Development of Thrust Chamber Assembly for LOX - LNG Expander Cycle Liquid-Propellant Rocket Engine

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Abstract

This article summarizes the results of milestone collaboratively completed by Konstruktorskoe Buro Khimavtomatiki (KBKhA, Voronezh, Russia) and AVIO S.p.A. (Italy) towards developing thrust chamber of LM10-MIRA liquid-propellant rocket engine intended to be used at upper stage of LYRA LV.

The R&D works have been performing by KBKhA and AVIO propulsion team under the aegis of Italian Space Agency (ASI) since 2007, and they finally provide for a 7.5 ton class LOX-LNG expander cycle engine demonstrator manufacturing and testing.

1. Introduction

Since 2007 KBKhA and AVIO have been working together under the contract. The objective of the first milestone of the collaborative work is a conceptual design of 10 ton class (LM10-MIRA) LOX-LNG flight-type engine. This milestone was successfully completed in 2008 that allowed starting the next milestone providing LM10-MIRA engine demonstrator (further referred as Demo-engine) development, manufacturing and testing. This milestone is still in progress and will be resulted in Demo-engine firing tests at KBKhA test bench.

The interim milestone provided by the contract between KBKhA and AVIO stipulates collaborative activities for development and firing tests of Demo-engine thrust chamber incorporating an Injector Head (IH) developed by AVIO and a Thrust Chamber Assembly (TCA) developed by KBKhA.

In order to fulfill the work, the joint team of KBKhA and AVIO leading propulsion experts has successfully fulfilled a whole complex of TCA development, manufacturing and testing activities in complete compliance with European and Russian standards.

2. TCA Development and Collaborative Manufacturing

Design and manufacturing of all Demo-engine components including TCA and IH have been accomplished basing on technical specifications containing components' design and performance requirements jointly developed and agreed.

In the process of development, the TCA thermal-dynamic, gas-dynamic and structural analyses have been performed.

The TCA basic parameters are the following:

- chamber pressure – 60 bar;
- mixture ratio – 3.4;
- nozzle area ratio (min) – 89.6 mm;
- nozzle exit – 710 mm.

As it was said above, the TCA for UE2 experimental unit consists of an AVIO's injector head and a KBKhA's TCA welded between each other.

The AVIO's injector head (Figure 1) represents a single-block and brazed-welded construction. It has an oxygen axial supply line and a fuel lateral supply line. The injector head contains 60 jet-coaxial bi-propellant injectors located along four concentrically located circles.

Figure 1: AVIO's injector head

The KBKhA's TCA (Figure 2) consists of a combustion chamber, top and bottom nozzles welded between each other. To manufacture chamber parts and assembly units, the technologies and materials mastered in production and used in chambers developed by KBKhA have been used.

Figure 2: KBKhA's TCA

Before integration of injector head into TCA, a significant scope of research studies on definition of material weldability for injector head and TCA as well as welding condition selection has been performed. At the same time, the following activities have been performed by AVIO and KBKhA experts:

- determination of sample configuration for test verification of material weldability;
- development of sample experimental study program;
- weld sample pieces manufacturing by AVIO and delivery to KBKhA ;
- weld sample pieces manufacturing by KBKhA;
- welding of KBKhA's and AVIO's flat and cylindrical samples;
- welds inspection;
- welds mechanical properties definition and metallographic research studies;
- using the attained results analysis, the satisfactory weldability of the researched materials have been verified; welding wire, type and conditions of welding which allow to provide a qualitative welding have been selected.

The positive results received at studying enabled to start the activities with a standard TCA and injector head.

Welding of injector head with thrust chamber has been performed for selected conditions. After integration with the injector head, the thrust chamber has passed successfully through all types of inspections including dye-penetration, structural and leak tests. Proof tests have been controlled by an AVIO/KBKhA working team in compliance with coordinated programs and methods developed on base of chamber technical specifications and appropriate European standards.

The configuration of the TCA finally manufactured and inspected is depicted in Figure 3.

Figure 3: TCA configuration

3. Pre-Firing Activity

The component firing test of the thrust chamber has been performed in conditions of UE2 experimental unit newly developed. An UE2 schematic and a firing test plan have been worked out by KBKhA and AVIO propulsion team. The schematic is shown in Figure 4.

