Start-up and parasitic modes analysis in TE_{31} cavity resonator

D. D'Andrea[1], A. Malygin[1], J. Jelonnek[1], S. Kern[1], R. Schneider[1], A. Stock[2], J. Neudorfer[2], C.-D. Munz[2]

[1] *Institute for Pulsed Power and Microwave Technology, Karlsruhe Institute of Technology, Karlsruhe, Germany*

[2] *Institute of Aerodynamics and Gasdynamics, University of Stuttgart, Stuttgart, Germany*

Introduction

Gyrotrons belong to the family of coherent millimetre-wave sources, and are capable of producing high power operation ranging from short pulse to continuous wave at microwave and millimetre wavelengths for various technological, scientific and industrial applications, like electron cyclotron resonance heating in thermonuclear fusion reactors, high power communications, industrial heating and material processing etc.. In order to evaluate a new type of controlled-porosity reservoir emitter, a 10kW/28GHz gyrotron has been designed. For cavity profile optimization a self-consistent single-mode code was used. For the cavity design we selected two modes at the second harmonic of the cyclotron frequency: $TE_{1,2}$ with the cavity radius 9.08 mm and beam radius 3.13mm and $TE_{3,1}$ with the cavity radius 7.16 mm and the same beam radius as for the $TE_{1,2}$ mode. Main spurious mode is the $TE_{1,1}$ mode on the first harmonic of cyclotron frequency. In order to suppress generation of this mode, the proper profile of the magnetic field had to be chosen. For multi mode non-stationary start-up calculations of the gyrotron resonator, the HALO-PIC code was used. The HALO-PIC code is a novel, highly flexible, high-order tool developed in the frame of a co-operation between the Institute of Aerodynamics and Gasdynamics, University of Stuttgart, Stuttgart, Germany and the Karlsruhe Institute of Technology, Institute for Pulsed Power and Microwave Technology, Karlsruhe, Germany for the numerical solution of the Maxwell-Vlasov equations (MVE) in six-dimensional phase space [3] without the use of any physical approximation. The numerical solution of the MVE in six-dimensional phase space is achieved through a Particle-In-Cell (PIC) approach [1, 5]. The Maxwell solver is based on discontinuous Galerkin (DG) methods which allows for polymorphic grid cell arrangements [2] and for, in principle, arbitrary high-order accuracy in both space and time. Additional numerical accuracy is provided adopting divergence cleaning technique [3]. Finally, particles are advanced in the new phase space coordinates solving the law of classical Newtonian mechanics, with a low-storage explicit Runge-Kutta method [4]. This work and its results represent a new frontier in the exploitation of HALO-PIC potential: conceived as research code, it shows here how it can be applied as design and/or verification code in case of relatively small devices.

Self-consistent single-mode simulations

In order to make optimization of the cavity profile in case of $TE_{1,2}$ and $TE_{3,1}$ cavity a self-consistent single-mode code has been used. As a first assumption we took a constant magnetic field along the cavity profile. Fig.2a shows efficiency versus magnetic field calculated with the self-consistent single-mode code for the $TE_{1,1}$ (first harmonic) and $TE_{1,2}$ (second harmonic) modes. One can see that from B=0.424T there is a transition from $TE_{1\ 1}$ forward wave, to the backward wave. For the sake of clearness, we specify here that forward means propagation of the mode to the direction of the output window, while backward wave means the microwave power of the mode is radiated to the gun region. In addition, one can see that at the region of the $TE_{1,2}$ generation there is also the presence of a $TE_{1,1}$ backward wave.

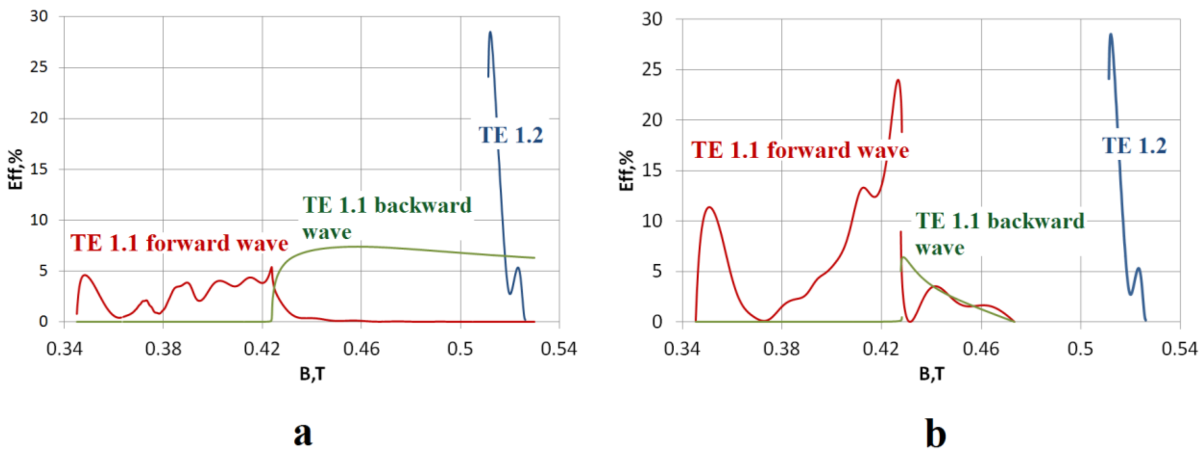

Fig. 2 Dependence of the efficiency for the modes $TE_{1,1}$ and $TE_{1,2}$ vs. maximum value of the magnetic field, in the case of (a) – constant magnetic field; (b) – magnetic field with tapering.

