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BEAM SIMULATIONS OF THE ALBA AND BESSY II ELECTRON GUNS

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Abstract

The ALBA and BESSY II Linacs consist of a dc-grid thermionic Pierce-type electron gun that delivers e- at 90 keV in pulses of 1 ns. The gun is followed by a set of standing wave cavities for bunching purposes and traveling wave accelerating structures to further increase the beam energy, up to 50 MeV at BESSY II and up to 100 MeV at ALBA, while keeping the beam energy spread below 0.5% (rms). This paper studies the impact of the space-charge effects by simulating the beam parameters at the exit of the e-gun for different bunch charges. For that, electrostatic field maps have been obtained using the Superfish code, according to the technical drawings provided by the manufacturer Thales, and included in the simulation tracking code General Particle Tracer (GPT). Results from the simulations are compared to the values reported in the Thales technical documentation, and also to the real measurements performed at the BESSY II gun test-stand, leading to a better understanding of both Linacs.

MOTIVATION

In the past, a model of the ALBA Linac was developed in General Particle Tracer (GPT) tracking code and was successfully used to obtain an optimization procedure to minimize beam losses along the bunching stage of the Linac [1]. Since then, different adjustments of steers and focusing elements are used for Single Bunch (SBM) and Multi Bunch (MBM) modes to compensate the impact of space-charge effects in the beam transmission along the low beam energy section. The simulation model was lacking the electron gun field maps, hence the input electron bunch used in these simulations was defined at the exit of the gun (at the anode center), according to the specifications provided by the manufacturer, namely beam size and divergence, for the two different bunch charges or equivalently Linac operating modes (see Table 1).

Table 1: Beam parameters at the anode center provided by the Linac manufacturer, Thales.

	SBM	MBM
Charge/Bunch [nC]	0.4	0.02
Beam Size [mm]	2.9	1.8
Beam Divergence [mrad]	-13	5

The manufacturer obtained these values by simulating the electron gun using a similar gun geometry, but not the real one (see Fig. 1), from which only a few working points were provided, leading to a partial understanding of the electron beam at the exit of the electron gun.

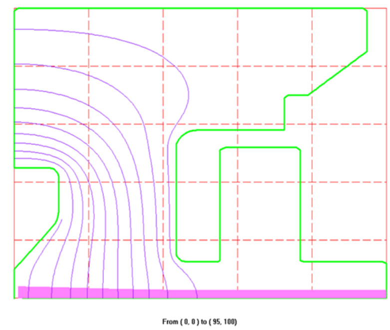

Figure 1: Electric potential lines of the electron gun simulated by Thales with SLACGUN code [2] in a geometry that does not coincide with the real electron gun installed at ALBA and at BESSY II.

Neither beam sizes nor beam divergences can be measured at the electron gun exit. However, the electron beam generation can be simulated more realistically by the use of electromagnetic field maps of the electron gun system. The field maps have been created by Superfish codes [3] and implemented in the GPT model. This way, the whole simulations accuracy will be as well improved. To validate the electron gun model the simulated beam sizes have been compared with the ones measured at the BESSY II gun test-stand at different Linac operating modes (SBM and MBM).

The Electron Gun

The ALBA and the BESSY II electron guns are almost identical [4, 5]. Both have installed an EIMAC Y845 thermal cathode, consisting of a tungsten cylindrical metal of 0.5 cm^2 surface diameter coated with BaO. The cathode is heated at 1200 degrees and set at -90 kV. The anode is a hollow cylinder set at 0V and placed 30 mm downwards.

Electron pulses are generated by modulating the cathode grid at 500 MHz. The modulation is defined at the non-programable digital electronics unit, the so-called timer unit, which allows generating pulses in different configurations (in multi- and single bunches). The timer unit is placed outside the Linac bunker and sends the pulses to the cathode via a high bandwidth analogue optical link. An optical receiver placed at the Cathode Diver Board (CDB) amplifies and transfers the pulses to the cathode by transistor polarization. The CDB also provides parameters like the filament current or the cathode voltage.

