THERMAL SIMULATIONS OF THE BIPERIODICAL ACCELERATING STRUCTURE WITH THE OPERATING FREQUENCY 27 GHZ

Yu.D. Kliuchevskaia, S.M. Polozov National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Moscow, Russia

Abstract

Biperiodical accelerating structure (BAS) represents a system based on disk loaded waveguide (DLW) with π/2 operation mode. The 1 cm band structure will have very compact transverse size. Such characteristics give it perspective to use in medical accelerators. The results of beam dynamics simulation and electrodynamics study was discussed early [1]. It will important to study the BAS electrodynamics taking into account thermal processes in structure and to design the cooling system. It is important because of the high pulse RF power (about 1.5 MW) necessary for the beam acceleration. The simulation results which are defined using CST code will presented in report. Calculation and definition of the thermal coefficient depending on speed, temperature and the water flow direction will make.

INTRODUCTION

Many medical applications need to design a compact electron accelerator. Compactness of accelerating structure can be reached by increase of the accelerating RF field frequency (frequency ranges of 6, 10 GHz are widely used and 17 and 30 GHz are also possible). Besides these accelerating structures demand lesser RF-power due to smaller internal volume and surface area. The effective medical accelerators operating on S-and H-bands are well-known [2-4]. The design of 17 GHz linear accelerator was offered [5]. BAS represents a modified structure on the π/2 mode in which case the accelerating cells length increase and coupling cells length decrease. The main aim of simulation was geometry definition providing the operating frequency 27 GHz. General view of the accelerating structure is shown in Figure 1. As a result of tuning the cell geometry with optimal characteristics was defined and they are presented in Table 1.

Table 1: Optimal parameters values of the BAS

Parameter	Value
Operating mode	π/2
Length of accelerating cell, mm	4.5
Length of accelerating system, mm	55
Frequency, GHz	27
Length of wave, mm	10
Radius of the drift tube, mm	4.5
Radius windows coupling, mm	0.8
Radius of the accelerating cell, R_{cell}, mm	8.8
Radius of blending sidewall, R_{lc}, mm	1
Radius of coupling cell, mm	3.8
Length of coupler, mm	50

High power pulse gyrotrons are one of possible power sources types in 30 GHz band. The power system of proposed linac will differ from conventional C-band medical linac therefore gyrotrons can produce the long pulses (hundreds of μs) with low repetition rate. High-efficiency pulse and CW gyrotrons of frequency range 27–30 GHz have been developed at the Institute of Applied Physics of Russian Academy of Sciences. Pulse power reaches to 15 MW at the efficiency of 50 % in gyrotrons with the high operating voltage 500 kV [6]. Accordingly to preliminary estimations based on the gyrotron theory and experimental results pulse and average power of the order the gyrotron is capable of producing 2 MW peak RF power in pulses with pulse duration 400 μs and a repetition rate of 10 Hz.

The combination of high electromagnetic fields and long RF pulse in resonators on operating frequency leads to temperature increase on the surface, to thermal deformations and to noticeable change the resonator characteristics during the RF pulse [7]. The thermal analysis was performed for such structure due to. Thermal calculations to define the frequency shift depending on temperature of cooling liquid were done.

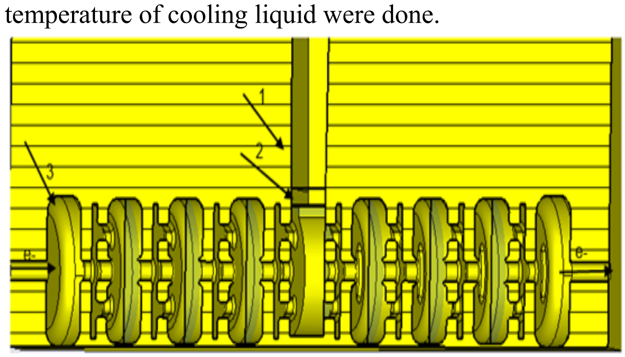

Figure 1: General view of the accelerating structure, 1 – coupler, 2 – power feeding waveguide, 3 – regular accelerating cell.

