SYSTEM INTEGRATION OF THE DEMONSTRATION SIEMENS ELECTROSTATIC ACCELERATOR

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Abstract

Siemens has proposed a novel compact DC electrostatic tandem accelerator to produce protons of a few MeV. Siemens is currently building a prototype of the accelerator at the Rutherford Appleton Laboratory. This paper reports on recent progress on the different components of the system as well as the commissioning of the whole machine.

INTRODUCTION

The novel electrostatic accelerator [1] proposed by Siemens, among other possible applications, aims to provide a simple and robust solution for the production of PET isotopes. It relies on a modified Cockcroft-Walton cascade voltage multiplier and promises to be smaller, cheaper and much easier to operate than a cyclotron.

The capacitances of the Cockcroft-Walton cascade are represented by two sets of concentric hemispherical metallic shells which are interconnected with the diodes of the CW setup. The highest electrostatic potential will be in the centre of the accelerator itself (so called terminal), which will be shielded by all subsequent sets of shells. A set of holes through the shells will act as beam tube. It will therefore be able to provide much higher gradients than conventional Cockcroft-Walton accelerators whilst keeping all the advantages. The accelerator will be operated with a negative ion source in tandem mode with a carbon stripper foil in its centre.

A dedicated lab has been set up at the Rutherford Appleton Laboratory (RAL, Didcot, United Kingdom) to build a prototype of the proposed accelerator. This includes a set of concentric metallic hemispherical shells interconnected with diodes placed in vacuum, which make up the voltage multiplier and beamline, an AC drive system to create a HV AC input signal of the order of 100 kV Pk-to-Pk at about 100 kHz for the multiplier and an H^- ion source to inject a particle beam into the beamline. The goal of the prototype programme is to demonstrate that the concept is able to successfully accelerate H^--beams with gradients as high as $10\,\mathrm{MV\,m^{-1}}$ up to an energy of the order of 10 MeV with beam currents suitable for radioisotope production (of the order of 100 µA). The first stage of the prototype programme works with a subset of shells to validate the components and demonstrate acceleration of beam with the proposed concept.

Figure 1: Off-the-shelf AC power supply (20 kHz to 100 kHz) by Hüttinger, normally used for induction heating

AC HIGH VOLTAGE POWER SUPPLY

A dedicated air core step up transformer has been designed to provide AC input to the cascade. It is driven by an off-the-shelf AC power supply normally used for induction heating (see Figure 1). The transformer together with the impedance of the rectifier cascade and an internal shunt capacitor have a resonance at about 80 kHz and are run on this resonance. As the feedback signal from the transformer primary side was too noisy, feedback from the secondary side (via a voltage divider in order to decrease the voltage) is used by the power supply to regulate the output frequency and maintain resonance. The AC supply system has been successfully commissioned and tested up to voltages of more than 120 kV Pk-to-Pk.

Most commercial high voltage vacuum feedthroughs are made of ceramics with relatively high dielectric loss angles. They heat up during RF operation and are therefore unsuitable. We designed and manufactured our own RF high voltage feedthrough made of Rexolite (see Figure 2), which has been successfully tested with DC voltage as well as AC voltage. The DC test went up to more than 120 kV and the AC test at 80 kHz went up to more than 120 kV Pk-to-Pk. Ceramic feedthroughs that we had used in earlier trials had severely heated up when used with 80 kHz AC voltage , the Rexolite feedthrough showed no measurable temperature increase during our trials even at highest voltages. The input voltage currently needed for our pro-

