Multiple Thruster Propulsion Systems Integration Study

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Abstract

Electric Propulsion Systems with simultaneous operation of several Hall thrusters integrated in one propulsion unit may be considered as a good candidate for orbit raising and interplanetary missions [1,2]. To achieve the demanding performance and system reliability goals for future spacecraft applications such as Teledesic, a propulsion system architecture such as the multi-thruster configuration will be needed [3]. There are several options of EPS architecture. The most interesting one is the scheme with several thrusters operating from one Power Processing Unit and Propellant Management System. Experimental study and demonstration of two thrusters with anode layer D55 parallel operation from one discharge power supply have been done for different locations and number of cathodes. Operation range up to 400V was tested with xenon mass flow rate 2.5...3.5 to each thruster. Any changes of the thruster parameters and operating range was not found as compared with scheme "one thruster/ one power supply". Possibility to operate with not equal discharge currents and mass flow rates in the thrusters operating in two thruster unit was demonstrated.

Introduction

The creation of electric propulsion systems (EPS) for spacecraft (S/C) orbit raising from low to higher working orbits and for interplanetary flights is the next logical application of modern EPS which is now used mainly for station keeping. Theoretically the problem of EPS application for these purposes has been considered for quite some time and, more over, it was the leading idea which initiated development of EPS throughout the world. However, in spite of the quantity of theoretical research conducted in this area and the development and application of relatively low power electric thrusters, the existing experience base is not enough for the technical realization for orbit raising or interplanetary flights.

As compared with existing EPS, electric propulsion transportation systems have to provide significantly more thrust, total impulse and be at least ten times more powerful. In current EPS applications, all electrical power at any one time is consumed only by one operating thruster. Obviously there are limits to this design approach thereby requiring alternate solutions if higher power operation is necessary. By analogy with launch vehicles, integrated thruster units used for the creation of a large thrust consisting of several basic engines working in parallel, it would be logical to consider the simultaneous operation of several electric thrusters assembled in one thrust unit. Similar to rocket engines, application of an integrated multi-thruster unit will enable a wide range of different and variable propulsion systems using a limited number of basic thrusters. In comparison with the total power consumption of the EPS, these thruster can be relatively low power and small in size which will significantly reduce facilitates cost for ground qualification and acceptance testing. More over, the application of the multi-thruster system architecture will allow greater operational flexibility and provide reserve system performance offering improved lifetime and reliability. The overall performance, mass, and reliability enhancements associated with the multi-thruster EPS has been realized and is currently the baseline approach for the Teledesic spacecraft [3].

Propulsion system architecture

Consideration of the multi-thruster EPS and preliminary design analysis of such systems were begun practically one temporarily with theoretical consideration of EP application and possible projects of EPS for interplanetary flights.There has been experimental work conducted in the past to evaluate dual thruster operation utilizing both ion and Hall type engines [1,2]. For example, a special Hall thruster was developed and tested [1] which consisted of two integrated anode layer unites sharing a common magnetic system, illustrated in Figure 1. In this design, the total mass of the thruster unit is about 20...25% less as compared with two individual thrusters. Due to the opposite direction of the magnetic fields in this design, the resultant torque generated by the thruster is zero. During operation of a single Hall thruster a torque, in addition to an axial thrust force is generated due to the interaction between the accelerated ion beam and the magnetic field in the discharge zone. Despite a long history of the idea to use integrated multi-thruster units, there are a lot of issues which need to be resolved prior to application of this EPS design approach. Initial analysis allows to point out two extreme variants of this EPS scheme, which are shown in Figures 2 and 3.

The EPS in Figure 2 is actually constructed of several independent basic EPS units with a single thruster in each one. Each thruster is equipped with its own cathode-neutralizer, propellant management system and power supply system. Common "points" of the propulsion system are only the propellant tanks and onboard S/C power electrical network .

In the second variant, illustrated in Figure 3, the EPS is separated into functional subsystems consisting of the thrusters, cathode(s), propellant management system, and power supply. Thus only one power supply, one PMS and one cathode are used to provide operation of several thrusters. The EPS schematics, shown in Figures 2 and 3, illustrate two system configurations extremes. It is possible to realize a number of intermediate versions.

