6. A. H. Nayfeh, Phys. Fluids, 13, 841-847 (1970).
7. M. P. Markova and V. Ya. Shkadov, Izv. Akad. Nauk SSSR, Mekh. Zhidk. Gaza, No. 3, 30-37 (1972).
8. W. T. Pimbley and H. C. Lee, IBM J. Res. Dev., 21, 21-30 (1977).
9. P. Lafrance, Phys. Fluids, 18, 428-432 (1975).
10. D. B. Bogy, Phys. Fluids, 22, 224-230 (1979).
11. D. F. Rutland and G. J. Jameson, J. Fluid Mech., 46, 267-271 (1977).
12. K. C. Chaudhary and L. G. Redekopp, J. Fluid Mech., 96, 257-274 (1980).
13. V. V. Blazhenkov, A. F. Ginevskii, V. F. Gunbin, and A. S. Dmitriev, Izv. Akad. Nauk SSSR, Mekh. Zhidk. Gaza, No. 2, 53-61 (1988).
14. H. C. Lee, IBM J. Res. Dev., 18, 364-369 (1974).
15. S. Sami, G. Collier, and D. L. Eddingfield, Comp. Meth. Appl. M. Eng., 60, 303-315 (1987).
16. D. B. Bogy, S. J. Shine, and F. E. Talke, J. Comp. Phys., 36, 294-326 (1980).
17. D. B. Bogy, J. Appl. Mech., 45, 469-474 (1978).
18. A. A. Novikov, Izv. Akad. Nauk SSSR, Mekh. Zhidk. Gaza, No. 2, 179-182 (1977).

POSSIBLE APPLICATIONS OF FIBER-OPTIC METHODS OF MEASURING PHYSICAL QUANTITIES FOR DIAGNOSTICS OF THE BREAKUP OF FREE JETS

V. V. Osipov and V. P. Ogorodnikov

UDC 532.5:537.86

The possible use of fiber-optic sensors of physical quantities to measure the parameters of drop generators is examined. The proposed fiber-optic devices can be used successfully in experimental studies of the monodisperse breakup of free jets.

Free liquid jets are used extensively in modern engineering and technology, e.g., in cryodisperse [1] and cryochemical technologies [2]. This stimulates the development of experimental methods of studying free jets. Measurements of the velocity profiles in thin jets (less than 1 mm in diameter) is the most complicated. Here we consider the possible use of fiber-optic methods to study the characteristics of jets and the monodisperse macroparticles formed as a result of induced capillary breakup of streams.

The restructuring of the velocity profile in a jet can be studied, e.g., with a Pitot tube, but its diameter should be 0.05-0.01 of the jet diameter d. If d = 500 μm, for example, the diameter of the Pitot-tube head should be 5-10 μm. Heads of this diameter are technically feasible but are very difficult to use because a sensor of this diameter has a very high inertia if the dynamic pressure on it is measured with an ordinary U-tube manometer. As our estimate showed [3] if the Pitot-tube diameter $d_P = 5 \cdot 10^{-6}$ m, the length of the Pitot-tube head $\ell = 5 \cdot 10^{-4}$ m, the liquid studied is water with density 10^3 kg/m^3 and dynamic viscosity 10^{-3} N·sec/m^2, and if the manometer tube diameter $d_m = 10^{-2}$ m, the time constant of such a sensor is $2 \cdot 10^8$ sec, which is unacceptable. The time constant of such a sensor must be reduced by roughly six orders of magnitude if the sensor is to be functional.

For this purpose we propose a fiber-optic manometer with a magnetohydrodynamic pump as reverse transducer, whose diagram is shown in Fig. 1. The manometer consists of a round U-shaped tube 1, whose lower segment is made in the form of a flat channel with copper buses 2 along the smaller sides and is placed in the gap of a permanent magnet 3. The voltage to the copper buses is supplied by a regulated source 10, which is controlled by a microcomputer.