The two electron guns are optimized at slightly different working points mainly due to different CDB electronics adjustments. At BESSY II the maximum charge per bunch is set to 0.35 nC whereas at ALBA single bunches have a maximum charge of 0.25 nC. This is regardless that both

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injectors operate at different nominal modes: 5 single bunches are fired at a repetition rate of 1 Hz at BESSY II while the ALBA Linac is set at one 40-bunch train at 3 Hz repetition rate.

Recently, the electron gun control system of the BESSY II Linac has been tested with the so-called Flexi-Gun system, which generates the pulses of electrons via FPGA instead of using the timer unit [6]. The new system provides high-flexibility pulse generation to fulfil the injection pattern demands of the BESSY II storage ring.

The BESSY II Gun Test-stand

The BESSY II gun test-stand consists of an electron gun system identical to the one installed at BESSY II Linac, used for testing repaired instrumentation and spare parts before being installed at the Linac gun. A schematic of the test-stand is shown in Fig. 2. The gun points to a Faraday cup and along the way the beam current and beam size can be measured, by a FCT and a YAG screen, respectively. A solenoid and a pair of steer magnets are used to focus and align the beam along the beam pipe. The magnetic beam profile of the solenoid is plotted in Fig. 3.

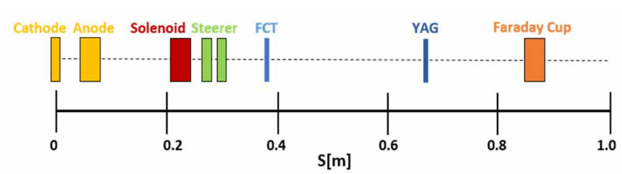

Figure 2: Schematic of the Bessy II gun test-stand.

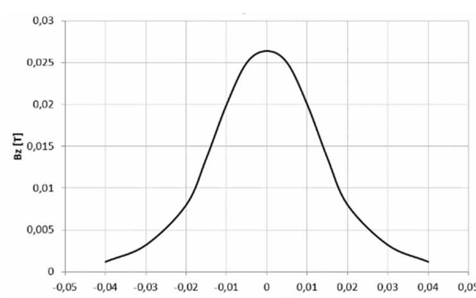

Figure 3: Magnetic field profile of the gun test-stand solenoid taken at current of 0.2 Amps.

THE ELECTRON GUN FIELD MAP

Superfish codes have been used to simulate the electric fields generated in the electron gun under different gun voltage settings. To define the 2D geometry of the different electron gun elements in the code, the technical drawings delivered by the manufacturer have been used. For the sake of accuracy, the dimensions have been crosschecked from a used Y845 cathode. The distance from the cathode to the anode center has been found to be 97.4 mm, instead of 95 mm used so far in the simulations provided by Thales.

Only one half of the geometry is introduced in the code due to cylindrical symmetry (see Fig. 4). To compute the potential and the electric fields a uniform mesh has been used, whose optimum size has been found to be 30×30 µm. The different gun elements are not connected among them for the e-fields computation, since it was found that it makes a small difference (lower than 1.3%) compared to connecting them. Also, the grid effect is not considered.

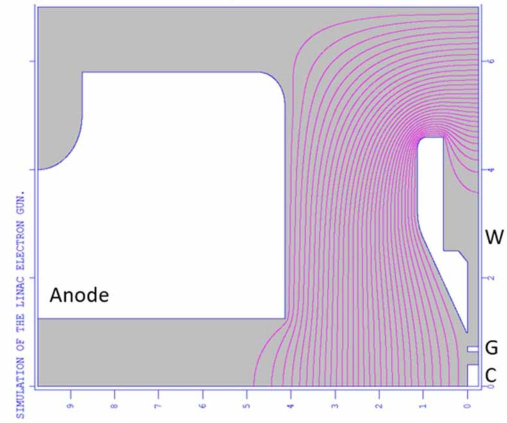

Figure 4: E-gun field map obtained with Superfish codes using the actual electron gun dimensions. Cylindrical geometry is used. The anode is plotted until its center. W refers to wehnelt, G to grid and C to cathode.

