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Design, Manufacturing, Cold and Hot-Fire Test of a Liquid Subscale Engine with Single Swirl Double Base Injector

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ABSTRACT

The ongoing developmental studies on the application of subscale liquid rocket engines as small thruster and laboratory tester are briefly reviewed. Then a detailed design and manufacturing process of a laboratory liquid subscale engine with single swirl double base injector of 300 N thrust for this reaserch is presented. For the preparation of pressurized water, fuel and oxide, a test facility has been prepared. Results of water analogy tests are presented. Initial firings using the real fuel and oxide were not successful. Low fuel flow, low mixing area of the fuel and oxide, and contamination in the TR-1 were considered to be the reasons. Overcoming to these problems resulted in successful firing of the subscale engine. Obtained results were adapted to design expected results.

KEYWORDS:

Double Base Swirl Injector, Subscale Engine, Liquid Propellant, Cold & Hot-Fire Test.

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1- INTRODUCTION

The best way to conduct a hot firing test before operational use of propulsion systems, is using a actual (full-scale) motor. But in fact, this is a rather exhaustive method in the viewpoints of cost and time, considering the recent economic constraint applied to the space industry programs. Due to the need to find effective methods to validate engine hardwares without ignoring it's main characteristics, a way is using a model (sub-scale) engine instead of the real engine in the tests. Today, many tests are done by using low-thrust engines in laboratories and space test centers and they have had very valuable results. However, the most important use of these engines is their application in space crafts Reaction-Control Systems [1].

2- MICROMOTOR DESIGN

All stages of creating a new product , is affected by "requirements definition" directly and by results of its performance inversely. Micromotor design requirements will determine what the final product is going to do and what is better way to fulfill the mission? Therefore, in this section, general requirements, assignments, constraints, design philosophy and criteria are noted, so it is natural that the constraints of cost and time required for development of the project (in the design, manufacture, testing and using), reliability, and sometimes geometric constraints and user interface set are added to the above items. The best way in simplification and holistic approach in designing a complex set is identifying and dividing it into sub-sets or sub-systems. Basis of the subset creation is depending on the characteristics of the initial system and can not provide a specific formula for it [2].

Creating subsets of the liquid fuel micromotor is done on the basis of set assembling. Subsets resulting from this approach are different and complementary in terms of performance. Micromotor design subsystems that should be considered, include the spray set and the body set, in turn, the recent set consists of two parts; the combustion chamber and the nozzle. The main design parameters that should be measured and controlled are the micromotor nominal thrust, specific impulse (Is), combustion chamber pressure, temperature near the wall, the pressure behind the injectors, the injector flow rate, number of injectors, the ratio of propellant components (oxidizer to fuel) and the cooling fluid inlet temperature. However, other parameters can be controlled in design, by the fulfillment of the above parameters and by using the experimental results, the other parameters are within permissible range.

In this study, for micromotor, the TM-185 as fuel and the Ak-27 is used as oxidizer for hot-fire testing. Engine operating time is considered 10 seconds. Engine specifications are presented in Table 1.

Table 1. Characteristics of micromotor

Characteristics of the engine	value	unit
Fuel mass ratio(o/f)	4.5	-----
Gas pressure in the combustion chamber	2.5	MPa
Gas pressure in the nozzle exit	0.04	MPa
Diameter of the combustion chamber Cross section	30	mm
Nozzle throat diameter	10	mm
Nozzle exit diameter	30.5	mm
Chamber to the nozzle connecting Arc	30	mm
Nozzle divergent portion length	28	mm
Nozzle convergent portion length	35	mm
Combustion chamber length	130	mm
Total length of the engine	190	mm

3- SPRAYING COLD TEST

To obtain enough experience about tests and ensuring about the correct spraying and formation of the spray umbrella, injectors fluid flow output compliance with the predicted values for the design, no leaks (in the fuel inlet ducts, pressure ports, injector plate and the plate between injectors), the motor assembly was tested under simulated test conditions by water and nitrogen.

