Optical Methods in Experimental Mechanics

Part 40: Photoelasticity XII—Recording Isoclinic Fringes

REVIEW AND PURPOSE

With our polariscope properly aligned and calibrated, we are now positioned to determine principal stress directions in the photoelasticity model through recording and interpretation of the isoclinic fringes.

This article first reviews the basic characteristics of isoclinic fringes, and some of the various uses of isoclinic fringe data are mentioned. Then, described in turn are methods of acquiring the stress direction data that are needed to satisfy various application requirements.

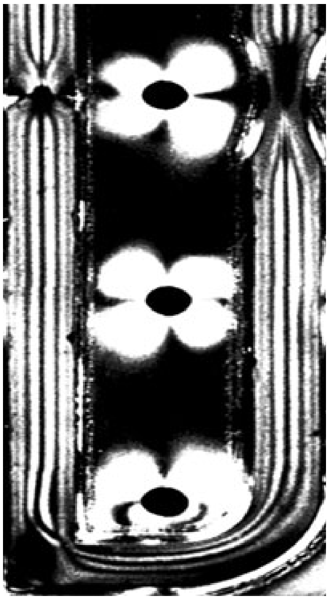
BASIC CHARACTERISTICS OF ISOCLINIC FRINGES

As our analysis of the phenomenon of photoelasticity showed (see Parts 31-33 of this series) an image of the loaded model taken with a so-called dark-field linear polariscope contains a dark fringe that extends through all points where the principal stress axes line up with the crossed axes of the polarizer and analyzer. This fringe is called an isoclinic. So, if the orientations of the polarizers are known, then the inclinations of the principal stress axes are established along that one fringe, and *only that one fringe*. Stress magnitudes throughout the model can be obtained from only one or two isochromatic fringe patterns, but the photoelastician cannot obtain a whole-field map of principal stress directions at a single go; some extra labor is required to obtain the entire family of isoclinics.

SOME APPLICATIONS FOR ISOCLINIC FRINGE DATA

Stress direction data, as obtained from isoclinic fringes, serve several different functions depending on experiment design and objectives. Some of the reasons for acquiring isoclinic fringe information include:

- discovering the best orientations for strain gages at critical stress points,
- measuring precise isochromatic fringe orders at particular points using techniques of goniometric compensation (analyzer rotation) or physical devices such as the Babinet compensator,
- obtaining separate principal stresses σ_1 and σ_2 by oblique incidence or shear difference methods,
- comparing experimental observations with finite-element analyses or elasticity solutions,
- visualizing the entire stress field for design improvement, particularly where singular points might be an issue.



Detail from a photoelastic study of fluid flow through a channel containing various types of orifices and bends. The fluid is a solution of milling yellow dye. The isochromatics, which represent velocity gradient, were photographed in white light. The higher-order colored fringes near the channel wall are barely visible in this reduction, and fringe details in the orifice and corner regions are also lost. The flower-like artifacts show the stressed regions surrounding the screws that bind together the plastic parts of the assembly. Original 8 × 10 photo by Dr. Gary Cloud, ca. 1965, digitally scanned.

This article:

- *reviews the basic characteristics of isoclinic fringes,*
- *mentions some various uses of isoclinic fringe data,*
- *describes in turn methods of acquiring the stress direction data that are needed to satisfy various application requirements,*
- *presents some advanced tips and techniques.*

An isoclinic fringe provides the inclination of the principal stress axes along only that one fringe. A family of isoclinics is needed to visualize the stress directions over the entire extent of the model.

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.

doi: 10.1111/j.1747-1567.2010.00628.x

OBTAINING PRINCIPAL DIRECTIONS AT A SINGLE POINT

Often, as when deciding how best to orient a strain gage rosette or obtaining fractional fringe order, stress directions are needed for only one or a few specific points in the model. In that case, all one needs to do is rotate the polarizer and analyzer, keeping their axes crossed, of course, until the isoclinic covers the point in question. The stress directions for that point are then read directly off the calibrated mounting rings of the polarizer and analyzer (see Part 39).

