RF PHOTOINJECTOR PARAMETERS OPTIMIZATION

T.V. Bondarenko, S.M. Polozov,

National Research Nuclear University (MEPhI), Moscow, Russia

Abstract

Sources of high-power electromagnetic radiation in THz band are becoming promising as a new method of a low activation introscopy. Research and development of accelerating RF photoinjector for THz source are reported. The photoinjector is based on disk loaded waveguide (DLW). Photoinjector consists of two accelerating structures: widespread 1.6 cell DLW structure and travelling wave resonator structure based on 9 cells traveling wave accelerating structure. The resonant models of these structures and the structures with power ports were designed. Electrodynamics characteristics and electric field distribution for all models were acquired. Electrodynamics models were tuned to the resonant frequency of 3000 MHz. Magnetic field coupling between cells of accelerating structure and optimization of the diaphragms sizes were analyzed to enlarge the structures efficiency. Diaphragms windows profiles were optimized to decrease the overvoltage on the windows edges and to eliminate the breakdown possibility.

INTRODUCTION

RF photoinjectors are accelerating structures and electron guns at the same time. The main work principle of photoinjector is based on photoemission electron generation type. Photoinjectors are used is applications that requires femto-picosecond time resolution beam such as free electron lasers that demand short bunches for generation of monochromatic radiation.

One of interesting applied usage of photoinjectors is a source of high intensity THz radiation based on Cherenkov irradiating capillary channel that can be used in the field of cargo introscopy [1]. This source implies travelling of about 5 MeV beam in the capillary with sub-mm transverse sizes.

Such facilities can be used not only in introscopy system as well as in biology, medicine, chemistry, solid state physics, radio astronomy, homeland security, environment monitoring, spintronics, advanced spectroscopy, and plasma diagnostics.

ACCELERATING STRUCTURES

The photoinjector must be formed of accelerating structure with one or two sections for achieving of the demanded beam energy, laser system for beam generation from the photocathode and focusing system for beam shape preserving.

RF power source feeding the photoinjector is based on 2.5 MW pulse power magnetron with 2.995-3.005 GHz working frequency. Hence the accelerating system must be formed of two accelerating structures – standing wave structure emitting and preliminary accelerating the

electron beam and travelling wave structure proceeding acceleration to the final energy.

Accelerating structures geometry was tuned to provide advanced operating mode of the structures and from here to reach the maximum possible efficiency of the structures.
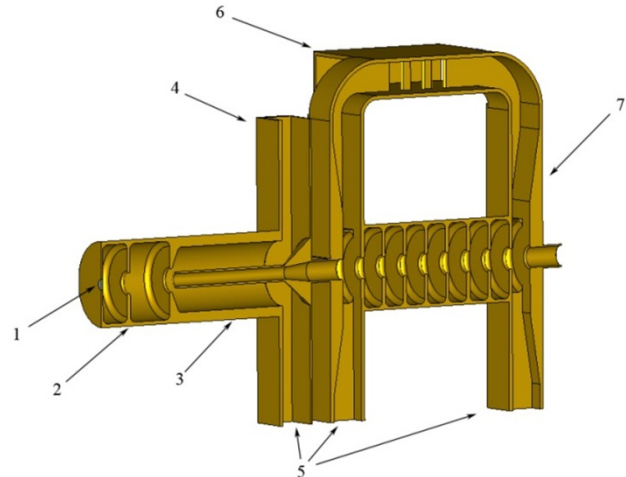

Fig. 1. General layout of accelerating system: 1 – photocathode, 2 – 1.6 cell DLW structure, 3 – coaxial wavetype transformer, 4 – RF power input, 5 – vacuum ports, 6 – directional coupler, 7 – travelling wave resonator structure.

Standing Wave Structure

1.6 cells accelerating structure was computed for 3000 MHz operational frequency. The general view of the accelerating system with MW power port is represented in Figure 2. The photocathode will be arranged in 0.6 cell's sidewall, therefore accelerating field on the sidewall's surface must be as high as possible. That is the reason of making half-cells length equal to 0.6 of full sized cell. Zero and π modes are excited in this structure, mode with $\mu = \pi$ phase shift per cell is the operating mode. The structure is characterized by the positive normal dispersion.

