THE ELBE ACCELERATOR FACILITY STARTS OPERATION WITH THE SUPERCONDUCTING RF GUN *

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Abstract

As the first superconducting rf photo-injector (SRF gun) in practice, the FZD 3+1/2 cell SRF gun is successfully connected to the superconducting linac ELBE. This setting will improve the beam quality for ELBE users. It is the first example for an accelerator facility fully based on superconducting RF technology. For high average power FEL and ERL sources, the combination of SRF linac and SRF gun provides a new chance to produce beams of high average current and low emittance with relative low power consumption.

The main parameters achieved from the present SRF gun are the final electron energy of 3 MeV, 16 µA average current, and rms transverse normalized emittances of 3 mm mrad at 77 pC bunch charge. A modified 3+1/2 cell niobium cavity has been fabricated and tested, which will increase the rf gradient in the gun and thus better the beam parameters further. In this paper the status of the integration of the SRF gun with the ELBE linac will be presented, and the latest results of the beam experiments will be discussed.

INTRODUCTION

The SRF gun developed within a collaboration of the institutes HZB, DESY, MBI and FZD was successfully installed and tested in 2007 [1]. It is designed for medium average current beams in CW mode, bunch charge of 80 pC to 1 nC, and the transverse emittance below 3 mm mrad.

The SRF gun was built highly compatible with FZD's present radiation source -- ELBE (Electron Linac with high Brilliance and low Emittance) in order to provide high brightness beams for the ELBE users, and at the same time to set up a practical test stand for the SRF gun technology.

The multiple beam facility ELBE provides routinely Bremsstrahlung, intensive X-rays, infrared FEL radiation, electrons, positions and neutrons for its users [2]. The new application of the SRF gun will improve the beam quality, especially the emittance and the bunch charge. For example, with the SRF gun the infrared FEL user will obtain the higher current beam with lower emittance; The neutron and positron users can have higher bunch charge primary beam (up to 300 pC) at the reduced repetition rate; New potential applications with the SRF gun injection are the production of short pulse THz-radiation and the x-rays by inverse Compton backscattering.

During the 2009/2010 winter shutdown, the beam line connected the SRF gun to the ELBE Linac was installed. The first beam from the SRF gun was successfully guided to ELBE in February 2010. Figure 1 shows the beam spot on the YAG screen after the first main accelerator module.

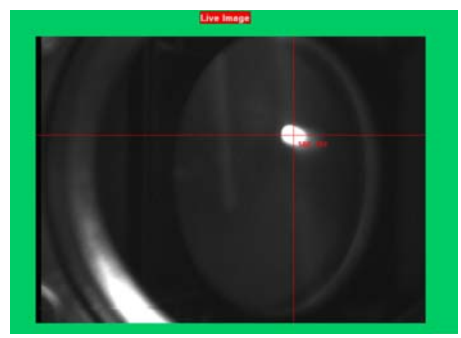

Figure 1: The first beam from ELBE injected with the SRF gun. The beam spot on the YAG screen after the first main accelerator module.

SRF GUN PARAMETERS

The 1.3 GHz niobium cavity consists of 3½ cells and an additional choke cell. In the cavity a normal conducting semiconductor photocathode, is thermally and electrically isolated from the cavity by a vacuum gap, hold by a special support system and cooled with liquid nitrogen. The cavity has two cavity tuners, two HOM couplers, and an ELBE-type input coupler for 10 kW. Details of the SRF gun design have been published elsewhere [3].

The first beam from the SRF gun was produced on November 12, 2007 with a copper cathode, and in March 2008 the first cesium telluride (Cs_2Te) photocathode was transported into the gun. From then on, four photocathodes have been used in the gun conditioning, best quantum efficiency in the gun reached 1 %. In the gun test, the acceleration gradient was set as 5.5 MV/m which belongs to 15 MV/m peak field in the cavity and about 7 MV/m on the cathode. A high power processing carried out in September 2008 improved the gradient to

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6.5 MV/m (17.6 MV/m peak field). With this gradient the beam energy reached 3 MeV, and the rms energy spread was 20 keV for the 5 pC/bunch beam. The energy spread rose obviously for the higher bunch charge beam due to the increased space charge effect. From the Astra simulation, under this gradient, the maximum bunch charge from the gun is 390 pC, which is limited by the space charge effect near the cathode surface. Figure 2 shows the laser phase scan for different laser repetition rates between 2 kHz and 125 kHz at constant laser power of 55 mW. The bunch charge (current) was measured with a Faraday cup about 1 m downstream from the gun. From this scan, the max bunch charge which can be achieved at the optimum laser phase was 300 pC, which could be limited by the laser pulse energy and the quantum efficiency of the photocathode.

