LASER SPECKLE TECHNIQUE FOR BURNER LINER STRAIN MEASUREMENTS

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ABSTRACT

Thermal and mechanical strains have been measured on samples of a common material used in jet engine burner liners, which were heated from room temperature to 870°C and cooled back to 220°C, in a laboratory furnace. The physical geometry of the sample surface was recorded at selected temperatures by means of a set of twelve single-exposure specklegrams. Sequential pairs of specklegrams were compared in a heterodyne interferometer which allowed high-precision measurement of differential displacements. Good speckle correlation was observed between the first and last specklegrams also, which showed the durability of the surface microstructure, and permitted a check on accumulated errors. Agreement with calculated thermal expansion was to within a few hundred microstrain over a range of fourteen thousand.

BACKGROUND

A number of problems confront the use of double-exposure speckle photography for strain measurement. First and foremost, there are limits to the minimum and maximum speckle displacements that can be determined from a specklegram. These lie at approximately one and fifty speckle diameters, where a speckle diameter may be approximated by the Airy disk associated with the imaging system. These limits impose severe restrictions in the bulk displacements allowed for an object under test. This difficulty has been dealt with by using separate photographic plates for each of the deformation states of the object. When separate specklegrams are compared, bulk displacements may be eliminated by translating and rotating one with respect to the other.

A second problem lies in the accuracy required when optical strain measurement is forced to compete with electrical strain gaging. For example, if strain is to be measured on gage length of 1 mm to within 10 microstrain, the end-point displacements must be measured to within 10 nanometers. This level of performance is routine for electrical gages, but it is quite taxing for optical systems. Assume, for example, that relative speckle displacements can be measured to 1.0 percent of a speckle diameter. The f/number of the imaging system must be reduced to about 1.3 before the speckles are sufficiently small to permit a 10 nanometer displacement measurement. Many troubles attend the use of such low f/numbers in speckle photography; for example, lens aberrations become severe and lead to different displacements for different speckle sizes and shapes, and depth of focus becomes very short.

The photogrammetric comparison of specklegrams by heterodyne interferometry was introduced recently[1] to deal with these problems. Separate specklegrams were placed in the two paths of an interferometer in such a way that their far-field diffraction patterns (halos) could be combined and made to interfere. Simultaneous translation of the two specklegrams (via a common translation stage) caused the number of fringes across the output plane to increase or decrease at a rate proportional to any strain present between the two specklegrams. The introduction of a doppler shift between the two beams of the interferometer caused the fringe pattern to sweep across the output plane at a constant velocity. A pair of detectors in the output plane were used to generate electrical signals whose phase difference was proportional to the number of fringes spanned by the detectors. Connecting these signals to a phase meter allowed measurement of changes in phase to 0.1^{o}. This corresponded to a measurement of relative speckle displacements to one thirty-six-hundredth of a speckle diameter. This increased precision in the measurement of speckle displacements made practical use of the optical systems with reasonable f/numbers (e.g., f/10) for high resolution strain measurements.

Two problems were identified with the initial implementation of heterodyne speckle photogrammetry: a random pattern of apparent strain that was highly correlated to the stage position, and an apparent strain associated with thermal drift of the equipment. Both problems have been dealt with by subsequent work.[2] Data averaging was used to eliminate the effects of thermal drift and other sources of random error. The stage dependent error was eliminated by reconfiguration of the interferometer, so that the plates could lie in the same plane, and by refined adjustment procedures.

With the major problems of heterodyne speckle photogrammetry under control, thought was given to its application to high temperature strain measurement. It was reasoned that speckle photographs could be made of a test sample at various times during a test program. Once developed and fixed, these photographs would serve as a permanent record of the deformation states of the test sample, and they could be processed later to yield strain distributions. Unlike strain gages, which provide continuous strain data at discrete geometrical locations, the speckle photographs would provide contiguous strain data at discrete time intervals. There were considered to be sufficient cases of thermomechanically generated strains, where the geometrical strain pattern was of more importance than its detailed temporal history, to warrant exploration of the technique. This decision was also encouraged by the fact that the technique should be practicable at very high temperatures.

