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Experimental and simulation study of a Gaseous oxygen/Gaseous hydrogen vortex cooling thrust chamber

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ABSTRACT

In this paper, RNG k-ε turbulence model and PDF non-premixed combustion model are used to simulate the influence of the diameter of the ring of hydrogen injectors and oxidizer-to-fuel ratio on the specific impulse of the vortex cooling thrust chamber. The simulation results and the experimental tests of a 2000 N Gaseous oxygen/Gaseous hydrogen vortex cooling thrust chamber reveal that the efficiency of the specific impulse improves significantly with increasing of the diameter of the ring of hydrogen injectors. Moreover, the optimum efficiency of the specific impulse is obtained when the oxidizer-to-fuel ratio is near the stoichiometric ratio.

1. Introduction

Vortex technology (also known as eddy current technology) has recently been used in many fields, such as eddy current inspection, cyclone separator, and trapped vortex combustion [1–3]. Indeed, thanks to the special structure of its flow field, this technology could be used to solve thermal protection problems in rocket propulsion. In early 2000, a new chamber design was proposed with a swirl injector organizing a vortex flow field in the combustion chamber. In this vortex cooling thrust chamber, the oxidizer is injected tangentially from the bottom of the chamber so as it forms a cold outer vortex flow that spirals upward along the combustion chamber wall. After the oxidizer reaches the faceplate of the chamber, it mixes with the fuel, which is injected from the top of the chamber, and forms a hot downward-spiraling inner vortex flow. The cold outer vortex flow isolates the thrust chamber wall from the high temperature gas, and then the heat load on the inner chamber wall surface is reduced so that its temperature remains low. The hot inner vortex flow promotes the propellant mixing so that the length of the combustion chamber can be reduced and the combustion efficiency improves. Previous researches showed that the vortex cooling technology has a great potential for simplifying the thrust chamber structure as well as reducing development costs and extending engine lifetimes.

In the U.S., the theoretical and numerical investigations to analyze the features of the vortex cooling thrust chamber using Gaseous oxygen/Gaseous hydrogen developed by Orbital Technologies Corporation (ORBITEC) in 2000 showed that the best specific impulse efficiency could reach up to 97% [4,5]. Later on, in 2005 Chiaverini et al. carried out many tests of this chamber design using Gaseous oxygen/Gaseous hydrogen, Gaseous oxygen /methane and Gaseous oxygen/kerosene as propellant combinations. In their investigations, they focused on the fuel injection methods and the design parameters of the chamber [6], verifying the feasibility of small-scale vortex cooling chambers. Afterwards, in 2011 ORBITEC developed a low-cost vortex cooling thrust chamber

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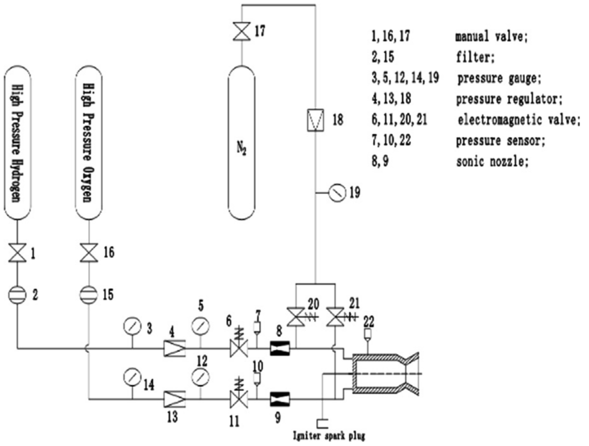

Fig. 1. Test system.

