XII. LASER APPLICATIONS[*]

Academic Research Staff

Prof. S. Ezekiel

Graduate Students

L. A. Hackel
P. D. Henshaw
J. A. Monjes
T. J. Ryan
J. W. Stafurik
J. P. Sullivan
D. G. Youmans

RESEARCH OBJECTIVES

Our interest is primarily in the application of lasers to a variety of measurement problems. In certain cases, the available lasers are not too suitable and considerable research has to be done to improve or modify the laser performance. Several projects are in progress.

1. Laser Frequency Stabilization

The motivation for this work stems from the need for a long-term frequency stabilized laser in the precision measurement length, i.e., length standards. Such a laser would find applications in earth strain seismometry, optical communication, and fundamental measurements, in particular, those related to experimental relativity.

The task, at present, is to stabilize the frequency of the 5145 Å argon ion laser. The stabilization scheme employs a resonance absorption line, observed in a molecular beam of iodine, which we have recently uncovered, as an absolute frequency reference. The absorption is measured by the resonance fluorescence induced by the laser in the molecular beam. Such an absorption line is an ideal reference element, because of the isolated and unperturbed conditions in the beam. Moreover, since the molecular beam can be oriented at right angles to the laser beam, the width of the iodine resonance is limited to its natural width which is inferred to be 50 kHz from lifetime measurements. Preliminary experiments indicate that it should be possible to stabilize the frequency of the laser to one part in 10^{13}.

Our major effort thus far has been the improvement of the short-term stability of the argon laser by suppression of plasma oscillations and noise in the laser plasma tube. This has enabled us to get a high-resolution absorption spectrum of I_2 in a molecular beam. The measured width of the individual I_2 lines is less than 10 MHz $[\Delta\nu/\nu \approx 10^{-8}]$, which includes approximately 6 MHz of Doppler broadening, because of the geometrical angular width of the molecular beam. Work is in progress to narrow the observed I_2 linewidths and also to lock the laser frequency to one of the iodine resonances.

2. Pulsed Ion Laser Holography

The purpose of this research is to investigate possibilities for generating pulsed, high-power, multicolor laser output by using a mixture of noble gases, such as argon, krypton and xenon, for interferometric and holographic applications.

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For pulsed color holography, a laser is needed that simultaneously puts out three primary colors of equal intensity in one short pulse. This work involves the study of excitation mechanisms in the presence of a mixture of noble gases to yield the desired laser output.

Aside from color holography, a hologram that is recorded with two colors (or frequencies) and reconstructed with only one color displays contour lines (lines of equal distance from the hologram plate) superposed over the surface of the holographic image. The spacing between contour lines, which represents surface changes, is proportional to the frequency separation of the two colors used in the recording of the hologram. For this type of application, an investigation is being conducted into schemes for generating two-frequency laser output where the frequency separation can be varied. Ultimately, we would like to use this surface contour generation method, which requires only a single short exposure, to study dynamic behavior of structures and materials and also for growth measurement in biological subjects.

A pulsed ion laser has been constructed with sufficient energy (~10 mJ) in one pulse, (single frequency and single color)to make a good quality hologram. By use of two dispersion prisms, a scheme for selecting various laser colors with the minimum of losses has been developed. Multicolor holography is in progress.

3. Flow Measurements

Laser Doppler techniques are being developed for measurement of both low-speed and high-speed fluid flow. We have a two-dimensional heterodyne scheme for measuring velocity distribution in vortex rings. Later this scheme will be used in the study of helicopter rotor-tip vortices. For high-speed flow greater than 10^3 cm/s a Fabry-Perot cavity is used as a frequency discriminator.

4. Closed-Loop Holographic Interferometry

We are investigating a new type of holographic interferometer. A diffuse object has been locked (within tens of angstroms) to its holographically stored virtual image by means of a servo loop. This technique is being explored for application to sensitive displacement detection using diffuse surfaces, and for measurement of monolayers.