Introduction of the tapering of the magnetic field (Fig. 3) decreases the excitation zone of the mode $TE_{1,1}$ and as one can see from Fig.2b mode $TE_{1,1}$ already does not exist at the zone where the $TE_{1,2}$ mode is excited. In contrast with the $TE_{1,2}$ cavity calculations, calculations of the $TE_{3,1}$ cavity showed that magnetic field with tapering cannot help to suppress $TE_{1,1}$ mode.

HALO-PIC code calculations

Already during the optimization of the $TE_{3.1}$ cavity, HALO-PIC results confirmed that if $TE_{1,1}$ mode is present at $TE_{3,1}$ excitation zone, due to the bigger coupling factor of $TE_{1,1}$ will suppress $TE_{3,1}$. HALO-PIC was also involved in the design of the $TE_{1,2}$ cavity: In order to catch the desired mode, the magnetic field profile was tapered and the energy of the beam was increased stepwise (5 steps, 50ns long each) from 17 KeV to the nominal value of 20 KeV.

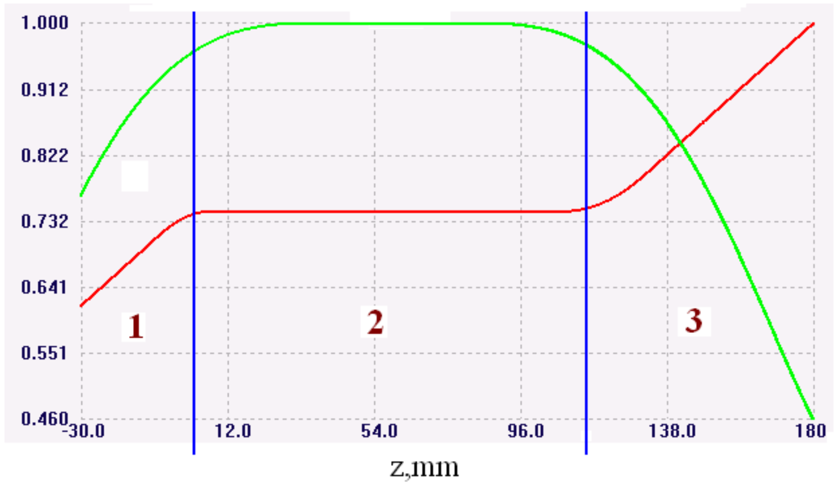

Fig. 3 - red line - cavity profile ((1) - down-taper, (2) - constant part, (3) - up-taper); green line - magnetic field profile with tapering.

The resonator was discretized with ~32000 tetrahedrons, the field and particle solvers are set to 4th order of approximation and the calculations were performed on 128 processors. The results presented In Fig. 4 show the B_z pattern at 150ns, corresponding to a beam energy of 18 KeV. Due to resources constraints, it is not possible to show at the present time, the fields profiles at the end of the foreseen start-up script. Nevertheless some considerations can be drawn: The value of B_z is still very low as expected from single-mode calculations, which predict that the excitation of the desired $TE_{1,2}$ mode should start around 18.5 KeV. However, at this stage, it is not possible to recognize that a particular mode is clearly excited. More accurate results will be published soon.

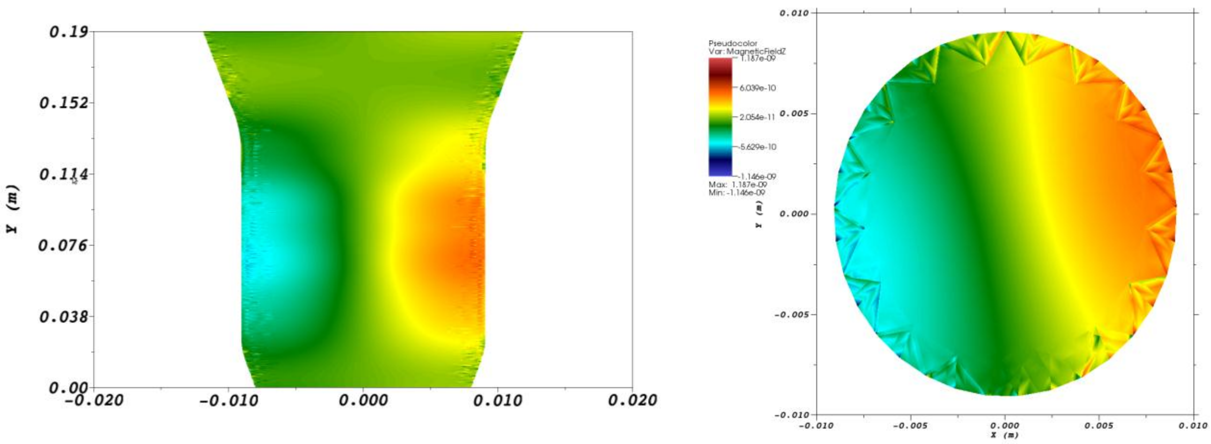

Fig. 4 - B_z field profile in the XZ (left) and XY (right) cross section of the $TE_{1,2}$ resonator

Conclusions

In order to evaluate a new type of controlled-porosity reservoir emitter, a 10kW/28GHz gyrotron has been designed. For the cavity profile optimization the self-consistent single-mode code was used. Start-up script simulations are being performed with the high-order HALO-PIC code. These simulations for the $TE_{3,1}$ cavity confirmed simulations that were done with single-mode code, and first harmonic $TE_{1,1}$ mode was excited in both cases with tapering and without tapering of the magnetic field. HALO-PIC simulations of the cavity with the main mode $TE_{1,2}$ are in progress.

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