This presentation covers the results to date of a program carried out to apply heterodyne speckle photogrammetry to high temperature strain measurement. It will begin with a consideration of the optical, mechanical, and electronic problems concerned with such a test. This will be followed by a description of the test procedures and the results obtained.

It will be shown that heterodyne speckle photogrammetry has significant potential application to strain measurement of objects at high temperatures. Because it is necessary to subtract thermal expansions, however, it is necessary to measure accurately the temperature of the sample surface under consideration. Because it is capable of generating strain distributions, attention must also be paid to temperature distributions on the sample. If varying temperature gradients exist in gas through which speckle photographs are recorded, then their effect must be removed by independent measurement and computation. Temporal resolution of changing strain patterns will be compromised by the need to record separate photographs of the sample surface at discrete time intervals. This may be compensated, however, by the extraordinary amount of spatial strain information available. In 1983, it is planned to apply this technique to the measurement of strain on the surface of a JT8D burner liner in a test stand.

REFERENCES

1. Smith, G. B., and K. A. Stetson: "Heterodyne Readout of Specklegram Halo Interference Fringes." Appl. Opt., Vol. 19, pp. 3031-3033, 1980.

2. Stetson, K. A.: "Strain Measurement on Rough Surfaces by Optical Heterodyning." .Proc. 1981 Spring Meeting, SESA, June 1-4, 1982, Dearborn, Mich., pp. 236-241.

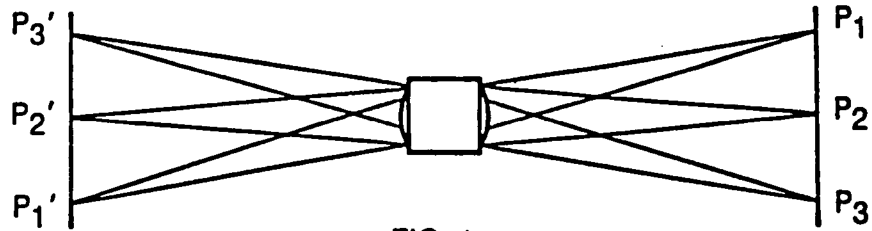

FIG. 1-a

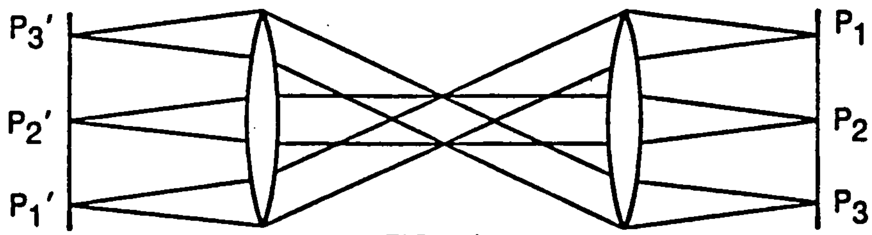

FIG. 1-b

CONVENTIONAL VERSUS TELECENTRIC LENS SYSTEM

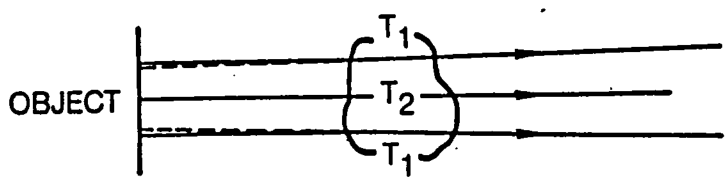

FIG. 2-a

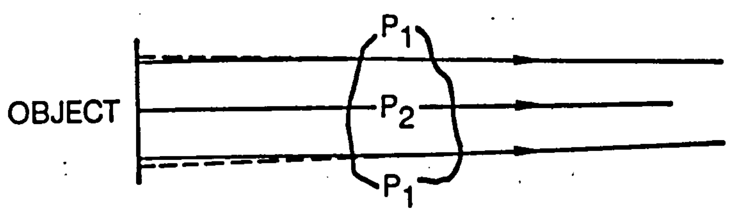

FIG. 2-b

LENSLETS CREATED BY TEMPERATURE AND PRESSURE INHOMOGENEITIES

a) Thermal Lenslet $T_2 > T_1$.

