Interferometer Sources

Fringe formation and data acquisition

The interferometer light source controls fringe formation and data acquisition. Long coherence (laser) simultaneously creates fringes over all cavity lengths, from less than a micrometer to many hundreds of meters. Whereas a broadband, white light source creates fringes in a narrow micrometer wide region. The source wavelength, spectrum and variability control data acquisition: If fixed wavelength mechanical phase shifting is required, if variable wavelength or spectrally controlled, fixed cavity length acquisition is possible.

One source type will not enable all applications. This paper will discuss various sources, associated data acquisition techniques and their application.

ABSTRACT

The interferometer light source controls fringe formation and data acquisition. Several sources are available and no single source type will enable all applications.

This paper discusses various sources, associated data acquisition techniques and their application.

1. Broadband or White Light Sources

Before the invention of the laser in the 1960's optical test interferometers were difficult to use and often had to be custom built for each application. Low-spatial and temporal coherence white light illumination required equal path interferometers like a Twyman-Green or Mach-Zehnder configuration. The Fizeau interferometers were large, very heavy, difficult to use and limited to measurements of flat surfaces.

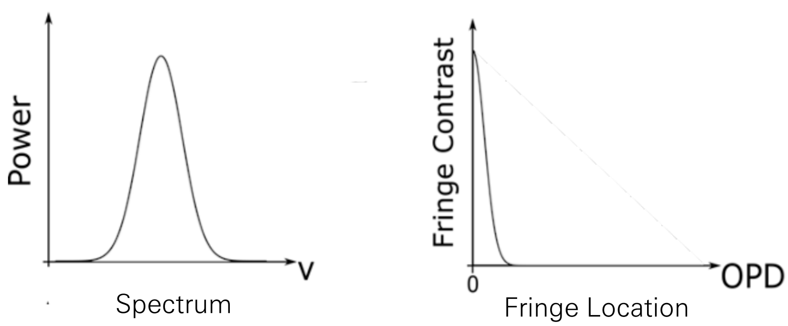

Figure 1: White Light Source

The broadband sources have the advantage of "clean" interference fringes yet they are difficult to use. The fringes form in a micrometer narrow region at the 0 optical path difference position (OPD) which is hard to find, refer to Figure 1. White light sources are so difficult to use that the broad application of interferometers in lens production required the invention of the laser. Next are discussed a few types of white light interferometers.

Test Plate Interferometer

A popular interferometer, though rarely considered one, is the Test Plate using Newton's Rings. A test plate is similar to a Fizeau configuration with only several micrometers of working distance. A test plate is the reference surface for a matched test surface and a low coherence filtered source is used. This is a visual only test.

Equal Path Interferometer

Today broadband sources are mostly used with interferometer microscopes. The interferometer configurations are equal-path length Mirau or Michelson interferometers. The fringes are formed at the equal-path condition and data is acquired via phase shifting interferometry (PSI) or coherence scanning interferometry (CSI). For both PSI and CSI the interferometer must be moved in relation to the test part to acquire data. Fixed wavelength requires a mechanical movement to acquire data.

Delay Line Interferometer

Fizeau interferometers are unequal path interferometers. If a broadband source is used it works like a Test Plate Interferometer, fringes are formed within micrometers of the reference surface. If two interferometers are coupled together, such as a Fizeau with a Twyman-Green "delay line", the broadband source fringes (small range of fringe production) can be moved away from the reference surface, at position l_{cav} in Figure 2, making fringes accessible to measure components. The distance the fringes can be moved is equal to the delay line length with fringe contrast 50% the maximum possible in a laser Fizeau.

Delay Line Data Acquisition

Data is acquired by moving the reference surface in either the Fizeau or the Twyman-Green interferometers. These systems are used to measure etalons and plane parallel plates. Just like all broadband interferometers the locating and aligning of fringes is difficult, especially for Fizeau configurations as the fringes are in a micrometer region in the hundred plus millimeters space in front of the reference surface.

