Testing the induction system of a new length-optimized version of an ion-thruster of RIT-type with ferrite pot-core

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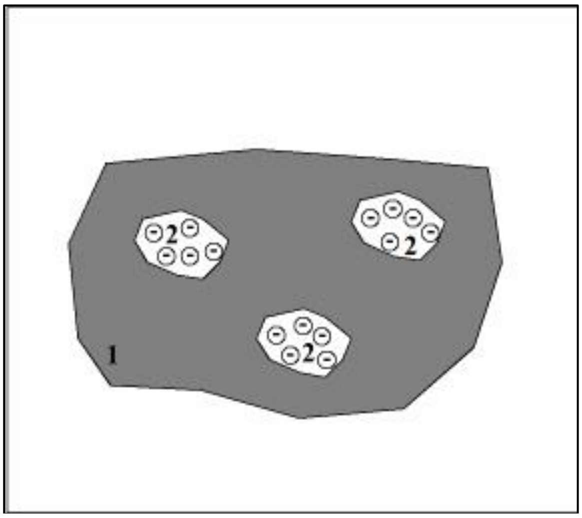
Abstract: The following paper aims for a new more efficient design of the discharge chamber of a Radio-Frequency Ion-Thruster (RIT). The discharge chamber contains plasma, which provides the charged particles for thrust-generation. The plasma is produced by ionization of gas. The ionizing discharge has to occur in the whole chamber; in the whole chamber energy needs to be expended to produce plasma. On the other hand, as shown in [3], only charged particles out of a small layer direct close to the plasma-grid are used to become accelerated for the generation of thrust. In order to achieve energy costs as efficient as possible; plasma should be produced only in this small layer, optimally. In the following an option is presented to reduce the length of the discharge chamber of a RIT. This is achieved by coupling in the ionizing electric eddy-fields from the top-end of the discharge chamber, no longer from the sides of the chamber. For this kind of field-coupling a new induction system is needed, where the induction coil is placed inside a ferrite pot-core. Within this paper a qualitative testing of the proposed new induction system is described.

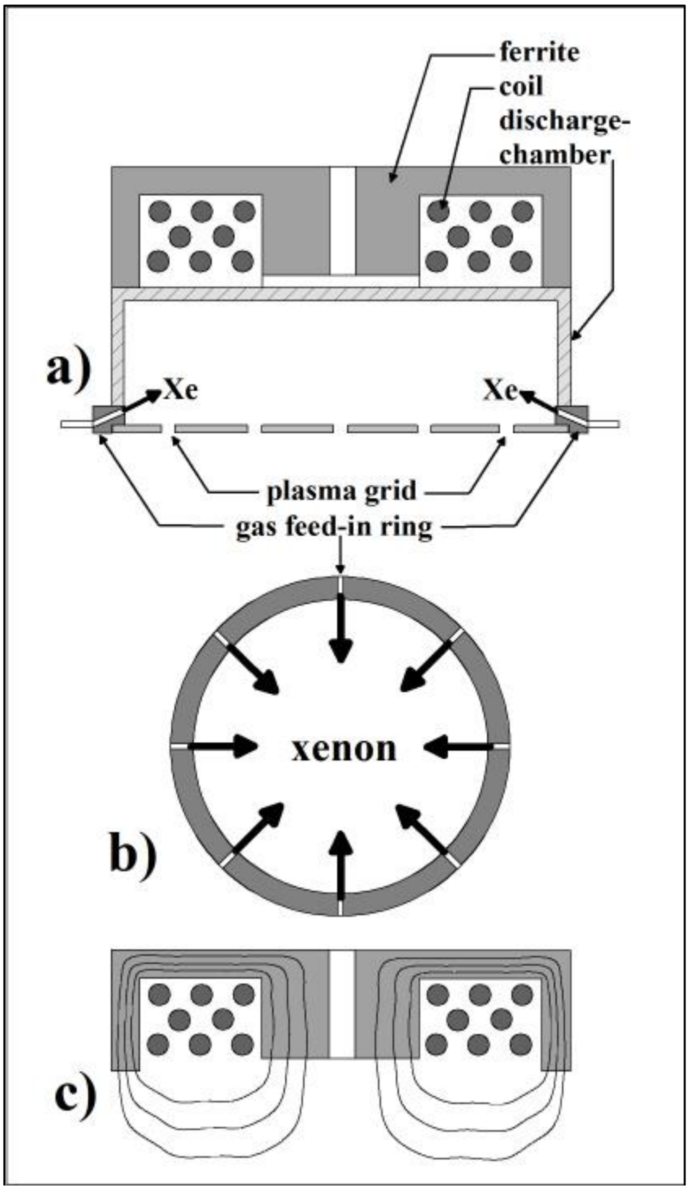
A gridded thruster uses electrostatic fields to accelerate charged particles. To enable the static electric fields to influence the particles, a neutral medium (usually gas) has to be ionized; neutral particles need to become charged. At the Radio Frequency Ion-Thruster an oscillating eddy-field effects the ionization of neutral gas by free electron acceleration and impact. Source of this eddy-field is a coil that surrounds the cylindrically shaped discharge chamber [1],[2]. The coil has a minimum size; because of a minimum number of coil-windings for emitting sufficient electric field-strength, a minimum gap between the windings for preventing proximity-effect and a minimum winding thickness for reducing Joule heating. Therefore, a coil that surrounds the discharge-chamber requires a minimum height of the chamber; the volume of plasma production isn't significant reducible.