b) Pressure Lenslet $P_2 > P_1$.

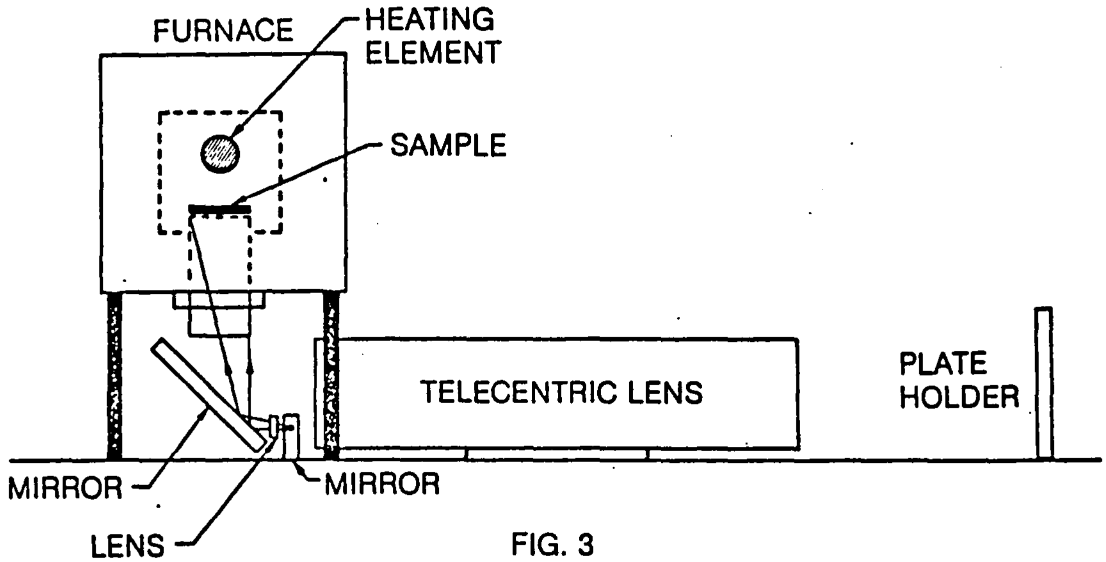

FIG. 3

LABORATORY FURNACE AND SPECKLEGRAM RECORDING SYSTEM

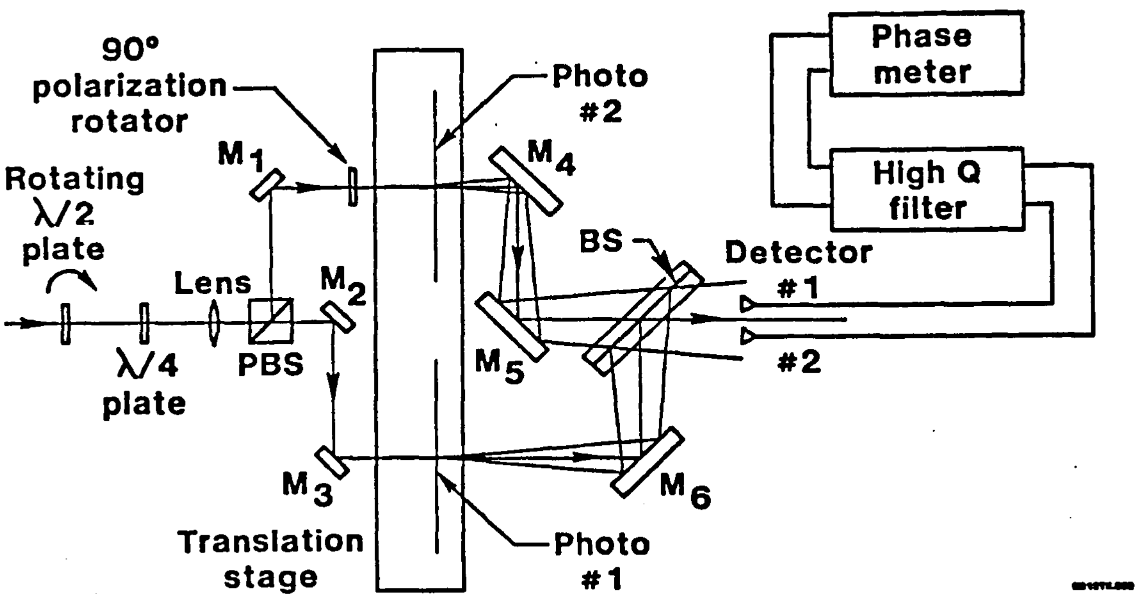

