S-BAND PS PULSE PHOTOINJECTOR FOR THZ RADIATION SOURCE

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Abstract

S-band photoinjectors with ps pulse are becoming promising as e-guns for high-intensity sub-mm wavelength pulse source. The development of the accelerating system for photoinjector with ps bunch is reported. The main aim is to develop a model of accelerating structure that provide high accelerating gradient with respect to high electric strength and low RF power uses. The accelerating structures consisting of 1.6 cell of disk-loaded waveguide (DLW), 3 cells and 2 half-cells of DLW, 7 cells and 2 half-cells of DLW and accelerating structure based on travelling wave resonator (TWR) with 7 cells and 2 half-cells of DLW are studying. The resonant models of these structures and the structures with power ports were designed. Electrodynamics characteristics, electric field distribution for all models were acquired. The accelerating structure consisting of 1.6 cells will operate in π mode of standing wave; all other structures operate in π/2 mode of traveling wave. Accelerating structure based on traveling wave resonator with 7 cells and 2 half-cells of DLW has most suitable electrodynamics characteristics and field distribution for ps-band photoinjector according to simulation results.

INTRODUCTION

The design of new generation of introscopy facilities is one of possible needs of photo guns. One of such facility based on Cherenkov or Smith-Parcell radiation given by short electron bunch with MeV energy and especially decelerating system was discussed in [1]. The radiation in ps and sub-ps bands can be generated using this scheme.

A photoinjectors main operation principle is based on next terms: short bunches of electrons are generated by laser pulses from the cathode located on the sidewall of RF accelerating structure. An accelerating structure provides high electrical gradient to make electron bunch relativistic at small acceleration trajectory. The bunch energy required for high-intensity sub-mm wavelength pulse source must be about 1-4 MeV. Optimal structure employed for acceleration of electrons in MeV range is DLW. At this point in time the majority of photoinjectors is based on 1.6 cells of DLW and operates in standing wave mode. It was interesting to compare electrodynamics characteristics of 1.6 cell system and travelling wave systems to investigate the possibilities to product more effective photoinjector with low electrical breakdown probability and high output energy of electrons with respect to lower requirements to the RF power system.

MODELING OF STRUCTURES

Standing Wave Structure

The acceleration system consisting of 1.6 cell simulations was performed on S-band RF frequency 2856 MHz. The recess of half diaphragm width was made in sidewall of full cell in order to calculate the model correctly. Zero and π modes of RF field are excited in this structure, π is the operating mode. The structure is characterized with positive normal dispersion. The resonant frequency of the structure was tuned to the desired value by means of cell radius variation. 1.6 cell photoinjector's electrical field strength is commonly around MV/m, fields of such strength can initiate electrical breakdown in the area near the iris where the electrical field intensity is comparable with the field along axis. Iris profile can be made rounded to eliminate the possibility of breakdown. The ratio of iris window to the wavelength was set to 0.1. This value is a trade-off between the wish to get maximum amplitude of accelerating field and except of the probable beam loss on the iris. Performance of the structure was also increased by rounding of shells edges. Rounding radius value was chosen to provide the highest possible shunt impedance and Q-factor.

The structure power supply is performed similarly to BNL Gun I photoinjector, i.e. standard S-band 34x72 mm cross-section waveguide was connected to the full cell through the coupling diaphragm [2]. The output of high order modes is connected symmetrically to the RF power input for better coupling and also to reduce the electromagnetic field asymmetry [3]. The output of high order modes is designed in form of the evanescent waveguide. The waveguide's cross-section matches sizes of coupling diaphragm. General view of the accelerating structure with RF power input and output of high order modes is shown in the Figure 1.

The full cell with RF port and high order modes output is a mode converter of this accelerating system. The mode converters tuning includes the coupling of supplying waveguide to the full cell and the coupling of full cell with half cell. The RF power input matching to the structure was performed: the lowest reflection coefficient from full cell to the RF port was achieved on the operating frequency of the structure. The electromagnetic field misbalance in cells was eliminated by means of half cell to full cell radius ratio value optimization. The accelerating field magnitude distribution along of the longitudinal axis of the structure is shown in the Figure 2 in case when 1 kW of RF power feeds to the port. Mean value of the accelerating field magnitude is equal to 312.3 kV/m here.

