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Investigation of a Low-power Thruster on Krypton Propellant

P.A. Saevets[a, *], V.P. Kim[b], D.P. Grdlichko[c], P.G. Smirnov[d]

[a]*Design-engineer, FSUE EDB Fakel, 181 Moskovskiy Prospekt Street, Kaliningrad, 236001, Russia*
[b]*Chief Scientist, Moscow Aviation Institute, 4 Volokolamskoe Shosse, Moscow, 125080, Russia*
[c]*Senior researcher, Moscow Aviation Institute, 4 Volokolamskoe Shosse, Moscow, 125080, Russia*
[d]*Engineer, Moscow Aviation Institute, 4 Volokolamskoe Shosse, Moscow, 125080, Russia*

Abstract

Nowadays, higher requirements are set for modern spacecraft,and, in particular, those related to the cost-efficiency of the mission. To ensure a reasonably long period of active life (approximately 10-15 years), stationary plasma thrusters (SPT) are successfully used in propulsion systems. Xenon is the substantial part of the cost of the propulsion system, which is why this could be significantly reduced, were xenon to be replaced with an alternative propellant.
On this basis, and taking into account the perspectives for the creation of multi- satellite orbital constellations and the tendency towards spacecraft miniaturizations, there is a demand for the development of a low-power thruster using an alternative propellant to Xenon. It is assumed that krypton is the most suitable replacement, albeit while using krypton there is a considerable decrease in the SPT thrust parameters. Therefore, it is necessary to perform investigations which reduce the negative consequences related to the use of krypton as a propellant.

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Keywords: Stationary plasma thruster; Krypton; Xenon; Propellant.

1. Introduction

At the present xenon is used in stationary plasma thruster to create reactive thrust. Xenon is used due to its high specific performance in comparison with other inert gases. However, notwithstanding this advantage, there is a factor which can limit xenon usage and that is, limited production of xenon lead at a high price.

Xenon, as well as all noble gases, is a by-product of nitrogen and oxygen production. As the content of xenon in the air is negligibly small (Table 1) there is no added-value by building a special plant for xenon production. This is why the rate of xenon production is not growing in hand with the increase in demand, and is totally restricted by oxygen production. These factors have an influence on the price of xenon, and make it more expensive than alternative propellants.

* Corresponding author. Tel.: +7-921-008-4262.
E-mail address: wolandxai@gmail.com

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It should be noted that on spacecraft with the present SPT construction, the replacement of xenon with an alternative propellant, in particular by krypton, will not lead to a in reduction in the cost of the mission.

Table 1. The amount of gases in the air

Substance	Symbol	Mass percent
Nytrogen	N_2	75.5
Oxygen	O_2	23.15
Argon	Ar	1.292
Carbone dioxide	CO_2	0.046
Krypton	Kr	0.003
Neon	Ne	0.0014
Methane	CH_4	0.000084
Hydrogen	H_2	0.00008
Helium	He	0.000073
Xenon	Xe	0.00004

Growth in the quantity of spacecraft and the creation of numerous orbital groups could lead to a shortage of xenon. It is not possible to increase xenon production, but its demand can be considerably decreased. A perspective alternative for xenon is krypton.

2. Comparison of Xenon and krypton as a propellant for SPT

There are a variety of reasons for xenon usage. Xenon has high atomic mass – 131 amu, and relatively low ionization potential – 12.1 eV. In addition, the inertness of xenon is able to eliminate the defects in operational safety, which occurred with mercury and cesium usage. In addition, xenon can be stored in heightened density, making it possible to decrease tank volume.

Krypton seems to be a perspective propellant in missions where heightened specific impulse is required. When compared to xenon, krypton has lower atomic mass – 83.8 amu, but higher ionization potential – 14.0 eV. Both xenon and krypton are inert gases, and xenon may be used as a propellant in propellant storage and feeding systems already developed, without essential upgrading. High ionization potential exerts a bad influence on thruster efficiency, but a lower atomic mass can theoretically increase specific impulse by 25 %. It can be useful for spacecraft keeping on geostationary orbit, but for transfer operations it will significantly increase the time of interorbital transfer.

A change in propellant can be carried out only if this change ensures acceptable performance. This is why the given research was conducted showing the change in the low power characteristics due to transition from Xe to Kr.

3. Operational characteristics of an SPT-50M working on xenon and krypton

Parametric tests of the thruster were conducted on different modes both on krypton and on xenon. These tests showed that under bounded discharge power (approximately 200 W):

- The best propulsion parameters are registering using xenon with a flow rate through accelerator channel of ~ 1 mg/sec and heightened discharge voltages (up to 250-300 V);
- Using krypton the thruster gets a considerably lower value of propulsion, specific impulse and thrust efficiency.

Voltage-current characteristics of the thruster working on xenon have a classical character. Voltage-current characteristics of the thruster working on krypton are of a varied character (Fig. 1), but in comparison with operation on xenon, for krypton the displacement of the initial zone of discharge current, increasing towards higher voltages is typical, and the zone with higher values of discharge current is practically absent.

This is natural, as krypton ionization requires a higher electron energy, which grows with the increase in discharge voltage. Another factor is that the decrease in flow rate results in a decrease in plasma density in the accelerator channel, as well as in the growth of free atom path before ionization. This is why, one and the same value of atoms-to-ions conversion is achieved with higher electron temperature, which is realized under higher discharge voltages.