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Visualization of refractive index gradients in a fluid-stream by carrier-restoration in dark-ground techniques

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The usual set-up for the dark-ground technique has been utilised for visualizing the refractive index gradients in a fluid medium. The carrier beam is first suppressed by an opaque stop and is subsequently restored in the field of view due to beam deflection on account of refractive index gradients. It is shown that a marked improvement in the qualitative visualization of the phenomena can be obtained by taking photographs of the image plane. As relatively short exposure times are required for recording this type of transient phenomenon, a 15 mw He-Ne Spectra Physics laser has been used in our experiment.

1. Introduction

When a beam of light passes through a fluid medium of varying density and therefore of varying refractive index, it is subjected to phase changes and to small deflections from its original direction of propagation. Various techniques are employed both for qualitative and for quantitative analysis of fluid flow to determine the deflections and to calculate the refractive index gradients set up within the medium. The Schlieren technique originally proposed by Toepler (1866), but more popularly known as the Foucault test, is the most common method for displaying the refractive index gradients in a fluid stream. This technique is particularly advantageous for measuring large deflections and calculating the refractive index variations from them. The shadowgraph method of Dvorak (1880) is essentially qualitative and exhibits the changes in the density gradient. Finally, there are interferometric methods (Kraushaar 1950, Sterrett & Erwin 1952) for regions of small gradients, which measure the density variations directly. Techniques for obtaining simultaneous records of a combination of Schlieren and interferometric methods have also been reported (Zobel 1947, Blue & Pollack 1952). All these techniques have widespread applications in diverse fields of aerodynamics, liquid diffusion, sedimentation, combustion research, heat transfer etc.

The above three fundamental techniques supplement each other and the ideal procedure will be to use all the three methods to obtain qualitative as well as quantitative information. There are again a few special variations to improve the performance of Schlieren systems by the use of graded filters (North

1952), coarse grid (Darby 1946), colour filters (Holder & North 1952), Savart plates (Savart 1840) and phase retardation plates (Zernike 1934). In this paper, we describe a qualitative method of visualizing the refractive index gradients in a fluid stream. In our experimental set up, the direct light coming from the object specimen in the test space is obstructed by an opaque stop placed in the back focal plane of the imaging lens. Thus in this case, unlike in a pure Schlieren system, only the carrier beam and no side band is suppressed. Incidentally, the same method is known as the dark-ground method in microscopy, diffrimoscopy in optical image formation, carrier suppression in communication theory and removal of zero frequency in spatial filtering techniques or optical data processing. The carrier beam can be subsequently restored by setting up a refractive index gradient which causes a deflection of the direct light from its original direction.

2. PRINCIPLE OF THE METHOD

Figure 1 illustrates the principle of the method. A parallel beam of light is allowed to pass through the test space *T* containing a fluid viz. a liquid of suitable refractive index. In the absence of any refractive index gradient within the medium, the parallel beam of light is focussed by the imaging lens *I* to a point *S* in its back focal plane. The point *S* is thus the image of the source of light. If an opaque stop is placed at *S*, no direct light will reach the image plane. Under these conditions, it is said that the carrier beam is suppressed and only the side-bands which correspond to the light diffracted by the object plane are allowed to pass. In a pure Schlieren system, a knife-edge is placed at *S* so that the carrier beam as well as side-band on one side are suppressed.

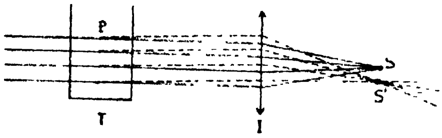

FIG 1

Fig. 1. Illustration of the carrier shift due to deflection.

Let now a refractive index gradient be set up within the test space in the region indicated by *P* by dropping another liquid of slightly different refrctive index. The beam of light passing through this region will be deflected from its original direction. There will be a shift of the carrier beam and the image of the source will now be formed at *S'*. The carrier beam can thus be restored in the image plane due to the variation of refractive index in the object space. This principle is utilised in the following experimental arrangement for fluid flow investigation.

3. Experimental Set up

As a powerful source of light is more convenient for recording this type of phenomena requiring relatively short exposure times, we employed a 15 mw. He-Ne Spectra Physics laser for our experiment. Figure 2 shows a schematic diagram of the experimental set up. The narrow beam of light from the laser L is expanded by the beam expanding unit E consisting of a microscope objective and a pinhole. The collimating lens O gives a beam of parallel light to iluminate the test space T which consists of a liquid cell containing pure castor oil. The refractive index gradient is set up by allowing drops of glycerine from the top. A Babinet compensator B and a polarioid A are used in between the test space T and the imaging lens I. The purpose of interposing the Babinet compensator with the polaroid will be explained later. However, as the laser beam is polarised, a separate polariser is not required before the Babinet compensator. An opaque stop made of an Indian ink dot on a good quality glass plate tested by a Fizeau interferometer is placed at S. A Zeiss recording camera model PP1021 with automatic control for single frame exposure is focussed on the image plane.

