Rutherford Laboratory
Technical leaflet

A32

DYNAMIC STRESS ANALYSIS

Introduction

The dynamic stress in parts of the main Nimrod alternators is being studied, while the machine is rotating in normal operation, by a combination of high speed flash photography with standard photoelastic techniques. The parts under examination are travelling at speeds of over 100 mph, 3 feet from the stationary camera. A thin piece of transparent plastic is stuck to the (moving) part to be examined (e.g. the end-plate of a pole-piece) by reflecting cement. Light from a fast flash-tube passes through the plastic to the cement where it is reflected back through the plastic towards a stationary analyser. The difference in the principal strains at every point in the plastic, and therefore at corresponding points in the substrate being studied, can then be determined from photographs taken with a camera viewing through the analyser. The light flash is synchronised to the rotation of the machine using electronic equipment developed in the Laboratory so that a selected region can be examined both by cine and single frame photography.

This technique is demonstrated using two models, one 'static' and the other 'dynamic'. These are described below, together with a brief outline of the principle of the photoelastic method.

The Principle of the Photoelastic Method

Although a reflection technique was used in the present work, the principle of photoelastic analysis is most easily described by considering the more conventional method in which polarized light is passed through a transparent model of the stressed object.

The transmission method is illustrated in figure 1. Referring to the top part of the figure, light from a source is passed through a polarizer adjusted so that the beam falling on the transparent specimen is polarized in a vertical plane (see vector (1) in the top right hand diagram). The specimen is loaded, resulting in the two mutually perpendicular principal stresses σ_1 and σ_2 shown by the large arrows.

For ease of explanation, it is convenient to resolve the plane polarized light incident on the specimen into two components, one along each of the directions of principal stress. It is found that the velocities of these two components are different. (This phenomenon, called 'birefringence', occurs because the applied stresses distort the electrons surrounding each atom of the material. The electrons therefore have different 'spring constants' in different directions. Since light waves are transmitted through the specimen by causing these electrons to vibrate, light waves vibrating in different directions will pass through the specimen at different velocities). Thus the phases of the two beams emerging from the specimen are shifted with respect to one another. This shift, which is proportional to the difference between the principal stresses ($\sigma_1-\sigma_2$), is measured by means of an analyser. If a 'white' light source is used, components of different colours, having different wavelengths, will be phase-shifted to different degrees. Hence, when observed through the analyser, different regions of the specimen take up different colours according to the local values of the stresses.

If the axes of polarizer and analyser are mutually perpendicular, black regions appear on the specimen in regions where the incident polarization direction is exactly along the direction of one or other of the principal stresses. These bands are useful in analysing the directions of the stresses; however, sometimes it is convenient to remove them, and this can be done by incorporating quarter-wave plates as shown in the lower part of figure 1.

The Static Model

In the present investigation, instead of making a transparent model of the object to be tested, stresses in the object itself are measured by sticking to its surface a piece of transparent plastic using reflecting glue. Stress patterns are observed exactly as described above, except that the polarizer and analyser are on the same side of the specimen, and the light passes twice through the plastic coating. This is shown in figure 2.

On exhibition is a frame in which a load is applied to a full-sized model of one of the 'end-plates' which hold together the laminations making up the 10 ft. long pole-pieces of the Nimrod alternators. This model, together with dynamic analysis on the alternator itself, has provided information about the stresses in these important parts of the machine.

Dynamic Stress Patterns

The addition of electronic flash units and appropriate timing circuits to the static photoelastic stress measuring equipment has enabled dynamic analysis to be performed on components in the Nimrod alternator, as mentioned above.

The timing system has been designed to provide synchronised lighting for visual observation, cine or still photography. The synchronisation is independent of alternator speed and relies on signals taken from a 540 tooth wheel on the alternator shaft and a single pulse per revoltuion derived from reflecting datum also on the alternator shaft. The technique involves counting a preset number of teeth occurring after the fixed shaft position datum. A further gating circuit is used to select the mode of operation and to enable single flash pictures to be taken at any part of the machine cycle. An example of the stress patterns obtained using the equipment, is shown in the display; a block diagram of the system is also on view.

For the purpose of demonstrating these techniques, a simple model has been constructed. The arms of the model are flexed by a centrifugal load, to put the front faces in tension. These faces are covered with "Photo Stress" plastic material, in front of which is placed a polariser and a quarter-wave plate. The stress patterns are clearly visible and change as the loading is altered. Particular note should be made of the large number of fringes occurring near the hole. Each fringe corresponds to a difference between the two principal strains of 0.000887 inches per inch. At a free boundary this corresponds to approximately 3 tons per square inch for the aluminium specimen used.

Two small test strips are available, which show stress patterns when flexed by hand.

Acknowledgement

This work is being carried out with the assistance of the Photographic Group, A.E.R.E. Harwell.