S. Ezekiel

A. HIGH-RESOLUTION LASER-EXCITED SPECTRUM OF I_2 MOLECULAR BEAM

A high-resolution spectrum of I_2 has been excited by a tunable single-frequency 5145 Å argon ion laser. This is part of our effort at long-term stabilization of the frequency of the 5145 Å argon laser by locking it to an I_2 resonance observed in a molecular beam.[1, 2]

Figure XII-1 is a schematic diagram of the apparatus. A single-frequency cw argon ion laser oscillating at 5145 Å excites a molecular beam of iodine at right angles. The laser-induced resonance fluorescence of I_2 is monitored on a photomultiplier. The frequency of the laser is tuned across the bandwidth of the laser gain medium to reveal the I_2 structure shown in Fig. XII-2. The width of the individual iodine lines is less than 10 MHz, which includes at least 6 MHz of Doppler broadening because of the

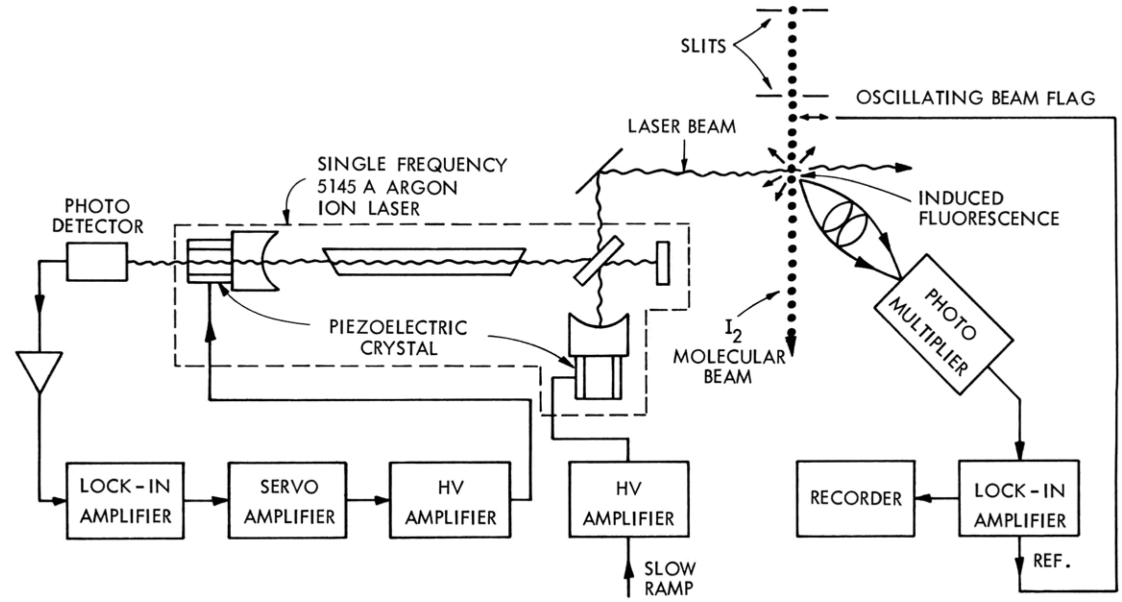

Fig. XII-1. Diagram of apparatus.

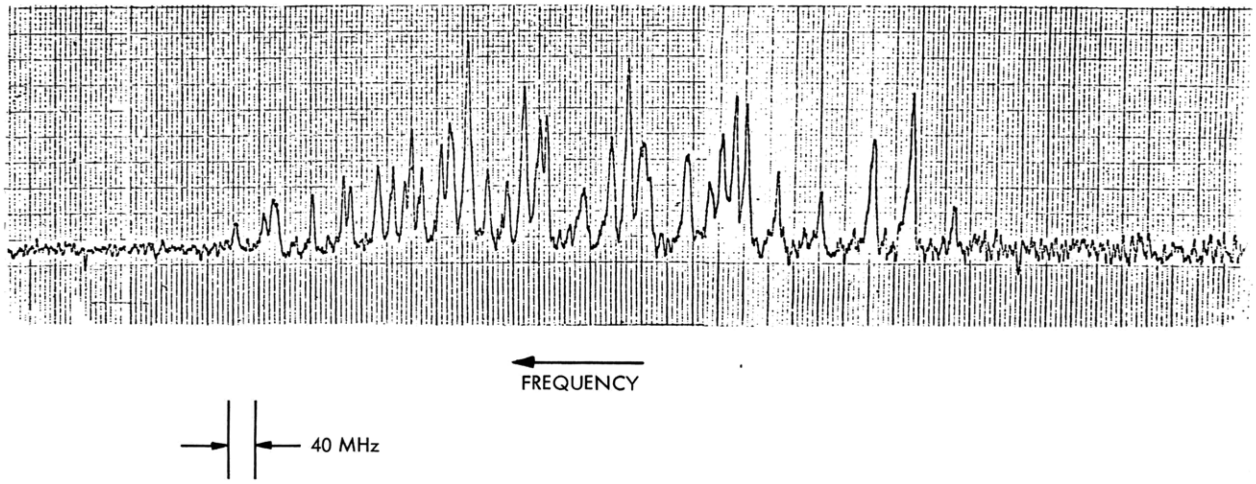

Fig. XII-2. Resonance fluorescence of I_2 molecular beam induced by tunable single-frequency 5145 Å argon laser.