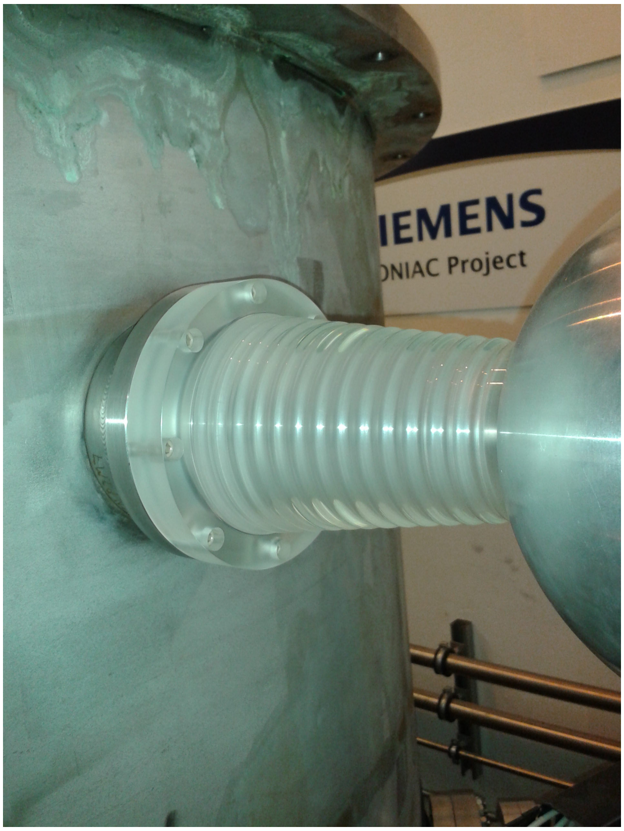

Figure 2: The Rexolite feedthrough designed by our team. Careful design of the inner conductor and outer geometry have yielded excellent voltage capability compared to off-the-shelf components

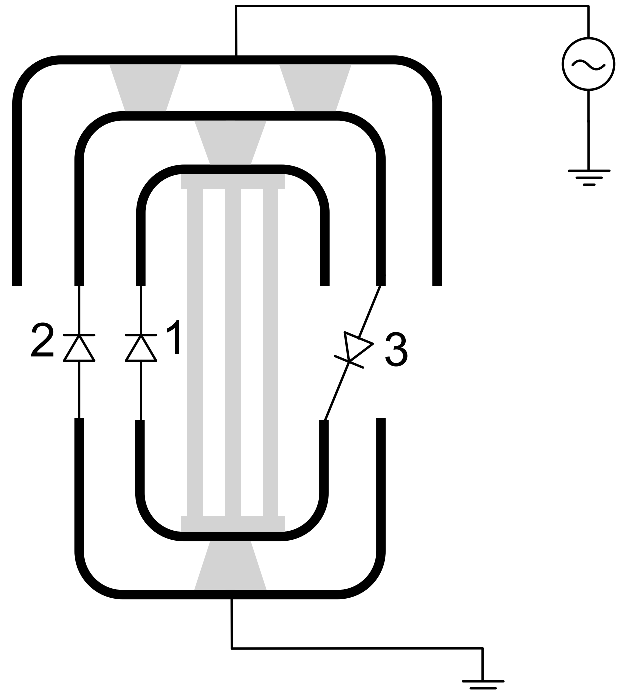

Figure 3: A schematic of the prototype rectifier with 5 shells. Systems of several MeV may have up to 80 shells. Subsequent design iterations work without the large insulator in the centre. With them the top set of shells is held from above and the shells fastened to each other via their insulators.

totype experiments is in the order of 100 kV Peak-to-Peak which is met by the current system.

RECTIFIER CASCADE

The rectifier cascade consists of concentric metallic shells spaced by insulators and diode strings interconnecting them (see Figure 3). The shells act as capacitances and voltage grading structure. The whole system is placed in a vacuum chamber. Tests have been done with a subset of five shells to test the insulators (see Figure 4). The current insulator design iteration is capable of withstanding more than 90 kV.

Surge current protection is an important component of every Cockcroft-Walton system. In conventional rectifiers surge protection resistors are installed in series with the connection between the high voltage terminal and the actual electrode in order to limit breakdown currents. In our system breakdowns mainly occur during the conditioning phase. However, they can occur across any of the capacitors. These breakdowns can initiate high surge currents in the diodes directly connected to the capacitor. For this reason every diode chain needs separate protection. We successfully protected our diodes with off-the-shelf 10 kΩ resistors which we installed in series with the diodes as part

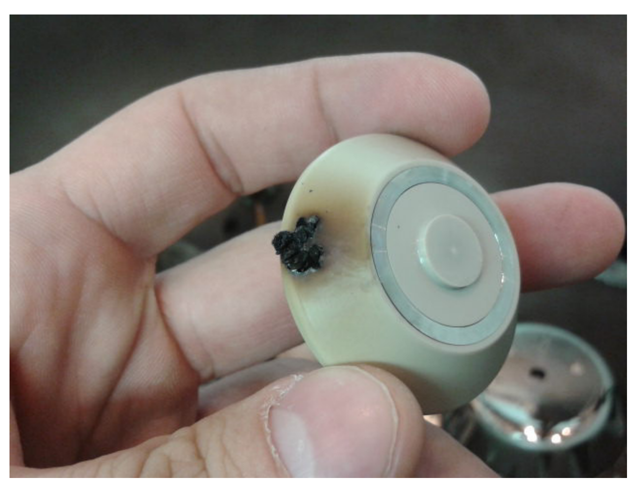

Figure 4: An insulator which was destroyed during the tests.

