OPTICAL METHODS Back to Basics *by Gary Cloud*

Optical Methods in Experimental Mechanics
Part 8: Michelson Interferometry

REVIEW AND PURPOSE

So far, this series has concentrated on basic concepts in interferometry and their applications to measurement in what we choose to call "classical interferometries." This segment presents a third and final example, drawn from the many possible, of a classical approach. Michelson Interferometry is important in the history of physics and engineering, it teaches much about the behavior of light, and it is the conceptual basis of several measurement techniques including certain forms of speckle and holographic interferometry.

MICHELSON AND HIS EXPERIMENTS

Albert Abraham Michelson (1852–1931) was an ingenious and energetic physicist who was born in Prussia and graduated from the U.S. Naval Academy in 1873. He was awarded the Nobel Prize in physics in 1907.

Michelson published in 1881 the description of an interferometric arrangement that used a partial mirror to create the interfering beams, thus overcoming some disadvantages of the other interference schemes that were being used at the time. The instrument was used by Michelson in at least three projects that are of lasting importance: (1) the ether-drift experiments that were conducted with E.W. Morley; (2) the first systematic study of the structure of spectral emission lines; and (3) the definition of the standard meter in terms of wavelengths of light. The ether-drift research is especially interesting in that it sought to answer questions about the existence of a luminiferous ether that was postulated by Maxwell as necessary for the propagation of electromagnetic waves. Michelson and Morley used interferometry to determine how the speed of light was affected by the velocity of the experimental reference frame relative to the ether. No such effect was discovered. This null finding led to Albert Einstein's proposal that the speed of light is a fundamental constant and contributed to the development of the Theory of Relativity.

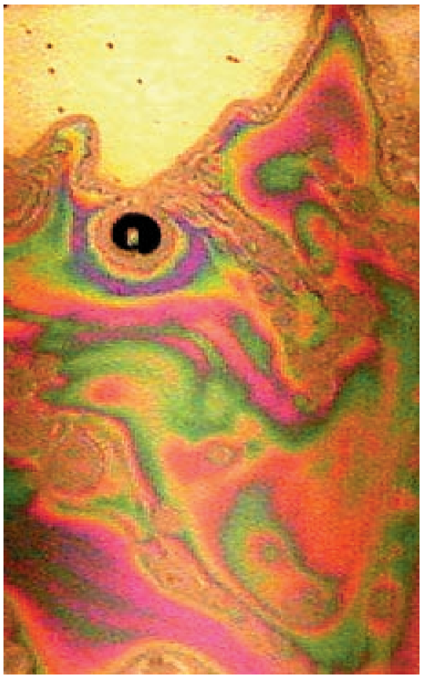
THE MICHELSON INTERFEROMETER

Michelson's original interferometers did not use collimated light from the source. This scheme is still used in some measurement contexts, including certain versions of laser Doppler interferometry. The usefulness of the device was greatly enhanced by the introduction of lenses to create broad-field collimated radiation, notably by F. Twyman and A. Green. The Twyman-Green configuration, patented in 1916, still is used for inspection of lenses and mirrors. Several other interferometric measurement systems that are modifications or extensions of Michelson's original have been devised. Discussed here is the basic whole-field version of instruments of this class. We refer to it as simply "the Michelson interferometer" in accord with common practice. This device is an example of "amplitude division" interferometry, as are Newton's fringes (Part 5 of this series).

Editor's Note: Optical Methods: Back to Basics, *is organized by ET Technical Editor, Kristin Zimmerman, General Motors, and written by Prof. Gary Cloud 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. Unless noted otherwise, graphics in this series were created by the author.*

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.



Newtonian Paisley, Newton's fringes in film of oil on water. Digital photograph by Gary Cloud, Dec. 2002.

Michelson interferometry:
- *is important in the history of physics and engineering*
- *teaches the behavior of light*
- *is the basis of many measurement techniques.*

Michelson invented the interferometer and used it in:
- *determining effects of velocity of observer on speed of light*
- *investigating the structure of spectral lines*
- *defining the standard meter.*

Twyman and Green, among others:
- *converted the Michelson device to large-field*
- *greatly expanded the usefulness of this type of interferometry*
- *used their device to measure the profiles of lenses and mirrors.*

Michelson interferometry and its variants are examples of "amplitude division" interferometry.

