PROGRESS TOWARDS A NOVEL COMPACT HIGH VOLTAGE ELECTROSTATIC ACCELERATOR

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Abstract

A proof-of-principle compact demonstrator system based on a Cockcroft-Walton (or Greinacher) cascade has been successfully built and tested. The concept has been developed using modern materials and a different design philosophy, which in turn can then enable this novel configuration to operate at much higher voltage gradients.

This paper explores the progress made over the past 12 months [1] and future plans to utilise the technology to develop one such concept for an energy efficient 10MV, 100µA, tandem proton accelerator, with a <2m^2 footprint.

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.

INTRODUCTION

Cockcroft and Walton [2] first adapted a Greinacher cascade [3] to achieve high voltage potentials for nuclear physics experiments. The main advantage over such accelerators has been their capability to generate high output current. However, application of the technology has revealed several practical limits that result in maximum output voltages around 2MV even when employing large physical structures [3, 4, 5].

As discussed previously [1], the key innovation for the proposed new concept is to integrate the DC voltage generator with the insulator and accelerator structure. Figure 1 shows a simple embodiment where the discrete capacitor components have been replaced by a stack of concentric shells, shaped to contain all the high potential electrodes within the smallest possible volume while maintaining nearly constant electric field amplitudes throughout the whole system. Whilst accelerating

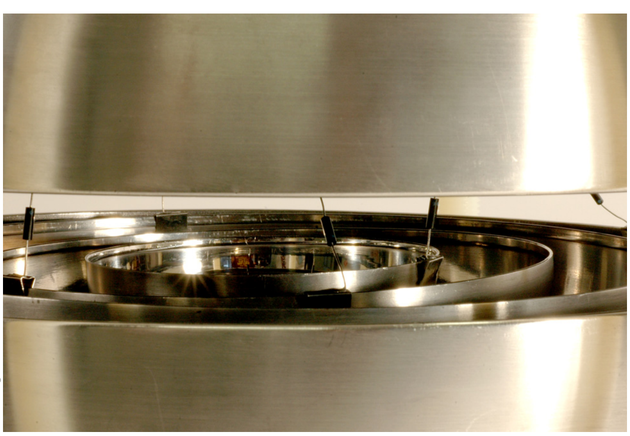

Figure 1: Simple air insulated proof-of principle configuration

structures utilising the compact concentric shell systems have been developed previously [6, 7], they have not 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 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

In order to evaluate the proposed concept quickly, a proof-of-principle experiment was performed using a simple, air insulated 4 shell structure.

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

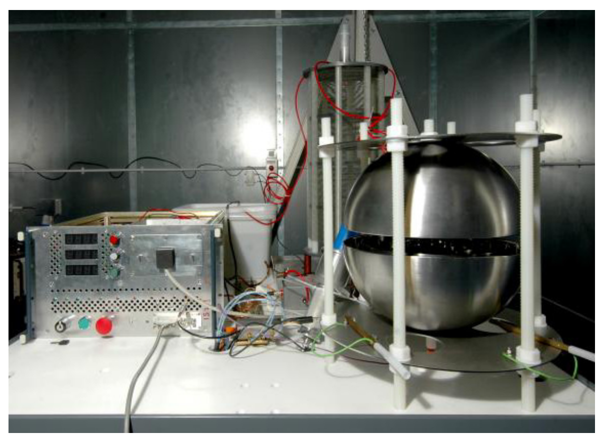

Figure 2: Experimental set up for the proof-of-principle measurements

variable 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. This was then used to feed a resonant LC circuit, which included 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, of order the inter-hemispherical gap, results in inter-shell

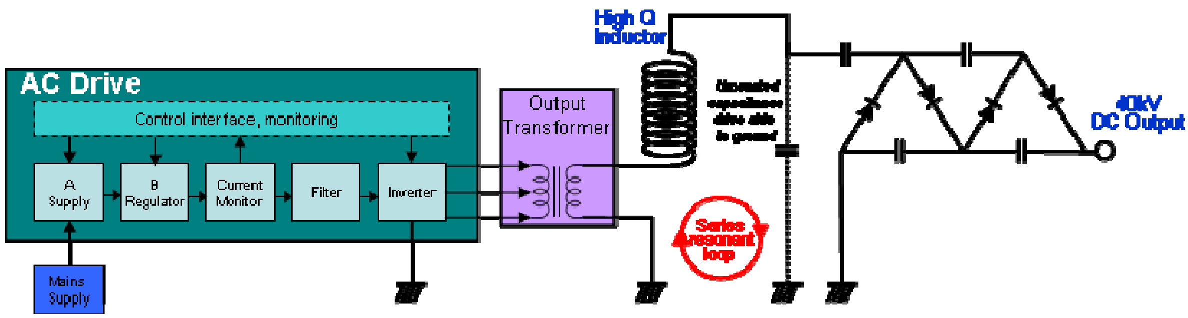

Figure 3: Schematic of the AC drive system, resonant circuit and configuration with the shell structure

capacitances that are an order of magnitude smaller (e.g 10-25pF compared with an anticipated ~180pF to >1nF for the range of shell sizes in a full scale system). To maximise the potential learning from the proof-of-principle hardware, additional discrete capacitors were connected in parallel with the shells. To ensure successful demonstration of the principle 1nF capacitors were initially 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, $U_{in}Sin(wt)$, or 3 times the peak-to-peak voltage (equation 1).