1 Inner structure of a ferrite. iron-grains (2) are embedded in an electric isolating ceramic (1).

In [1] it is proposed to place the ionizing coil at the top-end of the discharge chamber instead of surrounding the chamber. On this way the eddy-fields are coupled in from the top instead from the sides. As the result there is no more limitation of the reduction of the chamber height. The volume of plasma production can be optimized.

For a proper coupling of electric field into the gas/plasma in the discharge chamber, the coil is housed inside a pot-core made of ferrite. Ferrite is an isolating ceramic material with embedded grains of iron (figure 1). The conducting electrons of the iron-grains are able to move within the limits of the ceramic boundaries. On this way a magnetic flux can be conducted by ferrite, while simultaneously an electric electron current is impossible. The inductive effect of the coil can be transferred by the ferrite-core, but without an inductive effect like eddy-currents inside the core. The ferrite has a pot-shape with a cylinder in the center. The multi-layer coil is placed in the free space between pot-wall and center-cylinder. The open side of the pot-core is directed against the top-side of the discharge-chamber (see figure 2). According to the continuity condition the magnetic flux is closed through the discharge-chamber; the effect of the time-varying magnetic field is conducted into the chamber.

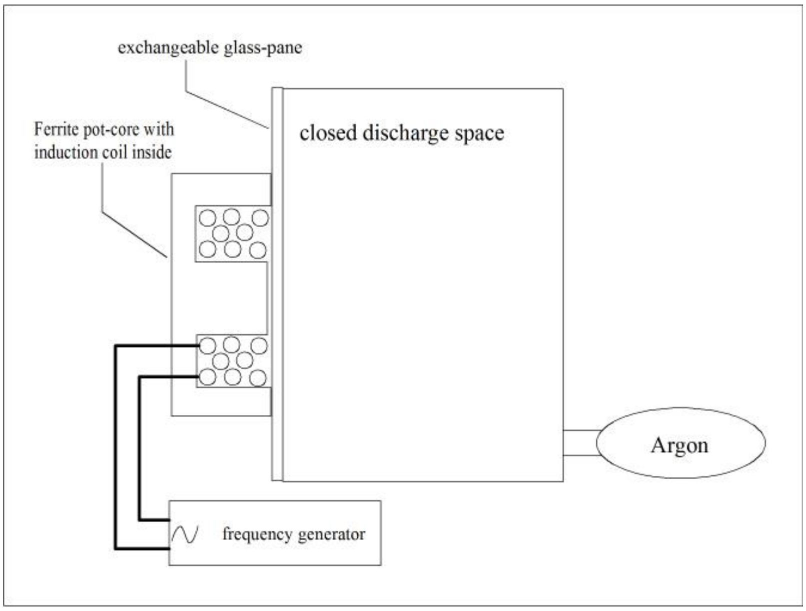


2 Scheme of a length-optimized thruster of RIT-type. (a)Setup of the thruster(sideview). (b)Ring-shaped gas feed-in(topview). (c)Scheme of magnetic flux inside and outside the pot-core.

