TUNING AND CONDITIONING OF A NEW HIGH GRADIENT GUN CAVITY AT PITZ*

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Abstract

A new 1.3 GHz photo cathode electron gun (prototype 4.2) for the Photo Injector Test facility at DESY, Zeuthen site (PITZ) was tuned in February 2007. The main difference in the mechanical design compared to earlier guns is a significantly improved cooling system. This gun is also the first copper gun cavity where a particle free cleaning using dry-ice technique was applied while in the previous guns the high pressure ultra pure water rinsing technique was used. The cavity has been installed in a new Conditioning Test Stand (CTS) at PITZ in autumn 2007. It has been conditioned to an accelerating gradient of 60 MV/m. Dark current measurements have been performed to monitor the improvement of conditioning and to compare with the results from the previous guns. In this paper, RF measurement and tuning results as well as results of the conditioning and dark current measurements will be presented and discussed.

INTRODUCTION

Main requirement of an electron injector for FELs, XFEL or Linear Collider is the ability to generate a reliable brightness beam with a very small transverse emittance and a reasonably small longitudinal emittance. The transverse emittance is an intrinsic property which can be obtained and optimized from the source while the longitudinal bunch length or the peak current is possibly improved later in the beam transport line, e.g. by using a bunch compressor. Therefore, it is very important to have the high quality electron source which can produce small transverse emittance from the beginning. This principle is realized at PITZ which aims to produce and characterize the small transverse emittance electron beam of about or less than 1 mm-mrad with a bunch charge of 1 nC and an energy spread of smaller than 1%. The results of the earlier stages at PITZ showed the clear possibility to achieve this small emittance value [1]. Recently, the PITZ beamline and related components have been upgraded to an intermediate stage PITZ1.7 to extend the ability of the facility to produce and characterize even smaller emittance beams. The main upgrades consist of a modification of the low energy diagnostic section, low energy dispersive arm (LEDA) and the first high energy dispersive arm (HEDA1). More details of the upgrades and the first results from PITZ1.7 can be found in another contribution of this conference [2]. The main discussion in this paper concentrates on tuning and conditioning of a new gun cavity at PITZ. First, it was installed on a Conditioning Test Stand (CTS) and was conditioned there starting from December 2007. Later, it was moved to be placed as the electron source in the PITZ1.7 beamline and further conditioning was started again in May 2008.

DESIGN AND TUNING OF GUN 4.2

A new 1.5 cell normal conducting RF gun cavity at PITZ, the so called gun prototype 4, has been designed with similar inner geometry to the previous design (gun prototype 3) with an improvement in the cooling system for operating with higher RF powers and longer pulses. In the gun prototype 3 (gun 3.1 and 3.2), two water input and one water output are used with only internal water distribution. The major improvement in the gun 4.2 is a new cooling channel design to supply more water to both end plates of the gun and to provide a better distribution of the cooling water around the outer cavity circumference by adding the possibility of measurement and control in each single water channel. Fourteen cooling channels are used to supply water with better control of the flow rate in individual channel. Uniform flow rate velocities of 2 m/s are used for all channels. Eighteen temperature sensors are placed at various locations on the gun walls and at the gun iris in order to observe and control the gun temperature.

Tuning of Gun 4.2

Fabrication of two guns (gun 4.1 and 4.2) according to the new design was finished at the beginning of 2007. Low level RF measurements and tunings of gun 4.1 and gun 4.2 were performed in February 2007. In this paper only the results of the RF measurements and tunings of gun 4.2 are

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reported. The first frequency measurements of the gun 4.2 showed that the resonant frequency in π-mode was detuned from 1.3 GHz by 313 kHz at an expected operating temperature of 55 ^{o}C and the accelerating field at the cathode, measured by using the bead-pull technique, was about 2% higher than that in the full cell. The gun was mechanically tuned by using a convenient and effective tuning device to slightly deform the cavity end walls to reach a desired resonant frequency with the field balance between the half and the full cell of 1.05. This field balance value is in the preferable range (1.05-1.10) in order to compromise between high momentum gain and a maximum gradient at the cathode for space charge compensation. The field profiles obtained from the bead-pull measurements before and after the tuning are shown in Fig.1. RF measurement results of gun 4.2 before and after the tuning are listed in Table 1.

parameter	unit	before tuning	after tuning
f_π	GHz	1.300 655	1.300 342
T_{op}	^{o}C	69	55
FB	-	1.02	1.05
Δf_c	kHz	296	270
$f_\pi - f_0$	MHz	5.187	5.159
S_{11} (π-mode)	dB	-34	-38
S_{11} (0-mode)	dB	-10	-10
Q_0 (π-mode)	-	-	20472
Q_0 (0-mode)	-	-	13684

Table 1: RF measurement results of gun 4.2 before and after tuning.

