RHETT/EPDM Flight Anode Layer Thruster Development.

A.Semenkin, A. Kochergin, V.Garkusha, G. Chislov, A.Rusakov
Central Research Institute of Machine Building (TsNIIMASH), Russia

S. Tverdokhlebov. TsNIIMASH-EXPORT

C. Sota , Teledesic Corporation, Seattle Wash.

Abstract

The goal of the work performed at TsNIIMash under RHETT-II/EPDM Program [1,2] was to elaborate anode layer thruster for flight demonstration on board US spacecraft. Laboratory thruster D55 was chosen as a base for flight thruster, called TAL--WSF after initially planed mission on board Wake Shield Facility. The created thruster incorporates several achievements have reached for single stage anode layer thrusters:

- hollow anode - to provide and maintain high ionization of a propellant, beam focusing and low plasma instabilities;
- external anode layer scheme to decrease discharge chamber erosion, caused by ion sputtering, and increase lifetime of the thrusters;
- Discharge chamber walls made from carbon material, which are most strong to ion sputtering among the materials using in electric thrusters.

Thruster design satisfies the US requirements for flight hardware. It's operation range is 600...1350 W, mass without cathode 2.2 kg. Operating point was varied without any changes of the thruster design from 300 V,1350 W to 600...900 W, 300 V due to power limit for EPDM flight. Ten thrusters were made for development and qualification purposes and three thrusters were delivered to US for tests and using for flight.

INTRODUCTION

The thrusters with anode layer (TAL), developed and made in TsNIIMASH, were investigated in USA since 1993 as a part of program, financed by NASA and BMDO. Two types of thrusters - D55 and D100 were delivered for tests. These thrusters are laboratory versions with nominal power correspondingly 1.5 and 4.5 kW. As a part of the Program called RHETT[1], executed under NASA management and financed by NASA and BMDO , various tests of the thrusters have been done in NASA LeRC and JPL [1,2,3,4].

The last stage of this Program, called RHETT II, was a preparation of a flight tests of the TAL, incorporated in a US propulsion system onboard of American spacecraft. During this stage in 1995-1996 time frame the development, manufacturing, test and delivery to US of the flight thrusters with anode layer have been done at TsNIIMASH . This efforts have been started as part of planed experiment onboard Wake Shield Facility and late continued as Electric Propulsion Demonstration Module Program [2].

HISTORY.

As a base for flight TAL development the laboratory thruster D55 was chosen [5]. The D55 was successfully tested earlier in NASA LeRC and JPL during the joint work between NASA and TsNIIMASH, and there are significant data base concerning thruster performances, lifetime capabilities and EMI characteristics.

The D55 thruster was developed at TsNIIMASH as a part of the research program, which have a goal to create new generation of electric propulsion thrusters with improved set of parameters.

At the beginning of 80-th most of interest and development activity at TsNIIMash was concentrated on xenon anode layer thrusters with relatively low specific impulse - 1000...2000 sec. The reason was wide potential application of such thrusters for orbit keeping of the commercial communication satellites. Elaborated early double-stage thrusters [6] have several very attractive features, but it's working range with good efficiency is at significantly higher Isp ,than it requires for typical orbit keeping mission. As a result of 1000-2000 sec Isp thruster elaboration effective single stage anode layer thruster was created [7].

There are several ideas, which provide effective TAL operation with Isp 1000 ...2000 sec and give attractive combination of it's characteristics:

- Hollow anode - to provide and maintain high ionization of a propellant, beam focusing and low plasma instabilities,
- External anode layer scheme to decrease discharge chamber erosion, caused by ion sputtering, and increase lifetime of the thrusters,
- Discharge chamber walls made from carbon material, which are most strong to ion sputtering among the materials using in electric thrusters.

The idea of a hollow anode was proposed and studied by E.Lyapin. In combination with controlled distribution of magnetic field in discharge zone, hollow anode allows to get high ionization of a propellant. In this case the anode hole acts similar to ionization chamber of Kaufman ion thrusters. Effective ionization and natural for TAL short acceleration zone allow to get good focusing of the ion beam. Using of the hollow anode in a single stage TAL appeared to be very fruitful and allowed to get high thrust efficiency and low discharge instabilities especially at Isp 1000...2000 sec.

