High-frequency stability evaluation of liquid rocket thrust chamber

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Abstract:

High-frequency instability of a liquid-propellant rocket engine (LPRE) during static firing tests is often accompanied by a significant increase in dynamic loads to 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. Calculation of acoustic combustion products oscillations parameters is important in the design and static firing tests of such rocket engines. Determination of the oscillation parameters (natural frequencies and stability margins such as oscillation decrement [1, 2]) is one of the problems solved in the LPRE design period as part of the development of measures to ensure the engine stability.

The main aim of the paper is to develop a numerical approach to determining the parameters of acoustic oscillations of combustion products in liquid-propellant rocket engines combustion chambers, taking into account the features of combustion space configuration and the variability of gaseous medium physical properties depending on the axial length of the chamber, acoustic impedance in critical throat and dissipation effects (damping experimental values) in shell structure and gas media in chamber. The approach is based on mathematical modeling of a coupled ‘chamber shell structure – gas’ dynamic system by using the finite element method and CAE (Computer Aided Engineering) system.

The developed approach testing and further analysis of the results out for the RD 253 engine using nitrogen tetroxide and unsymmetrical dimethylhydrazine as a propellant pair were carried out. The dynamic system shapes and frequencies of longitudinal, tangential and radial modes are determined. The results of mathematical modeling of the dynamic system indicate a satisfactory coincidence of the calculated decrements of the first longitudinal oscillation mode and third tangential oscillation mode with the experimental decrements obtained by hot-fire tests data [1]. From system harmonic analysis of the thrust chamber follows the dynamic pressure gain factor of gas media in chamber at first longitudinal mode frequency f1L is 1,6 times greater than the system dynamic gain at the tangential mode. At the same time the oscillation decrement for the system tangential mode is in 2 times smaller than oscillation decrement of the first longitudinal mode. This means that the thrust chamber tangential mode is more dangerous and can lead to the rocket engine combustion instability.

References

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