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PROGRESS IN OPTICAL STRAIN MEASUREMENT SYSTEM DEVELOPMENT

Christian T. Lant and Walid Qaqish
Sverdrup Technology, Inc.
Middleburg Heights, Ohio

A laser speckle strain measurement system has been built and tested for the NASA Lewis Research Center. The system is based on a speckle shift technique, which automatically corrects for error due to rigid body motion, and provides a near real time measure of strain. This paper covers the first of a multiphase effort in developing an optical strain gauge capable of mapping in two dimensions the strain on the surface of a hot specimen. The objectives of this first phase have been to provide a noncontact, one dimensional, differential strain gauge for experimental purposes, and to determine the maximum open air temperature limit of the system.

BASIC PRINCIPLES

Laser speckle is a phase effect caused by the diffuse reflection of spatially coherent light off of a rough surface. Its characteristically mottled intensity distribution is present in most laser applications. This optical strain measurement system is based on the speckle shift technique of Ichirou Yamaguchi (ref. 1), which utilizes the linear relationship between surface strain and the differential shift of speckle patterns generated by symmetrically incident laser beams. The speckle patterns created by the test specimen are interpreted as higher order interference fringes generated by a random diffraction grating, which is the naturally rough surface of the specimen. Strain induced on the specimen causes a change in spacing of the surface features, which in turn shifts the position of the interference pattern (speckles).

Theory shows that the displacement of a speckle pattern generated by a deformed specimen surface contains terms of translation, rotation, and strain, from which the strain term must be extracted. This extraction relies on the use of two symmetrically incident laser beams reflected sequentially onto a linear photodiode array. After the reference (before-strain) and shifted (after-strain) speckle patterns from each beam are correlated, taking the difference in shift between them leaves only the component due to surface strain.

The system has a gauge length of 5 millimeters given by the laser spot size, and a resolution of 16 microstrain determined by the sensor pitch of the photodiode array and the specimen-to-sensor separation. The theoretical strain measurement error is ±18 microstrain ±0.3 percent of the strain reading.

RESULTS

Uniaxial loads were applied to Inconel 600 test specimens by a testing machine. A number of data runs were performed with the system, confirming the expected response of the system as well as providing first-hand knowledge about sensitive parameters. Tests conducted during Phase I verified the stability of speckle patterns generated by an oxidized specimen subject to strains over 0.1 percent. Isothermal stress-strain plots as well as measurements of thermal strain showed good results up to temperatures of 450 °C. Stress-strain curves generated by the optical system were compared to data taken from conventional resistance strain gauges. The modulus of elasticity for each set of data was calculated using a least squares fit and compared for each run. Agreement of the optical data was typically within 3 to 10 percent of the measured or handbook values of Young's modulus.

The largest measurement error observed in the testing was due to incomplete cancellation of the out-of-plane term of rigid body motion. The resulting error in strain was caused by the radius of curvature of the laser beams. It was observed that the cause of the excessive out-of-plane motion encountered during testing was poorly machined specimen grips. However, by increasing the radius of curvature of the laser beams, the error due to out-of-plane movement and other rigid body motions can be completely cancelled.

CONCLUSIONS

The results of the test runs show a good response of the system to surface strain. The residual error due to out-of-plane movement of the test specimen can be eliminated through modifications to the optical system. Hysteresis of the optical data over a load cycle is shown to agree very well with resistance gauge data. Strain data is obtainable at temperatures up to 450 °C in the present open-air configuration. Reduction of time-varying thermal gradients near the specimen, which cause decorrelation of the speckle patterns at higher temperatures, can increase the temperature range of the system considerably.

REFERENCES

1. Yamaguchi, I: A Laser-speckle Strain Gauge. J. Phy. E., Sci. Instrum., vol. 14, no. 11, Nov. 1981, pp. 1270-1273.