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of the diode strings. We have also identified more robust resistors to prevent the event of resistor failure. We furthermore developed alternative protection concepts. One possible solution is limiting the currents between the lowest shell which is usually at ground voltage and the actual system ground via a resistor. This configuration protects all diodes in the system without having to add resistors to each chain. The concept worked well with the 5-shell prototype and enabled us to test the system with a drive voltage of more than 90 kV. The trials have validated the suitability of the diode strings as well as the voltage holding capability of the shells and insulators. For all high voltage tests an elaborate automatic conditioning software (see [2]) was used, which is integrated into the overall control system. Also a test setup

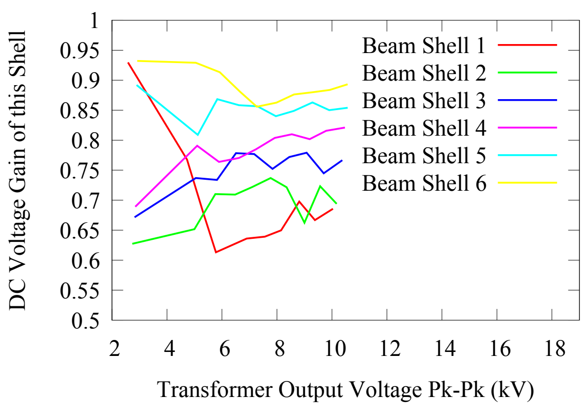

Figure 5: Contribution of each rectifier stage towards the total multiplication. The ideal value of a single stage would be 1.0. Beam Shell 6 is the lowest shell in the DC column and therefore has the highest impact. Note very strong noise on the measurement, e.g. the first two values of Beam Shell 1 are far too high.

with fourteen shells has been operated successfully in order to examine the multiplication of a system with a number of stages. The voltage on each shell of the DC column was measured with a voltage divider. The results were very encouraging, the six stage system (i.e. seven shells in each column, therefore fourteen shells) showed a multiplication factor of approximately five (see Figure 5).

OTHER COMPONENTS

The ion source for the accelerator has been successfully commissioned (see [3]) and is ready for operation. Further diagnostics for the ion source are under development (see [4]) and a wire grid and a Faraday cup for diagnostics of accelerated beams have been successfully commissioned. A stripper system with ultra thin diamond like carbon (DLC) has been developed and mounting of the carbon foils (as thin as 40 nm) has been successfully demonstrated (see Figure). A dipole configuration for energy measurement of extracted beams is currently under development too.

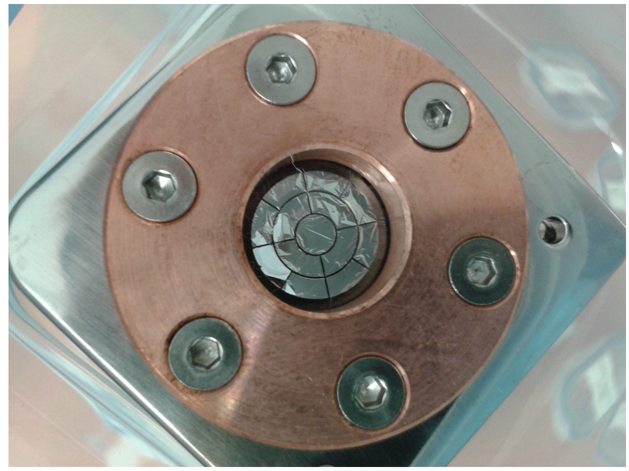

Figure 6: An $8\,\mu g\,cm^{-2}$ (i.e. about 40 nm thick) DLC foil mounted on a very fine steel grid. In a long term stability test the foil has stayed intact over several weeks.

CONCLUSION AND OUTLOOK

A suitable AC supply has been designed, manufactured and tested successfully. It provides voltages of 120 kV Peak-to-Peak and more which is sufficient for our current testing regimes. The rectifier principle has been tested and the shells, insulators and diodes have been successfully trialled at voltages as high as 90 kV. Suitable diode protection taking into account the peculiarities of the system have been developed and successfully used. The ion source and stripper foil are ready for experiments and suitable diagnostics have been commissioned or are in the final development stage. Experiments with a fourteen shell system accelerating a proton beam at gradients of several $MV\,m^{-1}$ are planned for the near future and will prove the feasibility of the concept as well as contribute to the further development of the components.

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