CONSTRUCTION OF A NOVEL COMPACT HIGH VOLTAGE ELECTROSTATIC ACCELERATOR

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Abstract

A compact proof-of-principle demonstrator system based on a Cockcroft-Walton (or Greinacher) cascade has been successfully built and tested. The plans for a subsequent full-scale vacuum insulated demonstrator system are also explored following the successful evaluation of the air insulated experiment.

This novel configuration was developed using modern materials and a different design philosophy, which could enable it to operate with much higher voltage gradients.

INTRODUCTION

Cockcroft and Walton [1] first adapted a Greinacher cascade [2] to achieve high voltage potentials for nuclear physics experiments. The main advantage of other such accelerators has been their capability to generate high output current. However, application of the technology has revealed several practical limits that have resulted in maximum output voltages around 2MV, even when employing large physical structures [2, 3, 4]. As discussed previously [5], the key innovation for the proposed new concept is to integrate the DC voltage generator with the insulator and accelerator structure.

In order to evaluate the proposed concept configuration quickly, a proof-of-principle experiment was performed using a simple, air insulated, 4 shell structure shown in figure 1 [6]. For such an embodiment, the discrete capacitor components have been replaced by a stack of concentric hemispherical shells, shaped to contain all the

Figure 1: Simple air insulated proof-of principle configuration

high potential electrodes within the smallest possible volume while maintaining nearly constant electric field amplitudes throughout the whole system. Accelerating structures utilising the compact concentric shell systems

have been developed previously [7, 8], they have not however, incorporated the combined functionality.

The interconnecting diodes can also be clearly seen in the equatorial spacing. The diode action automatically stabilises the grading electrode potential differences to twice that of the input voltage.

High electric field strengths can then be achieved by using vacuum insulation and a large number of small electrode gaps, which in turn, minimises insulator surfaces and associated flashover problems.

PROOF-OF PRINCIPLE

The input voltage for the first shell was generated by a bespoke AC drive system in combination with a tuning capacitor and air-cored inductor (figure 2). The variable

Figure 2: Experimental set up for the proof-of-principle measurements

frequency, AC drive equipment was comprised of a main rectification and smoothing, DC switch mode regulation and balanced push-pull inverter output. It was initially designed to transform conventional mains supply to 90V high frequency AC, which in turn supplied a resonant LC circuit, that included the stray capacitance of the shell configuration to produce an input voltage of >14kV on to the first shell. Figure 3 show a schematic of the experimental setup.

This four shell mechanical structure allows a simple demonstration of the principle but is not a realistic representation of a full scale configuration. Its small number of shell pairs and significantly large spacing, which are similar to the size of the inter-hemispherical gap, results in shell capacitances that are an order of magnitude smaller (e.g. 10-25pF compared with the anticipated ~180pF to >1nF for the range of shell sizes in the full scale system).
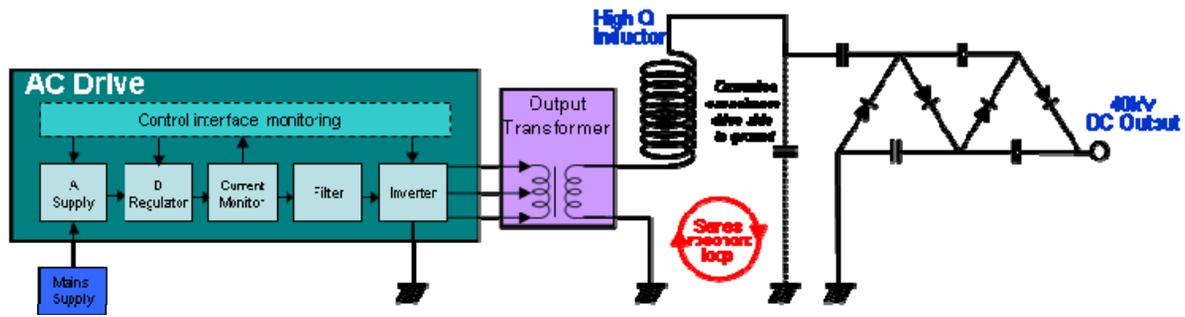
Figure 3: Schematic of the AC drive system, resonant circuit and configuration with the shell structure

To maximise the potential learning from the proof-of-principle hardware, additional discrete capacitors were connected in parallel with the shells. Initially, 1nF capacitors were chosen to represent the larger outer shells which were later reduced to 100pF, indicative of the inner ones.

For an ideal configuration with no load this set up should theoretically generate a DC output voltage with 6–fold multiplication of the AC input, $U_{in}Sin(\omega t)$, or 3 times the peak-to-peak voltage (equation 1).

$$U_{out} = 2NU_{in} - R_G I_{out} \qquad (1)$$

Here R_G represents the generator source impedance and I_{out} the load current which reduces the output voltage accordingly.

