Optical Methods in Experimental Mechanics

Part 35: Photoelasticity VII—Basic Polariscope Setups

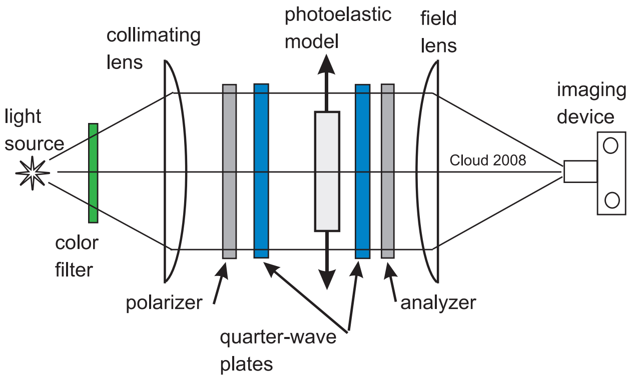
REVIEW AND PURPOSE

The previous article in this series introduced the concept of circular polarization, described one of several possible setups for the circular polariscope, and presented the equations for the amplitude of the electric vector of the light exiting the instrument. The objective is to obtain patterns containing only isochromatic fringes so that stress magnitude information may be obtained over the whole field.

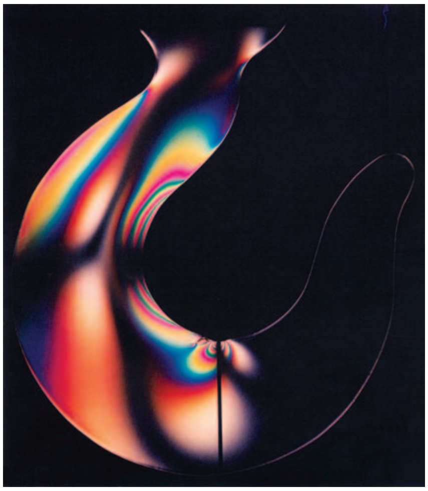
Before interpreting the equations and implementing the recording and practical utilization of isochromatic patterns, as was earlier promised for this article, it seems wise to first describe some basic polariscope setups that can be used to obtain both isoclinic and isochromatic data. A few setup details and pitfalls are offered to help the beginning practitioner to understand the setup and undertake the collection of valid data.

THE CLASSIC TRANSMISSION POLARISCOPE

The polariscope arrangement that evolved through the last few articles and was used to explain the fundamental concepts of photoelasticity is called the transmission polariscope. For the sake of completeness, the cross-sectional sketch of this instrument is reproduced below from Part 34 of this series with a few things added.



The optical components of this instrument are usually mounted on a sturdy optical bench so that their relative positions can be adjusted. Care must be taken to set the distances between the optical elements according to the rules mentioned in part 33.



Photoelastic pattern for a loaded crane hook taken with white light and showing several isochromatic orders in addition to the zero-degree isoclinic. Photo courtesy of Dr. Eann Patterson, Mechanical Engineering Department, Michigan State University.

Basic polariscope setups that can be used to obtain both isoclinic and isochromatic data are described.

The classic transmission polariscope:
- *contains, in order:*
  - *a point light source,*
  - *usually a monochromatic filter,*
  - *a collimating lens,*
  - *the polarizer,*
  - *the first quarter-wave plate,*
  - *the photoelastic model,*
  - *the second quarter-wave plate,*
  - *the analyzer,*
  - *a field lens,*
  - *an imaging system,*
- *is the version most often used for precise photoelasticity experiments,*
- *utilizes light efficiently,*
- *requires two large lenses, so tends to be expensive,*
- *requires careful setup.*

The series, Optical Methods—Back to Basics, *is written by University Distinguished Professor Gary Cloud of Michigan State University in East Lansing, MI. It began by introducing the nature and description of light and will evolve, with each issue, into topics ranging from diffraction through phase shifting interferometries. The intent is to keep the series educationally focused by coupling text with illustrative photos and diagrams that can be used by practitioners in the classroom, as well as in industry. Unless otherwise noted, the graphics in this series were created by the author.*

The series author, Professor Gary Cloud (SEM Fellow), is internationally known for his work in optical measurement methods and for his book, Optical Methods of Engineering Analysis.

If you have comments or questions about this series, please contact Jen Proulx Tingets, journals@sem1.com.

