A METHOD OF MEASURING THE TOTAL MOMENTUM FLUX OF GAS JETS

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Inzhenerno-Fizicheskii Zhurnal, Vol. 14, No. 1, pp. 144–147, 1968

UDC 532.522

A description is given of an instrument for measuring the total momentum flux of gas jets based on the rotation of the flow through 90° and on the measurement of the force exerted by the flow on the rotating mechanism. The instrument is used to measure the momentum of continuous and pulsed gas jets.

In modern experimental gasdynamics, extensive use is made of various methods of measuring the momentum of a moving gas. Well known is the gasdynamic

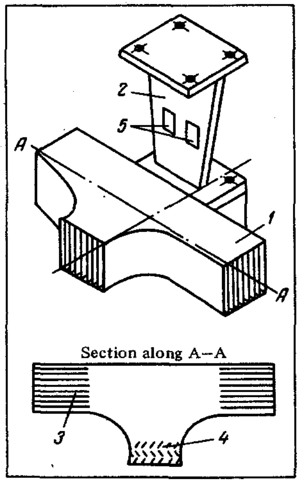

Fig. 1. Device for measuring the total momentum flux of gas jets: 1) probe; 2) elastic element; 3) guide vanes; 4) inlet blades; 5) strain gauges.

method of determining the total momentum flux [1, 2] by measuring the total and static pressure distribution over the jet cross section. However, this method can be used only when the moving gas obeys the equation of state PV = RT, and the jet has a cross-sectional area large enough to accommodate the necessary number of total and static pressure probes. Moreover, the accuracy of the momentum determination depends on the temperature and chemical composition of the gas.

Direct measurement of the momentum of the gas jet as the reaction applied to the source is possible employing the ballistic pendulum method [3]. It involves the hinged suspension of the object from which the jet discharges and consists in measuring the amplitude of the oscillations of the pendulum thus obtained. When the weight and size of the jet source are large, the use of this method involves the construction of clumsy structures, and when the source is rigidly connected with stationary objects it is completely inapplicable. Moreover, the accuracy of the measurements falls as the ratio of pendulum weight to measured momentum increases.

The present article is concerned with a much less common method of measuring the total momentum flux of gas jets, which, however, can be employed successfully when the above-mentioned methods are unsuitable.

This method is based on the use of a gas probe that smoothly rotates the jet through 90° and discharges it radially. Obviously, the force exerted by the gas flow on the probe is equal in magnitude to the total momentum flux of the original jet.

A possible variant of an instrument operating on this principle is shown in Fig. 1. Gas probe 1 is a flat box made of sheet steel. The inlet section is square with sides 30 mm long. The probe is rigidly attached to elastic element 2, which acts as a fixed cantilever with uniform bending resistance. At the probe outlets there are guide vanes 3 ensuring that the outflow of gas is strictly radial. On the inlet section there are three rows of blades 4 designed to increase the flow resistance of the inlet. Two pairs of strain gauges 5, connected to a bridge circuit with an output to a loop oscillograph, are bonded to the elastic element.

We will consider the problem of a gas flowing into a medium at known pressure P_a for an arbitrary jet shape (Fig. 2). In accordance with the law of conservation of momentum the force exerted on the probe by the flow will be equal to the sum $I + P_a S_1$.

Moreover, an unbalanced force will be exerted by the medium pressure on an area S_2 of the probe surface. Obviously, $S_2 = S_1 + S_a$. Thus, if the outlet nozzle is circular, the resultant force acting on the elastic element will be

$$F = I - P_a \frac{\pi d^2}{4}.$$

The force F acting on the probe causes corresponding deformations of the elastic element, which are recorded on the oscillograph chart.

The total momentum flux of a submerged turbulent jet remains unchanged along its length [4] if the pressures in the ambient medium and in the jet are equal. Thus, partial deceleration of the jet and the corresponding entrainment of the medium at the interface as a result of turbulent mixing do not affect the instrument readings.

The readings depend on the distance between the inlet section of the probe and the outlet section of the nozzle. As this distance increases, the instrument readings remain unchanged as long as the entire jet, including the turbulent mixing zone, enters the probe. The maximum distance at which the entire jet enters the probe can be estimated from the data of [4], in which it was shown that the angle formed by the boundary of a turbulent submerged jet and its axis on the principal section is on the order of 12.5°.

An experimental model of the instrument has been tested using a gas jet whose momentum was first carefully measured by the gas-dynamic method correct to 1–2%. This jet was obtained by allowing the gas to flow out of a tank through a convergent nozzle with a calibrated orifice without a cylindrical section at the outlet. The diameter of the outlet section was 3 mm. The gas left the nozzle, which has a Busemann profile, with a supersonic pressure drop. Under these conditions the total momentum flux in the outlet section depends only on the pressure in the tank and on the diameter of the outlet orifice and can be determined very accurately.

The results are presented in Fig. 3. The abscissas (I^*) are the values of the momentum measured by the gasdynamic method and the ordinates (I) give the momentum of the same jet measured with our experimental instrument. Calibration of the deflection of the oscillograph beam and the force acting on the sensitive element was first obtained using a set of weights. The experiments were repeated several times in the range of momentum values from 0.3 to 2.2 newtons. The instrument error lies within the limits of error of the gasdynamic method.

When the distance from the outlet section of the nozzle to the inlet section of the probe was varied, the instrument readings remained unchanged as long as this distance did not exceed 65 mm, which is in good agreement with the estimate given above. It was also established that the instrument readings are not affected by a small angle of attack (up to 4°).

The measurement of the momentum of a pulsed flow was done with a fast-acting shutter. The dimensions of the shutter opening were selected so that the jet acted on the instrument for approximately 0.1 sec. In this case the oscillogram representing the motion of the elastic element was a sinusoidal curve corresponding to its natural vibrations. The momentum corresponded, correct to 1%, to the distance from the zero mark on the oscillogram to the axis of the sinusoid.

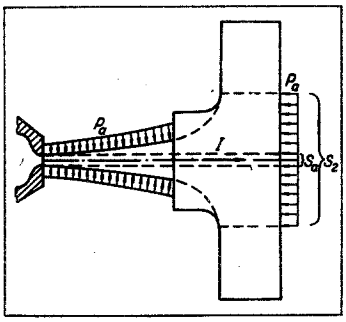

Fig. 2. Derivation of the equation for determining the total momentum flux from the instrument readings.

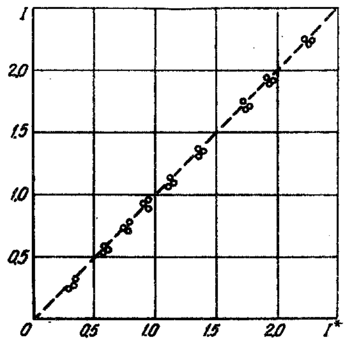

Fig. 3. Comparison of experimental data with the results of measurements made by the gasdynamic method (I, I^* in N).

The natural frequency of the elastic system was about 30 Hz, i.e., the time of action of the jet was several times greater than the period of the natural vibrations. In these circumstances there are no dynamic errors associated with the inertia of the vibrating system.

Thus, as the results presented show, in certain cases the described method of measuring the total momentum flux of gas jets can be employed successfully together with other methods. There may also be cases where this method is the only one suitable.

NOTATION

I is the total momentum flux at the nozzle outlet section; P_a is the pressure of the medium into which the jet flows; S_1 is the projection of the area of liquid contour of the jet on the plane perpendicular to the flow axis; S_a is the area of the nozzle outlet section; F is the force exerted by the flow on the elastic element of the instrument; and d is the diameter of the nozzle outlet section.

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27 February 1967