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Numerical simulation of temperature deformation for radio frequency ion thruster electrodes

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Abstract

An ion-extraction system (ISE) assembly is the most complicated unit of an ion thruster (IT). The IES electrodes made as thin-walled dished grids are subject to non-uniform radial heating. This is accompanied by grid deformation. An IES assembly should provide the stability of the interelectrode gap with strict tolerances. To investigate the influence of the grid form (a value of initial deflection) on the thermal deformation (thermal deflection) the behavior of a screen (SG) and accelerated (AG) dished grids has been simulated for different compatible materials and geometry as follow:

- SG: thickness is 0.3-0.7 mm; diameter is 160 and 450 mm for molybdenum alloy, titanium alloy, carbon-carbon composite materials;
- AG: thickness is 1.0-2.5 mm; diameter is 160 and 450 mm for titanium alloy, carbon-carbon composite materials.

ANSYS software has been used for numerical analysis. For every combinations of materials and geometries there has been an initial form providing the thermal deformation in the ordered limits. The results of ANSYS analysis are compared with the dates received by a simplified algorithm giving a significant saving of time for calculation.

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Keywords: ion thruster; ion extraction system; perforation; deflection; construction orthotropy; temperature load; temperature deformation; thermal-mechanical model.

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Nomenclature

ρ_a	dimensionless radius of inner contour
k_0	auxiliary dimensionless parameter
λ_3	dimensionless loading parameter
w	additional deflection of grid
w_0	initial (technological) grid deflection
u	radial displacement of spherical panel
k_r	coefficient of constructive orthotropy in the cylindrical section
k_φ	coefficient of constructive orthotropy in meridian section
h	thickness of spherical panel
b	radius of external contour of spherical panel
ρ	dimensionless current radius of spherical panel
ξ	dimensionless additional deflection
ϑ	dimensionless initial (technological) deflection
$\lambda_{3,kp}$	critical value of dimensionless loading parameter λ_3
α	coefficient of thermal linear expansion
μ	Poisson coefficient
E	elasticity module of grid material
ΔT_r	temperature gradient along the grid radius

1. Methods

The thermoelasticity equations for a structurally orthotropic modeling plate of circular shape or spherical segment providing improved thermostability and prescribing unidirectionality of deformation have the following forms [7, 8, 10]:

$$\varepsilon_{rz}(r,z)=\frac{1}{E(r)}\cdot\left[\sigma_r(r,z)-\mu\cdot k_\varphi(r)\cdot\sigma_\varphi(r,z)\right]+\alpha(r)\cdot T(r,z) \tag{1}$$

$$\varepsilon_{\varphi z}(r,z)=\frac{1}{E(r)}\cdot\left[\sigma_\varphi(r,z)-\mu\cdot k_r(r)\cdot\sigma_r(r,z)\right]+\alpha(r)\cdot T(r,z) \tag{2}$$

The equation for the deformation compatibility is:

$$\frac{d}{dr}\left(\varepsilon_\varphi\cdot r\right)-\varepsilon_r+\frac{1}{2}\cdot\left(\frac{dw}{dr}\right)^2+\frac{dw}{dr}\cdot\frac{dw_0}{dr}=0 \tag{3}$$

where $\alpha(r)\cdot T(r,z)$ is the thermal load.

Equilibrium equations for the chosen element in view of the grid initial deflection w_o have the following form [6, 9, 11]:

$$\frac{d}{dr}\left(r\cdot N_r\right)-N_\varphi=0\,; \tag{4}$$

$$\frac{d}{dr}\left\{r\cdot\left[Q_r-N_r\cdot\frac{d(w+w_0)}{dr}\right]\right\}=0\,; \tag{5}$$