vicker's hardness tester to apply the pyramidal indentations, it is helpful to rotate the indentor 45° from the conventional position. This orients the axis of the x-y table with the direction of the interference patterns. The micrometer adjustments will then read the gage length directly, without the need for trigonometric formulas. Due to the time required to rotate and center the indentor, a dedicated hardness tester is very desirable.

Experiment using pyramidal indentations

Since the experiments using the circular indentation will not be using the computer apparatus it is necessary to get an idea of the accuracy obtained from using an alterative method. The method chosen was simply to trace the fringe patterns on a piece of paper. The idea of this particular experiment was to show just how crude the fringe processing can be and still get accurate results.

Two pyramidal indentations were set up to measure axial strain. The specimen was placed in a large MTS load frame and the laser and mirrors were positioned as shown in figure 4. A positioning mirror was used to aim the laser at the indentations. Besides being easy to adjust, the positioning mirror kept the laser and stand out of the way of the fringe patterns.

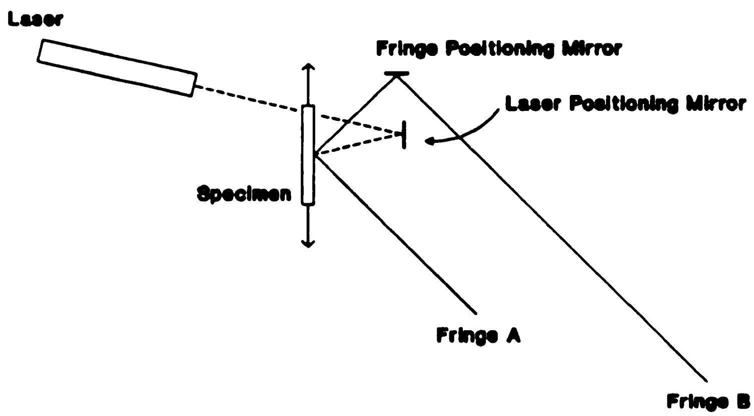

Figure 4. Setup for uniaxial measurement by tracing fringe patterns

The upper fringe pattern was reflected down to a table using a second mirror. The lower fringe pattern was found on the platen of the load frame. Paper was taped down and the fringes were traced. A load was placed on the specimen and the new position of the fringes was traced. The fringe tracings are shown in figure 5. Vernier calipers were used to measure the distances on the tracings. The strain indicated by the fringe translation was compared to strain indicated by the MTS displacement readout. The displacement readout was used due to problems with the load control section of the MTS controller.

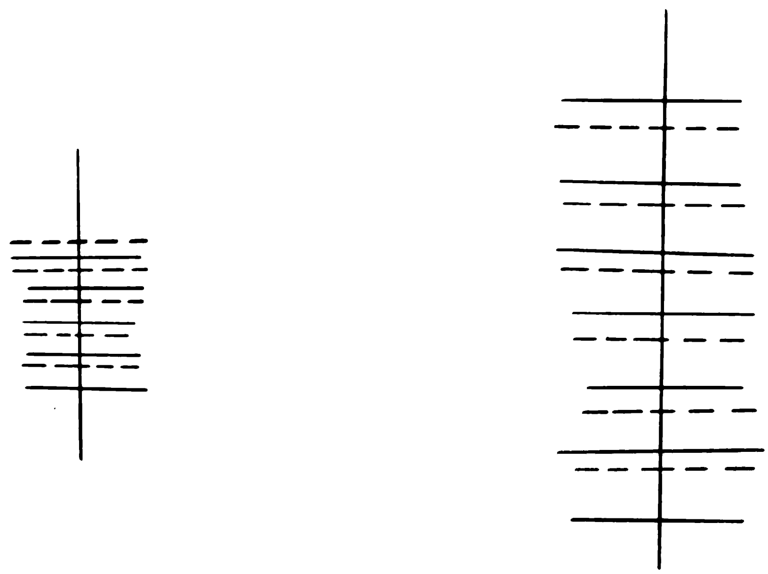

Figure 5. Fringe tracings for uniaxial strain using pyramidal indentations

The load chosen produced a fringe translation (δm) of approximately 1⅛. This translation over a 150μ gage length indicated a strain of 0.83%. The displacement readings of the MTS unit indicated a strain of 0.90% over the 2.5" gage length. The error between these two methods is 7.7%. This is pleasantly acceptable given the accuracy of the MTS displacement indicators and the tracing of the fringe patterns.

The motion of the fringe patterns indicated almost no rigid body motion of the specimen. This was a surprise. Even with such a massive load frame, some degree of rigid body motion was anticipated at such a large strain. Another observation about this experiment is the ability to accurately trace the fringe patterns with normal vision. Once adapted to night vision, the eye can distinguish the edges of the fringes well and fringe translation can be easily noticed.

The data from the experiment follows:

From the tracings:

$$\delta m_1 = 1 + (0.115" \div 0.375") = 1.307$$

$$\delta m_2 = 1 + (0.050" \div 0.164") = 1.305$$

$$\delta m = (\delta m_1 + \delta m_2) \div 2 = 1.306$$

$$\epsilon = \frac{1}{d_0} \cdot \frac{\lambda}{\sin\alpha} \cdot \delta m = \frac{1}{150\mu} \cdot \frac{0.6328\mu}{\sin 42^\circ} \cdot 1.306 = 0.0083$$

From the MTS displacement readout:

$$\Delta l = 0.2256" - 0.2031" = 0.0225"$$

$$\Delta l \div l_0 = 0.0225" \div 2.5" = 0.0090$$

<u>Circular Indentations</u>

The circular indentation shown in figure 6 is made by spinning a pyramidal indentor around an axis perpendicular to the specimen. When monochromatic light is aimed at this indentation it produces concentric fringe patterns, shown in figure 7. As the specimen deforms, the circular indentation becomes elliptic and the concentric patterns change into elliptical patterns, as shown in figure 6. The translation of the pattern in any direction can be used to find the strain in that direction.

Obviously, measuring displacement in three known directions results in complete plane strain information. With the concentric fringe pattern the user is free to pick any convenient directions while still using the same indentation. To eliminate unnecessary measurements the directions choosen may be aligned with principle strain directions or with the geometry of the specimen.

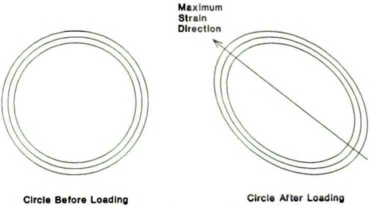

Figure 6. Deformation of a circular indentation

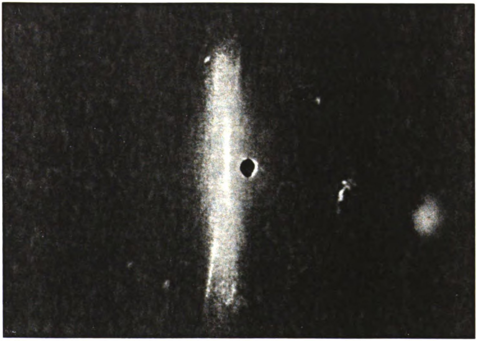

Figure 7. Circular fringe pattern

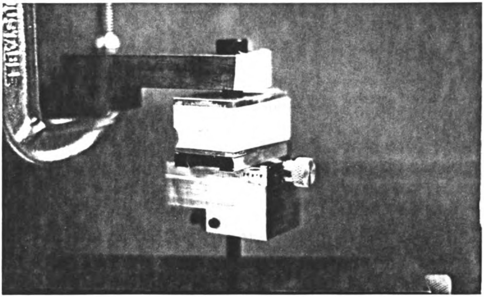

Figure 8. Device used to scribe circular indentations

The circular indentations were made with a relatively crude device shown above in figure 8. The indentor from the Vicker's hardness tester was attached to the bottom of a small x-y table. The top of the x-y table was attached to a shoulder bolt that ran through a slip-fit hole in the support. By moving the x-y table the indentor was adjusted to trace out small circles and the diameter measured using a metalurgical microscope.

The play in the system generally did not produce very good circles. A more precise fixture would produce even clearer indentations and fringe patterns. An improved fixture would also allow better control of the indentor pressure. Regulating the downward force by hand is somewhat difficult but can still produce adequate results.

Also, a different shaped indentor may be better suited to carve out the circular grove. Using the Vicker's indentor was very convienent and seemed appropriate. Although it produced satisfactory results, an indentor shaped more like a tool bit should produce smoother cuts.

A design for a different apparatus to scribe circular indentations was drawn up but never used because of the lack of equipment and funding. The new design employed a rotating platform placed on the x-y table of a standard Vicker's hardness tester. This aproach is opposite of what was finally used; it keeps the indentor stationary while moving the specimen.