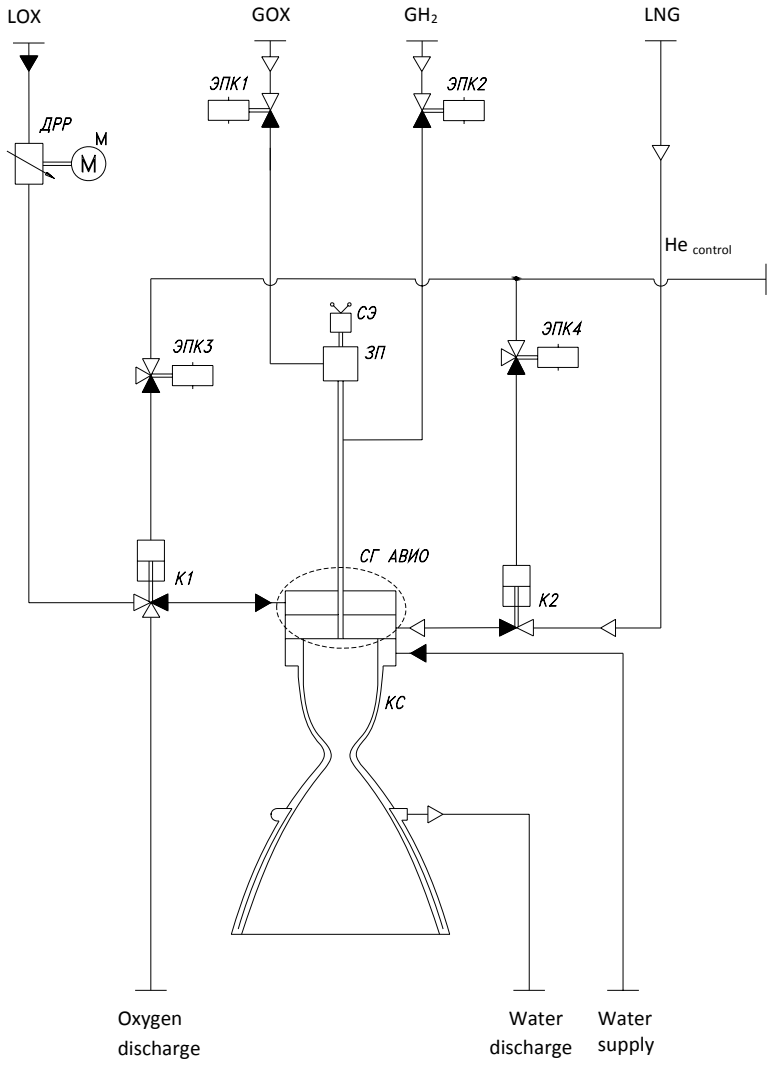

Figure 4: UE2 Experimental Unit Schematic

Besides the thrust chamber it incorporates the following main systems:
an ignition system;
a control and regulation system;
a water cooling system.

An ignition system includes a GH_2/GO_2 electric-plasma igniter arranged along the injector head axis; an electric spark, an ignition unit, and a high-voltage cable.

A control and regulation system includes the valves admitting propellant to the chamber (*К1, К2)*, the electric-pneumatic valves admitting propellants to the igniter (*ЭПК1, ЭПК2),* and the electric-pneumatic check valves (*ЭПК3, ЭПК4)*. A regulating system consists of a throttle (*ДРР)* with a driver providing the required oxidizer pressure at the unit inlet.

A cooling system includes water supply and discharge manifolds into a chamber cooling duct at its autonomous testing. As a result of chamber cooling analysis, there were defined: water flow rate, water pressure and temperature at chamber cooling duct inlet and discharge. Maximum temperature of bronze wall from hot gas side is not more than 640 K, from steel wall side – not more than 830 K that is significantly lower than the ultimate permissible temperatures.

The UE2 experimental unit is shown in Figure 5.

Figure 5: UE2 Experimental Unit

UE2 test plan comprises 4 firing tests within two testing days: the first testing day – one firing test with duration of 40 sec, the second testing day – 3 firing tests with duration of 15 sec. each.

At firing the following critical issues have been solved:

- verification of joint KBKhA/AVIO chamber functioning;
- experimental operation data received at start up, main mode, and shut down conditions;
- chamber operation cyclogram verification;
- chamber cooling ability verification;
- chamber combustion stability parameters estimation.

The UE2 mounted at KBKhA's test bench is given in Figure 6.