The scheme with external anode layer was proposed and developed to provide lifetime of the thrusters [5].Main process, limiting the Hall thrusters lifetime, is the erosion of discharge chamber walls due to ion sputtering. In the thruster with external anode layer discharge zone is placed downstream from the thruster elements and direct interaction between accelerated ion flow and any part of the thruster totally eliminated. This particular TAL technology is unique among other types of electric thrusters and allows to get very high thruster lifetime. The measured erosion in such TAL is at least ten times less as compared with other Hall thrusters [3,7]. Low erosion of the thruster parts leads also to several enough important features: stability of the thruster parameters, low contamination of the spacecraft surface, such as solar arrays, optic devices and so on, by sputtered material.

One of the basic TAL features - conductive walls of discharge chamber - gives a natural opportunity to use wide spectrum of materials, including most strong - carbon materials, for manufacturing of the sputtered thruster parts.

The attractive properties of carbon materials such as ,for example, different types of graphite, are well known. But their application in another types of thrusters have some difficulties. For SPT it leads to total changes of working processes in discharge. For ion thrusters using carbon materials to produce thruster electrostatic grids requires special technology and materials.

The possibility to use different material with different sputtering coefficient without changes thruster performance allows to simplify erosion tests of the TAL. The erosion data ,obtained in short tests with using relatively "soft" materials(for example - copper, steel) for thruster parts, can easily be recalculated for the case when these part are made from any another strong material. This technology have been used in the erosion test of the D55 at JPL.

The D55 design incorporates all mentioned above single-stage TAL design features and technologies. This thruster was elaborated as basic thruster for set of TALs, using same design principles. Tests of the D55, which were made in USA on previous phases of the RHETT Program, in general included the following:

- Performance and plume characterization [3,4],
- EMI study [4,9],
- Endurance erosion tests [3].

Existing data allow to say that among other Hall thrusters TAL have competitive level of performances, plume divergence, lowest erosion of the thruster parts, and acceptable EMI. D55 have smaller size, than stationary plasma thrusters with identical power level [3,4,8,9].

FLIGHT THRUSTER DEVELOPMENT

Tested D55 was a ground laboratory version of the thruster. Therefore for participation in the flight test under the RHETT II Program the thruster had to be redesigned in accordance with flight hardware requirements.

The new thruster was called TAL-WSF after the name of the Wake Shield Facility, where the flight tests were initially planed. It's design includes all perspective technical solutions tested earlier on laboratory thrusters. Initial design working point of the TAL-WSF was 300 V, 1350 W of consumed power, thrust about 8 G, specific impulse without cathode mass flow rate not below 1700 sec.

The development of a new engine included on the one hand, requirement to save without changes the positive characteristic, which were achieved on the laboratory D55 in respect to efficiency, EMI, small erosion and plasma beam focusing. On the other hand the design should satisfy whole spectrum of the requirements to a flight hardware, such as, vibration and acceleration environments, corrosion resistance, material outgassing, thermal cycles, electrical, mechanical and thermal interface with other propulsion subsystems and so on.

Also required quality control system was used for all stages of the flight thruster design, manufacturing and tests.

Design of the thruster have been made in accordance with detailed Technical Specification prepared by Olin Aerospace Company (OAC) and agreed by TsNIIMASH. OAC also have provided some US elements and materials for thruster electrical interface.

Ina very compressed schedule - from September 1995 to June 1996 - at TsNIIMASH was performed the program of TAL-WSF design ,manufacturing, including several iterations, tests and delivery of flight hardware. For successful fulfillment of this Program were used as well as contractual founding from NASA as internal resources.

As a result 3 thrusters have been delivered - one for ground tests and two thrusters ready for flight application. In total 10 thrusters have been made and passed through various test. All manufacturing hardware have passed performance characterization and vibration test. Two thrusters were tested on thermal cycling, one sample was tested under acceleration environment and proof pressure tests. Limited erosion tests have been done with 1 thruster to confirm potential lifetime of the TAL-WSF. All materials used in the TAL-WSF have been verified with the requirements of the US standards for space hardware.

