Development of Electric Propulsion Standards - Current Status and Further Activity.

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Abstract

Growing application of EP systems, appearance of various suppliers in different countries require to establish common "language" and "rules" to describe and determine parameters of plasma flows, EP thrusters and entire systems. Currently specific of the EP systems does not fully reflected in existing space standards. A preliminary analysis shows that the list of an electric thruster's special characteristics includes the following:

- *thrust, flow rate (due to the smallness of measured values);*
- *characteristics of plasma plume;*
- *characteristics of electromagnetic oscillations.*

Using measurement methods and technique are not the same in different test centres, correspondingly, results are not fully comparable. The paper discuss approach to development of specific EP standards with a goal to establish some common criteria and provide comparability between results from different laboratories.

Introduction

Evolution of any technology (including the rocketry and the space one) eventually requires regulation of product improvement, production and test phases. The necessity in such regulation is obvious, and it increases with expansion of application volumes of one or another technology and coming of various manufacturers. Finally, such regulation ensures the reliability and lifetime of expensive space systems.

Today the volume of electric thruster application is continuously increasing; in different countries new manufacturers of thrusters appears. Therefore, the regulation of electric thruster working characteristics definition has become an urgent problem.

The rocketry and space technology already has a well-developed base of standards regulating phases of development and types of tests for a space vehicle propulsion system.

It is possible to group these standards into three classes:

1. ensuring of a product resistance to environment exposure during all phases of its life cycle (impact of climate, vibration, radiation in space, etc.),

2. methods of functional characteristics verification (thrust, reliability, etc.)

3. compatibility of a product with other spacecraft (S/C) subsystems (e.g., the level of electromagnetic noise, plasma impact on a surface, etc.)

From the environment point of view - e.g., ensuring resistance to vibrations, heat and acoustic impacts - an electric thruster does not differ from other types of propulsion. The level of various impacts, the ways and the means of ground tests for any technology used on SV are regulated by present norms and standards which are fully applicable to electric thrusters.

An electric thruster has the same set of required working characteristics as any other propulsion. However, due to the low values of thrust and some features of ground tests an electric thrusters and electric propulsion systems differ from other one. Additional possible impacts of an electric thruster system on SV's systems are connected with a thruster's peculiarities: presence of plasma and high-energy particles, generation of electromagnetic oscillations in electrical discharges and plasma flows, etc.

In general the task of any standard and norm is to ensure:

a) completeness of product development and reliability of test results, using for the product characterization;

b) identity of criteria used for a product characteristics estimation and proven methods for their definition (measurement), and - as a result - comparability of the data obtained on different test facilities and during real application.

Therefore, activities in the area of standards establishment for electric thrusters should be in general aimed at the following:

a) validation of test results and their conformity to a thruster characteristics in a flight conditions;

b) development of calibration methods for non-standard measurement means;

c) unification of methods and means being used for measurements;

d) ensuring the comparability of measurement results obtained on various stands.

There is no doubt in the need of the first task decision, and to obtain it some purposeful activities are required. This is a very big area which can not be discussed in one publication and should be subject of special consideration. However, even in conditions of some uncertainty, for a product development and manufacturing the second condition should be ensured at the least. Notice that the development of methods for comparison the results obtained at various conditions is especially urgent, because a significant base of experiment data has been already collected and requires an analysis.

The obtaining of comparable results can be organized in two ways:

1. Via development of unified techniques and means for test realizations; and establishment of criteria which implementation allows to compare measurement results;

2. Via testing various propulsions on the same test facility and measuring means. In this case comparability is provided with that the various propulsions operate at identical conditions. In practice, it would mean necessity of establishment of a certification center where all propulsion systems should be tested.

Actually, to develop an approach to establishing of specialized standards for electric thrusters it is necessary to answer the question:

Is it possible to develop such techniques and means which will ensure comparability and validity of test results for various propulsions and different stands, or to ensure the comparability should ALL THRUSTER/Propulsion Systems be tested on one and the same stand?

From the other side several national centers should be then established in countries engaged in electric thrusters manufacture and use. So, the task on comparison the data obtained in several test centers remains in any case.

A preliminary analysis shows that the list of an electric thruster's special characteristics includes the following:
- thrust, flow rate (due to the smallness of measured values);
- characteristics of plasma plume;
- characteristics of electromagnetic oscillations generated at a thruster operation.

