Overview of the present status of the SRF gun design and construction

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Abstract

A status report on the SRF photo-injector activities at FZR within the CARE/PHIN project is given. The new SRF gun has been designed for CW operation at the ELBE linac with an average current of 1 mA, 77 pC bunch charge, and 10 MeV energy. The basic concept of the gun, operating a normal conducting, thermally insulated photo-cathode within a superconducting cavity, has been taken from the first SRF half-cell gun which was successfully tested at FZR. In this report, the design layout of the SRF photo-injector, the parameters of the superconducting cavity and the expected electron beam parameters are presented. The SRF gun will have a 3+1/2-cell niobium cavity working at 1.3 MHz and will be operated at 2 K. The cavity consists of three full cells with TESLA-like shape and a half a cell in which the photocathode is located.

1. Introduction

For the ELBE superconducting electron linear accelerator an rf photo-injector with superconducting cavity (SRF gun) is under development. At present, rf photo-injectors with normal conducting cavities are widely used. They can produce electron beams of excellent beam quality with respect to bunch charge, transverse and longitudinal emittance. As for all normal conducting rf accelerating structures, the high rf power losses require pulsed rf operation with comparably low duty cycles. The use of a superconducting cavity could overcome this limitation and would allow continuous wave operation resulting in high average current. The idea of such an SRF photo gun was proposed by Piel at al. [1]. Later, R&D activities on this topic have been continued at the FZ Rossendorf [2] with the first successful operation of an SRF photo-injector in 2002 [3].

Due to the progress in fabrication technology and surface treatment, superconducting cavities with high quality factors and very high maximum accelerating gradients are available [4]. But up to now, it is not clear whether these parameters can be reached also for SC gun cavities. Problems and open questions are i) if the specific geometry of the gun cavity with a photocathode inside allows to reach the same high field gradients, ii) the question of operation of the photo cathode itself at cryogenic temperature, iii) the problem of possible contaminations of the cavity by particles coming from the photocathode surface resulting in a fast Q degradation and a low gradient, and iv) the lack of experience in tuning a superconducting cavity with very unequal cells.

There are ongoing research and development projects on SRF photo-injectors in several laboratories. The approaches are very different depending on the planed applications, the expected importance of the problems mentioned above, and the existing experience. At Peking University a DC-SC photoinjector has been developed [5]. It has a 1.5 cell superconducting Nb cavity, but the photocathode is outside the cavity so that compatibility problems are avoided. A DC field is applied in the gap between cathode and back wall of the cavity. Due to the low electric field which accelerates the electrons from the cathode, the transverse emittance is comparably high. At BNL an all-Niobium SC gun [6] has been developed. Here the back wall of the half-cell cavity itself serves as photocathode. The quantum efficiency could be increased by laser cleaning of the niobium surface from $2x10^{-7}$ to $5x10^{-5}$ but is still low compared to semiconductor photo cathodes. To keep the illuminated spot superconducting, the driver laser power is limed, with the consequence that the gun will have a comparably low average current. An 800 MHz SC photo gun with a half-cell and a full cell separated by a short drift tube is under development at Advanced Energy Systems Inc. [7]. The approach for the photo cathode in the half-cell is similar to that proposed in [2]. The normal conducting photocathode is thermally isolated from the sc cavity by a vacuum gap and an additional rf filter prevents rf power losses. The use of two separate cavities simplifies the tuning and rf power coupler problems and allows higher beam currents.

2. Cavity Design

The principal approach of the new SC photo-injector has been adopted from the successful proof-of-principle experiment with the half-cell cavity at FZR [3], but the SC Nb cavity now has 3.5 cells. As before, the back wall of the half-cell has a hole in the centre for the cathode. The diameter of the cathode is smaller than this hole, so that the circular vacuum gap ensures a thermal isolation between cathode and cavity. The cathode is normal conducting and is held on liquid nitrogen temperature. This is done by means of a special cooler with a liquid N_2 reservoir. Behind the half-cell a choke filter, also made of superconducting Nb, prevents rf losses through the coaxial line formed by cathode and cavity opening.

