END TO END SIMULATIONS OF THE RX2 BEAM TRANSPORT

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Abstract

RX2 is a project aiming to produce a high flux of X-rays for radiography purpose. We proposed an RF linac using a DC photo-injector producing 20 bunches with 100nC each at 352 MHz. The beam is injected in 4 RF superconducting cavities and accelerated to 50 MeV. It is then focused on a target producing X-rays. Here is presented the design, the specificities, and the beam simulations from the cathode to the target by coupling 2 multiparticle codes: PARMELA and PARTRAN.

INTRODUCTION

We are aiming to produce a high flux X-rays short pulse with a very intense 50 MeV electron beam colliding a production target. The electron 55-ns short pulse is made of 20 bunches repeated at 352 MHz. Each bunch has a 100 nC charge and is about 100 ps long. A schematic layout of the accelerator is presented on figure1. These bunches are produced in a pulsed 2,5 MV DC photo-injector (figure 2). The laser spot size on the cathode is 50 mm diameter. These bunches are then accelerated with four 352-MHz LEP-like 4-cells superconducting cavities to an average energy of 51 MeV. The beam is then focused on a target with a solenoid lens. The goal is to reach a beam spot size smaller than 1 mm.

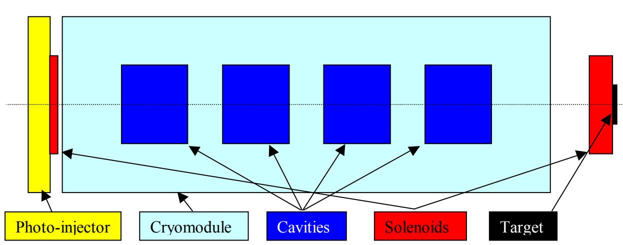

Figure 1: Accelerator schematic layout.

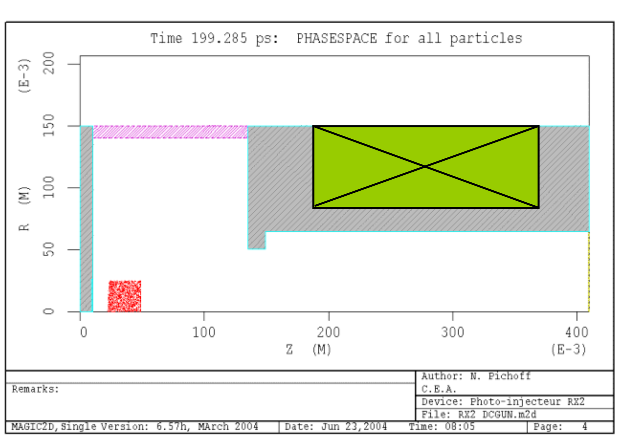

Figure 2: DC photo-injector schematic layout.

After having presented the specificities of this accelerator, we will show how different codes have been coupled together to allow simulations of the transport of the full pulse made of 20 bunches beam in the full accelerator.

RX2 SPECIFICITIES

A 7,5MV/m conservative value has been chosen for the accelerating field in the cavities. Cavity length is about 1.7 m, giving a 12.75 MeV maximum energy gain in each cavity. RF phase is set to get almost the maximum energy gain in the cavities (12.6 MeV per cavity). The final energy of the first bunch on the target is then about 43 MeV.

The specificity of RX2 accelerator is the following: The power taken by the pulse from the cavity is about: 100nC×12.6MV×352MHz = 444 MW. It is unbelievable to feed the cavity with such a high power in order to maintain the field level in the cavity !! As a consequence, each cavity is previously filled with a low power generator (a few tens of kW) to its maximum energy (160 J) and each bunch takes to the cavity an energy of about 100nC×12.6MV = 1,26 J. The voltage of the cavity is then decreasing bunch after bunch (stored energy is proportional to square of electric field amplitude) from 12.6 MV to about 11.6 MV. This 1 MV voltage drop per cavity induced a final 4 MeV beam energy spread at the end of the linac. The consequence is important: This energy spread increases significantly the minimum beam size that can be reached on the target.

PHOTO-INJECTOR SIMULATION

Two codes have been used to calculate the beam dynamics in the photo-injector: PARMELA [1] and MAGIC [2].

- PARMELA is a very popular and fast LANL code used in many laboratories for electron guns calculation. Dynamics of each electron is solved with time in external electric and magnetic field maps. Space-charge is calculated at a given lab.-frame time by solving Poisson equation in the bunch frame. In cylindrical symmetry, the SCHEFF routine has been used. Cathode is modelled with image charges.
- MAGIC is solving the Maxwell equations in a mesh using finite difference model. It takes into account particle positions and velocities as well as metallic and open boundaries. Particles motion equation is solved at each time-step.