Measuring technique and test methods using to characterize listed parameters have a different level of development. Below, the parameters are considered as objects of regulation.

Electric propulsion system characterization

Thrust Measurements

Everywhere the measurements of thrust value are taken on thrust-measuring stands equipped with a system of direct calibration with reference loads. The value of thrust is measured as the difference of signals from a thrust-meter loaded and unloaded by an force from a thruster and from a appropriate standardized load. It provides high accuracy of measurement. However, even for one and the same type of thrusters, e.g., Hall-effect ones, the test procedures may have some differences resulting in deviation of measuring value:

- during thrust measuring only the anode voltage is turn off, while the propellant flow rate is kept unchanged, the discharge in the cathode-neutralizer is not turned off;

- during thrust measuring all power sources and also propellant feeding are cut off .

In the second case the measured value most corresponds with its true meaning, but technologically the procedure is more complex, therefore most measurements follow the first procedure. In this case, the measured thrust value is underestimated in comparison to its true value for 0.5...1 % /1/. It is obvious that the distinctions are not significant, however at it is advisable to mention the details said above while defining and also measuring a thrust value.

Influence of Test Conditions on the Results of Thrust and Power Characteristics Measurement

The mode of a thruster operation depends on residual pressure in a vacuum chamber, because atoms of residual gas have an opportunity to penetrate into the zone of discharge, thus creating an additional (secondary) flow of propellant and residual gases /2, 3/ resulting in thrust, discharge current and efficiency deviation.

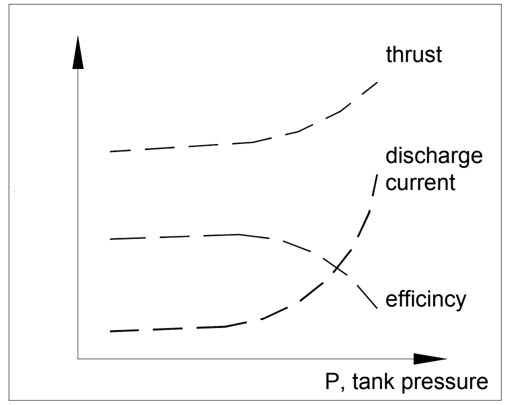


Fig.1 Typical dependencies of Hall thruster parameters versus tank pressure.

In Hall-effect thruster such effect is especially intensive at pressure values 10^{-4} torr and higher. To estimate the reliability of thrust measurements it may be recommended to take the measurements at several pressures in a vacuum chamber and extrapolation of an obtained curve on other pressures, for example, on typical ones for real conditions of a thruster operation.

Contamination by material sputtered from vacuum chamber, oil vaporous and etc may also affect thruster performances and life. Existing information on this subject is very limited and is not analyzed well. So that dedicated efforts are necessary.

Nevertheless comparability of thrust measurements can be provided for tests in various conditions. That is proved to be true by, for example, numerous statistics on tests of Russian Hall-effect thrusters in Russia and NASA's Centers.

Plasma Plume

The parameters describing a plasma exhaust plume are the following:

- angular distribution of ion current,
- energy/velocity spectrum of ions,
- temperature of electron components.

The parameters can be specified independently in themselves or can serve as initial data for a computer model of plasma plume allowing to predict a plasma flow behaviour at a significant distance from a thruster.

At present, two directions of diagnostics are being developed: the contact one - by means of probes, and the contactless one - by means of optical methods (LIF, spectroscopy).

Below, the features of application of the most widespread, contact methods are considered.

Measurements are taken by electrical probes and retired potential analyzers (RPA). Though the means are constructed on the basis of uniform principles, they can have completely different designs. As a result there is no opportunity to compare the measurements taken on various test beds, and also the results of tests on the same stand will essentially differ if the design of a probe is replaced.

The measured values of angular beam distribution and power spectrum of ions depend on the following parameters /3,4,5/ at the least:

- distance from a thruster up to a probe and characteristic dimension of the collecting surface of a probe,
- orientation of the collecting surface in relation to a thruster's axis,
- the value of solid angle from which a probe is able to collect ions,
- residual pressure in a vacuum chamber,
- relation between initial plume size (type-size of a thruster), size of vacuum chamber and distance to a probe

Below, we consider the above parameters and try to formulate common recommendations that will allow getting the comparable data or to interpret the data obtained in various conditions.