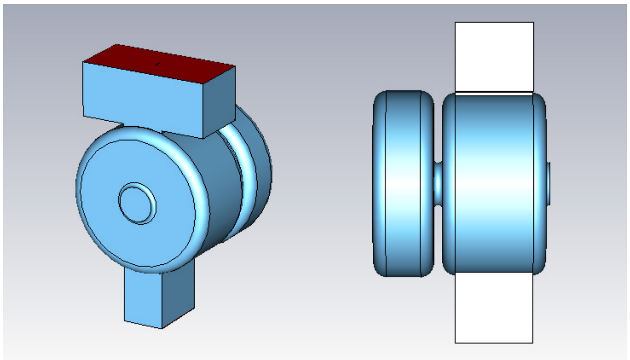

Figure 1: General view of 1.6 cell accelerating system

Traveling Wave Structures

The model of accelerating structure with 3 full cells and 2 half-cells was simulated analogous to the previous structure. This structure was tuned to the π/2 operating mode on the frequency 2856 MHz, π/2 was chosen as the operating mode because it has the high linear shunt impedance rate and the maximal frequency separation between adjacent modes. The iris width, iris window's radius and shell ring's rounding radius were equal for all structures to make the comparison of traveling and standing wave structures more correct. This structure operates on traveling wave mode, so the structure must include RF power output. RF input and output are connected to the half cells. As the half cells length is shorter than the supplying waveguide's smaller side, the power is fed and put out using the waveguide cross-section change. The output of the high order modes was connected symmetrically to the RF power input and output similarly to the previous structure. The outputs of high order modes are designed in form of evanescent waveguide that are replicates the power input and output with width equal to the larger side of coupling diaphragm.

During the modeling process it was shown that the structure consisting of 3 cells and 2 half-cells appeared unable to provide the necessary level of accelerating field. That can be easily explained because the traveling wave mode have a half of amplitude of RF field achievable for standing wave. To achieve the necessary energy, the length of the structure was increased twice and therefore the system consisting of 7 cells and 2 half cells was considered. The accelerating field magnitude distribution along the longitudinal axis of the structure is shown in the Figure 3 in case when 1 kW of RF power feeds to the port. The structure was also tuned to the travelling wave mode. The accelerating field magnitude in adjacent cells differs from each other les then 3% and the phase shift per each cell is 90 degrees as it is clear from Figure 3. The mean value of the accelerating field magnitude is 103.8 kV/m.

Traveling Wave Resonator

Next improvements of this system were held and converse it into the so called travelling wave resonator (TWR). TWR based accelerating system consists of travelling wave structure with rectangular waveguide connected between RF input and output (Figure 4). The power is fed into the structure through the directional coupler (Figure 5). If the length of the TWR circuit equals to the full number of generator wavelengths, the magnitude of electromagnetic fields in TWR reaches its maximum and magnitude of the wave incoming to the load from the waveguide turns to minimum. The difference between TWR and cavity resonators is that in the TWR circuit the wave is traveling instead of standing wave in cavity resonators.

The critical mode is the optimal operation regime of such structure. Part of RF power is fed into the accelerating system through the directional coupler and fills in the power resistance losses in the cells sidewalls in this regime. In this case the part of power that is fed into the port 2 from the circuit is summed with the one from generator in the opposite phase and gives the minimal magnitude signal coming to the load. Two main parameters are determines the efficiency of TWR: the TWR circuit power attenuation factor and the directivity factor of the directional coupler.

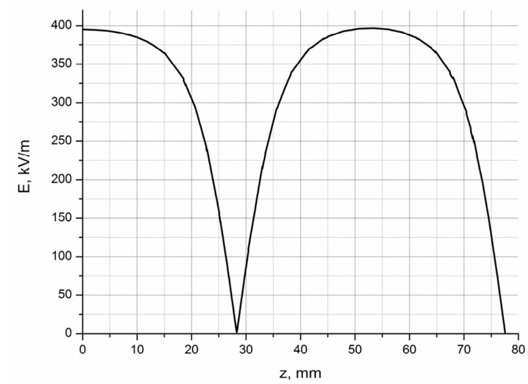

Figure 2: Accelerating field distribution along 1.6 cell structure axis.

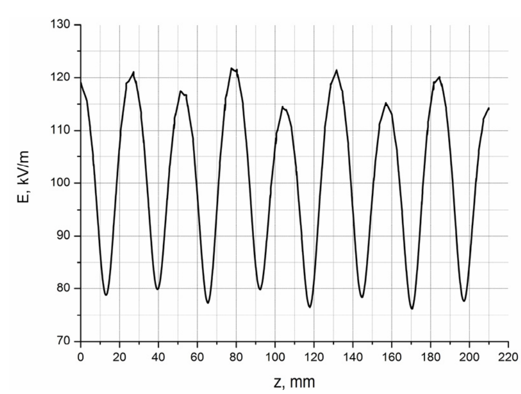

Figure 3: Accelerating field distribution along 7 cell and 2 half-cell structure axis.