Iris profile was made rounded to eliminate the possibility of breakdown. This was done to reduce the electric field in the window's aperture because of high-rate accelerating fields in 1.6 cells accelerating structure that can lead to electrical 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 probable beam loses on the iris. The structure performance was also increased by rounding of shells edges. The rounding radius value was chosen to provide the highest possible shunt impedance.
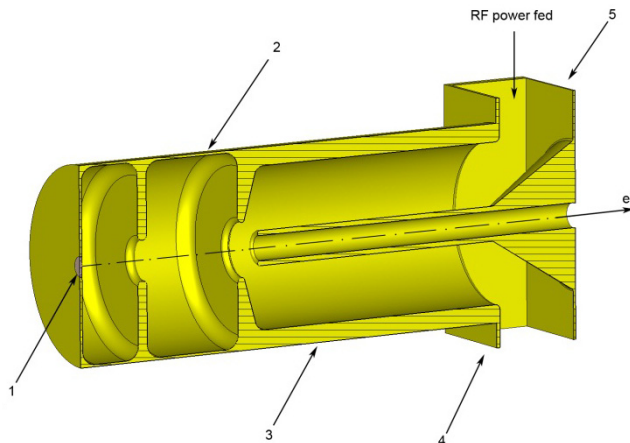
Fig. 2. 1.6 accelerating structure: 1 – photocathode, 2 - resonator, 3 – coaxial wave type transformer, 4 – vacuum port, 5 – power input.
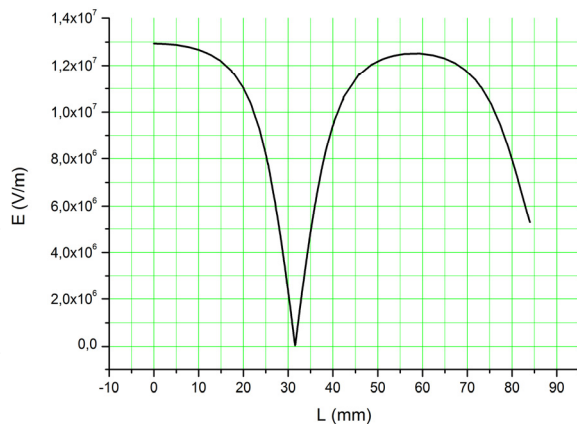

Fig. 3. Electrical field distribution in 1.6 cell structure.

Structure RF power input in organized by S-band standard rectangular waveguide with the coaxial coupler. This type of wave transformer differs from recently used RF power inputs in photoinjectors like ones in BNL Guns [2]. That type was exploiting the scheme of power input through the coupling diaphragm directly into the full-sized cell of the structure in this wise full cell was a wave transformer. RF power is fed into the structure through only one of the connected waveguides; another is used for structure field symmetry and will be applied for vacuum system and other accompanying connections. This scheme provides high level of field symmetry in the system that leads to better quality of the accelerated beam.

Travelling Wave Resonator Structure

Travelling wave resonator is a type of ordinary linear accelerator structure with some additions. Basically the accelerating wave propagating in acceleration structure is travelling wave type but the trait that makes this system a resonator is energy recuperation coming out of interlocking RF power input with output and feeding power with directional coupler (figure 2). If the length of the TWR circuit is devisable to the generator wavelength,

the magnitude of electromagnetic fields in TWR reaches its maximum and magnitude of the wave incoming to the load from the ring turns to minimum [3].
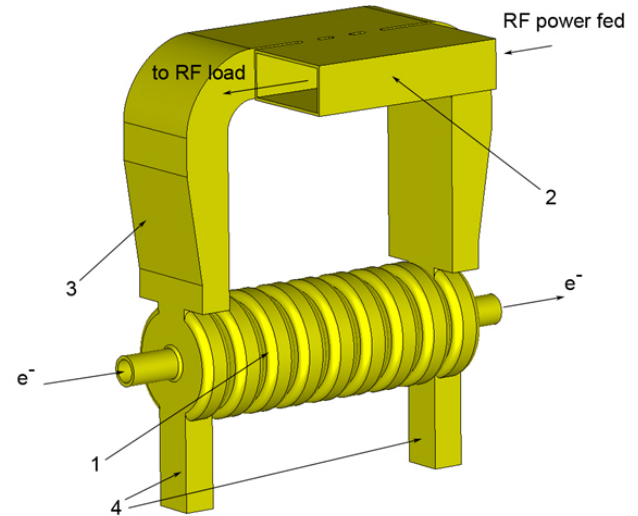

Fig. 4. Travelling wave resonator structure: 1 – accelerating structure, 2 – directional coupler, 3 – TWR ring, 4 – vacuum ports.