In Fig. 1 the schematic design of the cavity is presented. The three full cells have TESLA shapes [8] with exception of the TESLA cell adjacent to the gun half-cell, where the left side has been shortened in order to obtain a better phase matching of the electron bunch. The design of the gun half-cell is the result of combined rf-field and beam-dynamical numerical optimization process and taking into consideration the constructional and technological constrains for superconducting cavities. The main optimization conditions were, that the electric and magnetic surface field strengths in the gun half-cell do not exceed the corresponding values in the TESLA cell (0.11 T and 52 MV/m for 25 MV/m accelerating field strength), and that the electric field in front of the cathode has its maximum at the launching phase.

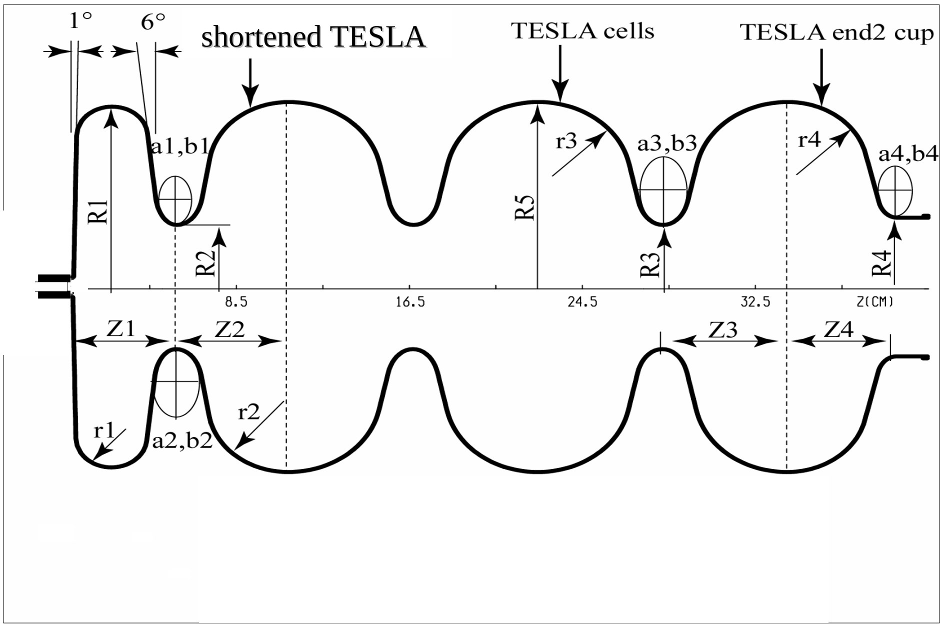

Fig. 1: Schematic cavity layout with design parameters.

3. Electron Beam Parameters

The beam parameters of the new SRF photo-injector are determined by requirements of the ELBE electron linac. The maximum beam current will be 1 mA at a pulse repetition rate of 13 MHz and a corresponding bunch charge of 77 pC. The final electron energy will be approximately 10 MeV. The rf power of 10 kW required is adequate to that of a TESLA module of the ELBE accelerator. Thus coupler, power and low-level rf system can be copied. On the other hand, a second mode of operation has been defined, which should allow more general studies at higher bunch charges up to 1 nC. So, beam parameters, cathode behavior and other critical aspects can be investigated for future application of the gun. This mode requires a reduced micro pulse frequency of 1 MHz and is, therefore, not suited to drive the ELBE FEL. A summary of the parameters is given in Tab. 1.

parameter	ELBE mode	high bunch charge mode
beam energy	9.5 MeV	
average current	1 mA	
pulse frequency	13 MHz	1 MHz
bunch charge	77 pC	1 nC
transverse emittance	0.5 mm mrad	2.5 mm mrad
photo cathode	Cs_2Te	
driver laser wave length	262 nm	
average laser power	0.8 W	1 W
laser pulse length	5 ps	15 ps

Table 1: Gun parameters.

