Optical Methods in Experimental Mechanics

Part 39: Photoelasticity XI—Polariscope Calibration

REVIEW AND PURPOSE

The previous three articles in this series (Parts 36–38) dealt with the acquisition of isochromatic fringe data from a photoelastic model, the conversion of isochromatic information to stress, and the transfer of the resulting stress amplitude data from the model to the prototype.

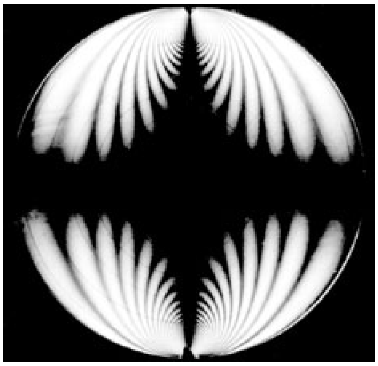
We begin at last to wind down our discussion of photoelasticity by learning how stress directions are obtained from the model through the use of isoclinic fringes. Accuracy of the isoclinic data, as well as of some of the isochromatic data, depends on the care taken to calibrate your polariscope. This brief article extends the discussion of Part 35, which dealt with polariscope setups, and describes a quite simple approach to properly align the axes of the polarizers and quarter-wave plates. Explanatory commentary is added along the way, we hope to a tolerable degree, so that the reasons for each step are understood.

THE NEED FOR CALIBRATION

Experimentalists of superior breeding will always have in mind the following axiom: *No data can be better than the calibration of the instrument used to acquire that data*.

Unfortunately, it is all too easy and too common to purchase an instrument (e.g. a thermometer, a testing machine, or a modal analysis system) and put it to use gathering experimental data without first calibrating it or, at the least, checking the calibration data provided by the purveyor. That we get away with this practice so often reflects credit onto the manufacturer of the apparatus; but the habit is fraught with risk, especially when dealing with instrumentation that is advanced in age or that has been moved or used by someone else. Many high-class research and manufacturing organizations require regular documented recalibration of measurement devices, especially in fields where safety is an issue.

The calibration requirement applies to optical devices such as the photoelastic polariscope. Polarizing materials are sold with a label that identifies the polarizing axis. Likewise quarter-wave ($\lambda/4$) retarder stock usually has the "fast" or "slow" axis marked, but sometimes there is no indication which is which. In either case, experience shows that the markers provided are sometimes not quite correct. When purchased in large sheets, the axes of the materials might even vary over the extent of the sheet. Further, when pieces are cut from the sheets so as to fit them into set of polariscope mounting rings, the polarization or quarter-wave axis markers are usually lost. There is no way to correctly identify the important axes through simple visual inspection. If a prefabricated polariscope is purchased, then it should be recalibrated at delivery and periodically after that in order to assure the accuracy of acquired data.



Photoelastic fringe pattern for a disc in diametral compression obtained with a dark-field linear polariscope. This specimen is the same as the one shown in Part 32 of this series, but the gamma of the image has been boosted to emphasize and narrow the zero-degree isoclinic so that it can be used for polariscope calibration. The feather-like structures are residues of the isochromatic fringes, and they assist in detecting asymmetry of the isoclinic. Original photo by Dr. Gary Cloud, ca. 1964.

A simple approach to properly align the axes of the polarizers and quarter-wave plates in a polariscope is described. This calibration is required before accurate photoelastic data can be obtained.

No data can be better than the calibration of the instrument used to acquire that data.

- *This axiom applies to all measurement apparatus, including optical devices.*
- *It is not wise to trust the calibration provided by others.*

The series, Optical Methods—Back to Basics, *is written by University Distinguished Professor Gary Cloud of Michigan State University in East Lansing, Michigan. 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 Tingets, journals@sem1.com.

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POLARISCOPE CALIBRATION PROCEDURE

The process of calibrating an ordinary transmission polariscope is outlined below. Some exceptions and modifications of the procedure might be appropriate, depending on the actual hardware at hand. Take heart; the calibration procedure takes longer to describe than to perform.

