Analysis of the effect of combustion chamber length on the gas oscillations characteristics

A O Malakhov, V M Larionov, A R Khalilov, S A Nazarychev and N V Konstantinov
Kazan Federal University, 18 Kremlyovskaya st., Kazan 420008, Russian Federation
E-mail: aleks19bass@yandex.ru

Abstract. In this paper, the case of the influence of a change in the length of the vortex combustion chamber on the amplitude-frequency characteristics of gas oscillations is considered. Experimental data were obtained, on the basis of which the graphs of the dependence of the amplitude and frequency of the combustion chamber on the excess air ratio were received.

1. Introduction
Vibration combustion is a complicated and complex process. It is known that under certain conditions in combustion chambers it occurs in a pulsating or, as it is also called, vibration mode of combustion. The appearance of thermoacoustic oscillations of the gas is due to many factors: pressure pulsations, thermal heterogeneity in the combustion chamber, flow mechanism and the influence of the geometry of the fuel supply system and the combustion chamber itself. This case is considered in this paper.

2. Experiment procedure
The experiments were carried out on the developed and earlier described vortex chamber of vibration combustion [1, 2, 3]. The first basic experiment was carried out with an initial volume of the combustion chamber equal to 418 cm³, the height of the working area from the piston to the outlet was L = 460 mm, and the inner diameter of the fuel supply nozzle was 3.5 mm. After receiving the data, the operating range of the installation was determined based on the flow rate, it was 25.8 L / min of air and 1.1 L / min of fuel.

The unit is equipped with a plug-in acoustic probe to measure the sound pressure inside the combustion chamber. This device is designed to measure sound pressure in a small volume of the combustion chamber, as well as near of acoustic vibrations source – a vortex pulsating flame. The probe has a thin tube 15 cm long and 3 mm in diameter, at the end of the tube there is a labyrinth with absorbing material, which prevents the reflection of sound waves from the end of the tube. An electret-measuring microphone with the required calibration is located at the side of the tube end.

To changing the internal volume of the combustion chamber, special extension nozzles were used, which were tightly fixed through couplings with a threaded connection of 1.25L and 1.5L length, which is 575mm and 690mm, respectively.
The experimental technique implied a fixed heating of the combustion chamber at room temperature (23°C): the unite was started and warmed up to operating temperature, focusing on a slight change in frequency, with a stoichiometric fuel-air ratio. Further, the mode was adjusted in accordance with the experiment, the amplitude-frequency characteristics of the flame were measured, after which the combustion in the unite was stopped for a fixed time (1.5–2 minutes). Further, in the combustion chamber, combustion was initiated again at $\alpha = 1$ and the heating was fixed in time (no more than 1 minute), then the mode was adjusted to the new experimental condition and the next measurement was carried out.

3. Results and discussions

Several verification experiments were carried out, after which the following data were obtained (table 1, 2, 3):

| Table 1. Experiment No. 1, combustion chamber length L |
|-----------------------------------------------|---------|---------|---------|---------|
| $G_{\text{fuel}}$, L/min | $G_{\text{air}}$, L/min | $\alpha$ | $F$, Hz | $N$, dB |
| 1,01 | 25,8 | 1,07 | 257 | 133,17 |
| 1,05 | 25,8 | 1,03 | 256 | 144,25 |
| 1,09 | 25,8 | 1,00 | 254 | 153,80 |
| 1,13 | 25,8 | 0,96 | 259 | 136,37 |
| 1,17 | 25,8 | 0,93 | 264 | 129,65 |
| 1,21 | 25,8 | 0,90 | 268 | 125,01 |
| 1,25 | 25,8 | 0,87 | 272 | 123,97 |
| 1,29 | 25,8 | 0,84 | 274 | 121,86 |
| 1,33 | 25,8 | 0,82 | 275 | 121,20 |
| 1,37 | 25,8 | 0,79 | 276 | 121,51 |
| 1,41 | 25,8 | 0,77 | 277 | 121,51 |