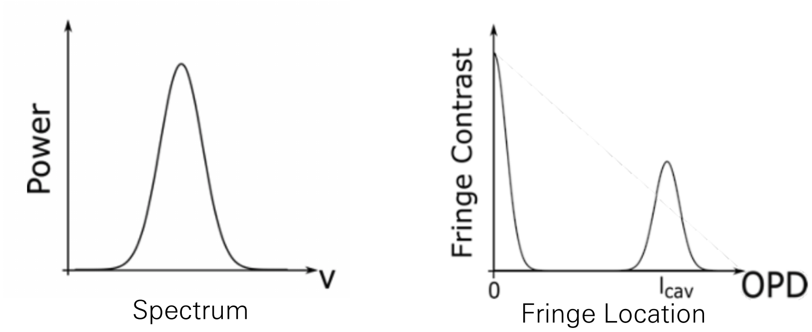

Figure 2: White Light Delay Line

2. HeNe Laser

HeNe lasers are the default light source of Fizeau interferometry. The long coherence length and relatively simple design enables the unequal path Fizeau to work. When the term laser Fizeau is used, typically a HeNe laser is implied. Today HeNe lasers are stabilized, meaning that only one wavelength of one polarization is emitted from the laser. The spectrum and fringe location for a laser is shown in figure 3. The extreme narrow line spectrum produces interference fringes over all OPD's out to hundreds of meters, or everywhere.

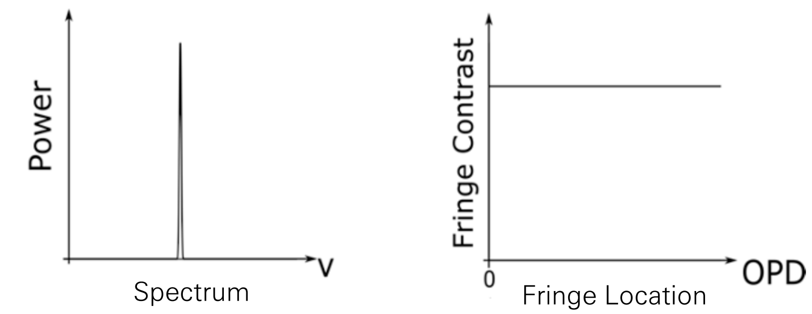

Figure 3: HeNe Laser

HeNe Laser Data Acquisition

Phase measurements require a mechanical motion of the reference or test surface to shorten the interferometer cavity length, creating a phase shift in the fringes. Phase measurements are acquired at camera frame rates in milliseconds, inviting averaging to be used, along with modern vibration tolerant algorithms. Requiring mechanical phase shifting limits the aperture size for phase shifting to ~600 mm and this is expensive. Requiring mechanical phase shifting eliminates fixed cavities or solid optics like a plate of glass from being measured.

3. Single Mode Laser - Laser Diode

Until recently laser diodes were of limited use for interferometry. Laser diodes did not have the stability or long coherence length of a HeNe laser. Today stabilized Laser Diodes have almost identical performance characteristics to a HeNe laser with long coherence and stable wavelength, see figure 4.

They offer the added advantages of high output power in a compact and low heat generating package. The higher illumination power output enables an "alignment mode" where the interferometer output can be seen in a laboratory, like a directed flashlight, to simplify the alignment of large optics.

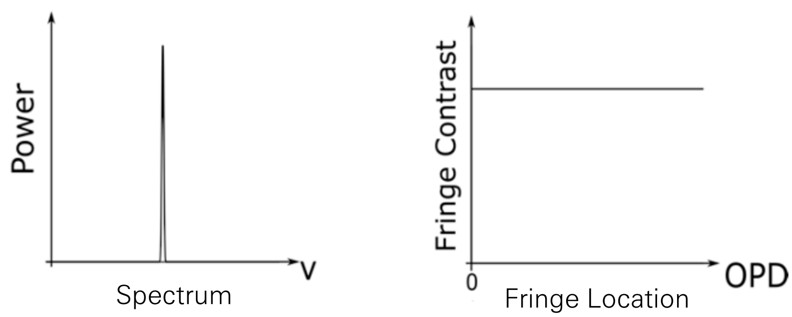

Figure 4: Single Mode Laser - Laser Diode

Regarding heat, HeNe lasers operate hot and heat adds an error source for the nanometer level metrology of interferometry. Therefore laser diodes decrease the heat load to improve the overall metrology environment.