geometrical angular width of the molecular beam. The natural width of the I_2 lines is ~100 kHz, inferred from a lifetime measurement (3 μs) previously performed in the beam.[1] The discrepancy between measured width and natural width, aside from geometrical Doppler broadening of the beam, is being studied. At present, the major cause of frequency jitter of the laser is acoustic noise. Coherent plasma oscillations have been suppressed.[3] An analysis of the I_2 spectrum will be the subject of a future report.

Work is now under way to lock the laser to the center of one of the I_2 resonances. An effort is also being made to observe the "Lamb dip" in the fluorescence at the center of the line when the molecular beam is subjected to a standing-wave field instead of a traveling-wave field. The width of the dip is approximately that of natural width, and it would be extremely useful for frequency stabilization.

T. J. Ryan, D. G. Youmans, L. A. Hackel, S. Ezekiel

References

1. S. Ezekiel and R. Weiss, "Laser-Induced Fluorescence in a Molecular Beam of Iodine," Phys. Rev. Letters 20, 91 (1968).
2. S. Ezekiel and R. Weiss, Quarterly Progress Report No. 88, Research Laboratory of Electronics, M.I.T., January 15, 1968, pp. 61-66.
3. D. C. Galehouse, U. Ingard, T. J. Ryan, and S. Ezekiel, "Investigations of Coherent Oscillations in an Argon Ion Laser Plasma Tube," Appl. Phys. Letters 18, 13 (1971).

B. TWO-DIMENSIONAL LASER DOPPLER VELOCIMETER FOR FLUID FLOW[*]

Traditionally, the velocity of a time-variant flow field has been measured by using a hot-wire anemometer. The use of a hot wire in the wake of a helicopter poses two

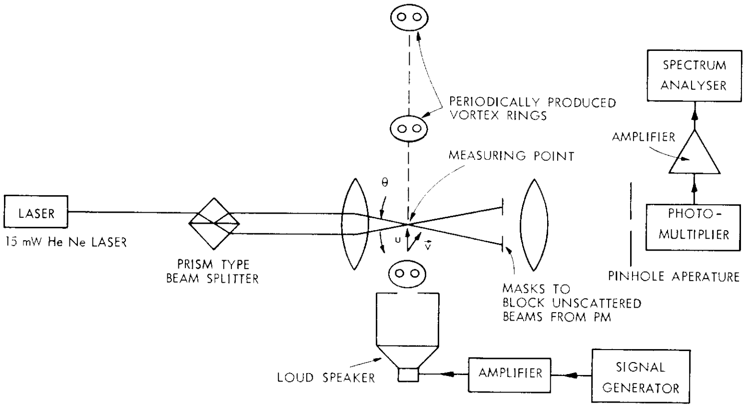

Fig. XII-3. One-dimensional dual scatter LDV system.

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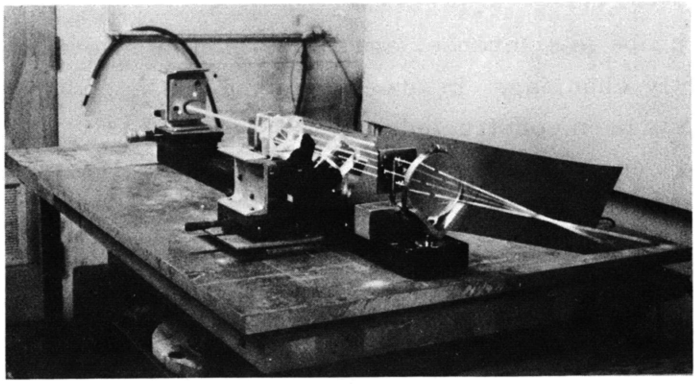

Fig. XII-4. Two-dimensional LDV system.