Electric field simulations show that electrons reach the maximum voltage before arriving at the anode (see Fig. 5), i.e., the field is not uniform between the cathode and anode.

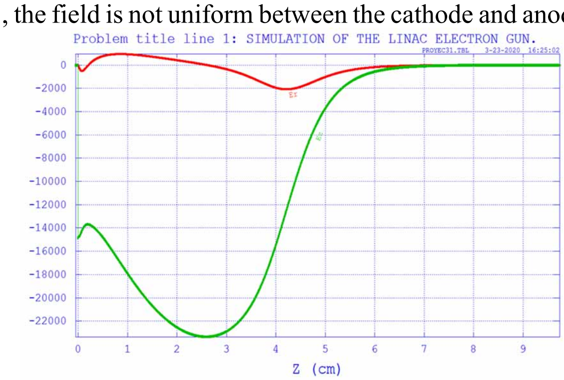

Figure 5: Electric field (longitudinal in green and radial in red) along the central axis of the electron gun. Notice that the main acceleration occurs within the first 10 mm.

RESULTS

Beam Size and Divergence at Gun Exit

Tracking simulations from the cathode to the center of the anode are carried out by GPT code using the obtained e-gun field maps. The extracted beam size and divergence can be compared with those values reported by Thales in Table 2.

Table 2: Beam size and divergence for two bunch charges. The values from the specifications of the manufacturer and from the GPT simulations agree on the beam size, but not on the divergence.

Charge/Bunch	**SBM (0.4 nC)**		**MBM (0.02 nC)**	
	Specs	**GPT**	**Specs**	**GPT**
Beam Size [mm]	2.9	2.8	1.8	1.75
Divergence [mrad]	-13	9	5	2.1

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Beam size values are well consistent with those reported by Thales. Simulated divergences have been found to be higher for higher charge bunches, as one expects due to space-charge effects. However, the divergence values given by Thales show the opposite trend, where higher charges have lower divergences, which is not yet understood.

Beam Size at BESSY II Gun Test-stand

The GPT gun code has also been used to perform tracking simulations of the beam at the BESSY II test-stand under different bunch charge and different electron gun voltage, with the aim to obtain the beam size behaviour.

Figure 6 shows the simulated beam sizes along the gun test-stand for two different bunch charges and for a solenoid current fixed at 0.28 Amps. Beam sizes show a strong dependence on space-charge. Right after the gun the beam size of the SBM bunch is twice that of the MBM bunches and they are also focused at different positions along the test-stand. Besides that, the beam sizes have shown a low dependence on the voltage applied between the cathode to anode, hence all simulations consider a voltage difference of -90 kV.

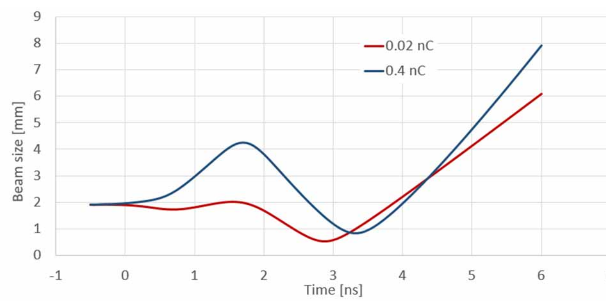

Figure 6: Horizontal beam size along the test-stand for two different bunch charges with solenoid set at 0.28 Amps. The YAG screen is set at 4.5 ns.

To crosscheck the simulation results, beam size measurements were taken at the YAG screen of the BESSY II test-stand for 0.3 nC bunches at different solenoid currents. Figure 7 shows that the minimum beam size was found at 2.7 mm for a solenoid current of 0.28 Amps.