We assume that the polarizers and quarter-wave plates can be mounted loosely in holders or rings that allow them to be independently rotated and then clamped into place once their axes are established. Further, the holders are assumed to rest in mounts that allow the elements to be independently rotated by known angular increments after calibration. These mounts are attached to the polariscope chassis, often via platforms that slide on the ways of an optical bench. The optical bench is assumed to be level with respect to earth. Beyond these assumptions, we start from scratch with no prior knowledge of the orientations of the principal axes of the optical elements.

1. Fabricate or obtain a calibration specimen. The idea is to use a model that will show a well-defined known isoclinic fringe that is sensitive to misalignment of the polarizers. This goal can be attained by producing the zero-degree isoclinic in a model having an axis of symmetry for both geometry and loading. A disc of model material is easy to make and works well as a specimen for calibrating polariscope elements. Diametral lines can be scratched on the disc surface to assist in alignment.
2. Set the empty holders to zero rotation angle in their mountings.
3. Establish approximately the polarization axis of the polarizer. An easy way to do this is to treat it as a sunglass. Look through it at light, maybe sunlight, that is reflected from a roadway or a body of water. That light will be somewhat horizontally polarized. Rotate the polarizer to produce minimum intensity of the reflected light. The polarizing axis will then be close to vertical. Mark it with a piece of tape and mount it loosely in its holder with its axis maintained as close to vertical as you can manage.
4. Repeat step 2 with the analyzer, but mount it so its polarization axis is horizontal.
5. Tweak the polarizers in their holders so as to produce minimum intensity of the transmitted light. This step assures that the polarization axes are crossed. The human eye is very good at detecting this maximum darkness if working in a darkened room, but a photometric device can be used to advantage. If a light meter is used, then the accuracy of the minimum light setting can be improved by averaging the settings at which a given intensity is produced on either side of the minimum. In any case, the polarizer and analyzer are now crossed, but their axes are probably not absolutely vertical and horizontal with respect to global coordinates.
6. Mount the calibration specimen in the load frame of the polariscope and apply sufficient load to produce the desired isoclinic fringe. Arrange the disc so it is loaded in exact diametral compression and use a plumbline to assure that the loading is along the vertical.
7. Establish the directions of the transmission axes of the polarizer and analyzer with respect to earth. Rotate the polarizer and analyzer together within their respective holders, keeping their axes crossed, until the isoclinic appears along the appropriate axes of the model. For a disc, it will look something like a Celtic cross, an example of which appears in the photograph above. The transmission axes of the crossed polarizer and analyzer are thus known to be lined up parallel and perpendicular to the principal stress axes on the horizontal and vertical model axes. Symmetry requires that the principal stresses on these axes be parallel and perpendicular to these axes, so this procedure aligns the transmission axes of the polarizer and analyzer with respect to the specimen. Because the specimen load axis was set to vertical, the polarization axes now match global horizontal and vertical. Carefully clamp the polarizer and analyzer in their respective holders. At this point, you have a properly calibrated linear polariscope of the sort described in Parts 31-33 of this series.
8. Locate the directions of the transmission axes in the first quarter-wave plate by placing it between the polarizer and the model. Rotate it within its

Assume that:

- *the polarizers and quarter-wave plates can be mounted loosely in holders that allow them to be rotated during calibration and then clamped,*
- *the holders rest in mounts so that they can be independently rotated through known increments,*
- *the mounts are attached to the polariscope chassis, likely using platforms that slide along an optical bench,*
- *the optical bench is level.*

Calibration steps are summarized as follows:

- *Make or obtain a calibration specimen.*
  - *This specimen must show a well-defined known isoclinic that is sensitive to misalignment of the polarizers.*
  - *A disc in exact diametral compression is commonly used.*
- *Set the holders to zero rotation angle in their mountings.*
- *Establish approximately the polarization axis of the polarizer by creating extinction of obliquely reflected light. Mark this axis and mount the polarizer loosely in its holder with its axis vertical.*
- *Repeat the above step for the analyzer, but mount it so its axis is horizontal.*
- *Get the axes of polarizer or analyzer crossed by rotating one relative to the other to create minimum intensity of the transmitted light.*
- *Mount the calibration specimen in the load frame and apply load.*
  - *A plumb line assures that the load is along the vertical diameter.*
- *Rotate the crossed polarizer and analyzer together to create the zero-order isoclinic in the specimen image.*
  - *For a disc, the isoclinic will be a cross.*
  - *This step fixes the polarization axes relative to earth.*

holder until maximum extinction is observed and the zero-degree isoclinic is restored in the model. In this position, the principal axes of the wave plate are lined up with the transmission axes of the polarizer and analyzer. Clamp the wave plate into its holder. The procedure does not tell us which is the fast principal axis of the $\lambda/4$ plate. This deficiency does not matter for the purpose of setting up the polariscope, because there is a simple means of telling when the fast axes of the two $\lambda/4$ plates are crossed, and that is all we need to know.

9. Remove the first $\lambda/4$ plate from the system. Actually, it need not be removed, but it is a good idea to do so for various reasons. Place the second $\lambda/4$ plate between the specimen and the analyzer and repeat step 8.
10. Now put the first $\lambda/4$ wave plate back into the polariscope and check to see that the symmetrical isoclinic in the calibration specimen is reproduced. If the background intensity is minimum and the isoclinic is correct, then the calibration is finished and the fast axes of the quarter-wave plates are properly crossed. If the background is light, then the fast axes are parallel. To correct, simply rotate one of the quarter-wave plates by 90° before clamping it into its holder.
11. At this stage, the device is properly calibrated and aligned to operate as a linear dark field polariscope. The $\lambda/4$ plates are within the instrument, but, since their axes are aligned with the axes of polarizer and analyzer, they are not serving any function except to reduce overall light intensity and diminish contrast. For observation of isoclinics and maybe even isochromatics with the linear polariscope, it is best but not mandatory to remove the wave plates entirely from the system, meaning that they should be mounted separately from the polarizers.
12. To convert to the linear light-field arrangement, simply rotate the polarizer or the analyzer by 90°.
13. Now, to convert the linear dark-field polariscope to the circular dark-field configuration, the transmission axes of the $\lambda/4$ plates must be arranged so that they are at 45° to the axes of the polarizer and analyze but with their fast axes still crossed. To reach this state, simply start with the linear arrangement arrived at in the previous steps, and rotate both $\lambda/4$ plates in the same direction 45°. Either clockwise or counterclockwise is fine.
14. If one wishes to change from dark-field circular to light-field circular, rotate either the polarizer or the analyzer through 90°. This procedure places the polarizers parallel, with the two $\lambda/4$ plates still being crossed. Recall that, in the dark-field arrangement, the whole-order isochromatic fringes will be dark. With the light-field arrangement, it is the half-order isochromatic fringes which appear dark, and they will fall between the fringes observed with dark field. Good practice is to obtain data from both the light-field and dark-field arrangements.

- *Clamp the polarizer and analyzer in their respective holders.*
  - *At this point, the device is calibrated and set up in the linear dark-field configuration.*
- *Place the first quarter-wave plate between polarizer and model and adjust it to regain the zero-degree isoclinic, then clamp it in its holder.*
  - *The quarter-wave plate axes are now aligned with the axes of polarizer and analyzer.*
  - *Remove this plate from the system.*
- *Place the second quarter-wave retarder between model and analyzer, and repeat the step above to align it.*
- *Put the first quarter-wave plate back into the system and check the isoclinic with both wave plates in place.*
- *If the background has become light instead of dark, rotate one of the quarter-wave plates in its holder by 90° in either direction, then reclamp it.*
- *At this point, the polariscope is calibrated, the axes of all four optical components are properly aligned, and the quarter-wave plate fast axes are crossed.*

The setup is now in the dark-field linear configuration, even with the quarter-wave plates in the optical path. For isoclinic studies, it is better to remove the quarter-wave plates.