TWR is based on 8 cell travelling wave S-band structure with $\pi/2$ operating mode. To enhance the shunt impedance of the structure the magnetic coupling between cells was introduced into the scheme of the structure. Another way applied to increase shunt impedance is to insert a drift tube, which can help to concentrate the electric field near the axis and provide an RF-focusing of the particles [3]. By means of used drift tubes and magnetic coupling windows the shunt impedance of the system was enhanced from 54 MOhm/m to 71 MOhm/m.
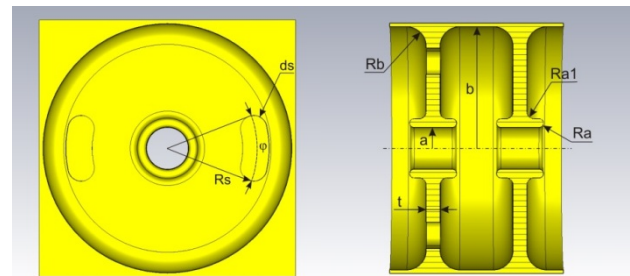

Fig. 5. DLW with magnetic field coupling cells and drift tubes

The optimal operation regime of the structure is critical mode. In this regime part of RF power is fed into the accelerating system through the directional coupler and fills in the power resistance losses in the resonators sidewalls. In this case the part of power that is not branched into the TWR ring is summed with the one from generator in the opposite phase and gives the minimal magnitude signal coming to the load. Two main parameters determining efficiency of TWR are the circuit

power attenuation factor and the directivity factor of the directional coupler.

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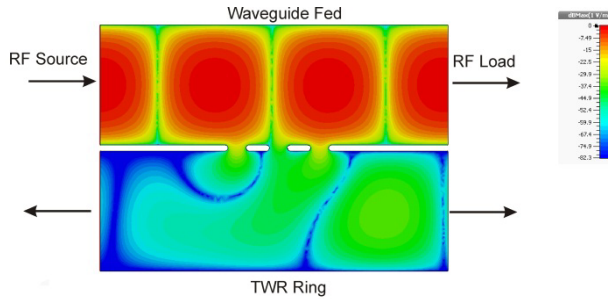

Fig. 6. Directional coupler field distribution in non-steady case.

Three coupling window model was applied to provide high directivity level of directional coupler. Enlarging the number of coupling windows doesn't improve the directivity coefficient.

Taking into account part of the signal branching in the opposite direction and intensity attenuation factor, expression for the magnitude of electrical field spreading in TWR storage ring for critical mode can be written as:

$$A_{TWR} = \pm j \frac{1}{\sqrt{1 - e^{-2\alpha_T}}} \frac{C - |\Gamma|}{C} A_{input}, \qquad (1)$$

here A_{TWR} - TWR circuit electrical field intensity magnitude, α_T - TWR ring signal intensity attenuation factor, A_{input} − RF generator signal intensity magnitude [4].

In considered case transition coefficient of directional coupler *C*=1.71% that equals to TWR ring decay coefficient at the 10.94 mm coupling window width, sidewall width between waveguides is 4 mm. Sidewalls width doesn't have much impact on directivity coefficient but ought to be wide enough to provide coupler ruggedness. Transfer coefficient in the opposite direction of TWR ring equals Γ =-55.5dB. Thus directivity coefficient of directional coupler is *D*=23dB. Using the formula (1) power in TWR multiplies 9 times vs. input power level and field intensity – 3 times vs. input power level.
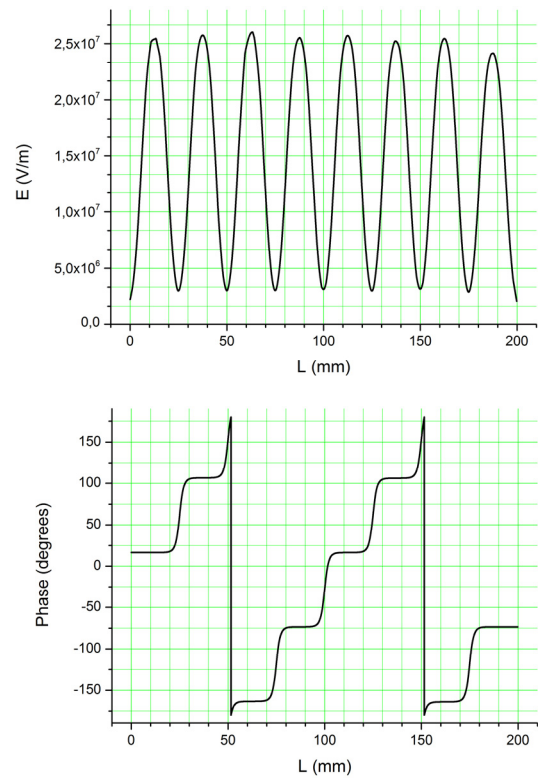

Fig. 7. Travelling wave resonator structure electrical field distribution (upper) and phase distribution (lower).

CONCLUSION

RF accelerating system was investigated and modeled for high-power THz generator. RF accelerating system is based on two accelerating sections: 1.6 cell standing wave structure with coaxial power input and travelling wave section based on travelling wave resonator.

Both structures are fed by 2.5 MW magnetron working on the frequency of 3 GHz. Updates made for the structures include coaxial power input in 1.6 cell structure and drift tubes and magnetic coupling windows in TWR structure. These changes in structures models enlarged the system efficiency.

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