Figure 4a shows the achieved multiplication performance and 4b the voltage rectification performance for configurations incorporating a 1nF and 100pF shunt capacitance, measured with a resistive load of 100MΩ. This represents a ~300µA beam load on the system, at 30kV.

The reduction in the inter-shell shunt capacitance to 100pF results in an increased weighting of the inter-hemispherical or stray capacitance and thus load on the system. This in turn produces a degradation of the observed multiplication factor (figure 4a). Further
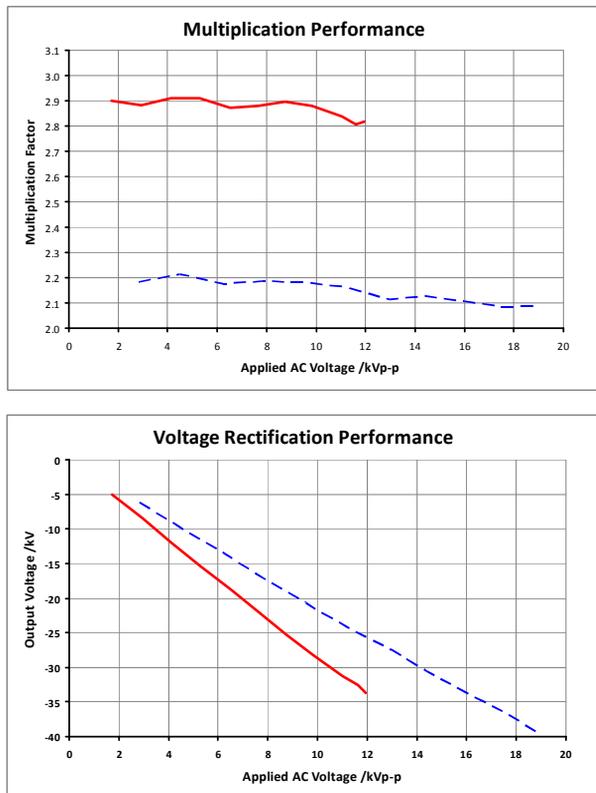

Figure 4: a) Multiplication performance b) Output DC voltage for various Input AC voltages. The solid red line is for 1nF and dashed blue line for 100pF shunt capacitances for a 100MΩ load resistance
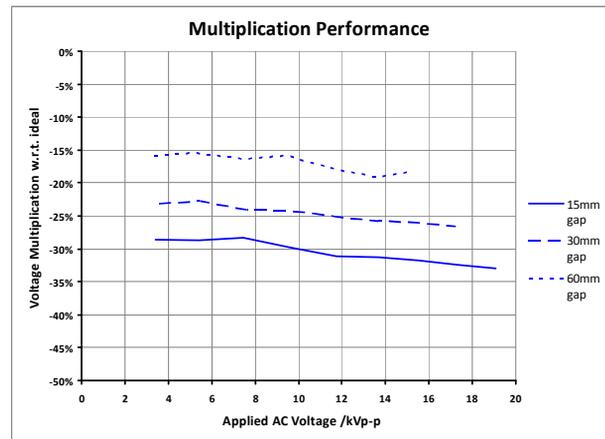

Figure 5: Variation of multiplication performance for various inter-hemispherical separations

evidence of the effects of stray capacitance can be seen in figure 5 where the degradation of the measured multiplication factor is presented for different hemispherical separations and 100pF inter-shell shunt capacitance, with 100MΩ resistive load.

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FULL SCALE DEMONSTRATOR

Following the successful demonstration of the proof-of-principle concept, design work on a full scale vacuum insulated system has begun. This will require the design and manufacture of a dedicated vacuum chamber and larger AC drive system.

The full scale demonstration system will be designed to offer a more representative evaluation of the concept and associated technologies with the necessary flexibility of incorporating an ion source, a wide range of shell pairs, beam diagnostics, targets and beam optics. The initial target specification of this system is:

- Vacuum vessel dimensions - 1.5m diameter, 1.7m high
- 40+ shell pairs with a voltage gradient $\leq$11MVm^{-1}
- Variable input voltage onto the first shell <150kV$_{p-p}$ at ~100kHz.
- Vacuum pressure $\leq$1x10^{-4}mBar when full populated with the maximum number of shells
- Tandem configuration in combination with H$^-$ ion source
- Interchangeable particle beam targets and diagnostic equipment

As outlined in the target specification for the full demonstration system, in order to achieve a maximum internal shell voltage of order 5MV will require many shell pairs (>40).

CONCLUSION

The proof-of-principle experimental setup has successfully demonstrated the concept feasibility and also highlighted some of the important parameters to be considered during the current design of the full-scale vacuum insulated system that is now under investigation. This configuration was capable of generating a maximum DC output voltage of ~41kV before a breakdown current was detected, derived from an input voltage of 90V in the AC drive.

The development of such a compact high voltage particle accelerator, with high current capability has the potential to access a wide range of commercial opportunities outside the laboratory.

ACKNOWLEDGEMENTS

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