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Author: Mr. Ping LI
Xi'an Aerospace Propulsion Institute, China, lipg2000@163.com

Dr. Wenlong LI
Xi'an Aerospace Propulsion Institute, China, liwl_casc@sina.com
Mr. lyu shunjin
CASC, China, lvshunjin@yeah.net

SYSTEM SCHEME AND THROTTLING METHODS OF VARIABLE THRUST LIQUID ROCKET ENGINES FOR CHINA'S DEEP SPACE EXPLORATION

Abstract

Throttleable LREs undoubtedly play a significant role in planetary entry and landing. In December 2013, a ratio of 5:1 deep throttling engine with 7,000N thrust class has been demonstrated in Chang'e-3 unmanned lunar exploration mission, which realized the first soft landing on the surface of an extraterrestrial body by a Chinese spacecraft. To begin with, several typical engines that have successfully demonstrated throttling, such as Apollo LMDE, SSME, CECE, J-2S, and RD-862 were evaluated with a discussion of engine system scheme and component interactions, followed by a breakdown of components in order to discuss special considerations that need to be made for throttling applications. The key difficulty in throttling LREs is maintaining an adequate pressure drop across the injector, which is of critical importance to sustain sufficient propellant atomization and mixing. For the thrust chamber, heat transfer and cooling capability limited by coolant flow rate may be an issue at low thrust levels. For turbomachinery, the primary considerations are to avoid cavitation, stall, bearing leakage flows, as well as rotor dynamics. Furthermore, it is necessary to design valves and actuators that can achieve accurate flow control at all thrust levels. Secondly, this paper discussed a number of throttling methods, including high-pressure-drop injection system, dual-manifold injectors, variable area injector, gas injection, multiple chambers, pulse modulation, and throat throttling. Critical concerns and issues such as combustion instability, performance degradation, and excessive heat transfer were examined for each method, and the advantages and shortcomings of different methods were also compared. It is important to note that several throttling solutions are typically used together for deep throttling requirements. Deep throttling will be required on the future China's space activities, including manned lunar landing and Mars exploration operation, etc. Lastly, a conceptual design and full system scheme of deep throttling engine with pump pressure feed system are presented for special mission requirements. As for expander cycle LOX/Methane engine, it is necessary to achieve high special impulse deep throttling that high-pressure-drop injector or pintle injector, and turbine-driven gas by passing. By contrast, the LOX/Kerosene staged-combustion cycle engine requires additional system issues that touch every component and the feed system, including LOX/Syntin (synthetic kerosene) propellant combination, high-pressure-drop injector or dual-manifold injector, throttling of pre-burner liquid oxygen and kerosene flow, regulation of kerosene flow rate and responding mixture ratio of thrust chamber, as well as setting the affluent of pre-burner oxygen-rich gas, and so on.