GT-50 THRUSTER FOR SMALL SATELLITES: MARKETABILITY ANALYSIS

Technical report

Contents

State of the art review

If one were to compare prospective solutions in the area of electric propulsion for small satellites, the mass range from 30 to 1000 kg would be of particular interest. For such comparison, we will use the list of all small satellites launched since 2000 that equipped with electric propulsion systems [1].

Let us then exclude the thrusters with specific impulse less than 600 sec, thus studying only high specific impulse class. Such problem setting is due to the trend of using high-impulse thrusters in space missions for reducing initial mass and thus improving commercial efficiency of the mission.

Table 1 shows thrusters launched on 30-1000 kg satellites with specific impulse more than 600 sec.

Table 1 – Modern electric thrusters for satellites

Name	**Satellite (Launch date)**	**Power, W**	**Thrust, mN**	**Isp, sec**	**Type**	**Prop. System mass, kg**
HEPS [2]	Deimos-2 (19 Jun 2014)	300	7	1000	Hall thruster	> 13
SPT-50 [3]	Kanopus-V (22 Jul 2012)	317	14	850	Hall thruster	25
APPT-45-2[4]	MKA-FKI PN2 (8 Jul 2014)	75-150	1.44-2.9	1100	Pulsed plasma thruster	10.5
BHT-200[5]	TacSat-2 (16 Dec 2006) FalconSat-5 (20 Nov 2010)	200	12.8	1390	Hall thruster	No information
MIPS[6]	PROCYON (3 Dec 2014) Hodoyoshi 4 (19 Jun 2014)	27	0.2	740	Ion thruster	8.1

As of today, Busek Co. Inc. is a renowned leader in electric propulsion development. It is evident, that performance of the company's Hall thruster BHT-200 is far better than that of the competitors. Let us study Busek Co. Inc.'s planned missions (Table 2).

Table 2 - Prospective electric thrusters for satellites

Name	**Satellite (Launch date)**	**Power, W**	**Thrust, mN**	**Isp, sec**	**Type**	**Note**
BHT-200-I [7,8]	iSat (launch planned on 2018, s/c undergoes preflight tests)*	200	12.8	1390	Hall thruster	Fig. 1
BIT-3[9]	Lunar IceCube (planned launch on SLS, s/c ready for preflight tests)	75	1.15	2100	RF Ion thruster	Fig. 2

**It is worth mentioning that this mission is already third demo mission for BHT-200 thruster, but the manufacturer publishes neither first flight test results, nor the essence of decisions made after the flight.*

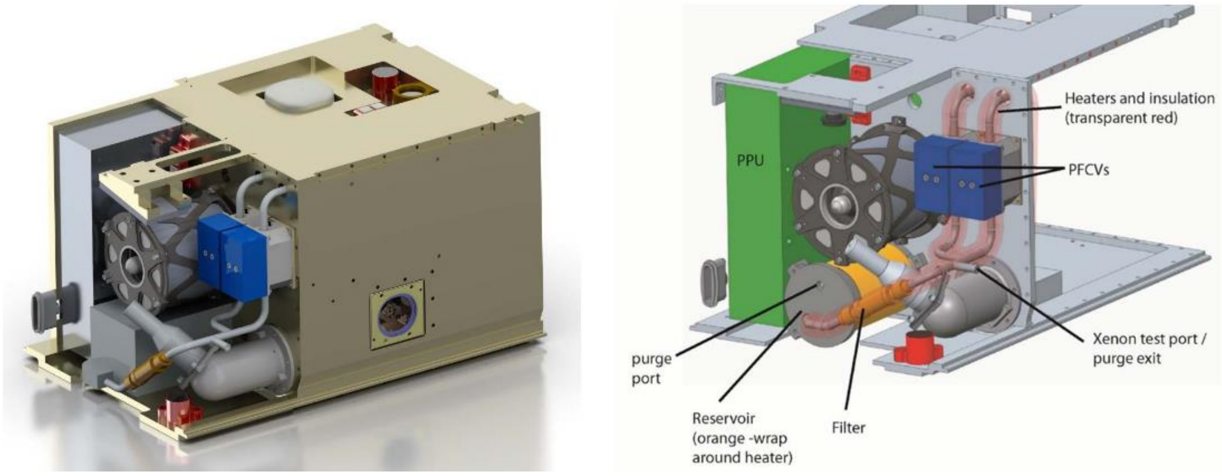
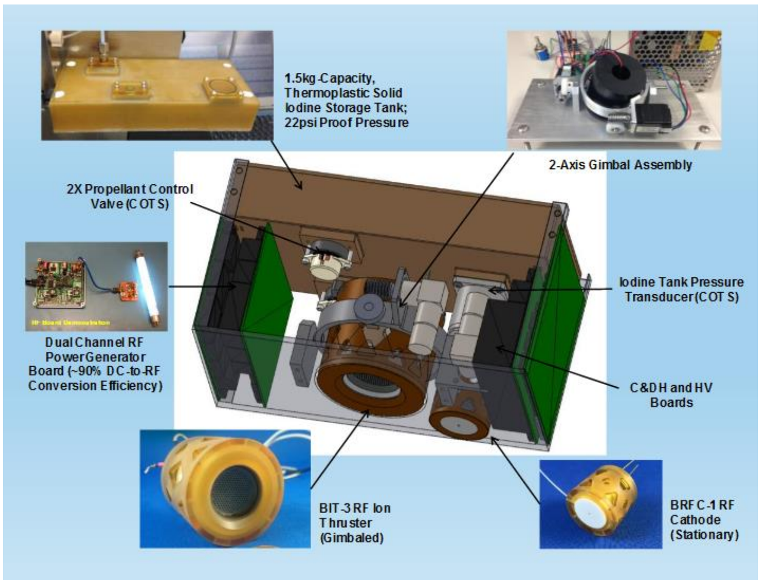


