A SUPERCONDUCTING PHOTO-INJECTOR WITH A 3+1/2-CELL CAVITY FOR THE ELBE LINAC

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Abstract

After successful tests of an SRF gun with a superconducting half-cell cavity, a new SRF photo-injector for CW operation at the ELBE linac has been designed. In this report the expected gun operating parameters, the design and the parameters of the superconducting cavity are presented. The SRF gun consists of a 3+1/2-cell niobium cavity working at 1.3 GHz and will be operated at 2 K. The three full cells have TESLA-like shapes. In the half-cell the photocathode is situated which will be cooled by liquid nitrogen.

INTRODUCTION

At the Forschungszentrum Rossendorf (FZR) an rf photo-injector with a superconducting cavity (SRF gun) is under development. The goals of this SRF gun project are to build a new electron injector for the ELBE superconducting linear accelerator and to demonstrate the capability for future applications in FEL light sources and energy recovery linacs. The use of a superconducting cavity allows cw-mode operation and thus high average currents. On the other hand, such a photocathode gun can generate short pulses and high-brightness electron beams, as known from conventional photo-injectors. The first proposal for an SRF gun was published by Piel et al. [1] and first experimental tests were carried out at the University of Wuppertal [2]. Later, at the FZR an SRF gun with a half-cell cavity was developed and built up [3]. In a proof-of-principle experiment, the operation of such a photo-injector was successfully demonstrated [4]. A crucial question is, if the photocathode inside the superconducting cavity lowers the quality factor and the maximum attainable field gradient due to particle pollution. During about 200 hours operation such an effect was not seen [4], but these experiments the average current of a few µA was rather low.

SRF GUN PARAMETERS

The ELBE accelerator is designed for continuous wave operation with an average current of 1 mA at a pulse repetition rate of 13 MHz and a corresponding bunch charge of 77 pC. Its TESLA type cavities are operated with a nominal accelerating gradient of 10 MeV/m (10 MeV energy gain per cavity). These values determine the basic parameters of the SRF gun as presented in Tab. 1. For the new gun the ELBE rf system (10 kW klystrons), the rf low-level control and power couplers will be adopted. Using the full rf-power capacity a beam energy of 9.5 MeV is intended. Besides this ELBE operation mode, the gun will be operated with high bunch charges and reduced pulse repetition rate. Beam parameter measurements at 1 nC and the long-term behavior are important for future use.

CAVITY DESIGN

The principal gun design is similar to that of the previous half-cell SRF gun [4], but the cavity has now 3.5 cells. The back wall of the half-cell has a slightly conical shape and a centered hole for the photocathode. The photocathode itself is normal conducting and cooled with liquid nitrogen. A circular vacuum gap ensures thermal insulation between cavity and photocathode. Therefore the heat produced in the cathode does not burden the helium bath. On the other hand the coaxial line formed by this geometry causes rf power losses of the cavity. Attached to the coaxial line an additional choke filter, also made of superconducting niobium, prevents this effect.

Table 1: SRF gun operating parameters.

Parameter	**ELBE mode**	**high bunch charge mode**
Rf frequency	1.3 GHz	
rf power	10 kW	
nominal beam energy	9.5 MeV	
average current	1 mA	
operation mode	cw	
repetition rate	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	
quantum efficiency	≥1 %	
Laser power needed	0.5 W	
laser pulse length	5 ps	15 ps

The contour shape of the cavity is shown in Fig. 1. The three full cells have TESLA shapes [5] with exception of the TESLA cell adjacent to the gun half-cell, where the left cup 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 a 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. In Tab. 2 the corresponding design parameters are presented.

Table 2: Cavity shape parameters, all lengths in mm.

cell	shape parameter	name	value
gun half-cell	back wall angle		1°
	cathode hole diameter	d_0	12
	length	Z_1	37.7
	equator radius	R_1	102.5
	iris radius	R_2	35
	circular arc radius	r_1	11.44
	ellipse horizontal half axis	a_1	9
	ellipse vertical half axis	b_1	16
shortened TESLA midcup	length	Z_2	52
	equator radius	R_5	103.3
	iris radius	R_2	35
	circular arc radius	r_2	37.12
	ellipse horizontal half axis	a_2	12
	ellipse vertical half axis	b_2	19
TESLA midcup	length	Z_3	57.7
	equator radius	R_5	103.3
	iris radius	R_3	35
	circular arc radius	r_3	42
	ellipse horizontal half axis	a_3	12
	ellipse vertical half axis	b_3	19
TESLA endcup	length	Z_4	56
	equator radius	R_5	103.3
	iris radius	R_4	39
	circular arc radius	r_4	40.3
	ellipse horizontal half axis	a_4	10
	ellipse vertical half axis	b_4	13.5

The cavity has an rf power coupler, two higher-order mode couplers, and a pick-up. All of them must be placed at the end tube of the cavity. The designs are adopted from the TESLA cavity [5]. It is intended to use two different tuners, one for the three TESLA cells and one for the cathode half-cell. Therefore an additional pick-up placed in the choke filter cell will be used for the tuning of the cathode half-cell.