MAGIC model is more sophisticate than PARMELA's one, but calculation time is also bigger. Some other

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simulations [3] have been done with the MAFIA [4] code, but there results have not been implemented for end-to-end simulations yet.

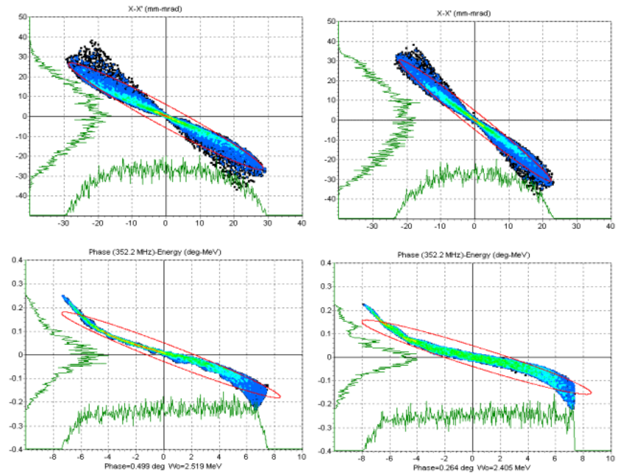

Figure 3: Transverse and longitudinal phase-space at photo-injector exit. Left : PARMELA; right: MAGIC.

The beam transverse and longitudinal phase-space distributions obtained with both codes at photo-injector exit (80cm from the cathode) are plotted with PlotWIN code [5] on Figure 3.

Even if using different models, code results are in pretty good agreement. However, the transverse dynamics is slightly different due to different beam output energy : At 2.5 MeV (beam energy given by PARMELA) the beam is more rigid than at 2.4 MeV (given by MAGIC). This difference of energy is due to the influence of the vacuum chamber taken into account by MAGIC and not by PARMELA. Nevertheless, an increase of the focusing force in PARMELA gives a sufficiently good approximation (at this stage of the project) for the beam dynamics calculations.

LINAC SIMULATION

First Bunch Transport

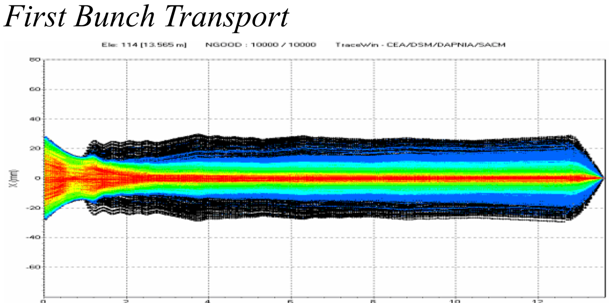

Figure 4: First bunch transverse density profile along the accelerator.

The first bunch distribution given by PARMELA is injected at input of PARTRAN [5] code. The bunch is transported through cavities RF-field maps calculated with SUPERFISH [6] code. The bunch synchronous phase in cavities is slightly negative in order to give a little more energy to earliest particles to compensate the space-charge longitudinal effect at low energy giving more energy to early particles than later ones (see Figure 3). At the end of the linac, the bunch energy spread is as low as possible. The bunch transverse density profile along the accelerator is plotted on Figure 4. The bunch is then focused with a solenoid lens as small as possible (envelope diameter : 0.54 mm) on the target. Its phase-space distribution is plotted on Figure 5.

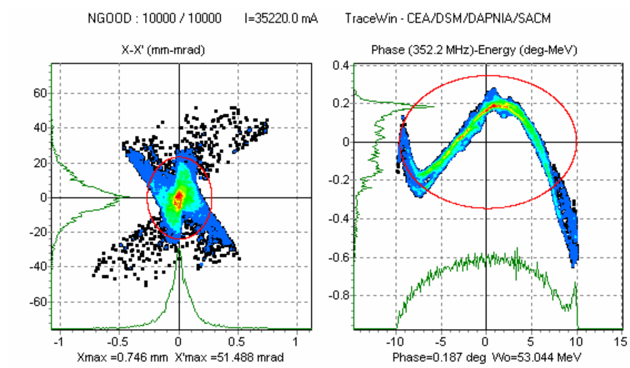

Figure 5: First bunch transverse and longitudinal phase-space distribution on the target.