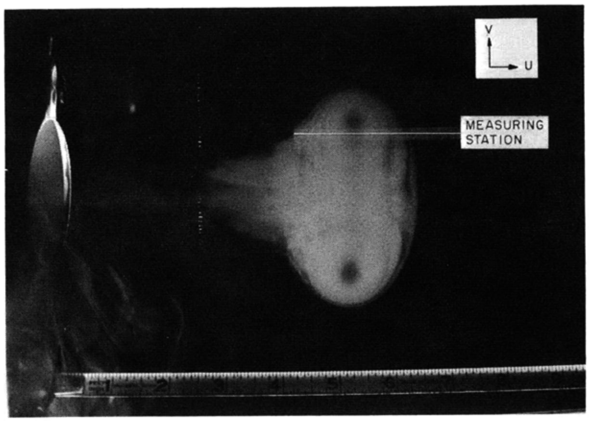

Fig. XII-5. Vortex ring.

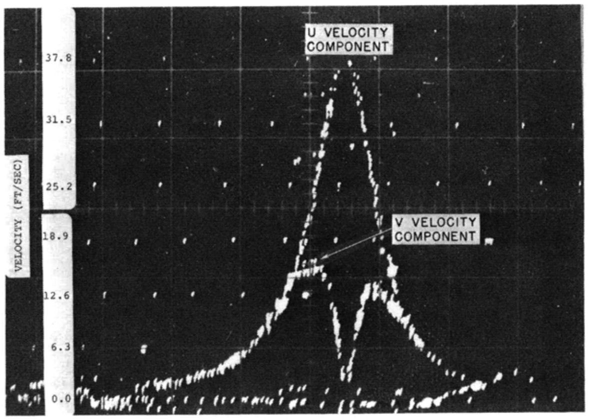

Fig. XII-6. Velocity distribution through vortex ring.

serious problems: probe interference, and calibration in a flow field where the flow direction is constantly changing. In order to avoid these problems a laser Doppler velocimeter (LDV) has been constructed.

The LDV, introduced by Yeh and Cummings[1] measures the Doppler shift of laser light scattered from small particles (smoke, dust, polyethylene spheres) which follow the flow field.

The actual LDV system constructed is a dual scatter or fringe system.[2,3] A one-dimensional dual scatter system is shown in Fig. XII-3. The laser beam is split into two parallel beams and then focused together. A particle traveling through the intersection of the two beams scatters light of frequency f_1 from one beam, and of f_2 from the other. The photomultiplier detects the difference or beat frequency of the scattered light, which is

$$f_D = \frac{2U \sin \theta/2}{\lambda_o},$$

where U is the velocity component perpendicular to the bisector of the two beams (see Fig. XII-3); λ_o laser frequency = 6328 Å; and θ is the angle between the two beams. The system is also called a fringe system, since a set of interference fringes is formed at the intersection of the two beams. The particle scatters from a bright fringe, moves into a dark fringe, then scatters from a bright fringe, and so forth.

A two-dimensional system has been constructed by adding another beam splitter to form 4 parallel beams. A photograph of the actual system is shown in Fig. XII-4. This system has been used to measure the velocity distribution in periodically produced vortex rings (smoke rings). The rings are similar to a helicopter rotor wake because regions of time-variant concentrated vorticity are produced yet the flow field is simpler, since it is axisymmetric. A picture of a vortex ring is shown in Fig. XII-5 and the corresponding velocity distribution in Fig. XII-6. The velocity curves are the U and V components (Fig. XII-5) of velocity vs time as the vortex ring travels by the fixed measuring point. There is a 180° ambiguity in the velocity vector because frequency is always positive. Flow visualization indicates that the U component is always positive, while the V component is positive to the left of the central zero and negative to the right.

The measurement of the velocity distribution in the vortex rings demonstrates the capability of measuring fluid velocities in flows containing time-variant concentrated vorticity. In the future the two-dimensional LDV system will be used to make velocity measurements in the wake of helicopter rotors.

J. P. Sullivan, S. Ezekiel

References

1. Y. Yeh and H. Cummins, Appl. Phys. Letters 4, 176-178 (1964).
2. M. J. Rudd, J. Phys. E. 2, 55-58 (1969).
3. A. E. Lennert, E. B. Brayton, and F. L. Crossay, Summary Report of the Development of a Laser Velocimeter to be Used in Arnold Engineering Development Center Wind Tunnels, AEDC-TR-70-101, July 1970.

C. CLOSED-LOOP, REAL-TIME, HOLOGRAPHIC INTERFEROMETRY

Using a real-time holographic interferometric arrangement as shown in Fig. XII-7, we have been successful in locking the real-time holographic image to the real object by means of a feedback loop. In this way, a displacement of the surface of the real object may be monitored with extreme sensitivity. Our preliminary results indicate that it is possible to detect displacements of the order of 10 Å, and it is not unreasonable to expect that this number can be reduced by several orders of magnitude by further refinements of our scheme.