DETERMINING AREAS WHICH HAVE A PARTICULAR PRINCIPAL DIRECTION

In some experiments, the locus of points having a particular inclination of principal axes is needed. To do this, set the polarizer and analyzer mounting rings at that particular rotation angle and record the path of the corresponding isoclinic fringe using one of the methods described below for whole-field mapping.

WHOLE-FIELD MAPPING OF PRINCIPAL DIRECTIONS

Characterization of the entire stress field requires mapping the principal directions over the full extent of the model. This process requires the recording of a complete family of isoclinics for incremental rotational settings of the polarizer and analyzer. The result is called an isoclinic pattern.

Various methods can be implemented for acquiring the complete isoclinic fringe pattern in a photoelastic model.

Although it seems at first glance to be rather crude, imprecise, and old-fashioned, one of the easiest, quickest, and best techniques is to simply trace the isoclinics by hand for successive angular rotations of the crossed polarizer and analyzer. Detailed steps to execute this straightforward method are given below along with a sample student result and comments about precision. Some alternative techniques are then presented.

1. Set up the linear dark-field polariscope in a darkened laboratory with the polarizer mounting rings set to 0° rotation as established through the polariscope calibration procedure.
2. Put the model in place and in known alignment with the previously determined axes of the polarizers.
3. Use a large-format view camera in the polariscope to focus an image of the model on the ground glass camera back.
4. Tape a sheet of tracing vellum or clear acetate to the ground glass.
5. Place enough load on the model to clearly establish the isoclinics in the image.
6. Use a marking pen to trace the outline of the specimen, the load points and load direction.
7. Trace the centerline of the observed isoclinic and label it as the 0° isoclinic.
8. Indicate clearly on the drawing the direction in which the polarizers are to be rotated in order to create successive isoclinics. Clockwise or counterclockwise makes no difference, but you must record the choice and stick to it.
9. Rotate the crossed polarizer and analyzer by a certain increment, say 10° in the direction chosen.
10. Trace the centerline of the new isoclinc and label it appropriately.
11. Repeat step 10 until 90° rotation is attained, at which point the isoclinic should be the same as the one recorded in step 7.
12. Switch on the lab lighting and examine your tracing to be sure you have not skipped an increment or wobbled too much in your tracing. It is easy to go back and correct mistakes at this stage.

Reasons for acquiring isoclinic fringe data include:

- *discovering the best orientations for strain gages,*
- *measuring precise isochromatic fringe orders at particular points by compensation methods,*
- *obtaining separate principal stresses σ_1 and σ_2 by various techniques,*
- *comparing experimental observations with numeric or analytic solutions,*
- *visualizing the entire stress field for design improvement.*

To obtain principal directions at a particular point in the model:

- *rotate polarizer and analyzer until the isoclinic covers the point of interest,*
- *read the inclination of the stress axes off the calibrated mounting rings containing the polarizers.*

To obtain the locus of points in the model having known orientations of principal axes,

- *Set the polarizer and analyzer to that angular orientation,*
- *record, as by tracing, the complete isoclinic.*

The complete family of isoclinic fringes is called an isoclinic pattern.

Creating the isoclinic pattern requires recording each isoclinic for several incremental rotations of the polarizers. Various techniques can be implemented to accomplish this task.