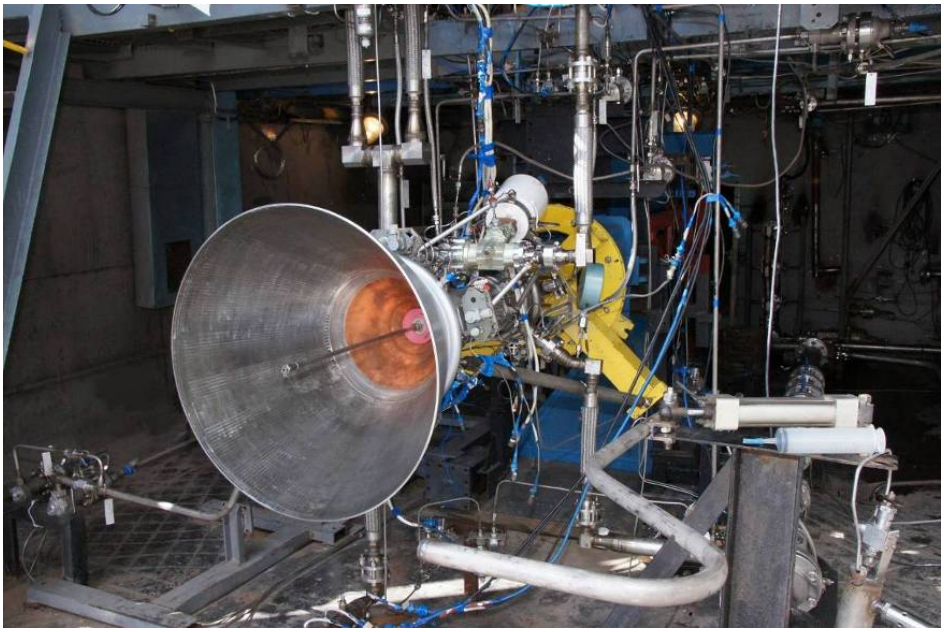

Figure 6: UE2 Mounted at Test Bench

As agreed between KBKhA and AVIO, the test bench included the following main systems:
- propellant and water supply system;
- control system;
- emergency systems for the unit and test bench
- parameter measuring and processing system;
- gas supply system, etc.

Preparing for firing test of chamber in UE2 conditions at test bench, the «cold» tests have been successfully conducted, their objectives were the following:

- LOX supply system functioning inspection, the system hydrodynamic properties definition, the system adjustment for dedicated conditions;
- GCH_4 supply system functioning verification, GCH_4 mass flow-rate calculation procedure verification, the system adjustment for dedicated conditions;
- GOX and GH_2 supply system to igniter functioning verification, measuring throttle devices actual flow coefficient determination, the system adjustment for dedicated conditions;
- cooling water supply system functioning verification, the system hydraulic properties definition, the system adjustment for dedicated conditions.

The activities listed above were followed by the chamber firing test readiness review with participation of ASI representatives. At this review meeting, the KBKhA, AVIO, and ASI experts looked through the «cold» test results, checked hardware and test task, confirmed conformity of the works fulfilled with the requirements of the Russian and European standards and gave a conclusion about test bench systems readiness for firing tests.

4. Firing Tests and Results

On September 6, 20012, the first TCA firing test in the unit conditions has been performed at KBKhA' test bench according to the task, with firing time of 41.5 sec. At this testing, the chamber parameters specified on pressure (60 bar) and mixture ratio (3.4) have been attained. The task requirements were accomplished in corpore.

Profiles of chamber pressure (ДКС1), oxidizer pressure (ДОФК) and fuel pressure (ДГФК) in the injector head at testing are presented in Figure 7, oxidizer (ТОДУ) and fuel (ТГДУ) temperatures at the unit inlet, as well as oxidizer (МО) and fuel (МГ) flow rates – in Figure 8.

