LASERS AS LIGHT SOURCES FOR MACH – ZEHNDER INTERFEROMETER

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Applications of lasers as light sources in interferometers are analyzed. An experimental circuit is described. Interference patterns obtained with a Mach–Zehnder interferometer using a laser-like source are given.

Double-beam interferometry is widely employed in qualitative and quantitative analysis of gas-dynamic problems [1-3]; this has stimulated the further development of standard interferometer arrangements. It seems very promising to employ lasers as sources of monochromatic and coherent light for interferometers [5, 6]. The most significant deviations of the characteristics of a Mach–Zehnder interferometer from those of an ideal system result from problems with the light sources ordinarily used, which deliver a spectrum of finite width and which as a rule is not coherent [1, 4]. The finite spectral width of the source restricts the number of contrasting interference bands that can be obtained, while to obtain a coherent field from a noncoherent source of finite extent it is necessary to employ aperture stops which, in the last analysis, result in substantial losses in the light introduced into the interferometer. Moreover, since most of the media investigated are nonstationary, the coherence of the interfering beams depends on the time required for photographic recording of the interference pattern. As a consequence, short exposures are required to record the pattern, and this is very difficult to accomplish, given the ordinary light sources.

In terms of the above, a laser-like source would be ideal. The spectrum emitted by a laser is actually so narrow that it cannot be measured even by means of high-resolution spectrometers. Heterodyne experiments [7, 8] have shown that a He–Ne laser, for example, has a monochromicity that reaches $\Delta\lambda/\lambda \approx 10^{-14}$; owing to the finite spectral width, this gives a permissible interferometer path difference of $\delta = \lambda^2/\Delta\lambda \approx 10^{10}$ cm. Laser emission has a high degree of temporal and spatial coherence, while the time amplitude stability is also good [7]. Thus interference can be observed with very significant optical-path differences for the interfering rays with no reduction in band contrast.

In the high-power mode, these characteristics make laser emission preferable to ordinary light-source output for interferometer purposes.

The availability of Q-switched pulsed lasers, generating giant pulses lasting only a few dozen nanoseconds more or less, expands the possibilities of investigating both rapid processes and nonstationary processes, such as those in turbulent media, since any turbulent flow can be considered to be quasistationary within such short time intervals.

Utilization of laser-like sources in Mach–Zehnder interferometers is of interest to those concerned with experimental gas dynamics, among other fields. We speak here of a new trend in optics, holography and, in particular, holographic interferometry [2, 8, 9]. Holography makes it possible to accomplish the total optical experiment – to record both amplitude and phase information about the investigated object. Thus it is possible to correct for the optical properties of the instruments employed in the experiment after the experiment has been completely run. For example, if we have a hologram of the investigated object, we can study it by various optical methods: interference, shadow, bright-point, etc. From the methodological viewpoint, we can classify holographic interferometry as double-exposure interferometry, which

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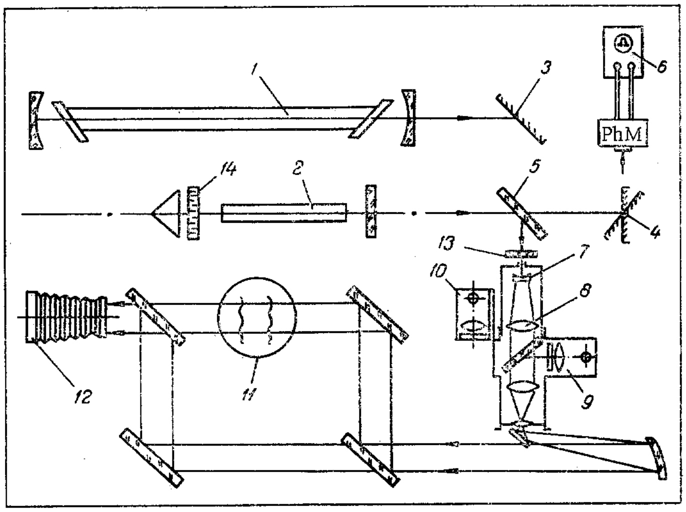

Fig. 1. Basic optical setup: 1) He–Ne laser; 2) ruby crystal; 3, 4) mirror; 5) plane-parallel flat mirror; 6) oscilloscope; 7, 8) two-lens laser-beam input system; 9) side element of mercury-vapor lamp; 10) upper hinged white-light element; 11) interferometer; 12) aerial-photography camera; 13) neutral filter; 14) active filter.

yields both ordinary two-beam and differential interferograms for two light beams intersecting in neither time nor space, with all the advantages entailed, and as interferometry with single exposure at two wavelengths, which yields differential interferograms carrying information on the dispersion properties of the investigated object and permitting us to investigate, for example, concentration and temperature fields, provided the medium possesses the refractive-index dispersion necessary for the two-wavelength method. It is particularly noteworthy that we can multiply the sensitivity of the interferometer method by using differential interferograms and successively superposing holographic patterns on a single hologram [8].