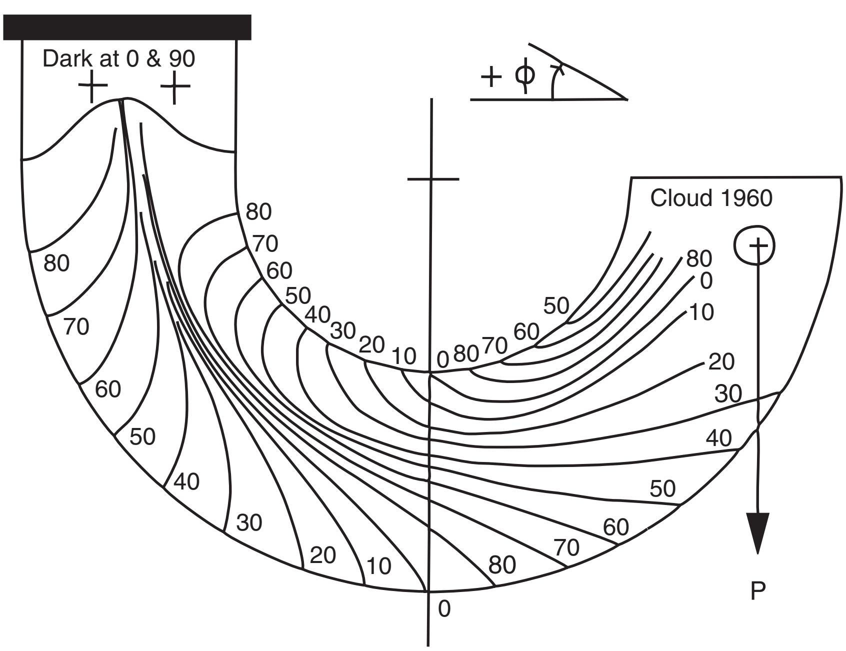
A simple and effective technique is to simply trace the isoclinics by hand. Detailed steps to accomplish the task are:

- *Set up the linear dark-field polariscope in a darkened laboratory with the polarizer mounting rings set to 0° rotation.*
- *Put the model in place and in known alignment with the previously determined axes of the polarizers.*

13. Remove the tracing from the ground glass and transfer it to a drafting table or lab bench. Use another sheet of tracing medium as an overlay and get busy with basic drawing equipment to manufacture a tidy version.

Because the procedure outlined above is performed in the dark and because you are finding and tracing the center of a black blob in the dark, it will seem difficult at first, and the tracing might appear rather shaky. Is the result any good at all? The human visual system, as has been pointed out several times in this series, is amazingly dependable in locating the center of a hazy black blob, and our highly developed hand-eye coordination gives us the ability to spear that center with considerable precision. These innate skills are as useful in the laboratory as they are in the bush. While a given traced isoclinic might appear to wander locally, it will be sufficiently accurate when smoothed up. An interesting sidelight on this topic is that the author, many years ago, gathered in nontechnical people and invited them to trace or locate with a digitizing tablet the centers of fringes in photoelastic, moiré, and speckle interferometry fringe patterns. The consistency demonstrated proved to be quite amazing. There were no attempts to quantify accuracy, but the grouping was good.

The figure below shows an isoclinic pattern obtained by the methods outlined above for the loaded bracket used as an example in Part 37 of this series. This result was recorded by the author while a student in his first course in experimental mechanics, taught by Prof. Clyde Work at Michigan Tech in Spring 1959. The original drawing was scanned into a computer and then traced and smoothed for this publication using CorelDRAW X4®. A few minor glitches can be discovered in this pattern, but, as the saying goes, "It is close enough for an engineer, or at least for a young one."



ALTERNATIVE TECHNIQUES AND A FEW TIPS

In case the low-tech implementation outlined above is not satisfying in today's world, some alternatives might be attractive, including the following, which are arranged somewhat in order of increasing complexity:

- Remove the field lens and place the analyzer close to the model. With a modicum of dexterity, you can reach around the analyzer and trace the isoclinics directly onto the surface of the model.

- *Use a large-format view camera to focus an image of the model on the ground glass camera back.*
- *Tape a sheet of tracing medium to the ground glass.*
- *Place enough load on the model to clearly establish the isoclinics in the image.*
- *Use a marking pen to trace the outline of the specimen, the load points, and load direction.*
- *Trace the centerline of the observed isoclinic and label it as the 0° isoclinic.*
- *Indicate clearly on the drawing the direction in which the polarizers are to be rotated in order to create successive isoclinics.*
- *Rotate the crossed polarizer and analyzer by a certain increment, say 10° in the direction chosen.*
- *Trace the centerline of the new isoclinc and label it appropriately.*
- *Repeat the above step until 90° rotation is reached and the isoclinics start to repeat.*
- *Switch on the lab lighting and examine your tracing. Fix mistakes as necessary.*
- *Remove the tracing from the ground glass and transfer it to a table. Use another sheet of tracing medium as an overlay and manufacture a tidy version with drawing equipment.*

Tracing the center of a dark blob in the dark will seem difficult and imprecise. But, the human eye coupled with our highly developed hand-eye coordination assures a good result when local wobbles in the tracings are averaged out.

