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TWO-DIMENSIONAL HIGH TEMPERATURE STRAIN MEASUREMENT SYSTEM

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The Instrumentation and Control Technology Division of the Lewis Research Center has developed the in-house capability to make two-dimensional optical strain measurements on high temperature test specimens. The first phase of this effort demonstrated one-dimensional strain measurement at temperatures to 450 °C, with a resolution of 18 microstrain (ref. 1). The phase II effort expands the phase I system to provide a two-dimensional strain measurement capability. This two-dimensional capability is implemented through a rotatable sensitive strain axis. Three components of surface strain can be measured automatically, from which the first and second principal strains are calculated. The phase II system demonstrated one- and two-dimensional strain measurements at temperatures beyond 750 °C with a resolution of 15 microstrain.

The system is based on the one-dimensional speckle shift technique of I. Yamaguchi (ref. 2). Some of the features of the technique include noncontact measurements, automatic cancellation of rigid body motion, no surface preparation requirement, and near-real time results. The Lewis system also features a short gauge length (<1 mm) and a programmably rotatable sensitive axis.

The speckle shift technique makes use of the linear relationship between surface strain and the differential shift of laser speckle patterns in the diffraction plane. Laser speckle is a phase effect that occurs when spatially coherent light interacts with an optically rough surface. Since speckle is generated by any diffusely reflecting surface, no specimen preparation is needed to obtain a good signal. Speckle shift is measured from a laser beam incident on a test specimen at 30° from the surface normal. By also measuring the speckle shift from a beam incident at an equal and opposite angle, potential errors due to rigid body motions are eliminated.

Figure 1 shows a schematic of the phase II optical system. An argon-ion laser beam is directed onto a test specimen at an angle. The Pockels cell and beamsplitting cube combination switches the beam from -30° to +30° by rotating the polarization of the beam. The acousto-optic modulator controls the exposure time of the line scan camera. The rotating assembly allows the plane of incidence of the beams onto the specimen to rotate, changing the sensitive axis of the instrument. A pair of 1/4-wave retardation plates maintains the polarization state of the beam going into the rotating assembly. Waist positioning lenses locate the laser beam waist at the specimen surface, improving the error cancellation of the system. It is suspected that a planar wave front at the specimen surface also stabilizes the speckle patterns in the presence of nonuniform heating. The optical pallet can be easily mounted on a multiaxis positioning table.

Figure 2 is a view of the actual test setup. The rotating assembly is shown mounted on a goniometer. The optical axis is coincident with the goniometer's axis of rotation. The test specimen is located within a thermal enclosure in order to decrease the temperature gradients near the specimen surface.

Testing was done on a flat specimen of Inconel 600 mounted in a fatigue testing machine. A load cell measured the stress on the specimen before and after acquiring the speckle data. Figure 3 shows one-dimensional strain data at room temperature. The coincidence of the data loading up and loading down demonstrates the repeatability of the instrument. Figure 4 shows a two-dimensional run at room temperature. Strain components were measured at 0° (parallel to the load axis) and at ±45°, and the plots indicate the calculated values of the first and second principal strains. The measured values of Young's modulus and Poisson's ratio are in good agreement with handbook values.

An RF induction heater was used to heat the specimen in the high-temperature runs. Good linearity of the principal strain moduli at high temperatures indicate precision and stability of the system. However, a systematic error in the high-temperature test setup introduced a scale factor in the slopes of the two-dimensional stress-strain curves. The scale factor is due to a gradual load relaxation during the retrieval of the three components of strain. The load relaxation occurred because, due to the spacing of the induction heating coils, the ends of the specimen were hotter than the test section; although the test section behaved linearly, the specimen ends were under plastic deformation. This result underscored the need for the load to be static during the system's data acquisition time of about 10 sec per two-dimensional strain point. No high temperature effects, however, have been observed to degrade speckle correlation.

Future efforts will include reading two-dimensional speckle patterns with an area array camera. This will allow the correlation peak to be maximized and will extend the range of tolerable rigid body motion. Dedicated correlation hardware will reduce the correlation times to the point that true real time measurements can be made.