<u>Experiments using a circular indentation</u>

Once it was determined that tracing the fringe patterns on paper could produce adequate results, the circular indentation was tested. The setup for this experiment was very similar to the previous experiment. The strain was determined at 0°, 45°, and 90° with respect to the axis of the specimen. To simplify the setup, measurements were made after three different loadings with the mirrors being repositioned between each.

Determining ϵ_{AXIAL}

First, the axial strain was measured. The setup for this measurement was almost identical to that of figure 11. The fringe tracings shown in figure 13 indicated a strain of 0.78%. The MTS displacement readout indicated a strain of 0.84% for an error of 7.1%.

The data from this experiment follows:

From the tracings:

$$\delta m_1 = 1 + (.0768" \div .186") = 1.413$$

$$\delta m_2 = 1 + (.177" \div .434") = 1.408$$

$$\delta m = (\delta m_1 + \delta m_2) \div 2 = 1.411$$

$$\epsilon = \frac{1}{d_0} \cdot \frac{\lambda}{\sin\alpha} \cdot \delta m = \frac{1}{170\mu} \cdot \frac{0.6328\mu}{\sin 42^\circ} \cdot 1.411 = 0.0078$$

From the MTS displacement readout:

$$\Delta l = 0.3726" - 0.3517" = 0.0209"$$

$$\Delta l \div l_0 = 0.0209" \div 2.5" = 0.0084$$

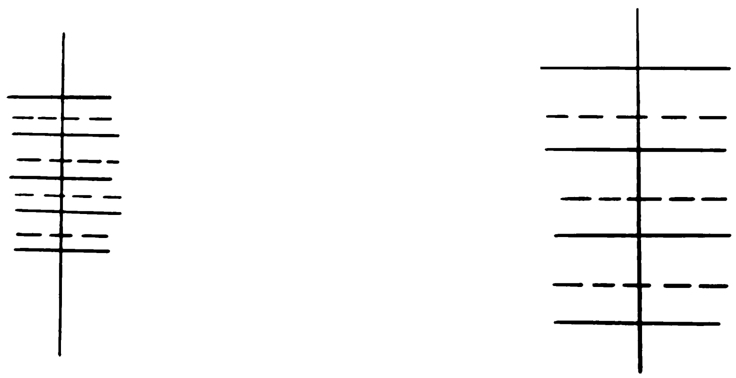

Figure 9. Tracings for determining axial strain using a circular indentation

Determining $\epsilon_{TRANSVERSE}$

To measure the fringe translation in the transverse direction a second mirror was added to the system. This measurement was the easiest of the three. The mirrors could be adjusted to widen both of the interference patterns and project them onto the platen of the load frame. Figure 14 details the mirror setup and figure 15 shows the tracings of the fringe patterns. The fringe translation indicated a strain of -0.27%. The MTS display and Poisson's ratio indicated a strain of -0.28%. The error between the two readings is only 2.54%. This results of this experiment were very encouraging.

The data from this experiment follows:

From the tracings:

$\delta m_1 = -(.201'' \div .408'') = -0.493$

$\delta m_2 = -(.236'' \div .497'') = -0.475$

$\delta m = (\delta m_1 + \delta m_2) \div 2 = -0.484$

$$\epsilon = \frac{1}{d_0} \cdot \frac{\lambda}{\sin\alpha} \cdot \delta m = \frac{1}{170\mu} \cdot \frac{0.6328\mu}{\sin 42^\circ} \cdot -0.484 = -0.00269$$

From the MTS displacement readout:

$\Delta l = 0.3194'' - 0.2963'' = 0.0230''$

$\Delta l \div l_0 = 0.0230'' \div 2.5'' = 0.0092 \times -0.30 = -0.00276$

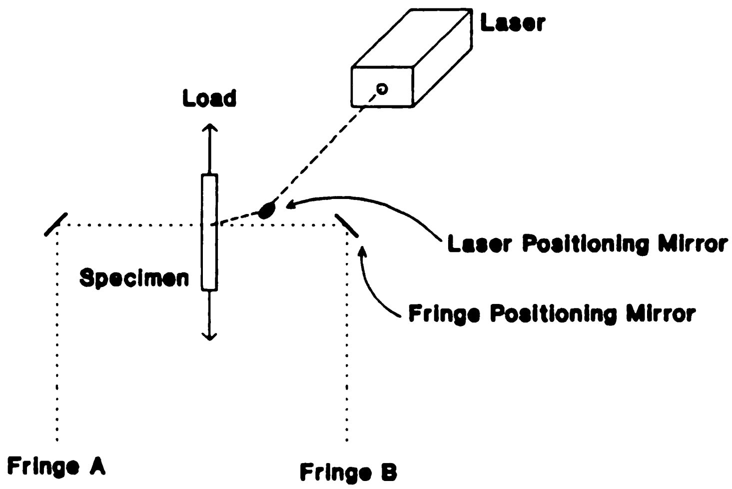

Figure 10. Setup for transverse strain measurement

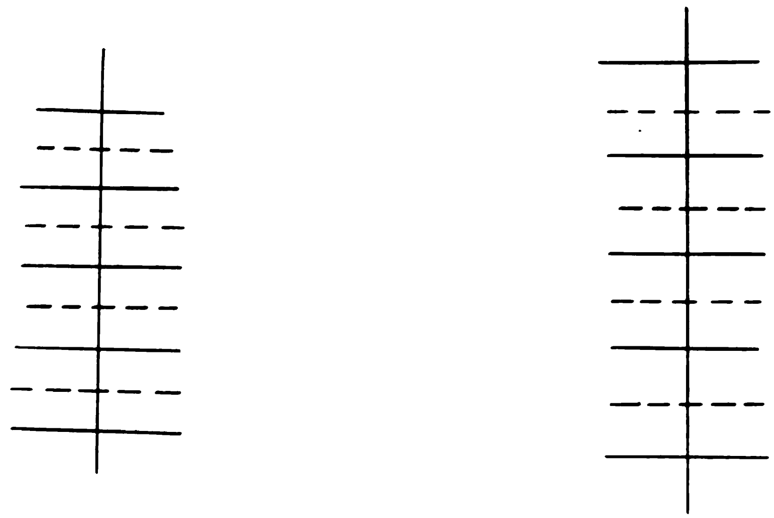

Figure 11. Fringe tracings for measuring transverse strain using a circular indentation

Determining ϵ_{45}.

To measure the normal strain on a 45° angle, a piece of graph paper was attached to the specimen. The graph paper was used to position the mirrors which projected the interference patterns down to the platen of the load frame. Once again the fringe patterns were traced before and after loading. The mirror setup is shown in figure 12 and the fringe tracings are shown in figure 13. The fringe translation indicated a strain of 0.34% and the MTS display, along with Mohr's circle for strain, indicated a strain of

0.30%. The error between the two readings is 13%. This is the largest error of the different readings and can be attributed to angular misalignment and eye fatigue.

The data from this experiment follows:

From the tracings:

$\delta m_1 = .391" \div .616" = .635$

$\delta m_2 = .240" \div .400" = .601$

$\delta m = (\delta m_1 + \delta m_2) \div 2 = .618$

$$\epsilon = \frac{1}{d_0} \cdot \frac{\lambda}{\sin\alpha} \cdot \delta m = \frac{1}{170\mu} \cdot \frac{0.6328\mu}{\sin 42°} \cdot .618 = .0034$$

From the MTS displacement readout:

$\Delta l = 0.2886" - 0.2671" = 0.0215"$

$\Delta l \div l_0 = 0.0215" \div 2.5" = 0.0086 \times 0.35 = 0.0030$

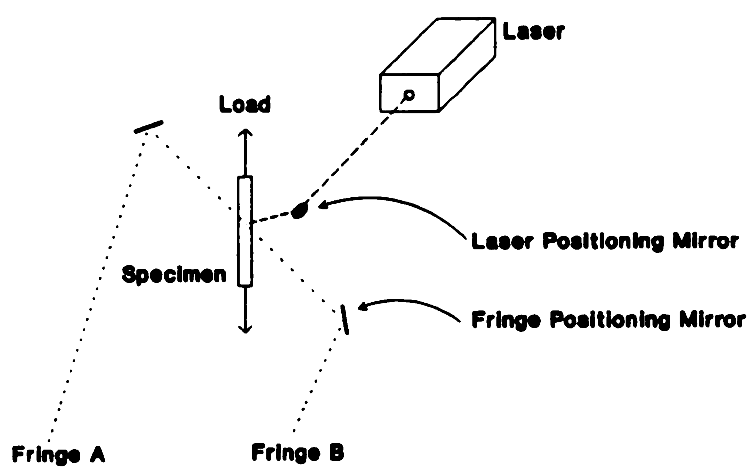

Figure 12. Setup for measuring ϵ_{45}.