The gas feed-in is realized via a ring that is placed between the open side of the pot-core and the plasma-grid (figure 2b). The neutral gas flows inside this ring, symmetric arranged holes in the ring conduct the gas into the discharge-chamber. The holes are directed towards the pot-core and away from the thruster exit. This enables the neutral gas to stay as long as possible under influence of the ionizing inductive field; the ionizing efficiency is enhanced by this way. An additional benefit of the pot-core is the shielding of inductive effects on the opposite side; the closed side of the pot-core. Electric sensitive devices behind the thruster are protected by this way.

The option to couple in the ionizing electric field from the top of the discharge-chamber via a ferrite pot-core opens the opportunity to optimize the efficiency of RIT-type thrusters. First it is possible to reduce the size of a thruster; a not unimportant fact for space-systems design. The second and more important opportunity is to minimize the energy-costs of such a thruster. A major part of the energy is consumed by the ionization of neutral gas; by the production of charged, accelerate-able particles, which is the basis of thrust generation. This energy can be minimized by producing of plasma only at places, where ions are accelerated from. To limit the ion production to these significant places is the prime benefit the described thruster-concept offers.

In the framework of [1] a qualitative test was made to confirm working principle of the proposed length-optimized RIT-version and to investigate the boundary conditions of functionality. The related experimental setup (figure3) consists of a closed chamber, wherein the discharge occurs. This chamber was filled with the noble-gas Argon that should be ionized. The gas-pressure of the Argon inside the chamber was variable, to investigate the pressure-dependency of plasma ignition. At one side of the chamber an exchangeable glass-pane was mounted. The strength of the eddy-field generated by the induction coil inside the ferrite core depends on the distance from the coil. Only in a limited distance the field is strong enough to cause a discharge in the Argon gas. With glass-panes of variable thickness the maximum possible wall-thickness for the discharge chamber of the length-optimized thruster could be determined. The induction system, the ferrite pot-core with the coil inside, was mounted outside on the variable glass-pane. The coil and ferrite induce an eddy-field that generates the Argon plasma inside the chamber through the glass-pane. The coil was supplied by a frequency generator that provides an oscillating voltage to the coil.



3 Experimental setup to test new induction system

With the described experimental setup it was possible to ignite plasma with the ferrite core induction system. The frequency generator supplied the induction coil with a frequency of 850 kHz. In the pressure range of 0,1 mbar to 1 mbar the induced eddy-fields were able to ionize the gas and to produce plasma. The experimental setup was driven with three different thicknesses of glass-panes; 1,5 mm, 2 mm and 3 mm. Through the 3 mm glass-pane it was not possible to cause a discharge. Through the two thinner panes the generated eddy-field was strong enough to ionize the Argon gas.

One major problem that was figured out during the test was the produced Joule heat by the electric current inside the coil. Since the coil is housed inside the ferrite pot-core a heat-accumulation appears. The worst case was the melting of the isolating coat of the coil wire that leads to an electrical bypass. The coil wire needs to have a minimum diameter to prevent the increasing of heat by decreasing of resistivity. On the other hand, the more windings of a coil are placed inside the pot-core the higher is the strength of the generated eddy-field. Hence, it has to be regarded a proper balance of maximization the field strength and minimization the heat production to find an effective coil wire diameter.

References:

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[3] D.Kirmse:"On the microscopic mechanism of ion-extraction of a gridded ion propulsion thruster"; Dresden 2013; http://arxiv.org/abs/1312.5629