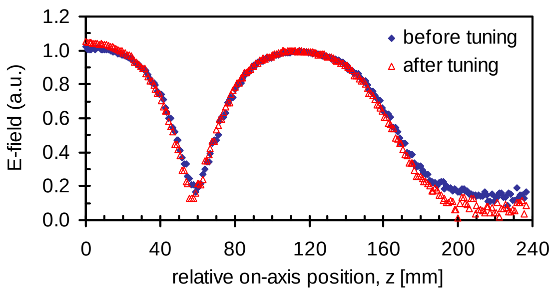

Figure 1: Electric field profile in gun 4.2 cavity before and after tuning.

The quantities f, T_{op}, FB, Δf_c, S_{11} and Q represent the resonant frequency, the operating temperature, the field balance, the different frequency with and without inserting a cathode, the reflection coefficient and the unloaded quality factor for the π- and the 0-mode, respectively. The resonant frequencies listed in Table 1 were measured at room temperature and in ambient air.

Cleaning of Gun 4.2

After the tuning, the gun 4.2 was cleaned using dry-ice sublimation-impulse cleaning. The dry-ice sublimation-impulse cleaning or simply called the dry-ice cleaning (DIC) is an effective cleaning technique for removal of the particles and filed emission sources in the resonant cavity [3]. The cleaning process acts locally, dryly and without residues from a chemical cleaning resulting in removal of particles of size down to 100 nm. A special vertical cleaning setup with 110^o rotating nozzle was applied to clean gun 4.2 for effective surface cleaning of the complex surface geometry of the RF gun.

CONDITIONING OF GUN 4.2

The gun 4.2 was installed on a Conditioning Test Stand (CTS) and has been conditioned up to a maximum gun gradient of about 60 MV/m. The CTS is a short and simplified version of the low energy section of the main PITZ beamline. It consists of an RF gun with a molybdenum (Mo) cathode and simplified diagnostic systems. The RF gun is operated with 10 MW klystron and its related RF system. The gun cavity is surrounded by the main and the bucking solenoid magnets for beam focusing and space-charge compensation. The diagnostic system combines a Double Diagnostic Cross (DDC), two screen stations in the straight section and one in the dispersive arm, a dipole magnet serving as an electron spectrometer and Faraday cups in DDC section and at the end of the straight section and the dispersive arm. The dipole magnet in the dispersive section can be used to deflect the beam up to maximum momentum of about 10 MeV/c. A schematic layout of the CTS is shown in Fig.2.

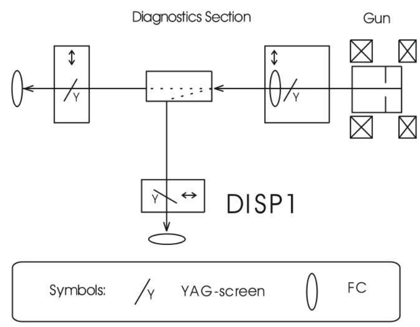

Figure 2: Schematic layout of the Conditioning Test Stand (CTS). Electron propagates from right to left.

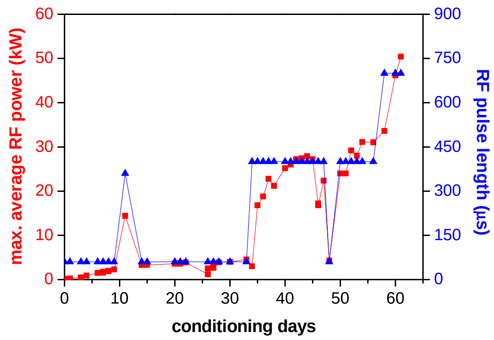

Figure 3: Maximum average RF power (red square) and RF pulse length (blue triangle) history of gun 4.2 during the conditioning on CTS.