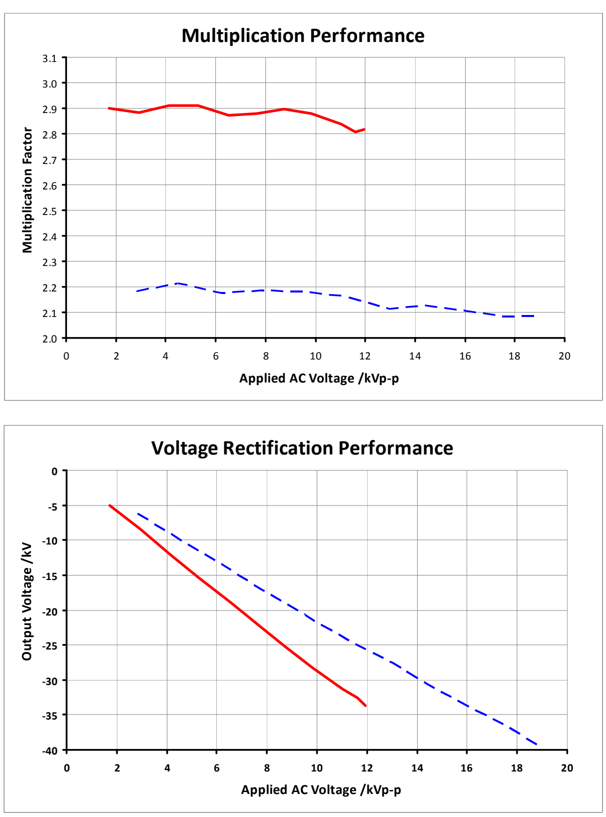

Figure 4: a) Multiplication performance b) Output DC voltage for various Input AC voltages. The solid red line is for 1nF and dashed blue line for 100pF shunt capacitances for a 100MΩ load resistance.

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

Here R_G represents the generator source impedance and I_{out} the load current that will reduce the output 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 serious load on the system, capable of drawing ~300μA 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 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.

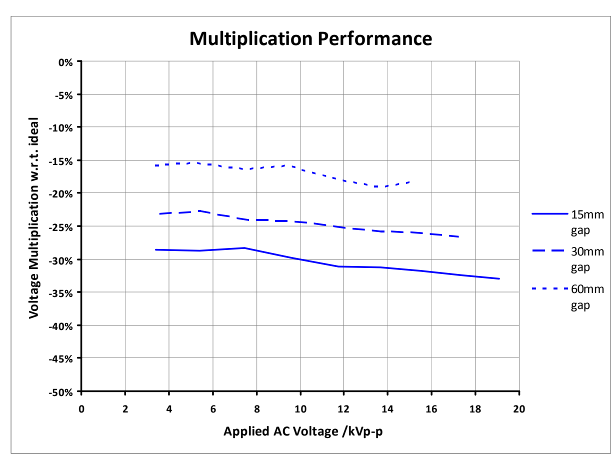

Figure 5: Variation of multiplication performance for various inter-hemispherical separations

FUTURE WORK

Following the successful demonstration of the proof-of-principle concept, a full-scale vacuum insulated system is planned. This will require the design and manufacture of a dedicated vacuum chamber and larger AC drive. However, it is still anticipated to utilise conventional mains supply to generate >100kV$_{p\text{-}p}$ at 100kHz as an input for the first shell using the modified AC drive and resonator. Finally, a compact set of some 40+ shell structures would then be capable of multiplying the AC input to around 5MV on the centre shell.

CONCLUSION

In summary the experimental set up has successfully demonstrated the proof-of-principle of this concept and also highlighted some of the important parameters to be considered during the design of the full-scale vacuum insulated system that is currently under investigation.

The small, air insulted proof-of-principle hardware 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.

A voltage multiplication factor of 0.97 of ideal was achieved whilst under load and using 1nF inter-shell capacitors for an inter-hemispherical spacing of 30mm. This multiplication factor was reduced to 0.75 of the ideal, under significant load, with the use of 100pF inner-shell capacitors. However, this set up emulates better the inner shells of a full size configuration.

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