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Corresponding author: AHN Kyubok
e-mail of corresponding author: kbahn@cbnu.ac.kr
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Title
Throttling hot-firing tests of methane engine thrust chamber with uni-element shear coaxial injector

Authors
*Cheolwoong Kang [1], Shinwoo Lee [1], Hadong Jung [1], Sunwoo Han [1], Kangyeong Lee [1], Dongwoo Choi [1], Changyoung Oh [1], Kyubok Ahn [1]**

** Corresponding author*
[1] School of Mechanical Engineering, Chungbuk National University, Cheongju, Chungbuk, 28644, Korea, kbahn@cbnu.ac.kr

Abstract
Liquid rocket engines with variable thrust have been studied and researched since the late 1930s. The upper stage launch vehicle engine limits acceleration through thrust changes. Throttling can also reduce the mass of a launch vehicle by reducing the amount of propellant required, and is also used for planetary entry and descent, orbital maneuvers including space orientation and stabilization, and hovering during planetary landings. As mentioned above, throttleable vehicles can efficiently perform various missions [1]. Therefore, combustion characteristics with the recess length of the injector at various thrusts were confirmed in this study through thrust control hot-firing tests of a methane engine thrust chamber equipped with a uni-element shear coaxial injector.

The 3 tonf-class methane engine with expander closed cycle is a model of a uni-element thrust chamber. The thrust chamber of the expander closed cycle engine is cooled by liquid cryogenic fuel passing through cooling channels. The fuel whose temperature has risen during the cooling process is supplied to the turbine and injector in a vaporized state. So, a shear coaxial injector was adopted because the propellant combination is a liquid oxygen/gaseous methane. A shear coaxial injector is mainly applied in liquid/gas propellant combinations. The shear coaxial injector consists of an inner injector (center orifice) through which liquid oxygen is supplied at low velocity and an outer injector (annular gap) through which gaseous methane is injected at high velocity. There are three types of shear coaxial injectors with the same taper angle of 15° but different recess lengths. The cylinder part and nozzle part of the uni-element thrust chamber was manufactured to have cooling channels by simulating regenerative cooling. The uni-element thrust chamber is cooled with water passing through a cooling channel. The cylinder part was machined to have 60 cooling channels. Since the cross-sectional diameter of the nozzle part is reduced, the nozzle part is additively manufactured to smoothly reduce 38 cooling channels to 19. The combustion chamber pressure is measured in the cylinder part, and the temperature and pressure of the cooling channel are measured in both the cylinder and the nozzle part.

Hot-firing tests were conducted at Chungbuk National University's 1 kN class methane engine combustion test facility, and the thrust was continuously changed from 100% to 20% (Δ20%). Regardless of thrust, the existence of the recess length has led to an increase in combustion efficiency and heat flux. This is considered to be due to the improvement of atomization and mixing performance and the change of the flame structure because of the increase in the recess length. In all combustion tests, the RMS value of the pressure fluctuation versus the combustion chamber pressure was less than the criterion of combustion instability ($p'_{RMS}/P_c < 3\%$), so combustion was stable regardless of the recess length.

References

[1] Casiano, M. J., Hulka, J. R., and Yang, V. 2010. Liquid-Propellant Rocket Engine Throttling: A Comprehensive Review. J. Propuls. Power. 26(5): 897-923.