- Reflect the image from a mirror inclined at 45° to the optical axis of the polariscope so as to focus the image onto a horizontal ground glass and thereby facilitate making a tracing.
- If the available polariscope light source is bright enough, an ordinary lens can be used to focus the image onto a large tablet supported vertically in an easel, thereby eliminating the need for a large view camera.
- Instead of using a view camera, which might not be available in a so-called modern lab, install a monochrome video camera into the polariscope and couple it directly to a monitor. A piece of acetate film is then taped directly to the monitor screen and the successive isoclinics traced with a marker. An advantage is that the brightness can be adjusted to give the narrowest and sharpest definition of the isoclinic fringes. The main disadvantage is that the tracing surface is well forward of the image plane, so parallax will cause the image to shift with respect to the tracing as the eye is moved. To minimize this problem, maintain the eye in the position that keeps the image coincident with the traced specimen boundary.
- Scan the traced image into a computer and use the tracing function in good graphics software to "trace the tracing." The software should allow the adjustment of sensitivity, smoothing, corner rendition, and centerline functions, so no manual labor is needed to obtain a pretty result.
- Use a video camera, a computer, and a digital projector to create a large image on white posterboard tacked to the wall or a drawing easel. The isoclinic tracing will be easy to make with a coarse marker because it is large in size and the ambient lighting can be at high level. When the large tracing is photographed or otherwise shrunk to normal size, the wobbles in the tracing will seem to vanish.
- Connect the video camera to a computerized digital image capture system. Record the successive isoclinic fringes separately and narrow them down or trace their centers using the imaging software. Then combine them into one comprehensive pattern. A potential problem is that, without numerical filtering and such, the digital system might not correctly locate fringe centers. Software to overcome this difficulty is available.
- Direct analog photography with film, including multiple exposures of the succession of isoclinics, does not seem to work very well without nonlinear processing.
- Often it is difficult to distinguish isoclinics from isochromatics, especially in complex geometries (see the lead photo in Part 35). For this reason, white light is often used for observation of isoclinics so that all but the isoclinic and the zero-order isochromatic will be rendered in colors. Additional improvement is achieved by making a model for the isoclinic study from a plastic, such as Plexiglas®, that has limited stress-birefringence, thereby keeping the isochromatic orders low at the loads required to give good rendition of the isoclinics. Also remember that when you change the load a little bit, most of the isochromatics move while the isoclinic remains static.

More advanced techniques and useful tips to generate isoclinic patterns include, in increasing order of sophistication:

- *Place the analyzer close to the model and trace the isoclinics directly on the model surface.*
- *Reflect the image from a mirror onto a horizontal ground glass or tablet to facilitate tracing.*
- *Use an ordinary lens to focus the image onto a large tablet.*
- *Install a video camera into the polariscope and couple it directly to a monitor. Tracing medium is then taped directly to the monitor screen and the successive isoclinics traced with a marker.*
- *Scan the traced image into a computer and use the tracing function in graphics software to "trace the tracing" and smooth it.*
- *Use a video camera, a computer, and a digital projector to create a large image on posterboard, trace it with a coarse marker, then reduce the picture.*
- *Employ a video camera with a computerized digital image capture system to record the successive isoclinic fringes separately and then combine them into one comprehensive pattern.*
- *Direct analog photography, including multiple exposures of the succession of isoclinics does not seem to work very well without nonlinear processing.*
- *Use white light for observation of isoclinics. Make a model for the isoclinic study from a plastic that has limited stress-birefringence to keep the isochromatic orders low.*

WHAT IS NEXT?

Visualization of the principal stress directions over the entire field from the isoclinic fringe pattern is not easy for most of us. The next article, the penultimate one in this series on photoelasticity, will describe how to convert the isoclinic pattern into stress trajectories that are easily comprehended. ■

The next article will describe how to convert the isoclinic pattern into stress trajectories that facilitate visualization of the stress field.