The Figure 2 schematic can be implemented using standard hardware including thrusters, EP subsystems and units. Probably this configuration will have the minimum complexities and specific integration features. However, for the perspective EP systems employing high-voltage solar arrays and "Direct-drive" operation of the EPS, [4,5] the second EPS configuration looks more logic and preferable. Preliminary estimation of the EPS presented in Figure 3 indicates, that it will be lighter than the Figure 2 configuration. Obviously, the EPS illustrated in Figure 3 can be configured to minimize the number of reserved elements in order to maintain reliability and lifetime. However, this approach contains specific features which have not been tested and have to be experimentally studied.

TEST RESULTS

With respect to the development of a multi-thruster propulsion system, the following configurations will need to be studied:

- operation of several thrusters from a single discharge power supply;
- operation of several thrusters with one cathode or several cathodes operating in parallel.

For experimental research a system of two D55 type thrusters [6] have been assembled.

The following cathode locations were investigated:

- cathodes are far away from each other and were located on an external border of two thrusters assembly;
- cathodes are mounted near each other between two thrusters.

The experimental system allowed reconfiguration of the experimental setup without opening the vacuum chamber The test variables included, operation of the thrusters from one or two discharge power supplies, xenon mass flow to the thrusters from two independent lines or from one common line to two anodes in parallel, to supply the magnet coils of the two thrusters from two independent power sources or a single supply, independent management of the parameters of the cathodes. During the tests, all electrical parameters of the thrusters and cathodes, as well as xenon mass flow rate in each line were measured and controlled. The tests were conducted in a $5m^3$ vacuum chamber at TsNIIMash with residual pressures not higher than 2 .0 x10-4 Torr [7].

Figures 4 and 5 show the engines operating with different cathode locations and quantity of cathodes. A variety of discharge voltages up to 400 V have been tested. The xenon mass flow rates in each thruster were independently varied in a range from 2.5 to 3,5 mg/sec. The above mentioned study focused on the characterization of functioning multi-thruster systems including the stability of the two TAL unit during simultaneous operation at different operating regimes. The thruster unit was tested with a controlled difference between the discharge currents of the thrusters and current of the magnetic coils. The start-up processes of the system were studied also.

The tests are not yet completed but preliminary results are summarized as follows.

- Opportunity of two TAL operation from one discharge power supply is confirmed;
- All measured parameters of each thruster in the integrated unit completely corresponded to the parameters of the D-55 obtained in variant "one thruster/one discharge power supply".
- In the tested system any changes of the thruster characteristics were not found.
- The parameters of thrusters mass flow rates, currents of magnetic coils can be varied in enough wide ranges independently without negative influence between thrusters.
- The two thrusters operation can be executed as well with single, as with two cathodes-neutralizers without changes of the thruster unit parameters.
- In the start processes of the two-thruster unit were not found out any qualitative changes, as compared with transients processes in the circuit with single thruster/single power supply.

Conclusion

The preliminary results obtained from this testing confirm the opportunity to realize the EPS scheme based on simultaneous operation of several thrusters and show real possibility to implement this scheme in real practice.