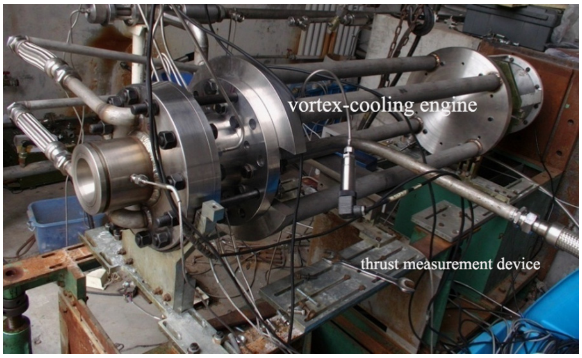

Fig. 2. The real engine.

with hybrid fabrication techniques, which was used in some high attitude simulation tests [7].

In China, Jiawen Li and other researchers from Beihang University investigated the vortex cooling thrust chamber using Gaseous oxygen/Gaseous hydrogen as propellants with different thrust levels [8,9]. These tests measured the temperature at the faceplate, chamber inner sidewall and nozzle throat with the aim of evaluating the capability of the vortex cooling technology. Furthermore, the performance of the chamber was also assessed using the thrust values. In addition, their numerical simulations allowed to capture the characteristics of the vortex flow field in the chamber, and confirmed which factors influence the specific impulse [10]. In addition, they developed a 300 N thrust vortex chamber and analyzed the design through numerical simulations in order to sort out the influence of the design parameters of the chamber and injection conditions on the engine performance [11].

It should be pointed out that as the complexity of the combustion in the vortex cooling thrust chamber, the main direction of preview simulations is to verify the flow field [12–14]. They used a chamber, which has done some test to do simulation to verify the flow field structure but there is a lack of comparison study with test results about the influence on the specific impulse with different design parameters. It cannot provide some help to design a new chamber with different thrust level or different mass flow rate. Based on the experiments results and three dimension steady state numerical simulations results, this paper study the performance of specific impulse influenced by the diameter of the ring of hydrogen injectors (D_{H_2}) and oxidizer-to-fuel ratio (γ). Then a chamber structure called optimum specific impulse structure is proposed to provide references for the design of vortex cooling chamber.

Table 1
Parameters of Sensors.

Sensor	Model no.	Range	Precision/%
Thrust	BK-1A	0–200 kg	$\pm$0.1
P_1, P_2, P_3	CYB-20S	0–2 MPa	$\pm$0.5
T_1, T_2, T_3	Exposed-size	273–800 K	$\pm$0.25
T_4	Exposed-size	273–1200 K	$\pm$0.25

Table 2
Parameters of the test engine.

Parameters	Value
Thrust F/kN	2
Propellants	GO_2/GH_2
Pressure of chamber P_c/MPa	1.5
Atmosphere pressure P_a/MPa	0.1
Diameter of throat D_t/mm	36.1
Diameter of chamber D_c/mm	144.5

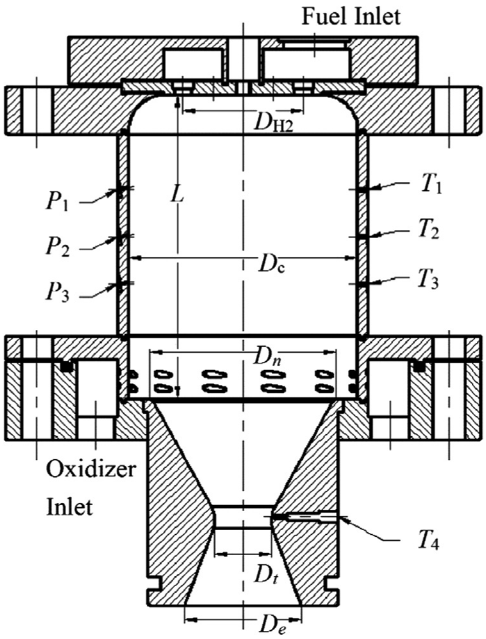

Fig. 3. Assembly view of the engine.

2. Experimental facilities and methodology

2.1. Experimental system and apparatus

A schedule of the hot-fire test system is depicted in Fig. 1. Gaseous oxygen and hydrogen are supplied by reservoirs.