Application of Visualization Methods

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The contribution treats the principles of optical visualization methods applied to the flow characteristics and velocity profiles measurement and to the evaluation of properties of optically transparent materials , especially transparent polymeric foils.

1. Introduction

Fluids, and particularly gases, are normally transparent and therefore invisible. It is necessary to use special optical visualization methods that enable one to observe the flowing fluid. The most common means of visualizing flow field is to record the refractive behavior of transparent flowing liquid when illuminated by a beam of visible light. There has been a very rapid improvement of shadow, schlieren and interferometric optical visualization method connected with the availability of lasers and holographic methods during the last decade. A major problem requiring a solution is development of efficient evaluation procedures .

2. Deflection and Retardation of Light in a Density Field

It is necessary to solve the problem concerning to the transmission of the light through the flow field that represents now in optical terms, a phase object with variable index of refraction. The refractive index n is considered to vary as a function of the three spatial coordinates x, y and z, e.g.,
$n = n\ (x, y, z)$.

Let's imagine, that an incident light beam, initially parallel to the z direction, is transmitted through the flow (fig.1). In a practical arrangement viewing windows are normal to the z direction. According to Fermat's principle [1] describing the propagation of a single light ray in the phase object, the variation of optical path length along a light ray in the object must vanish. Then

$$\delta \int n\ (x,y,z)\ ds = 0\ , \tag{1}$$

where s denotes the arc length along the ray, and ds is defined by

$$ds^2 = dx^2 + dy^2 + dz^2 \tag{2}$$

The main problem consists in determining $x = x(z)$ and $y = y(z)$ describing the path of the light ray through the refractive index field. To solve the system it is necessary to determine an initial condition specifying the particular light ray in the transmitted, parallel beam, that means to specify coordinates $x = \xi_1$ and $y = \eta_1$, where the ray enters the test volume. From the solution of the system also the coordinates ξ_2 and η_2 of the ray in the exit plane of the flow test volume as well as the inclination of the ray at the exit point can be determined. There is l the distance between the recording plane and the exit plane of the test volume in an optical arrangement in fig.1. In order to predict the observable pattern in the recording plane one has to determine, for each ray, three quantities:

- the displacement QQ^* of a deflected or disturbed ray with respect to an undisturbed ray (ray passing through a homogeneous field)
- the deflection angles ε_x and ε_y of the ray at the end of the test volume

- the retardation of the disturbed ray with respect to an undisturbed ray that can be expressed by the time difference Δt between the arrival of the two rays in the recording plane.

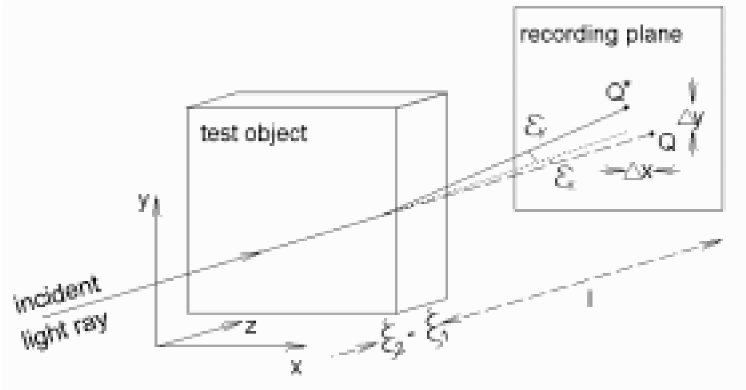

Fig. 1 Deflection of a light ray in an inhomogenous test object

It is possible to determine these quantities only under some simplifying assumptions:

- the deviations from the *z* direction in a compressible flow are negligibly small, but the ray may leave test volume with a unnegligible curvature
- the slopes of the ray, *dx/dz* and *dy/dz* are very small as compared with unity.

