FIRST OPERATION RESULTS OF THE SUPERCONDUCTING PHOTOINJECTOR AT ELBE*

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Abstract

In November 2007 the first electron beam was generated from the superconducting RF photo electron gun. The injector together with the UV driver laser system and the diagnostic beam line were developed and constructed within a collaboration of BESSY, DESY, MBI and FZD.

After the cool-down of the cryostat the RF properties of the 3½-cell niobium cavity like pass band mode frequencies, unloaded quality factor versus accelerating gradient, Lorentz force detuning, and He pressure influence were measured. The first beam was extracted of a Cu photo cathode using the laser with a repetition rate of 100 kHz and 0.4 W laser power. Later, caesium telluride photo cathodes have been applied. First results of of beam parameter measurements are presented.

INTRODUCTION

Many of future electron accelerator projects like advanced light sources or energy recovery linacs require high peak and average current as well as low emittance electron beams. Currently, radio-frequency photo injectors with normal conducting cavities can produce beams with very high brightness [1]. But in most cases their average currents are small caused by the low duty factor of the pulsed RF. Thus for CW operation, DC photo injectors [2] are applied. Their disadvantage is the comparably low peak current. An RF photo injector with superconducting cavity combines both advantages and can produce high brightness beam in CW.

An SRF photo injector has been developed and installed at the superconducting CW linac of the radiation source ELBE [3]. The injector comprises the 3½ cell niobium cavity, the liquid He cryomodule, the RF supply system, the support, cooling and exchange system for the photocathodes, the UV driver laser with its optical beamline, a solenoid for emittance compensation downstream the gun, and a diagnostic beamline. The SRF gun uses normal conducting photocathodes which are thermally separated from the cavity and cooled with liquid nitrogen. The standard material is Cs_2Te. A design picture of the SRF gun cryomodule is presented in Fig. 1. Details of the design have been published elsewhere [4].

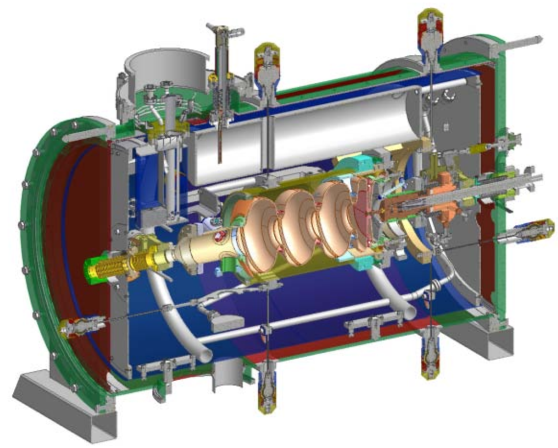

Fig. 1: Design picture of the SRF gun cryomodule.

The SRF gun cryomodule was installed in the ELBE accelerator hall in July and the first cool-down was performed in August 2007. In the following weeks the RF system was put into operation. At the same time the driver laser system was delivered by MBI and tested, and the optical components of the laser beamline were installed and adjusted. The autumn shut-down of ELBE was used to complete the installation of the diagnostics beam line. Fig.2 shows a photograph of the setup. End of October, the gun was cooled down for the second time. After readjustment of the laser beamline the first accelerated beam could be produced on November 12, 2007. The electrons were extracted from a Cu photocathode. The time until end of 2007 was spent for commissioning and test of the beamline components. In March 2008 the cathode transfer system was mounted and the first Cs_2Te photo cathode was inserted into the gun in May 2008.

COOL-DOWN

After two days for cooling and filling with liquid nitrogen the cavity was cooled down with 10 K helium gas for about 24 h. After a break in which the two ELBE modules were cooled with He gas, the tank was filled with liquid He. Finally, the tank was pumped to 30 mbar in order to get the working temperature of 2 K. Pressure stabilization is performed with cold compressors for all

* We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 "Structuring the European Research Area" programme (CARE, contract number RII3-CT-2003-506395) and the support of the German Federal Ministry of Education and Research grant 05 ES4BR1/8.

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three cryostats (ELBE 1, ELBE 2, SRF gun) together using a pressure sensor near the ELBE 1 cryomodule.

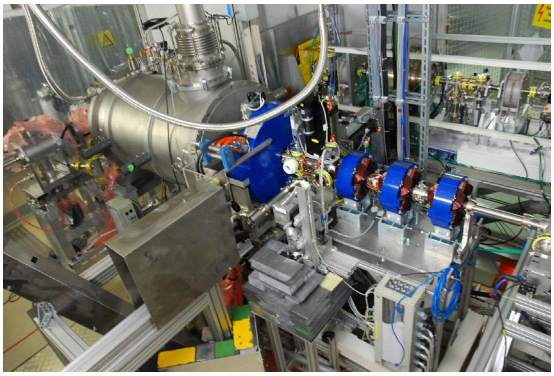

Fig. 2 : Photograph of the SRF gun and the diagnostic beamline in the ELBE accelerator hall.

