Advantages of on-axis PBS based Fizeau interferometers

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In optical shop testing, Fizeau interferometers are established as versatile and reliable measurement instruments [1], [2]. But the minimum uncertainty of the measurement is limited by multiple beam reflections being present in the Fizeau cavity. Furthermore, PZT based PSI is slow and do not allow for an integration into industrial environment. Herein, a solution to these problems will be explained.

1 Introduction

The coaxial common path arrangement of Fizeau interferometers is the reason why they are most commonly used for the measurement of optical flats, spheres and aspheres. However, the interference signal of the surface under test (SUT) and the reference (REF) is not sinusoidal (see Figure 1). This results in an increased uncertainty of the measurement. The potential of phase shifting interferometry (PSI), which means the potential of error compensating algorithms, cannot be used [3]. How to make use of the advantages and how to avoid the drawbacks?

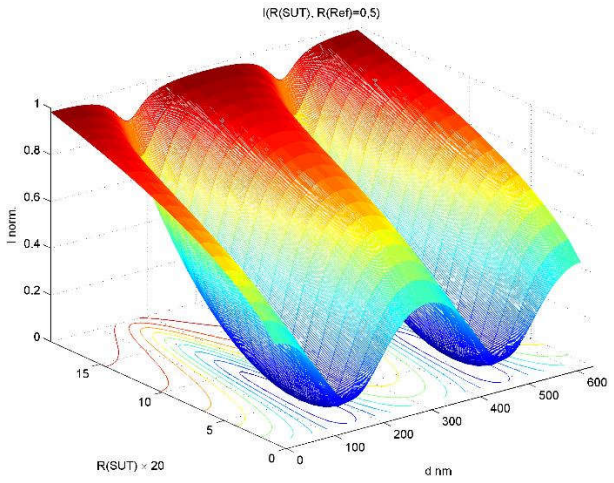

***Fig. 1** Calculated interference contrast V in dependence on the reflectance of the surface under test (SUT).*

2 Working principle of an on-axis PBS Fizeau

The interferometer, which is in the building phase, is based on the separation of TM and TE polarized light. A wire grid polarizer (WGP), which is placed at the reference surface (REF), provides the required on-axis separation [4]. Figure 2 depicts the beam path. A laser, which has a coherence length of e.g. z_c(HM) = 20 mm, is sufficient. A Pockels cell is preferred in order to introduce the phase shift, which is present between orthogonal polarization states of the light illuminating the Fizeau cavity, which is formed by the REF and the SUT. Both are imaged onto the detector plane at maximum resolution, placed within the range of telecentricity and placed within the depth of field (DOF). Thus, identic magnification and identic image distortion is realized. A telecentric lens from Sill Optics GmbH (DE) is used, which guaranties a minimum distortion. Spatial wave length can be measured down to Λ_{min} = 54 µm, which is important in regards to the detection of mid-spatial frequency (or slope) surface errors. Thus, exact mapping can be obtained and e.g. used for magnetorheological figuring (MRF), fluid jet polishing (FJP) or ion beam figuring (IBF).