To create the linear light-field system from the linear dark-field configuration, rotate the polarizer or analyzer by 90°.

To convert the linear dark-field polariscope to circular dark field, rotate both quarter-wave plates by 45° in the same direction.

To change from dark-field circular to light-field circular, rotate either the polarizer or analyzer through 90°.

SOME DETAILS AND TIPS

Polarizing material containing a linear polarizer permanently laminated with a $\lambda/4$ plate already oriented at 45° to the polarizer axis is often used for setting up simple polariscopes. If incident light strikes the $\lambda/4$ side first, it will exit the other side as linearly polarized. If the light passes first through the linear polarizer, then the transmitted light is circularly polarized. For calibration and for subsequent use as a linear polariscope, set up these plates with the linear polarizer sides facing the model. When you are ready to convert to a circular polariscope, simply turn each plate around so that the $\lambda/4$ plates face the model. Alternatively, just swap the one for the other. While very convenient, these combined plates do not allow the options available when separate plates are used. Pieces of this material are, however, valuable as teaching aids. Each student can carry his/her own little polariscope in a pocket or purse.

The reason that the disc in diametral compression serves so well for polariscope calibration is that the symmetry of the zero-degree isoclinic is very sensitive to misorientation of the crossed polarizers, and the human visual system is very sensitive to asymmetry in a pattern. To convince yourself of this fact, rotate the crossed polarizer and analyzer by only a half-degree or so and examine the resulting isoclinic fringe.

To make the zero-degree isoclinic as narrow as possible, use a reasonably large load and the highest available level of light from the light source. White light will cause most of the isochromatics to wash out. If using a digital camera or a video imaging system, try a nonlinear response curve or just overexpose to near saturation of the image.

Study of the photoelasticity equations (see Parts 31 and 34 of this series) indicates that several alternative arrangements of optical elements in the circular polariscope are viable. The best setups are those that keep the axes of the quarter-wave plates crossed. The "fast" axis of one must coincide with the "slow" axis of the other. The reason is that it is difficult to make perfect retarder plates, but it is simple to make them in pairs which have similar errors; all you need do is cut the pair from the same sheet. The "error" in a $\lambda/4$ plate is the amount by which the relative retardation deviates from exactly one-quarter of the wavelength. If the plates are used in matched pairs and their axes are kept crossed, then errors in isochromatic data will be minimized. In practice, it is not necessary to know which are the fast and slow axes of each of the quarter-wave plates. The orientations of their axes and the crossed configuration are easily established during the polariscope calibration with the disc as discussed above.

Some of the concepts applied in calibrating a polariscope are useful in setting up other optical systems that involve polarizers and retarders. For example, light from a laser is usually polarized, and polarization correction is often necessary in systems for holographic interferometry and digital speckle interferometry, to name two.

Additional useful comments:

- *Sheets that combine a polarizer and a quarter-wave plate are available and are useful for simple polariscopes.*
- *The zero-degree isoclinic in a disc is very sensitive to misorientation of the crossed polarizers, hence its usefulness as a calibration specimen.*
- *Use a reasonably large load and intense light to narrow the isoclinic.*
- *White light illumination will wash out distracting high-order isochromatics.*
- *Nonlinear processing of the image can help sharpen the isoclinic.*
- *Several alternative setups are possible.*
- *Errors are reduced if the fast axes of the quarter-wave plates are kept crossed.*

WHAT IS NEXT?

With the polariscope properly set up, isoclinic fringes can finally be recorded and their interpretation explored. ■

The polariscope is now properly set up, so the next article can proceed with the recording of isoclinic fringe patterns.