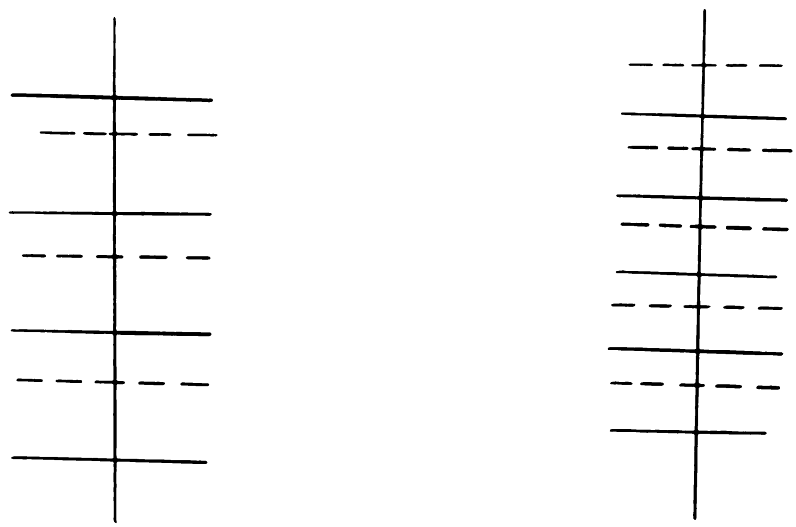

Figure 13. Tracings for measuring $\epsilon_{45^{\circ}}$ using a circular indentation

Some things were learned while conducting these experiments. First, the fringe patterns should be projected onto a very sturdy object such as the load frame. A table may get bumped into while moving around in the dark. Second, the eye needs a few minutes to adjust to darkness. Any bit of stray light, such as around doors, was very detrimental when tracing the fringes. A red light nearby can illuminate the floor while still preserving night vision. Lastly, a fine pencil should be used. A line was first drawn perpendicular to the fringe patterns and the intersections were just checked off on this line. This eliminated tracing all of the fringes.

The circular indentation was completely sucessful. The indentations contained all of the information necessary to determine the complete state of plain strain over the gage area. The error was also very much within experimental limits.

Comments on Both Types of Indentations

Surprisingly, specimen preparation for either indentation scheme is not overly critical. The finish obtained from wet 600 grit sandpaper was used throughout the tests. After polishing the specimen with the sandpaper it was cleaned with alcohol and the location where the indentations were to be made was marked with a pen. The indentations can be difficult to see with the naked eye; an ink mark on the specimen makes the laser alignment much easier. Additionally, lubrication on the indentor did not have a noticeable effect on the interference patterns.

Obviously, the indentations must remain reflective throughout the test. There are two methods that have been used to measure non-reflective materials with this method. One method is to apply a reflective coating in the area of the indentations. This can be done with a vacuum-sputtering operation[6]. The second method is to make seperate tabs from a reflective material. Indentations are placed on these tabs and the tabs are applied to the specimen in a manner similar to a strain gage[7].

METHODS OF MEASURING FRINGE TRANSLATION

Once the appropriate interference patterns are produced, a method to monitor the pattern translation (determining δm) must be found. A suitable method must be able to determine the translation in a direction normal to the fringe patterns. Recording the fringe and measuring the translation can be done a few different ways. Different methods may be more appropriate for faster recording times, larger fringe translations, or obtaining permanent records of the fringe patterns.

The most basic way to monitor fringe translation is to project the fringe patterns on a piece of paper and trace the fringe patterns before and after loading. This method, however simplistic, can produce decent results for large fringe translations. The human eye is very good at determining fringe locations and tracing them. This method has been used (see section 2) with an error less than 7%.

Another basic way to determine fringe translation is to take a series of photographs of the fringes. The fringes can project directly onto the film or onto a screen. A suitable reference point can then be used to measure the translation of the fringes. This method is slow, due to the development time, and quite tedious. Still, conceptually speaking, it is a clear method and provides great presentation material. See reference 2 for the particulars of this method.

The most recent method to measure the fringe translation is to use linear diode arrays[8]. These devices contain a row of small diodes which provide a voltage cooresponding to light intensity. When a fringe pattern falls on the array a digitized version of the pattern can easily be recorded. Modern arrays have acceptable resolution (upwards of 4096 pixels) and interface well with computer controlled systems. They are also somewhat easy to position, similar to a camera.

Photomultiplier tube, scanner and laser arrangement

A photomultiplier tube (PMT) and scanning mirror arrangement was used for some experiments in this paper[4,9]. The primary reason for using this system was availability. It is also easy to visualize the operation of the system and is very flexible to setup initially.

This device is shown schematically in figure 14. For the sake of clarity, the figure illustrates only the arrangement for uniaxial measurement. Multiaxial measurement is simply done by arranging more uniaxial systems in different planes. For example, a system for measuring orthogonal normal strains (see figure 3-b) would include a pair of scanner mirrors and PMTs arranged as shown in figure 14 plus another set perpendicular to the paper.

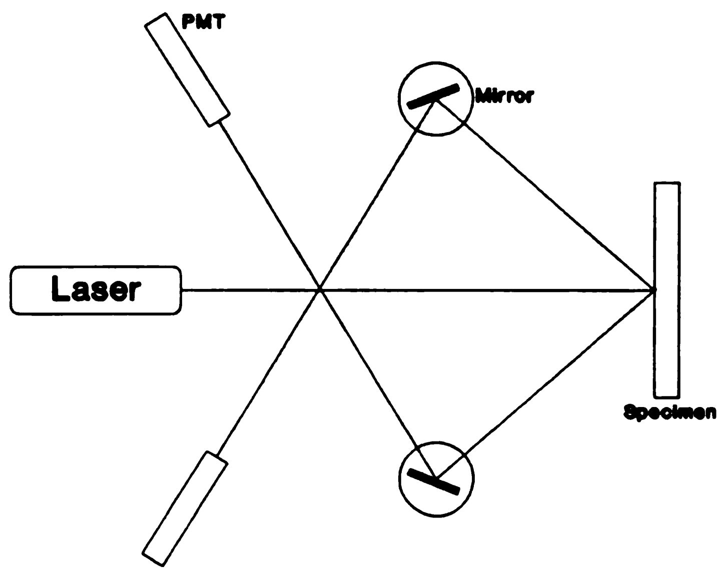

Figure 14. Setup of a PMT and scanner mirror measurement system

A laser illuminates the indentations and the interference of the scattered light produces fringe patterns. The mirrors are positioned in the resulting fringe patterns and reflect them into the photomultiplier tubes that provide a voltage proportional to the fringe brightness. The computer then directs the scanner controllers to rotate the mirrors in a step-wise fashion so as to sweep the patterns past the photomultiplier tubes.

The voltage output from the photomultiplier tubes is received into the computer and stored with the step number of the mirror. A more detailed setup is shown if figure 15.

From the computer programs point of view, a voltage is sent out and then a voltage is read in. The output voltage is sent to the scanner controller to rotate the mirror to the next step. The input voltage is the voltage from the PMT. This voltage is proportional to the brightness of the fringe shining on the PMT. The number of the mirror step and the PMT voltage are then stored as a data pair.

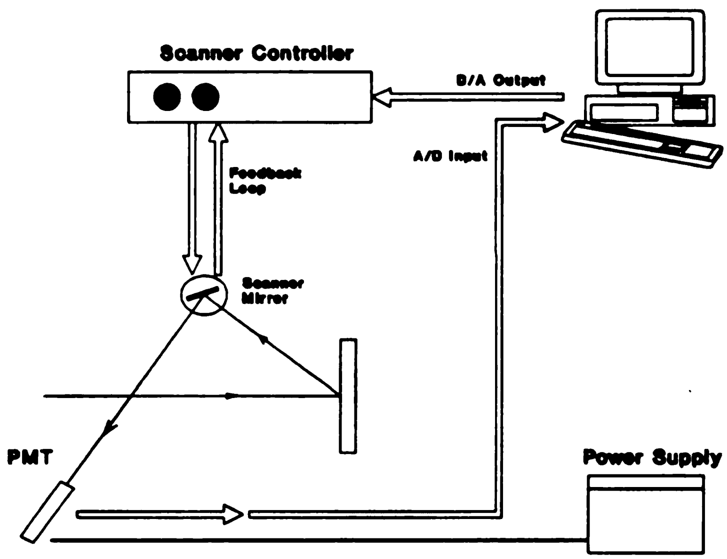

Figure 15. Detailed setup of a PMT and scanner mirror measurement system

Parts description

The following is a brief parts description of the arrangement used above. The photomultipler tubes, model R1213, are made by the Hamamatsu Corporation. They are magnetically shielded by a close fitting tube as well as being protected by an outside container/mount. A band-pass filter is used over the tube to filter out room light and allow only the HeNe laser light to reach the tube. The tubes have proven to be very reliable devices.