In a difference from the initial D55 design, which was developed as multipurpose laboratory hardware and have significant margin, the TAL-WSF was developed for a given working range. It allowed to reduce its weight from 4 kg to 2.2 kg.

For initially planed experiment on board Wake Shield Facility the working point was 300V,4.5 A. Finally for EPDM flight, due to maximum available power, thruster operating range was established 600...900W. Change of the working point have been done without any changes of the thruster design and were made by adjustment of magnet current.

The general view of the TAL WSF is shown on a photo Figure.1. Figure 2 shows the scheme and it's overall dimensions.

Each delivered flight thruster passed agreed with OAC Acceptance Tests Procedure at TsNIIMASH. The ATP included performance measurement, vibration tests, checking of the electrical and mechanical interfaces and parameters. The performance tests were conducted in vacuum chamber with volume 5 cubic meters and pressure not more than 0.0002 mm Hg. Typical TAL WSF parameters received during tests at TsNIIMASH are given on the Figure.3 an Figure.4. The performance mapping was done in a range of power 500 up to 1350 W. At discharge voltage 300V and discharge current 4.5A TAL-WSF have thrust not less than 8 Grams and efficiency not below 0,5. The results are confirmed by statistics of 10 thrusters tests. Deviation of the thrust value between all 10 thrusters in a base point 300V, 4.5 A was not more +/-0.1 grams.

Measured at TsNIIMASH characteristic of delivered thrusters practically coincided with test results obtained at NASA LeRC during integration of the total propulsion system [2].

CONCLUSION

As a results of TsNIIMASH efforts under RHETT Program, the first flight thruster with anode layer was developed. This design have passed through required ground qualification test program and satisfies to the requirements, accepted in US space industry. Despite essential reduction of weight, essential change of the design as compared with basic laboratory D55, developed flight thruster TAL-WSF has saved efficiency, flexibility of regulation and low erosion of discharge chamber elements, achieved earlier on laboratory D55. Authors would like to note very high level of mutual understanding, scientific and technical support between NASA, OAC and TsNIIMASH participants, which have helped to perform this Program.

This work was performed under the Contract between TsNIIMASH-EXPORT and Olin Aerospace Company.

References

1. IEPC-95-132, L.H.Caveny, J.M. Sankovic, D.M. Allen, G.Herbert, C.E. Garner.The BMDO electric propulsion flight readiness program.

2.AIAA 97-2917, J.Sancovic, L.Caveny,P.Lynn The BMDO Russian Hall Electric Thruster Technology (RHETT)Program from laboratory to orbit.

3. AIAA-94-3010, C.E.Garner et al, Experimental evaluation of Russian anode layer thruster.

4. AIAA-94-3011, J.M.Sankovic et al, Operating characteristics of the Russian D55 thruster.

5. IEPC-93-231, A.Semenkin, Investigation of erosion in anode layer thrusters and elaboration high lifetime design scheme.

6. Grishin C.D., et al, Electrical rocket engines., Moscow, "Engineering", 1975.

7. Garkusha V.I. Leckov L.V. Liapin A.V.,Plasma accelerators with anode layer.,"Plasma accelerators and ion injectors", Moscow,1984.

8. AIAA-95-2667, C. Garner et al, Cyclic Performance and Wear Test of SPT-100.

9. Dickens J.C., "Communications impact of Hall Effect Plasma Thruster", PhD Thesis, Texas Tech University,1996.

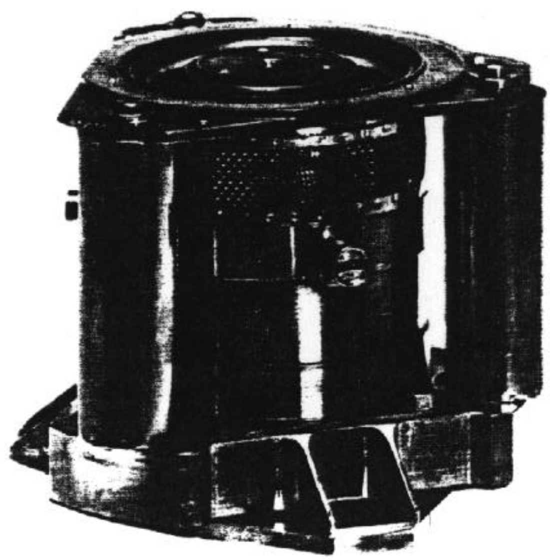

Fig.1
Photo of the flight TAL-WSF thruster, developed under RHETT-II/EPDM Program.

