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CHAMBER OF PULSEJET ENGINE DURING FILLING
PROCESS

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Wright-Patterson Air Force Base, Ohio

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by

Ye. P. Polebichek, V. V. Zhdanov



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CALCULATING PRESSURE IN COMBUSTION CHAMBER OF PULSEJET ENGINE DURING FILLING PROCESS

Ye. P. Polebichek, V. V. Zhdanov

In [1, 2] the working cycle of a supercharged pulsejet engine was investigated under maximal idealization of its current processes.

One of the assumptions made in these studies was the absence of pressure losses in the valve device during filling. The pressure in the combustion chamber during filling, and, consequently, at the beginning of the combustion process was assumed to be equal to the pressure of the working medium in front of a valve device.

In the present article the filling process of the combustion chamber in a pulsejet engine is studied with hydraulic losses on the valve device (valve) considered, a dependence is established between valve pressure loss and the main factors which determine the current process, and a simple approximate formula is derived, which enables us at a degree of accuracy sufficient for engineering problems to determine pressure in the combustion chamber as it is being filled with a fresh working medium.

During the filling process the fresh working medium - a fuel/air mixture or air (depending on the mixture formation method) enters combustion chamber 2 (Fig. 1) through valve 1, while the combustion products remaining in the chamber from the preceding cycle are exhausted through nozzle 4 into the surrounding medium. Let us introduce the following hypothesis:

1. The working medium is an ideal gas.
2. There is no mixing of the fresh working medium which enters the combustion chamber through the valve with the combustion products found in the chamber.
3. Interface 3 (Fig. 1) between the fresh working medium and the combustion products is flat and is perpendicular to the axis of the combustion chamber.
4. There is no heat exchange between the fresh working medium and the combustion products or between them and the external medium.

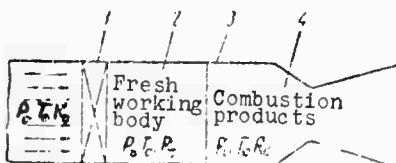


Fig. 1. Combustion chamber filling system for pulsejet engine: 1 - valve, 2 - combustion chamber, 3 - interface between fresh working medium and combustion products, 4 - nozzle.

The fresh working medium is throttled as it flows through the valve, and as a result the pressure in the combustion chamber declines. During damping the temperature of the working body remains (under assumptions 1, 2, and 4) unchanged.

The per-second flow of fresh working medium G_1 entering the combustion chamber through the valve is determined by the formula

$$G_1 = \mu_1 f_1 \chi_1 \frac{P_0}{\sqrt{R_0 T_0}}, \quad (1)$$

where μ_1 and f_1 represent the flow rate coefficient in the area of the flow through section of the valve; P_0 , T_0 , R_0 - pressure, temperature, and the gas constant of the working medium in front of the valve, respectively; χ_1 - a coefficient dependent on the properties of the fresh working medium and the conditions of its flow through the valve.

We will only investigate the precritical flow regimes of the working medium through the valve, since in supercritical regimes pressure losses on the valve would be too great to be admissible. We know that precritical flow regimes will occur

$$\frac{P_1}{P_0} > \beta_{kp1} = \left(\frac{2}{k_0 + 1} \right)^{\frac{k_0}{k_0 + 1}}, \quad (2)$$

where P_1 - pressure behind the valve (in the combustion chamber); β_{kp1} - critical pressure ratio (for valve); k_0 - adiabatic exponent of fresh working medium. For air ($k_0 = 1.4$) $\beta_{kp1} = 0.528$.