A sharp boundary between the wetted and unwetted surfaces is organized in the tubes of the manometer to eliminate the effect of surface tension on the manometer readings. For this purpose a wetted ring 4 (e.g., of amalgamated copper) is inserted into the unwetted tubes of the manometer. If the volume of mercury in the manometer is such that the interface is at the level of the boundary between the wetted and unwetted surfaces of the tube, the interface is flat and the role of the surface tension is minimized. The change in the mercury

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Moscow Power Institute. Translated from Inzhenerno-fizicheskii Zhurnal, Vol. 60, No. 4, 561-566, April, 1991. Original article submitted July 31, 1990.

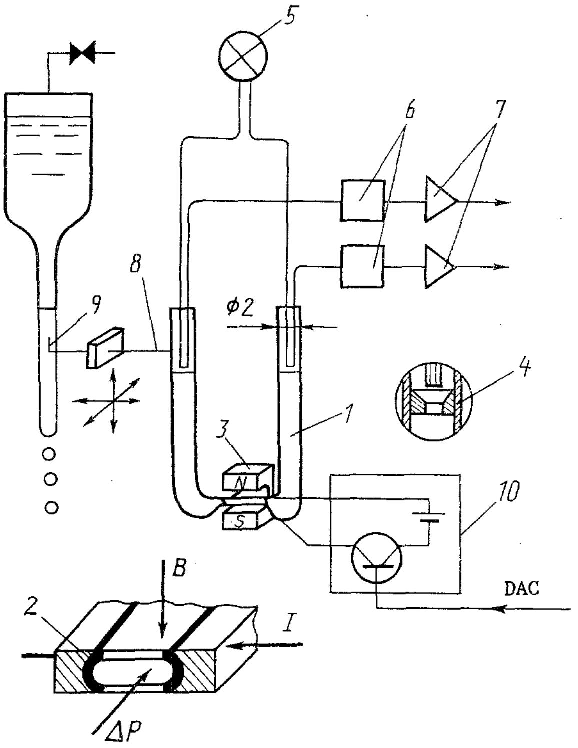

Fig. 1

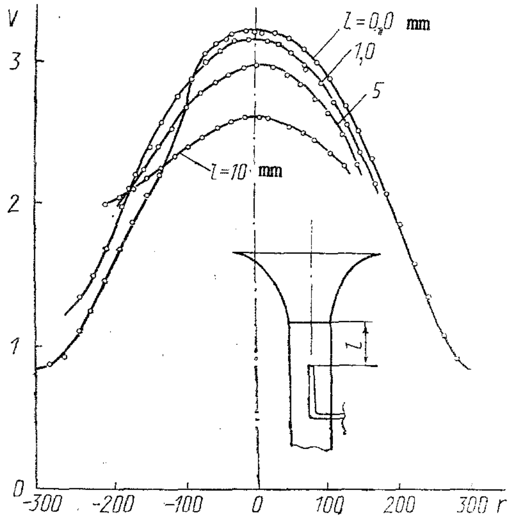

Fig. 2

Fig. 1. Diagram of velocity meter based on a Pitot tube and a fiber-optic manometer.

Fig. 2. Measured velocity profiles V (m/sec) in a free jet at different distances r (μm) from a capillary exit.

level in the manometer is measured with two optical-fiber bundles, part of whose filaments are connected to the light source 5 and part are connected to the photodetectors 6. The photodetector signals are fed through the amplifier 7 to the ADC, which is connected to a microcomptuer. One tube of the manometer is connected to the atmosphere and the other is connected to the Pitot-tube head 9 through the flash tube 8. The copper buses of the MHD pump 2 are connected to the current source 10.

The velocity meter functions as follows. The presure from the Pitot tube is fed into the manometer tube where it changes the position of the mercury menisci relative to the end faces of the optical-fiber bundles. This changes the photodetector signals entering the computer, which generates a control signal and transmits it through the digital-analog converter to the controlled current source. The latter supplies power to the MHD pump which produces a counterpressure that balances the pressure being measured.

The level of the mercury menisci remains practically constant during the pressure measurement and its displacement depends only on the feedback through the computer and can be regulated in a programmed way. If standard optical-fiber bundles with 20-μm filaments are used, the fiber-optic sensor measures the mercury-surface displacement in the manometer tubes over a total range that also is roughly 20 μm. The working displacement of the mercury level can be decreased to almost 1 μm by increasing the feedback factor. In this case, as shown by estimates [3], when manometer tubes with a diameter of 2 mm are used the time constant of the velocity meter will be roughly 60 sec, which is entirely acceptable.