The directional coupler with narrow or wide side coupling represents the connection of two waveguides by coupling windows with space shift of quarter wavelength between the windows irradiating in the opposite directions of jointed waveguide. The directional coupler computation included receiving of the required transfer coefficient in the forward direction of jointed waveguide C and simultaneously keeping the transfer coefficient in the opposite direction of jointed waveguide $|P|$ below the certain level.

Taking into account part of the signal branching in the opposite direction and the intensity attenuation factor, the expression for the magnitude of electrical field spreading in TWR compressor can be written as [4]:

$$b_4 = \pm j \frac{1}{\sqrt{1-e^{-2\alpha_T}}} \frac{C}{|P|} a_1, \qquad (1)$$

Here a_1 – RF generator signal intensity magnitude, α_T - TWR ring signal intensity attenuation factor, b_4 - TWR circuit electrical field intensity magnitude.

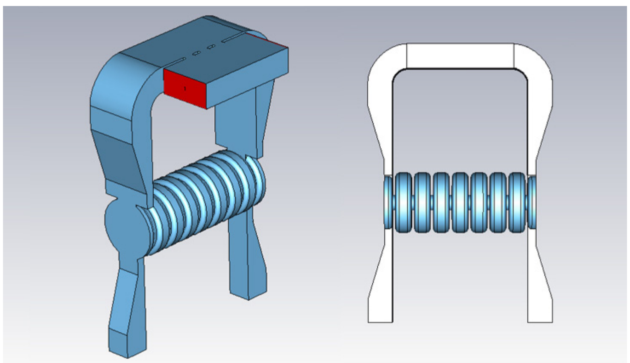

Figure 4: General view of TWR accelerating system.

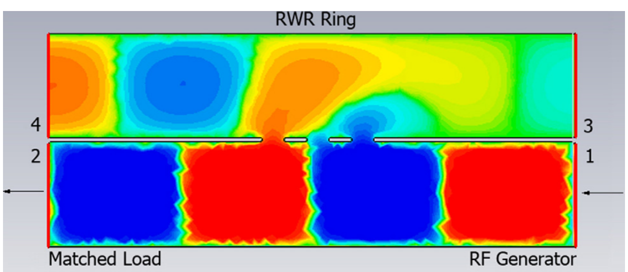

Figure 5: Directional coupler electrical field distribution.

TWR accelerating system modeling primarily was directed to the design of connecting power input and output ports of the system: waveguide bends were attached to the ports. The waveguide bends were computed to provide the minimal possible reflections on the operating frequency. The reflection coefficient of waveguide bends is S_{11}=-32.8 dB after optimization.

Three coupling window model was applied to provide high directivity level of the directional coupler (see Fig. 5). The number of coupling windows enlargement doesn't improve the directivity coefficient. The waveguide coupling was made by using of the rectangular coupling windows located on the narrow waveguide side to eliminate the possible electrical breakdown of waveguide due to small window's sizes. Each coupling window has the corners rounding radius of half spacing between the waveguides. Transition coefficient of directional coupler is $S_{41}=C$=3.9% that equals to TWR ring decay coefficient at the 6.5 mm coupling window width, sidewall width between waveguides is equal to 4 mm. Sidewalls width doesn't have much impact on directivity coefficient. The transfer coefficient in the opposite direction of TWR waveguide equals $S_{31}=P$=-53 dB. Thus directivity coefficient of the directional coupler is D=12.4 dB.

The magnitude of electromagnetic field can be increased three times using TWR comparatively to the ordinary 7 cells and 2 half-cells accelerating structure (or necessary RF power decreased 9 times) at given values of the transition coefficient of directional coupler, the directionality and the decay factor of TWR ring, under the assumption of the equation (1) for the strength of electromagnetic field in port 4 of the directional coupler. The mean value of accelerating field magnitude in case of 1kW input power equals to 321.9 kV/m (see Table 1).

Table 1: Main Parameters of the Models

	1.6 cell	3 cells and 2 half cells	7 cells and 2 half cells	TWR
Operating mode	π	π/2	π/2	π/2
Structure length, mm	77.6	105	210	210
E_{mean}, kV/m (1 kW input power)	312.3	103.8	107.3	321.9
Q-factor	16530	9290	10800	10800
R_{shunt}, MOhm/m	57.9	49.1	54.9	54.9

CONCLUSION

The analysis of electromagnetic characteristics of four models shows that accelerating system based on TWR with 7 cells and 2 half-cells can provides the energy comparable to the 1.6 cells resonant accelerating system with equal values of input power. It allows decreasing of the magnitude of accelerating field and can decrease the possibility of electrical breakdown in the system.

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