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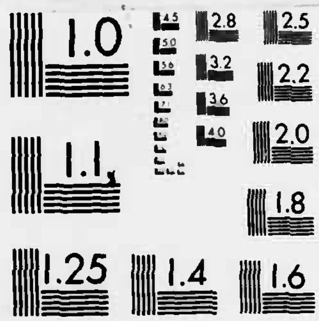

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FOREIGN TECHNOLOGY DIVISION

VORTEX MOTION IN A PRECOMBUSTION CHAMBER
WITH INTERSECTING JETS

by

A.S. Ippolitov, S.P. Safronov

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О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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VORTEX MOTION IN A PRECOMBUSTION CHAMBER WITH INTERSECTING JETS

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A large number of theoretical and experimental studies is devoted to laws governing the vortex motion in a limited volume. These studies are of a great practical value and make it possible to calculate the main characteristics of the cyclonic chambers. At the same time, many questions have remained unanswered.

To describe the vortex motion in the chambers, many researchers [1, 2, 3] divide the volume of the cyclone into two sections: the zone of potential motion II and zone of intrinsic vortex I (Fig. 1). Used for zone II are solutions obtained in the problem of the flat infinite vortex of an ideal incompressible medium. For the nucleus of the vortex, from the experiment, the distribution of velocities is taken according to the law of rotation of a solid. According to [4], the regularities in the cyclones are determined by a turbulent transfer of the moment of momentum in the whole volume of unity; and, therefore, the breakdown of the cyclone into the zone of potential motion and zone of the nucleus of the vortex is not obligatory. In [5] it is confirmed that it is impossible to apply the law of conservation of the flow of the moment of momentum for the cyclonic chambers.

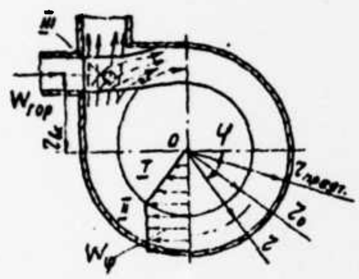


Рис. 1

Fig. 1.

The object of the investigation in this article was the vortex motion in the precombustion chamber with intersecting jets (IJ). The precombustion chamber with intersecting jets is a horizontal chamber with tangential input of jets through slotted burners. The exhaust of gases from the precombustion chamber into the cooling chamber is limited in the partitions between the burners also tangentially. Conditions of input of the jets and output of the flow from the precombustion chamber provide uniformity of twisting and most closely from existing devices approximate the motion in it to a pattern of a flat vortex. In this investigation the intersection zone was not used, and conducted were only measurements of the integrated results of the interaction of the jets such as the relative magnitude of the total transfer of the mass of burner jets from the precombustion chamber $G_{вын}$), the coefficient of the conservation of speed (ϵ) and others.

According to our concepts, with the vortex motion of a viscous incompressible medium, two zones are formed: the zone of potential motion and zone of nucleus of the vortex. The main law of the conservation forming the vortex motion is the law of conservation of the flow of the moment of momentum. In using this law, for the vortex motion we must consider the second and third Helmholtz theorems. The vortex motion in the precombustion chamber of the IJ is formed only because of the forces of pressure. ~~The vortex motion in the precombustion chamber of the IJ is formed only because of forces of pressure.~~ This is the impulse of forces of pressure, which creates motion of the mass at the input into the burner, and forces of pressure on the wall of the precombustion chamber creating the vortex. It is known that the forces of pressure have a potential. Hence, in conformity with the Helmholtz theorems, it follows that the moment of momentum of the burner jets is expended for the rotation of the mass of nucleus of the vortex, and in the period of the entire time of motion the nucleus of the vortex consits of the same particles, i.e., the mass of the nucleus is idly rotated.

Thus the use of the Helmholtz theorem makes it possible to confirm that the law of conservation of the flow of the moment of momentum must be applied to the mass ensuing from the burners and moving in the zone of the intrinsic vortex (potential zone). Under conditions of the viscous medium, the flow of the moment of momentum is transferred with losses, i.e., we can write the equation

$$\eta_{вых} q_{гор} W_{гор} r_{вх} = \int^{r_{пред}} \rho H (W_{\varphi}^{I})^{2} r\,dr, \quad (1)$$

where $\eta_{вых} < 1.0$.

We can show that ensuing from the law of conservation of the moment of momentum is the law of the conservation of the potential mass flowing out from the burners and moving in the zone of the intrinsic vortex. Let us assume that moles of the potential mass do not have rotation around the axis of the precombustion chamber.

Figure 1 shows a physical model of the vortex motion of the viscous turbulent incompressible medium in the precombustion chamber of IJ. The cyclone has three zones: zone of the nucleus I, zone of the intrinsic vortex II and zone of intersection III. The boundary layer between the walls of the chamber and vortex, in connection with its small thickness, is excluded from the investigation. Zones I and II are the object of the investigation.

