DESIGN AND SIMULATION OF AN S-BAND RF PHOTOGUN FOR GENERATION OF TWISTED ELECTRONS.

Y. A. Samofalova

JINR, Dubna, PAC 2022

Introduction

The theoretical prediction and subsequent experimental confirmations of the hypothesis of the presence of intrinsic orbital angular momentum (OAM) in photons, electrons, neutrons, ions, etc. pushed scientists towards the rapid development of this direction in modern quantum physics in atomic physics, spin, and hadron physics, neutron optics. However, now, all existing technologies for generating particles with a large OAM are limited to the relatively low energies available in modern electron microscopes (no more than 300 keV). Within the project, we propose to develop a unique source of relativistic (few MeV) electrons with a high OAM.

For generating electrons with a large intrinsic orbital momentum it is proposed to develop the 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.

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

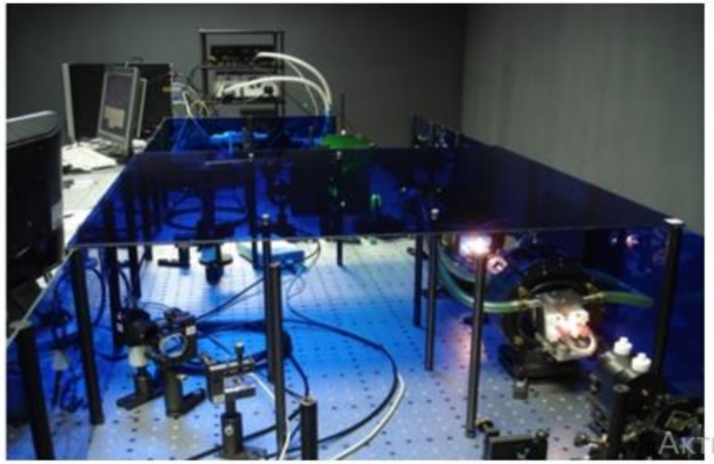

Figure 1: External view of the IAP RAS laser.

RF photo gun concept

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

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 [3] (herein-after 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.

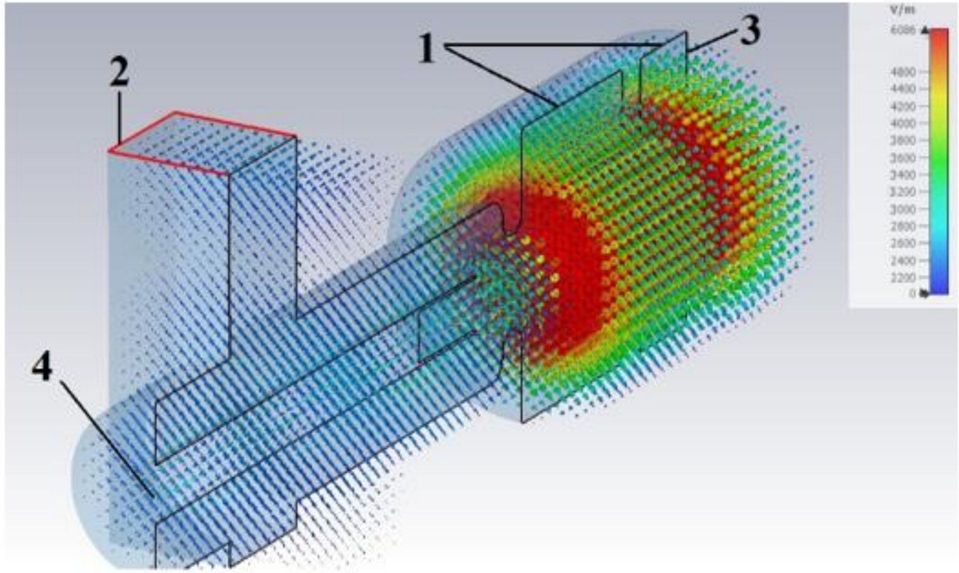

Figure 2: RF photogun layout (1-accelerating cavities; 2-RF power input; 3-cavity wall with a photocathode; 4-cavity for laser input and beam output).The electric field in the accelerating cavities corresponds to an input microwave power of 4 MW.