FIG. 4

INTERFEROMETRIC COMPARATOR FOR HETERODYNE READOUT OF SPECKLEGRAM HALOS

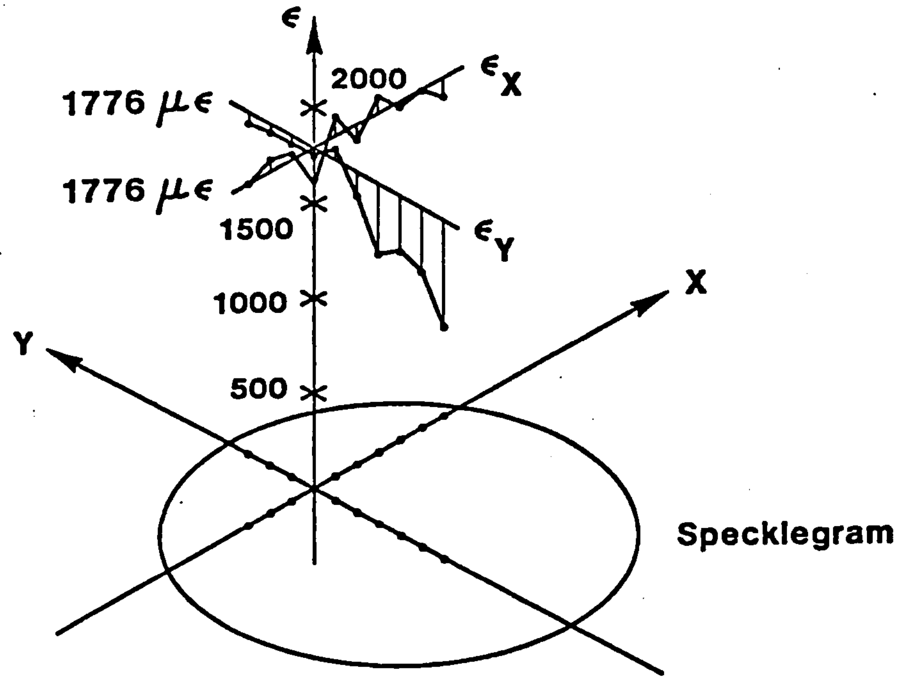

FIG.5

ISOMETRIC PLOT OF A THERMAL STRAIN DISTRIBUTION

