A 15 MeV ACCELERATOR SCHEME BASED ON A DC PHOTO-INJECTOR AND A RF SUPERCONDUCTING LINAC

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Abstract

A 15 MeV accelerator[1] scheme based on a DC photo-injector and a RF superconducting linac has been proposed as a new facility for radiography applications. The design of a 15 MeV, 2 kA peak current, CEA electron accelerator project is presented.

A limited number of bunches up to twenty electron micro-pulses of 100 ps_time duration and 200 nC bunch charge is emitted at 352 MHz repetition rate from a Cs_2Te photocathode and accelerated to 2.5 MeV in the DC diode before injection into a superconducting linac.

A general description of the main accelerator components and the beam dynamics simulations are presented. The overall beam dynamics simulations using LANL POISSON-SUPERFISH and PARMELA codes and diode E.M. simulations are reviewed.

INTRODUCTION

In order to produce flash X-ray pulses from very intense electron beams impinging a high Z material target, we studied a new versatile scheme based on well-tested technologies. In order to achieve compactness and low cost, this machine consists of a DC photo-injector coupled to a RF superconducting accelerator and a final focusing line that allows a very tight beam on the target (Fig. 1). A pulsed power supply composed of a prime power, a Blumlein and coaxial transmission lines drives the diode accelerating voltage.

Electron bunches are emitted from a CsTe photocathode driven by a 266 nm wavelength laser and extracted up to the energy of 2.5 MeV in a DC gun. A short drift section between the photo-injector and the linac allows room for the injection of the photocathode laser beam, a vacuum valve and several beam diagnostics. A 352 MHz RF-cavity accelerates the 1μC total charge beam to a final energy of 15 MeV.

To guarantee long life to the photocathode (several weeks), the diode vacuum level must be about 10^{-10} mbar. The interface separating the dielectric coaxial transmission line from the vacuum of the diode part has to withstand high voltage insulation, mechanical stresses and UHV vacuum. We optimized geometries and shapes with several material candidates.

We studied three beam distributions in time:

- 10 electron bunches carrying 100 nC each
- 5 electron bunches carrying 200 nC each
- 20 electron bunches carrying 50 nC each

Beam dynamics have been computed using a simulation chain based on LANL codes POISSON-SUPERFISH [2] and PARMELA [2]. Beam transport optimizations and simulations for the whole accelerator are presented.

DIODE SIMULATIONS

The interface separating the oil dielectric inside the coaxial transmission line from the vacuum of the diode part is a major component of the photo-injector. The design must take into account the high voltage hold off, the mechanical size and stresses, the required vacuum as low as 10^{-10}mbar and the feasibility with low cost.

Maximum E fields are localized on the vacuum side and on the triple points (junction point between vacuum, insulator and conductor). To determine the E field limits, we have simulated with OPERA code [4] the AIRIX diode [3] operating at 3.9 MV. (Note: this geometry cannot withstand Ultra High Vacuum). We determined that the fields must be lower than 130 kV/cm and 80 kV/cm on triple points.

We ended up with two different solutions (fig. 2): a borosilicate plain disc panel and a stack column made of alumina rings and intermediate metallic washers. Electrode geometries have been optimized to achieve the lowest and constant E peak field values on surface of electrodes. Voltage hold off must be safe up to the maximum accelerating voltage of 2.5 MV during 100 ns.

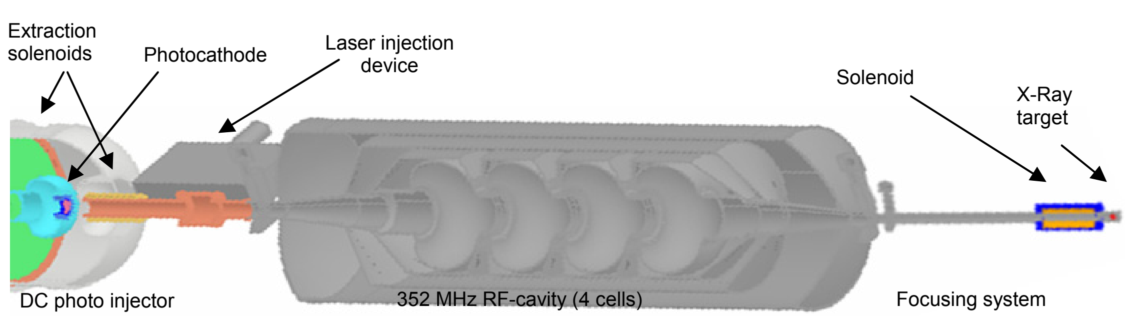

Figure 1: Scheme for the 15 MeV RF proposed machine.