In a precritical flow regime

$$\chi_1 = \sqrt{2k_0 \frac{k_0}{k_0 + 1} \left[\left(\frac{P_1}{P_0} \right)^{\frac{2}{k_0}} - \left(\frac{P_1}{P_0} \right)^{\frac{k_0 + 1}{k_0}} \right]}. \quad (3)$$

The per-second mass flow rate of combustion products G_2 flowing from the combustion chamber through the nozzle is determined by analogy to (1):

$$G_2 = \mu_2 f_2 \chi_2 \frac{P_1}{\sqrt{R_1 T_1}}, \quad (4)$$

where μ_2 and f_2 represent the flow rate coefficient and the area of the flow-through (critical) section of the nozzle; T_1 and

R_1 - temperature and gas constant of combustion products remaining in combustion chamber from preceding cycle; χ_2 - coefficient dependent on properties of combustion products and mode of exhaust from nozzle.

Let us investigate only supercritical regimes for the exhaust of combustion products through the nozzle. These will occur when

$$\frac{P_H}{P_1} < \beta_{kp} = \left(\frac{2}{k_1 + 1} \right)^{\frac{k_1}{k_1 - 1}}, \quad (5)$$

where P_H - pressure of the surrounding medium; β_{kp} - critical pressure ratio (for nozzle); k_1 - adiabatic exponent of combustion products.

The conditions under which supercritical regimes are attained for discharge from the nozzle can be established by transforming the left side of inequality (5):

$$\frac{P_H}{P_1} = \frac{P_0}{P_H} \cdot \frac{P_1}{P_0} = \frac{1}{\pi} \frac{P_1}{P_0} < \beta_{kp},$$

or

$$\pi > \frac{1}{\beta_{kp} \frac{P_1}{P_0}}, \quad (6)$$

where $\pi = P_0/P_H$ - degree of compression during supercharging. For conditions of supercritical outflow from the nozzle

$$\gamma_2 = \gamma_{2kp} = \sqrt{2g \frac{k_1}{k_1 - 1} \left(\frac{2}{k_1 + 1} \right)^{\frac{2}{k_1 - 1}}}. \quad (7)$$

In order to find pressure P_1 in the combustion chamber during the filling process when the working medium has a fixed flow

regime through the valve and nozzle, we use the obvious equality of the volume flows of the working medium through the valve and nozzle referred to the conditions of the combustion chamber

$$\frac{G_1}{\gamma_{\text{лср.р.т}}} = \frac{G_2}{\gamma_{\text{лпр.ср}}}, \quad \text{Reproduced from best available copy.} \quad (8)$$

where $\gamma_{\text{лср.р.т}}$ - specific weight of the fresh working medium in the combustion chamber; $\gamma_{\text{лпр.ср}}$ - the specific weight of the combustion products in the chamber, or

$$G_1 R_0 T_0 = G_2 R_1 T_1. \quad (9)$$

If in (9) we substitute G_1 and G_2 with respect to (1) and (4) considering (3) and (7), then after simple transformations we get

$$\frac{P_1}{P_0} = \frac{1}{\bar{f}_{\text{ср.2,р}}} \sqrt{\frac{R_1 T_1}{R_0 T_0}} \sqrt{2g \frac{k_0}{k_0 - 1} \left[\left(\frac{P_1}{P_0} \right)^{\frac{2}{k_0}} - \left(\frac{P_1}{P_0} \right)^{\frac{k_0 + 1}{k_0}} \right]}, \quad (10)$$

where $\bar{f}_{\text{ср}} = \mu_2 f_2 / \mu_1 f_1$ - relative flow through section of the nozzle.

It is not possible to solve equation (10) for the unknown quantity P_1/P_0 in a general form. In each specific case it must be solved by a graph-analytical method or by the method of successive approximations. Thus, the equation (10) which is obtained is not convenient for practical application in calculation or theoretical study of the working process in the combustion chamber of a pulsejet type of engine.

