STABILIZATION OF THE GRADIENT OF THE REFRACTIVE INDEX IN A GRADIENT-REFRACTOMETRIC GAS ANALYZER

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A method for increasing the stability of the optical nonuniformity in a gas analyzer by means of Karman streets is proposed and justified.

It follows from published data that present methods and equipment for local gas analysis do not fully meet modern operating requirements. This is manifested especially when the gas-analytical equipment must provide continuous and automatic monitoring of complex gaseous media during prolonged operation, and under extreme production and climatic conditions without human participation.

This problem can be solved to one extent or another by the gradient-refractometric method. This method consists of creating a gradient of the refractive index in the flow of the medium under study and measuring the spatial characteristics (the deflection angle or diameter) of the probing beam of light [1]. The physical prerequisites of this method are as follows: 1) the refractive index of the gas medium must depend on the parameters of the different physical fields (for example, the electric field intensity) and the nonuniformity distributed thermodynamic parameters of this medium (temperature, pressure, composition); 2) it must be possible to form on this basis a gradient of the refractive index in the gaseous medium and a dependence of the gradient on the composition (and other characteristics) of the medium with fixed parameters (determining the gradient); and 3) the nonuniformity of the refractive index in the gas flow must be highly stable with respect to gravitational convection. It is easy to see that the widespread practical use of this method is determined by the actual methods used to create an optical nonuniformity in the medium under study.

The gradient of the refractive index can be created both in a moving gas and in a gas at rest. But there are more possibilities to do this in a flow. In this case, the interaction of different fields (for example temperature and velocity) as well as some hydrodynamic effects can be used. The typical experimental setup which implements the gradient-refractometric method is described in [2]. A distinguishing feature of this setup is that the measuring cell is made in the form of a channel open at the ends. The use of such a gas analyzer in practice can lead to measurement errors owing to the effect of the perturbations in the external medium, for example, the atmosphere, acting through the open ends of the measuring cell on the gradient of the refractive index in it.

The optical nonuniformities induced in the gaseous medium moving in a semibounded volume (for example, in a channel with open ends) can be stabilized by the so-called hydrodynamic windows or "gas plugs" [3]. The implementation of the well-known methods for creating "gas plugs," however, requires substantial flow rates of the gaseous medium, which significantly restricts their application in gradient-refractometric gas analyers, especially in serially produces analyzers. For this, we shall examine the specially developed method for reducing the effect of external perturbations on the nonuniform medium. This method is based on the properties of Karman vortex streets [4].

Consider two parallel vortex streets (Karman vortex streets, see Fig. 1), such that the distance between two neighboring vortices for both streets equals ℓ, while the intensity of the top street is Γ_1 and that of the bottom street Γ_2, and the distance between the streets is h. We shall examine the collection of "solid" streets, i.e., streets for which the distances between all vortices remain cosntant. In this case [4]

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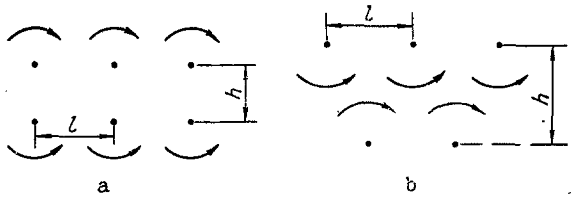

Fig. 1. Arrangement of vortices in a Karman street:
a) parallel street; b) checkerboard street.

$$\Gamma_2 = -\Gamma_1, \tag{1}$$

i.e., the intensities of the streets are the same in magnitude and opposite in sign.

There are two variants of the arrangement of the streets. In the symmetric order the streets are arranged so that a vortex in one row lies above the vortex in the second row (see Fig. 1a); in the checkerboard order the vortices in the bottom street lie between the vortices in the top street (see Fig. 1b). The velocity of such streets [4] is given by

$$V = \frac{\Gamma}{2l} \operatorname{cth} \frac{\pi h}{l}, \tag{2}$$

for the symmetric order and by

$$V = \frac{\Gamma}{2l} \operatorname{th} \frac{\pi h}{l} \tag{3}$$

for the checkerboard order.