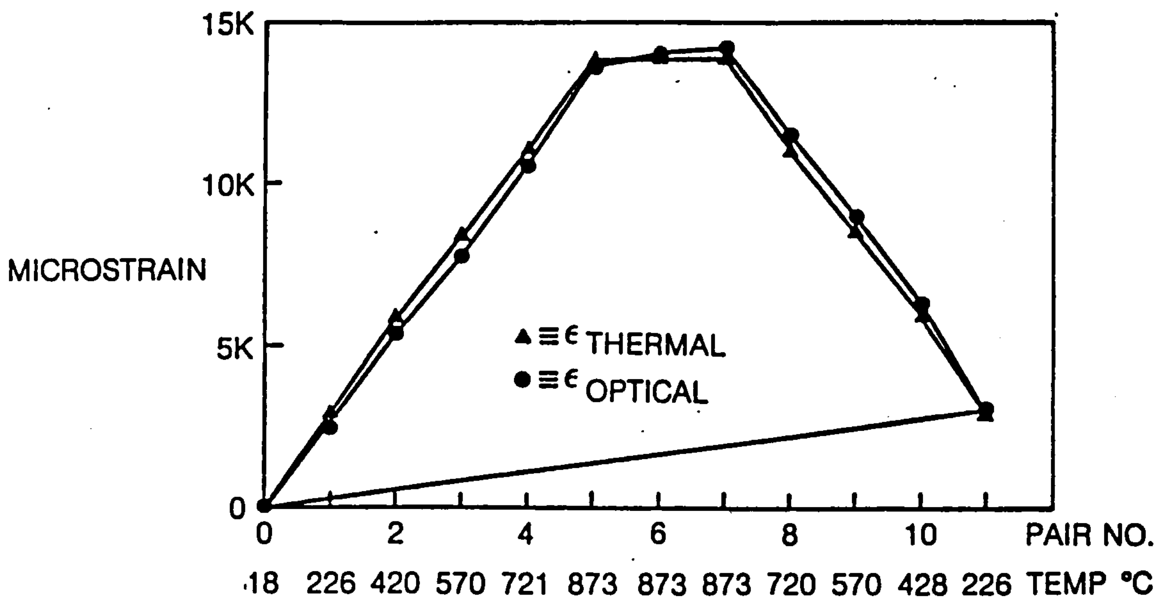

FIG. 6

STRAIN HISTORY OF AN UNCONSTRAINED SAMPLE OF BURNER LINER MATERIAL

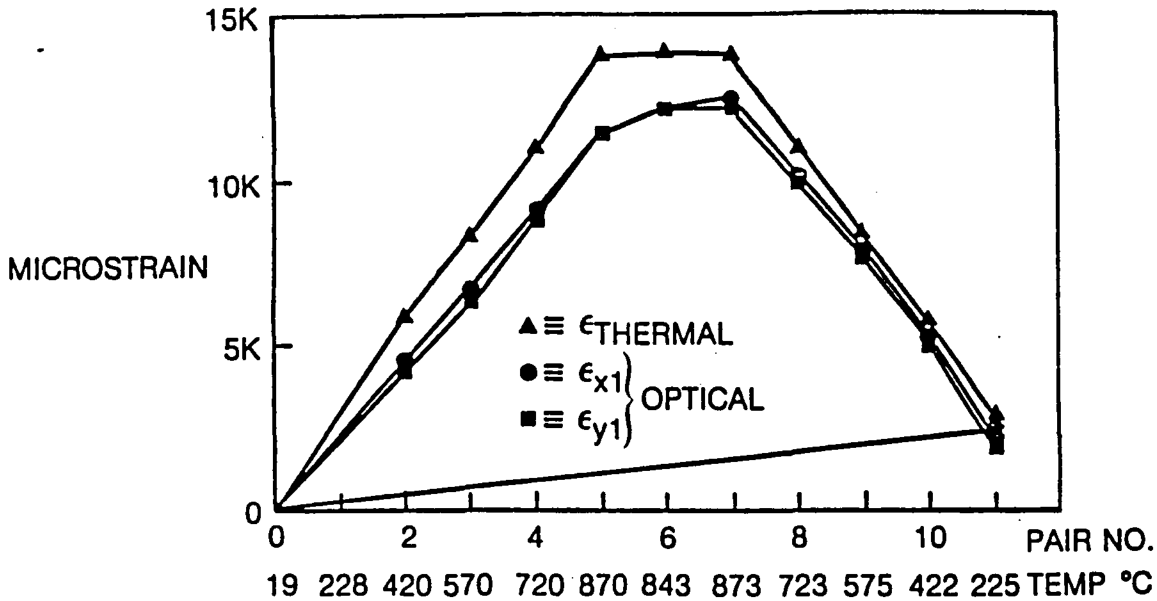

Fig. 7