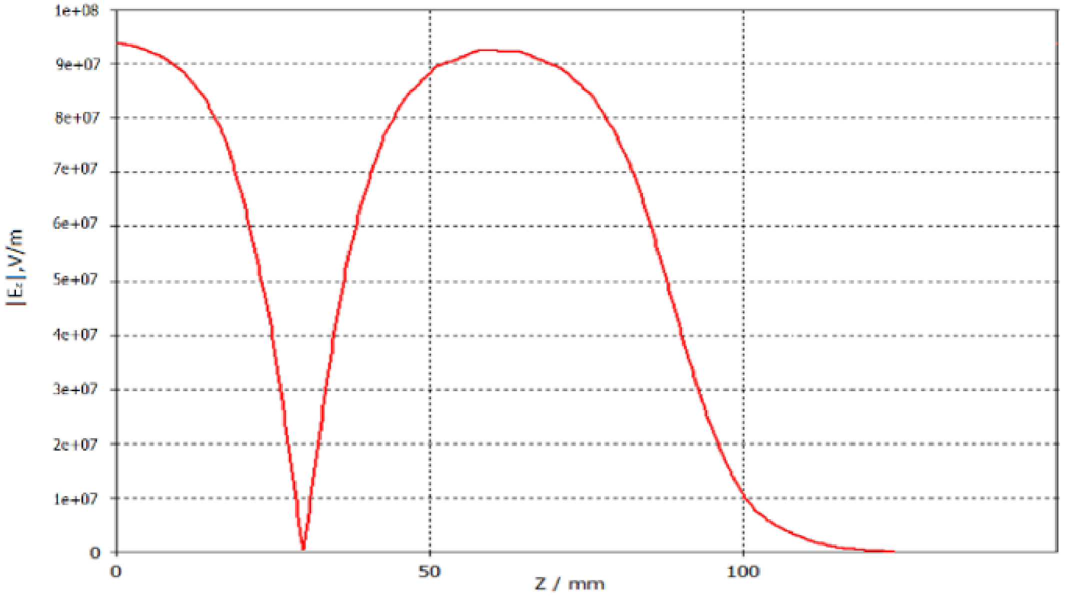

Figure 3: Dependence of the amplitude of the accelerating field on the axis of the cavities on the longitudinal coordinate.

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 Figure 4.

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 Figure 5. In the calculation, the electron yield from the photocathode was assumed to be equal to 32nC.

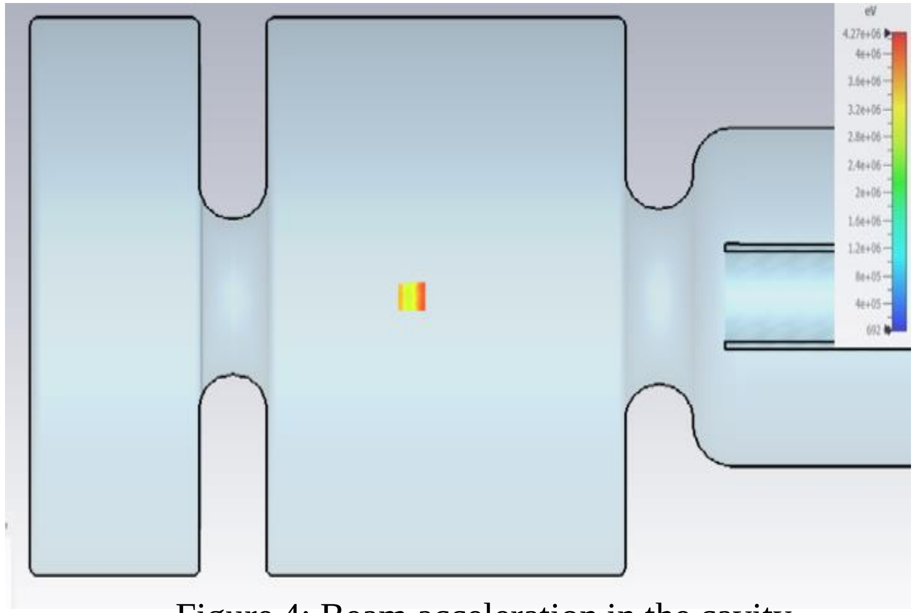

Figure 4: Beam acceleration in the cavity.

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.the injected microwave power and the pulse characteristics of the laser.

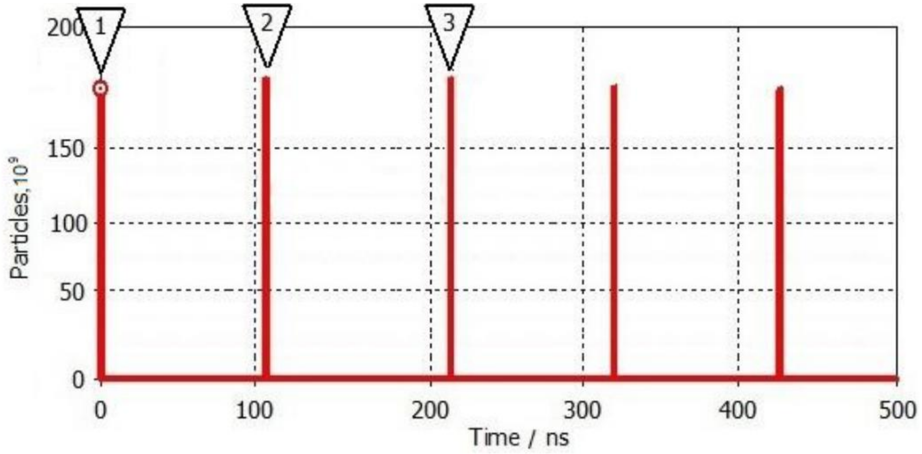

Figure 5: Distribution of beams at the cavity exit as a function of time, when the cavities are already filled.

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 source of high energy twisted electrons.

- 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
- It is planned to study the dynamics of the electron wave packet inside the particle accelerator (energies from several MeV to tens of MeV). The research involves the development of theoretical models of dynamics and the development of a set of technical requirements for the type of electromagnetic fields used for focusing and transporting the package in the accelerator.

REFERENCES

- [1] Simulation of a Radio-Frequency Photogun for the Generation of Ultrashort Beams / D. A. Nikiforov, A. E. Levichev, A. M. Barnyakov [et al.] // Technical Physics. – 2018. – Vol. 63. – No 4. – P. 585-592. – DOI 10.1134/S1063784218040163.
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