PRE-BUNCHED ELECTRON BEAM EMITTANCE SIMULATION AND MEASUREMENT

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Abstract

The LUCX facility at KEK is used as the high brightness pre-bunched electron beam source for radiation experiments. Emittance measurement and optimization is one of the important research activities for newly developed operation mode of the facility. Characterization of the pre-bunched beam (THz sequence of a hundred femtosecond bunches) properties opens a possibility to establish detailed simulation of the THz FEL radiation yield and continuously improve pre-bunched beam dynamics insight. Emittance has been measured by the Q-scan method. The measurement results and possible ways of emittance optimization are discussed. The measurement results are compared with beam dynamics simulation done by self-consistent BEAMDULAC-BL code.

INTRODUCTION

The Laser Undulator Compact X-ray (LUCX) accelerator was originally designed to test and develop new RF-guns, study beam loading effect and explore new possibilities to generate high brightness electron beams. Nowadays facility is aiming to develop an intense X-ray source based on inverse Compton scattering and investigate various mechanisms for generating EM radiation including undulator radiation, Smith-Purcell and other special cases of polarization radiation (see Figure 1). The S-band 3.6cell RF-gun [1] has been used to generate both ps- and fs- electron beams. The cavity shape consists of smooth curves to increase the Q-factor of the cavity and to reduce dark current from the surface. It is equipped with Cesium Telluride (Cs_2Te) photocathode which is formed on the surface of the Molybdenum substrate of the cathode plug. The cathode is attached to the cavity by the load-lock system. An electron beam is emitted from the cathode by irradiating 266 nm UV laser pulse. The beam is accelerated up to 8 MeV with 1.0 MV/cm RF field amplitude on the cathode surface [2]. When photocathode is illuminated by a femtosecond laser pulses it can produce sub-picosecond electron bunches [3]. In this case emittance measurement and optimization is one of the important research activities since space-charge dominated beam properties are expected throughout initial acceleration in the RF gun. Moreover, characterization of the pre-bunched beam (THz sequence of a hundred femtosecond bunches) properties opens a possibility to establish detailed simulation of the THz FEL radiation yield and continuously improve pre-bunched beam dynamics insight.

BEAM DYNAMICS SIMULTION IN ACCELERATOR

The beam dynamics analysis in the accelerator was done using of BEAMDULAC-BL code [4]. The program allows simulation of the beam dynamics taking into account the beam loading effect and quasi-static components of the beam self-coulomb-field.

Simulation was done for electron gun which consists of four accelerating cells, first of them has $0.6\beta_{ph}\lambda/2$ and other has $\beta_{ph}\lambda/2$ cells length. Operation frequency is equal to 2856 MHz. Aperture radius for the entire channel is equal to 14 mm. For beam dynamics simulation in electron gun the following beam injection parameters were used: peak current 15 A and pulse duration about 1 ps, beam diameter on accelerating structure front-end is about 1 mm, focusing solenoid field on the channel axis is 0.3 T. The main parameters of the RF gun and beam dynamics simulation results are listed in Table 1.

Figure 2 shows main results of the numerical simulation of the beam dynamics in the RF gun: RF field amplitude distribution (a), the phase velocity (black) and the average energy of the electrons along the length of the accelerator channel (b), beam envelopes (c) in two transverse planes, beam cross-section (d) and energy spectrum (e). Initial beam parameters are shown by red points and lines and output – by blue. The graphs show a reasonable agreement with measured values taken at RF gun construction and tuning stages. Small deviation from typical RF gun output energy can be explained by lower accelerating gradient achieved for routine operation.

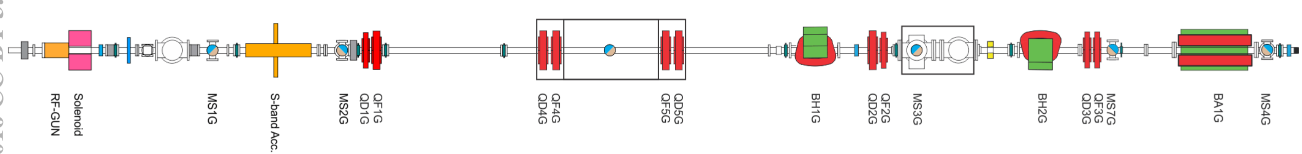

Figure 1: LUCX accelerator schematics.