The frequency of the SRF gun cavity during the cool-down is plotted in Fig. 3. For the frequency shift from RT to 2 K a value of 2.02 MHz was found which is equal to the shift of TESLA resonators in the ELBE cryomodules. Unfortunately, the pre-stress adjustment of the SRF gun tuners was wrong. Thus, the final frequency obtained is about 400 kHz too high. The tuning range of the step-motor driven tuners amounts to ±225 kHz around this value. Whereas the gun can be separately operated without restrictions at present, a readjustment to 1.3 GHz is needed for the future operation as injector at ELBE.

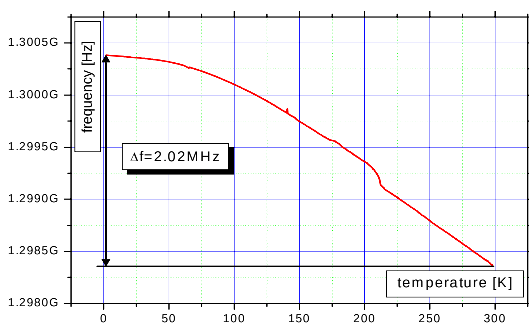

Fig. 3: Cool-down curve showing the cavity resonance frequency versus temperature.

RF MEASUREMENT

The SRF gun cryostat has an electrical heater in the helium tank. For constant liquid He input flow and constant He level in the cryostat, the RF heat dissipation is obtained from the changes of the heater power. These values were measured as function of the acceleration gradient. For Q_0 versus E_{acc} the results in Fig. 4 were obtained. The red curve in the figure shows the corresponding radiation level due to field emission in the cavity. It is obvious that the drop down of Q_0 is connected to field emission. Nearly the same maximum gradient has been found as in former measurements in the vertical test cryostat [5]. Due to cleaning difficulties and the damage produced during high pressure rinsing this gradient is below the design value.

In order to measure the Lorentz force detuning of the SRF gun cavity, a network analyzer (NWA) was used as a driver unit for the klystron amplifier. To increase the cavity field, the output power of the NWA was raised in steps of 1 dB while the gradient was calculated by the calibrated pickup voltage. The achieved typical transmission plots are shown in Fig. 5. For the quadratic dependence of the frequency shift $\Delta f = a\, E_{acc}^2$, the factor $a = -5\ \mathrm{Hz/(MV/m)}^2$ was found, which is about five times larger than that for TESLA cavities. The SRF gun also has a higher He gas pressure sensitivity (230 Hz/mbar).

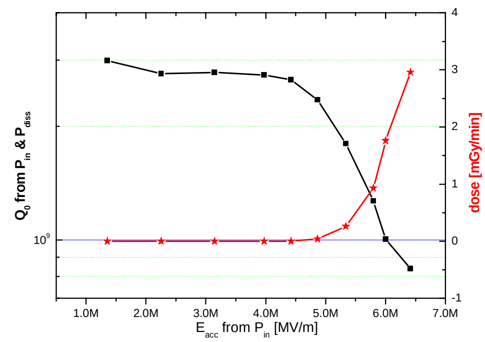

Fig. 4: Quality factor Q_0 versus acceleration gradient and corresponding field emission dose.

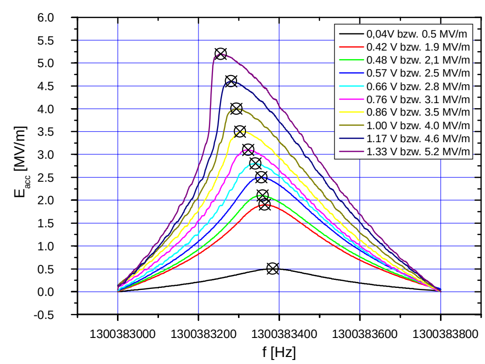

Fig. 5: Measurement of the cavity resonance curve (pickup signal vs. frequency) for increasing input power.