A type IT-14 Mach–Zehnder interferometer has been used in conjunction with a He–Ne gas laser and a Q-switched ruby laser. The gas laser had an output power of about 15 mW at 6328 Å. The glass discharge tube was about 1.15 m long, with an inside diameter of 7 mm. A directly heated oxide cathode and a tantalum anode were used as the electrodes. The tube was supplied by a high-voltage rectifier. In peak-power mode, the discharge current was 50 mA. A 30 kΩ ballast resistor was connected in series with the discharge tube. The discharge was initiated by a capacitor, charged to twice the rectified voltage, and connected across a portion of the ballast resistor. As a result, triple the supply voltage was applied to the discharge tube. The beam was taken out through a window set at the Brewster angle. One of the laser mirrors was nontransmitting, while the other had a reflection factor of 98.5% at 6328 Å. The resonator mirrors had radii of curvature of about 1.2 m, and operated under nearly confocal conditions. Thus numerous modes were generated simultaneously, so that a fairly uniform intensity distribution could be obtained in the laser-beam cross section. The discharge tube and mirror were contained within a dust-proof rigid housing, and were installed on a shock mounting.

The Q-switched pulsed ruby laser was constructed as a single portable unit containing all the laser elements: the laser head, pumping-lamp supply and control systems, a closed-loop water-cooling system, and so forth. The active element was a ruby 90 mm long and 7.5 mm in diameter. The modulator was a cell filled with phthalocyanine dissolved in chloroform. The ruby laser had the following basic characteristics: emission wavelength 6943 Å, energy emitted per pulse, 0.1-0.3 J, nominal pumping energy 600 J; pulse length 50-70 nsec; the device could be operated periodically at 2 Hz, or in one-shot mode, with manual firing.

Figure 1 shows the basic arrangement used to introduce the laser beams into the collimator of a standard type IT-14 Mach–Zehnder interferometer. Slight structural modifications were made in the illumination portion of the interferometer. The upper lamp element, containing the white-light source, was made hinged. This made it very simple to introduce the laser beams into the interferometer, without eliminating the possibility of white-light operation. The two-lens system was installed at the location of the first condenser lens, which was then mounted at the bottom of the upper white-light element. The two-lens system

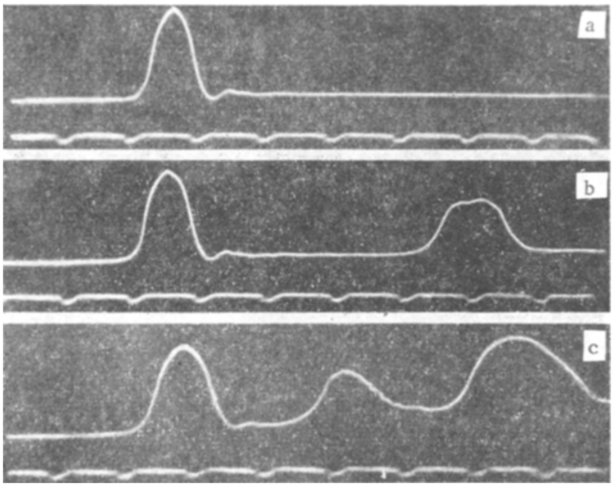

Fig. 2. Oscillograms of ruby-laser pulses: a) single; b) double; c) triple. Markers are 100 nsec apart.

converts the nearly parallel narrow beam of laser light into a parallel beam of the required width in accordance with the optics employed: the first short-focus lens 7 of this system was negative, to prevent the formation of a high-intensity focused laser beam, which could lead to breakdown in the air or in the lens itself.