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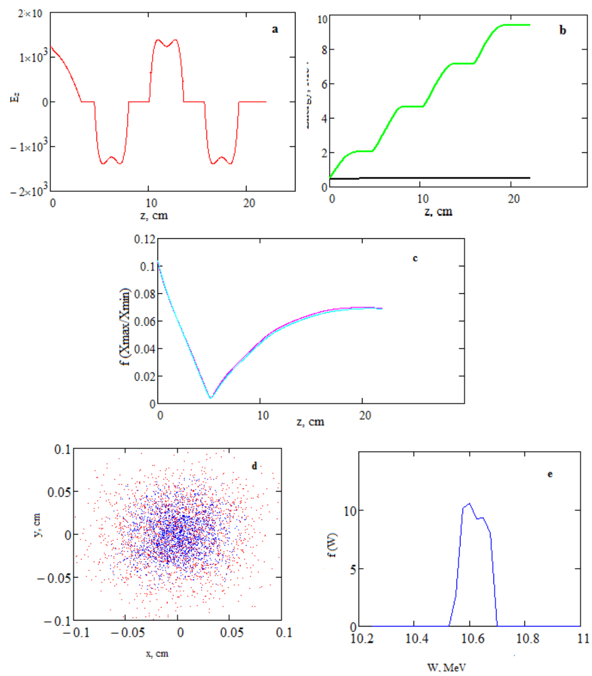

Figure 2: RF field amplitude distribution (a), graph of the phase velocity (black), the average energy of the electrons along the length of the accelerator (b), beam envelopes for both transverse axes (c), beam cross-section (d) and energy spectrum (e). E_{max} = 1.3 kV/cm.

Table 1: LUCX RF Gun Section Parameters and Results of the Beam Dynamics Simulation

Parameter	Value
Intensity/bunch max, pC	100
Length of wave, cm	10.504
Operating mode	π
Q – factor	16000
Shunt impedance, MΩ/m	35
Bunch length, min, fs	250
Bunch length, max, ps	10
Injection beam current, A	15
Beam energy, MeV	8
Current transmission coefficient, %	93.6
Longitudinal particles losses, %	6.4
Frequency, MHz	2856

Further the beam was simulated for different values of the RF field amplitude ranging from 1.0 to 1.3 MV/cm on the cathode for the analysis of the beam dynamics. Phase portraits for different values of the RF field amplitude are shown in Figure 3. It is also important to simulate the injection phase influence of the electron bunch output energy and to compare such dependences with experimental data. Results of such simulation are presented in Figure 4. It is clear that the length of the bunch is weakly depends of the injection phase and of the RF field amplitude.

To summarize beam dynamics simulation results one can emphasize that the electron beam can be effectively bunched and accelerated to the energy up to 10 MeV. The total current transmission coefficient for full structure reaches value of 93.6 %. Longitudinal loses are 6.4 %.The beam envelope can be effectively controlled.

TRANSVERSE EMITTANCE MEASUREMENT

The transverse emittance measurement at LUCX is routinely performed by means of a quadrupole scan [5]. However, it can not be measured for low charge femtosecond comb electron beam. The transverse beam size variation is measured for different current values of quadrupoles QD1G and QF1G (see Fig. 1). At first QF1G was set to 3.58 A and variation of the electron beam transverse distribution at CP1G luminescent screen was measured for various settings of QD1G. Then the QD1G was set to 3.05A and beam size was measured for various settings of QF1G. Dependences of the quadrupole current are showed in Figures 5 and 6. The typical beam image is shown at Figure 7.

Further analysis of the measured data reveals the value of transverse normalized emittance of 4pi mm*mrad in the vertical plane and 5 pi mm*mrad in the horizontal one. This result strongly correlates with laser injection parameters and solenoid magnet settings. With no doubt further detailed study on space-charge driven beam dynamics is required.

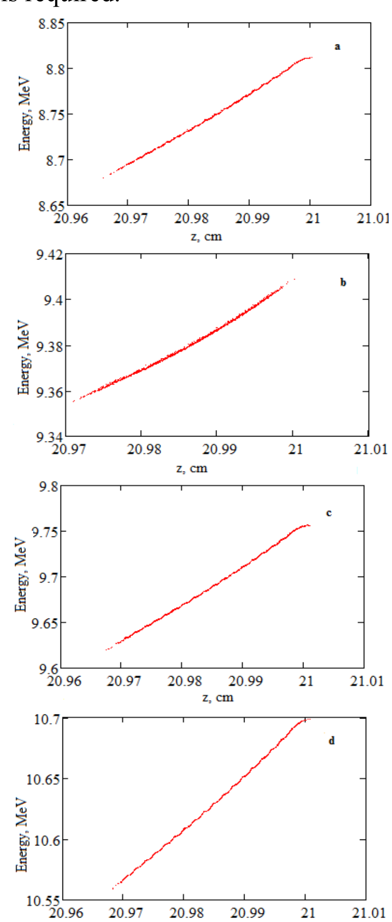

Figure 3: Phase portrait for E_{max} = 1.0 (a), 1.1 MV/cm (b), 1.2 (c) and 1.3 (d) MV/cm on cathode.