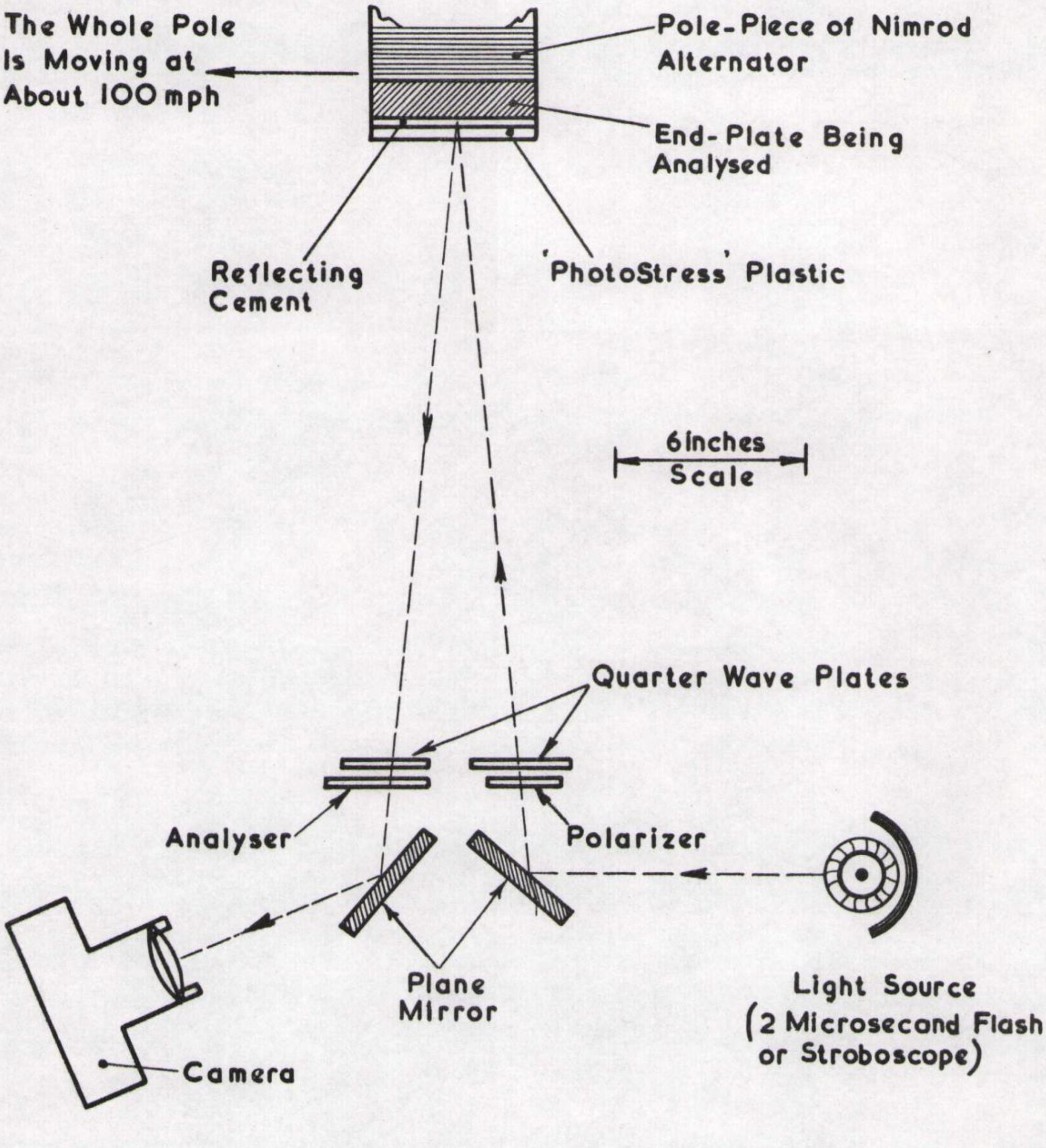
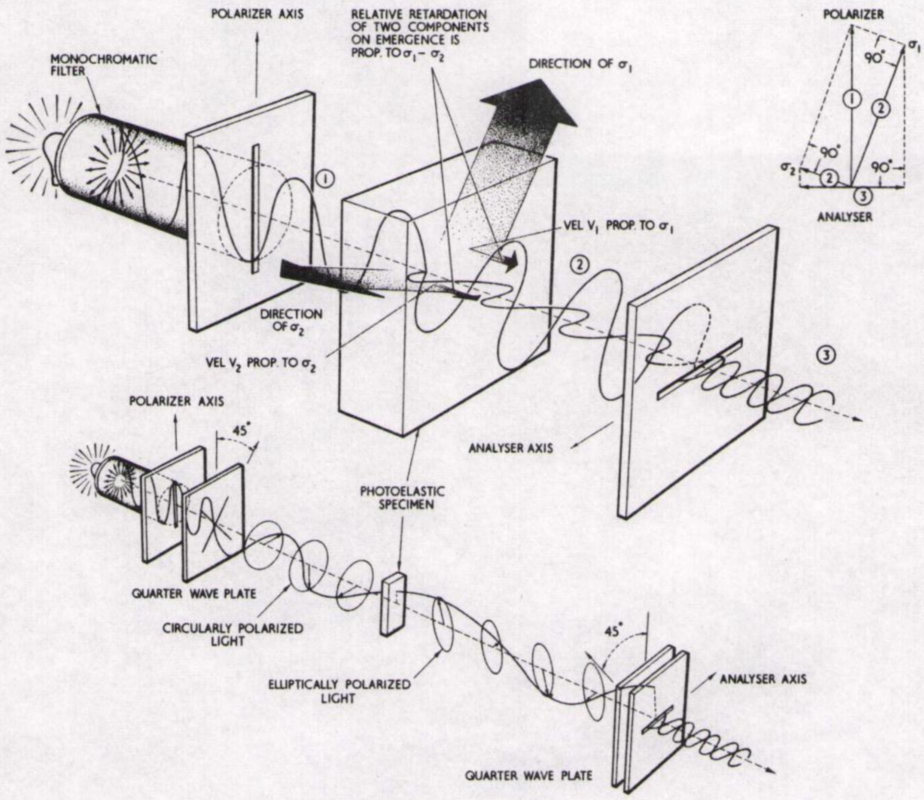


Figure 2. General arrangement of the photoelastic method used to analyse the dynamic stresses in end-plates on the main Nimrod alternators while the machines are rotating.



<u>Figure 1.</u> Principle of photoelastic stress analysis using the transmission method with a transparent specimen.
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