A system of flat mirrors (Fig. 1) is used to introduce the beam from the gas or ruby laser into the two-lens system. As a result, at the collimator focus we obtain an extremely bright light source with almost zero equivalent dimension. The ruby laser is adjusted by an autocollimation method with the aid of the exposed gas-laser beam. This involves the use of some of the light reflected from plane-parallel flat mirror 5; this light was directed to the face of the ruby by means of flat mirror 4, perpendicular to the beam formed by the reflected portion of the gas-laser beam. After the multiple reflections between the flat mirror and the ruby face were combined, it could be assumed that the light generated by the ruby laser would propagate along the same path as that which had been followed by the exposed gas-laser beam. Mirror form was then so adjusted that the transmitted light from the ruby laser struck a photocell in the circuit 6 used to monitor the emission pulse characteristics.

Experiments with both ruby and gas lasers showed that despite the multimode nature of the emission and, therefore, the nonuniform distribution of light intensity across the beam cross section, interferogram quality was quite satisfactory (see Fig. 3).

Thanks to the high-intensity laser light, it was possible to use Isopanchrome-13 wide-format 19 cm aerial-photography film. In work with the helium–neon laser, exposures of from 1/1000 sec to 1/25 sec were used, depending on the magnification of the interference pattern from the investigated objects. For the "giant-pulse" ruby laser, we used a portion of the light reflected from the transparent plane-parallel flat mirror 5, attenuated by a factor of ten by the neutral light filters 13.

When laser emission is used, there is almost no need for compensation of the interfering-beam optical paths, or for elimination of angular deviations and displacements of the beams with respect to one another, i.e., the instrument initially requires no attention for production of a high-contrast pattern. When the pulsed laser is used, a gas laser is used for the initial adjustment.

Figure 2 shows oscillograms of the emission from a ruby laser. Multiple pulses can be eliminated, and pulse length reduced to 20-30 nsec by means of an active filter with carefully selected transmission coefficient.

Figure 3 shows typical interferograms obtained in a long series of experiments involving the investigation of concentration fields with a foreign gas blowing sharply through a porous surface into a laminar air flow. The CO_2 secondary gas was supplied through a flat porous plate, mounted flush in one wall of a square 40×40 mm channel. The main gas flow moved at a rate of $U_\infty = 1.2$ m/sec, with the foreign gas supplied at $W \approx 1$ liter/sec. The interferograms clearly show the zone of maximum concentration gradients, which

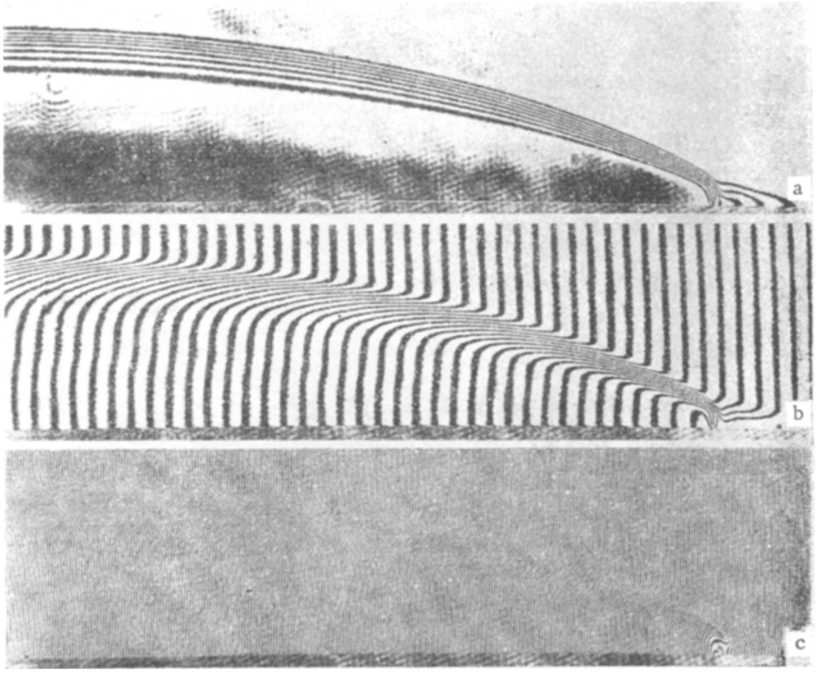

Fig. 3. Interferograms showing CO_2 in an air stream, obtained with laser light source (the main flow is from right to left, while the CO_2 enters through the bottom porous wall): a) adjustment for bands of equal concentration; b, c) adjustment for broad and narrow bands of equal thickness.

becomes fairly tenuous at large distances from the porous surface. Analysis of the interferograms shows that the zone containing 100% concentration of the foreign gas component occupies a considerable region.

Thus the use of laser-like sources in interferometers considerably simplifies the operations involved, while improving the reliability and accuracy of interferometer research.

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