MahrSurf FI 3100 VB Overview

Introduction

The **MarSurf FI 3100 VB** interferometer from Mahr-ESDI is a unique interferometer based on a Fizeau geometry that is capable of taking measurements in the presence of vibrations and other environmental disturbances with virtually no compromise. Piezo or wavelength phase-shifting interferometers acquire multiple interferograms sequentially over time to create a single wavefront map of the part under test. The time involved to make the measurement allows vibration, mechanical drift, or air thermal currents to introduce errors. Other interferometers acquire a single interferogram using a technique requiring a significant amount of tilt. This tilt acts like a spatial carrier that can be used to reconstruct the wavefront. However, this method can introduce aberrations (mostly coma) that need to be calibrated out. Also the carrier method cannot be used for highly aberrated parts due to the local fringe densities exceeding that of the Nyquist limit. There are some polarization based phase-shifting interferometers on the market that solve the vibrations problems quite well for many applications, but have some compromises such as utilizing a non-common optical path which introduces some retrace errors. Other polarization based interferometers have a common optical path using non-coherent sources which work very well for measuring flats and films over short distances, but cannot be used for long distance measurements.

The **MarSurf FI 3100 VB** interferometer, from Mahr-ESDI, uses a coherent laser source and polarized light as a principle of its operation in a common path Fizeau interferometer. The design solves many of the problems associated with other systems. The **MarSurf FI 3100 VB** generates three phase-shifted interferograms simultaneously. The three interferograms are recorded at the same time by three independent cameras. In order to generate multiple interferograms it is required that reference and test beams be orthogonally polarized. To achieve this, a Fizeau interferometer layout has been modified by creating two spatially separated and orthogonally polarized sources. As shown in Figure 1A, two orthogonally polarized beams originating from two sources within the interferometer propagate out through the interferometer's collimator at a slight angle.

The two beams reflect from a transmission optic (flat or sphere) mounted outside the collimator and from the measured object. The transmission optic and the measured object are tilted in such a way that they reflect two orthogonally polarized beams along the optical axes of the optical system of the interferometer. The remaining two beams reflected by the transmission optic and the test object are blocked from entering the interferometer by a spatial filter placed in the focal plane of the interferometer. This arrangement is illustrated in Figure 1B. Note that in order to reflect two orthogonally polarized beams along the optical axis of the interferometer the transmission optic and the test object must be slightly tilted with respect to each other. However, both reference and test "return" beams follow back through the optical system of the interferometer along a common path. This is important to minimize interferometer retrace errors.

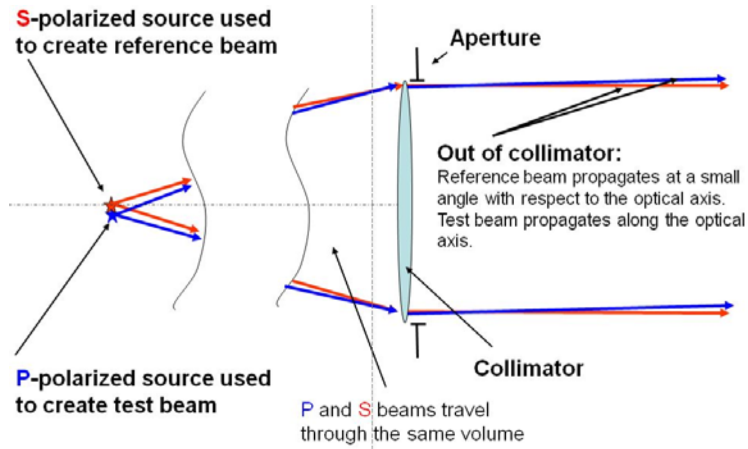

Figure 1A. Illuminator portion of a simultaneous phase shifting Fizeau interferometer.

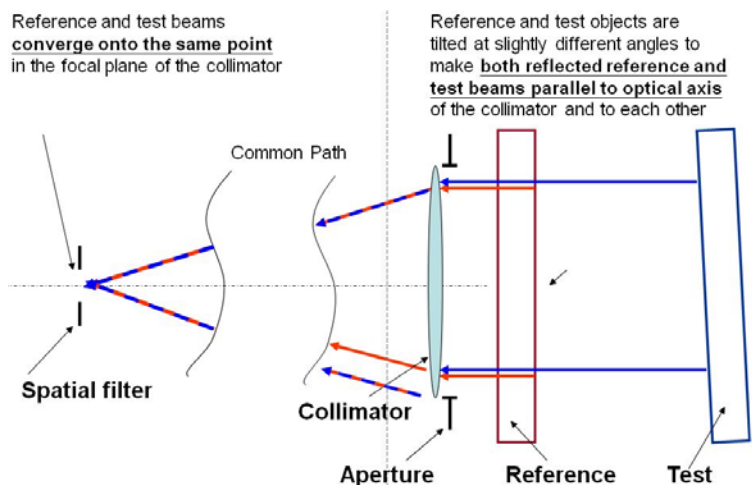

Figure 1B. Arrangement of the transmission flat and the measured object in the simultaneous phase shifting Fizeau interferometer.