The actual output wavelength of a 633 nm laser diode, though picometer stable, can vary by a few tenths of a nanometer in center wavelength. This is enough offset to make laser diodes impractical for Computer Generated Hologram applications where a HeNe laser is the best choice.

Single Mode Laser - Laser Diode Data Acquisition

Just like a HeNe laser phase measurements are performed by mechanically changing the cavity spacing and acquired at camera frame rates in milliseconds, inviting averaging to be used, along with modern vibration tolerant algorithms. The same limitations to aperture size and fixed cavities exist for SML - laser diodes as HeNe lasers.

4. Wavelength Shifting - Laser Diode

Wavelength shifting (WS) lasers are tunable laser diodes. They have a center wavelength of 633 nm and the ability to change wavelength at a specified rate, with the long coherence of fixed laser diodes, refer to figure 5 regarding the spectrum and fringe formation. As the wavelength is changed the phase of the Fizeau interferometer cavity will change. This enables phase measurements in interferometer cavities that are ridgid. Two types of data acquisition phase measurements are possible: standard phase shifting and Fourier phase shifting interferometry.

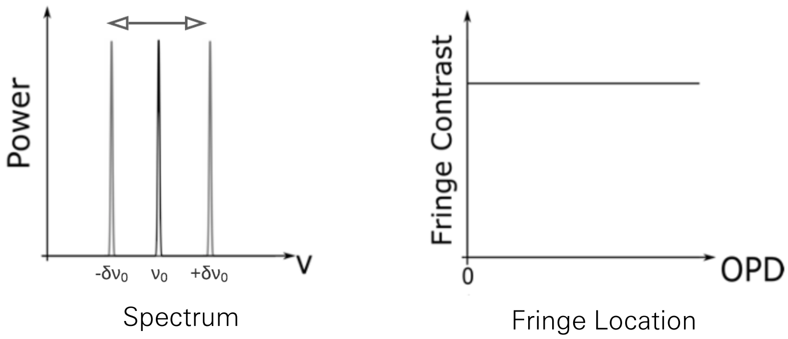

Figure 5: Wavelength Shifting Laser - Laser Diode

WS: Data Acquisition - Phase Shifting

Wavelength shifting data acquisition measurement length is limited by the range of wavelengths the laser can scan. For short cavities a *large* change in wavelength is required. For long cavities *small* wavelength changes are required. There are limits to both the large and small wavelength ranges of wavelength shifting lasers and this limits the measurable cavity lengths (optical path length) to between ~5 mm to ~2 meters.

Data acquisition speed is limited to the slower of the camera frame rate or the maximum scan rate of the laser. Therefore data acquisition can be slower than mechanical phase shifting (HeNe or Laser Diode) or electronic phase shifting (SCI) and thus be potentially more vibration sensitive. Except for speed of acquisition vibration tolerant algorithms can be utilized.

WS: Data Acquisition - Fourier Phase Shifting

Fourier phase shifting acquisition takes advantage of the relationship of short and long cavity responses to a specific wavelength change in the laser. Fourier phase shifting scans the laser at a fixed rate, and long cavity fringes modulate faster than shorter cavities. A Fourier analysis of the full scan separates the different cavity lengths in the interferometer measurement based on frequency of fringe modulation. Measurements take up to a minute to complete therefore Fourier Phase Shifting is sensitive to environmental vibration and turbulence. Since measurements require a long time, averaging is impractical.

