MEASURING STATIC PRESSURE WITH MINIMUM ERROR BY MEANS OF DRAINAGE ORIFICES

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We present results from an experimental study into the influence exerted by a countersunk inlet section of a drainage orifice on the error in the measurement of static pressure.

Static pressure in a moving fluid is usually measured by means of drainage orifices positioned on the streamlined surface. However, the presence of such orifices on the surface unavoidably leads to perturbation of the flow in the boundary layer near the orifice and, consequently, to a deviation in the measured static pressure P_{mea} from the true pressure P_{tru}. The influence of the geometric dimensions of a circular drainage orifice with a rectangular inlet edge on the error in the measurement of the static pressure was studied in [1]. The present study presents the results from our investigation into the influence exerted by the geometric shape of the inlet portion of the drainage orifice on the magnitude of the error in the measurement of $\Delta P = P_{mea} - P_{tru}$.

The studies were conducted for drainage orifices in which the ratio of the orifice depth to its diameter amounted to $l/d \geq 4$, since in this case, as demonstrated in [1], the diameter of the tubes connecting the drainage orifices to the pressure indicator has virtually no effect on the measurement results. We examine possible deviations in the shape of the inlet portion of the drainage orifice from that of a circular orifice with a rectangular leading edge, namely the deviation of the orifice axis from the normal to the streamlined surface, the rounding of the leading edge, and the drilling damage to the inlet portion of the orifice (chip fragments). In these cases, the flow pattern near and inside the orifice exhibits its own unique features, and these affect the results obtained in the measurement of static pressure.

Particular attention is devoted to studying the influence exerted by the countersinking of drainage orifices insofar as this affects the results obtained in static-pressure measurements. It was noted in [2] that the removal of the outer face layer at the inlet to a circular drainage orifice slightly reduces the static pressure relative to the case in which the orifice has a rectangular leading edge. However, studies into the effect of countersinking of drainage orifices as regards the absolute error in the measurement of static pressure ΔP have not been covered in the literature.

In the present study we have undertaken systematic investigations into the influence exerted by the countersink angle α for a drainage orifice and that of its relative depth h/d (the depth of the facing) on the error in the measurement of static pressure, thus allowing us to establish an optimum design for the drainage orifice to ensure minimum measuring error.

In addition to the quantitative measurements, we also undertook visualization of the microstructure of fluid motion in the drainage orifices, where the inlet portion of the orifice had various shapes. The visualization which is achieved by means of an optical-polarization method [3] enabled us to ascertain the mechanism involved in the processes of vortex formation in drainage orifices from which the outer facing had been removed, thus enhancing the reduction in the errors generated in static-pressure measurements.

For the true static pressure P_{tru} in this study we took the pressure values measured by means of a drainage orifice covered with a smooth porous metal disk that was flush with the streamlined surface. It was demonstrated in [1] that the static pressure measured in this manner can be taken as the true pressure in view of the small pore size within the porous disk (~10 μm). In order to reduce the inertia of the P_{tru} measurements, the static-pressure orifice covered with the porous disk was made to have a comparatively large diameter (10 mm), whereas the diameter d for the drainage orifices under consideration for the determination of P_{mea} was 0.5 and 0.8 mm.

The experiments were conducted in a rectangular channel with which the boundary layer was in direct contact [1] for flow velocities of 47, 54, and 60 m/sec. The measured pressure differences were recorded by means of a high-sensitivity alcohol manometer calibrated in divisions of 0.003 mm of water column, in which the alcohol level was tracked automatically by means of photodiodes and an electronic relay control circuit.