With the aid of these assumptions we can express the displacement *QQ** and the deflection angle ε in terms of the respective *x* and *y* components :

$$\left(\overline{QQ}^{*}\right)_{x} = l\int_{\xi_1}^{\xi_2} \frac{1}{n}\frac{\partial n}{\partial x}dz \qquad \left(\overline{QQ}^{*}\right)_{y} = l\int_{\xi_1}^{\xi_2} \frac{1}{n}\frac{\partial n}{\partial y}dz \qquad (3)$$

$$tg\varepsilon_{x} = \int_{\xi_1}^{\xi_2} \frac{1}{n}\frac{\partial n}{\partial x}dz \qquad tg\varepsilon_{y} = \int_{\xi_1}^{\xi_2} \frac{1}{n}\frac{\partial n}{\partial y}dz \qquad (4)$$

$$\Delta t = \left(\frac{1}{c}\right)\int_{\xi_1}^{\xi_2} \left[n(x,y,z) - n_{\infty}\right]dz \qquad (5)$$

In (5) *c* is the velocity of light in vacuum, n_∞ the refractive index of the undisturbed test field in which the reference rate propagates and ξ_1 a ξ_2 are the z coordinates of the points where a ray enters and leaves the test field. The quantity Δt can be converted into the optical phase difference $\Delta\varphi$ between an undisturbed and disturbed ray in the recording plane

$$\frac{\Delta\varphi}{2\pi} = \frac{1}{\lambda}\int_{\xi_1}^{\xi_2} \left[n(x,y,z) - n_{\infty}dz\right] \qquad (6)$$

There are three main optical visualization methods. The shadowgraph is a technique which visualizes the displacement *QQ** as represented by (3) and the Schlieren system measures the deflection angle ε described by (4). Optical phase changes experienced by a light ray in the flowing field according to (5) can be made visible with optical interferometers. It can be shown, that these three visualization methods exhibit different behavior. The shadowgraph is sensitive to changes in the second derivative of the liquid density ρ, the schlieren system visualizes changes in the first derivative of ρ, and interferometers enable to measure changes of absolute density.

3. Visualization by Means of Light Deflection

Shadowgraph method uses a parallel light bounded by a plane viewing windows transmitted through the test flow field. Shadow pattern produced by the phase object is recorded in a vertical plane placed behind the test object.

In a Schlieren system an optical disturbance in the optical transparent phase object will produce variations of the light intensity recorded onto the recording plane. A parallel light traversing test medium is focused by means of "schlieren head" (lens or spherical mirror). A knife edge is placed in the plane of the light source image to cut off part of the transmitted light. The camera objective focuses the test object onto the recording plane, where a reduced intensity of light can be observed [2]. The fundamental Schlieren system has found a great variety of modifications introducing colour, using the double-pass Schlieren system, Doppler principle or combination of the Schlieren system with holographic methods.

In an interferometric system one visualizes the interference of the ray passing through the test object with the second ray travelling to the recording plane along the different path. If the condition of optical coherence is fulfilled, the conjugate rays may interfere with one another and produce a certain interference pattern in the recording plane onto which a camera lens focuses the test object.

Considering the available instrumental facilities and the required sensitivity of measurements, we have chosen the Schlieren visualization method. A special optical apparatus constructed after J. Bolf [2] allows to record the static state or the dynamic phenomenon. At present we obtain the image by means of the optical system of a high-quality slide projector and a CCD camera. The image obtained in this way is directly recorded into the computer memory. Pre-processing of images consists in modifying the recorded picture into a form which is suitable for further processing.

The schlieren method is mainly used for qualitative purposes, but with a much higher degree of resolution than the shadowgraph. Photographic or digital records enable to distinguish between laminar and turbulent flow, that plays an important role while studying hydrodynamic properties of water valves, and especially of cardiac valve prostheses. Some quantitative results, e.g. velocity profiles of the particles carried by the stream can be investigated as well. For such an experiments salt crystals has been used.

Fig. 2 presents a photographic record of streamlines and velocity profiles for a Saint-Jude Medical bileaflet heart prosthese.