Let us consider an elementary - but most widespread - version: a probe is flat and collects ions from a hemisphere.

From the point of view of test conditions the main physical process impacting the parameters of a spreading plasma flow is the fast ions charge exchange on the atoms of residual gas. Therefore, it is possible to group the conditions of ion flow measurements into two categories:

- measurements at the distances much less than the characteristic length of charge exchange;
- measurements at the distances comparable to or longer than the length of charge exchange.

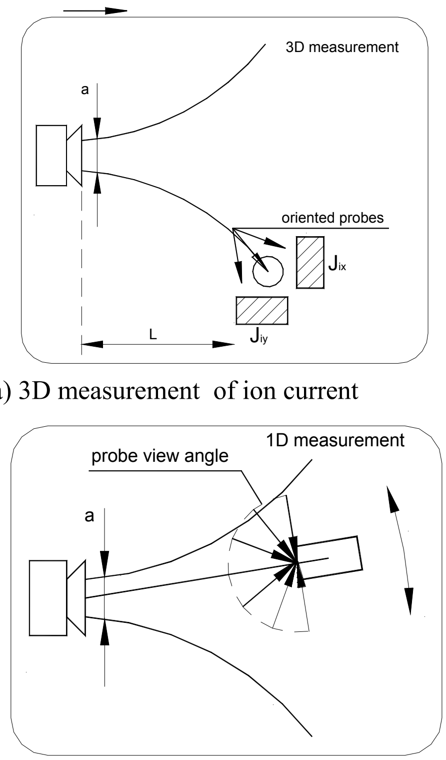
The characteristic length of charge exchange for xenon ions of 300-eV energy at pressures in a vacuum chamber of 10^{-5}... 10^{-4} torr varies from units of meters up to tens centimeters. Most measurements of an ion current are taken at the distances compared to the said sizes, so the measured value is already essentially different from the value of initial flow generated by a thruster. In this case, the comparability of the results obtained in various test conditions is conditioned by fulfillment of the equation:

$$\mathbf{p_1 \times l_1 = p_2 \times l_2},$$

where **p** – residual pressure in a vacuum chamber;

l – distance from the exit of a thruster up to a probe.

The most reliable result for an ion current angular distribution can be obtained from a measurement of three perpendicular components of an ion current by probes oriented, for example, along and across the line of a plume movement – Fig2,a. In practice, it is common when the measurements are taken during the movement of a probe round a circle – polar system on Fig.2,b. The centre of the circle is on the thruster's axis, and the collecting surface of a probe is always oriented along the radius of such circle. It is also supposed that the source of ions is a point one, located in the centre of the circle, and the trajectories of ions are straight-linear.



a) 3D measurement of ion current

b) ion current measurement in a polar system

Fig2. Ion current measurement

Such approximation is possible if the distance between a thruster and probe is much longer than the characteristic dimension of an initial plasma plume coming out of a thruster. From the condition of geometric similarity the ratioes follow which characterize such measurements: ***d/l*** and ***a/l,***
where ***l*** - distance from the exit of a thruster up to a probe, ***a*** – initial diameter of a plume, ***d*** – linear dimension – diameter of a probe.

The equality of these ratioes allows comparing of the measurements in various conditions or for various thrusters.

Comparability of measurement results is not the guarantee of their reliability yet. With reference to characterization of a plasma plume the most reliable result can be obtained, if in each point of the space being investigated both the spatial and energy distributions of particles are known, i.e. the 3-component measurements of both density and energy for ion and electron flows are taken. This task is technically more complex, but also (as in the elementary case described above) application of some criterions to measurement of each component allows to ensure the results comparability.

In resume, it is possible to notice that comparability of measurement results for a plasma flow parameters can be potentially reached and the problem is not the question of principle.

