A SCHLIEREN STUDY OF THERMOELASTIC STRESSES

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Serious difficulties arise in examining thermoelastic stresses by optical polarization methods [1], which arise partly from the difficulty of reproducing this state of stress in a model and also from the need to determine simultaneously the temperature distribution and the components of the stress tensor. The reason is that the optical polarization method records only the optical path difference, which is proportional to the difference of the principal stresses. These difficulties may be overcome by schlieren methods [2, 3], which record the deflection angles of beams at optical nonuniformities produced by heat in homogeneous transparent solids. It has been suggested [2, 3] that thermoelastic stresses can be determined by first establishing the relationship between the temperature gradient and the corresponding deflections of the beams by photographing shadow pictures and simultaneously making thermocouple measurements. However, the need to insert thermocouples disrupts the continuity of the solid, which results in additional errors of measurement of the order of 4-5%, especially in determining the coordinates and the temperatures, while there are various rather uncertain errors associated with distortion of the temperature distribution and the stress pattern. However, preliminary measurements can be avoided if one uses a model of an appropriate material and a minor modification to the optical system of a schlieren instrument.

In fact, the deviation angle in the direction of the x axis is [4]

$$\varepsilon_x = \frac{L}{n^*} \cdot \frac{\partial n}{\partial T}. \tag{1}$$

If a glass model is used, the refractive index is dependent on the temperature and on the thermoelastic stresses:

$$n = n(\sigma_i, T), \tag{2}$$

where

$$\sigma_i = \sigma[T(x, y, z, t)]. \tag{3}$$

The following is [5] the relation of refractive index to the principal stresses to a first approximation:

$$\begin{aligned} n_0 - n^* &= c_1\sigma_1 + c_2(\sigma_2 + \sigma_3), \\ n_e - n^* &= c_1\sigma_2 + c_2(\sigma_1 + \sigma_3). \end{aligned} \tag{4}$$

In a planar state of stress

$$\sigma_3 = 0. \tag{5}$$

From (2)-(5), we put (1) for the ordinary wave in the form

$$\varepsilon_x = \frac{L}{n^*}\left(C_1 \frac{\partial \sigma_1}{\partial T} + C_2 \frac{\partial \sigma_2}{\partial T} + \frac{\partial n_0}{\partial T}\right) \frac{\partial T}{\partial x}. \tag{6}$$

If one uses K15 optical glass as the model material, in which C_1 is less than C_2 by a factor 13.3 [6], the $C_1(\partial\sigma_1/\partial T)$ of (6) can be neglected, which results in an error of 1.67% when one uses light of wavelength 486.13 nm or 1.83% at 656.28 nm. The maximum error of the method does not exceed 4%. Figure 1 shows the system of the schlieren instrument, which enables one to use two angles in one experiment:

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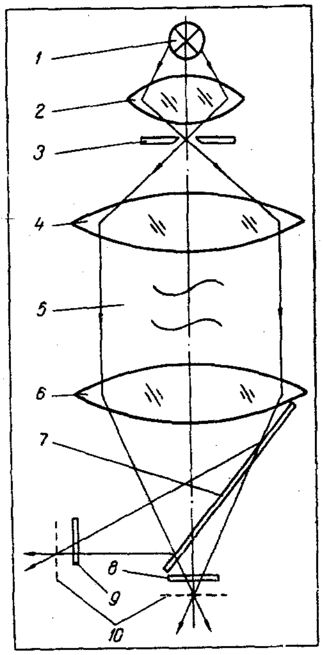

Fig. 1. Optical schlieren system: 1) light source; 2) condenser; 3) slit; 4) collimator lens; 5) optical inhomogeneity; 6) main lens; 7) beam splitter; 8 and 9) filters passing λ_1 and λ_2 respectively; 10) isolating stops.

$$\left.\begin{aligned} \varepsilon_{\lambda_1} &= \frac{L}{n^*}\left(C_2\frac{\partial\sigma_2}{\partial T} + \frac{\partial n_{0\lambda_1}}{\partial T}\right)\frac{\partial T}{\partial x} \\ \varepsilon_{\lambda_2} &= \frac{L}{n^*}\left(C_2\frac{\partial\sigma_2}{\partial T} + \frac{\partial n_{0\lambda_2}}{\partial T}\right)\frac{\partial T}{\partial x} \end{aligned}\right\}, \tag{7}$$

and these enable one to determine the distribution of the temperature gradient and hence the temperature distribution itself together with the distribution of the second principal stress.

The state of stress set up under isothermal conditions by a mechanical load is a particular case and can also be examined by the schlieren method.

NOTATION

ε_{λ_1}, ε_{λ_2}	are the deviation angles of monochromatic beams;
n_0, n_e	are the refractive indices for ordinary and extraordinary beams;
n^*	is the refractive index of undisturbed medium;
C_1, C_2	are the photoelastic constants of glass for light vibrating parallel and normal to the principal directions;
T	is the temperature;
$\partial n_{0\lambda}/\partial T$	is the temperature coefficient of relative monochromatic refractive index;
L	is the length of model;
σ_1, σ_2, σ_3	are the principal stresses;
$\partial T/\partial x$	is the temperature gradient.

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