BEAM DYNAMICS SIMULATIONS FOR A 15 MEV SUPERCONDUCTING ELECTRON LINAC COUPLED TO A DC PHOTO-INJECTOR

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Abstract

A 15 MeV accelerator scheme based on a DC photo-injector and a RF superconducting linac has been proposed as a new facility for radiography applications. The beam operating condition is a limited number of bunches up to twenty electron micro-pulses of 100 ps time duration and 200 nC bunch charge at 352 MHz repetition rate.

The overall beam dynamics simulation process based on LANL POISSON-SUPERFISH and PARMELA codes, is presented and the results will be reviewed.

INTRODUCTION

A new versatile scheme based on well-tested technologies has been studied in the purpose to produce flash X-ray pulses from very intense electron beams impinging a high Z material target [1].

This machine consists to a DC photo-injector coupled to a RF superconducting accelerator. A final beam transport allows tight beam focusing on the target. Electrons bunches are emitted from a photocathode driven by a 266 nm wavelength laser and extracted up to the_energy of 2.5 MeV in a DC gun. The beam is accelerated in a 352 MHz RF-cavity to a final energy of 15MeV (Fig. 1). Among several applications, one requires a total accelerated charge of 1µC. In this scope, we studied two beam distributions in time: either ten electron bunches carrying 100 nC each (pulse time duration of 28 ns) or five electron bunches carrying 200 nC each (pulse time duration 13 ns).

Beam dynamics have been computed using a simulation chain based on LANL codes POISSON-SUPERFISH [2] and PARMELA [2]. The optimizations of the photo-injector beam transport and the final focusing on the target are presented. The results for the whole machine simulation are reviewed for the two different configurations.

BEAM DYNAMICS CHART

Our beam dynamics study is based on the LANL POISSON-SUPERFISH and PARMELA codes. We have linked them together through a graphical interactive interface which was developed specifically for this use (Fig. 2). POISSON-SUPERFISH first computes electromagnetic field maps of the photo-injector, the RF cavity and final focusing. These results are used as input data in PARMELA to calculate the beam dynamics along the machine. We have developed coupling and post processing tools compatible with CEA-PLOTWIN software (*.plt) [3] which allows powerful, interactive and friendly viewing of the beam behaviour.

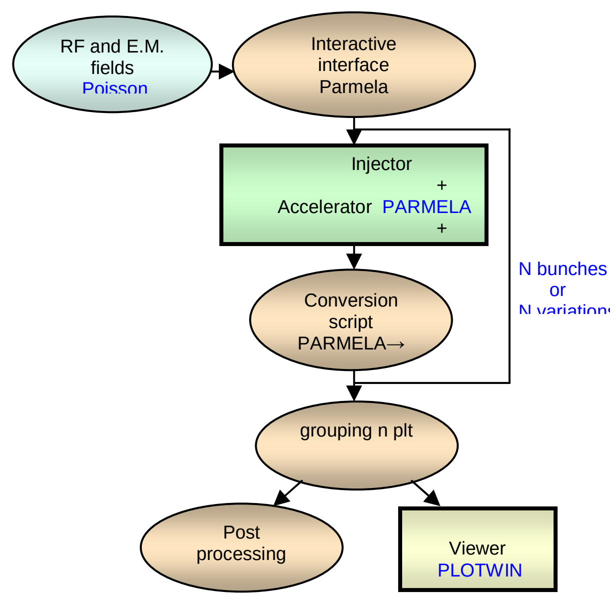

Figure 2: Beam dynamics simulation chart.

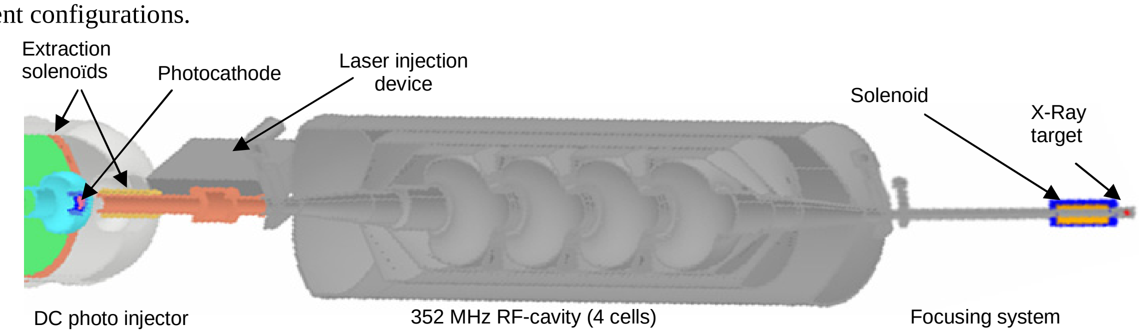

Figure 1: Scheme for the 15MeV RF proposed machine.

For identical beam input conditions, comparisons with other codes (MAGIC, PARTRAN) and experimental validations have been carried out in order to validate this beam simulation scheme.