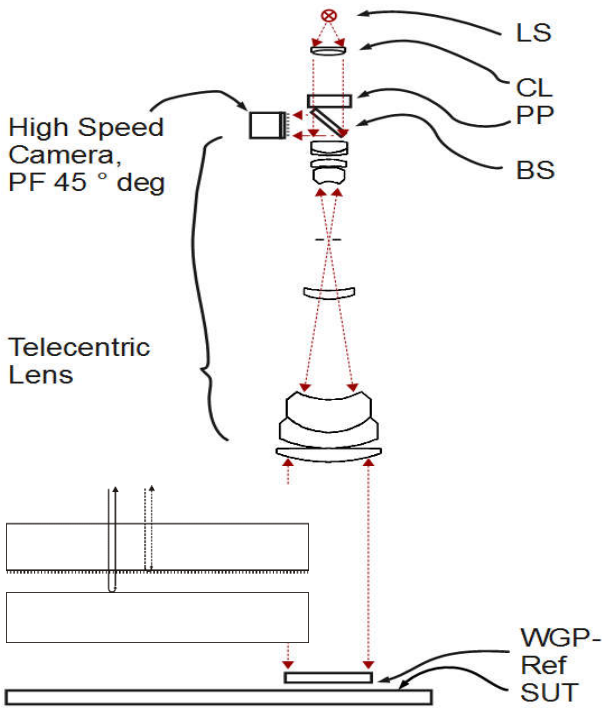

***Fig. 2** Beam path of an on-axis PBS based Fizeau Interferometer (LS: light source, CL: collimating lens, PP: glass plate, BS: beam splitter, WGP-Ref: wire grid type reference surface, SUT: surface under test, PF: polarization filter). The Fizeau cavity is shown at the lower left.*

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The images of the SUT and the REF have orthogonal polarizations. Thus, a polarization filter (PF), which is orientated at 45 ° deg, has to be mounted in front of the CMOS detector array. The PF is referred to as analyzer. The detector array has to be synchronized with the Pockels cell. The propagation length of acoustic waves with frequencies $\nu \geq 200$ Hz is negligible. Thus, a frame rate of 1 kHz is sufficient for five frame PSI. Residual stress birefringence can be calibrated and stored in a separate φ(TE,TM,x,y)-map, which is equivalent to a look up table (LUT). Note that the REF and the SUT can be rotated and the entire Fizeau cavity too. In other words, although a calibration, which is based on error separation, is mandatory, a correction of intrinsic phase offsets is not an issue [5].

The on-axis PBS approach provides a decoupling of the surfaces generating a Fizeau cavity (REF $\Leftrightarrow$ SUT). However, it will not avoid reflections, which are generated by a non-index-matched backside. An impedance match, which means to use an absorber with a real part of the refractive index n of $\hat{n}$ ($\hat{n} = n(1 + i\kappa)$), which is lower than the one of the object under test and taking the attenuation index κ of the absorber into account, can be used to do so [6]. In other words, the remaining, non-modulated DC offset can be eliminated too. However, in most cases it is a small reduction of the detector arrays dynamic range only, e.g. < 10 % of 12 Bit.

3 Conclusion

A Fizeau interferometer can profit from the implementation of an on-axis polarization beam splitter (PBS). Here, a wire grid polarizer (WGP) is the preferred on-axis PBS. As it can be seen in Figure 2, the reference flat is orientated face down. Thus, the WGP is placed close to the SUT, which means e.g. at 2 mm distance only. This also enables the use of a reduced coherence length z_c.

This modification of the Fizeau cavity, which includes the illumination unit too, results in a sinusoidal modulation of the detected interference. Thus, the full potential of phase shifting algorithms can be used. To give an example, for the five phase algorithm a linear phase drift of 20 % is compensated to a very small residual phase error of $2\pi/2000$ only.

In addition, advanced analysis of the discrete PSI algorithm used can reduce the uncertainty even further. An interference contrast of V > 0.9 can be obtained for a wide range of the degree of reflection of the SUT. Furthermore, no moving parts are required. This enables measurements in vibration-exposed environments. For instance, a five phase shifting algorithm might be carried out within less than 1/200 s. This enables a significant reduction of the uncertainty of the phase measurement. It opens up new applications in the field of dynamic interferometry.

For instance, an on-axis PBS based Fizeau interferometer might be used for the flatness measurement of electro-statically chucked lithographic masks (even with large variation of the local reflectance R(x,y)) working at the soft X-ray wave length of λ = 13.5 nm. Note that the influence of vibrations, which are e.g. due to vacuum pumps, can be reduced significantly.

Although the preliminary analysis pointed out, that an on-axis PBS based Fizeau interferometer can provide unique measurement capabilities, practical test have to verify this in the near future.

4 Acknowledgement

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