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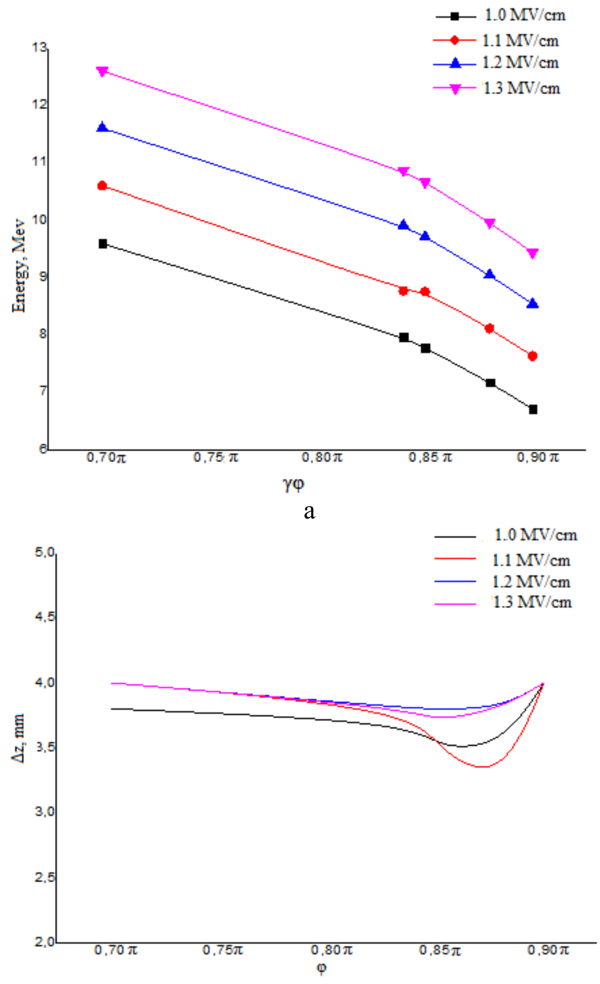

Figure 4: Dependence of the electron bunch average energy (a) and the bunch length (b) vs. injection phase δφ and RF field amplitude.

CONCLUSION AND FUTURE PLAN

We present the first attempt on measurements of transverse emittance of the femtosecond comb electron beam recently generated at KEK:LUCX facility. The emittance was measured by a Q-scan method.

The beam dynamics simulation also shows promising results and reasonably agrees with experimental data. The analysis of the particles loss reasons and further machine optimization will be continued.

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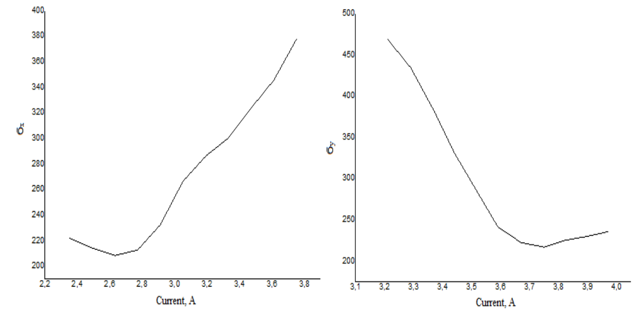

Figure 5: Electron beam transverse distribution at CP1G luminescent screen as a function of QD1G Quadrupole current. QF1G was set to 3.58 A.

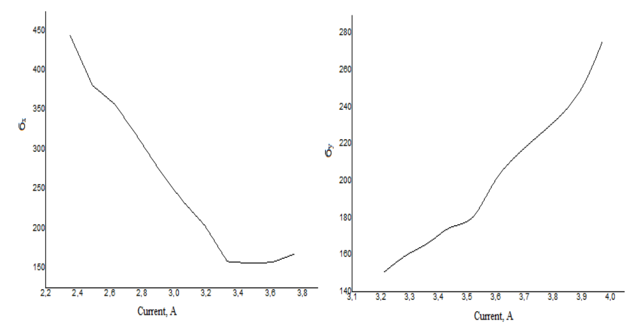

Figure 6: Electron beam transverse distribution at CP1G luminescent screen as a function of QF1G Quadrupole current. QD1G was set to 3.05A.

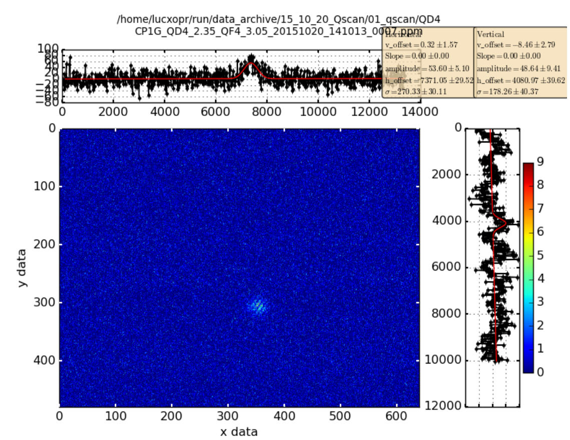

Figure 7: Typical electron beam transverse profile at CP1G luminescent screen.

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