PHOTO-INJECTOR OPTIMIZATION

The photo-injector [4] delivers to the linac the required 2.5 MeV pulsed e-beam with the smallest achievable emittance. Every bunch is emitted at 352 MHz and has an initial uniform transverse distribution as well as a 100 ps FHWH time Gaussian distribution.

The photocathode shape, the electrode geometry and the focusing lens contribute to the beam quality (Fig. 3). A cathode recess and the magnetostatic focusing system have been optimized to deal with the space charge effect at the emission and during extraction.

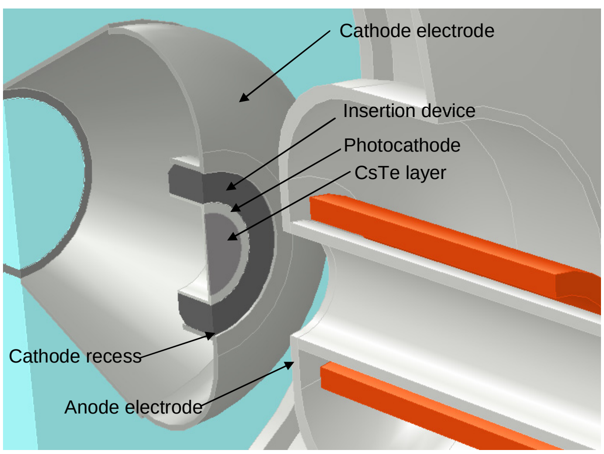

Figure 3: Cathode electrode with photocathode structure.

Cathode Recess

The emitive surface of the photocathode has a 40 mm diameter Cs_2Te deposit layered on a 50 mm diameter molybdenum substrate. The photocathode assembly is mechanically inserted by remote handling under ultra high vacuum.

We have performed beam dynamics simulations for different cathode recess values. The cathode recess locally curves the electric field lines. This effect induces a transverse electric field component which contributes to transverse focusing. Since the electron beam is early focused at emission, the space charge is under better control and nonlinear effects are limited.

The beam dynamics has been optimized to provide a parallel beam at the linac entrance (Fig. 4). The best beam transport (lowest emittance) is obtained for a 4 mm length cathode recess. The net gain in emittance is close to 30%.

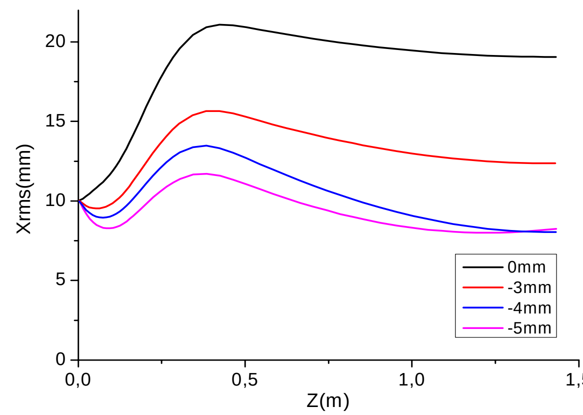

Figure 4: RMS beam envelope for different cathode recess.

Magnetic Focusing at Extraction

The magnetostatic focusing at extraction is based on a solenoid lens. Two options were considered. The first one is made of a main solenoid surrounding the anode vacuum tube and a bucking coil at the cathode surrounding the vacuum vessel. Initial momentum condition is then nil and increase in emittance is limited. The second option consists to a single solenoid which has been magnetically shielded. This last solution produces a stronger magnetic field localized in a restricted volume and acts as a short magnetic lens (solenoids must be considered as long magnetic lenses). In addition, no need for a bucking coil is required in this case. Tune is consequently eased.

Former results (Fig. 5) showed that the solenoid location along the beam axis is a critical parameter. After optimization of the two options, the second one (shielded coil) leads to a decrease of the beam emittance by about 10%.

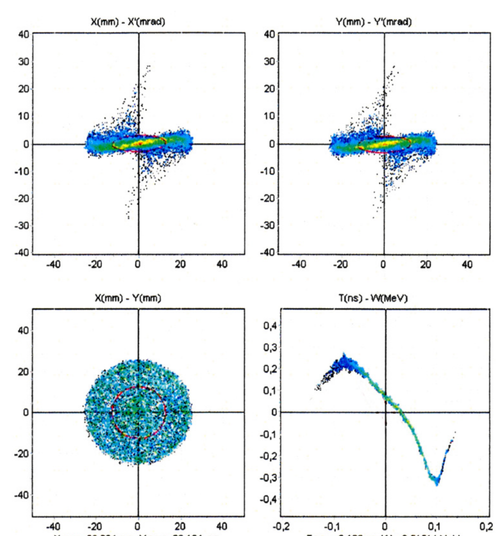

Figure 5: Phase space diagrams with the optimized shielded coil at the linac entrance.

