PROPOSAL FOR A 15 MeV SUPERCONDUCTING ELECTRON LINAC FOR THE DEINOS PROJECT

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Abstract

The design of a 15 MeV, 2 kA peak current, electron accelerator for the DEINOS project is presented. It is dedicated to a new radiographic facility. The accelerator is based on a DC photo-injector and a RF superconducting linac. Up to twenty electron micro-pulses, 100 ps time duration and 200 nC bunch charge are 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.

INTRODUCTION

The former DEINOS project which name stands for "**DE**monstrateur d'**IN**jecteur **O**ptimisé pour un accélérateur **S**upraconducteur**"** was consisting of a DC photo-injector coupled to a RF superconducting accelerator (Fig. 1). It is a new versatile scheme based on rather well tested technologies. It has been proposed to produce flash X-ray pulses from very intense electron beams impinging on a high Z material target. A final beam transport allows tight beam focusing on the conversion target [1].

In order to meet the specifications of the radiographic need, 2 µC- 51 MeV- 60 ns, compactness and low cost, the machine could be made of the assembly of a 352 MHz RF linear accelerator and a photo-injector, provided the photo-injector delivers the proper bunches.

Electrons bunches are emitted from a Cs_2Te photocathode driven by a 266 nm wavelength laser and extracted in a DC gun. A pulsed power supply made of a prime power, a Blumlein and coaxial transmission lines drives the diode accelerating voltage.

The voltage applied to the accelerating gap of the diode can reach a value up to 2.5 MV. Time duration of the voltage plateau is set by the Blumlein to be 60 ns.

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 beam diagnostics.

Optimizations of the photo-injector, the RF accelerator and radiographic parameters led to a design for which the accelerator machine could deliver 20 bunches at 352 MHz. Each bunch of 100 ps time duration would carry 100 nC. This can be done with a UV laser illuminating the photocathode in synchronism with the linac RF in order to recapture the bunches in the RF cavities without any losses.

All the main technical issues that were identified to building the photo-injector (large size diameter and high quantum efficiency Cs_2Te photocathodes, UH Vacuum level - 10^{-10} mbar, high voltage insulator barrier, electron gun and diode geometry, stability of the high voltage driver and stability of the laser) could be worked out with this new demonstrator, at lower budgetary cost. A new orientation has been decided for the project in order to build a reduced scale model.

Then a 15 MeV accelerator scheme based on the early architecture consisting of a DC photo-injector and a superconducting RF linac made of only one cavity, has been proposed as a new facility for radiography applications.

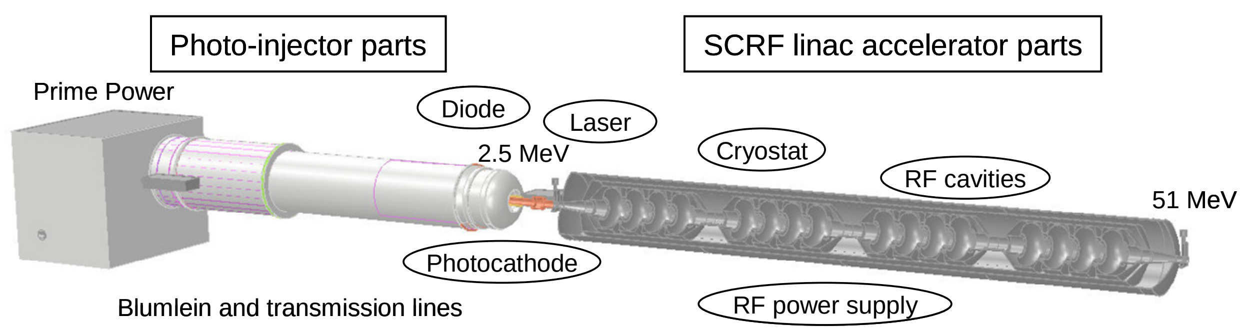

Figure 1: Artist's view of the DEINOS project.

PHOTO-INJECTOR

The photo-injector consists of a pulsed DC high voltage gun diode under UH Vacuum. High voltage can be tuned from 1.5 to 2.5MV.

The diode is followed by a solenoid lens either to propagate the beam through a short beamline along which various beam diagnostics are installed (emittancemeter, Faraday cup, pulsed current transformer, Cerenkov screen, streak camera), or to focus the beam at a waist before entering the next SCRF accelerator module, a 266 nm laser illuminating a removable Cs_2Te 40 mm diameter emissive size photocathode which is inserted under vacuum through remote handling and a high voltage pulse power generator [2].