Fig. 1 - iSat - 12U Cubesat (23.5 kg)



Unprecedented performance

- 180x88x102mm system envelope

- 3.0kg wet, 1.5kg propellant loading

Rad-tolerant, miniaturized PPU

- 28-37V unregulated input, RS-485 comm

- Designed for 55-75W power draw

Fig. 2 –Lunar IceCube's thruster

Table 2 shows vast possibilities in size reduction for Hall thrusters, as well as RF ion thrusters. GT-50 thruster developed by Avant-Space Systems represents the latter. Cutting-edge microelectronics allows solving integration problems, as well as the problem of RF-generator size for powering ion thruster's RF antenna.

GT-50 thruster target parameters

Modern small satellites for telecom and Earth observation normally use low operational orbits, and typically have mass from 50 to 300 kg.

For these types of missions, a series of ballistic analyses was carried out, which established, that for station-keeping of such spacecraft 5-7 mN of thrust and 1500 seconds of Isp should be satisfactory. It is also important to try to reduce the propulsion system's power consumption, because the capabilities of satellites' EPS are quite limited. Having analyzed the marketability, and estimated the basic technology, we came up with the target parameters for the GT-50 thruster (Table 3).

Table 3 - GT-50 thruster target parameters

Model	Power, W	Thrust, mN	Isp, sec	Propellant	Size	Mass, kg	Efficiency, %
GT - 50	180/240	5.0/7.0	2000+	Xe	Up to 4U Cubesat	Up to 8	> 70

It is worth mentioning that using this thruster aboard satellites heavier than 300 kg is also possible, but requires more than one ion thruster within the propulsion system.

In 2017, a number of experimental works was done do establish the optimal configuration of the ion thruster. As a result, the parameters were obtained that are shown in Table 4. High efficiency and discharge stability were reached by applying external magnetic field with parameters corresponding to excitation of resonant waves in plasma. This is what is different in our thruster compared to analogues.

Table 4 – GT-50 Laboratory model parameter measurement results

Model	Beam current, mA	Power, W	Thrust, mN	Isp, sec	Propellant	Discharge chamber size
GT - 50	100/150	155/290	5.0/9.1	2700/3400	Xe	50 mm × 50 mm

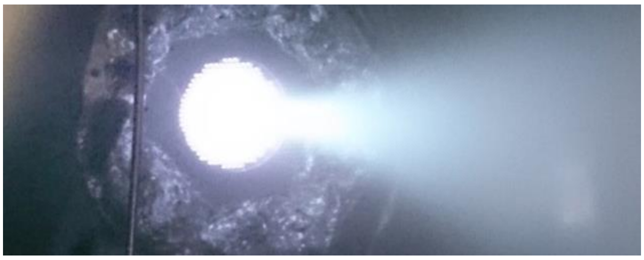


Fig 3 - GT-50 lab model vacuum chamber test

The main competitors, as shown in the first section of the present document, are the Hall thrusters. The more detailed comparison of the Hall thrusters vs. RF ion thrusters is in the section below.

SPT vs RF ion thruster comparison

Table 5 shows results of comparing the two concepts.

Table 5 – SPT vs RF ion thruster comparison

	Performance feature	Influence on the s/c	Lifetime	Subsystem mass	Reliability
RF IT	Key advantage is high ISP (up to 3000 sec).	Beam divergence angle no more than 10°.	20000+ hours	The subsystem mass is defined mostly by technical excellence of the whole system, and may be connected with the "ion source + neutralizing cathode" system choice, the whole logic of the power supply and control system, etc. Thus, comparing by this criterion is complicated given the present project development phase.	For the developed systems with little to no flight heritage, there is no way to correctly estimate reliability parameters.
SPT	Key advantage is relatively high absolute thrust given low power consumption	Beam divergence angle reaches 45°, which influences the outline of the whole mission which uses this thruster type	Up to 1000 ч (for low-power thrusters). This low value is due to ablation of the thruster structure, which leads to unstable performance and may diverge the thrust vector from the nominal.		