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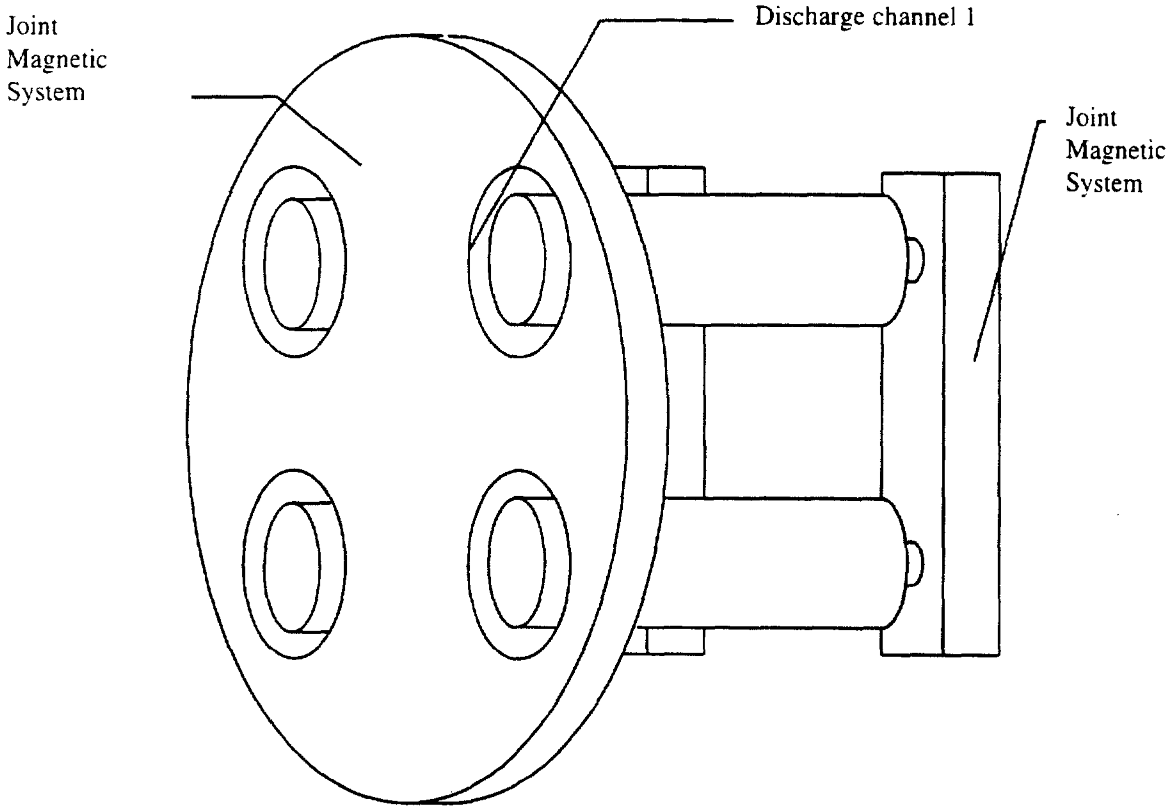

Fig.1.
Scheme of the Multi-Channel Hall Thruster Unit.

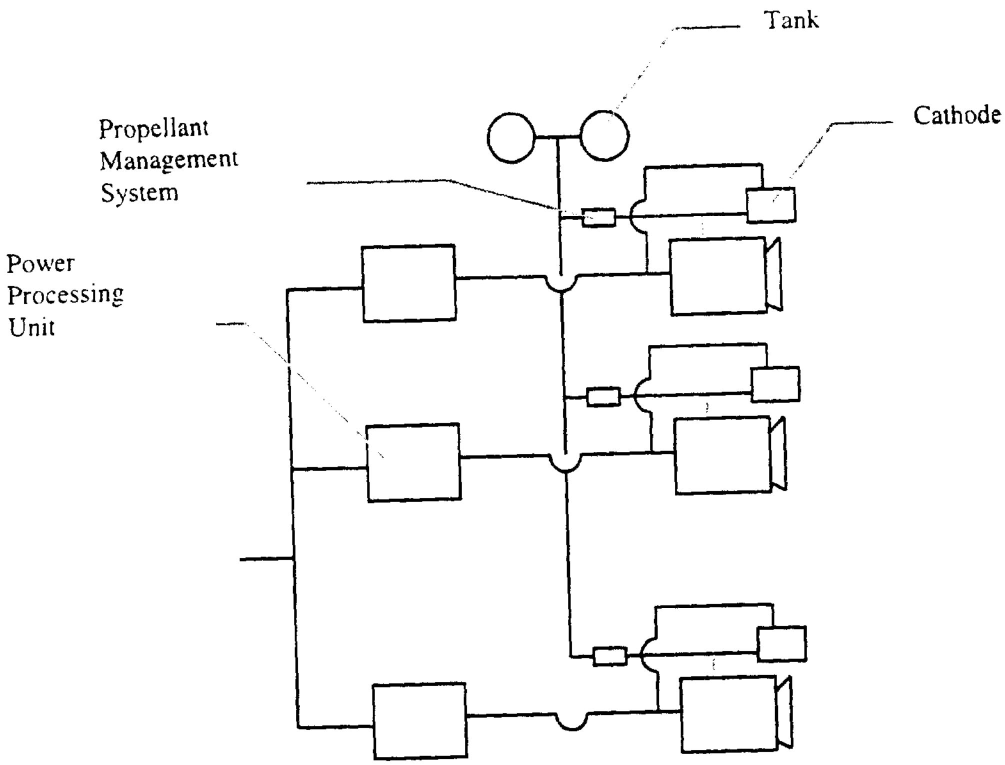

Fig.2.
Scheme of Multiple Thruster Propulsion System based on independent electric propulsion subsystems.