The use of a fiber-optic manometer to measure the dynamic pressure of a Pitot tube makes it possible to reduce the time constant in comparison with that of an ordinary U-tube manometer by roughly seven orders of magnitude and makes such a velocity meter suitable for studying the velocity profile in capillary jets. A fiber-optic microrotameter, however, can be used as an indicator of the equality of the dynamic pressure from the Pitot tube and the counterpressure created by the reverse transducer. Figure 2 shows measured velocity profiles in a free jet flowing out of a 0.6-mm capillary with a length of 90 mm, at various distances from the capillary exit.

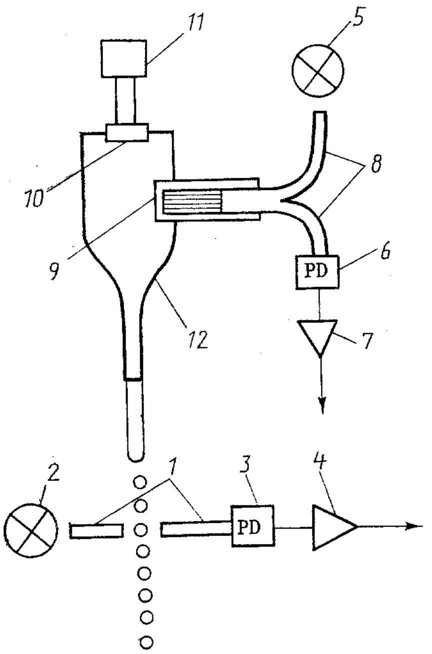

Fig. 3

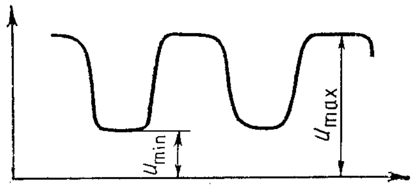

Fig. 4

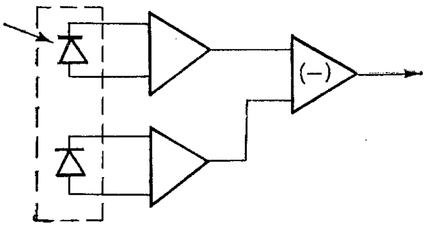

Fig. 5

Fig. 3. Drop generator equipped with fiber-optic sensors: 1) fiber waveguides; 2) light source; 3) photodetector; 4) amplifier; 5) light source; 6) photodetector; 7) amplifier; 8) fiber waveguides; 9) membrane; 10) piezoelectric element; 11) signal generator; 12) drop generator.

Fig. 4. Example of the graph of the dependence of the sensor signal on the drop diameter.

Fig. 5. Circuit for compensating for the drift of the photodiode dark current.

As seen from Fig. 2 the proposed method has a high resolution and high accuracy (mean-square deviation of 1%), making it possible to study the law governing the relaxation of the velocity profile of a free jet.

Another metrological problem that arises in the study of the breakup of a free jet is that of measuring the drop diameter during breakup. The fiber-optic sensor shown in Fig. 3 can be used for this purpose. It consists of two fiber waveguides 1, one of which is coupled optically to the light source 2 and the other is coupled to the photodetector 3. The signal from photodetector 3 is transmitted through the amplifier 4 to the ADC of a microcomputer. The waveguides are arranged so that drops cover the light beam as they pass through the gap between their ends. The waveguide diameter d_{wg} satisfies the condition $d_{wg} > d_c$.

Figure 4 shows a graph of the sensor signal as a function of time when drops pass through the gap between the ends of the fiber waveguides. The difference $u_{max} - u_{min}$ depends on the cross sectional area of the drops, provided that the light source is stable and no thermal drift of the photodetector dark current occurs. Under real conditions both the light source and the photodetector dark current undergo drift and, hence, measures to reduce the errors indicated above must be taken to enhance the accuracy of measurements with fiber-optic sensors.