The main challenges in SPT development

For Hall thruster, decreasing of the efficiency and lifetime with reducing power consumption is a very well-known problem [10-14]. Much experimental data exists that shows that decreasing power consumption reduces the thrust efficiency in classic SPTs so that it does not exceed 30%. A typical dependency of thrust efficiency vs. power consumption for SPT-25, 35, 50, 60, 70, 100, developed by Fakel OKB, is shown in fig. 4. First point in fig. 4 represents SPT-25, the last one – SPT-100.

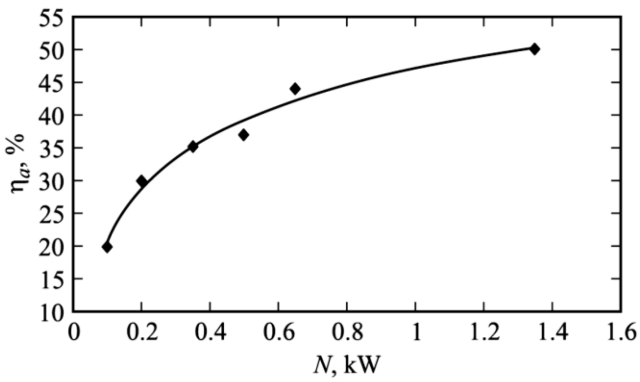


Fig. 4 – Thrust efficiency vs power input in SPT [15]

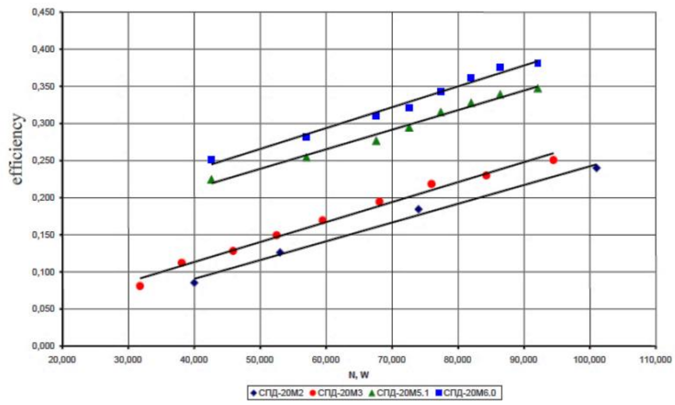


Fig. 5 – Experimental curves of efficiency vs power for low-power SPT [13]

The main reason of performance fall is believed to be bad surface area to volume ratio of the discharge chamber [12, 14].

Table 6 – Low power SPT parameters comparison

Name	Power, W	Thrust, mN	Isp, sec	Eff-cy, %	Ref.
CAM200	250	14	1570	43	[11]
XHT-200	38	1	950	5-10	[12]
SPT-20M	100	4	1400	38	[13]
Low power hall thruster, Japan	50	2	600	5-13	[14]

In addition, reducing the discharge chamber volume leads to a significant lifetime reduction due to the ablation in the discharge channel. This may lead to unstable performance and may diverge the thrust vector from the nominal.

The main challenges in RF IT development

The most complicated part of the RF IT are the gridded electrodes of the ion-optical system (IOS). For improving the reliability of the IOS of an RF ion thruter, several approaches exist.

Firstly, IOS electrodes can be made of a material with low sputtering yield: molybdenum alloys, pyrolytic graphite, RCC composite materials [18]. As of today, the technologies have been worked out for making electrodes of all the mentioned materials. RCC electrodes, for example, have shown to withstand operating for 20000+ hours [17, 20].

In addition, there exists software that allows precise calculation of different material electrode erosion versus operating time [17, 19, 20, and 22]. The information about the erosion dynamics allows reducing destructive effect by tuning electrode voltage [22].

Also, for protecting the thruster from electrode short-circuiting, a technique exists of cleaning them. It allows removing the short circuit of the electrodes caused by sputter by heating the electrodes with pulse current [16]. The measures described are utilized in modern ion thrusters.

Another complex element of an RF IT is the onboard RF-generator. Its architecture must provide simple integration into the satellite, minimum heat dissipation and extremely fast adaption with respect to changes of the plasma. It is known, that this problem has been successfully solved in the BIT-3 thruster.

Avant – Space Systems LLC’s specialists are also developing a modern onboard RF-generator. The generator operates as a resonance pulse power source. This technology is known to be the most energy-efficient, because it minimizes the losses in transistors during switching. By using gallium-nitride MOS transistors, we have reached a very compact size of the generator, as well as low heat dissipation, which is important in space. The prototype is equipped with a fast 100MSPS analogue-digital converter, which allows registering currents and voltages of the inductor with a very high resolution. The company’s specialists are planning to apply for a patent for this solution after the test cycle of the lab model is finished.

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