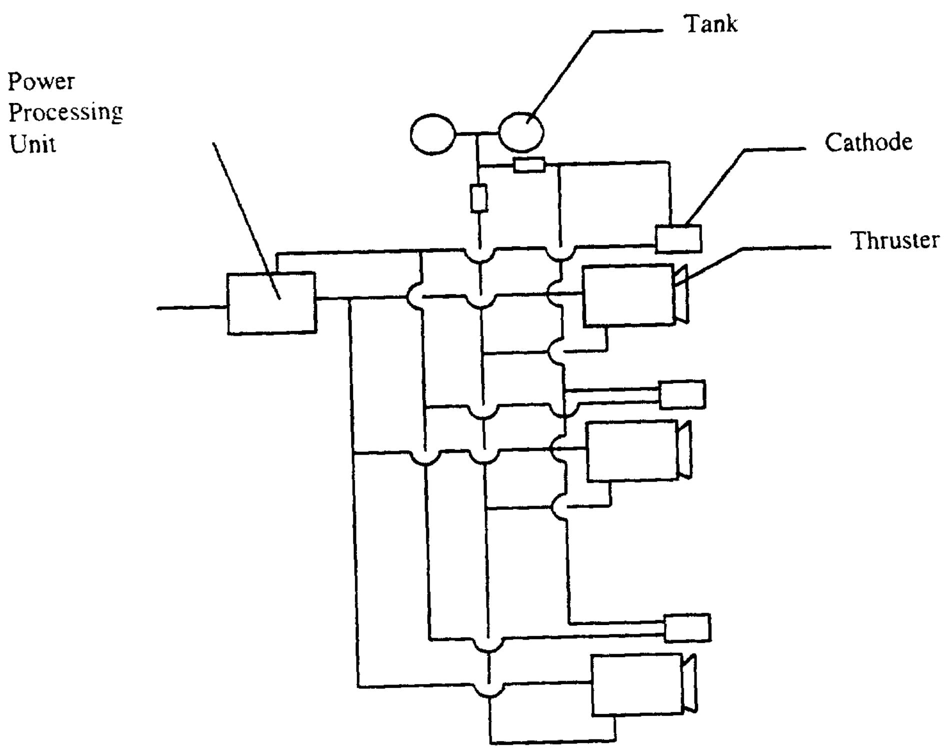

Fig.3
Scheme of Multiple Thruster Propulsion System based on simultaneous operation from one common Power Processing Unit and Propellant Management System

