Research Institute of Applied Mechanics and Electrodynamics MAI (RIAME MAI)

RADIO-FREQUENCY ION THRUSTER WITH MAGNETIC PROTECTION OF THE DISCHARGE CHAMBER WALLS

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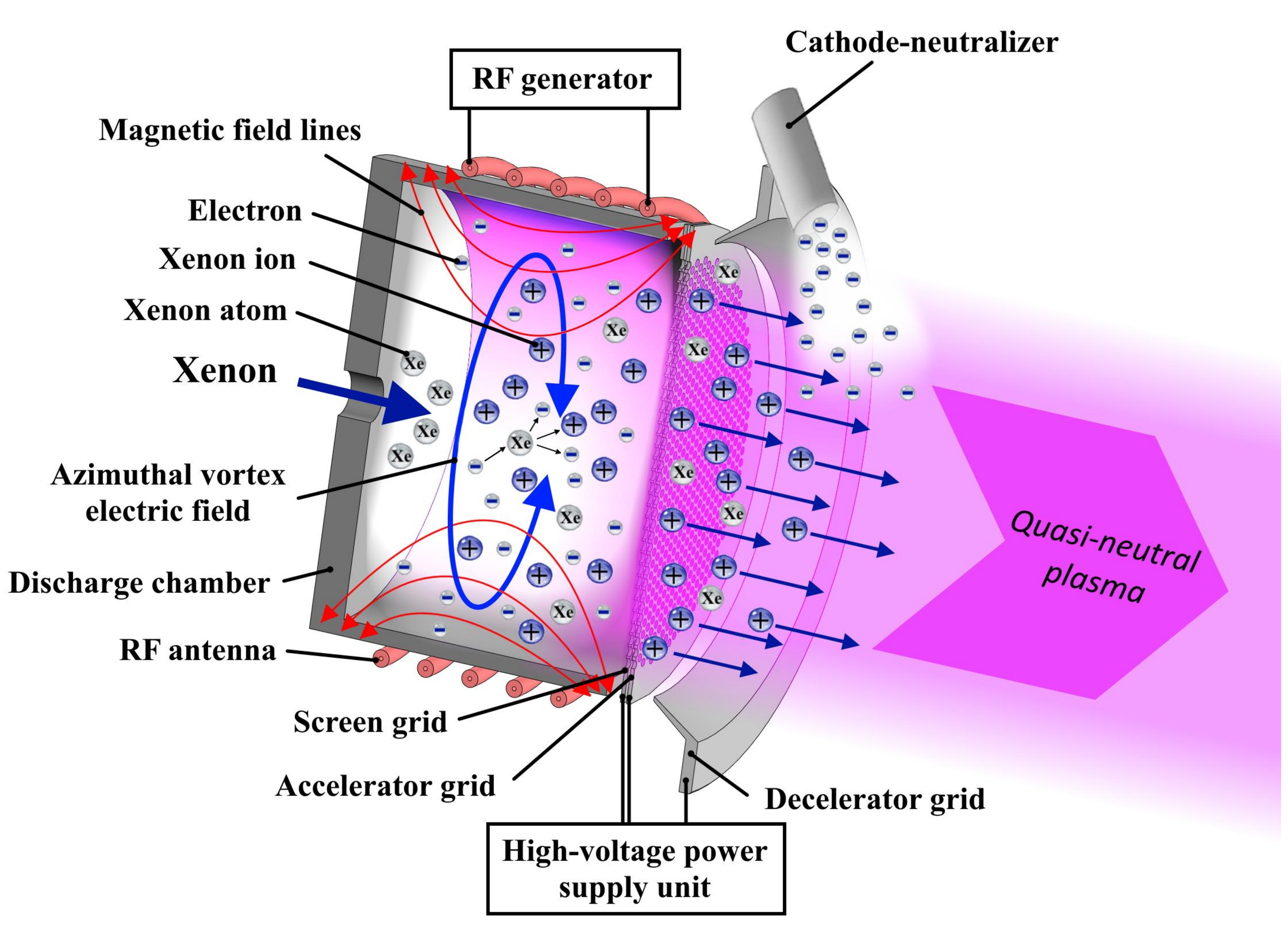
The computational studies to optimize of the shape of the main elements of a radio-frequency ion thruster (RIT) - the discharge chamber (DC) and the ion-extraction system (IES) grids, as well as to assess the possibility of further improving the integral characteristics by using an additional magnetostatic field (MF) in the RF region discharge, were carried out using an engineering physical and mathematical model. The calculations were carried out for one of the currently relevant standard sizes of thrusters with an ion beam diameter of 80 mm. The results obtained in this work can be used to improve the existing RIT models, which will increase their energy efficiency.

