Interferometric alignment-method in holographic flow measurements

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The main task of holographic flow measurements before data evaluation is to overlay two reconstructed images in space as exactly as possible. This is usually achieved by additional measurements of appropriate calibration objects. In this article a new fast and easy-to-use alignment method is introduced with which no additional calibration measurements are required.

1 Introduction

In holographic flow velocimetry (HPIV) a field of small particles is recorded in double-exposure transmission holograms (pulsed Nd:YAG laser) obtained with two reference waves.

For noise suppression a low-coherence version of particle holography has been invented. This method – called *light-in-flight holography* – imposes certain restrictions on the optical setup[1]. In summary, the reference waves have to reach the holographic plate with identical azimuthal angles α and elevation angles $\pm\beta$ (Fig. 1). This guarantees, that reference wave R_1 serves as reconstructing wave R_2 (and vice versa) in the generation of the real image fields after rotating the hologram by 180° in the plane of incidence. The fields are obtained with collimated reference beams under CW-illumination in a replica of the pulse laser setup. Particle positions are extracted from CCD-based 3D-scans of the real images.

Since particle displacements are to yield the velocity, the reconstructed image space of both exposures has to coincide precisely. Usually, non-ideal practical conditions induce a small offset between the images:

→ Incorrect rotation:
the wrong angle of incidence produces mainly a lateral offset δx, δy.

→ Insufficient collimation:
the wave curvature is not complex-conjugate in recording and reconstruction which causes mainly a longitudinal offset δz.

Any bias displacement must be minimized because it reduces the measurement accuracy. By monitoring the location of image spaces it should be possible to adjust the reconstructing geometry for optimum coincidence.

2 Auxiliary point source for field matching

For high-quality flow mapping HPIV employs particle field correlation with sub-pixel accuracy[2].

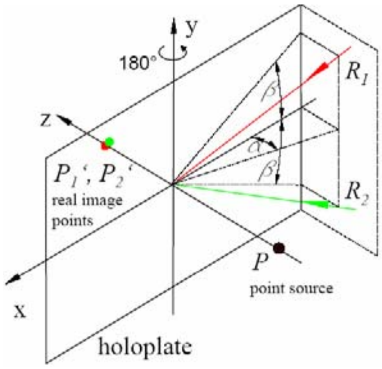

***Fig. 1** Geometry of the holographic setup*

This rules out any intensity-based matching of the location of the two image spaces as could be achieved by aligning ordinary calibration marks for overlap. Furthermore, the longitudinal offset would be very difficult to detect.

The basic concept of our new alignment-method is to record additionally a fixed point-source P on the hologram during both exposures. When reconstructing both images simultaneously the two light fields interfere and generate a fringe pattern in space (Fig. 2 – offset over-scaled). This pattern is recorded on a CCD-target to guide in minimizing any offset between the reconstructed point sources. One of the reconstructing waves is adjusted in curvature and angle of incidence until the fringes disappear.

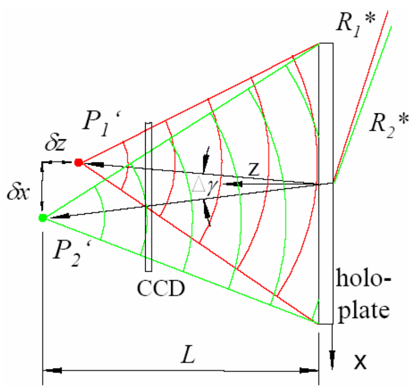

***Fig. 2** Interference of two point-source fields*

3 Modeling of point-source displacement

The position of a holographically reconstructed real-image point source is obtained from imaging equations that take into account the deviations in reconstruction angle and collimation[3]. On this basis a simulation software was created that generates the interference pattern on the CCD-target as a function of the geometry of recording and reconstructing setups.

Even in case of a non-matching reconstruction wave a first order approximation of the holographic imaging equations assuming paraxial conditions yields spherical waves that reconstruct the point-source images.

An error $\Delta\alpha$ in the direction of the incident wave results in a tilt $\Delta\gamma$ of the wave image (Fig. 2 – offset over-scaled). This tilt determines the fringe spacing D_x of the interference pattern on the CCD. The lateral offset δx can be calculated by

$$\delta x = L\Delta\gamma = \frac{\lambda L}{D_x} \qquad (1)$$

where *L* is the distance between hologram and point source. An analogous equation is valid for the y-direction.

A deviation from collimation that can be expressed by a reconstructing wave with a radius of $R < \pm\infty$ results in a longitudinal offset

$$\delta z \approx \pm \frac{4L^2}{R} \qquad (2)$$

The collimation is controlled with a *shear-plate-interferometer.* Thus the remaining radius should be at least 50 km which corresponds to a longitudinal offset $\delta z = 7\mu\mathrm{m}$ for $L = 0.3\mathrm{m}$.

4 Demonstration of alignment strategy

The calculated fringe patterns are compared with experimental results to yield data for the alignment procedure of one of the reconstruction waves. Furthermore, estimates give the smallest offset that can be achieved when adjusting the fringes for maximum spacing.

In Fig.3 some typical patterns are shown with their matched simulated patterns respectively to demonstrate the occurring fringe patterns and the alignment strategy. A predominant lateral offset δx or δy yields typically parallel fringes (Fig.3a, *Young´s Fringes*). If an additional longitudinal offset δz is present due to a misaligned collimation the fringes get curved (Fig.3b). Finally it is intended to maximize the fringe spacing. This is reached when there is only one fringe left (Fig.3c). Thus the accuracy with which the two images coincide lies in the subpixel domain.

The minimum detectable longitudinal offset δz is found to be $2\,\mu\mathrm{m}$

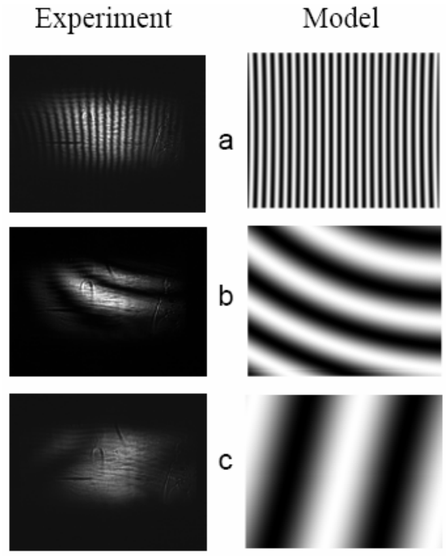

Fig. 3 *Hyperboloid interference patterns of two point sources*[4]*, (a)* $\delta x = 30\mu m$*, predominant,*
(b) $\delta x = 2\mu m, \delta y = 7\mu m, \delta z = 7\mu m$
(c) $\delta x = 2.4\mu m, \delta y = 0.6\mu m$

5 Conclusion

It is shown that an interferometric calibration of a holographic flow measurement is possible and that it has some advantages in comparison to traditional calibration objects or markers. Though the achieved accuracy is comparable the new method is non-iterative and a fast on-line adjustment without further calibration measurements is possible.

Furthermore a longitudinal offset could easily be detected and removed without scanning the CCD along this direction. The shown method is also less sensitive to noise in comparison to intensity-based matching of conventional markers with subpixel fitting. It is also useful to have a fixed reference point for navigation in the reconstructed flow volume.

The remaining problems of this method are on the one hand that beam-profiles of state-of-the-art high energy lasers are far from ideal which complicates the adjustment of the fringe pattern. On the other hand the *light-in-flight* technique requires a small aperture for reconstruction which reduces resolution.

References

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