4. Design of other Subsystems

Fig. 2 shows the design of the Nb cavity together with the He vessel, the cathode cooler with liquid N_2 reservoir, the cathode and transfer rod. Two separate tuners, one for the three TESLA cells and one for the gun half-cell, will be used. Furthermore, a fine adjustment of the cathode cooler which defines the cathode position in the cavity, can be done after cooling-down from outside of the cryostat.

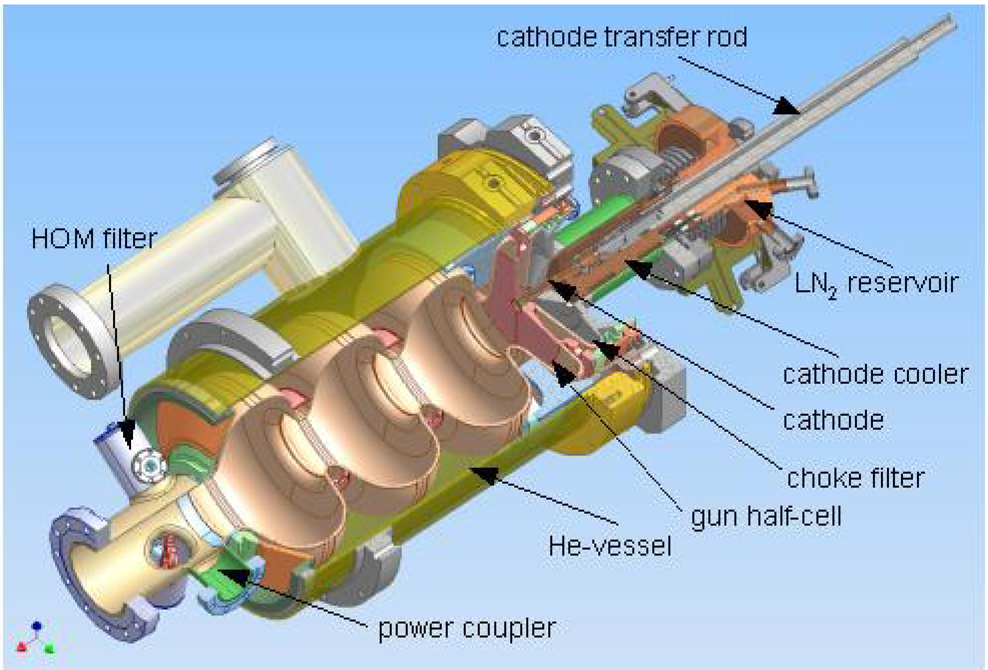

Fig. 2: Niobium 3.5 cell cavity design with He vessel, and cathode cooling system.

The laser system will have a diode-pumped Nd:YLF actively-modelocked 26 MHz oscillator with 1.047 µm wavelength. Following pulse selectors produce either 13 MHz or 1 MHz repetition rate. In two different channels for each pulse frequency the power is raised with diode pumped Nd:YLF amplifiers and then the frequency quadrupled with LBO and CLBO crystals to a wavelength of 262 nm. The final laser power will be 0.8 W in the 13 MHz and 1.0 W in the 1 MHz channel. This requires a quantum efficiency of at least 1 % of the Cs_2Te photo cathodes. The production of the photo cathodes will be performed in a newly designed preparation chamber adopting the co-evaporation technology developed at CERN [9]. An UHV storage and transportation chamber will allow the exchange of the photo cathodes between the preparation lab and the electron gun.

5. Project Status

During the first months of the project, the superconducting cavity design has been finished and two complete cavity systems have been ordered, the first for technology test and bench measurements and the second, using premium grade niobium, for the final application. The cavity tuners have been fabricated and the design of the photocathode cooling system is complete and now in fabrication. The design of the cathode transfer system and preparation chamber is complete. Within the next months a test bench for the photocathode cooling system will be build up and the assembly of the cathode preparation chamber will be started.

Acknowledgements

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