APPLICATION OF PULSED OPTICAL QUANTUM GENERATORS (O.Q.G.) AS LIGHT SOURCES FOR SHADOW AND INTERFERENCE INSTRUMENTS

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APPLICATION OF PULSED OPTICAL QUANTUM GENERATORS (O.Q.G.) AS LIGHT SOURCES FOR SHADOW AND INTERFERENCE INSTRUMENTS

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The shadow and interference methods used in the study of aerodynamic and aerophysical processes make it possible to solve a broad class of problems in modern gas dynamics. For the investigation of rapidly occurring phenomena, in many cases it becomes necessary to use high-speed optical recorders. Until recently their application was limited mainly by the absence of light sources possessing high brightness with a comparatively small size of the luminous body. Optical quantum generators (o.q.g.) satisfy these requirements.

O.q.g.' s have already found application as light sources in optical visualization instruments. In interferometry their use has made it possible to improve the quality of the interference pattern (⌒1), to diversify and simplify a number of interference schemes, since in this case the difficulties associated with the need to correct the chromatic aberration of optical elements are completely eliminated, and the possibility is opened of using schemes with a nonzero path difference and with different cross sections of the reference and working arms of the interferometer, etc. (⌒2, ⌒3).

Optical quantum generators are also successfully used in combination with shadow instruments (^{3}-7).

Alongside their advantages, schemes with o.q.g.' s also have certain drawbacks. For example, on interferograms obtained with the aid of an o.q.g., quantitative calculation of density is difficult in the presence of density jumps at which the interference fringes are discontinuous. In shadow schemes, a serious problem is obtaining uniform illumination over the working field, as well as ensuring the preservation of the knife edge and slit at high energy-flux densities of o.q.g. radiation.

Fig. 1

Figure 1: Fig. 1

Up to the present time, investigations using an o.q.g. as a light source for interferometric-shadow instruments have been carried out either with gas lasers or with o.q.g.' s with modulated Q-factor (^4, ^9, ^8). These types of generators are unsuitable for high-speed photographic recording because of the low output power in one case and the excessively short generation time in the other. The present article presents the results of the development and application of pulsed o.q.g.' s (in the free-running mode) as light sources for shadow and interference instruments in the investigation of unsteady processes in shock tubes.

Figure 1 presents the optical scheme of the o.q.g.—interferometer—motion-picture camera system. A parallel beam of light from the o.q.g. 1 enters the illuminator of interferometer 2, from which the condenser, necessary when working with ordinary light sources, has been removed, and is focused in the plane of the entrance slit 3 of instrument 4. The interference pattern is recorded by photorecorder 5 and motion-picture camera 6. An interferometer of the type was used

Mach–Zehnder (IZhK-454). One of its receiving sections was used to obtain an interference pattern of the entire observed field (frame-by-frame photography), the other to obtain a continuous sweep on a photographic recorder in order to determine the velocities of the shock wave and contact surface, to investigate the structure of the shock wave, and to monitor the uniformity of the flow.

In order to avoid vignetting of the light beam by the rims of the mirrors and beam-splitting plates of the interferometer, the optical axis of the quantum generator is aligned with the optical axis of the illuminator by means of an auxiliary gas laser and special diaphragms.

Fig. 1

To couple the motion-picture camera to the interferometer, an optical system 7 was used, consisting of two standard I-37 lenses located at twice the focal length from one another. The coaxial alignment of the interferometer and the motion-picture camera was achieved by superposing the centers of the pupils and the centers of the fields of view of both instruments. In an analogous manner, the ultrahigh-speed photographic recorder was also joined to the interferometer. In this case the slit of the photographic recorder was located in the plane of the intermediate image of the interference pattern.

Figure 2 shows the optical scheme of the system: optical quantum generator—shadowgraph instrument (IAB-451)—motion-picture camera. Here the parallel light beam from the optical quantum generator 2, through the relay optics 3, falls on the entrance slit of the collimator of the shadowgraph instrument 4. After passing through the receiving section of the shadowgraph instrument 5,

Fig. 2

Figure 2: Fig. 2

the beam is focused in the plane of the Foucault knife 8. Then, by means of the optical system (standard I-51 lens 6, condenser of the receiving section of the shadowgraph instrument 9), the image of the slit in the plane of the Foucault knife is projected onto the entrance pupil of the motion-picture camera 7.

Fig. 2

The I-51 lens is set at the focal distance from the plane of the image of the shadow pattern obtained behind the condenser of the receiving ···

[Fig. 4]

Fig. 4

[Fig. 3]

Labels visible in the figure:

- **Sweep direction**
- **Direction of motion of the shock wave**
- **reflected wave**
- **incident wave**

Fig. 3

parts. To obtain a sharp image on the motion-picture film, the entrance lens of the motion-picture camera must be set to the "infinity" position.