The Navier-Stokes motion equations in the Reynolds form, the continuity equation and the energy equation in Euler form (for the potential zone) are used in the mathematical description of the vortex motion in zones I and II. The law of the conservation of the flow of the moment of momentum and law of the conservation of potential mass in the treatments given above were used in the form of boundary conditions for determining the integration constant. An analysis of the continuity equation and experimental data showed that in zones I and II the problem is one-dimensional. This means that the velocity vector, having only only a tangential component (W), and all the scalar values are a function of one coordinate - the radius.

Conditions of one-dimensionality made it possible to simplify considerably the mathematical description. Thus the Reynolds equation took the form:

$$\frac{W_\varphi^2}{r} = \frac{1}{\rho}\frac{\partial p}{\partial r}. \qquad (2)$$

$$\frac{\partial}{\partial r}\left(\overline{W_\varphi' \cdot W_\varphi}\right) + 2\,\frac{\overline{W_r' W_\varphi'}}{r} = 0. \qquad (3)$$

The hypothesis of Prandtl was used on the connection of stress vectors with the velocity components causing them

$$\tau_{r\varphi} = -\rho \overline{W_r' W_\varphi'} = A\left(\frac{\partial W_\varphi}{\partial r} - \frac{W_\varphi}{r}\right), \qquad (4)$$

$$A = \rho l^2 J \; (4') \qquad l = \alpha r. \qquad (4)''$$

A - the coefficient of turbulent velocity; l - the drift path.

For our one-dimensional problem

$$J = \pm\left(\frac{\partial W_\varphi}{\partial r} - \frac{W_\varphi}{r}\right). \qquad (5)$$

Replacing the sign of the partial differential by a standard one, and performing transformations, we finally get

$$\frac{W_\varphi^2}{r} = \frac{1}{\rho}\frac{dp}{dr} \cdot \quad (2')$$

$$(\alpha r)^2\left(\frac{dW_\varphi}{dr} - \frac{W_\varphi}{r}\right)\left[\frac{d}{dr}\left(r\frac{dW_\varphi}{dr}\right) - \frac{W_\varphi}{r}\right] = 0 \cdot \quad (3')$$

The integration of equation (3') made it possible to find the following solutions for the tangential velocity

$$W_\varphi^{I} = C_1' r \cdot \quad (6)$$

$$W_\varphi^{IIб} = C_1'' r + \frac{C_2}{r} \cdot \quad (7)$$

$$W_\varphi^{IIа} = \frac{C_2'}{r} \cdot \quad (8)$$

From the differential equation (2), using expressions (6), (7) and (8), expressions for determining pressures in zones I and II are found:

$$p^{I} = \frac{\rho(C_1')^2}{2} r^2 + C_{01} , \quad (9)$$

$$p^{IIб} = \frac{\rho(C_1'')^2}{2} r^2 - \frac{\rho C_2^2}{2 r^2} + C_{02} , \quad (10)$$

$$p^{IIа} = -\frac{\rho(C_2')^2}{2 r^2} + C_{03} \cdot \quad (11)$$

Using the expression for the angular velocity of the one-dimensional vortex

$$\omega_x = \frac{1}{2}\left(\frac{dW_\varphi}{dr} + \frac{W_\varphi}{r}\right) \quad (12)$$

and expression (4), we found values of ω_x and A for zones I, IIa and

II6

$$\omega_x^{I} = \frac{C_1'}{2\pi} , \quad A^{I} = 0$$
$$\omega_x^{IIa} = 0 , \quad A^{IIa} = 2\rho\alpha^2 C_2' = Const_1$$
$$\omega_x^{II\delta} = \frac{C_1''}{2\pi} , \quad A^{II\delta} = 2\rho\alpha^2 C_2 = Const_2$$

Theoretical solutions showed that the tangential velocity in the precombustion chamber of IJ can vary only according to two laws, namely,

$W_y = \frac{C_1}{r}$ -

- the potential motion (13)

$W_y = C_1 r$ -

- the nonpotential motion (14)

In zone I of the nucleus, the velocity is always changing according to equation (14). For this zone the Euler equation is not satisfied,

$$p + \frac{\rho W_y^2}{2} = Const .$$

Two types of motion are possible in zone II of the potential motion: without the inflow of the nonpotential mass "A" and with the inflow of the nonpotential mass "Б". In modes of the A and Б type, the velocities vary correspondingly according to laws

$$W_y^{IIa} = \frac{C_a^{I}}{r} \quad (15)$$

$$W_y^{II\delta} = \frac{C_\delta^{I}}{r} + C_\delta r . \quad (16)$$

Experimental studies are conducted on models of the precombustion chamber with intersecting jets with an extensive change in the geometric characteristics. A total of 37 variants of the models was investigated. A diagram of the apparatus and drawing of the model are given on figures 2 and 3. Table 1 gives limits of the change in basic geometric parameters of the model of the precombustion chamber being varied during the investigations.