REFERENCES

1. Lant, C.T.; and Qaqish, W.: Optical Strain Measurement System Development - Phase I. (Sverdrup Technology, Inc.; NASA Contract NAS3-24105) NASA CR-179619, 1987.
2. Yamaguchi, I.: A Laser-Speckle Strain Gauge. J. Phys. E. Sci. Instrum., vol. 14, no. 11, Nov. 1981, pp. 1270-1273.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

PHASE II OPTICAL DESIGN

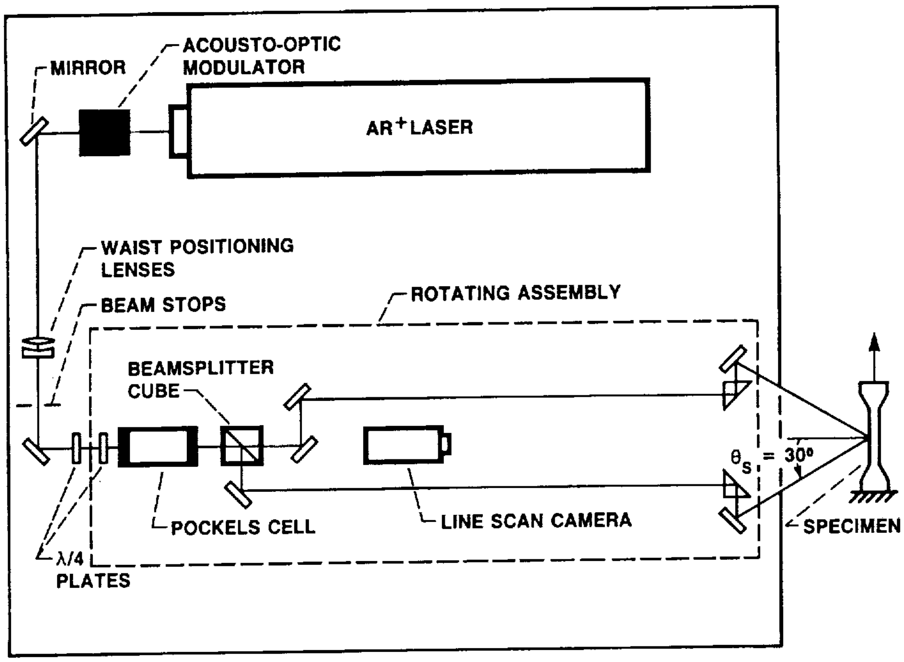