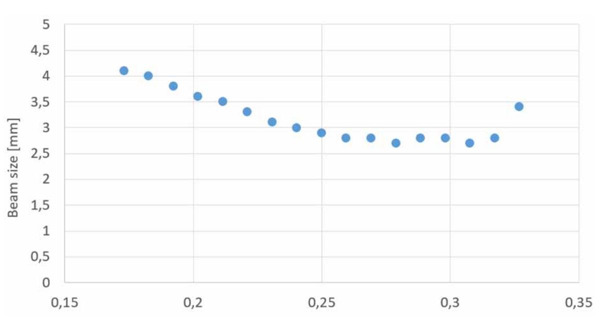

Figure 7: Preliminary experimental beam size measurements at the YAG screen position at the BESSY II gun test-stand of 0.3 nC bunches for different solenoid current. The minimum beam size is 2.7 mm for 0.28 Amps at solenoid.

These are preliminary results since measurements were not easy to perform at the gun test-stand due to several issues like beam misalignment while adjusting the solenoid current and due to poor sensitivity detection at low charges at the YAG screen.

On the other hand, simulated beam sizes at the YAG screen position obtained from scanning the solenoid current for different bunch charges are presented in Fig. 8. As observed, higher charge bunches need higher solenoid currents to focus the beam at the screen. In particular, the data points in orange show both, the simulated and measured beam sizes for 0.3 nC bunches. Despite the differences in beam size, it is significant that both, the measured and simulated solenoid focusing current fit very well.

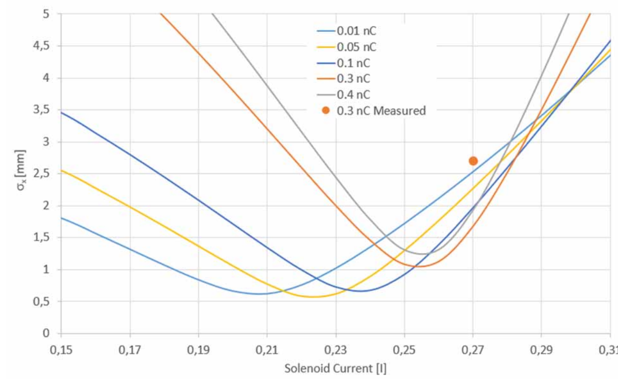

Figure 8: Horizontal beam sizes vs solenoid beam current at the YAG screen position at the gun test-stand for different bunch charges.

SUMMARY AND CONCLUSIONS

Electromagnetic field maps of the ALBA and BESSY II electron gun systems (both are identical) have been created in Superfish and implemented in the GPT tracking code to obtain the beam sizes and divergences for different beam charges. Beam size measurements at the test-gun at BESSY II validate the more realistic simulation set-up, which is crucial to determine the beam properties at any given point in the ALBA and BESSY II Linacs.

REFERENCES

[1] E. Marin *et al.*, “Optimization of the Alba Linac Operation Modes”, in *Proc. IPAC’19*, Melbourne, Australia, May 2019, pp. 1086-1089. doi:10.18429/JACoW-IPAC2019-MOPTS095

[2] A. Setty, “Beam Dynamics of the ALBA Linac”, THALES report, 2007.

[3] Poisson-Superfish manual report: https://lib-www.lanl.gov/pubs/LA-UR-87-126.htm

[4] A. S. Setty *et al.*, “Commissioning of the 100 MeV Preinjector for the ALBA Synchrotron”, in *Proc. PAC’09*, Vancouver, Canada, May 2009, paper FR5REP088, pp. 4984–4986.

[5] T. Atkinson *et al.*, “Commissioning of the 50 MeV Preinjector Linac for the BESSY II Facility”, in *Proc. IPAC’11*, San Sebastián, Spain, September 2011, paper THPC108, pp. 3140.

[6] D. Schüler *et al.*, “Flexi-Gun Research and Development Project at BESSY II”, presented *at IPAC’23*, Venice, Italy, May 2023, paper TUPL123, this conference.