Pulsating combustion of gas fuel in the combustion chamber with closed resonant circuit

E V Yallina1, V M Larionov1, O V Iovleva1
1Kazan (Volga region) federal university

E-mail: evgeniya.yallina@gmail.com

Abstract. In the combustion chambers of the pulsation of gas flow oscillation greatly accelerate heat dissipation to the walls of the combustion chamber and improve combustion efficiency as compared with a uniform combustion mode. This allows you to effectively solve a number of problems of industrial power, including an environmentally friendly combustion products. Significant drawback of such systems - the emitted noise exceeding the permissible requirements. One solution to this problem - the separation of the resonance tube into 2 parts connected at the output to the interference of sound waves. The results of theoretical studies pulsating combustion technical mixture of propane in the system, consisting of a combustion chamber and two resonance tubes forming a closed resonant circuit. Resonators have a variable length. Calculations have shown that under certain oscillation of the resonator length to the first resonant frequency of the system is achieved by reducing SPL more than 15 dB. For oscillations at a second resonant frequency is the complete elimination of noise while maintaining intense oscillations in the combustion chamber.

1. Introduction

In this paper we consider the system with two resonance tubes of different lengths. In this case, the path length of sound waves in the resonator is different, and it may happen that pressure pulsations of the outlet tubes have opposite phase. When the pipe ends have a common outlet for the combustion products, the sound waves emitted will interfere. Condition, when the path difference of the sound waves will be equal to half the wavelength, it is possible to achieve a minimum of intensity of sound holes required for combustion products. Furthermore, the use of two tubes will increase heat-transfer surface, and further intensify the heat exchange process in heating installations pulsating combustion. The aim of this work - the development of a mathematical model of the process of excitation of oscillations in the combustion chamber of gaseous fuel with two resonance pipes and assess the possibility of reducing the level of noise emitted by the system under study.

Fig. 1 is a schematic diagram of study unit.

2. Relations defining the conditions of excitation, frequency and amplitude of the oscillations gas when resonance tube are connected to the outputs

Figure 1 is a schematic diagram of the study unit.
Pulsation rate and pressure in the combustion chamber and the resonance pipes described known [1] expressions.

\[ v_k'(x, t) = C_k e^{i \omega t} (1 - \frac{b x_k}{a})^{1/2} \cos(\varphi_k - \psi_k), \psi_k = \frac{\omega b}{c} \ln (1 - \frac{b x_k}{a}), \]  

where the index \( k \) is 2, 3, 4, \( c_k \) - speed of sound, \( \varphi \) - angle depending on the boundary conditions at the ends of the channel, \( a \) - a linear coefficient of sound velocity distribution, \( b \) - the gradient of the speed of sound in the hot gas, \( \rho \) - gas density, \( \beta = [1 - (b/(2\omega))^{2}]^{1/2} \) parameter in the solution of the wave equation; \( \omega \) - the maximum amplitude of vibration velocity, \( \alpha \) - angle (cyclic) frequency.

At the entrance to the resonance tubes (\( x_3 = 0, x_l = 0 \)) boundary conditions after the linearization of the equation of conservation of mass and momentum take the following form:

\[ (S_3/S_4) v_{3,0} + v_{4,0} = (S_c/S_4) \varphi_{3,0}/Y_{2,1} + p_{3,0} = p_{4,0} , \]  

where \( Y_{2,1} \). The output impedance of the combustion chamber [2]. At the exit of the conditions of the resonance tubes:

\[ S_3 v_3' (l_3, t) + S_4 v_4' (l_4, t) = S_l v_1', p_{3,l} = p_{4,l} \]  

Believe \( p_1 = i Y_l \delta t_l \), obtain \( (S_3/S_4) v_{3,l} + v_{4,l} = (S_l/S_4) p_{3,l} / (i Y_l) \) \( p_{3,l} = p_{4,l} \)If the resonance tubes have a common outlet opening, then:

\[ Y_l = \rho_l c_{1} t g (\omega l_t' / c_i), l_t' = l_t + 0.61 R_l . \]

We denote the \( S_3/S_4 = \sigma_3 A_l; \rho_{3,3,2,3} (S_c/S_4)/Y_{2,1} = \sigma_0(\omega) \), \( \sigma_3, \lambda_3, \sigma_4, \rho_{3,3,2,4} (S_l/S_4)/Y_l = \sigma_l . \)

From the boundary conditions (3), (4) taking into account the expressions (1), (2) we obtain the following relations:

\[ \varepsilon_{3,4} C_4 \cos \varphi_3 + C_4 \cos \varphi_4 = \sigma_0 C_3 \left( \frac{b}{\omega} \cos \varphi_3 + \beta \sin \varphi_3 \right), \]

\[ C_3 \left( \frac{b}{\omega} \cos \varphi_3 + \beta \sin \varphi_3 \right) = C_4 \left( \frac{b}{\omega} \cos \varphi_4 + \beta \sin \varphi_4 \right), \]