The laser that was used is a 15mW unit from Jodon Incorporated - Ann Arbor, MI. This unit is strong enough to produce bright fringe patterns for most tests. When using stationary software techniques, discussed on page 39, a laser unit with less drift is required. The laser drifted enough to make this technique ineffective.

The mirror scanners, model G120DT, and the scanner controllers, model CX6120, are made by General Scanning Inc. A ±5V input to each scanner controllers sweeps the mirror scanners through a maximum rotation angle of 15°. An amplitude setting on the controller is used to limit the mirror rotation angle. This allows only a few fringes to be swept past the photomultiplier tubes. Internal heaters in the scanners help to eliminate the influence of room temperature variations.

The computer interface is a model DT2811 I/O board manufactured by Data Translation. This is a 12 bit card with eight analog bipolar inputs used for photomultiplier input and two bipolar analog outputs used to control the scanner controllers. Typically, one of the outputs is daisy-chained to control all the scanner controllers. The other is used to output a signal corresponding to strain, displacement, etc. for plotter use.

The computer that was used to control the system was a Zeinth personal computer. It uses an 8088 processor and a CGA video interface. All the programming was done in MicroSoft QuickBasic version 4.5.

The disadvantage of using this antiquated computer system is that the recording/processing time was very limited. However, as a tribute to the interferometric technique, the tests still produced favorable results. A more modern computer would simply increase the flexability of the system.

SOFTWARE TECHNIQUES

Before discussing the processing of the fringe patterns, it is worth noting that this interferometric technique can measure displacement as well as strain. In fact, the displacement is found first and the strain is calculated using the initial gage length. Although the experiments in this paper center on finding strain, this method of interferometry has been used to measure crack opening displacements[8].

Information from the initial fringe pattern

Once the fringe pattern is recorded by the computer there are different ways to monitor the fringe translation. However, certain variables must first be determined from the initial pattern. The essential variables are the spacing of the fringes (m_0) and a starting location to keep track of.

Using the setup discussed previously the computer can record the fringe pattern as shown in figure 16. The intensity (brightness) of the fringe, seen as voltage from the photomultiplier tubes, is plotted as the ordinate. This intensity is stored as a voltage but can be converted to light intensity if desired. The position of the mirror is plotted as the abscissa. The mirror position is in arbitrary units.

The mirror positions are uniform and must be consistent throughout the test. The mirror position can also be thought of as the voltage level output to the scanner controllers or the angle of the scanner mirrors.

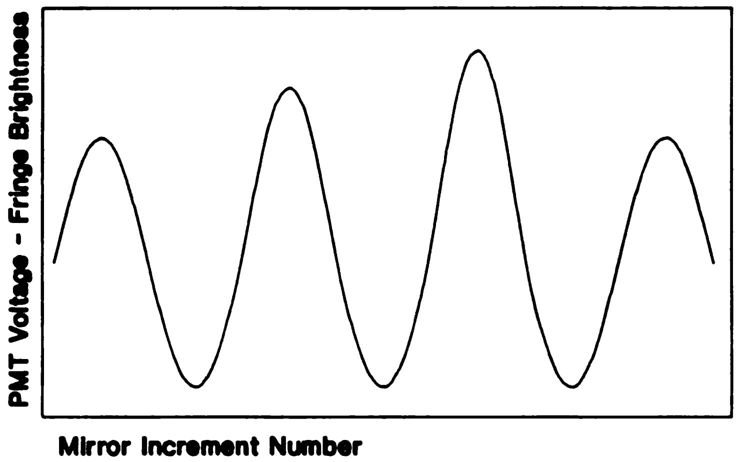

Figure 16. Computer representation of a fringe pattern

Typically, the amplitude on the scanner controllers are set so that a full scale output signal (±5V) from the computer will pass two or three fringes past the PMTs. This gives the best resolution. A 12 bit I/O card provides 4096 discrete voltage levels. Each voltage can produce a different mirror location. At each of these mirror locations a voltage corresponding to fringe brightness can be recorded. To speed up the process only 256 or 512 discrete mirror steps are generally used. If more (and therefore closer) mirror steps are used the resolution will be increased but the scanning process will take considerably longer.

An alternative method of obtaining the voltage vs. position information is to use a function generator to provide the input voltage to the scanner. The function generator can be set to produce a ramp voltage from -5V to +5V when triggered by the computer. The voltages sweeps the fringe pattern past the PMTs. This technique relieves the computer from the burden of calculating the mirror steps and sending out the appropriate values to the scanner controllers. However, the problem of not having a definite location for a given intensity value is presented. Experience has shown that the difficulty of this idea outweighs the speed advantages.

The most obvious method of monitoring the fringe translation is to pick a spot on the curve and follow it during loading. The maximum intensity value is the best choice, since it is more defined (due to its brightness). Also, a simple "if" statement included in the software is all that is needed to locate the maximum spot during the initial scan.

Alternately, a minimum point on the curve may be chosen. This requires a bit more computer code since all the minimum points are (ideally) equal to zero. In finding minimum values the slopes of the adjacent points must be considered. The code included in section 5 locates the minimum points only on the initial scan and uses these positions to calculate the fringe spacing, m_0.

After each change in load a new scan is made to find the new position of the key point. Fortunately, subsequent scans of the fringe pattern do not have to be as complete as the initial scan. Recall that only δm is now needed to determine the relative displacement of the indentations. Since the fringe spacing m_0 was found from the first scan, all that is needed to find δm is the amount of translation. There are two general techniques to determine the amount of translation: oscillating techniques and stationary techniques.

Oscillating Techniques

These techniques oscillate the mirror around the previous position of the key point to decide the new position of that point. For example, if the loading is known not to produce strain equal to twenty mirror spacings, then the mirrors only need to scan twenty positions on either side of the previous position. If more is known about the load, then the scanned range may be shifted even more; for example, five spacings one way and ten the other. Once the new location of the key point is found, the range is updated for the next scan. This is illustrated more clearly in figure 17.

An advantage of this technique is that the large fringe translations can be measured easily. If the applied load were to move the key point beyond the limits that the mirror is set for ("off the screen") a new key point can be easily chosen. The search range is moved back into the range of the mirror by a distance equal the fringe spacing. This is rarely necessary because a large strain is needed to cause a δm of 2.

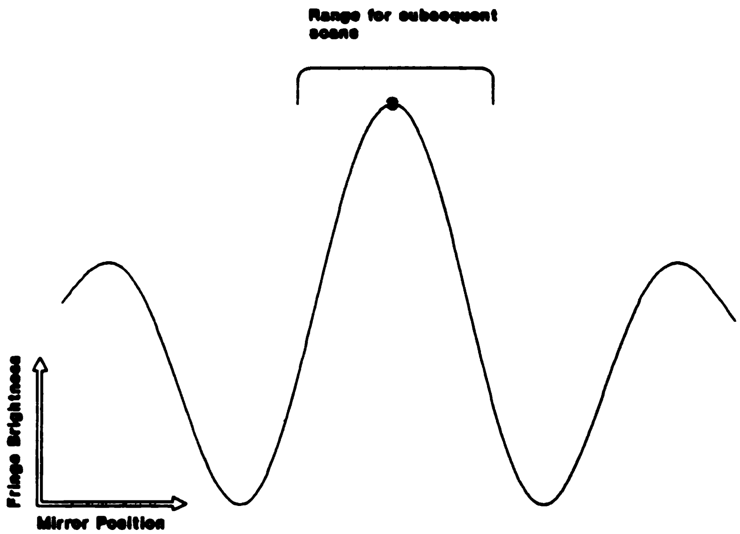

Figure 17. Use of an oscillating technique on a fringe pattern

The disadvantage to this technique is that the resolution is limited by the number of mirror increments in the fringe spacing, m_0. For example, if the fringe spacing is 200 mirror increments then the smallest detectable fringe movement is 200^{-1}. Using the standard values of

$\alpha = 43°$ using Vicker's indentor

$\lambda = 0.6328\mu$ He-Ne laser light

$$\delta d = \frac{\lambda}{\sin\alpha} \times \frac{\delta m_1 + \delta m_2}{2} = 0.95 \times 200^{-1} = 0.00475\,\mu$$

If the gage length, d_0, is 175μ then the resolution for strain measurement is $27\mu\epsilon$.