The motion of the Karman streets is stable, if for small displacements of the vortices the distance between any two vortices throughout the motion remains close to the initial distance between these vortices. From this definition Karman obtained the stability condition

$$h/l = 0{,}2806. \tag{4}$$

If, now, the street with this ratio of the parameters h and ℓ is fixed and the vortices in this case rotate, then the street will create a flow with a definite velocity and direction. Placing the street at a channel with open ends in which a nonuniform gaseous medium flows and the direction of motion of the gaseous medium out of the channel will be the same as the direction of the flow created by the Karman street, it is easy to show that it will create an additional resistance to hydrodynamic disturbances incident on the open end of the channel, if they are present in the medium surrounding the channel.

We shall estimate the magnitude of the velocity of the flow created by the Karman streets under the condition that there is not flow from the channel owing to other perturbations of the flow rate.

It it is assumed that the vortices are created by a paddle rotating with a velocity w and having a radius r, then the circulation of the velocity Γ is given by

$$\Gamma \approx \oint \mathbf{V} d\mathbf{r} = \int_0^{2\pi} wr^2 d\varphi = 2wr^2\pi. \tag{5}$$

Taking the last equality (5) into account, the formulas (2) and (3) for the velocity of the vortex streets can be written in the form

$$V = \pi \frac{wr^2}{l} \operatorname{cth} \frac{\pi h}{l}; \tag{6}$$

for the symmetric order and in the form

$$V = \pi \frac{wr^2}{l} \operatorname{th} \frac{\pi h}{l} \tag{7}$$

for the checkerboard order.

The relations obtained make it possible to estimate the flow velocity generated by a stationary system of vortices in a damping setup. Setting w = 950 sec^{-1}, r = 0.02 m, h/ℓ = 0.2806, h = 0.04 m, for the velocities we obtain V ≈ 11.84 m/sec for the symmetric order and V ≈ 4.69 m/sec for the checkerboard order.

Using Bernoulli's equation, we evaluate the magnitude of the pressure drop created by the vortex street when one end of the channel is closed:

$$\Delta P = (P_0 - P) = \frac{\rho V^2}{2}. \quad (8)$$

Setting for air $\rho = 1.29$ kg/m^3 we find that $\Delta P \approx 90$ N/m^2 for the symmetric order and $\Delta P \approx 14$ N/m^2 for the checkerboard order.

Experimental studies of the method with a more efficient symmetric arrangement of the streets with three vortices in one street gave pressure drops which were somewhat lower than the computed values. In the experiment the pressure drop under the same conditions chosen above equalled $\Delta P \approx 25$N/m^2 for the symmetric street. The lower value of ΔP obtained in the experiment can be explained by the approximate nature of the determination of the value of Γ in the theoretical calculations, and also by the effect of energy dissipation owing to viscous friction.

From the estimates obtained above it is evident that the method developed enables increasing not only the stability of the optical nonuniformities, created in the flow of the gas medium analyzed in the channel with open ends (velocity estimates), but it can also be used to organize a flow of a gaseous medium in a channel (pressure estimate).

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HIGH-EFFICIENCY AIR PLASMATRON

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The results of an investigation of a 1.2-MW plasmatron with air injected through the porous channel in an insert between the electrodes and an efficiency of 0.95 are presented.

The efficiency of energy conversion and the operating lifetime of electric-arc plasmatrons are being increased by increasing their voltage—current ratio U/I. The reduction of the current owing to an increase in the voltage with fixed power enables reducing erosion and the thermal losses in the electrodes. In linear plasmatrons, with the plasma-forming gas injected through a porous channel in an interelectrode inset (IEI) the thermal losses are recovered, and the interaction of the cold gas with the discharge is intensified [1]. This increases the electric-field intensity in the arc channel and enables creating highly efficient small plasmatrons, whose efficiency reaches 0.9-0.95 [2].

In this work, we studied an arc discharge in the flow-through channel of an air plasmatron (Fig. 1). The cathode 1 has a zirconium thermal-emission inset with a diameter of $5 \cdot 10^{-3}$ m. Nitrogen is injected between the cathode 1 and the cathode diaphragm 2 in order to screen the Zr insert ($G_c = 10 \cdot 10^{-3}$ kg/sec). Air was injected ($G/p = 0.1$-0.75 kg/sec) through the porous channel 3 of the IEI ($d_c = 28 \cdot 10^{-3}$ m, $\ell_c = 150 \cdot 10^{-3}$ m). The porous channel was fabricated from an electric insulation material (cordierite). It contains a viewing window

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