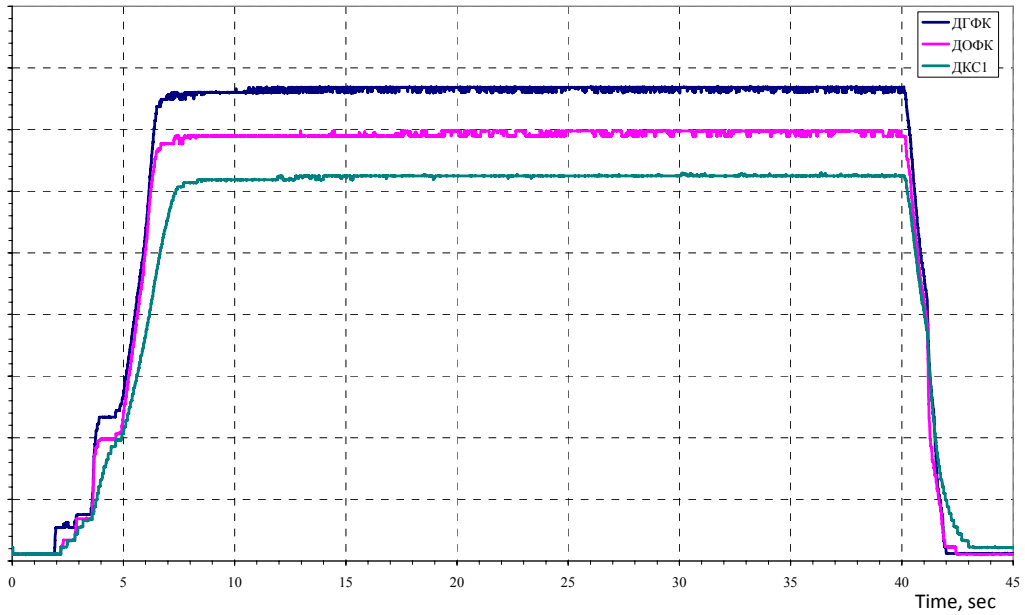

Figure 7: Chamber pressure profiles (ДКС1, ДОФК and ДГФК)

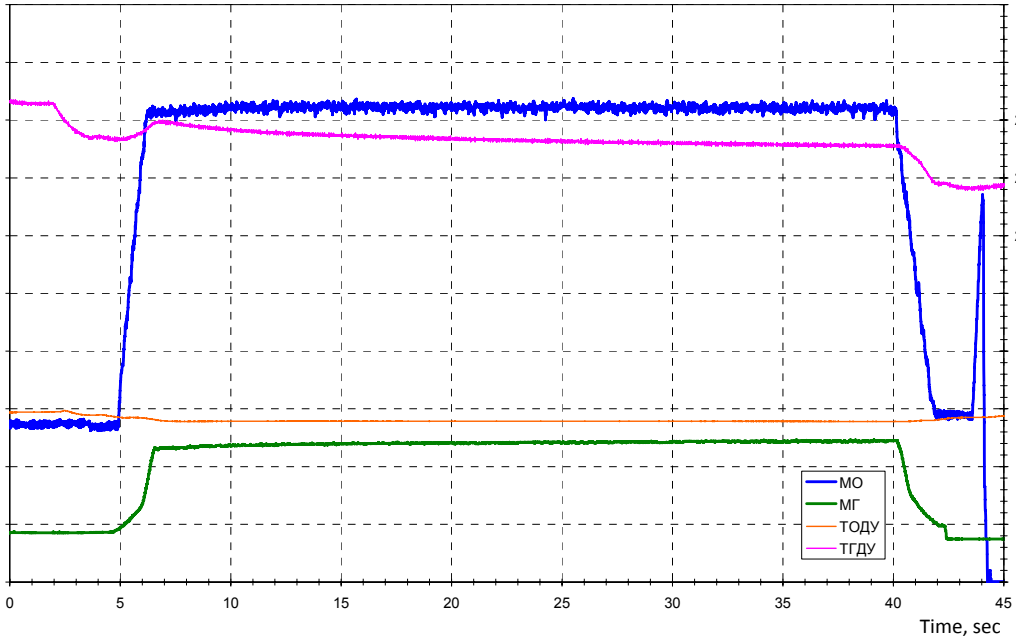

Figure 8: Temperature and flow rate profiles (ТОДУ, ТГДУ, МО and МГ)

Chamber operation process stability was estimated using the pulsation sensors ПОФК and ПГФК. Oxygen and methane pulsation pressure levels at the unit testing were insignificant and did not exceed in sum 0.69 kgf/cm^2 for oxidizer pulsation and 0.4 kgf/cm^2 for fuel pulsation (Figure 9).