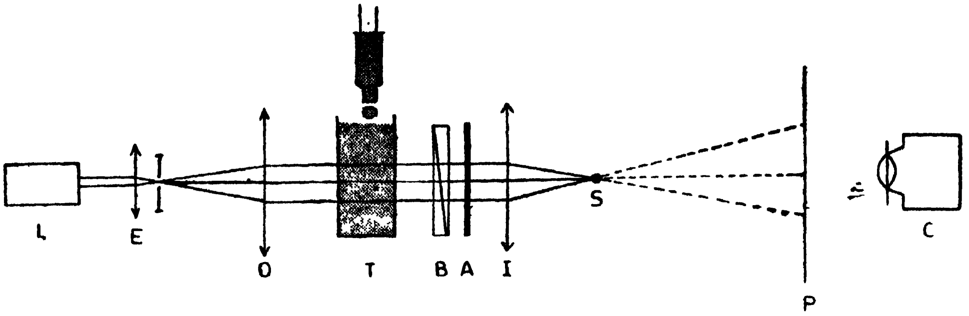

FIG. 2

Fig. 2. Schematic diagram of the experimental set up ; Code : L-Laser; E-beam expander; O-collimating lens; T-test space; B-babinet Compensator; A-Polaroid; I-imaging lens; S-Opaque stop; P-Image plane; C-Camera.

4. Results and Discussions

Pandya *et al* (1972) has recently suggested the use of Babinet compensator for measuring the deflections which are related to the refractive index gradients set up in the test space. We also chose a Babinet compensator with a different view so that it would be possible to visualize the system of sharp fringes within the glycerine drops whenever the carrier beam would be restored in the field of view. Thus, whereas their aim was to make a quantitative analysis of the phenomenon by *deflection mapping*, we have turned our attention towards an improvement of its qualitative visualization. To achieve this we focussed the recording camera on the image plane, whereas Pandya *et al* focused the camera on the test space

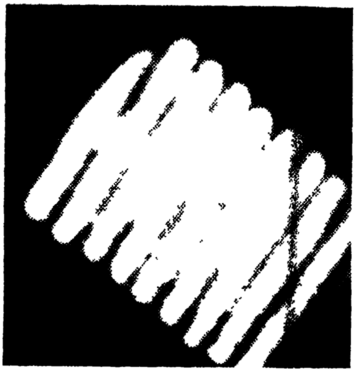

Fig. 3(a) Photograph of the image plane when the carrier beam is not suppressed.

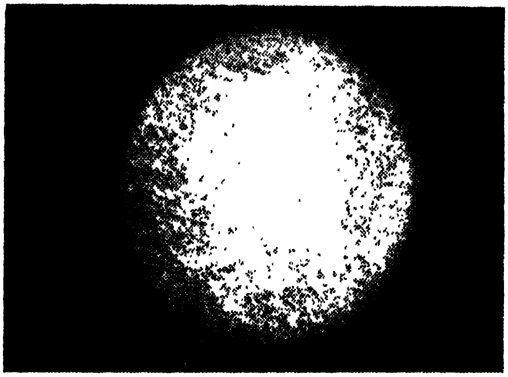

Fig. 3(b) Photograph of the image plane when the carrier beam is suppressed.

Fig. 3(c) Photograph of the image plane as the glycerine drop enters the field of view.

thereby reducing the magnification to a great extent and losing much of the information as to what is happening within the drop.

Figures 3(a), 3(b) and 3(c) show the photographs of the image plane under different conditions. These photographs were taken on ORWO 35mm films with exposure times of 1/125th of a second. The Agfa-Gevaert fine grain developer was moderately diluted and the exposed film was developed for 25 minuites at 20°C. Figure 3(a) shows the photograph of the image plane when the opaque stop is not used. The Babinet compensator was rotated about its horizontal axis and was fixed in a convenient position to give an inclined system of fringes. Figure 3(b) shows the photograph of the image plane when the carrier beam is suppressed by placing the opaque stop at S. The illumination on the image plane has evidently decreased due to the obstruction of the carrier beam. The factor by which the illumination on the carrier suppressed image plane is reduced, can be determined from a knowledge of the illuminance of the source, the height and the width of the illuminating beam, magnificantions and focal lengths of the collimating and the imaging lenses and the area of the opaque stop. Figure 3(c) shows the photograph of the image plane when the carrier beam is restored as the glycerine drop moves through the castor oil and enters the field of view. The distrotions in the restored fringe system reveal the presence of local variations in the refractive index within the drop

5. Conclusion

The conclusion from the present study is that one can record what is happening in the test space with a marked improvement in its qualitative visualization by taking photographs of the image plane.

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References

Blue R. & Pollack J. 1952 *Rev. Sci. Inst.* **23**, 754.
Darby P. 1946 NAVORD Report 74-46.
Dvorak V. 1880 *Wiedemann's Ann. Phys. Chem.* **9**, 502.
Holder D. & North R. 1952 *Nature* **169**, 466.
Kraushaar R. 1950 *J. Opt. Soc. Am.* **40**, 480.
North R. 1952 Brit. A.R.C. No. 15099.
Pandya T. P., Saxena A. K. & Srivastava B. C. 1972 *Rev. Sci. Inst.* **43**, 1185.
Savart M. 1840 *Ann. Physik.* **49**, 292.
Sterret J. & Erwin J. 1952 NACA TN 2827.
Toepler A. 1866 *Pogg. Ann. Phys. Chem.* **127**, 556.
Zernike F. 1934 *Physica* **1**, 689.
Zobel T. 1947 NACA TM 1184.