SIMULATION RESULTS OF THE WHOLE ACCELERATOR MACHINE

Beam dynamics of the whole accelerator machine has been carried out thanks to the simulation chain described above. The optimized values of the photo-injector are used. The linac RF cavity phase is tuned to provide the lowest RMS beam energy spread. The final focusing system is adjusted to provide the smallest spot on the target. Two different bunch configurations have been studied: 5 bunches of 200nC/bunch and 10 bunches of 100nC/bunch. Differences between these configurations are essentially the total beam duration from 13 ns to 28 ns, the space charge effects and the beam loading in the RF cavity.

The beam envelopes and the phase space diagrams on the target are shown on the figures below (Figs. 6-8).

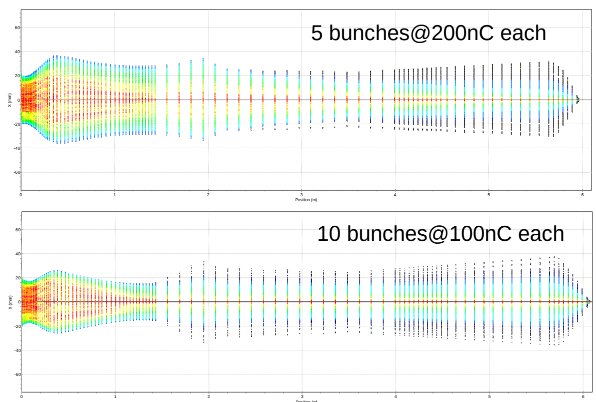

Figure 6: RMS beam envelope for the two configurations.

Although the number of bunches and charge per bunch are very different, the simulations for the two accelerated beam configurations give very close results (difference of only 5% on the spot size). The larger energy spread due to the beam loading of the 10 bunches train configuration carrying 100 nC each is balanced by the higher space charge effect of the 5 bunches train configuration carrying 200 nC each.

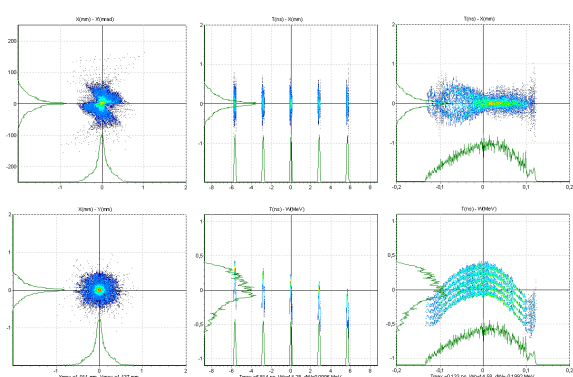

Figure 7: Phase space diagrams on the target for the 5 bunches@200nC per bunch configuration.

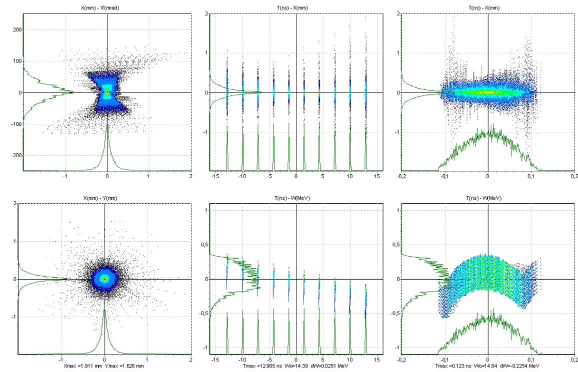

Figure 8: Phase space diagrams on the target for the 10 bunches@100 nC per bunch configuration.

The 5 bunches train configuration @200nC leads to faster radiographic imaging (13 ns) at same spot size and dose. In addition, the total length of the high voltage generator part of the photo-injector is shorter allowing a more compact overall radiographic facility.

CONCLUSION

Beam dynamics simulations for a new X-ray radiographic project have been performed with an interactive, fast and accurate chain simulation codes based on POISSON- SUPERFISH and PARMELA .

Photo-injector beam transport calculations have showed that a single shielded solenoid achieves best beam qualities (10% reduction in beam emittance) than the usual focusing configuration using long solenoid and bucking coil. Thanks to a cathode recess, the early space charge effect is limited in the photo-injector. In consequence the beam emittance is lowered by 30% for a 4 mm optimized cathode recess.

The whole machine simulations for a 1µC total charge beam have been carried out for two beam configurations: 5 bunches of 200 nC each and 10 bunches of 100 nC. Quite similar beam characteristics are obtained on the target. Spot size and dose are the same. The 5 bunches train configuration @200nC allows faster radiographic imaging (13 ns). The total length of the high voltage generator part of the photo-injector is also shorter allowing a more compact radiographic facility.

REFERENCES

[1] "Beam Dynamics simulation and DC photo-injector Design for CEA RF Accelerator", S. Pichon, D. Guilhem, Pulse Power Conference 2007.
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[4] "A 2.5 MeV Pulsed Photo-Injector Demonstrator for Radiographic Applications", J-L. Lemaire, IPMC 2008, Las Vegas, USA.