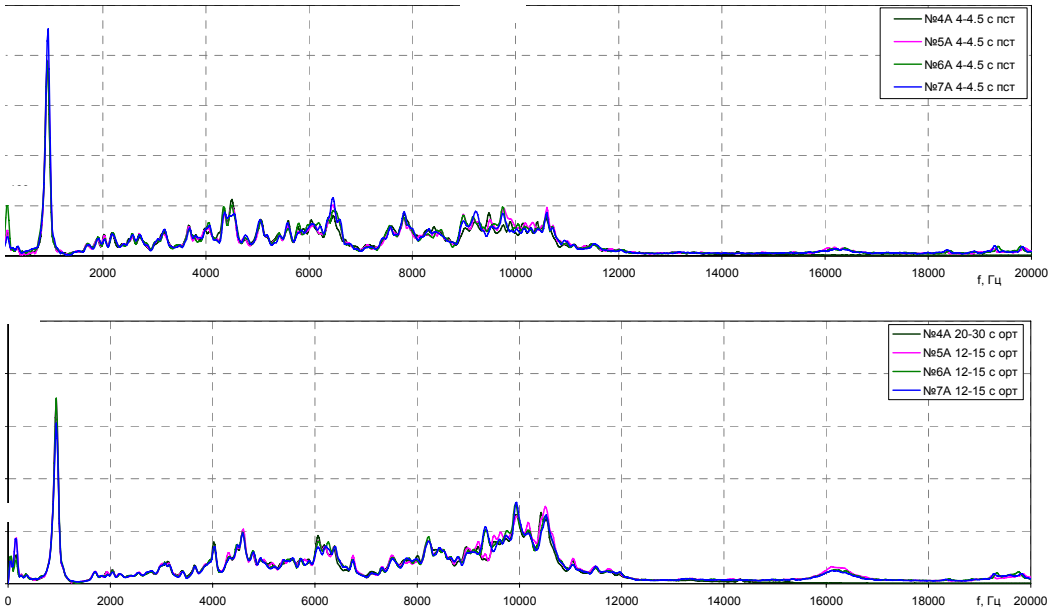

Figure 9: Amplitude-frequency spectrum profiles

Figure 10 represents water parameters for chamber cooling: water flow rate (РВ), water chamber inlet temperature (ТВДРК) and discharge temperature (ТВПРК). The experimental water preheating in a cooling duct attained at firing testing meets the design requirements.

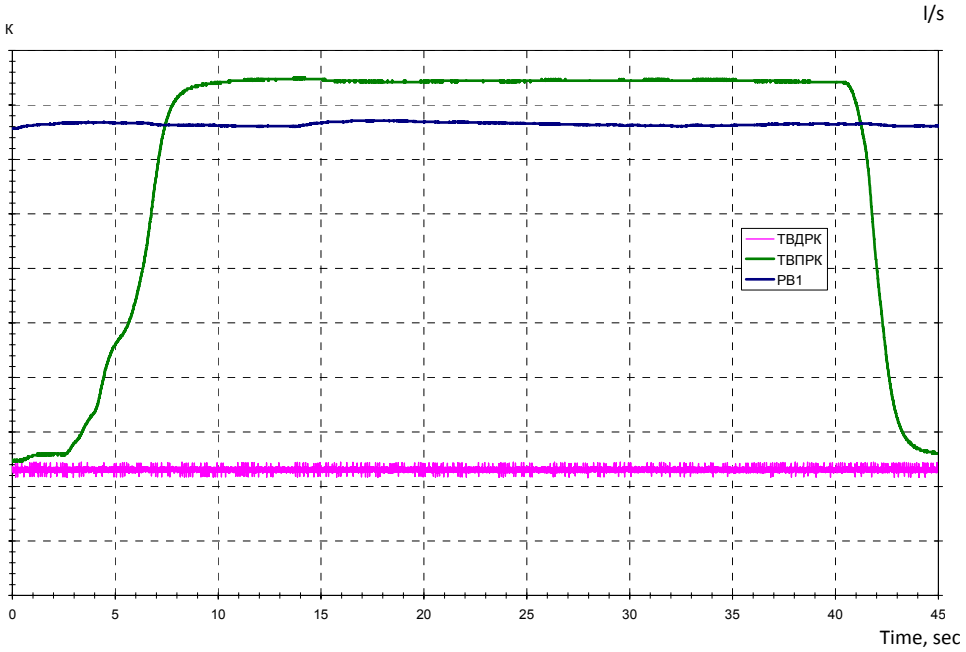

Figure 10: Water flow rate and temperature profiles (РВ, ТВДРК, ТВПРК)

Three firing test campaign was conducted in accordance with the test plan within a single testing day, September 17, 2012, that allowed certifying the requirement of multiple chamber ignitions in flight. Duration of each firing was 16.5 sec. The tests were performed in complete compliance with the task and positively resulted in reaching chamber pressure 60 bar and mixture ratio 3.4. The chamber main parameters behavior is analogous to the first firing parameters. After each testing, according to express-information, the coordinated solution on test results and possibility of the next testing performance was accepted by KBKhA and AVIO expert team.