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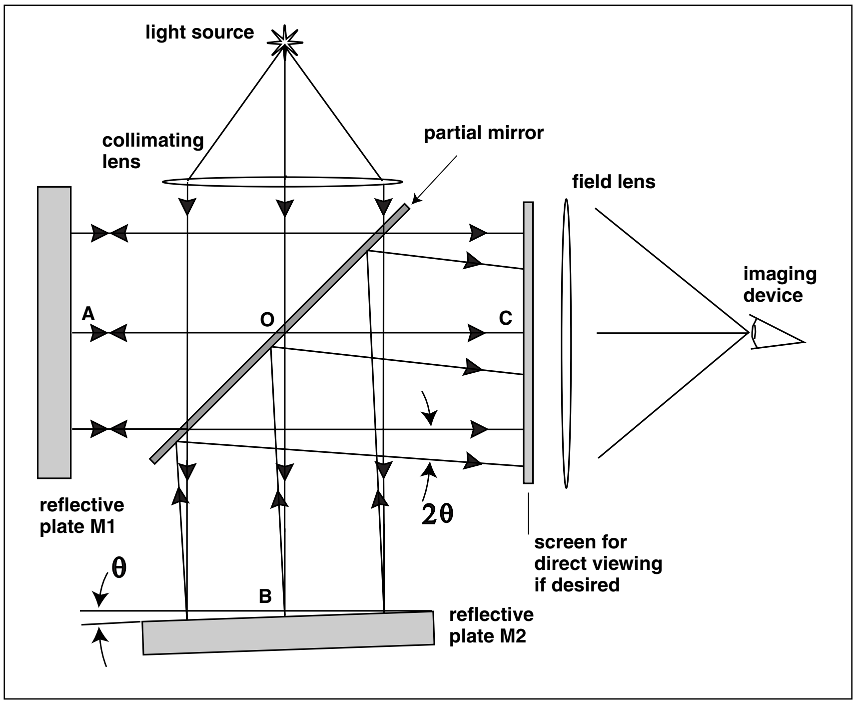
OPTICAL METHODS IN EXPERIMENTAL MECHANICS

The configuration of a large-field version of a Michelson interferometer is shown in the sketch. A lens is used to collimate radiation that is projected upon a beam splitter. A portion of this beam is directed to the flat (for now) fixed mirror M1, where it is reflected back through the splitter to the observation screen. Some of the incident light passes directly through the beam splitter to fall upon another flat (for now) mirror or test object M2. It is reflected or scattered back to the splitter, and part of this light is redirected to the viewing screen. Of course, each interaction with the beam splitter causes another amplitude division, meaning there are some extra waves bouncing around in there that can cause problems with imaging and measurement. These spurious waves are often directed out of the system using optical wedges and such. Only the important divisions and reflections are shown in the sketch. Also, the beams are shown slightly separated for convenience of illustration. For actual experimentation, the viewing screen is usually replaced by some sort of whole-field imaging system, shown here as a field lens and the eye. The imaging system will typically be focused on one of the mirrors.



Now, if the system is originally adjusted to be perfectly square, two separate but parallel wavefronts arrive at the screen. The path length difference (PLD) for the labeled wave path will be $[OA + AO + OC] - [OB + BO + OC] = 2[OA - OB]$. That is, the PLD for any interfering pair of waves is twice the local difference between the distances from the beam splitter to each of the mirrors. Clearly, this effect might be useful for measuring motion of one of the mirrors relative to the other one, or to compare the profiles of the mirrors.

For a perfectly square setup, the PLD between any two waves arriving at the viewing screen is twice the difference between the distances from the beam splitter to each of the mirrors or test surfaces.

If the PLD is a multiple of the wavelength of the radiation, then we expect the screen to be light. If either of the mirrors M1 or M2 are translated axially, then the irradiance at the screen will be alternately bright and dark according to expectations from our study of collinear interference (Part 2). The same will happen if a test cell is placed in the arm OB and the refractive index of the cell content is changed.