| Table 2. Experiment No. 2, combustion chamber length 1,25L |
|-----------------------------------------------|---------|---------|---------|---------|
| $G_{\text{fuel}}$, L/min | $G_{\text{air}}$, L/min | $\alpha$ | $F$, Hz | $N$, dB |
| 0,89 | 25,8 | 1,22 | 200 | 126,78 |
| 0,93 | 25,8 | 1,17 | 196 | 132,15 |
| 1,01 | 25,8 | 1,07 | 199 | 130,99 |
| 1,09 | 25,8 | 1,00 | 205 | 138,55 |
| 1,17 | 25,8 | 0,93 | 205 | 130,99 |
| 1,25 | 25,8 | 0,87 | 205 | 126,78 |
| 1,33 | 25,8 | 0,82 | 205 | 126,78 |
| 1,41 | 25,8 | 0,77 | 205 | 124,91 |

| Table 3. Experiment No. 3, combustion chamber length 1,5L |
|-----------------------------------------------|---------|---------|---------|---------|
| $G_{\text{fuel}}$, L/min | $G_{\text{air}}$, L/min | $\alpha$ | $F$, Hz | $N$, dB |
| 0,89 | 25,8 | 1,22 | 168 | 126,78 |
| 0,93 | 25,8 | 1,17 | 169 | 124,03 |
| 1,01 | 25,8 | 1,07 | 168 | 125,83 |
| 1,09 | 25,8 | 1,00 | 170 | 137,19 |
| 1,17 | 25,8 | 0,93 | 170 | 126,78 |
| 1,25 | 25,8 | 0,87 | 172 | 126,78 |
| 1,33 | 25,8 | 0,82 | 175 | 123,19 |
| 1,41 | 25,8 | 0,77 | 176 | 123,19 |
Based on the results, the graphs of the dependence of the amplitude and frequency of the combustion chamber on the excess air ratio for different lengths were plotted (Fig. 1, Fig. 2).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig1.png}
\caption{Dependence of the combustion chamber amplitude on the change in its length L.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig2.png}
\caption{Dependence of the combustion chamber frequency on the change in its length L.}
\end{figure}

As a result, for a combustion chamber with a length L from 460 to 690 mm, the most optimal conditions for a vibration combustion mode are as follows: an air flow rate of 25.8 l / min, an excess air ratio in a mixture $\alpha$ from 0.77 to 1.22.
4. Conclusion

The combustion temperature of the stoichiometric mixture and the speed of sound at the entrance to the combustion chamber have a maximum value. As is known, the frequency of acoustic oscillations of a gas in a tube is directly proportional to the speed of sound [4]. Therefore, one could expect that at $\alpha = 1$ the frequency of gas oscillations is maximum. Measurements of the acoustic pressure at the inlet to the combustion chamber (Fig. 2) showed that the maximum vibration amplitude is observed at $L = 460$ mm, $\alpha = 1$, as opposed to the oscillations frequency, the parameters of which, contrary to expectations, decreased closer to stoichiometry. Thus, as the combustion chamber lengthens, the maximum amplitude decreases on average by 20 dB. The oscillation frequency also decreases, but the minimum at $\alpha = 1$ on the $f(\alpha)$ curve disappears (Fig. 1).

Acknowledgements

The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University.

References

[1] Sadikov K G, Malahov A O, Larionov V M, Saifullin E R and Larionova I V 2018 Journal of Physics: Conference Series 1058 012060

[2] Malahov A O, Larionov V M, Iovleva O V, Gaianova T E, Gaponenko S A 2020 Journal of Physics: Conference Series 1588 (1) 012026

[3] Larionov V M, Sadikov K G, Mitrofanov G A 2016 Journal of Physics: Conference Series 669 012042

[4] Larionov V M 2004 Mechanisms and conditions for the excitation of gas self-oscillations in installations with combustion