The fringe spacing can be increased by setting the scanner amplitude controls so that only one or two fringes pass by the PMTs. As expected, this decreases the range of the system. A happy medium must be found that will give adequate resolution and sufficient range.

Another item that needs to be mentioned regarding this technique is the rigid body motion problem. Since the subsequent scans must contain the maximum point, the scanning range must be wide enough to include translation due to strain and rigid body motion. The rigid body motion may or may not be very important. The experiments in this paper were conducted on a very large load frame that appeared to have little rigid body motion. Presumably, if a less massive loading system was used then rigid body motion may be a significant problem.

Stress - strain relationship using an oscillating technique

A simple uniaxial tension test was used to illustrate the operation of the software shown in section 5 and the PMT scanner mirror system described in section 3. The software recorded the specimen load and the fringe shift for each fringe pattern. Figure 18 shows the load and the average fringe shift. By using the displacement equations derived in section 1, the fringe shift, δm, is converted into a displacement. The displacement is also shown in figure 18 as the right hand ordinate axis.

Since the cross-sectional area and the gage length are known, the load and displacement data can be readily converted to stress and strain information. The stress - strain diagram is shown in figure 19. The non-linearity of the curve could be attributed to a few factors. The most likely factor is vibration in the system. Although unlikely, it is possible that electrical interference caused mirror oscillation or fluctuations in the PMT output. Even with this non-linearity, a value of Young's modulus was found to be 9.88e6 psi. This is very acceptable.

Repeatability tests indicated that the system used above would drift ± 1 mirror increment for a fringe spacing around 75 to 100 mirror increments with no specimen load. At first this does not seem to be very alarming. However, a false fringe shift of one mirror increment with a fringe spacing of 75 increments gives a δm of 75^{-1} and a displacement of 0.0124μ. Over a 150μ gage length, the indicated strain is $82\mu\epsilon$. Even though for most situations this is acceptable it must be considered whenever using this type of system.

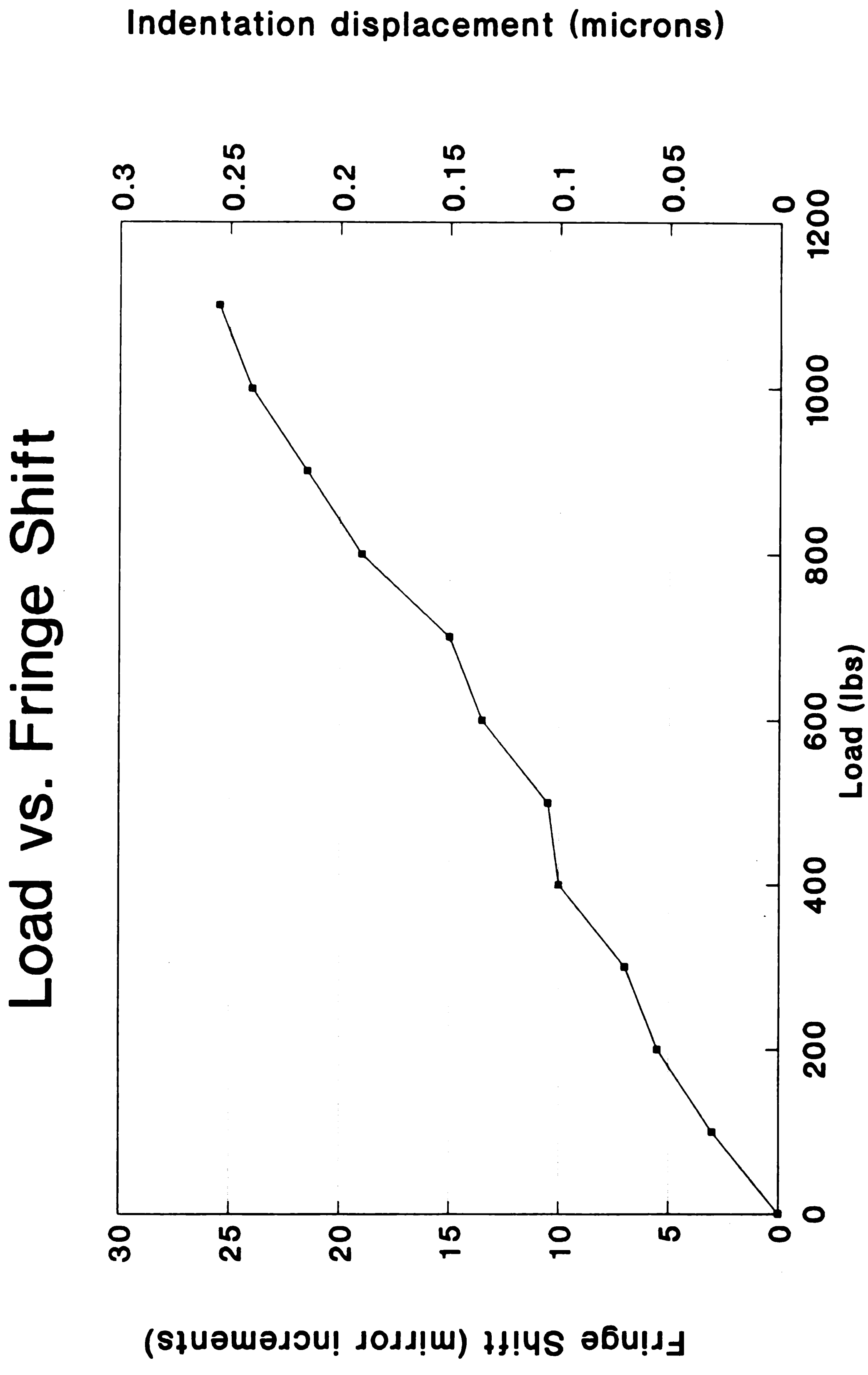

Figure 18. Load vs. Fringe shift for Aluminum specimen

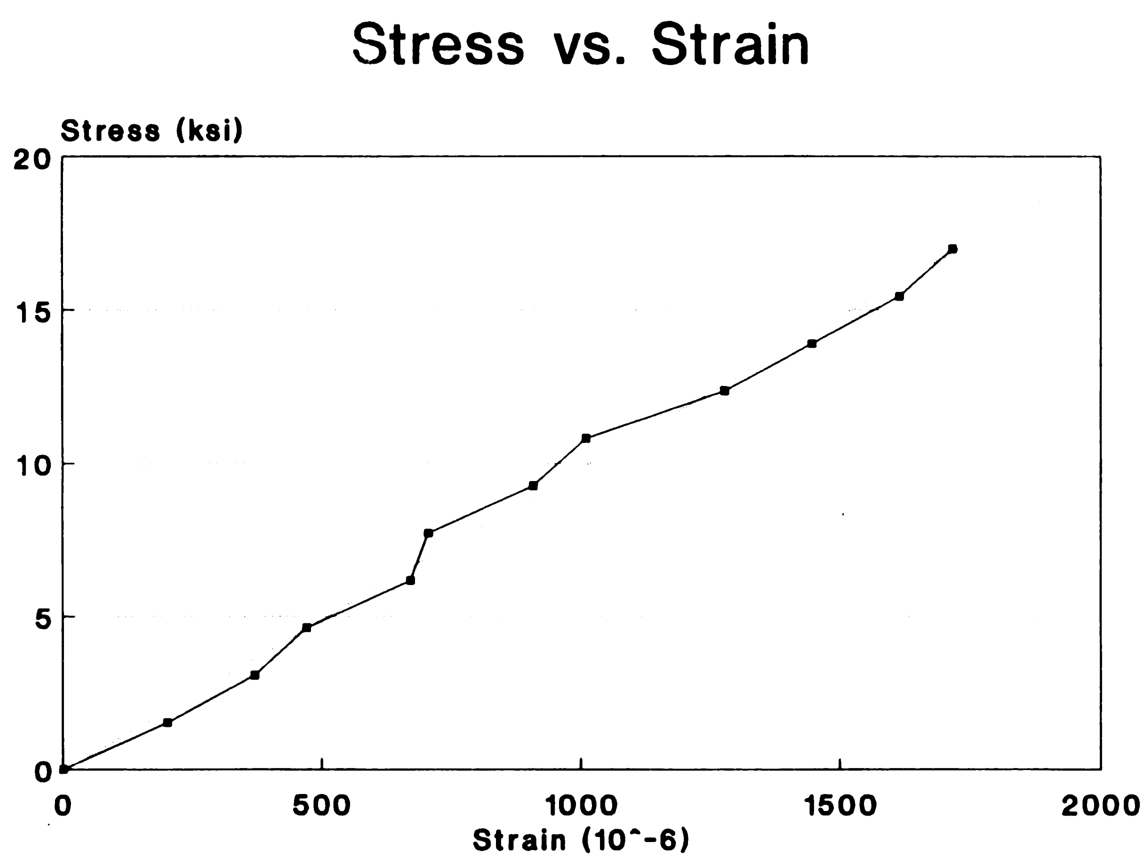

Figure 19. Stress vs. Strain
for Aluminum specimen

Stationary Techniques

This technique solves the resolution problem by using curve fitting techniques. However, the range is somewhat limited. A section of the curve from a minimum point to a maximum point is fitted with an n^{th} degree polynomial. The mirror is then held stationary at a point contained in the curve. The voltage input from the PMTs at that location is used to determine the position that the mirror should be. If this position is different from the actual mirror position the fringe movement can be calculated by subtracting the two.