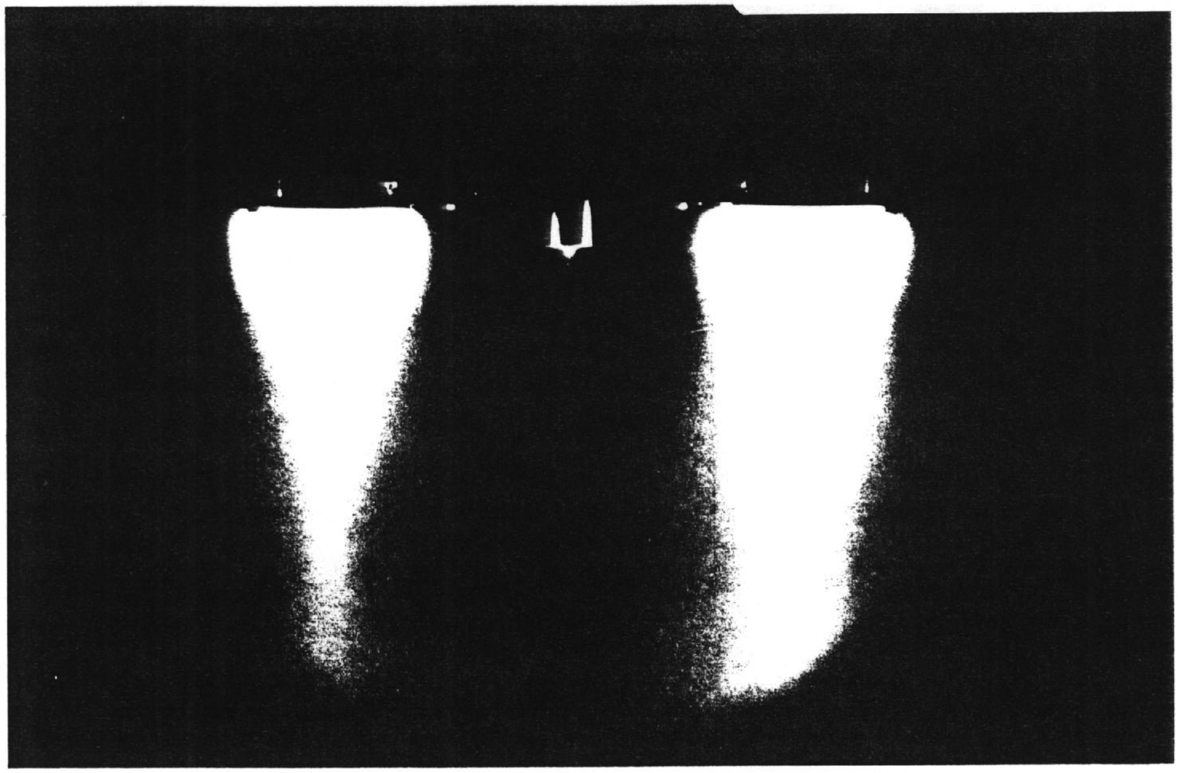

Fig.4
Two thrusters operation with cathode located between thrusters

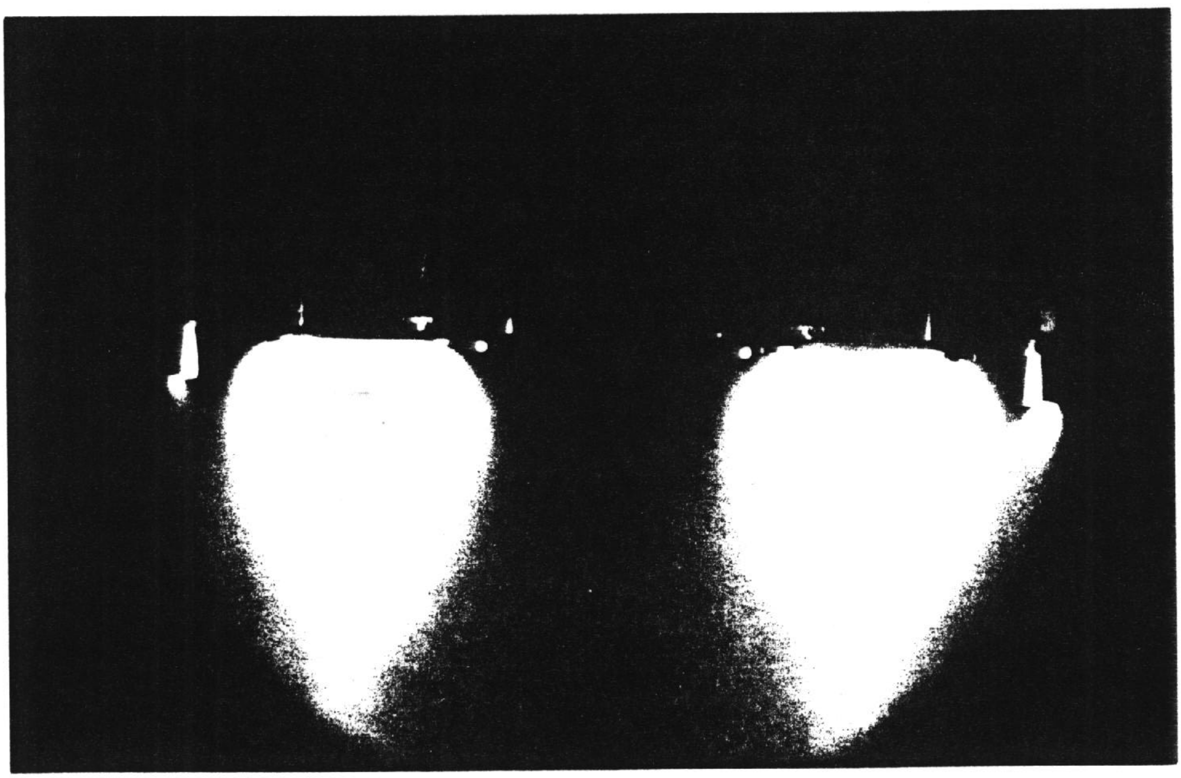

Fig.5
Two thrusters operation with cathodes located at the outer boundary of the assembly.