Figure 11 reproduces a photo of the unit UE2 at firing.

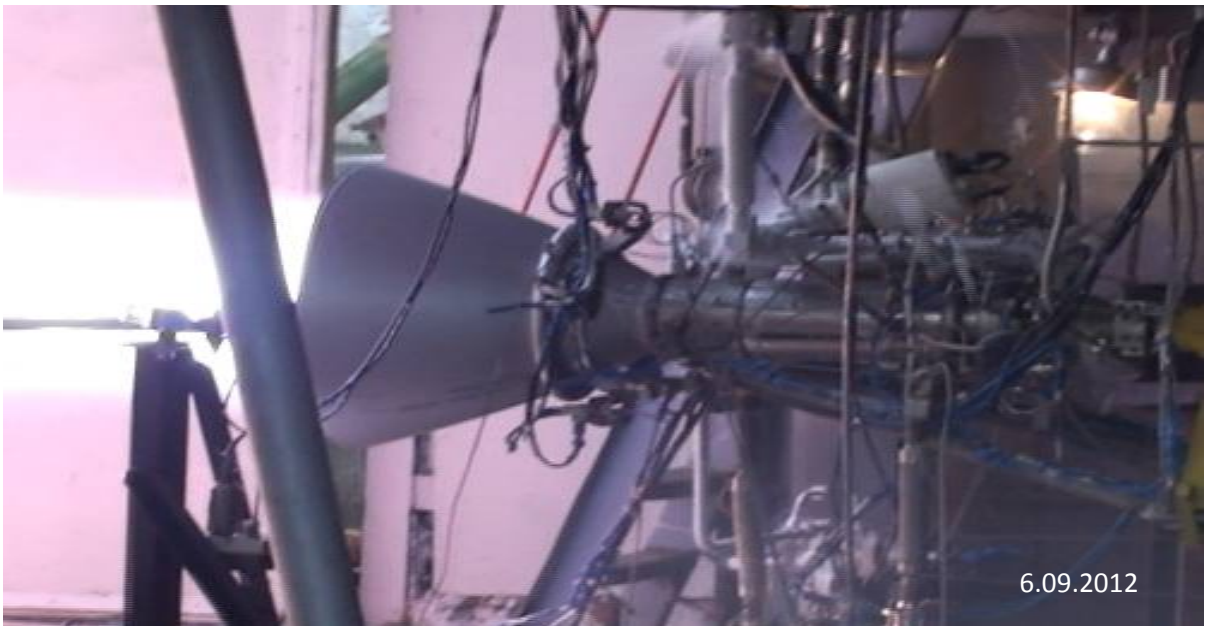

Figure 11: Firing of TCA in UE2 conditions

After each testing day, according to the specifications jointly developed by KBKhA and AVIO, the TCA was health monitored. According to the results of firing, the state of the injector head and TCA was estimated as a good one (Figures 12).

Figure 12: UE2 after firing

Conclusion

1 In September 2012, the component firing tests of the TCA jointly developed and manufactured by KBKhA and AVIO was performed successfully in conditions of the UE2 experimental unit at KBKhA test bench.

2 At TCA firing:

- its functioning and cyclogram selected were confirmed;
- main parameters required: chamber pressure 60 bar, propellant mixture ratio 3.4 were attained;
- reliable water cooling was verified, experimental parameters of cooling satisfied the design values;
- possibility of chamber multiple starts in one and the same testing day was demonstrated;
- chamber combustion stability was certified.

3 Chamber state after four firing tests is good. Further chamber application is possible in conditions of the experimental unit.

4 Tests performed have become a significant stage of cooperation between two companies within the frames of research studies performed under order of Italian Space Agency (ASI).

5 In the process of development, manufacturing, «cold» and fire chamber autonomous testing performed by a team of experts from AVIO and KBKhA, a complex of production-technological tasks have been solved and validity of design solutions was experimentally verified. A complex of collaborative works was performed on base of technical specifications coordinated in strict compliance with the schedule and the standards accepted by European space association.

6 The tests performed provide initiation of Demo-engine testing at KBKhA test bench in 2013.

References

[1] L. Arione, D. Scarpino, M. Ciranna, M. Rudnykh, G. Caggiano, A. De Lillis, E.D'Aversa, S.D. Lobov, V.P. Kosmacheva, S.V. Chembartsev, A.A. Gurtovoi. Development of new technologies applied to LOX-LCH_4 Propulsion. 63rd International Astronautical Congress, Naples, Italy, 2012.