Schematic diagram of the RF ion thruster



Main assumptions of the mathematical model:

- the ions recombination in the volume of the DC is not taken into account;
- energy in plasma is transferred only due to mass transfer;
- the condition of plasma quasi-neutrality is preserved in the entire DC volume;
- the behavior of electrons and ions is considered in the liquid macroscopic approximation;
- the capacitive component of the discharge is not taken into account;
- processes in the near-wall layer are not considered;
- the electron energy distribution function corresponds to the Maxwellian.

Five related tasks are solved to find:

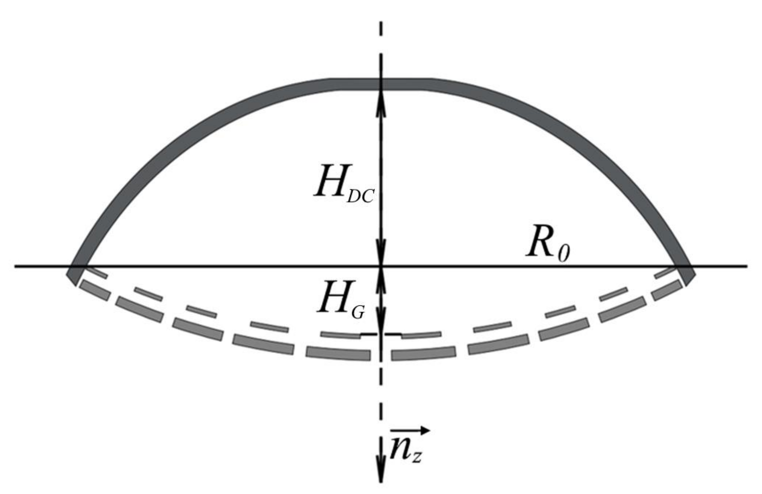
- distribution of the electromagnetic field;
- distribution of an additional magnetostatic field;
- distribution of the concentration of propellant atoms;
- distribution of the charged particles concentration;
- integral characteristics.

For the solution, the Nelder-Mead optimization method is used.

Initial data:

Xenon mass consumption - $\dot{m}$;
Current frequency on the RF antenna - f_{RF};
Current strength on the RF antenna - I_{ant};
The temperature of the surface of the DC inner wall – T_w;
Screen grid transparency – σ_{SG};
Accelerator grid transparency – σ_{AG}.

Parameter	Value
Ion beam diameter, cm	8
Propellant	xenon
Propellant consumption, mg/s	0,3
RF power put into the discharge, W	75
Current frequency on the RF antenna, MHz	2
Screen grid transparency	0,7
Accelerator grid transparency	0,4



Geometric parameters of the discharge chamber and ion-extraction system

DC relative height:

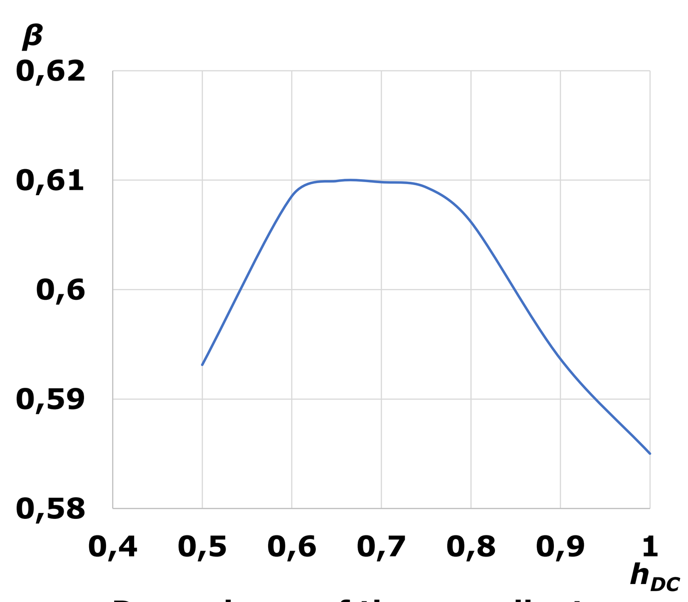
$$h_{DC} = H_{DC}/R_0$$

Relative IES grid deflection:

