OPTICAL METHODS Back to Basics *by Gary Cloud*

Optical Methods in Experimental Mechanics

Part 5—A Classic Interferometry: Newton's Rings

REVIEW AND PURPOSE

Part 4 treated oblique interference of two beams and ended with a description of Lloyd's mirror, which is an easy way to demonstrate this type of interference.

In this segment, a classic interferometric experiment is described. It is a valuable instructional paradigm. It is also of fundamental importance in several measurement techniques, so it should be thoroughly studied.

Newton's fringes

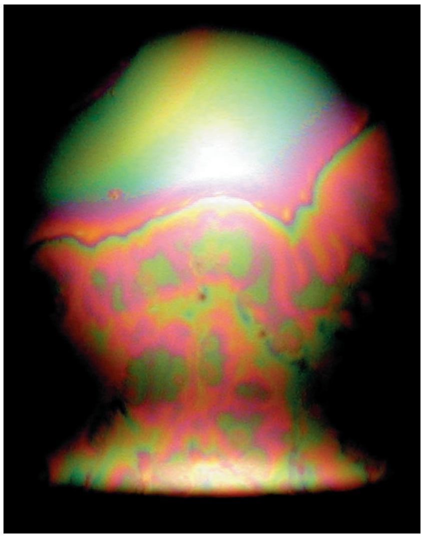
Newton's fringes (a.k.a. Newton's rings) are ubiquitous, and they are easy to spot in everyday life. Examples include the lovely colored pattern seen where a film of oil floats on water—look around the gas pumps at a garage after a rainy day. Perhaps you have been annoyed by the fringes that appear when you mount a valuable color slide between glass plates or when you mount a glossy photo behind glass. Most of us have enjoyed the colors seen in soap bubbles.

Sir Isaac Newton (1643–1727) did not invent the fringes that are named after him, neither was he the first to notice or describe them. He was, however, the first to offer a reasonable explanation of this phenomenon and to quantify the relevant parameters. This success is very interesting, because Newton did not subscribe to the wave theory of light; yet, he devised a workable model for the formation of interference fringes based on "fits" of transmission and obstruction of the particles that he thought constituted light. That is, Newton managed to incorporate wavelike periodicity into his particulate theory.

One easy way to see Newton's fringes is to place a clear dish of water on a black cloth and let it settle down. Switch off the lights except for a diffuse lamp a few meters away, such as your kitchen ceiling light fixture. Stand so that the you can see the reflection of the light in the surface of the water. Dip a pencil or a toothpick into some oil (cooking oil works), then touch the pencil to the surface of the water. You should see Newton's fringes form and drift over the water as the oil film spreads. Nice patterns can be created by touching the oil to the water in various places or by giving the water a little stir.

The following sketch is a bare-bones setup to explain Newton's fringes and their relationship to what we have learned about interference. In this instance, only one illuminating wave is shown, and the surfaces are assumed smooth and partially reflective, as would be the case if the plates were smooth glass or plastic.

The incident wave impinges on the first surface of the glass plate, where part of it is reflected. The rest goes to the second glass surface, where another portion is reflected. The remainder strikes the third surface, where the same thing happens unless this surface is polished metal so that the entire remaining wave is reflected.



Newton's Egg, *Newton's fringes in a film of oil on water; 3-d illusion caused by meniscus. Digital photograph by Gary Cloud, Dec. 2002.*

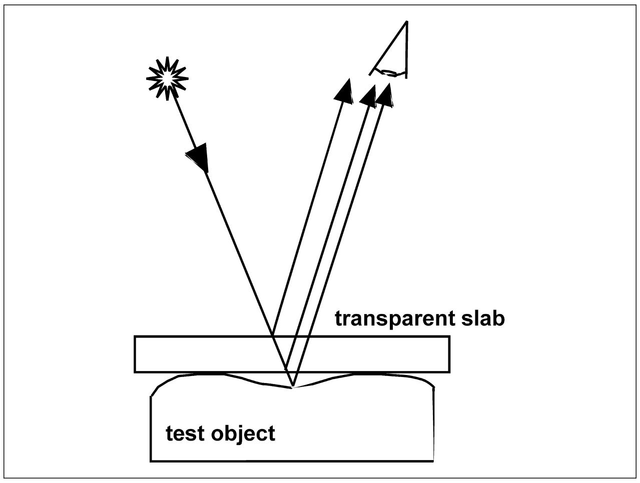
Newton's rings are all around us and may be seen:

- *in a film of oil on water or glass*
- *when glass is pressed onto a glossy photo*
- *at the interface of a crack in clear plastic.*

Editor's Note: Optical Methods: Back to Basics, *is organized by ET Technical Editor, Kristin Zimmerman, General Motors, and written by Prof. Gary Cloud (SEM Fellow) of Michigan State University in East Lansing, MI. The series 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.*

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

If you have any comments or questions about this series, please contact Kristin Zimmerman, Kristin.b.Zimmerman@gm.com.