Figure 20 helps to illustrate this idea. It is necessary to limit the length of the curve as shown so that any voltage input (ordinate value) will only give one value for a mirror position (abscissa value). If the entire curve were to be fitted with an equation, a given voltage could suggest several possible mirror positions.

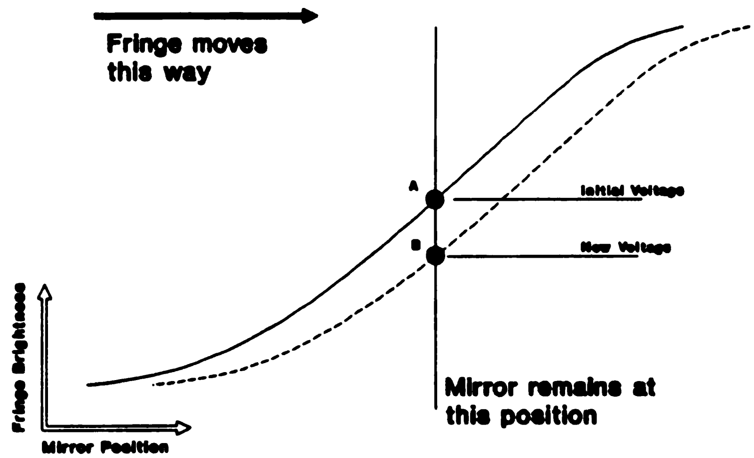

Figure 20. Using a stationary technique on a fringe pattern

Point *A* is where the mirror remains. After a fringe shift, the voltage from the PMT and the curve equation indicate that the voltage used to be at position *B*. The difference between *A* and *B* is the amount of the fringe shift. For each strain reading it is only necessary to input one voltage and calculate two simple equations. With a fast computer this can almost be done in real time.

A disadvantage of this technique is that it is very susceptible to drift in the setup. If the laser intensity, voltage to the scanner controllers, or the scanner controllers themselves drift, then false fringe translations will be reported. The setup used in this paper tended to have too much drift to use this method reliably.

Since both of these methods involve the use of a computer, a warning must be expressed. Computers are very good at generating numbers and somewhat poor at interpreting whether they are ridiculous or not. The use of a computer to monitor interferometric measurement is especially dangerous since the interference patterns are not always easily seen. Care has been taken in the programs to warn the user of unusual inputs. Obviously, not all situations can be foreseen; and certain inputs can be both good and bad depending on the circumstances.

With this warning in mind two recommendations are made. First, there is no substitute for knowing what the results should be (within reason) and what is happening to the specimen. A few simple calculations should show whether the results are correct or not.

Secondly, the use of an oscilloscope to monitor inputs and outputs is encouraged. A multichannel digital storage oscilloscope can give a good indication of what is happening. In fact, a good oscilloscope could be substituted for the computer setup for certain measurements. This is the oscilloscope analogy to taking pictures of the before and after fringe patterns. Early experiments using interferometric measurement used oscilloscopes in this way[10].

COMPUTER PROGRAM CODE

During the course of this research many different computer routines were written to try different ideas. These programs ranged from simple voltmeter type programs to many different versions of fringe intrepreting programs. A representative of the latter is shown here.

It will soon become obvious that this program was written by an engineer and not a computer programmer. The program is not stream-lined very much. As an example, the conversion of the A/D input from the card to a decimal number is very long. It was left in this rather ineloquent form so the the process could be followed more closly. Also, rearanging the code to fit in the prescribed page format left the arangement of some sections slightly cluttered.