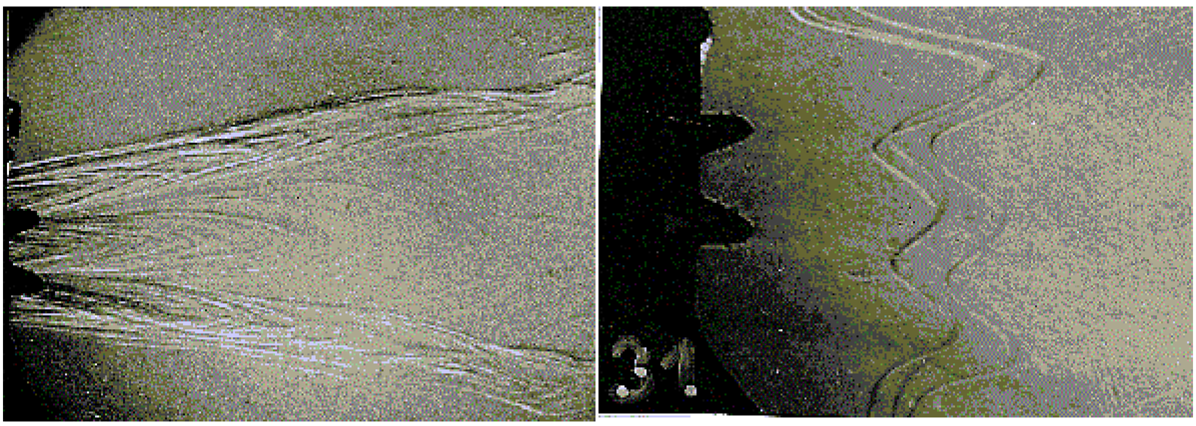

Fig.2 Streamlines and velocity profiles for St.Jude Medical bileaflet heart valve

Schlieren method can provide useful information on the visually inaccessible objects such as optically transparent polymers and, especially, polymeric foils are. The intensity of photon absorption changes in the area of deformation, which results in a change of the refraction index. The main advantage is that the information on the refraction index changes after photographic or digital recording, is available for further processing. It is necessary to keep identical conditions while recording all samples and to assure that the optical apparatus and surrounding will affect neither the digital nor the graphical representation. It is important to maintain identical conditions while recording all samples and to assure that the optical apparatus and surrounding will affect neither the digital nor the graphical representation [3], [4].

Visual quality assessment allows to locate, on a pre-processed picture, the places with elastic strains and with stress regions which are marked by variations in the level of brightness (grade of grey). This method is suitable for on-line evaluation of the quality of foils in their production. On some types of foils we have deliberately created defects for the purpose of visualizing the area of strain as illustrated in Figs.3.

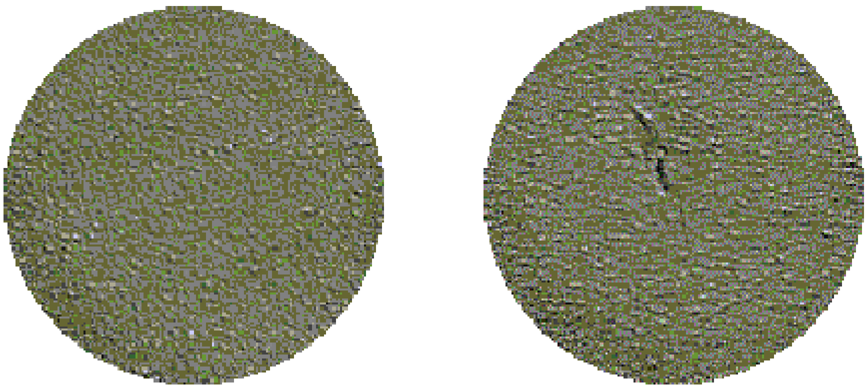

Fig.3: Picture of a defect-free foil KX40 and of the same foil with a deliberately created defect

Conclusion

The above mentioned optical visualization methods enable to study flow field and thus hydrodynamic properties of various objects. Schlieren method applied for assessing optical transparent polymeric foils allows to locate even very small deformations and defects .Paper [5] is devoted to the possibilities of applications of this method for the defectoscopy and identification of polymeric foils using statistical approaches.

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