COOLING SYSTEM FOR BIPERIODICAL STRUCTURE AT 27 GHZ

The simulation of BAS thermal characteristics was done using the model consisting of one accelerating cell and one coupling cell operating on frequency of 27 GHz. The geometry of the BAS cell is shown in Figure 2. The copper BAS based on the DLW with magnetic coupling was studied, it operates on the standing wave. The high operating frequency 27 GHz is the feature of this structure

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which is much higher than the standard frequency used for electron accelerators (2856, 2898 or 5712 MHz).

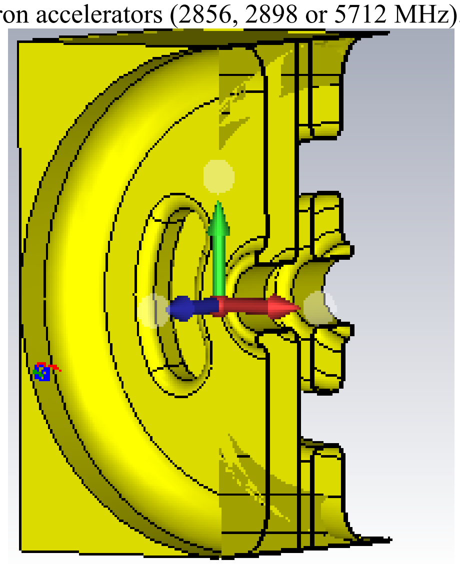

Figure 2: The geometry of the BAS cell, the shell material – copper.

The influence of pulse high-frequency heating effects for accelerating structure with magnetic coupling both negative dispersion and rejecting structure with bores in walls of cells was investigated, the methodology was described in [8]. Modeling was performed using the three-dimensional electrodynamics code CST STUDIO SUITE [9].

Eight water tubes oriented along of the BAS and spaced radially from cells were added to the model (see Fig. 3). The diameter of tubes is equal to 8 mm.

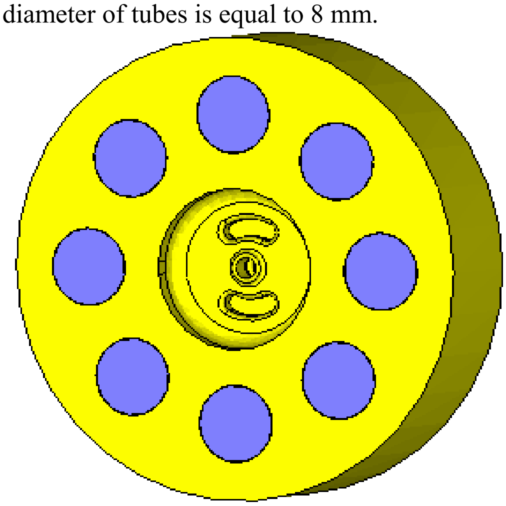

Figure 3: View of the BAS cell with cooling system.

Adiabatic boundary conditions were used at all structure cell's walls before start of the thermal analysis. The water temperature in the cooling tubes was defined equal to 20 C.

Microwave power losses in structure wall's were defined with:

$$P = \frac{\omega W}{Q} \tag{1}$$

where ω – frequency, W – storaged energy, Q – Q-factor.

The calculation of a water flux is one of important aims at developing of cooling system also. It is determined by the equation:

$$G = U\pi d^2 \tag{2}$$

where U – liquid of the velocity, d – diameter of the tube.

Thermal analysis of structure includs continuous process of structure heating simulation and it's cooling by water flux study. As it was defined by electrodinamics simulations that the value of pulse power loses in structure walls are equal to 1.05 MW. Average power loses are equal to 2.7 kW per one period with pulse length 400 µs and pulse repetition 10 Hz.

Distributions of frequency shift and maximal temperature in structure versus water flux are presented in Figures 5-6. It was shown that water flux should be equal to 0.33 l/s for one channel to limit the maximum temperature into the cell by 34 °C. The frequensy shift is negligible with such temperature in the structure. The temperature distribution in structure with water flux and temperature of 0.3 l/s and 34 °C accordingly is shown in Figure 7. At the obtained parameters the maximum temperature in structure reaches 40 °C and gives the frequency shift of 290 kHz down.

