PHOTOELASTIC METHOD FOR ANALYZING
RESIDUAL STRESSES IN COMPACT DISKS

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The issues of size and shape stability are especially important in modern high technologies, in particular, in the compact disk technology. Stability in this case is substantially affected by residual stresses that occur in disks because of the imperfection of their production process. The objective of the present study was to develop a simple optical method to estimate the stress state of compact disks.

Key words: residual stresses, relaxation, photoelasticity.

Introduction. Residual stresses have a substantial effect on the long-term serviceability of modern compact disks (CDs). Sometimes, redistribution of residual stresses is responsible for crack initiation in disks at one of the production stages or such a redistribution increases the stresses to a critical value for which even insignificant external loading results in fracture of CDs. Relaxation is one of the main reasons for residual-stress redistribution, and this process can occur without external loading or heating. Residual stress relaxation can lead to size and shape changes, and this is unacceptable in modern high technologies, in particular, in the production and use of CDs for information storage.

Modern CDs are made of polycarbonate, which exhibits a birefringence effect. This allows stresses in CDs to be estimated by a photoelastic method. A metallized coating applied to one of the CD surfaces ensures ideal conditions for recording a reflected-light interference pattern. In studies of stresses in CDs using a V-shaped reflective polariscope, the resulting equations become similar to those employed in the photoelastic coating method. The present papers discusses the results of investigation of residual stresses in CDs with various service lives produced by various manufacturers using various technologies (molding, laser recording).

1. Experimental Method. Photoelasticity is an experimental method for stress and strain analysis that is especially useful in studies of objects of complex geometry under complex loading conditions. In some cases where theoretical methods are laborious or inapplicable, an experimental analysis is preferred in studies of dimensional problems, problems of dynamic loading, residual stresses, and inelastic behavior of materials [1].

Light propagates in air at a velocity \( C = 3 \times 10^8 \) m/sec. In transparent bodies, the velocity \( V \) is lower and the ratio \( C/V \) is called the index of refraction. In homogeneous media, this index is constant and does not depend on the propagation direction or the orientation of the plane of vibrations of the electric intensity vector of the light wave. Some materials, especially plastics, are isotropic in the absence of loading but become anisotropic under loading. The variation in the index of refraction under loading is similar to the resistance variation in strain gauges [2].

When a polarized light beam with amplitude \( a \) propagates through a CD made of polycarbonate with thickness \( t \), it is separated into two polarized beams propagating in the planes \( X \) and \( Y \) coinciding with the directions of the principal stresses at the point considered (Fig. 1). If the stresses along the \( X \) and \( Y \) axes are equal to \( \sigma_1 \) and \( \sigma_2 \) and the velocity of light in these directions is \( V_x \) and \( V_y \), respectively, the relative delay \( \delta \) between these two beams is given by

\[
\delta = C(t/V_x - t/V_y) = t(n_x - n_y),
\]

where \( n \) is the refraction coefficient.
According to Brewster's law,

\[ n_x - n_y = K(\sigma_1 - \sigma_2). \]

(2)

The constant \( K \) is called the optical activity coefficient and characterizes the physical properties of a material. This constant is usually determined by calibration and is similar to the sensitivity of resistance strain gauges. From Eqs. (1) and (2), we have \( \delta = tK(\sigma_1 - \sigma_2) \) for transmission and \( \delta = 2tK(\sigma_1 - \sigma_2) \) for reflection (light passes twice through the sample).

Hence, in the photoelastic method, the main relation for stresses is given by

\[ \sigma_1 - \sigma_2 = \delta/(2tK) = N\lambda/(2tK). \]

(3)

Because of the relative delay \( \delta \), these two light waves are not cophased when they pass through a flat sample. Analyzer A allows only one component (parallel to the analyzer axis) of these two waves to pass, as shown in Fig. 1. These waves interfere, and the resultant intensity is a function of the delay \( \delta \) and the angle between the analyzer axis and the direction of the principal stresses \( \beta - \alpha \).

In the case of a flat polariscope, the light intensity \( I \) is

\[ I = a^2 \sin^2 2(\beta - \alpha) \sin^2 (\pi \delta/\lambda). \]

The light intensity is equal to zero for \( \beta - \alpha = 0 \) or when the crossed analyzer/polarizer is parallel to the principal stress direction. Thus, a flat polariscope is used to measure the principal stress direction [3].

2. Analysis of Fringe Patterns. The photoelastic method allows one to interpret fringe patterns over the entire field, to estimate nominal the stresses and gradients, and to perform quantitative measurements. In particular, it is possible to determine the principal stress directions at all points of the photoelastic model, the value and sign of tangential stresses along the free boundaries and in all regions where the stressed state is uniaxial; for plane stresses, it is possible to determine the value and sign of the difference of principal stresses at selected points of the object being studied.

The photoelastic method can used to identify overloaded and underloaded regions. Success in using the method depends only on the accuracy in determining the fringe color (isochrome) and the relation between the fringe order and the stress value [4].

Under sequential loading of a sample, isochromes first appear at the most loaded points. As the load increases, new fringes appear on the sample surface and are shifted toward the lowest stresses. The fringes can be assigned ordinal numbers (the first, second, third, etc.) in accordance with their appearance, and they retain their individual numbers with load variation. Isochromes appear sequentially, do not intersect and merge with each other, and always occupy their positions in strict order.