STRAIN HISTORY OF A CONSTRAINED SAMPLE OF A BURNER LINER MATERIAL

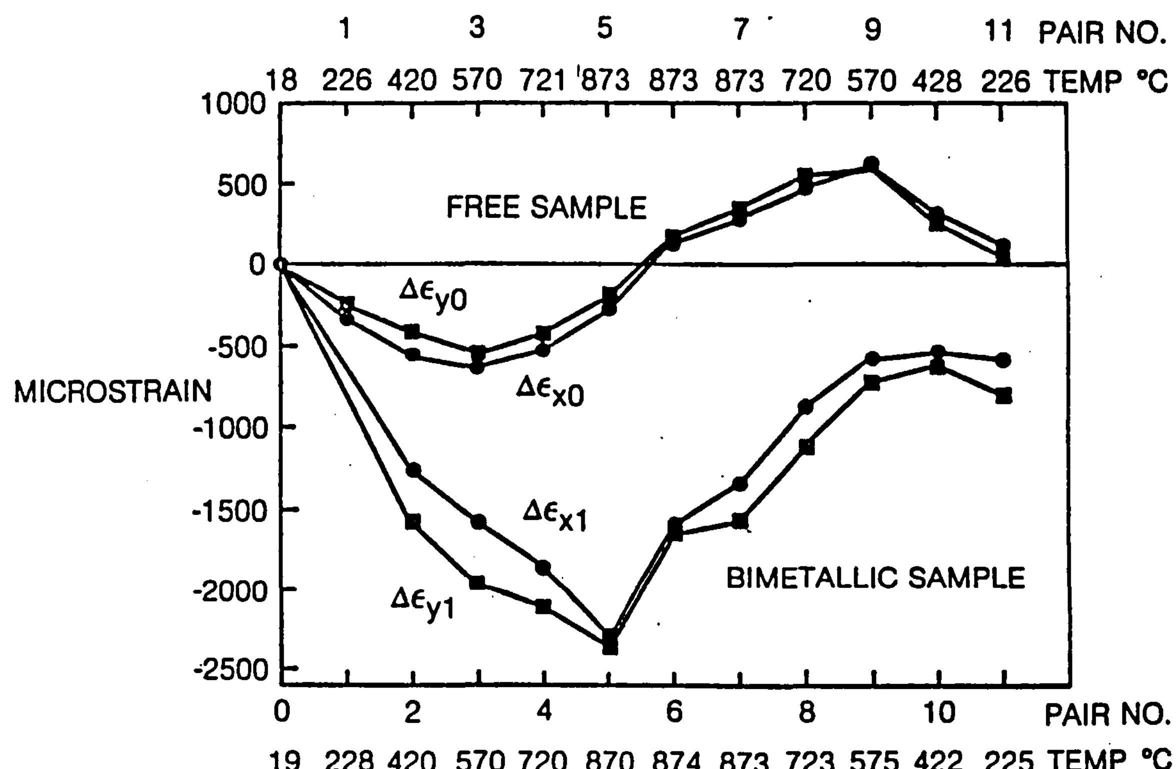

FIG. 8

MECHANICAL STRAIN OF THE CONSTRAINED AND UNCONSTRAINED SAMPLES