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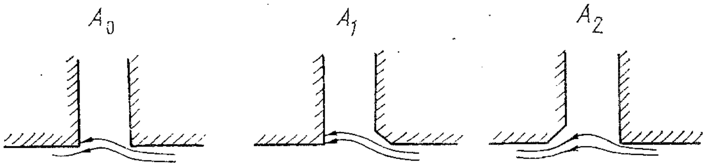
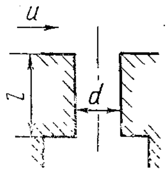
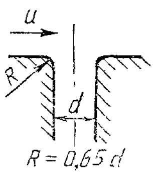
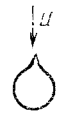
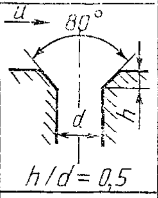
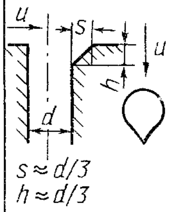
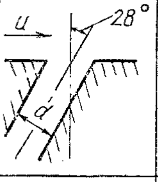
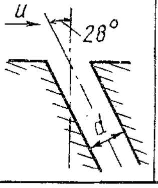


Fig. 1. Schematic representation of the streamlines in the static-pressure drainage orifices, with damaged inlet edges.

TABLE 1. Effect of Drainage-Orifice Shape on Static-Pressure Measurement

Orifice shape	u, m/sec	$\frac{\Delta P}{\frac{1}{2}\rho u^2}$, %	$\frac{\Delta P_1}{\frac{1}{2}\rho u^2}$, %	Orifice shape	u, m/sec	$\frac{\Delta P}{\frac{1}{2}\rho u^2}$, %	$\frac{\Delta P_1}{\frac{1}{2}\rho u^2}$, %	$\frac{\Delta P_1^*}{\frac{1}{2}\rho u^2}$, %
	60	1,0	0		60	1,75	0,75	0,68**
	54	0,97	0		54	1,67	0,7	
	47	0,95	0		47	1,57	0,62	
	60	1,3	0,3		60	~0,8	~-0,2	-0,3
	54	1,3	0,33		54	~0,8	~-0,2	
	47	1,26	0,31		47	~0,8	~-0,2	
	60	0,64	-0,36		60	0,74	-0,26	0
	54	0,62	-0,35		54	0,74	-0,23	
	47	0,63	-0,32		47	0,7	-0,25	
	60	0,96	-0,04		60	1,69	0,69	0,3
	54	0,97	0		54	1,72	0,75	
	47	0,94	-0,01		47	1,64	0,69	

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*Experiments from [2].

**Interpolation.

Table 1 shows the values of the measurement errors ΔP normalized by the velocity head and the quantities $\Delta P_1 = P_{mea} - P_h$, where P_{mea} is the pressure measured by means of a drainage orifice with an arbitrarily shaped inlet portion and P_h is the pressure measured by means of a circular orifice with a rectangular edge. When the edge fragment of the drainage orifice is positioned to meet the incident flow, the error in the static-pressure measurement increases by a factor of approximately 30% in comparison to the case in which the edge of the drainage orifice has not been damaged, and the error in the measurement is reduced by ~35% when the fragment is situated in a direction opposite to that of the incident flow. When the edge fragment of the drainage orifice is positioned to the side, it exerts virtually no influence on the value of the measured static pressure.

The derived results may be governed by the appearance of the Pitot effect for the streamlines attached to the streamlined surface, and these become distorted, dropping down into the drainage orifice. This is shown clearly in Fig. 1. If in case A_1 the fragment promotes more pronounced distortion of the attached streamline and the related intensification of the Pitot effect, then in the A_2 case the fragment will weaken the Pitot effect relative to the streamlining of the normal