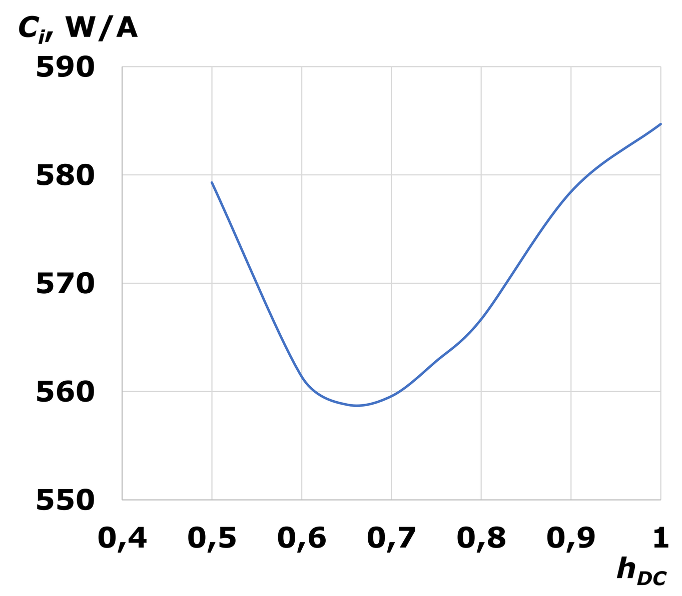
$$h_G = H_G/R_0$$

Effective thrust:

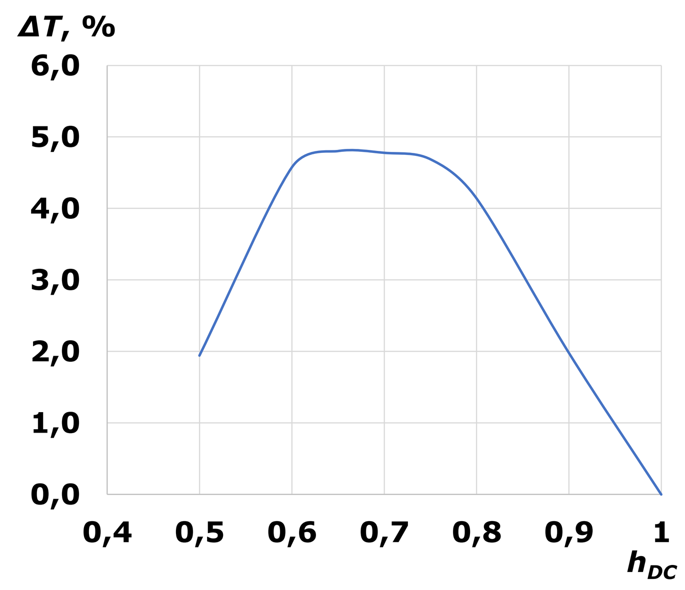
$$T \sim \iint_{S_{IES}} (\vec{j_B}, \vec{n_z})\, d\sigma$$