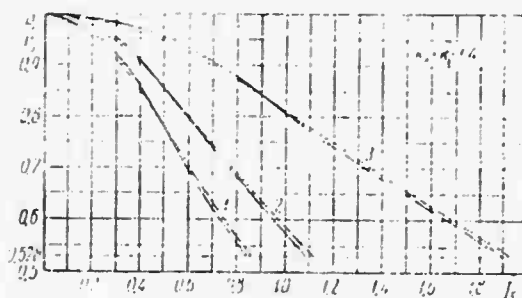


Fig. 2. Theoretical dependences of hydraulic losses on valve during filling of a pulsejet combustion chamber: — from dependence of (10); - - - according to formula (12); 1 - $R_1 T_1 / R_0 T_0 = 5$; 2 - $R_1 T_1 / R_0 T_0 = 3$; 3 - $R_1 T_1 / R_0 T_0 = 1$.

It is desirable to obtain a simpler approximate formula which would enable us to express with a sufficient degree of accuracy and in an explicit form the dependence of the unknown ratio P_1/P_0 on the remaining quantities found in the right part of equation (10).

It was noted in [3] that the flow of air for the entire range of precritical flow conditions on the throttle can be approximately determined according to the flow rate formula for the case of an incompressible fluid if in this formula we substitute the specific weight of the air, which is calculated from pressure behind the throttle. The per-second mass flow rate of the fresh working medium through the valve is determined by formula

$$G_1 = \rho_1 f_1 V \sqrt{2g \gamma_{\text{air}} (P_0 - P_1)}. \quad (11)$$

If in (9) we substitute (4) and (11) with transformations, we get the approximate formula for determining relative pressure in a pulsejet type of combustion chamber during filling for precritical flow conditions on the valve and a supercritical flow in the nozzle:

$$\frac{P_1}{P_0} = \frac{1}{1 + \frac{1}{2g} \lambda_{\text{exp}}^2 \left(\frac{R_1 T_1}{R_0 T_0} \right)} \quad (12)$$

The dependences of P_1/P_0 on $\bar{f}_0$ when $k_0 = k_1 = 1.4$ for different values of $R_1 T_1 / R_0 T_0$, corresponding to formulas (10) and (12) are shown in Fig. 2.

As is apparent in the figure, for the entire studied range ($P_1/P_0 > \beta_{\text{кр}1}$) the calculation results from approximate formula (12) are in good agreement with the solutions of equation (10) with relative error not exceeding 3%.

From the dependences which have been obtained it is apparent that the magnitude of pressure loss on the valve, other conditions remaining equal, is the least when $R_1 T_1 = R_0 T_0$, i.e., when the fresh working medium is exhausted through the nozzle. Consequently, it is rational to increase relative pressure in the combustion chamber as it is being filled, since a certain quantity of the fresh working medium is ejected through the nozzle prior to the ignition of the mixture.

The experimental studies of the filling process in a pulse check combustion chamber were performed in a blowing chamber which followed the system shown in Fig. 1, except that adjustable throttle disks with different flow-through areas were used in place of valve 1 and nozzle 4. The pressure of the compressed air used for the cold blowing was taken in front of the valve and in the chamber. During the experiment air pressure in front of the valve was measured at 3-5 atm(abs.).

Figure 3 shows experimental points for chamber blowing with compressed air for different flow-through section areas in the throttle disks. Here also are the results of calculating the analogous case by formula (12).

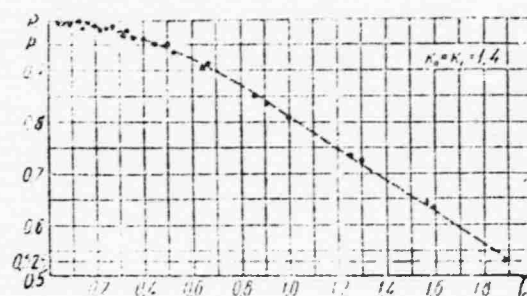


Fig. 3. Results of experimental cold blowing and theoretical dependence of hydraulic losses on valve during filling of a pulsejet combustion chamber when $R_1 T_1 / R_0 T_0 = 1$: ● - experiment; ---- according to formula (12).

From the figure it is apparent that the approximate formula (12) obtained to determine pressure in the combustion chamber of a pulsejet engine during filling is in good agreement with the cold-blowing results.

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