Irradiance at any point on the viewing screen depends on the PLD between the waves arriving at that point.

If either object M1 or M2 is tilted by some angle θ, the reflected beam will undergo a deviation of 2θ relative to the undisturbed beam. The beams will interfere according to the rules discussed for oblique interference (Part 4) and create a system of parallel fringes. Simple collinear interference calculations give the

If one or both the mirrors or test surfaces are tilted:
- *the waves arriving at the screen meet obliquely*

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same result if one realizes that tilting the object creates a linear-varying PLD over the field that is proportional to 2Sinθ. The spacing of the fringes indicates the tilt of the object. If the object is then translated axially, the tilt fringes will move across the screen. If a point radiation detector is placed at some location in the screen, an oscillating signal proportional to the changing irradiance will be produced. These ideas are applied in determining displacements and velocities of objects.

• they interfere according to the rules for oblique interference
• a pattern of parallel fringes is formed
• fringe spacing indicates the relative tilt of the mirrors.
If one of the mirrors is then moved, the fringes translate across the screen.

The fringes discussed above are so-called fringes of equal thickness (constant PLD), otherwise called "Fizeau fringes." A different fringe system, called "Haidinger fringes," will be seen if the imaging system is focused at infinity. These are fringes of equal inclination and, for the square setup, will take the form of concentric circles.

Much of the usefulness of this interferometer derives from the fact that it is a differential or comparison-type measuring device. The two paths are separate in space, but the path lengths are still subtracted from one another. If only one of the mirrors is absolutely flat, for example, the resulting fringe pattern will be a contour map of the other mirror. If neither are flat, then the fringe map will give the difference between the two profiles. If both move, then the difference between the motions will be measured. Clearly, this device is both flexible and powerful.

The Michelson interferometer:
• is a differential measuring device
• compares two physically separate paths
• generates fringes that are loci of constant PLD (Fizeau fringes)
• yields the difference in contours and / or relative motions of the mirrors.

While being able to compare two physically separate paths offers advantages, they come at a serious price. Any spurious or unwanted change of one PLD with respect to the other appears as a change in the fringe pattern. The desired fringe data are contaminated by effects that are caused by vibrations or air currents. One must minimize unwanted PLD changes by careful setup and isolation of the device, or, alternatively, by actually evaluating the noise-induced data and subtracting it out later. Often, the sensitivity of this interferometer to vibrations is put to good use in assessing the stability of certain environments. An example is in testing the mounting pads for sensitive apparatus such as electron microscopes.

Since this interferometer compares separate paths, it tends to be affected by vibrations. Careful setup and isolation are required.

In general, a useful way to classify interferometers is whether they are "common-path" or "separate-path" devices. Common-path interference setups, including photoelasticity, basic shearography, and Newton's fringes (Part 5), for example, are very tolerant of vibrations because noise-induced PLD changes affect both paths equally, and, so, are subtracted out. Separate-path devices, including those for holography, ordinary speckle interferometry, and Lloyd's mirror (Part 4), are highly susceptible to disturbances because the PLD's can be affected unequally. Photoelasticity is performed easily on an ordinary table or in the classroom with a transparency projector. Holography usually is done in the laboratory with the components mounted so they are isolated from the environment.

Common-path interferometers:
• compare PLD between waves that follow the same physical paths
• are resistant to vibrations
• include, among others:
○ photoelasticity
○ Newton's fringes
○ many shearographic techniques

Separate-path interferometers:
• Compare PLD between waves that follow different physical paths
• are susceptible to vibrations
• include, among others:
○ Michelson interferometry
○ holography and holographic interferometry
○ most speckle interferometry
○ Lloyd's mirror

While the experimental mechanician is not likely to need a classic Michelson or Twyman-Green interferometer, the type is very important. Many of the techniques that are used in experimental mechanics, including holographic interferometry, speckle interferometry, and laser Doppler methods utilize the separate-path Michelson configuration. ■

Michelson interferometry is a paradigm for many optical measurement techniques, including:
• holographic interferometry
• most digital speckle interferometry

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