ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-TUPSB44

DESIGN AND SIMULATION OF AN S-BAND RF PHOTOGUN FOR A NEW INJECTOR OF THE ACCELERATOR LINAC-200 AT JINR

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Abstract

A new 1.5-cell 2.856 GHz S-band RF photogun is simulated for the generation of ultrashort electron beams at the Linac-200 accelerator at JINR. The beam parameters at the photogun output are determined to meet the requirements of the Linac-200 injection. The general design of the photogun is presented. The electrodynamic parameters are determined and the accelerating field distribution is calculated. The particle dynamics is simulated and analysed to obtain the required beam properties.

Introduction

Commissioning of a new electron test beam facility Linac-200 [1] comes to the end at JINR (Dubna, Russia). The facility is based on the MEA accelerator that was transferred from NIKHEF to JINR at the beginning of the 2000s. Linac-200 provides electron beams with energy up to 200 MeV, beam current as much as 40 mA. The principal purpose of the facility is providing test beams for particle detector R&D, studies of novel approaches to the beam diagnostics, and training and education of students. Increasing the charge in the bunch from replacement the injector will give the opportunity to use the accelerator as a driver for a source of terahertz, synchrotron, and transition radiation in the soft X-ray range and to study the characteristics of image detectors, drastically expanding the range of available applied.

RF Photogun Concept

The design of the electron injector of the accelerator Linac-200 includes such elements as a triode type DC electron gun with a thermionic cathode, a chopper, a prebancher and a buncher, which is a short section of the accelerating structure designed for bunching a beam. The parameters of the gun and injector of the Linac-200 accelerator are presented in Table 1. The beam charge is 120nC in a 3 us pulse.

Table 1: Linac-200 Accelerator Injector Parameters

Parameter name	Injector	Electron gun
Pulse current, mA	60	200
Output energy, MeV	6	400

It is proposed to replace the existing injector with a 1.5-cells RF photogun with a cathode integrated into the end wall of the RF cavity. Significant advantages of the photogun include minimization of the emittance growth due to nonlinear components of the transverse electric and magnetic fields owing to the choice of optimal geometry of the accelerating structure.

The design is based on a 1.5-cell RF S-band photogun, similar to the design of the Budker Institute gun [2]. The gun is simulated for the existing laser (Fig. 1) developed by IAP RAS [3], the impulse characteristics are shown in Table 2.

Table 2: IAP RAS Laser Parameters

Parameter name	Value
Wavelength, nm	262
Bunch train repetition rate, Hz	10
Bunch train duration, us	800
Bunches in train	8000
Bunch duration, ps	10
Bunch energy, uJ	1.5

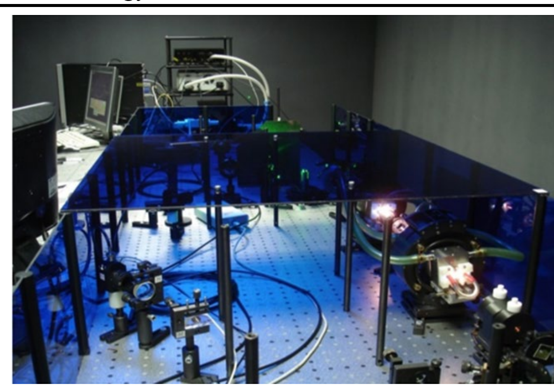

Figure 1: External view of the IAP RAS laser.

One can expect to obtain up to 960 nC in a 3 us pulse using this laser and assuming 10% quantum efficiency of a photocathode.

Simulation of a High Frequency Photogun

The simulation of the RF photogun design model is realized by the software CST Studio Suite 2021 [4] (hereinafter the software). In this work the calculations of the electric and magnetic fields, photoelectron emission and the dynamics of high-frequency ultrashort beams of the photogun were performed using the software. The design model of the RF photogun is 1.5 accelerating cells operating at a 2856 MHz frequency with a π mode oscillation. Microwave power is injected into the cavity by means of a rectangular waveguide and a coaxial line. The calculated standing wave factor is $\rho = 1.1$, the Q-factor is 15000. The estimated output beam energy reaches the set value (Fig. 2) and can regulated by the input power, which indicates the correct operation of the calculation model. Figure 3 shows the layout of the simulation model of the photogun and the simulation results with the electric field distribution along the axis of the cavities.