Full Pulse Transport

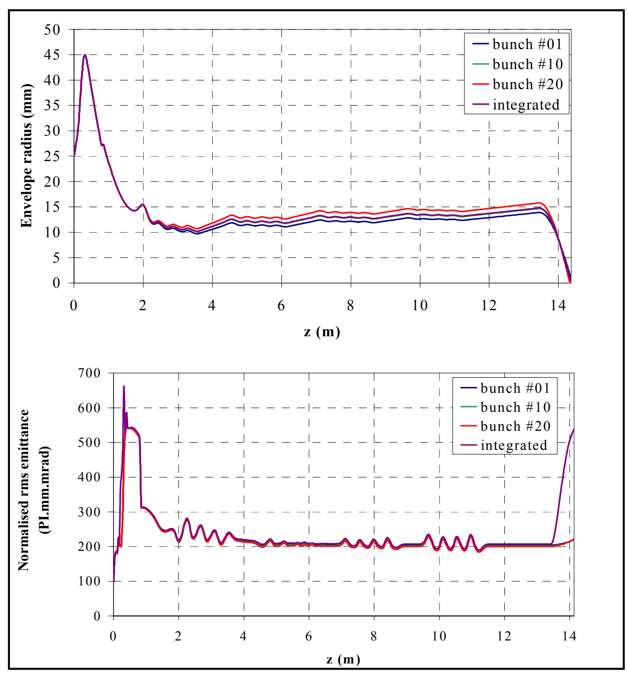

Figure 6: Evolution of beam (first, middle and last bunch, full pulse) parameters along the accelerator. UP: Envelope radius, DOWN: rms normalised emittance.

In order to simulate the transport of the full pulse containing 20 bunches, the PARTRAN and PARMELA code have been integrated in one code that calculates automatically the transport of the 20 bunches. Its principle is the following:

It calculates the phase and the field in each cavity taking into account the beam loading, generates the codes input files, runs the transport codes and process and merge their results.

The result is an evolution of the parameters of the individual bunches and full pulse (Figure 6) in the line and the bunch and pulse particle distribution on the target (Figure 7).

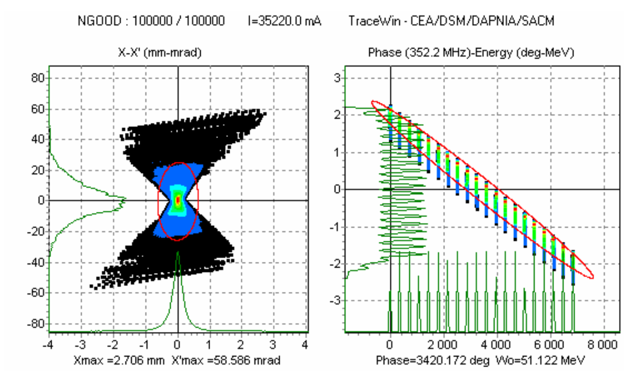

Figure 7: Full pulse transverse and longitudinal phase-space distribution on the target.

The bunch envelopes are almost the same except the cavities transverse kicks due to different field in them. The bunch emittances are the same. The emittance of the full pulse increases in the focusing region because of the chromaticity induced by the solenoid lens.

The triangular shape of the full pulse distribution in the transverse phase-space on the target is due to chromaticity of the focusing solenoid lens. The first bunch, with its energy of 53 MeV is under-focused on the target as the last bunch, with its energy of 49 MeV is over-focused. A zoom of the bunch envelopes in the target region (Figure 8)) shows very well this effect.

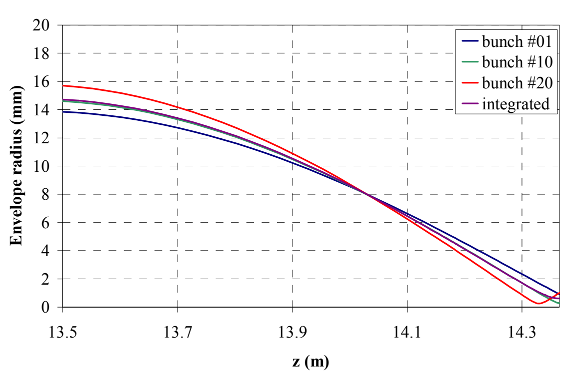

Figure 8: Zoom of the bunch envelopes in the target region.

The pulse envelope diameter on the target is: 1.24 mm. The contribution of the bunch to bunch chromaticity can be estimated to 1.1 mm.

Some studies are made to reduce the chromaticity of the focusing section. We have shown that the chromaticity can be easily reduced by 25% by using 2 solenoid lenses rather than 1.

CONCLUSION

Two codes, PARMELA and MAGIC have been used to simulate the beam production in the photo-injector. The effect of image charge reduces the beam exit energy from 2.5 MeV to 2.4 MeV, changing a little the rigidity of the beam and then its focusing by the solenoid lens.

The codes PARMELA and PARTRAN have been coupled to simulate the full pulse made of 20 bunches taking into account the field decay in the cavities. The effect of the chromaticity of the focusing lens have been estimated and it has been shown it is limiting the minimum spot size than can be achieved on the target.

The decay of field in cavities has been considered only on the main RF-mode (352MHz). In the future, we have planed to evaluate the excitation of other modes and their effects on the beam energy spread or transverse displacement.

REFERENCES

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