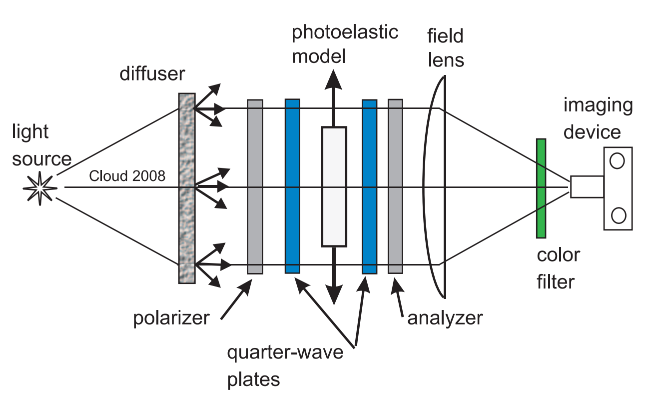
doi: 10.1111/j.1747-1567.2008.00459.x

The polarizers and quarter-wave plates should be mounted in rotating mountings that carry accurately calibrated scales to indicate angular position. Monochromatic light is usually employed with the transmission polariscope, except that white light is often needed when recording isoclinic fringes. The source is often a mercury or sodium spectral lamp. The sodium variety offers light with an overpowering spectral band centered at 589-nm wavelength, so it can be used without filtering. Mercury lamps emit several strong wavelengths, and one of them, most often the one at 546 nm, is isolated by inserting a filter in the optical path. Alternatively, an intense white-light point source, such as an arc lamp, can be employed. Narrow-band filters are then added to obtain an approximation to monochromatic light.

The transmission polariscope has the outstanding advantage of utilizing light efficiently, so it produces brilliant images having high contrast ratio even when low-power spectral light sources are used. If a dense optical filter is needed to produce highly monochromatic light, or if a pinhole is used to approximate a point source, then available light is further reduced, but this efficient setup still produces excellent fringe pattern photos. For these reasons, the transmission model with two lenses is usually chosen for in-depth photoelasticity research, and it is very flexible in its range of applications. The transmission system does have some disadvantages. First, it requires two large-diameter lenses, which should be matched. Such lenses, especially in larger sizes, tend to be expensive. The system is somewhat difficult to align in order that the full field is uniformly illuminated. These problems are especially vexing when the light source does not approximate a true point source. In this instance, a condensing lens and pinhole should be added to the system, which increase complexity.

THE DIFFUSED-LIGHT POLARISCOPE

A very useful and very common form of the polariscope is implemented by replacing the collimating lens in the transmission instrument with a diffusing plate. The layout of this type of polariscope is illustrated in the sketch below.



The diffused-light polariscope:

- is identical to the transmission instrument except that the collimating lens is replaced by a diffuser,
- can utilize a common fluorescent light fixture as the source,
- works best if the monochromatic filter is placed near the imaging system,
- is less expensive than the transmission polariscope,
- is very common and is capable of yielding good results when properly set up,
- is not efficient in its use of light,
- requires that the distance from field lens to imaging system be exactly equal to the focal length of the field lens.

The obvious advantage of this configuration is that it eliminates one of the expensive lenses. Instead, the diffuser scatters the light in all directions. Only some of the scattered light passes through the photoelastic model along the normal to the model surface. This particular column of light is collected by the field lens and converged so as to enter the aperture of the imaging system. The rest of the light is wasted. The associated disadvantage is that this system is not efficient in utilization of available light, so it is somewhat more difficult to obtain fringe photographs with high contrast ratio, and, whatever the contrast ratio, longer exposures are required than for the transmission setup.

A second singular advantage of this arrangement is that the light source can be very simple, and it need not approximate a point source. Ordinary fluorescent lamps, such as the light fixture from your kitchen, may be used. Near-monochromatic light is then obtained by installing a narrow-bandpass filter immediately in front of the imaging system. For less precise work, a large-field color filter (e.g., a Wratten filter) can be placed in front of the light source. Otherwise, intense monochromatic light such as from a high-pressure sodium lamp can be used to illuminate the diffuser. Many different combinations of lamps and filters will serve, but these will not be enumerated here.