4- HOT-FIRING TEST

Self ignited fuel, fuel and oxidizers tanks were charged and their pressures were set. In the first test, despite oxidizer and fuel injection, ignition failed. Because the engine is single-injector and fuel mixing percentage is lower than multi-injector engines, the motor starting was faced with problems. They are: low fuel flow rate in compared with the oxidizer flow rate, impurities in the self ignited fuel TR-1 that cause clogging of the fuel injector. Recent event is the cause of the first reason. Again, by cleaning the injector orifice and reducing pressure and flow rate ratio of oxidizer to fuel, hot-firing test was successfully conducted with the results which are shown in Figure 1.

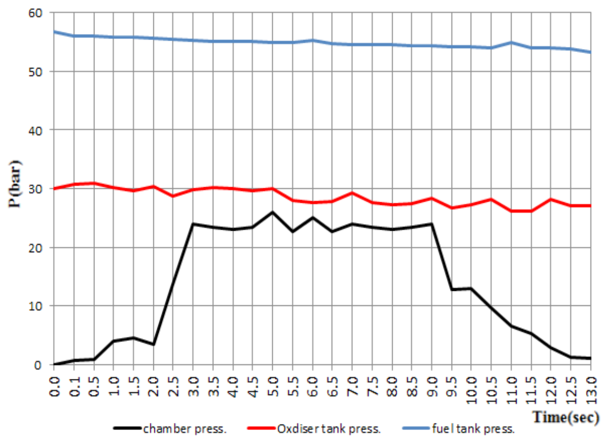

Figure 1. Pressure-time curve in hot-firing test

Fuel and oxidizer tanks pressure slightly reduced during test time due to leaks in test fuel lines and valves fuel tank pressure is reduced little more than pressure drop value in oxidizer tank.

5- CONCLUSIONS

Because the engine is single-injector, fuel mixing percentage is lower than multi-injector engines, low fuel flow rate to the oxidizer and the presence of impurities in the self-ignited fuel TR-1 causes clogging of the fuel injector. In the second test, after three seconds, the pressure of the combustion chamber reaches to the desired pressure (about 25 bar) and then about 6 seconds works in this range, goes to reduce chamber pressure and engine Off.

In hot-firing tests, micromotor in about 7 seconds operation time reaches about 25bar pressure and it's special impulse was measured and calculated about 210 to 225 seconds.

This values is close to the designer expected values and results of software modeling of hot-firing tests, this event represents the rational and applicable design process of sub-scale engine for double-base injector hot-firing test and it's results accuracy.

So because of the small size of this laboratory engine and single injection, the costs of design, construction and testing is very reduced, therefore the desired tests can be performed many times and even if degraded or unpredictable events happen during the tests, designer can make same samples with lower costs and less time by correcting errors and reach to a final optimized design.

After collecting the results and considering the amount of thrust needed for a real full-scale engine needed to launch satellites or other applications according to client needs, one can increase the number of injectors, change in design methodology, to increase power of the engine to be an executive project in the space industry.

6- REFERENCES

[1] Ommi, F; Movahednejad, E; Kargar, A, "Experimental Investigation of Characteristics of a Double-Base Swirl Injector in a Liquid Rocket Propellant Engine ", Leonardo Journal of Sciences ISSN 1583-0233 , pp. 92-111, January-June 2009.

[2] Krishnan, S., Ahn Sang-Hee., Lee Choong-Won., "Design and Development of a Hydrogen-Peroxide Rocket-Engine Facility", Jurnal Mekanikal, pp. 24 – 36, June 2010

[3] Ellerbrock, H., Ziegenhagen, S.; "Liquid rocket test facility engineering challenges", Acta Astronautica, Vol. 59, No. 30, pp. 1123–1134, 2006.

[4] Leroy J. Krzycki., " How to design build and test small liquid fuel rocket engine", China Lake, California, Second Edition ,1971.

[5] Zinner, W., Haeseller, D., M¨ading, C., Rubinskji, V., Gorochov, V., Hrisanfov, S., and Nikulin, G., "Development of Advanced Technologies for Future Cryogenic Thrust Chamber Applications", AIAA Paper 1997-3312 , 1997.