Note that these programs were written in MicroSoft QuickBasic Version 4.5. This programming language is more than adequate for what was required, and it is very easy to use. As an unpaid testimonial, it is a shame that so many people shy away from this langauge since they still have the idea of Basic "not being a real language".

```
' TEST1.BAS

' This program only finds two fringe distances between
' minimum voltage values on either side of the maximum
' voltage value.  This allows the fringes to be more spread
' out.  The maximum value should be centered and it should
' contain two minimum values.

' This program must stop when the followed peak goes off the
' screen.  Also, this program was written for the 0 to +5V
' UNIPOLAR input setting and the -5V to +5V BIPOLAR output
' setting.

' NOTE: After the initial constants/locations have been
' figured out the maximum value is the location on the curve
' that will be tracked to determine strain/displacement.

' -----------------------------------------------------------

10   CLOSE
     DIM PKS1(260, 2), PKS2(260, 2), CH$(260, 2), PKS(260,
2)
     FLOG = 0: L1Max = 0: L2Max = 0: FlagForLimit = 0
     LMaxN(1) = 0: LMaxN(2) = 0: RP = 6
     FMT$ = "       ###       ####          #### "
     FMT2$ = "    ###            ####        ####
####        ####"
     FMT3$ = "   #        ###                ###
     ###"
     FMT4$ = "       ###        ##.###         ##.### "
     FMT5$ = "&     +######.#     +#.#######    +#######.#
 +##.##    +#.#####µm"
     FMT6$ = "Minimum value found at ### for PMT_# #"

' ------Get initial information----------------------------

     CLS : COLOR 5: PRINT
     PRINT TAB(25); "C A L C U L A T E   S T R A I N "
     PRINT TAB(25); "  (Small Displacement Version)"
     COLOR 13: PRINT STRING$(80, 205): COLOR 3
     LOCATE 8, 5
     INPUT "Enter the value for Young's modulus.... ", E$
     E = INT(ABS(VAL(E$)))
     LOCATE 8, 67: COLOR 9
     PRINT USING "###.##^^^^ "; E: COLOR 3

75   LOCATE 10, 5: PRINT STRING$(74, " ")
     LOCATE 10, 5
     INPUT "Enter the gage length in µm............ ", Gl$
     Gl = INT(ABS(VAL(Gl$)))
     IF (Gl <= 0 OR Gl > 1000) THEN Gl = 150
     COLOR 9: LOCATE 10, 68
     PRINT USING "###.# "; Gl
```

```
     COLOR 3: LOCATE 12, 5
     PRINT "Save data as a Harvard Graphics file (Y or N) ?
"
77   OP$ = INKEY$: IF OP$ = "" THEN GOTO 77
     IF UCASE$(OP$) = "Y" THEN
         COLOR 9: LOCATE 12, 43: PRINT UCASE$(OP$)
         COLOR 3: LOCATE 13, 5
         INPUT "Enter the filename to save as (8 characters)
", HGNAME$
         IF HGNAME$ = "" THEN HGNAME$ = "IMPORT"
         HGNAME$ = LEFT$(HGNAME$, 8) + ".HG"
         OPEN HGNAME$ FOR OUTPUT AS 2
         PRINT #2, "Strain, Stress, Displacement, Load" +
CHR$(34)
         HGLOG = 1
         COLOR 9: LOCATE 13, 68
         PRINT USING "\           \"; HGNAME$: COLOR 3
     ELSE
         COLOR 9: LOCATE 12, 48
         PRINT "N": COLOR 3
     END IF

     LOCATE 15, 5: PRINT "Record session in an ASCII file (Y
or N) ? "
80   OP$ = INKEY$: IF OP$ = "" THEN GOTO 80
     IF UCASE$(OP$) = "Y" THEN
         COLOR 9: LOCATE 15, 38: PRINT UCASE$(OP$)
         COLOR 3: LOCATE 16, 5
         INPUT "Enter the filename to save as (8 characters)
", FILENAME$
         IF FILENAME$ = "" THEN FILENAME$ = "NOTE"
         FILENAME$ = LEFT$(FILENAME$, 8) + ".DOC"
         COLOR 9: LOCATE 16, 68
         PRINT USING "\          \"; UCASE$(FILENAME$)
         COLOR 3
         OPEN FILENAME$ FOR OUTPUT AS 1
         PRINT #1, "Log file started on "; DATE$; " at ";
TIME$
         LOCATE 18, 5
         PRINT "Please enter a description for the ASCII
file "
         LOCATE 20, 5: INPUT "-> ", TITLE$
         PRINT #1, TITLE$: PRINT #1, " "
         PRINT #1, STRING$(79, "-")
         FLOG = 1
     ELSE
         COLOR 9: LOCATE 15, 43
         PRINT "N": COLOR 3
     END IF

' ---------------------------Load Array With Data --------

500  LOCATE 23, 1
```

```
     PRINT STRING$(38, " "); : LOCATE 23, 5
     PRINT "Press any key to start data collection";
     DO WHILE (INKEY$ = ""): LOOP

     CLS : SCREEN 1: VIEW: '    320x200 with 4 colors (CGA)
     WINDOW (0, -1)-(256, 5)

     LINE (0, 0)-(256, 0), 1, , &HAAAA
     LOCATE 21, 36: PRINT "0V"
     LINE (0, 1)-(256, 1), 1, , &H3333
     LOCATE 17, 36: PRINT "1V"
     LINE (0, 2)-(256, 2), 1, , &H3333
     LOCATE 13, 36: PRINT "2V"
     LINE (0, 3)-(256, 3), 1, , &H3333
     LOCATE 9, 36: PRINT "3V"
     LINE (0, 4)-(256, 4), 1, , &H3333
     LOCATE 5, 36: PRINT "4V"

     LOCATE 23, 5: PRINT "Dark = PMT#1, Bright = PMT#2";

     FOR XX = 20 TO 220 STEP 32
         LINE (XX, -.2)-(XX, .2), , , &H3333
     NEXT XX

     OUT &H218, &H10
     FOR I = 1 TO 400: NEXT I

     LB = INP(&H21A): HB = INP(&H21B): Counter = 0
     LMax(2) = 0: LMax(1) = 0

     FOR V = 4096 TO 32 STEP -16
         V$ = HEX$(INT(V))
         V$ = STRING$((4 - LEN(V$)), "0") + V$
         LVol = VAL("&H" + RIGHT$(V$, 2))
         HVol = VAL("&H" + LEFT$(V$, 2))
              OUT &H21A, LVol
              OUT &H21B, HVol
              Counter = Counter + 1
                  OUT &H218, &H0
                  OUT &H219, 128 + 1
510               CSR = INP(&H218)
                  IF CSR < 128 THEN GOTO 510
                  LB = INP(&H21A): HB = INP(&H21B)
                  LB$ = HEX$(LB): HB$ = HEX$(HB)
                  LB$ = STRING$((2 - LEN(LB$)), "0") + LB$
                  HB$ = STRING$((2 - LEN(HB$)), "0") + HB$
                  XX$ = "&h" + RIGHT$(HB$, 2) + RIGHT$(LB$,
2)
                  CH$(Counter, 1) = XX$
                  V1 = VAL(XX$) * (5 / 4096)
                  PSET (Counter, V1), 2
                  IF V1 > LMax(1) THEN
                      LMaxN(1) = Counter
```

```
                    LMax(1) = V1
                END IF

                OUT &H218, &H0
                OUT &H219, 128 + 2
511             CSR = INP(&H218)
                IF CSR < 128 THEN 511
                LB = INP(&H21A): HB = INP(&H21B)
                LB$ = HEX$(LB): HB$ = HEX$(HB)
                LB$ = STRING$((2 - LEN(LB$)), "0") + LB$
                HB$ = STRING$((2 - LEN(HB$)), "0") + HB$
                XX$ = "&h" + RIGHT$(HB$, 2) + RIGHT$(LB$,
2)
                CH$(Counter, 2) = XX$
                V2 = VAL(XX$) * (5 / 4096)
                PSET (Counter, V2), 3
                IF V2 > LMax(2) THEN
                   LMaxN(2) = Counter
                   LMax(2) = V2
                END IF
     NEXT V
     LINE (LMaxN(1), 0)-(LMaxN(1), 5), 2
     LINE (LMaxN(2), 0)-(LMaxN(2), 5), 3

'    Use lines 23 and 24 for messages
     LOCATE 23, 1: PRINT STRING$(39, " "); : LOCATE 23, 4
     PRINT USING "PMT_#1 maximum of #.## at ###"; LMax(1);
LMaxN(1);
     LOCATE 24, 1: PRINT STRING$(39, " "); : LOCATE 24, 4
     PRINT USING "PMT_#2 maximum of #.## at ###"; LMax(2);
LMaxN(2);
     DO WHILE (INKEY$ = ""): LOOP

' ------Redo the fringe pattern or continue ---------

     LOCATE 24, 1: PRINT STRING$(39, " ");
     LOCATE 23, 1: PRINT STRING$(39, " "); : LOCATE 23, 1
     PRINT "  Press C to cont. another key to redo";
150  OP$ = INKEY$: IF OP$ = "" THEN GOTO 150
     IF UCASE$(OP$) <> "C" THEN GOTO 500

' ------------------------Find the valleys -------------

700  LOCATE 23, 1: PRINT STRING$(38, " ");
     LOCATE 23, 5: PRINT "Resetting array values..."
     FOR N = 5 TO 256
         PKS(N, 1) = 0: PKS(N, 2) = 0
     NEXT N

     LOCATE 23, 1: PRINT STRING$(38, " ");
     LOCATE 23, 5: PRINT "Calculating minimum values..."

     FOR I = 1 TO 2
```

```
        FOR N = 6 TO 250
            IF (VAL(CH$(N - 1, I)) > VAL(CH$(N, I))) AND
(VAL(CH$(N + 1, I)) >= VAL(CH$(N, I))) THEN
                IF (VAL(CH$(N - 2, I)) > VAL(CH$(N, I)))
AND (VAL(CH$(N + 2, I)) >= VAL(CH$(N, I))) THEN
                    IF (VAL(CH$(N - 3, I)) > VAL(CH$(N, I)))
AND (VAL(CH$(N + 3, I)) >= VAL(CH$(N, I))) THEN
                        IF (VAL(CH$(N - 4, I)) > VAL(CH$(N,
I))) AND (VAL(CH$(N + 4, I)) >= VAL(CH$(N, I))) THEN
                            IF (VAL(CH$(N - 5, I)) >
VAL(CH$(N, I))) AND (VAL(CH$(N + 5, I)) >= VAL(CH$(N, I)))
THEN

     PKS(N, I) = N
     PSET (N, (VAL(CH$(N, I)) * (5 / 4096))), (I + 1)
     DRAW "BH2 r4 d4 14 u4"
     IF FLOG = 1 THEN
        PRINT #1, USING FMT6$; N; I
     END IF

                            END IF
                        END IF