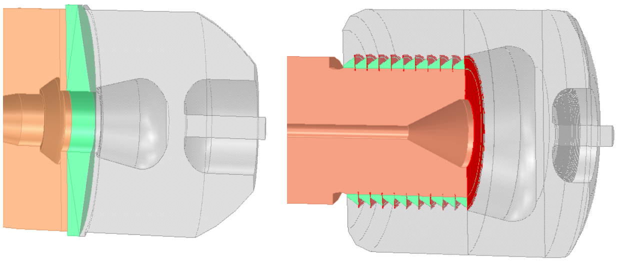

Figure 2: optimized diode geometries.

On the first geometry (borosilicate plain disc barrier), we minimized the diameter (90 cm) and optimized the vacuum conic surface angle to 10° (fig. 3). With the conic surface, the field lines are curved which preserves the borosilicate barrier from electrons emitted from the triple points.

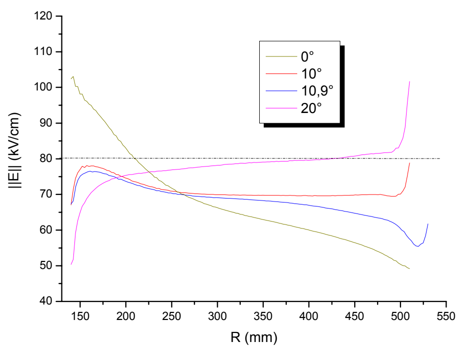

Figure 3: E field on the vacuum side of the conical disc.

Stack column have been tested and used up to 1 MV in several laboratories. Working at 2.5 MV is a new challenge. Our solution consists of 10 alumina rings (90 cm diameter) with intermediate metallic washers. For safety reasons, we took a factor 2 margin on the E field on the vacuum side from our calculated limits (fig. 4).

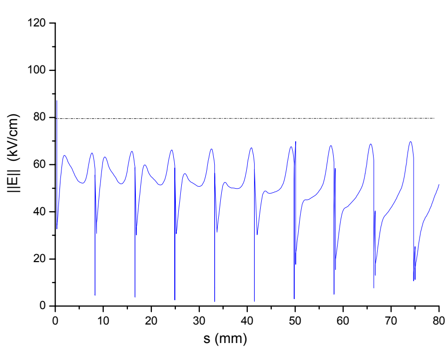

Figure 4: E field along the vacuum surface of the stack.

BEAM DYNAMICS

Our beam dynamics study is based on the LANL PARMELA code to calculate the beam transport along the machine and POISSON-SUPERFISH code for the electromagnetic field maps calculations of the photo-injector, the RF cavity and final focusing. We have linked them together through a graphical interactive interface and coupled with CEA-PLOTWIN software (*.plt) which allows powerful, interactive and friendly viewing of the beam behaviour. 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.

Three different bunch configurations have been studied: 5 bunches, 10 bunches and 20 bunches. Differences between these configurations are essentially the bunch charge, the total beam duration from 13 ns to 58 ns, the space charge effects and the beam loading in the RF cavity.

To optimize the beam transport in the machine, we first minimized the emittance at emission and during extraction by tuning the cathode recess and the magnetostatic focusing system. The cathode recess (fig. 5) 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. We have performed beam dynamics simulations for different cathode recess values in order to provide a parallel beam at the linac entrance. The best beam transport @100 nC (lowest emittance) is obtained for a 4 mm recess. The net gain in emittance is close to 30%.

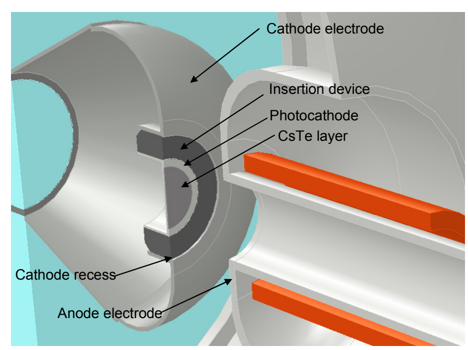

Figure 5: Cathode electrode with photocathode structure.

We have also minimized the rms energy spread in the linac by tuning the phase cavity to reduce the final focussing solenoid chromaticity effect. This dispersion comes from two distinct RF cavity effects: on one hand the beam longitudinal extension produces an intrabunch energy spread when passing through the RF field cavity, on the other hand the beam loading in the cavity reduces the accelerating field which induces a mean energy spread between the bunches.