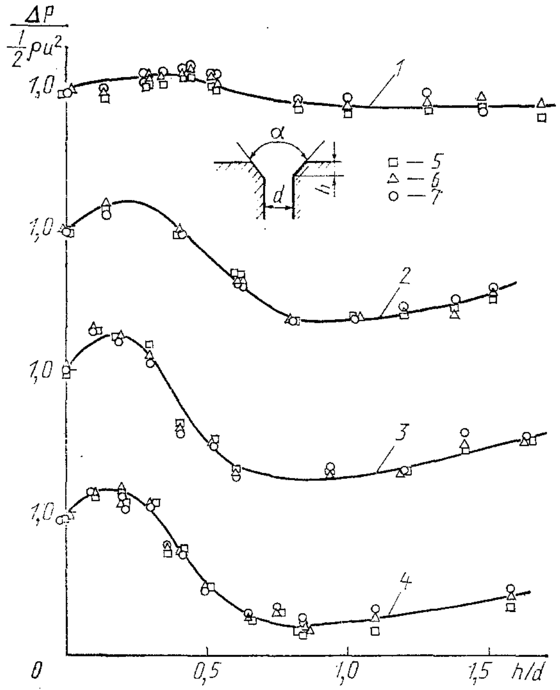

Fig. 2. Error in the measurement of static pressure as a function of the countersink depth in a drainage orifice with a diameter of d = 0.8 mm: 1) α = 60°; 2) 80; 3) 100; 4) 120°; 5) u = 47 m/sec; 6) 54; 7) 60. ΔP/(ρu²/2), %.

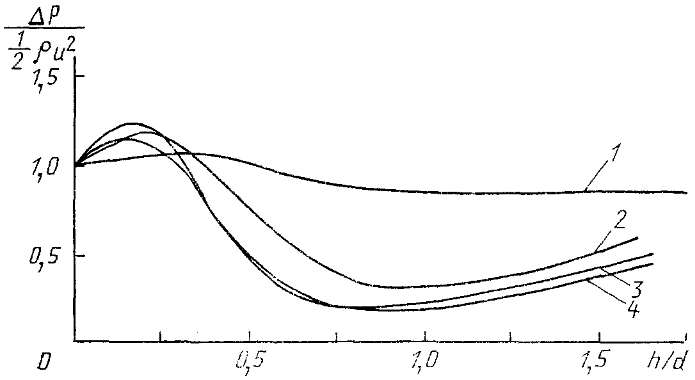

Fig. 3. Influence exerted by the countersink angle for the drainage orifice with a diameter of 0.8 mm on the nature of the function ΔP/(ρu²/2) = f(h/d): 1) α = 60°; 2) 80; 3) 100; 4) 120°.

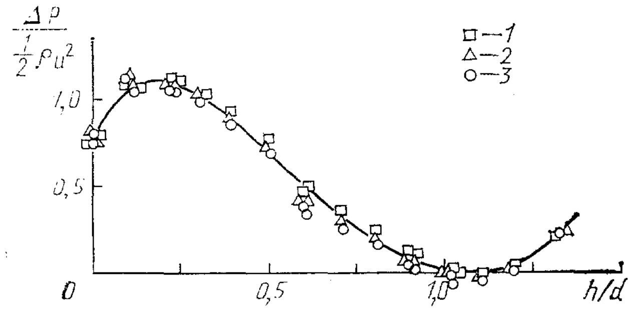

Fig. 4. Error in the static-pressure measurement as a function of countersinking depth in drainage orifice with diameter d = 0.5 mm for α = 100°: 1) u = 47 m/sec; 2) 54; 3) 60.