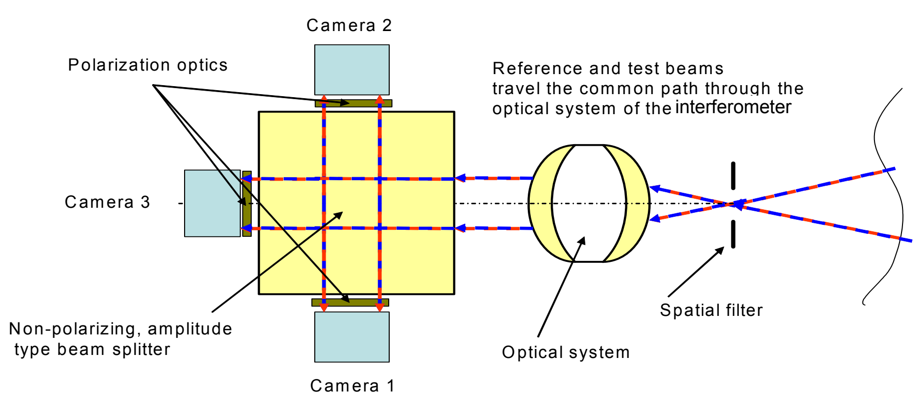

Figure 1C: Diagram showing the optical path and layout of optical elements inside the simultaneous phase shifting Fizeau interferometer.

Real-Time Phase Shifting

In order to generate three independent interferograms, the test and reference beams are split at the same rate into three channels in a special module in place of a standard camera in **MarSurf FI 3100 VB**. In each channel, phase delays are introduced independently in a controlled fashion so that the phase shifts between the interfering beams are set to 120^0 between consecutive interferograms. The three interferograms are captured simultaneously and transferred to the computer. The exposure time to capture the interferograms is typically 0.25 ms, but can be as low as 10us, and is limited only by the amount of available light and the capabilities of the cameras. Note that splitting the incoming beam into three channels does not violate the principle of the common optical path as the two interfering beams are split the same way and they traverse the same optical path all the way to the detectors. Figure 1C illustrates the beam arrangement inside the interferometer.

Note: Although the **MarSurf FI 3100 VB** uses three cameras, they are sub pixel aligned and monolithically bonded together along with the beam splitting and polarization optics into a package smaller then two decks of cards stacked on top each other. The result is a rigid camera system similar to high-end 3-Chip color cameras with lifetime alignment. The advantage of using three cameras is that each of the interferograms retains the true resolution of the camera.

Measurements

Although the **MarSurf FI 3100 VB** is a modification of a Fizeau interferometer it has certain characteristics that make it different from standard temporal phase shifting instruments:

1. The interferometer collects the interferograms in a very short time. This allows capturing measurements in the presence of vibrations, air turbulence, etc. This however does not eliminate the influence of air turbulence on the measurements. Since air turbulence and other similar disturbances are stochastic processes they can be eliminated from the measurements by averaging a certain number of them. Usually averaging 8 to 16 measurements is sufficient to obtain good, repeatable results but in reality this number will depend on the severity of these disturbances and the required quality of the measurement. In fact, the presence of vibrations increases accuracy of the measurements by reducing the probability of systematic errors.
2. As the test and reference beams are orthogonally polarized it is possible to adjust their mutual intensities. This allows high contrast of the interference fringes for a large range of reflectivity of measured surfaces (from 0.1% to 100%) without the need to replace the reference elements or the use of attenuating pellicles.
3. As the **MarSurf FI 3100 VB** interferometer uses polarized light, it is sensitive to measurements of objects that may change the state of polarization of the illuminating beams. Thus measurements of birefringent parts, parts with polarization altering coatings, surfaces illuminated at shallow angles, as well as other similar cases may be difficult or even impossible. Depending on the external optical system there are often solutions to this, such as adding an external polarizer or waveplate to reorient the incoming polarization.
4. Two beams leaving the interferometer propagate through the collimator lens at a slight angle with respect to each other (for **MarSurf FI 3100 VB** the angle difference is 3.6mrad). This asymmetry causes a small violation of the principle of a common optical path (for the out-going beams) and results in small aberrations being added to the measurement. This error is a function of the angle between the two beams and the optical design of the collimator lens. In case of measurements with transmission spheres, this error will be slightly higher. However, this error can be completely eliminated by taking two measurements with the role of the two illuminating

beams being reversed (i.e. if the first measurement is made with the P-polarized beam reflecting from the reference optic and the S-polarized beam reflecting from the measured object, the second measurement should be done with the polarizations reversed). One of these measurements is inverted and averaged with the other in software, resulting in complete cancellation of these types of errors. With the assistance of ASML, Mahr-ESDI has demonstrated and documented **MarSurf FI 3100 VB** instrument errors to be less than λ/100.

Accessories

The **MarSurf FI 3100 VB** interferometer is capable of taking measurements of flat as well as spherical surfaces. The beam diameter is 100 mm and the instrument accepts all industry standard 4" (100mm) bayonet mounted reference optics.

Comparison to Other Types of Real-time Phase-Shifting

1. Fizeau Design
    a. The **MarSurf FI 3100 VB** is the only coherent laser based interferometer capable of producing measurements equal in accuracy to a classical Fizeau common path interferometer. This is due to the **MarSurf FI 3100 VB**'s patented simultaneous phase-shifting technology.
2. Spatial Carrier Methods
    a. Spatial Carrier methods use a significant amount of tilt between the test and reference beams to generate a spatial phase-shift in a single interferogram. Since only one interferogram is used, vibration insensitivity is achieved. But the tilt generates coma aberrations which must be calibrated out. Also this method does not allow large local slopes to be measured. This means heavily aberrated optics cannot be measured.