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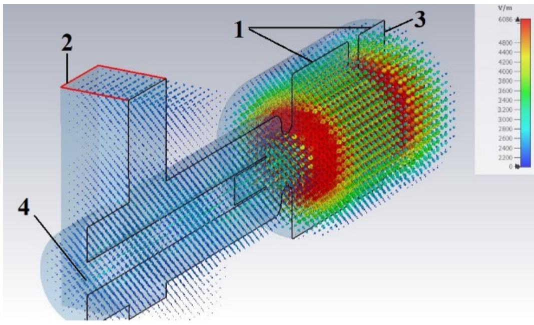

Figure 2: RF photogun layout (1-accelerating cavities; 2-RF power input; 3-cavity wall with a photocathode; 4-cavity for laser input and beam output).

The electric field in the accelerating cavities corresponds to an input microwave power of 4 MW.

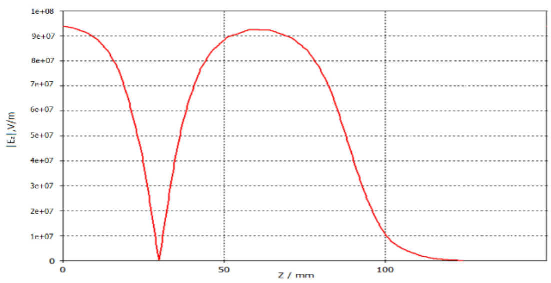

Figure 3: Dependence of the amplitude of the accelerating field on the axis of the cavities on the longitudinal coordinate.

Beam Dynamics in an RF Photogun

Beam dynamics are simulated for the developed computational model using a specialized software module. For these purposes, an idealized electron source with an initial energy corresponding to the photoelectron energy and a temporal structure set according to the specified laser parameters (Tab. 2). The results of beam simulation are presented in Fig. 4.

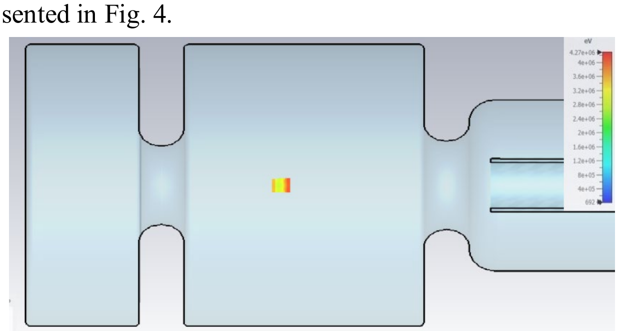

Figure 4: Beam acceleration in the cavity.

The correct operation of the model also required to determine with high accuracy many parameters that directly affect the energy characteristics of the installation as a whole. In particular, to achieve the best performance of the accelerating structure, time moment (the initial phase of microwave power oscillations), in which the electric field with the maximum accelerating potential develops, was coordinated with the transit time of the laser pulses. Then, in order to obtain time-stable energy characteristics of the computational model it was necessary to determine with high accuracy the interval be-tween micro- and macro-pulses, based on which, taking into account the duration of the microwave power pulse, the number of macro pulse bunches was determined. The obtained matched electron beams versus time are shown in Fig. 5. In the calculation, the electron yield from the photocathode was assumed to be equal to 32nC.

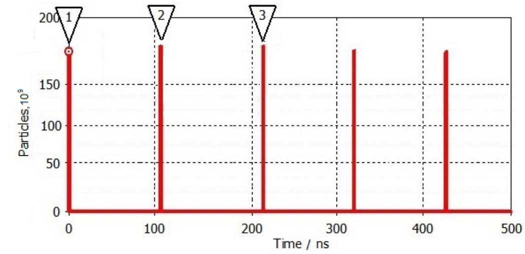

Figure 5: Distribution of beams at the cavity exit as a function of time, when the cavities are already filled.

The results of beam dynamics computational modeling by using the software (Fig. 4 and Fig. 5) demonstrate the expected acceleration electron bunch in accordance with the structure concept, as well as a high degree of agreement between the oscillations of the injected microwave power and the pulse characteristics of the laser.

CONCLUSION

In this work, we propose an RF photogun based on a one-and-a-half-cell high-frequency accelerating structure of the S-band accelerating structure and a powerful pulsed laser, which can be used as an electron source driver for the Linac-200 linear accelerator.

A computational model of the selected accelerating structure has been developed, which makes it possible to evaluate the high-frequency electromagnetic field in the structure and the electron beam dynamics. The parameters of the idealized source, the electrodynamic characteristics of the structure, and the distribution of the accelerating electric field are estimated. For the selected beam parameters, the particle dynamics analysis was performed, the results demonstrated the characteristics of the gun with this laser, close to the expected parameters.

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