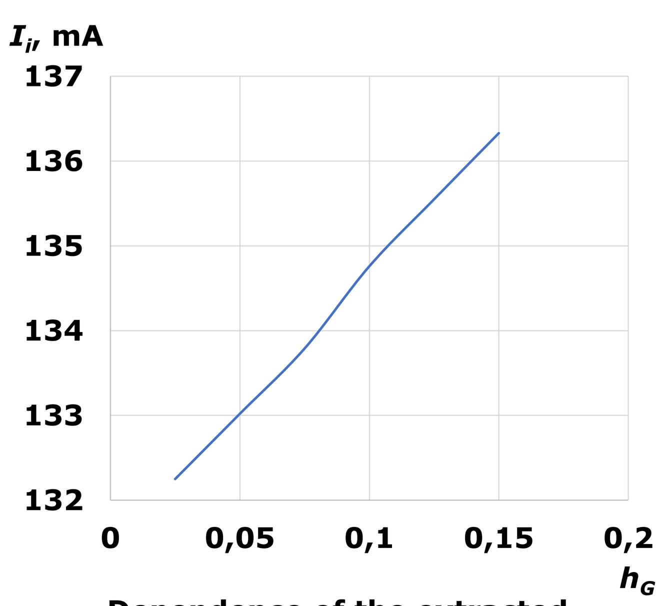
Dependence of the propellant utilization factor β on h_{DC}



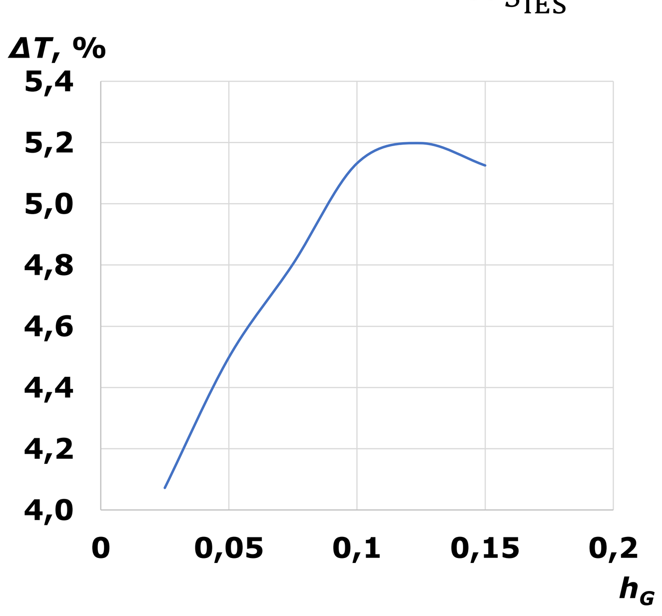
Dependence of the ionization cost C_i on h_{DC}



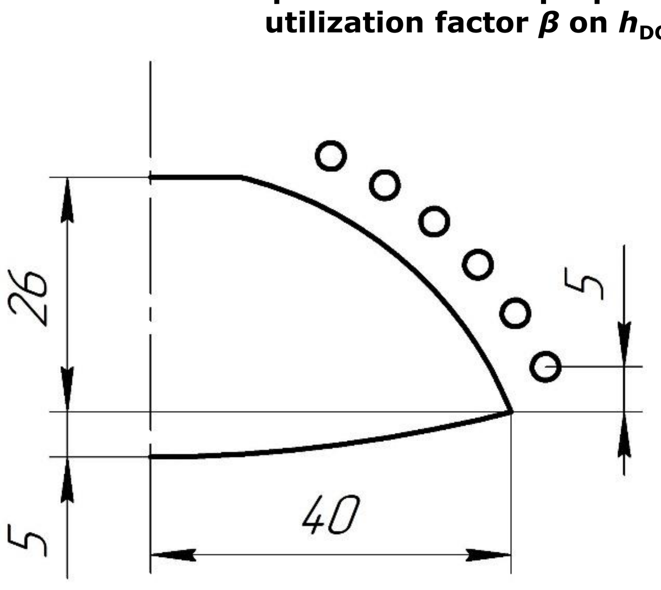
Dependence of the increase in effective thrust on h_{DC}