4. SpectrÄ: Patented Spectrally Controlled Interferometry (SCI)

SCI electronically controls 1) the source coherence enabling switching from laser to broadband, 2) moving the fringe position distant from the Fizeau reference surface, and 3) modulating the phase of the fringes. The SCI source is unique to Äpre Instruments. Figure 6 shows the unique spectrum of SCI that produces fringes at a specific cavity location shown as l_{cav}.

The source bandwidth controls the narrowness of the interference fringes (wider source, narrower fringe location). The frequency of the spectral lines controls the position of the fringes (higher frequency the farther from the reference surface). The phase of the spectral lines controls the phase of the fringes in the interference cavity. This feature combination enables previously impossible or very difficult to measure applications. In 2020, 660 nm is standard with other wavelengths possible.

In the laser mode the source creates fringes everywhere making alignment easy. The source electronically switches to broadband mode in milliseconds locating the fringes to a narrow area in front of the interferometer. The fringes are electronically moved towards or away from the reference surface to the measurement surface. The positioning can be made at camera frame rates, so a test setup with known surface positions can be repeatedly measured in milliseconds. The surfaces on etalons as thin as 100 μm physical thickness can be measured, first front then back, without any physical movement or special surface preparation and each reported separately.

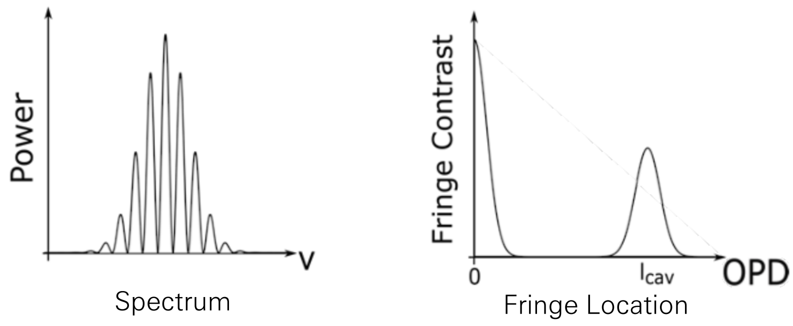

Figure 6: Spectrally Controlled Interferometry

SCI: Data Acquisition

Phase measurements are also performed electronically with the SCI source itself. Phase measurements are performed on a fixed cavity, no moving parts. Further phase can be measured in milliseconds regardless of the interferometer cavity distance (not true with wavelength shifting lasers), be that 100's of millimeters or 100 μm, this is unique to the SCI source. Phase measurements are acquired at camera frame rates in milliseconds, inviting averaging to be used, along with modern vibration tolerant algorithms

SCI is a new technology and new applications continue to be discovered.

SCI Can be used on any interferometer

No change or special configuration is require for a Fizeau interferometer to use an SCI source. All ÄPRE interferometers can use SCI source, as well as HeNe laser, Laser Diode, Wavelength Shifting by only changing the fiber optic feed from the remote source...like four interferometers in one.

Upgraded interferometers can be modified to exclusively use an SCI source, but without the flexibility of an ÄPRE interferometer.

Summary

The interferometer source controls both how the interference fringes are formed, the data acquisition techniques available and possible applications. One source does not do it all and care must be taken regarding which source to choose. The performance of the various light sources is seen in the table below.

	White Light	White Light Delay Line	Laser/ Laser Diode	Wavelength Shifting LD	SCI
Fringe Formation	µm narrow region	µm narrow region	everywhere	everywhere	µm narrow region
Cavity Range	<0.05 mm	<500 mm	>10,000 mm	1,000 mm	500 mm
Data Acquisition	Mechanical PSI/CSI	Mechanical PSI	Mechanical PSI Carrier Fringe Polarized PSI	WS PSI	Spectral Phase Shifting
Ease of Use	Difficult	Difficult	Easy	Easy	Easy - Laser Mode

For more information and how to choose the best source for your configuration please contact ÄPRE today.

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