The rms beam size on the target has been optimized by adjusting the length and the field in the final solenoid and the target position from the solenoid to reduce the chromatic solenoid and space charge effects.

The figure below (Fig. 6) shows the optimized beam envelopes of the whole accelerator and the phase space diagrams on the target. Although the number of bunches and charge per bunch are very different, the simulations for the two accelerated beam configurations give very close results (5% on the spot size). The larger energy spread due to the beam loading is balanced by the higher space charge effect of the higher charge bunch configuration.

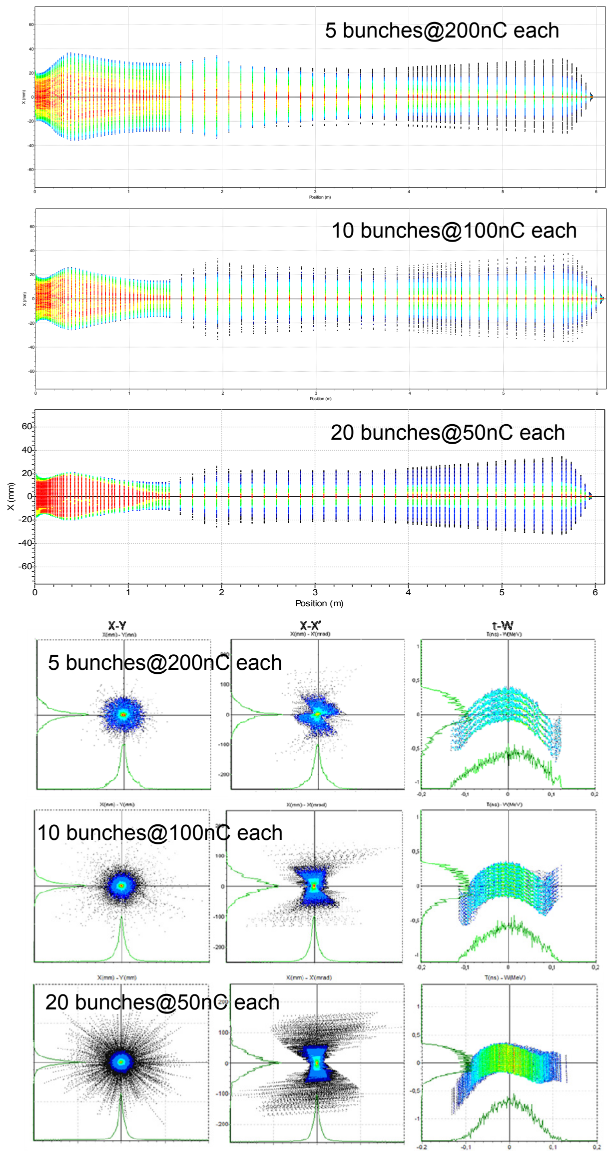

Figure 6: Beam envelope and phase space diagrams on the target for the three configurations.

The five bunches train configuration @200nC allows the fastest radiographic imaging (13 ns) with a 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

To develop a new radiographic facility, we studied a new versatile scheme based on a DC photo-injector coupled to a RF superconducting accelerator.

We have presented studies on the interface between the HT generator and the diode, which is a kee part of the photo-injector. We have designed it taking in account the high voltage hold off (2.5 MV/100ns), the mechanical stresses, and the 10^{-10} mbar vacuum required for the photocathode. We have determined the E field limits from AIRIX diode simulations: 130 kv/cm and 80 kv/cm on triple points. We ended up with a borosilicate 90 cm diameter conical plain disc panel with an 10° optimized angle and a 90 cm diameter stack column made of alumina rings and intermediate metallic washers.

We have performed beam dynamics simulations of a 1µC total charge beam for the whole machine with our interactive, fast and accurate chained simulation codes based on POISSON- SUPERFISH and PARMELA. We have optimized the beam transport for 5 bunches of 200 nC each, 10 bunches of 100 nC and 20 bunches of 50 nC. We have minimized the emittance with a cathode recess, the spread energy tuning the cavity, the beam size adjusting the final solenoid length and the distance from the target. For the three configurations, the beam characteristics on the target are quite similar. However, the 5 bunches@200nC configuration allows faster radiographic imaging (13 ns), and the HT generator length of the photo-injector can be shorter, allowing a more compact radiographic facility.

REFERENCES

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