The gun 4.2 has been conditioned on the CTS for about 60 days (from December 2007 to February 2008) with the maximum RF peak power up to about 7.5 MW for different RF pulse lengths (flat-top) from 60 to 700 μs. Only one Mo-cathode has been used during the gun conditioning on the CTS and another one on the PITZ beamline. The history of the average RF power and the RF pulse length in the gun 4.2 during the conditioning on the CTS are shown in Fig.3. The maximum average RF power which could be reached during the conditioning on the CTS was about 50 kW for the RF peak power of 7.2 MW with an RF pulse length (flat-top) of 700 μs at the repetition rate of 10 Hz. This condition corresponds to the gun gradient of about 63 MV/m.

Dark Current Measurements

Dark current has been measured using a removable Faraday cup located downstream of the RF gun in the DDC at various gun peak powers for different settings of the solenoid magnet current. The dark current signals were measured at the end of the RF pulse. The maximum current value from the measurement of the dark current as a function of the main solenoid currents are plotted for different gun peak powers in Fig.4. The results show more than factor 10 lower amount of the dark current in the gun 4.2 when comparing with the previous guns [4].

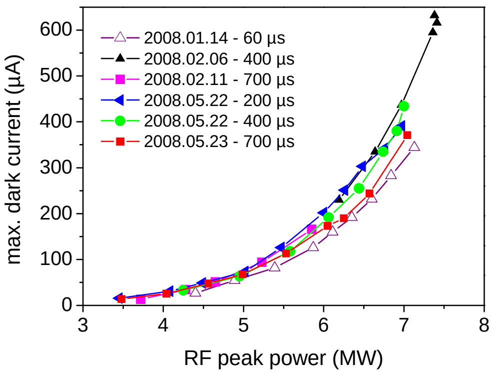

Figure 4: Maximum dark current as a function of gun power for different dates on CTS (January-February 2008) and on PITZ beamline (May 2008).

The gun 4.2 was moved to be installed in the PITZ1.7 beamline in May 2008 and the conditioning has been continued. Similar conditioning results for the reachable RF powers and the dark current levels have been achieved at the first month of its conditioning on the PITZ beamline. Operation in June 2008 showed worse vacuum condition and increased level of dark current. Further investigation at PITZ is ongoing in order to understand and to improve the situation again.

Dark Current Momentum Studies

The maximum momentum of the dark current spectrum has been measured at the CTS dispersive section for various gun peak powers from about 5 to 7.5 MW. Experimental results are plotted in Fig.5 showing that the highest momentum value achieved from the gun 4.2 while conditioning on the CTS was about 7.2 MeV/c at the RF peak power of 7.7 MW and the RF pulse of 60 μs flat-top with 32 μs filling time.

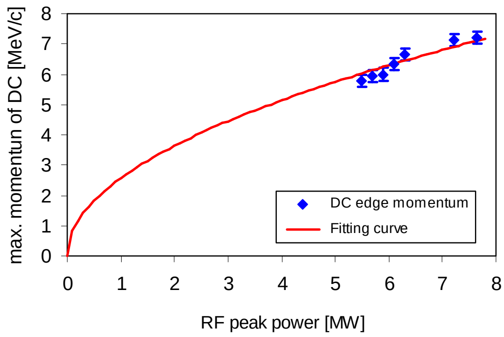

Figure 5: Maximum momentum of the dark current (DC) spectrum as a function of the gun peak power with the fitting curve.

The fitting function $p_z\,[\frac{MeV}{c}] = A\sqrt{P_{RF}[MW]}$ was applied to the measurement results where p_z is the maximum momentum of the dark current spectrum, the fitting coefficient A is 2.57 $\frac{MeV}{c\sqrt{MW}}$ and P_{RF} is the RF peak power. From the fitting curve, the maximum momentum of the dark current spectrum is about 6.6 MeV/c for the gun gradient of 60 MV/m. This momentum value is in reasonable agreement, within uncertainty of RF measurement and measurement precision, to the expectation from the simulation for the gun with the field balance of 5% which should be about 6.8 MeV/c [5].

CONCLUSION

The gun 4.2 is designed with improved water cooling system in order to be able to operate the gun cavity with higher gun RF power and longer pulses and also for better control of water flow rate in individual channel. After fabrication, tuning and cleaning it has been installed as the electron source at PITZ and has been conditioned on the CTS since the end of 2007 and the further conditioning is presently ongoing on the PITZ1.7 main beamline. Results of the conditioning showed that it has been conditioned to reach a gun gradient of about 60 MV/m with 700 μs RF pulses length and 10 Hz repetition rate.

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