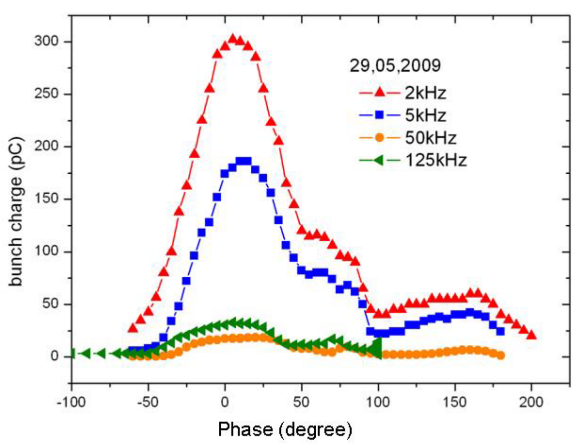

Figure 2: Laser phase scan with 55 mW laser power at different laser pulse repetition rates.

Table 2: Measurement Results and Designed Parameters of the FZD SRF Gun

	measured	Designed	
		FEL mode	high charge mode
Max. energy	3 MeV	3 MeV	
peak field	17.6 MV/m	18 MV/m	
laser rep. Rate	1-125 kHz	13 MHz	2-250 kHz
laser pulse length (FWHM)	15 ps	4 ps	15 ps
laser spot size	1~6 mm	5.2 mm	5.2 mm
bunch charge	≤ 300 pC	77 pC	400 pC
average current	18 µA	1 mA	100 µA
peak current	20 A	20 A	26 A
transverse rms emittance	3±1 mm·mrad @ 80 pC	2 mm·mrad	7.5 mm·mrad

The solenoid scan method and the multi-slit method are used to measure the transverse emittance. With the low bunch charge the beam emittance is less than 3±1 mm·mrad. The bunch length was measured with Cherenkov-radiation method, which gave out 12~32 ps (rms) for the beam with bunch charge 8 pC [4]. This work is still going on. The main beam parameters measured in the operation showed in table 2.

The most important information is that the measurement of the quality factor Q_0 of the cavity showed that no visible degradation of the cavity performance has be found after about 500 hours operation with Cs_2Te cathodes inside [5].

In order to improve the cavity gradient, a new large-grain 3½ cell Nb cavity with optimized shape and a new cryo-module are under development [6]. The beam quality for high charge mode is hoped to benefit from the higher accelerating field in the cavity, and then the lower energy spread, lower transverse emittance, shorter bunch length for the high bunch charge mode will be available.

ELBE SRF LINAC WITH SRF GUN

The superconducting electron accelerator ELBE has been in user operation since 2002. ELBE accelerates electrons up to 40 MeV with an average beam current of 1 mA in continuous wave (cw) mode or pulsed mode. It serves as a driver to generate several kinds of secondary radiation and particle beams. A driver for these different kinds of secondary radiation must be characterized by the high average beam current and the small transverse and longitudinal emittance which depend on the electron source. The present 250 kV DC gun combined with bunch compressor can deliver pulses with a bunch charge up to 77 pC at 13 MHz repetition rate and the transverse emittance in this case is about 10 mm mrad caused by the electric-field deformation close to the grid [7].

The SRF gun will provide the beams with higher bunch charge and lower emittance than the DC gun, which makes the new application experiments like THz-radiation, high intensity Compton backscattering possible to perform.

The layout of ELBE radiation source with SRF gun is showed in figure 3. After the dog-leg connection beam line from the SRF gun to the ELBE Linac was installed in the end of last year, there were two ELBE shifts using SRF gun as the injector. The main goal was to adjust the beam line elements and to measure the beam parameters.