\[ (\varepsilon_{3,4} \lambda_3 C_3 \cos (\varphi_3 - \psi_{3,1}) + \lambda_4 C_4 \cos (\varphi_4 - \psi_{3,1})) = \sigma_1 \lambda_3 C_3 \left( \frac{b}{\omega} \cos (\varphi_3 - \psi_{3,1}) + \beta \sin (\varphi_3 - \psi_{3,1}) \right) + \beta \sin (\varphi_3 - \psi_{3,1}), \]

\[ \rho_{3,3,2,3} \lambda_3 C_3 \left[ \frac{b}{\omega} \cos (\varphi_3 - \psi_{3,1}) + \beta \sin (\varphi_3 - \psi_{3,1}) \right] = \rho_{4,4} C_4 \lambda_4 C_4 \left[ \frac{b}{\omega} \cos (\varphi_4 - \psi_{3,1}) + \beta \sin (\varphi_4 - \psi_{3,1}) \right] \]

The condition of uniqueness of the solution of these systems of equations for the unknown \( C_3, \varphi_3, C_4, \varphi_4 \) allows you to find the frequency of oscillation of gas. The formula for calculating the amplitude of the pressure oscillations in the combustion chamber was the energy method [1] has the form:

\[ P_c = \frac{a_c^{(L)} - A_{c,3} - A_{c,4} - a_l^{(L)}}{a_c^{(N)} + a_l^{(N)}}, \]
where \( a_r, a_w, a_l \) – the dependency ratio \( A_r, A_w, A_l \) the amplitude of the pressure fluctuations in the plane of the heat input, the indices \( L \) and \( N \) represent linear and non-linear approximation, respectively.

3. Calculation of oscillation gas depending on the geometrical parameters of the installation

Were calculated amplitudes of velocity fluctuation of the gas outlet pipe resonance depending on the length of one of the tubes at a constant length of a resonant circuit. These data are given the phase difference of velocity fluctuations in the gas pipe ends are shown in Table. 1. The calculation results show that, depending on the location of the outlet in the resonant circuit of the gas velocity pulsations are the same or the opposite phase when the value \( U_{l4} \) becomes negative. Comparison of tabular data with the results shown in Fig. 2 shows that the minimum value of the sound pressure level in the outlet corresponds to the condition where the gas velocity fluctuations at the ends of the resonance pipes have the same amplitude and opposite phase.

Table 2. Dependence frequency oscillations excited gas ultrasound, gas velocities at the ends of the resonance tubes and the level of noise emitted from a single length of pipe resonance circuit at a constant length, \( L = 0,5 \). (secondharmonic)

| \( l_1 \) | f, Hz | \( p_{1t}, \text{dB} \) | \( U_{l3}, \text{м/с} \) | \( U_{l4}, \text{м/с} \) | \( p_{1t}, \text{dB} \) |
|---------|-------|-----------------|----------------|----------------|----------------|
| 0,05    | 862   | 129,0           | 0,50           | -0,24          | 75,5           |
| 0,06    | 847   | 129,5           | 0,49           | -0,29          | 72,5           |
| 0,08    | 838   | 129,5           | 0,40           | -0,33          | 61,5           |
| 0,09    | 840   | 129,0           | 0,34           | -0,34          | 39,5           |
| 0,091   | 841   | 129,0           | 0,34           | -0,34          | 3,5            |
| 0,092   | 841   | 129,5           | 0,33           | -0,33          | 39,5           |
| 0,095   | 843   | 128,5           | 0,31           | -0,33          | 51,0           |
| 0,1     | 847   | 128,0           | 0,29           | -0,33          | 57,50          |
| 0,12    | 868   | 125,0           | 0,18           | -0,27          | 65,00          |
| 0,14    | 899   | 120,0           | 0,09           | -0,18          | 65,0           |
| 0,16    | 937   | 105,5           | 0,02           | -0,04          | 53,5           |
Fig. 1 The dependence of the sound pressure level on the length of one of the resonance tube at a constant contour length \( L = 0.5 \text{ m} \);

4. Conclusions

1) The mathematical model and method of calculation of the excitation conditions and parameters of gas oscillations in the combustion chamber of the pulsation of fuel with two resonance tubes, which form a closed loop.

2) Found that for a fixed length of one of the resonators, extending the second resonator can be achieved alternating excitation of oscillations of the first gas and the second frequency system.

3) It was found that at an elongation of one of the resonators with respect to another can be achieved by phase transition to the gas velocity pulsations antiphase output of the resonators and reduce the noise by more than 15 dB for a first oscillation frequency of the system.

4) Complete elimination of the noise occurs at the excitation oscillations of the gas with the second frequency system when the pulse rate of the gas from the resonance tubes have the same amplitude but opposite phase.

5) When designing industrial installations denoised recommended geometric parameters of the combustion chamber and resonance tube set such that the excited vibration with the frequency of the second system, and the outlet was located at the resonant circuit at a point to which one longer than the other part of the circuit by an amount equal to half the length sound wave.

References

[1] LarionovVM, ZaripovRG 2003Self-oscillations of gas in installations with combustion 237 (KSTU, Kazan)

[2] LarionovVM, Beloded O V 2006Vibrationcombustion in a tube with jump of cross-sectionIzv. VUZ.AviatsionnayaTekhnika (vol 1)pp 30–33