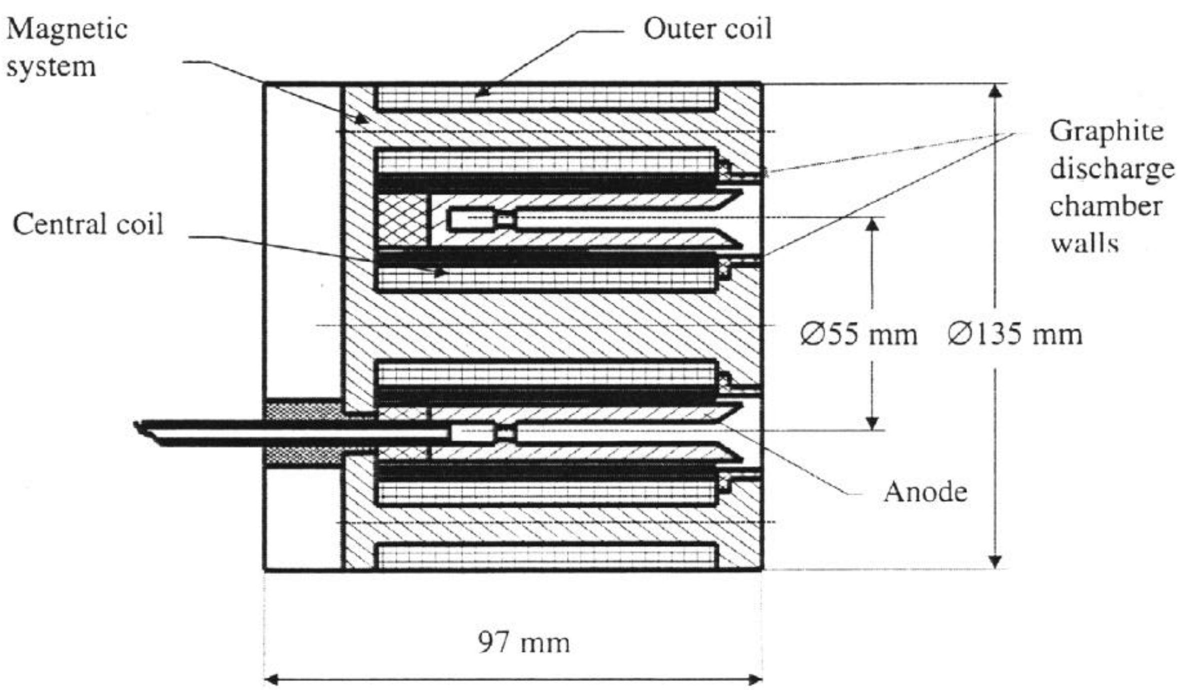

Fig.2
Scheme of the TAL-WSF thruster.