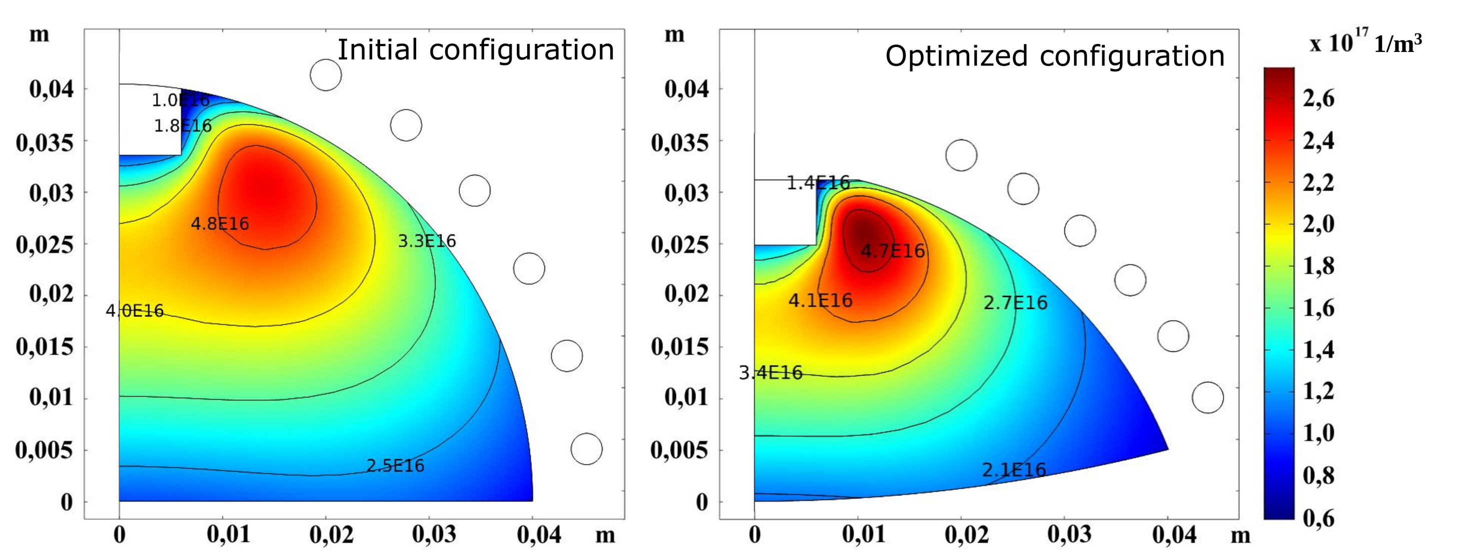
Dependence of the extracted ion current I_i on h_G



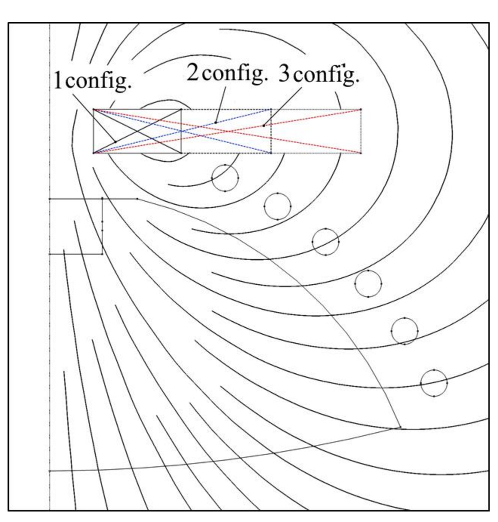
Dependence of the increase in effective thrust on h_G