BEAM DIAGNOSTICS

In the injection test, the SRF gun beam with the bunch charge of 4 pC and the repetition rate of 50 kHz passed through the connection beam line and the two cryo-modules, with totally four 9-cell cavities, whose gradient were 7.59 MV/m, 7.28 MV/m, 2,35 MV/m, 2,82 MV/m, respectively, achieving the mean energy up to 25.4 MeV.

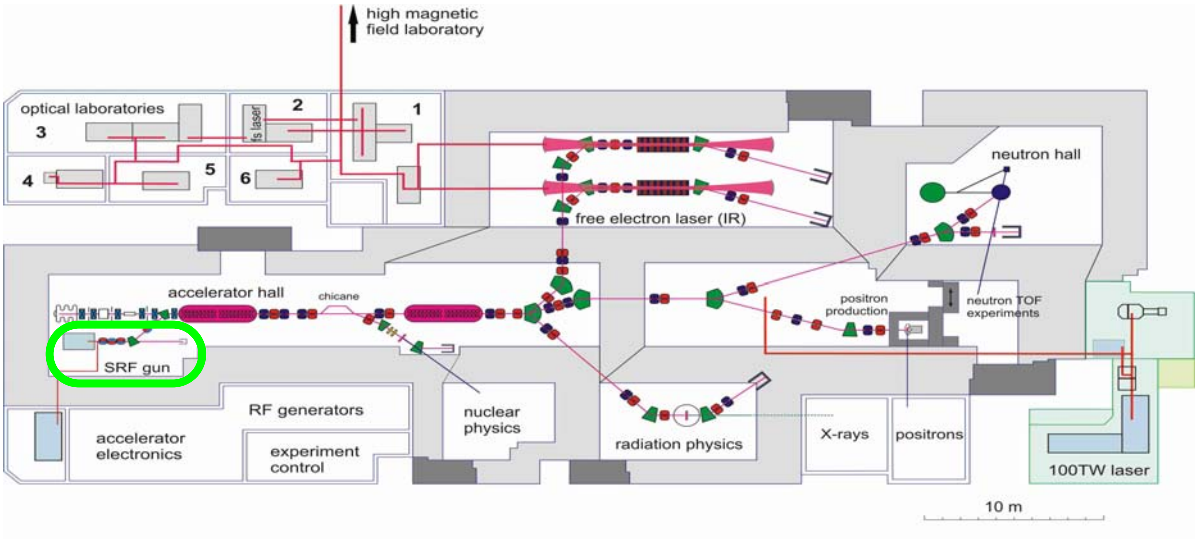

Figure 3: The layout of the ELBE radiation source with SRF gun beam line

The energy and energy spread have been determined carefully after the first cryo-module [8]. Figure 4 shows the measurement result of the energy and energy spread after the first module versus the phase of the first cavity (with the optimized phase for the second cavity). The two hyperbolic-like curves indicate a best accelerating phase range from 20 deg to 35 deg., corresponding mean energy of 17.9 MeV~ 18 MeV and energy spread of 56 keV~100 keV, or relative energy spread 0.3%~0.6%. The other beam parameters will be measured during the next beam time.

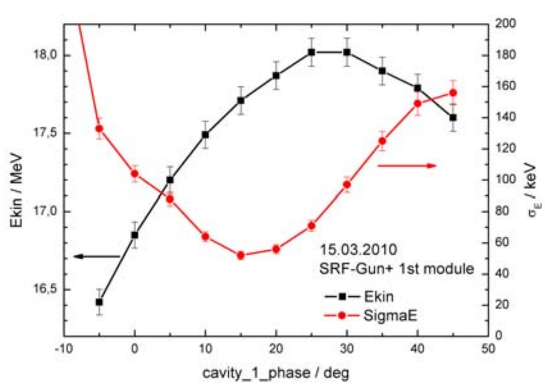

Figure 4: The energy and energy spread after the two 9-cell cavity versus the phase of the first cavity (with the optimized phase of the second cavity). The black curve with squares is the mean energy, and the red curve with dots is the rms energy spread.

SUMMARY

The Superconducting RF photoinjector within a collaboration of HZB, DESY, FZD, and MBI has been successfully connected to the ELBE SRF linac. The ELBE linac injected with SRF gun can provide high brightness beam for the second-beam users and brighten the application of this radiation source. Before IPAC'10 two shifts were used for the beam optimizing and the beam diagnostics. The mean energy and energy spread have been measured.

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