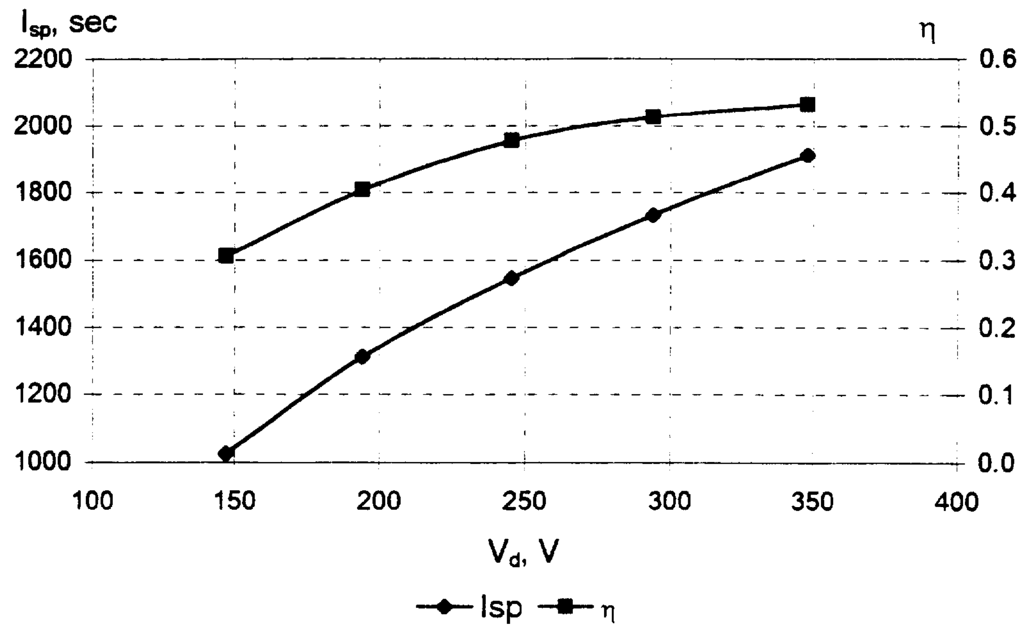

Fig.3
TAL-WSF specific impulse and efficiency versus discharge voltage.

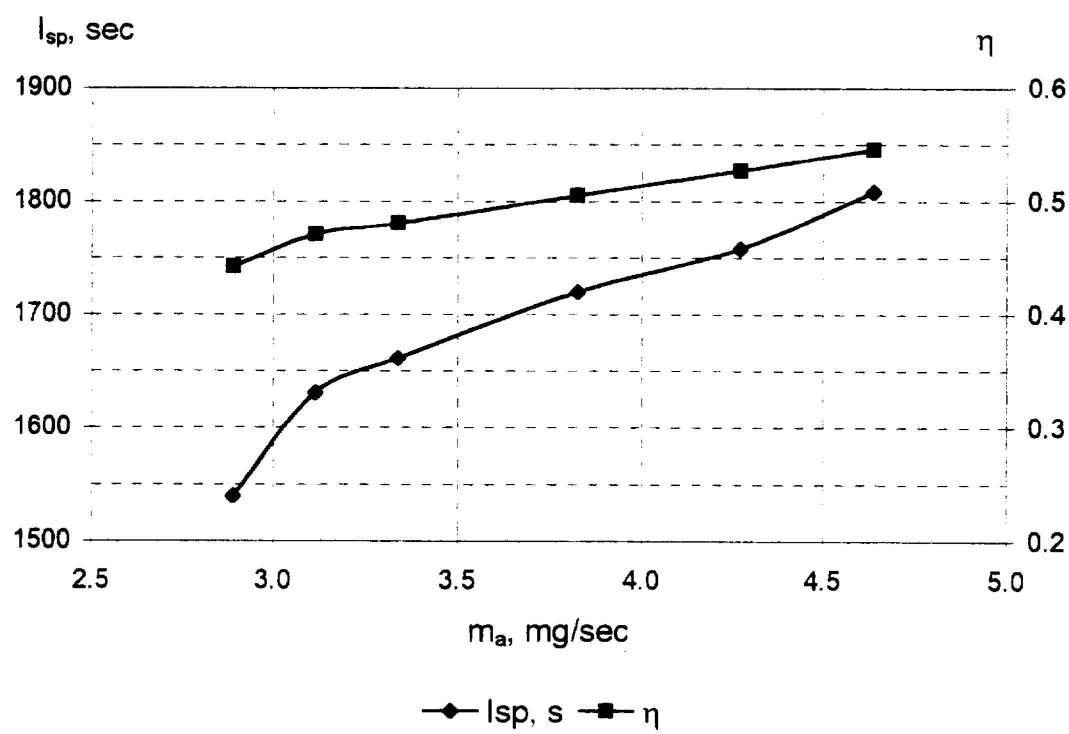

Fig.4
TAL-WSF specific impulse and efficiency versus xenon mass flow rate.