$r_{пр}$ мм	1) число горелок	$h_к/b$	l/b	$r_к/r_{пр}$	$b_{ок}/r_{пред}$
140,167,206	1,2,3	0,25÷11,6	1,17÷6,17	0,41÷0,74	0,29÷0,58

Table 1 Key: 1) Number of burners.

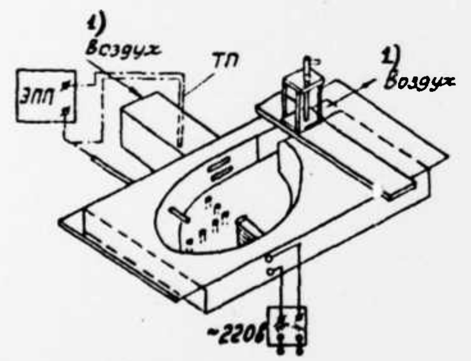


Fig. 2. Key: 1) Air.

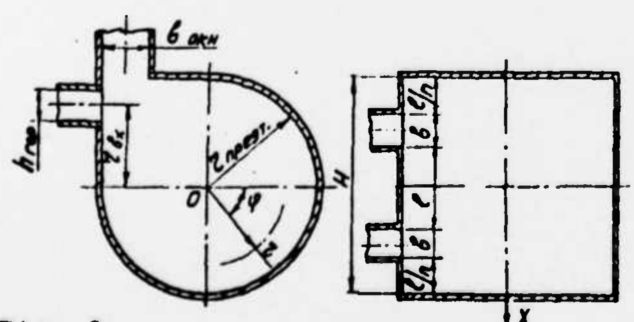
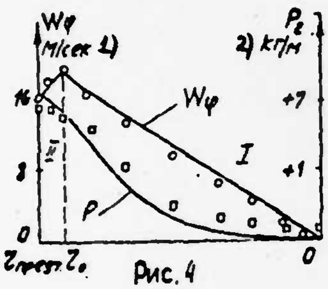


Fig. 3.



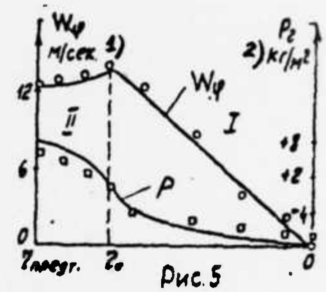


Fig. 4.

Fig. 5. Keys [both figures]: 1) m/s; 2) kg/m².

Figures 4 and 5 show the calculation curves and experimental data on the change in the tangential velocity (W) and pressure in the function of the radius for motion of types A and Б, respectively.

Using the law of the conservation of the potential mass, found in the work are expressions for determining the radius of the nucleus of the vortex in modes "A" and "Б"

$$R_0^A = \frac{r_0^A}{r_{\text{предм}}} = \frac{1}{e^{\frac{(1-G_{\text{вн}})\Pi b h_{\text{зоp}}}{\varepsilon H r_{\text{вх}}}}} . \tag{17}$$

$$R_0^Б = \frac{r_0^Б}{r_{\text{предм}}} = \frac{1}{e^{\frac{2((1-G_{\text{вн}})\Pi b h_{\text{зоp}}}{\varepsilon H r_{\text{вх}}}}} . \tag{18}$$

It has been established by investigations that the balance of the flow of the moment of momentum both in the case of motion of type "A" and type "Б" must be produced according to the magnitude of the potential velocity component for the whole mass circulating in zone II.

1) число горелок n	1	2	2	2	3	3	3
$b \times h_z$ 2) мм	99x85	38x73	22x73	17x73	10x60	10x85	10x11[illegible]
$l_{пред}$ 2) мм	206	206	206	206	206	206	206
R_0 3) опыт / 4) расч.	$R_0^A \frac{0,95}{0,90}$	$R_0^A \frac{0,95}{0,95}$	$R_0^Б \frac{0,69}{0,71}$	$R_0^Б \frac{0,74}{0,76}$	$R_0^Б \frac{0,85}{0,81}$	$R_0^Б \frac{0,80}{0,77}$	$R_0^Б \frac{0,78}{0,74}$

Table 2 Comparison of experimental and calculation data. Key: 1) Number of burners; 2) mm; 3) experimental; 4) calculation.

In conclusion, we can conclude that the agreement of the calculation formulas with experimental data confirms the correctness of the accepted model of the vortex motion in the precombustion chamber with IJ.

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