Electromagnetic Compatibility

The conditions for tests of space equipment on electromagnetic compatibility are regulated by the standards available in every country producing space vehicles. The standards regulate the threshold of electromagnetic interferences in feed circuits, the threshold of electromagnetic fields generated near an operating device. However, from the point of view of appropriate tests for electric thrusters a lot of problems require refinement:

1. The object of requirements - what it is and whose characteristics should be verified at the phase of improvement and manufacturing:
a thruster ;

a thruster + cabling + power sources.
It is obvious, the second gives the most reliable result. However, it means that a real electric propulsion system should be used in tests, i.e., a system configuration should correspond to normal conditions **and** ALL its COMPONENTS must be placed in a vacuum chamber for tests. As it is known, elements of the control and power supply systems of a thruster are spatially distributed on a S/C, so there can appear difficulties with placement of such assembly in a test chamber. It is essential that in this case the test results characterize a particular propulsion system, and not its components. To get an independent characteristic of a thruster operating mode from the point of view of electromagnetic noise generation, measurement of the levels of discharge current oscillations in a discharge circuit of a thruster are used. However, such characterization is reasonable, if some standard power supply circuit is used. Today, various power supply systems are used in tests, and criterions for characterization of their parameters

and for estimation of test conditions comparability have not been worked out yet. Specific and application of such "standard" systems is a subject of further study and coordination.

2. Impact of test conditions. It is obvious that in relation to operation in open vacuum a conductive vacuum chamber distorts the picture of electrical fields generated by any source /6/. This defect is compensated by calibration of a vacuum chamber itself with an independent source of electromagnetic oscillations placed inside the test volume. Such calibration allows then recomputing the levels of background noise from a propulsion system taking into account resonant effects. However, as a rule, such calibration is made in a chamber without plasma. The presence of plasma can deform the results of calibration. The problem may be resolved by calibration on an operating thruster background, but due to complexity of the thruster/plasma/antenna interaction special research are necessary prior to any technical recommendation will be formulated.

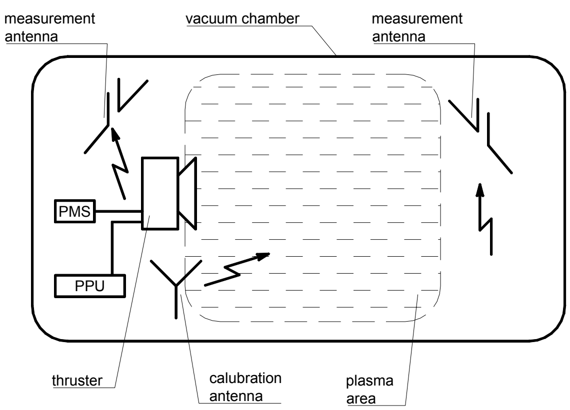


Fig.3 EMI tests in vacuum tank.

3. An operating electric thruster is capable to have a peculiar influence on a S/C that is caused by a contact of the surface of S/C to non-equilibrium plasma. Along the plasma various oscillations propagate, causing spatial-temporary fluctuations of both density and temperature of plasma near a S/C surface. Such fluctuations are capable to cause electric currents in the part of S/C that has electric contacts to such inhomogeneous flow.

Until present, the said peculiarity of a thruster operation has not been considered in details. However, importance of similar effects will increase with increase of electric thruster power and sizes of S/C. For example: extended solar panels which electric connections are not protected from a contact to external plasma.

Conclusion

Summing up it is possible to say that most tests of electric thrusters potentially can be successfully regulated that will ensure identical reliability of the data obtained in various conditions, and also the data comparability. Nevertheless plume characterization and EMI measurements require dedicated scientific and organization effort to develop and prove some recommended test procedures. Some types of tests on electromagnetic compatibility tests can become an exception. Today the said types of tests characterize a particular electric propulsion for a particular S/C, so the problem is resolved by each S/C developer himself in reference to a particular case. But in future to ensure characterization of electric propulsion components (thrusters, first of all), the test methods in “standard” conditions permitting to receive comparable results can be quite developed.

With regard to development of standards or regulated procedures, the following nearest activities looks reasonable:

1. Analyze and select the most successful means for electric propulsion parameters measurement.
2. Develop and publish the recommendations on use of the said means ensuring comparability of data obtained in various conditions.
3. Offer methods and means of calibration for nonstandart measuring means being used for electric propulsion tests. Development of, for example, “standard” ion sources will allow to simplify essentially the testing of the instrumentation for plasma parameters measurement.

It is obvious that to begin with, the results of such activity should have a character of recommendations and should also pass practical approbation before it will be possible to speak about implementation of mandatory standards in electric propulsion test conditions. Nevertheless, the result of the activity will essentially regulate experimental efforts, and will make easier the problem for the users of space electric propulsion, the S/C developers.

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