UDC 681.128(088.8)

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Laser flowmeter for optically active liquid-lubricant materials

The principle of the laser speed flowmeter (LSF) is based on the Doppler effect [1]. The most widespread was the differential LSF scheme with two probing beams having matched polarizations. However, in the diagnostics of optically active media, the use of such a sensing scheme becomes ineffective. When two probing beams pass through the optically active medium, the azimuth of polarization changes, which leads to a low degree of polarization matching of the beams that are mixed on the photocathode, and ultimately to a decrease in the signal-to-noise ratio and accordingly to the accuracy.

The solution of the problem of increasing the accuracy of measuring the speed and flow of optically active media is proposed to be achieved by using a single laser and four probing beams that have mutually orthogonal circular polarizations in pairs.

FIG. 1 is a schematic diagram of the proposed laser Doppler velocity flowmeter (LDVF).

LDVF works as follows.

The laser 1 emits a beam 2 that passes the polarizer 3 with a transmission axis azimuth $\alpha = 90°$ and is further converted by a quarter-wave plate 4 into a left-circularly polarized beam 6 that is focused by the lens 5 at a point O located on the axis of the conduit 14. Further, the bundle 6 passing through the conduit 14 , is collected by the lens 10 and, after reflection from the two mirrors 11, is focused by the lens 10 at the point O (in the measuring volume O). The lenses 5 and 10 have, respectively, the focal lengths F1 and F2 (F1 = F2), in addition, their optical axes coincide with the axis OX of the conduit 14. The probing beam 7 has a left-circular polarization. The beam 7 is collected by the lens 5 and, after reflection from the mirror 11, becomes circularly polarized. Further, this beam 8 is focused by the lens 5 in the measurement volume O, then collected by the lens 10 and then reflected from the two mirrors 11, this beam-9 is focused in the region D. Thus, in the measurement zone, the lens 5 focuses two beams 6 and 8, and the lens 10 two beams 7 and 9. These beams intersect at an angle γ and have mutually orthogonal circular polarizations, so when they pass through the optically active medium moving through the conduit 14, there is no change in the state of their polarization. The beam 9 is collected by a lens 5 and converted by a quarter-wave plate 4 into a horizontally polarized beam. This beam is suppressed by the polarization filter 3 and does not enter the optical resonator of the laser 1.

Through the measurement zone O, which is an ellipsoid of revolution, the liquid medium moves at a velocity V containing micro particles (these particles have a diameter commensurable with the wavelength λ of the laser beam 2). The 26º radiation scattered on the micro particles is assembled by a receiving block consisting of 16, 18 and 20, the output of which is optically matched to the input of the light guide 22.

The second receiver unit, consisting of 15, 17 and 19, collects scattered radiation 27 which is directed to the input of the light guide 21. The outputs of the light guides 21 and 22 are optically matched to the input of the photodetector 23. Thus, by means of the light guide 21 (similarly to the light guide 22) to the photocathode Four scattered beams are sent to the photodetector: $\overline{E_{s6}}$ и $\overline{E_{s7}}$,, which have left-circular polarizations, as well as beams $\overline{E_{s8}}$ и $\overline{E_{s9}}$, having right-circular polarizations.

As a result of optical mixing on the photocathode of the photodetector of four scattered beams, a signal is formed at its output, the spectrum of which contains six high-frequency components at the following Doppler frequencies:

$$W_{g67} = (\overline{K_{06}} - \overline{K_{07}})\overline{V}; \ (1)$$

$$W_{g68} = (\overline{K_{06}} - \overline{K_{08}})\overline{V}; \ (2)$$

$$W_{g69} = (\overline{K_{06}} - \overline{K_{09}})\overline{V}; \ (3)$$

$$W_{g78} = (\overline{K_{07}} - \overline{K_{08}})\overline{V}; \ (4)$$

$$W_{g79} = (\overline{K_{07}} - \overline{K_{09}})\overline{V}; \ (5)$$

$$W_{g81} = (\overline{K_{08}} - \overline{K_{09}})\overline{V}; \ (6)$$

where $\overline{K_{0i}}$ is the wave vector of the "-i" probing beam.

If the scattered radiation 26 and 27 is collected in the direction of the OY axis at small angles, is symmetric to the OXY plane, then as shown in [3], this scattered radiation preserves the polarization state with respect to the polarization of the probing beam. Therefore, the scattered beams $\overline{E_{s6}}$ and $\overline{E_{s7}}$ have left-circular polarization, and the sheaves $\overline{E_{s8}}$ and $\overline{E_{s9}}$ are the right-circular polarization. For these pairs of beams, the polarization matching coefficient [3]

$$K_{n67}=1 \text{ и } K_{n89}=1. \qquad (7)$$

For other pairs of beams, the polarization matching coefficients are close to 0:

$$K_{n68} = 0; K_{n69} = 0; K_{n78} = 0; K_{n79} = 0. \qquad (8)$$

Therefore, when conditions (7) and (8) are satisfied, the high-frequency signals (crosstalk) (2), (3), (4) and (5) at the output of the photodetector 23 are suppressed, and the two useful signals (1) and (6) have same frequencies

$$W_{g67} = W_{g89} = \frac{4\pi}{\lambda}\cos\frac{\Upsilon}{2}V_x, \qquad (9)$$

where λ is the wavelength of the laser beams;

γ is the angle between the probing beams 6 and 8, and 7 and 9.

The useful signals at the frequency (9) proportional to the speed V_x are summed and then through the bandpass filter 24 enter the meter 26, which, according to known equations, calculates the instantaneous and total flow of the optically active medium moving through the pipeline 14.

The use of the LDVF scheme with clarified optics (Fig. 1) with four probing beams, the total power of which is almost equal to

PΣ = 4P2, where P2 is the power of the laser beam 2, can significantly increase the signal-to-noise ratio and, accordingly, the accuracy of measuring the velocity and flow rate of the liquid medium. In this case, in contrast to the prototype, which uses two lasers, the device uses only one laser with a power of P2. The nonreciprocal phase regulator 12-the Faraday cell, allows using two receiving blocks and two light guides 21 and 22 to also increase the power of the useful signal, because due to phase adjustment it provides a mode of in-phase reception of two signals (1) and (6) having the same Doppler frequencies .

In addition, the proposed LDVF has less weight and cost compared to the prototype, in which it is necessary to use instead of one two lasers.

References

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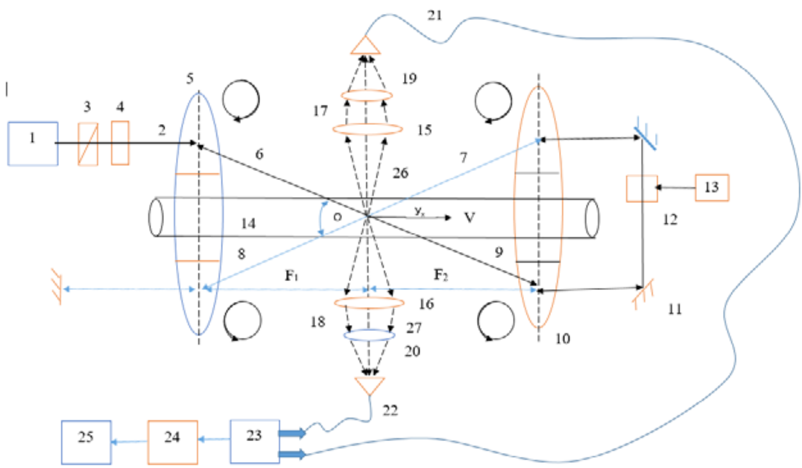

Fig.1