A photodiode with a linear characteristic $u = k\Phi + u_{dark}$ can be used as the photodetector for this purpose. Since the temperature dependence of the dark current of photodiodes of the same type has the same shape, the ratio of the dark currents of two photodiodes of the same type does not depend on the temperature. This circumstance can be used to compensate for the drift of the photodiode dark current. This can be done by using the circuit in Fig. 5. The circuit shows two photodiodes placed in a single copper block to equalize their temperatures. A measured luminous flux is applied to one photodiode while the other remains dark. The amplifier gains are chosen so that at zero luminous flux the subtracter output signal is zero. In this case the subtracter output signal u^+ at any temperature is

$$u^+ = u_1 - u_{1dark},$$

where $u_{1dark} = bu_{2dark}$ is the dark-current signal of the operating photodiode; u_{2dark} is the dark-current signal of the dark photodiode; $b = u_{1dark}(T)/u_{2dard}(T)$; and T is the photodiode temperature.

The error due to instability of the light source is multiplicative and, therefore, $(u^+_{max} - u^+_{min})/u^+_{max}$ is independent of the light-source drift.

If solid spheres are obtained as a result of the monodisperse breakup of a jet, as when a liquid-metal jet breaks up and the resulting drops cool during flight, a weighing method based on the use of fiber-optic microbalance can be proposed.

The use of such a balance showed that when 500-μm-diameter lead spheres are weighed the relative error is 0.15. This can be used to reliably study the diameter distribution function of spheres obtained in modern drop generators.

Another parameter that affects the monodispersion of the induced breakup of a jet is the level of pressure pulsations in the drop generator. A fiber-optic pressure sensor [4], whose diagram is shown in Fig. 3, can be used to measure this level.

In summary, these fiber-optic sensors can be used to operationally monitor the jet parameters that affect the monodispersion of the jet breakup and to measure the diameter of the drops produced.

NOTATION

d_m, diameter of the manometer tube; d_{wg}, waveguide diameter; d_c, capillary diameter; u, sensor signal; u_{max}, maximum sensor dignal; u_{min}, minimum sensor signal; u_{dark}, sensor output signal that depends on the photodiode dark current; k, photodiode sensitivity; Φ, luminous flux; b, ratio of dark signals; T, photodiode temperature; and u^+, reduced sensor signal.

LITERATURE CITED

1. V. A. Grigor'ev, Vestn. Akad. Nauk SSSR, No. 4, 84 (1987).
2. Yu. D. Tretyakov, N. N. Oleinikov, and A. P. Mozhaev, Fundamentals of Cryochemical Technology [in Russian], Moscow (1987).
3. V. P. Ogorodnikov and V. V. Osipov, Sb. Nauch. Tr. Mosk. Energ. Inst., No. 149, 103-110 (1987).
4. V. G. Zhilin, Yu. P. Ivochkin, V. P. Ogorodnikov, and V. V. Osipov, Teplofiz. Vys. Temp., No. 5, 54 (1979).

CAPILLARY BREAKUP OF A LIQUID-METAL JET IN AN OXIDIZING MEDIUM

B. V. Artem'ev and S. G. Kochetov

UDC 532.5:66

The effect of oxidation of a free liquid-metal jet on its capillary stability is considered.

We have studied how oxygen impurity in a gas surrounding a thin jet affects the capillary stability of the jet. Our work was prompted by an experiment in which an attempt was made to obtain monodisperse capillary breakup of a gallium jet with diameter 0.5 mm, velocity 7 m × sec^{-1}, and temperature 60°C, flowing into argon that contained oxygen impurity. The jet did not break up at all if the oxygen concentration was higher than 0.2-0.3%. The transition from normal breakup to complete "non-breakup" occurred discontinuously as the oxygen concentration varied smoothly.

Below we report the experimental data and analysis of the effect that oxygen impurity in the surrounding atmosphere has on the capillary breakup of thin liquid-metal jets. We propose a model of this effect, based on the assumption that an oxide film is formed on the surface of the jet by the reaction of the jet with the oxygen in the surrounding medium. Since the oxide film presumably gives the surface elastic properties, a pressure counteracting the curvature of the surface arises along with the capillary pressure and can protract or completely stop capillary breakup.

Translated from Inzhenerno-fizicheskii Zhurnal, Vol. 60, No. 4, pp. 566-571, April, 1991. Original article submitted July 31, 1990.