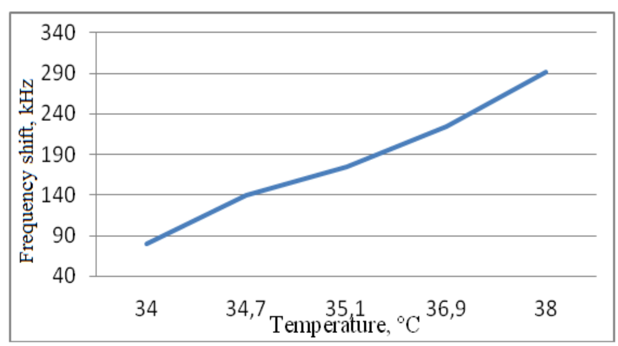

Figure 4: Frequency shift versus on temperature.

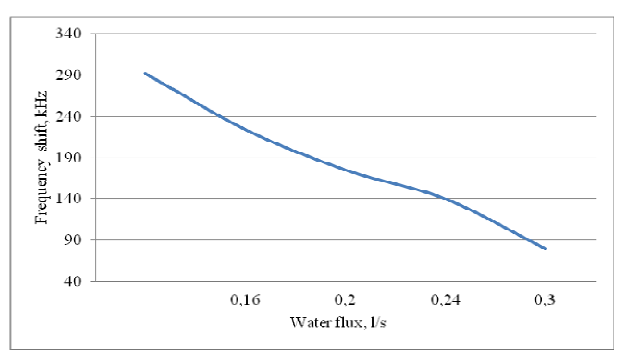

Figure 5: Frequency shift versus of water flux.

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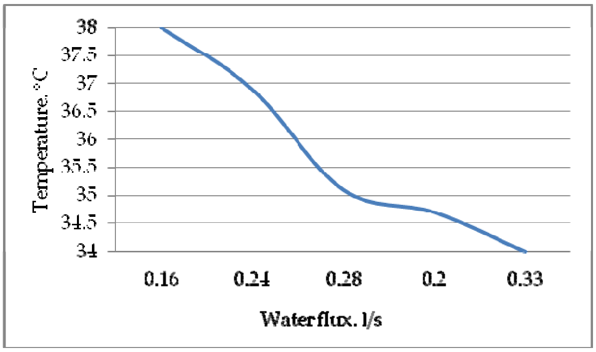

Figure 6: Maximal temperatue versus of water flux.

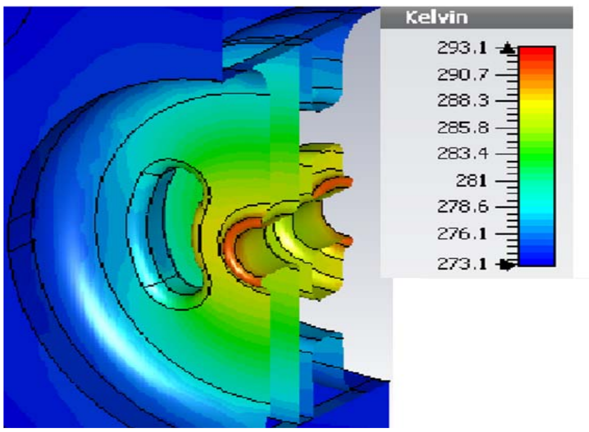

Figure 7: The view of the BAS section and temperature distribution ,water flux equal 0.3 l/s.

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CONCLUSION

The BAS was designed and tuned on 27 GHz operating frequency. The optimal geometrical parameters of the BAS necessary for π/2 mode were defined by means of accelerating and coupling cell tuning. The high power gyrotron was discussed as a perspective power source on 27 GHz. Numerical simulations of accelerating structure thermal characteristics were carried out. By the results of thermal calculations necessary parameters of cooling system were defined to limit the maximal temperature by 34 °C in which case the frequency shift is negligible. Liquid flux value should be equal to 0.33 l/s per each cooling tube and the frequency shift will limited by 80 kHz in this case.

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