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Figure 1

PHASE II TEST SETUP

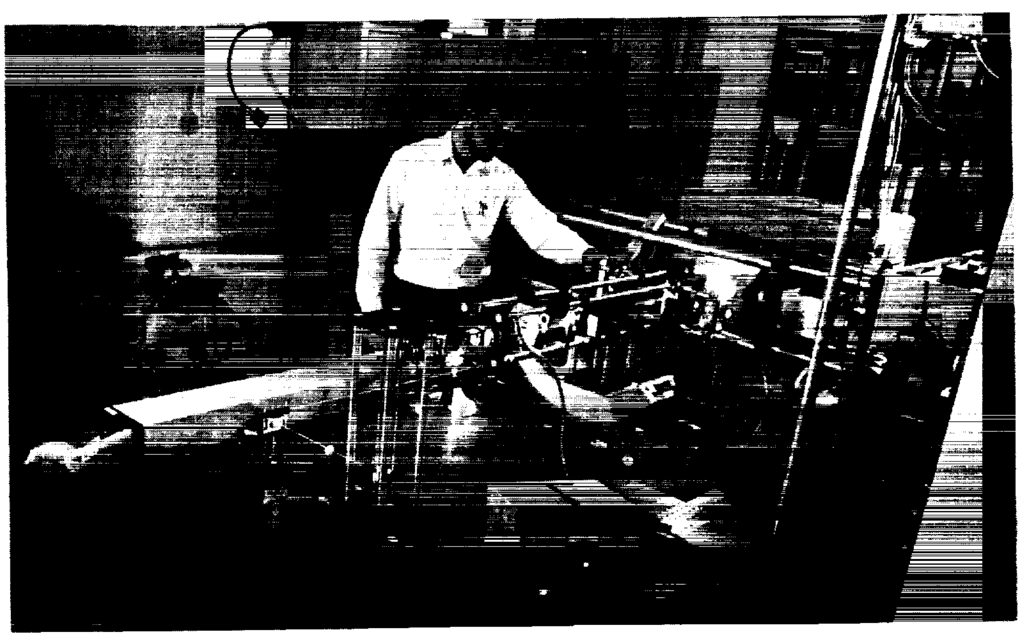

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Figure 2

ONE-DIMENSIONAL STRESS/STRAIN DATA

25 °C

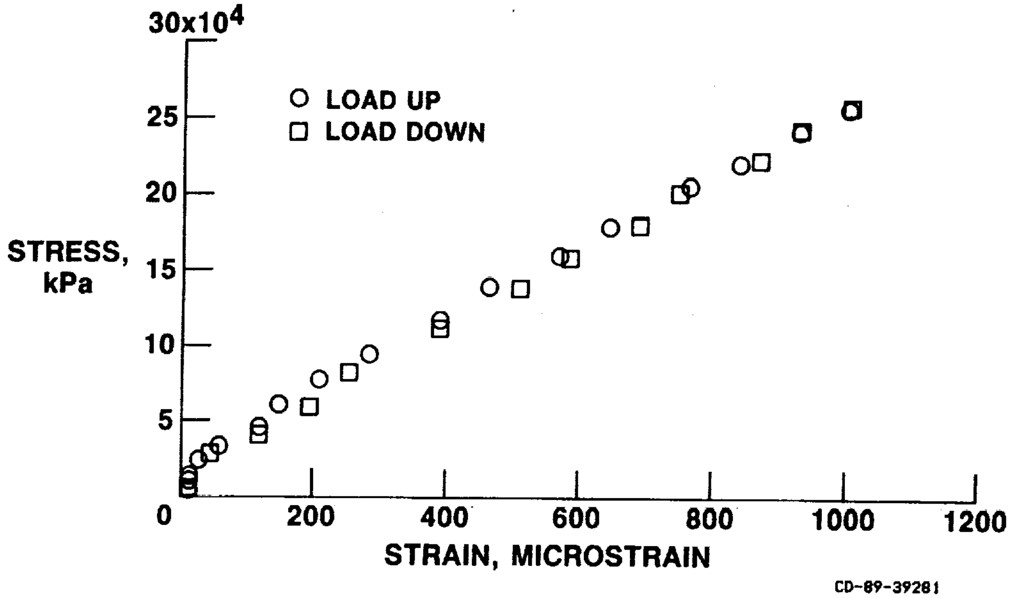

Figure 3

TWO-DIMENSIONAL STRESS/STRAIN DATA

25 °C

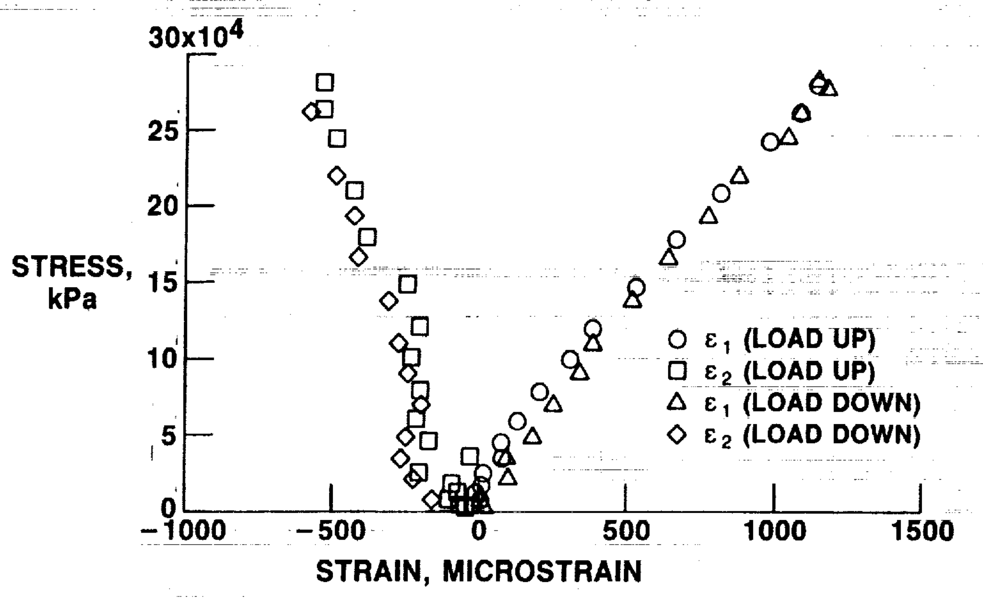

Figure 4