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Evaluation of the high-frequency oscillation parameters of a liquid-propellant rocket engine with an annular combustion chamber

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The high-frequency instability (HF instability) of a liquid-propellant rocket engine (LPRE) during static firing tests is often accompanied by a significant increase in dynamic loads on the combustion chamber structure, often leading to the chamber destruction. This dynamic phenomenon can also be extremely dangerous for the dynamic strength of a liquid-propellant rocket engine with an annular combustion chamber. Computation of the parameters of acoustic combustion product oscillations is important in the design and static firing tests of such rocket engines. The main aim of this paper is to develop a numerical approach to determining the parameters of acoustic oscillations of combustion products in annular combustion chambers of liquid-propellant rocket engines taking into account the features of the configuration of the combustion space and the variability of the physical properties of the gaseous medium depending on the axial length of the chamber. A numerical approach is proposed. The approach is based on mathematical modeling of natural oscillations of a “shell structure of an annular chamber – gas” coupled dynamic system by using the finite element method.

Based on the developed finite-element model of coupled spatial vibrations of the structure of the annular combustion chamber and the combustion product oscillations, the oscillation parameters of the system under consideration (frequencies, modes, and effective masses) for its dominant acoustic modes, the vibration amplitudes of the combustion chamber casing, and the amplitudes of its vibration accelerations can be determined. The operating parameters of the liquid-propellant rocket engine potentially dangerous for the development of thermoacoustic instability of the working process in the annular combustion chamber can be identified. For the numerical computation of the dynamic gains (in pressure) of the combustion chamber, a source of harmonic pressure excitation is introduced to the finite element model of the dynamic system “shell structure of an annular configuration – gas” (to the elements at the start of the chamber fire space).

The developed approach testing and further analysis of the results were carried out for an engine with an annular combustion chamber (with a ratio of the outer and inner diameters of 1.5) using liquid oxygen – methane as a propellant pair.

The system shapes and frequencies of longitudinal, tangential and radial modes are determined. It is shown that the frequency of the first acoustic mode in the case of a relatively low stiffness of the combustion chamber casing walls can be reduced by 40 percent in comparison with the frequency determined for a casing with rigid walls.

Keywords: *liquid propellant rocket engine, annular combustion chamber, methane–oxygen propellant, high-frequency engine instability, oscillation frequencies.*

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