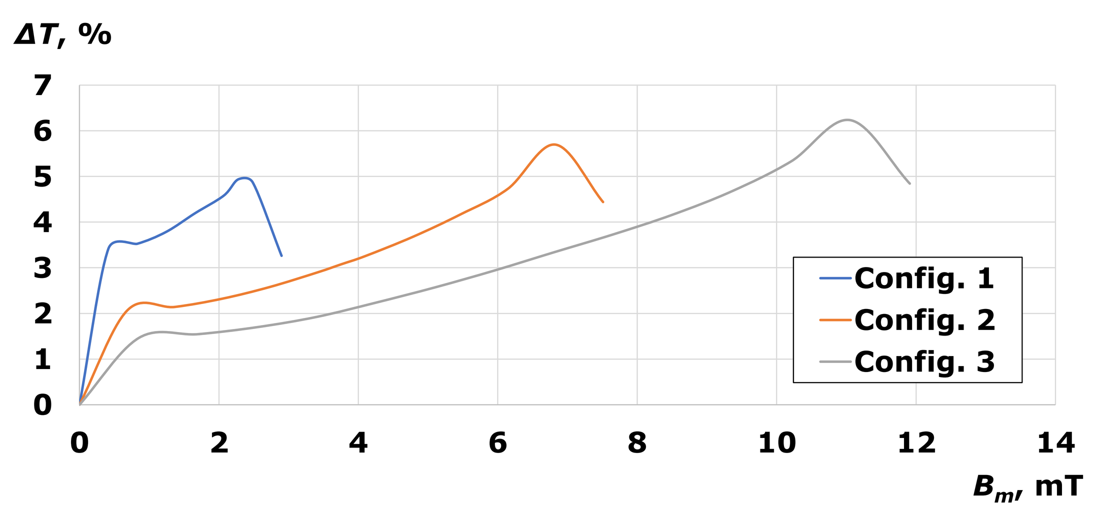
Optimized geometry of DC and IES grids



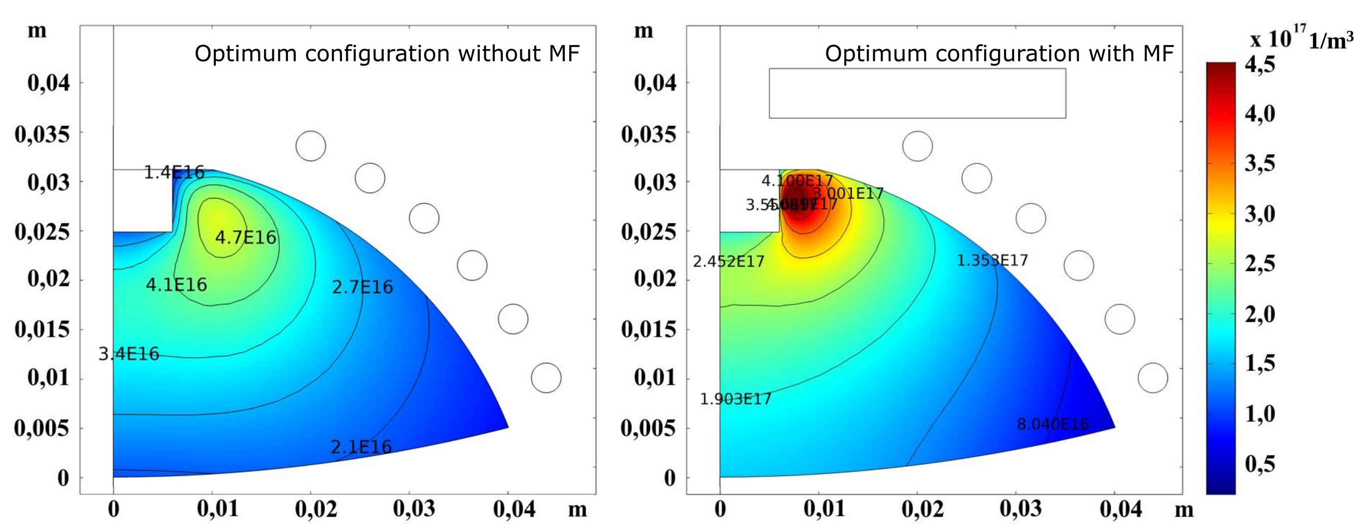
The charged particles concentration



Considered additional winding configurations



Dependence of the increase in effective thrust on the average induction of the additional magnetostatic field over the DC RIT B_m



Charged particles concentration in the absence and in the presence of an additional magnetostatic filed

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1. As a result of the theoretical studies carried out for RIT with a beam diameter of 80 mm, the optimal shapes of the DC and IES grids were determined. According to the calculations for this standard size of the RIT, the DC relative height is 0.65 and the relative deflection of the IES grids is 0.125. The expected increase in thrust with this configuration reaches 5.2%.
2. The study of the effect of an additional magnetostatic field in the region of the RF discharge on the RIT integral characteristics showed that the greatest increase in thrust, which reaches 6.2%, can be obtained when using the field configuration with the lowest radial induction gradient in the DC (winding configuration No. 3).
3. According to preliminary estimates, the use of the proposed methods for improving the RIT efficiency can increase the thrust by almost 12% in total compared to the traditional thrust configuration with a hemispherical DC and flat IES grids.