LASER

The UV drive laser, developed by MBI, is a frequency-quadrupled Nd:YLF system for CW operation. It consists of a mode-locked oscillator with 26 MHz, a regenerative amplifier, and a two-stage frequency conversion (LBO and BBO). The Pockels cells in the amplifier allow variable repetition rates up to 500 kHz of the output pulses. For 100 kHz and 2 kHz (diagnostic mode) the maximum pulse energies measured at 263 nm are 0.8 µJ and 50 µJ, respectively. A bunch charge of 1 nC requires 0.5 µJ pulse energy for a typical quantum efficiency of 1 %. The laser has a Gaussian temporal beam shape with a width of 15 ps FWHM. At present the spatial shape is also Gaussian with a spot diameter of about 1.3 mm FWHM. In future, a flat top profile will be produced by means of an aspheric telescope or an overfilled aperture.

The optical transport system comprises four lenses, five dielectric mirrors, a beam splitter (virtual cathode) near the input port, and one metallic mirror inside the vacuum tube. The last dielectric mirror is remote controlled and used for laser positioning onto the cathode or scanning for local QE measurements. With the virtual cathode the shape and position of the laser spot are monitored by means of a CCD camera and a position sensitive detector. A movable mirror in the electron beamline and a camera provide a view onto the cathode. Together with a special luminescence cathode the laser beam was adjusted.

PHOTOCATHODES

During the first phase of commissioning a Cu photo cathode was used, mounted into the cavity during the assembly of the cryomodule. But its QE measured to about 10^{-6} was very low. However, the beam current of about 50 pA at 100 kHz laser pulse rate was high enough for first tests. Electron beam images could be observed on all YAG screens.

After installation of the cathode exchange system, the first set of Cs_2Te cathodes were produced in the preparation lab. Two cathodes with QE of 4–5 x 10^{-2} after preparation were transferred into the storage chamber of the SRF gun. The first of them is now in operation in the SRF gun. A local QE measurement was carried out just after insertion into the cavity. Since the cathode is electrically insulated in the gun the photo current was measured directly applying a 5 kV DC voltage. Whereas the measured local fluctuations of about 20 % are rather good the overall QE of the photo cathode was dropped down to about 4 x 10^{-4}. We assume that the reason was the bad vacuum of 10^{-8} mbar in the transfer system which will be improved during the next ELBE shut-down. The QE measurement was repeated every weak without any further significant changes.

FIRST BEAM

The first electron beam was observed on November 12, 2007, produced with the Cu photo cathode at a cavity acceleration gradient E_{acc} = 5 MV/m (14 MV/m peak). The gun was always operated in CW mode with an RF power dissipation of 6 W. The maximum beam current obtained was about 50 pA. Fig. 6 shows the results of the laser phase scan at lower laser power. The beam current was measured in a Faraday cup about 0.6 m downstream the gun exit and the beam energy with the 180° magnet in the diagnostic beamline.

BEAM PARAMETER MEASUREMENT

The beam characterization with Cs_2Te photo cathodes have been started and will be continued until end of 2008. Beside commissioning of the diagnostic tools and software development (see Ref. [6]), first transverse emittance and energy spread measurements were carried out at low bunch charges. For the emittance measurement the solenoid scan method was applied as it is shown in Fig. 7.

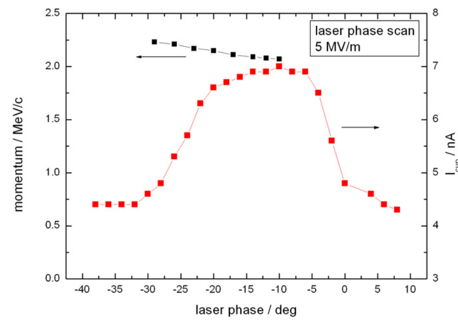

Fig. 6: Energy and Faraday cup current vs. laser phase.

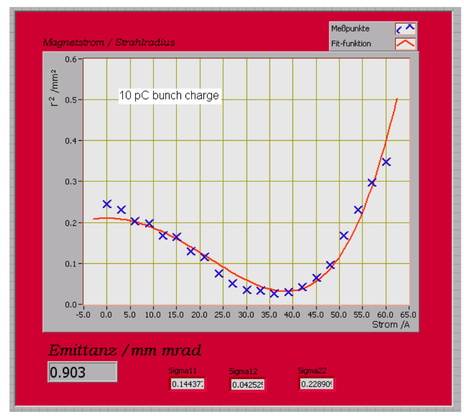

Fig. 7: LabView software tool for solenoid scan; fit curve and result for $\varepsilon_{x,n}$ at 10 pC bunch charge.

SUMMARY AND OUTLOOK

A SRF photoinjector has been installed at the ELBE linac in summer 2007. The commissioning phase has been started and will be continued until October 2008. It is intended to deliver beam to ELBE in 2009 after a correction of the pre-tuning and the installation of a connection beamline to ELBE. In parallel the gun will be a test bench for further SRF injector studies.

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