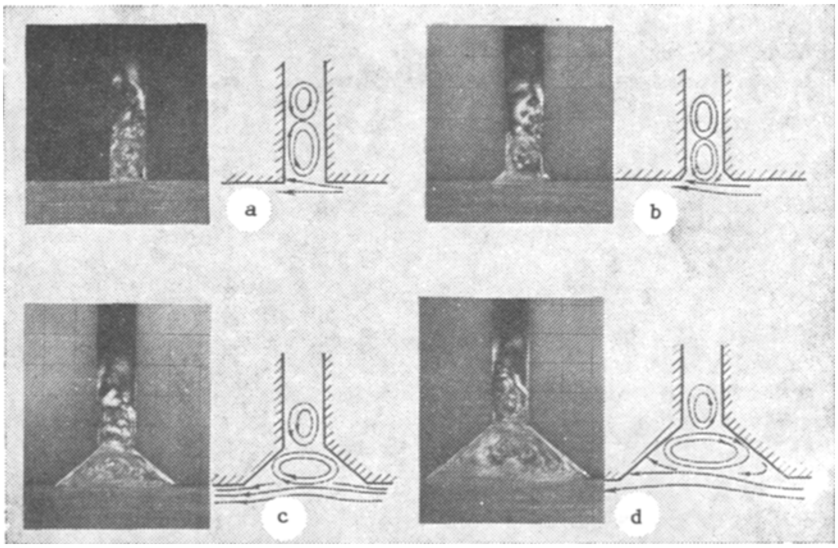

Fig. 5. Visualization of vortical fluid motion inside drainage orifice with $\alpha = 100°$: a) $h/d = 0$; b) 0.2; c) 0.9; d) 1.4.

orifice A_0. Intensification or weakening of the Pitot effect can serve also to explain the change in the measurement error which arises on deflection of the drainage-orifice axis from the normal to the streamlined surface (see Table 1).

For purposes of comparison, Table 1 also shows the experimental data [2] in which, owing to the absence of values for P_{tru}, only the quantity ΔP_1 was determined. As we can see, in the case of drainage orifices with a rounded inlet and for drainage orifices where the outer facing has been removed, the experiments [2] coincide satisfactorily with the results of our experiments. For inclined orifices the divergence remains significant.

The error in the measurement of static pressure by means of drainage orifices with a diameter of 0.8 mm in which the outer facing has been removed is shown in Fig. 2. Countersinking of the orifice is accomplished by means of a drill with rigorously specified tip angles α equal to 60, 80, 100, and 120°, and the facing depth h as a ratio of the orifice diameter d varied from 0.1 to 1.7. From Fig. 2 we can see that when $\alpha = 60°$ the increase in the relative depth of the countersunk orifice h/d has little effect on the magnitude of the error $\Delta P/(\rho u^2/2)$. However, when $\alpha = 80°$ the function $\Delta P/(\rho u^2/2) = f(h/d)$ is now clearly defined. With comparatively limited countersinking ($h/d < 0.3$) the relative error $\Delta P/(\rho u^2/2)$ increases in comparison to the error for a normal orifice that has not been countersunk ($h/d = 0$), and as h/d subsequently increases, this relative error diminishes, assuming a minimum value for $(h/d)_{min} \approx 0.9$, and then increasing once again. The experimental curves exhibit similar paths for $\alpha = 100$ and 120°, and the values of h/d at which the maximum and minimum in the relative error is observed, remain virtually unchanged as α increases. Moreover, with $\alpha = 100$ and 120° the very course of the experimental curves becomes stabilized. This can be seen from Fig. 3, which shows the curves smoothed out over the experimental points shown in Fig. 2 for various values of α.

Countersinking of a drainage orifice with a diameter of 0.8 mm at an angle of $\alpha = 100$ and 120° and with a relative facing depth of $h/d = 0.8$-1.0 thus makes it possible to reduce the relative error in the measurements by a factor of approximately 5 in comparison to the case $h/d = 0$ and the very magnitude of the relative error in this case does not exceed 0.2%. With a reduction in the drainage-orifice diameter the relative error drops and with $d = 0.5$ mm and $h/d \approx 1.0$ it becomes virtually equal to zero (Fig. 4).