                    END IF
                END IF
            END IF
        NEXT N
     NEXT I

     LOCATE 23, 1: PRINT STRING$(38, " ");
     LOCATE 23, 5: PRINT "Press any key to continue"
     DO WHILE (INKEY$ = ""): LOOP

' ------Find the distance between fringe valleys----------

     FOR I = 1 TO 2
900     FOR N = (LMaxN(I) + 1) TO 255
            IF PKS(N, I) <> 0 THEN
               DH(I) = PKS(N, I)
               GOTO 902
            END IF
        NEXT N

902     FOR N = LMaxN(I) TO 0 STEP -1
            IF PKS(N, I) <> 0 THEN
               DL(I) = PKS(N, I)
               GOTO 903
            END IF
        NEXT N
903  NEXT I

905  Dist1 = ABS((DH(1) - DL(1)))
     Dist2 = ABS((DH(2) - DL(2)))
```

```
     IF Dist1 = 0 OR Dist2 = 0 THEN
        SCREEN 0: WIDTH 80
        VIEW PRINT 7 TO 22: CLS : VIEW PRINT
        COLOR 12: PRINT : PRINT : PRINT : PRINT
        PRINT TAB(15); "One of the peak distances was found
to be zero."
        PRINT TAB(15); "This will cause division by zero in
the main"
        PRINT TAB(15); "displacement equation.  Please
re-run this "
        PRINT TAB(15); "program making sure that the initial
fringe"
        PRINT TAB(15); "pattern is scanned in correctly."
        COLOR 3: PRINT : PRINT
        PRINT USING "              DL(1) = ###    DH(1) =
###    Dist1 = ###"; DL(1); DH(1); Dist1
        PRINT USING "              DL(2) = ###    DH(2) =
###    Dist2 = ###"; DL(2); DH(2); Dist2
        LOCATE 23, 5
        PRINT "< Press   to Exit, any other key to continue
>"
        COLOR 4: LOCATE 23, 13: PRINT "X"
906     OP$ = INKEY$: IF OP$ = "" THEN GOTO 906
        IF UCASE$(OP$) = "X" THEN GOTO 1300
        GOTO 10
     END IF

     RESOLUTION = (.95) * ((1 / Dist1) + (1 / Dist2)) / 2

     SCREEN 0: WIDTH 80: CLS : COLOR 5: PRINT
     PRINT TAB(25); "C A L C U L A T E   S T R A I N "
     PRINT TAB(25); "  (Small Displacement Version)"
     COLOR 13: PRINT STRING$(80, 205): COLOR 3
     PRINT : PRINT
     PRINT "LMaxN(1) = "; LMaxN(1); "        LMaxN(2) = ";
LMaxN(2)
     PRINT
     PRINT USING "DL(1) = ###    DH(1) = ###    Dist1 =
###"; DL(1); DH(1); Dist1
     PRINT USING "DL(2) = ###    DH(2) = ###    Dist2 =
###"; DL(2); DH(2); Dist2
     PRINT
     PRINT "Resolution of displacement data is ...";
RESOLUTION
     PRINT "Resolution of strain data is .........";
(RESOLUTION / G1)
     PRINT : PRINT : PRINT "Press any key to continue":
PRINT

     DO WHILE (INKEY$ = ""): LOOP

     IF FLOG = 1 THEN
        PRINT #1, " "
```

```
        PRINT #1, "Brightest point for PMT#1 is at position
"; LMaxN(1)
        PRINT #1, "Brightest point for PMT#2 is at position
"; LMaxN(2)
        PRINT #1, " "
        PRINT #1, "Peak distance for PMT#1 is.............
"; Dist1
        PRINT #1, "Peak distance for PMT#2 is.............
"; Dist2
        PRINT #1, " "
        PRINT #1, "Resolution of the displacement data is
"; RESOLUTION
        PRINT #1, "Resolution of the strain data is ......
"; (RESOLUTION / Gl)
        PRINT #1, " "
        PRINT #1, "The gage length is "; Gl; " µm"
        PRINT #1, "The value for Young's Modulus is "; E
        PRINT #1, " "
        PRINT #1, STRING$(79, "=")
        PRINT #1, SPC(31); "Start of test data"
        PRINT #1, STRING$(79, "=")
        PRINT #1, " "
        PRINT #1, "TIME              LOAD          STRAIN
  STRESS    δm1-δm2    DISPLACEMENT"
     END IF

' ------Start the main testing loop------------------

     CLS : LOCATE 6, 1
     PRINT "TIME              LOAD          STRAIN
STRESS    δm1-δm2    DISPLACEMENT"
950  PRINT : LOCATE 23, 5: PRINT STRING$(74, " ")
     COLOR 3: LOCATE 23, 5
     INPUT "Enter the load for the next scan.... ", LOAD$
     LOAD = VAL(LOAD$)

' ------Scan in a smaller range of values--------------

     LMaxNOLD(1) = LMaxN(1): LMaxNOLD(2) = LMaxN(2)

     IF LMaxN(1) < LMaxN(2) THEN
        LLimit = LMaxN(1) - 30
        HLimit = LMaxN(2) + 30
     ELSE
        LLimit = LMaxN(2) - 30
        HLimit = LMaxN(1) + 30
     END IF

     IF LLimit < 0 THEN
        LLimit = 0
        FlagForLimit = 1
     END IF
```

```
     IF HLimit > 255 THEN
        HLimit = 255
        FlagForLimit = 2
     END IF


     HL = INT((4128 - (LLimit * 32)))
     LL = INT((4128 - (HLimit * 32)))

1000 COLOR 11: LOCATE 23, 5
     PRINT STRING$(70, " "): LOCATE 23, 5
     PRINT "< Press any key to start data collection>";
     DO WHILE (INKEY$ = ""): LOOP
     LOCATE 23, 5: PRINT STRING$(70, " ")
     LOCATE 23, 5
     PRINT "Incrementing from "; LLimit; " to "; HLimit; "
-->"

     L1Max = 0: L2Max = 0: Counter = 0

     OUT &H218, &H10
     FOR I = 1 TO 100: NEXT I
     LB = INP(&H21A): HB = INP(&H21B): Counter = LLimit

     FOR V = HL TO LL STEP -16
         V$ = HEX$(INT(V))
         V$ = STRING$((4 - LEN(V$)), "0") + V$
         LVol = VAL("&H" + RIGHT$(V$, 2))
         HVol = VAL("&H" + LEFT$(V$, 2))
              OUT &H21A, LVol
              OUT &H21B, HVol
              Counter = Counter + 1
                  OUT &H218, &H0
                  OUT &H219, 128 + 1
1010              CSR = INP(&H218)
                  IF CSR < 128 THEN 1010
                  LB = INP(&H21A): HB = INP(&H21B)
                  LB$ = HEX$(LB): HB$ = HEX$(HB)
                  LB$ = STRING$((2 - LEN(LB$)), "0") + LB$
                  HB$ = STRING$((2 - LEN(HB$)), "0") + HB$
                  XX$ = "&h" + RIGHT$(HB$, 2) + RIGHT$(LB$,
2)
                  IF VAL(XX$) > LMax(1) THEN
                     LMax(1) = VAL(XX$)
                     LMaxN(1) = Counter
                  END IF

                  OUT &H218, &H0
                  OUT &H219, 128 + 2
1011              CSR = INP(&H218)
                  IF CSR < 128 THEN 1011
                  LB = INP(&H21A): HB = INP(&H21B)
                  LB$ = HEX$(LB): HB$ = HEX$(HB)
```

```
                    LB$ = STRING$((2 - LEN(LB$)), "0") + LB$
                    HB$ = STRING$((2 - LEN(HB$)), "0") + HB$
                    XX$ = "&h" + RIGHT$(HB$, 2) + RIGHT$(LB$,
2)
                    IF VAL(XX$) > LMax(2) THEN
                       LMax(2) = VAL(XX$)
                       LMaxN(2) = Counter
                    END IF
                    LOCATE 23, 45: PRINT Counter
     NEXT V

' -------Calculate peak shift within the range---------

     Shift1 = LMaxN(1) - LMaxNOLD(1)
     Shift2 = LMaxN(2) - LMaxNOLD(2)

' ------Calculate the strain and stress--------------------

1200 Stress = 0
     DeltaD = (.95) * (((Shift1 / Dist1) + (Shift2 / Dist2))
/ 2)
     Strain = DeltaD / G1
     RBM = (Shift1 / Dist1) - (Shift2 / Dist2)

     IF E <> 0 THEN
        Stress = Strain * E
     END IF

     IF HGLOG = 1 THEN
        PRINT #2, STR$(Strain) + "," + STR$(Stress) + "," +
STR$(DeltaD) + "," + STR$(LOAD) + CHR$(34)
     END IF

     IF FLOG = 1 THEN
        PRINT #1, USING FMT5$; TIME$; LOAD; Strain; Stress;
RBM; DeltaD
     END IF

     RP = RP + 1: VIEW PRINT 7 TO 22: COLOR 11
     IF RP < 22 THEN
         LOCATE RP, 1
         PRINT USING FMT5$; TIME$; LOAD; Strain; Stress;
RBM; DeltaD;
     END IF
     IF RP >= 22 THEN
         LOCATE 22, 1
         PRINT USING FMT5$; TIME$; LOAD; Strain; Stress;
RBM; DeltaD
     END IF
     VIEW PRINT: COLOR 3

     IF FlagForLimit THEN
        COLOR 20
        LOCATE 23, 5: PRINT STRING$(70, " ");
```

```
        LOCATE 23, 5: PRINT "One of the limits has reached
the end of the screen!"
        DO WHILE (INKEY$ = ""): LOOP
        LOCATE 23, 5: PRINT STRING$(70, " ");
     END IF

     LOCATE 23, 5
     PRINT "< Press   to Exit, any other key to continue >"
     COLOR 4: LOCATE 23, 13: PRINT "X"
1210 OP$ = INKEY$: IF OP$ = "" THEN GOTO 1210
     IF UCASE$(OP$) = "X" THEN GOTO 1300
     GOTO 950

1300 CLOSE : VIEW PRINT: CLEAR : CLS : END
```

CONCLUSION

The ideas presented in this paper advance the techniques of basic interferometry. A circular indentation was used to construct an interferometric strain rosette. Testing of this strain rosette proved it to be both reliable and accurate.

A renewed interest in basic interferometry will certainly promote this technique even further. By combining the computer techniques, described in sections 3 and 4, with the circular indentation a convenient optical strain gage can be constructed. This gage will aid in many areas of experimental strain analysis.

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