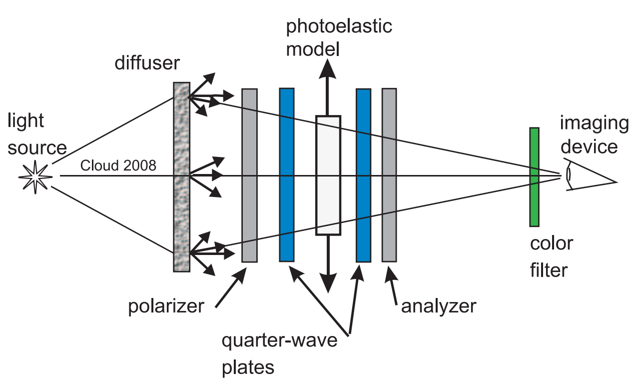
The diffuser in the diffused-light polariscope can be a piece of abraded glass or plastic, opal glass, a piece of white matte plastic, a diffuser that has been liberated from a light fixture, or even a sheet of heavy drawing vellum. Its transmittance should be low enough so that hot spots are not visible in the field. On the other hand, it should not be so dense that it absorbs too much of the available light.

In order that only the light passing through the model parallel to the optical axis of the system is utilized in forming the fringe photograph, and the light passing through the model at an inclination is rejected, the distance from the principal plane of the field lens to the aperture of the imaging system must equal the focal length of the field lens. No other lens-to-camera distance is acceptable for valid results. This rule is often violated by uninformed practitioners, and the data obtained by them must be questioned.

THE SIMPLE POLARISCOPE

A very simple polariscope is formed by removing the field lens from the diffused-light instrument, as suggested by the sketch below.

A very simple polariscope:
- *is identical to the diffused-light instrument except that the field lens is eliminated,*
- *is very economical,*
- *tends to induce errors because the incidence angle at the model varies over the field,*
- *requires that the imaging system be far removed from the model to reduce incidence angle errors,*
- *is exceptionally useful for demonstrations because fringe patterns can be seen from a range of viewing positions.*



The obvious advantage of this device is that no lenses are required. The light source and diffuser are simple and inexpensive, and they are the same as those that might be chosen for the diffused-light version. The glaring disadvantage of this instrument is that there is no way to create fringe patterns with only the light that enters the model along the normal to its surface. That is, the angle of incidence varies over the field, being maximum at its extremes. Refraction of the oblique entering waves causes the transmittance angle to differ from the incidence angle. Various errors in stress measurements are thereby introduced. This problem is reduced to some extent by limiting the field, meaning that the model must be small relative to the distance from model to imaging device. The imaging camera is located at considerable distance from the model, and a telephoto lens is used to obtain photos of acceptable size and resolution. In other words, the paraxial approximation is introduced, but it must be done with caution if reliable quantitative results are sought.

Apart from research or industrial measurement applications, this simple polariscope is exceptionally useful for qualitative demonstrations of photoelasticity to groups in the classroom or lab. The fringe patterns can be seen from a wide span of observation angles, so observers need not take turns, and the flow of fringes with added load can be observed by all in real time. In this case, the imaging system is the eye, although a video camera and monitor can be used to advantage for large groups. For some reason, however, brilliant fringe patterns are more satisfying when observed directly with no electronic devices between observer and model.

OTHER SETUPS

Many other polariscope configurations are possible and practicable, and the basic setups can be adapted to particular requirements. For example, a polariscope can be created inside a microscope so as to perform photoelastic studies of tiny objects or near a crack tip. The fundamental idea of a polariscope that is used to conduct point-by-point photoelasticity measurements was outlined in part 32 of this series. Strobe illumination allows the practitioner to obtain fringe patterns from moving specimens. A crude form of the transmission instrument can easily be set up within an overhead projector for demonstrations to classes and tourists. Reflection photoelasticity has not been mentioned yet, but it is an obvious extension of the concept. The polariscope configurations described above are, however, the most common, and they offer the broadest range of applications.

Many other polariscope configurations can be devised for particular applications, including, for example:
- *dynamic studies on moving models,*
- *microscopic photoelasticity on small specimens,*
- *point-by-point interrogation of the model,*
- *demonstrations using an overhead projector.*

WHAT IS NEXT?

Most probably, the next two articles will cover the elements of recording and interpreting isoclinic and isochromatic fringe patterns. Treatment of the fundamentals of photoelasticity will conclude with articles on the calibration of birefringent model materials and the transfer of stress results from model to prototype. ■

The next few articles will discuss:
- *recording and interpretation of isoclinic and isochromatic patterns,*
- *calibration of model materials,*
- *transfer of photoelastic results from model to prototype.*