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Title

One-dimensional Modeling of Ignition Timing for Hypergolic Bipropellant Thrusters

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Abstract

Hypergolic propellants, Hydrazine/NTO and MMH/NTO, are used for bipropellant thrusters, which are important components for spacecraft orbit and attitude control. One of characteristics of hypergolic propellant is auto ignition. Therefore, bipropellant thrusters do not need an igniter. In a spacecraft such as a lunar landing, throttling during landing is a possibility, and reliable auto ignition at a low flow rate is critical to mission success.

The chemical reaction model [1] and lab-scale ignition test [2] were studied and revealed the characteristics of the auto ignition in the previous works. However, there are very few studies on auto ignition in actual thrusters. In recent years, our group [3] has become clear that an oxidizer with high vapor pressure becomes a gas-liquid multiphase injection when the chamber pressure is close to a vacuum, such as at the start of propellant injection. And it induced a long ignition delay and a strong ignition pressure, which is called as a hard start. The understanding and simulation of the ignition delay are necessary to guarantee the auto ignition in pulse operation mode with short injection time and a low flow rate.

In this paper, one-dimensional model of chemical propulsion system is developed to predict the ignition timing. It includes all components with tanks, pipes, filters, valves, injectors, and combustion chambers. The chemical reaction time of hypergolic propellant is a few milliseconds for gas phase [1] and tens of microseconds for liquid phase [4]. The ignition delay for the actual thruster is tens milliseconds. Therefore, the ignition in the actual thrusters depend on the mixing of fuel and oxidizer. The mixture ratio of fuel and oxidizer before the ignition can be estimated using one-dimensional system simulation. As observed in the previous work [3], the gas-liquid multiphase injection of oxidizer at the start of propellant injection induced the long ignition time and the strong ignition pressure. Thus, the phase change of the oxidizer (NTO) has been taken into account in the one-dimensional simulation. Since the engine is started from a vacuum in space, it is necessary to reproduce the gradual increase in combustion chamber pressure due to the injection after the valve opens and the oxidizer changes from gas to liquid. Here, the saturated vapor pressure of the fuel is so small that the fuel is almost always in a liquid state and does not dominate the ignition phenomenon very much. The one-dimensional simulation with phase change of NTO could reproduce the long ignition delay for the low mass flow rate quantitatively.

References

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