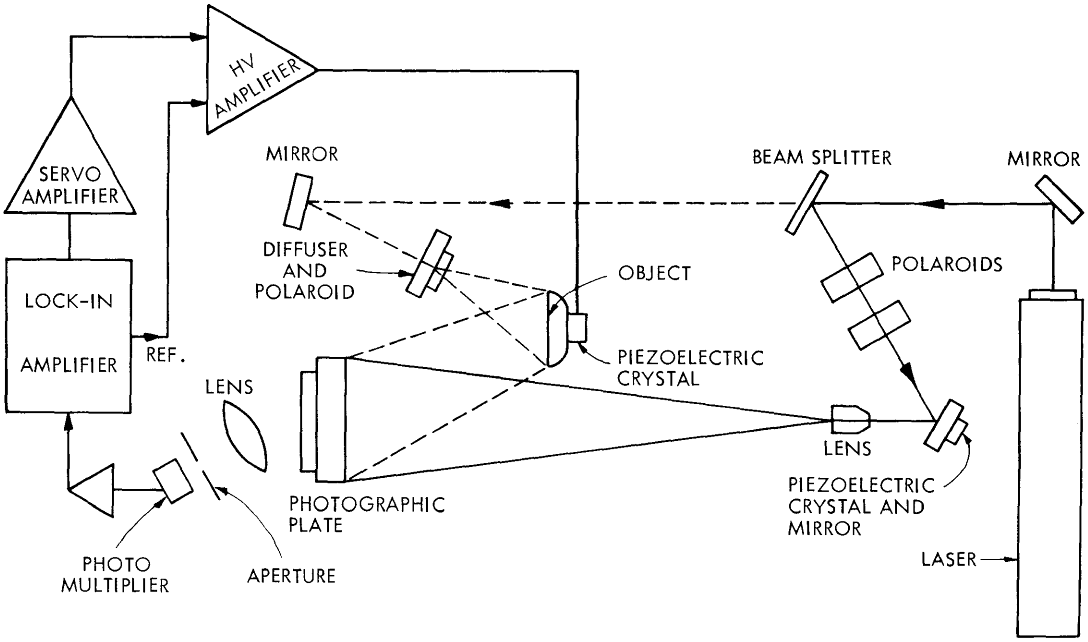

Fig. XII-7. Real-time holographic arrangement.

The real-time holographic interference pattern is imaged by suitable optics onto the photocathode of a photomultiplier. Any displacement of the object (an aluminum plate) with respect to the holographically stored image moves the interference pattern. This fringe-pattern movement is detected and used in a feedback loop so as to null the original fringe displacement. The feedback signal needed to maintain the fringe pattern at null gives a measure of the object displacement.

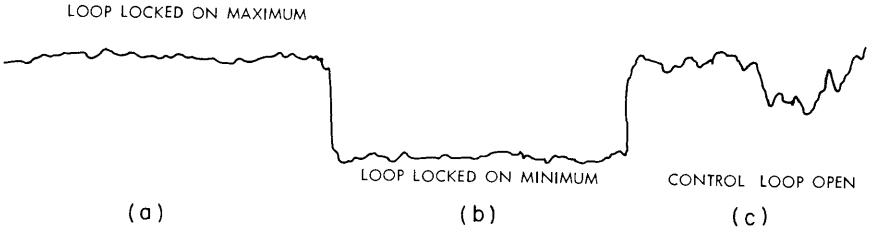

Fig. XII-8. Closed-loop performance of the preliminary feedback loop.

Figure XII-8 shows the performance of the preliminary feedback loop. Figure XII-8a and XII-8b shows the outputs of the photomultiplier when the feedback loop is locked to the maximum and the minimum fringe intensities, respectively. Figure XII-8c shows the output of the photomultiplier without the feedback loop, indicating the relative drift between the object and its stored image. The control element was a piezoelectric crystal mounted either behind the object or behind one of the mirrors in the reference beam as shown in Fig. XII-7.

Applications of this technique are being investigated for (i) measurement of thin-film deposition, (ii) gas-surface interaction studies, (iii) sensitive displacement detection with diffuse objects, and (iv) direct measurement of vibrational amplitude and frequency. Extension of this technique for measurement of small rotation and for 3-dimensional displacement is also being explored.

M. A. Dobbels, E. M. Stolle, S. Ezekiel