For visualization of unsteady processes by means of the system **optical quantum generator–shadow instrument–motion-picture camera**, special relay optics 3 were developed, installed between the optical quantum generator and the IAB-451 collimator. They make it possible to obtain an adjustable luminous area of the light source, both in illumination and in size. Alignment of the optical quantum generator, the relay optics, the shadow instrument, and the motion-picture camera was carried out with the aid of special diaphragms and an OKG-11 gas laser (7).

As recording apparatus, high-speed motion-picture cameras SSKS-3 (filming rate up to 250,000 frames/sec), FP-22 (up to 100,000 frames/sec), SFR-1M (up to 2,500,000 frames/sec), and an ultra-high-speed photorecorder (sweep speed up to 8000 m/sec) were used. As the light source for the interferometer and the shadow instrument, a ruby optical quantum generator specially developed for this purpose was used. Structurally, it consists of five separate units: the resonator, the optical head, the power-supply and pulsed-lamp ignition unit, including the synchronization circuit, the capacitor bank, and the remote-control console.

The principal parameters of the optical quantum generator are: radiation wavelength 6943 Å, pulse energy 10 J, generation duration 1 msec.

In time-resolved recording of the interference or shadow pattern of a process, the light source must provide approximately constant intensity over the entire required time interval. The generation pulse of a solid-state optical quantum generator, as a rule, consists of chaotic pulsations of radiation (spiking mode). This feature is most characteristic of a plane-parallel resonator with a comparatively small distance between the mirrors. One of the known methods for suppressing chaotic modulation of the radiation brightness is the use of a resonator with a concentric or confocal arrangement of spherical mirrors (9).

In view of the circumstances indicated, we chose a concentric resonator, which makes it possible to obtain a quasi-continuous (spike-free) generation mode.

The optical quantum generator was used as the light source for the interferometer in experiments investigating the unsteady flow around bodies by a gas stream moving behind a plane shock wave. The experiments were carried out in a shock tube according to a single-diaphragm scheme; the test gas was air. The optical quantum generator was triggered from a piezoelectric transducer through a thyratron delay line. Individual motion-picture interferograms of the flow around the model (shock-wave velocity $\bar{u} \approx 1070$ m/sec, pressure of the test gas $P = 8.7$ mm Hg) are presented in Fig. 3a. The filming rate was 100,000 frames/sec.

Analysis of the results obtained shows that the quality of the interferograms is no worse than with an ordinary light source. From the motion-picture records one can trace the development of the process of flow around the model in space and time, the shape and direction of motion of the density discontinuities, obtain the density distribution behind the detached bow shock, etc.

Figure 3b shows a streak photograph of the process, obtained simultaneously with the motion-picture record. In the streak photograph the front of the incident shock wave is visible. From the angle formed by the line of displacement of the front and the direction of the sweep, its velocity was determined. Behind the front of the shock wave there follows a region of uniform flow, whose interaction with the model leads to the formation of a bow shock, producing on the streak photograph a smoothly varying line. Approximately 150 μsec after the beginning of the interaction of the shock wave with the model, this line becomes horizontal, indicating the establishment of steady flow around the model.

The optical quantum generator—shadow instrument—motion-picture camera system was used in experiments to study the propagation of a self-luminous shock wave (pressure of the gas under study $P_{\mathrm{n}} = 100$ mm Hg, shock-wave velocity ≈ 700 m/s). Individual motion-picture frames of the process are presented in Fig. 4. The use of an optical quantum generator with a concentric resonator made it possible to obtain an image field of the shadow instrument that was uniform in illumination. The scatter in the blackening over a frame and from frame to frame (according to the results of photometry of blank frames) was within the accuracy of photometry, which makes it possible to carry out quantitative shadow studies. The motion-picture records provide a clear visualization of the process (the presence of the first and second shock waves, the flow behind the shock-wave front, and density jumps behind the second wave) with good sensitivity of the system. The slit width in the receiving part of the shadow instrument was 0.1 mm; the size of the open part of the slit image was 0.04 mm; the filming speed was 200,000 frames/s; the camera was an SFR-1M.

Thus, the use of an optical quantum generator as a light source for interference and shadow instruments makes it possible to record rapidly occurring gas-dynamic processes in time at a filming frequency of at least up to 200,000 frames/s and at a continuous-sweep speed of up to 500 m/s. The limiting numerical characteristics indicated were limited by the capabilities of the recording equipment used in our experiments and can be substantially increased.

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Note: Figure translations are in progress. See original paper for figures.