Newton's fringes:
- *are caused by interference between waves that are reflected from two surfaces that are separated by a small gap*
- *were noticed long before Newton*
- *were explained by Newton using his particulate theory of light.*

Now, if the gap between the second and third surfaces is small enough, the wave portions reflected from these surfaces will be nearly collinear; at least they will be close enough together to enter the iris of the eye and also interfere with one another. The path length difference (PLD) between the waves is found by trigonometry and converted to fringe order using the ideas presented in previous articles. The fringe order will depend on thickness of the gap, index of refraction in the gap, viewing and observing angles, and the wavelength.

Fringe order is a function of:
- *wavelength*
- *gap between the surfaces*
- *index of refraction*
- *angle of incidence of light*
- *angle of observation.*

If the first glass layer is thick enough, the portion reflected from the first surface will be relatively far from the other waves and, so, will not contribute to the interference process. This is not always the case. The same is true for other fragments of waves that will be created by various partial reflections.

The implication is that Newton's fringes can be used to measure the separation between surfaces over a large field, thereby obtaining a fringe map of the difference of contours between the surfaces. To accomplish this quantitative measurement, the angles of incidence and observation must be under control, and the nature of the surfaces must be appropriate. These goals can be achieved in several different ways. One setup is shown on next page.

Extension to a large field:
- *is accomplished using lenses and a partial mirror*
- *creates a full-field fringe pattern*
- *yields a contour map of the gap between the surfaces.*

In this arrangement, a collimating lens is used to create a parallel light beam that falls on the surfaces at normal incidence. The reflected waves bounce back close to the normal. A partial mirror is used to separate the incident and reflected waves. A field lens converges the reflected waves so that all of them reach the eye or camera aperture in order that the entire field can be viewed at once. Considerable light is wasted by this system; the main advantage is that interpretation of the fringes is very simple. The incidence and viewing angles are both zero, so the relationship between gap and fringe order reduces to,

$$w = \frac{N\lambda}{2n}$$

where: w = local gap between the surfaces
N = fringe order
n = index of refraction in the gap
λ = wavelength of light

Newton's fringes fall into the broad class called "interferometry by amplitude division," because each incident wave is split into two parts that are recombined after following separate paths.

Newton's fringes are an example of "interferometry by amplitude division."

As suggested above, Newton's fringes create a fringe map of the gap between two surfaces. They can be used to test the contours of lenses and mirrors, although more refined interferometers are usually used for this purpose. Carefully lapped

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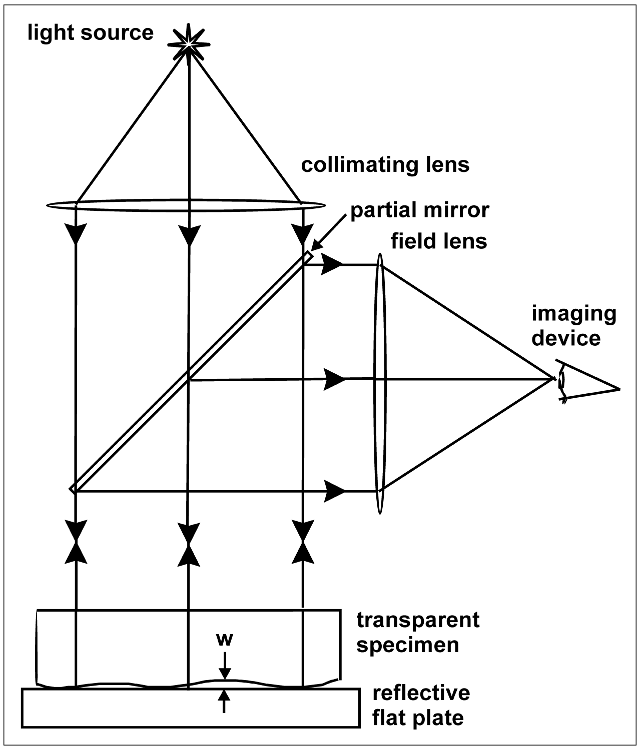

glass slabs, called optical flats, are used by machinists and others to test the flatness of surfaces by observation of these fringes. Another application, among many, is to measure the crack opening displacement in transparent fracture specimens.

Another reason that Newton's fringes are important is that the relation between fringe order and separation of the surfaces is exactly the same as is found for certain examples of more sophisticated techniques such as holographic interferometry and speckle interferometry.

The quantitative interpretation of Newton's fringes is the same as for fringes found by basic forms of other techniques, including:
- *holographic interferometry*
- *speckle interferometry.*

Two qualifications must be mentioned. First, the term "Newton's fringes" is typically used, as is the case here, in a sense that is larger than implied by history. Second, thorough analysis of this phenomenon is quite complex. For example, the phase changes that occur upon reflection from, say, metallic surfaces, must be considered in numbering the fringe orders.

Newton's fringes seem to have been somewhat forgotten by the experimental mechanics community, which is unfortunate since they can provide a simple solution to certain measurement problems.

What lies ahead?

The next segment of this series will describe Young's experiment, which is another important classical interferometry that is useful in several different ways. ■

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