Figure 5 shows the visualization of the vortex flow for fluid in drainage orifices countersunk at an angle of $\alpha = 100°$. The values of h/d have been chosen so as to correspond to the characteristic points of the experimental function $\Delta P/(\rho u^2/2) = f(h/d)$ (see Fig. 2). We can see that in the case of countersunk drainage orifices the vortices inside the orifice are transformed in comparison to the streamlining of orifices with a rectangular inlet edge ($h/d = 0$). The vortex attached to the streamlined surface assumes an elliptical shape and fills the funnel of the orifice so that the major axis of the vortex follows the direction of the flow. In this case, the vortex, on interacting with the incident stream, affects the behavior of the streamlines connected to the orifice, in a manner so as to enhance weakening of the Pitot effect. The optimum case is the one in which the elliptically shaped vortex is flush to the streamlined surface ($h/d \approx 0.8$-0.9). With deeper countersinking the vortex begins to sink into the funnel, which once again leads to an intensification of the Pitot effect (see Fig. 5d).

LITERATURE CITED

1. E. U. Repik and V. K. Kuzenkov, *Inzh.-Fiz. Zh.*, 57, No. 6, 913-917 (1989).
2. R. E. Rayle, Paper, *Am. Soc. Mech. Eng.*, No. A-234 (1959).
3. Yu. M. Bychkov, *Visualization of Thin Flows of an Incompressible Fluid* [in Russian], Kishinev (1980).

DETERMINATION OF DISTRIBUTION FUNCTIONS FOR THE CHARACTERISTICS OF HEAT AND MASS EXCHANGE PROCESSES BY MEANS OF BOLOMETRIC CONVERTERS

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We propose a method for reconstructing the distribution functions of temperature over the cross section of a flow on the basis of data derived from bolometers. We have optimized the algorithm based on approximation of the distribution functions by bicubic splines with subsequent pseudoconversion of the matrix equation.

The effectiveness with which bolometric converters can be utilized in the diagnostics of heat and mass exchange processes is associated with the high stability of these bolometers to thermal and chemical actions, to their mechanical strength, and to the simplicity of recording the response. For the moment, the basic area for the use of such converters is the measurement of integral characteristics, i.e., the average velocity or temperature of a flow, the total energy or power of radiation fluxes or streams of charged particles. For example, in order to measure the energy of laser emission, a converter has the form of a grid of mutually parallel cylindrical bolometers positioned perpendicular to the radiation flux, and these bolometers are connected in series to a device which recorded the change in grid resistance [1]. With the aid of a similar design it is possible to measure the temperature of a stream of gas or its velocity on the basis of the reduction in resistance in the bolometers heated by the current.

An important feature of these measuring converters (as described here) is the insignificant interaction with the flow being diagnosed, and this is proportional to the ratio of the bolometer diameter to the distance between them (the spacing of the grid), as well as the possibility of using such converters in flows of large cross section. In these energy measuring devices [1] the losses are on the order of 10^{-2}-$10^{-3}$with a flow diameter of up to one meter. With a reduction in the bolometer diameter the time constant of the response is also reduced (about 5 msec for platinum bolometers 10 μm in diameter) and it becomes possible to record high-speed processes.

However, in the integrated diagnosis of heat and mass exchange processes it becomes necessary to measure the distribution functions of the physical quantities through the cross section of the flow. It is not through measurement of the total resistance [1] that additional information on the utilization of bolometric grid converters can be achieved, but rather from the increment in the resistance for each of the grid bolometers. The derived totality of signals represents a projection of the temperature distribution function in the direction of the bolometer axes. In order to obtain the actual distribution it becomes necessary to solve an inverse problem of computational diagnostics, namely, to reproduce the sought function from the set of its projections (or affects) [2]. A unique feature of this problem is the requirement that we introduce the smallest possible number of perturbations, i.e., to optimize the number of projections and the bolometers within them. Estimates show that in real situations the number of bolometer grids cannot exceed 10.

Under the limited aspect conditions the existing a priori information is normally inadequate for effective application of the methods of integral transformation. The method involving the expansion of the sought function f(x) over the basis of some finite-dimensional space $\{S_k\}_1^N$, $x = (x_1, x_2)$ is therefore fundamental:

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