High Voltage Generator

Most of the subsystems needed for the high voltage generator are spare pieces from the PIVAIR prototype injector of AIRIX induction radiographic machine. Some have been rebuilt, some have been modified or replaced to deal with the present need. The prime power consists of a 1 µF capacitor bank, which is switched through the primary of an iron-core high voltage pulse transformer (Stangenese manufacturing).

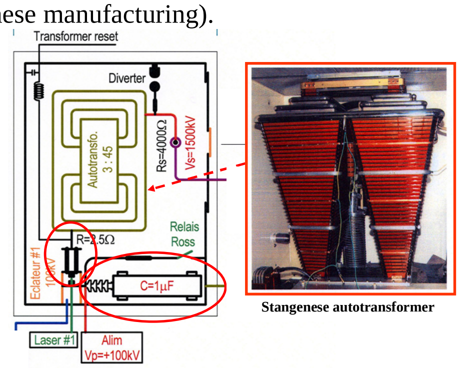

Figure 2: Prime power.

The secondary of the transformer is electrically tied to the Blumlein which is charged to a maximum voltage of 1.5 MV. The outer leg of the Blumlein is switched out with a laser triggered SF6 gas switch. Coaxial transmission lines also called output lines finally transform the output voltage to the required maximum 2.5 MV voltage on diode and parallel resistor load. Figure 2 shows parts of the prime power refurbishing, which is now completed.

Diode Geometry

The interface separating the oil medium insulator inside the coaxial transmission line from the vacuum of the diode part is a major component of the photo-injector. The insulator design is a challenge as far as fabrication is concerned. Compatibility between the high voltage hold off, the mechanical size and stresses and the attainable vacuum as low as 10^{-10} mbar during static operation (beam off) requires specific materials. Optimized geometries and shapes must be manufacturable from candidate like ceramic or borosilicate materials. Feasibility comparisons have been carried out. We ended up to a vacuum insulator stack made of alumina rings and intermediate metallic washers as shown in Fig. 3.

Electrode geometries have been optimized to achieve 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 applied for a time duration of 100 ns.

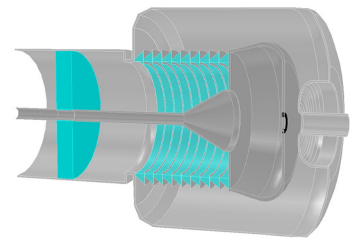

Figure 3: Reversed axial ceramic stack HV insulator.

Laser System

The driving laser must provide a maximum of bursts of 20 topped hat pulses of 100 ps FWHM separated by 2.84 ns. The laser system is shown in Fig. 4. It consists of a 500 mW, 1064 nm wavelength Nd:YVO_4 SESAM oscillator.

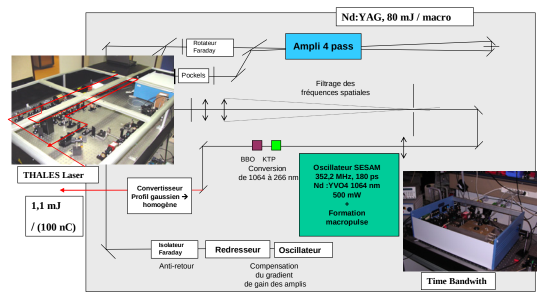

Figure 4: Laser chain.

It is actually able to deliver 2 separated in time trains. Each train of 60 ns time duration carries 20 bursts. After pulsed shaping, amplification and frequency quadrupling, the energy to be delivered to the photocathode is 25 µJ per burst at 266 nm. Rms jitter value is 2 ps and achieved value of beam homogeneity is 4% rms.

Photocathodes

Robust photoelectric cathodes are being investigated and fabricated in a separated photocathode bench. Transfer from this preparation chamber and the photo-injector is done thanks to a transportation system that moves cathodes one by one in a unit chamber tight to the diode vessel. A set of 3 cathodes is stored. The cathodes are kept under UHV wait then to be loaded in the DC gun using the remote handling device. Photocathode fabrication has started with 30 mm diameter molybdenum cathode. Tellure is first evaporated for 8 nm thickness followed by cesium deposition. Deposition is stopped when the measured photocurrent reaches a maximum and stays constant (Cs thickness is then about 50 nm). So far Q.E is not yet reproducible enough for our application mainly due to CO pollution. It varies from 1 % to 16 %

(Fig. 5). A parametric study is been carried on over several parameters such as cathode temperature value during deposition process, speed of evaporation, thickness of cesium deposit on tellure, surface emission homogeneity. Robustness of Cs_2Te photocathodes against specific gas pollution will be tested next before going to nominal larger size diameter cathodes.