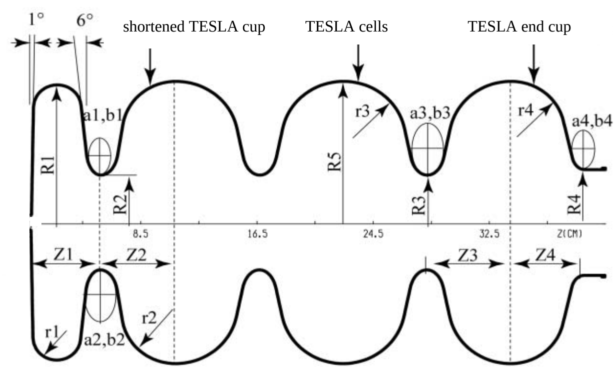

Figure 1: Schematic cavity layout with design parameters.

PHOTOCATHODE

Cesium telluride photocathodes will be used in the SRF gun which require an UV driver laser system with 262 nm wave length. The cw-mode laser power will be about 1 W, and including the losses in the optical transfer line a quantum efficiency of at least 1% is required. The Cs_2Te photolayers will be produced in a separate preparation system and then transferred to the SRF gun in an UHV storage chamber. Fig. 3 presents the photocathode design.

The cathode is held in the cooler with a bayonet fixing. The front stem riches into the cavity without mechanical contact. The conical part centers the cathode and ensures the thermal contact between cathode and cooler. The stem has a diameter of 10 mm, and the total length of the cathode is 130 mm. The stem and conical part of the cathode are made of Cu. It is possible to exchange the front of the stem part and to use different material. It is known, that e.g. Mo is more suitable for Cs_2Te cathodes at high bunch charges. Front stem parts of different lengths will also allow to study and optimize the rf focusing effect which appears for a slightly retreated cathode [6].

CATHODE COOLING SYSTEM

The niobium cavity with the He tank and the cathode cooling system is shown in Fig. 2. Also the photocathode and the transfer rod for cathode exchange are visible. The cooler, made of Cu, holds the photocathode and provides the thermal connection to the liquid N_2 tank, which is in the rear. They are separated by an electric insulator which allows to measure the cathode emission current as well as to apply a dc voltage for multipacting suppression and producing an additional focusing effect.

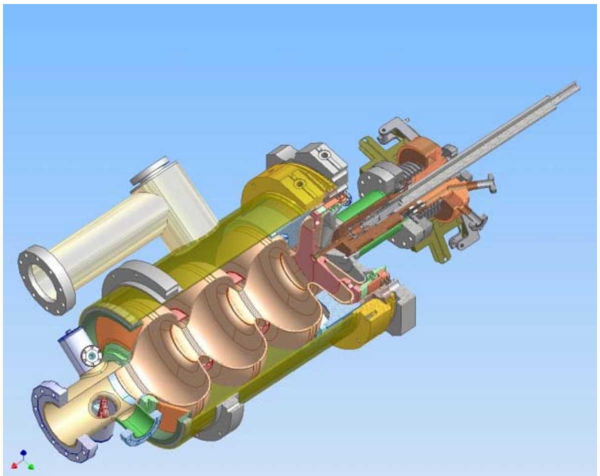

Figure 2: 3-D view of the cavity design with liquid He vessel, photocathode, cathode cooler, liquid N_2 reservoir and transfer rod.

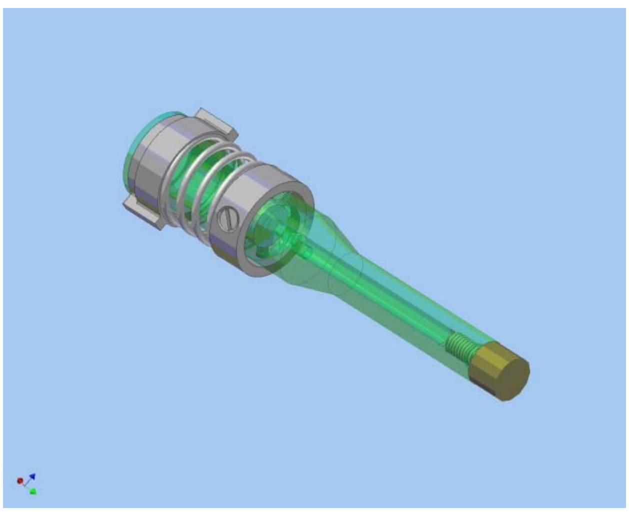

Figure 3: Photocathode design for the SRF gun.

SUMMARY AND OUTLOOK

An rf photo-injector with a superconducting niobium cavity has been designed for cw-mode operation in the ELBE electron linear accelerator laboratory. The design of the cavity and the surrounding components like He tank, cathode cooling system, and tuners are finished. The design of the cryomodule will be finished within the next month. The fabrication of the two cavities which are ordered will be finished until the end of this year. First rf tests are planned in spring 2005.

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REFERENCES

[1] H. Piel et al., FEL'88, Jerusalem, Israel, 1988.
[2] A. Michalke, et al., EPAC'92, Berlin, Germany, March 1992, p. 1014
[3] E. Barthels, et al., Nucl. Instr. and Meth. A445 (2000) 408.
[4] D. Janssen, et al., Nucl. Instr. and Meth. A507 (2002) 314.
[5] B. Aune, et al., Phys. Rev. Special Topics, Vol. 3 (2000) 092001.
[6] D.Janssen, V. Volkov, Nucl. Instr. and Meth. A452 (2000) 34.