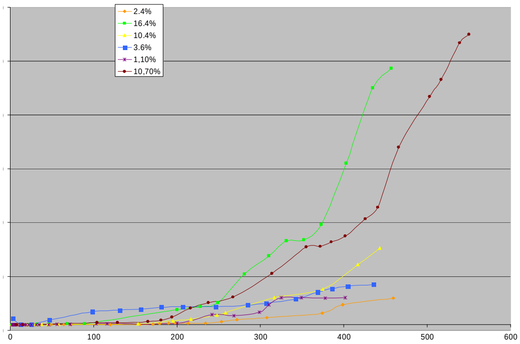

Figure 5: Q.E. vs Cs thickness deposit (x100A°).

SC-LINEAR ACCELERATOR

Superconducting accelerator structures give more compact machine for equivalent energy stored in the cavity than room temperature ones. To compensate for the loading in order to accelerate properly the high charged bunches, the linear accelerator has to be superconducting. Therefore mean beam energy from bunch to bunch decreases. Beam dynamics must deal with the resulting energy spread of the beam to be delivered on target.

LEP2-Like Cavity

The SC-Linac is a close replica of a 4 cells superconducting LEP2 module. We have presently chosen the niobium deposit on to copper manufacturing. The accelerating field of 7.5 MV/m fits the design. Q_0: 3.2 10^9. Total stored energy: 160 J and beam loading requirement is 1.2 J/ bunch@100 nC. Effort is being done to low down the static cryogenic losses.

RF System

Solid-state RF power supply can be used and requires 20 kW of RF power. A prototype unit of 2.5 kW was constructed successfully.

Beam Dynamics

Beam dynamics of the whole accelerator machine has been carried out thanks to the simulation chain described in [3]. The linac RF cavity phase is tuned to end up with the lowest rms beam energy spread. Two different machine configurations have been studied: 10 bursts of 100nC/bunch and 5 bursts of 200nC/bunch which accelerated beam simulation is shown in Fig. 6.

The two configurations give very close results (difference of only 5% in the spot size value). The 5 bursts train configuration @200nC per bunch allows a short radiographic imaging (13 ns) at same spot size for a 2 kA, 15 MeV beam delivering an integrated X-ray dose of 1.7 Rad. The radiographic facility is very compact.

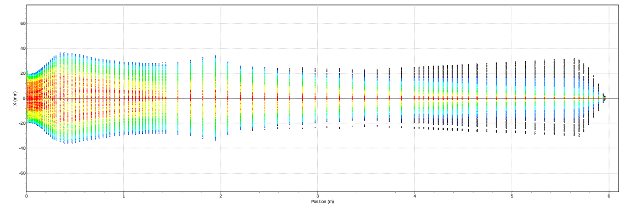

Figure 6: Beam envelope 5 bunches @200 nC per bunch.

FINAL FOCUSING

One drawback with the large energy spread of the accelerated beam comes from the spot size enlargement due to the chromaticity of the final focusing lens. Three parameters drive this effect:

- space charge of the high charge in every bunch,
- beam loading in the RF-cavity reducing continuously the net accelerating field,
- large longitudinal beam extension over the RF phase, generating RF energy spread.

In order to limit these effects, we have studied a conical solenoid geometry (figure 7).

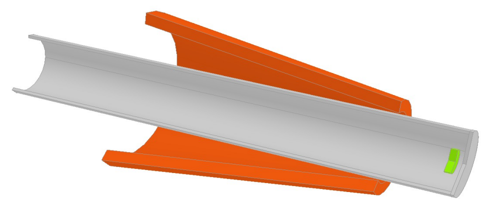

Figure 7: Conical solenoid geometry.

Beam dynamics simulations have showed that the beam spot size on the target can be decreased by about 15 to 20% for large energy spread.

CONCLUSION

We focused on the description of the accelerator components, achieved, under construction or to be fabricated in order to be used in view of a reduce scale demonstrator for a radiography applications. This new machine is made of a photo-injector, a superconducting RF accelerator and a final focusing. The whole machine simulations have been carried out for a 1µC total charge beam. Two beam configurations were considered: small spot sizes, short time exposure imaging as low as 13 ns can be obtained with electron bunches carrying 200 nC of charge.

REFERENCES

[1] "Design of a RF accelerator demonstrator for driving X-ray source", J-L Lemaire and al, Pulse Power Conference 2005, Monterey, USA.

[2] "A 2.5MeV pulsed photo-injector demonstrator for radiographic applications", JL. Lemaire, IPMC2008, Las Vegas, USA.

[3] "Beam dynamics simulations for a 15 MeV superconducting electron linac coupled to a DC photo-injector", D. Guilhem, J-L Lemaire, S. Pichon, these proceedings.