

HIGH VOLTAGE, HIGH POWER NESTED HIGH VOLTAGE ACCELERATOR

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The Nested High Voltage Generator (NHVG, North Star Research Corp. patent pending) is a unique new type of accelerator based on the principle of the Faraday cage. It consists of a number of individual high voltage sections which are placed inside of the adjacent accelerator section, or 'nested' one inside the other. Electronics internal to each of the NHVG stages sets the voltage between the inner and outer Faraday cage to some voltage V . By building N stages and placing them one inside the other, we can produce a DC voltage $N \times V$. In this paper we describe the advantages of this type of accelerator along with the results of work with the two small NHVG accelerators which we have built so far.

I. INTRODUCTION

Compact, light weight particle accelerators are desirable for a variety of applications including drivers for high power microwave generators, radiation processing, Positron Emission Tomography, and space based applications. The use of solid insulation is essential to reducing the size of high voltage equipment, and we believe that the NHVG is an approach which can effectively utilize solid insulation to very high (10 - 20 MV voltages). The use of solid insulation also leads to high stored energies which make pulsed operation possible as well as DC operation possible in the same device.

In this paper we first describe the fundamental principles of operation of the device (section II), and we then describe our first prototype accelerator (section III) and a tandem accelerator (section IV). We present conclusions in section V.

II. PRINCIPLE OF OPERATION

We describe the NHVG technique in more detail in this section. Figure 1 illustrates the principle of all NHVG accelerators. Topologically "nesting" high voltage systems allows us to isolate individual lower voltage systems without developing the full voltage across any one insulator. Each voltage generator is inside an adjoining generator. Reduced to it's essentials, the compact accelerator can be represented by a series of concentric conducting shells which are electrical nodes with individual voltage sources between the nodes. By the basic physics of electrostatics each of the 'generator' shells are totally isolated. This means that an

observer placed between two conducting shells cannot measure the potential of the spheres relative to ground potential.

The insulation required to insulate between the two conducting shells does not depend on the total voltage of the assembly, only on the interstage voltage. This is important because a fundamental property of solid insulation is that the electric field strength which an insulator can withstand drops as the insulation gets thicker. Therefore if we break a thick insulator into a number of individual thinner sections with the voltage equally divided, significant reductions in overall thickness, and therefore in overall weight and size can be achieved. A complete conducting shell will prevent the passage of the charged particles which we wish to accelerate as well as the passage of energy. In our application, however, small holes or slots will permit particles and energy to leave or enter the shells. If the scale size of the hole in the conducting shell is r , the field due to this hole will fall off exponentially over a distance of order r . Therefore holes only compromise the integrity of the conducting shell to a limited degree.

Holes and shells are necessary for two reasons - first to allow particles to travel through the device and gain full energy as described above. We must also supply the energy required by the high voltage generators through these holes or slots. Possible techniques for supplying energy to the shells through small holes or slots include:

- o Time varying magnetic fields (transformer action or inductive coupling) where the energy is allowed to pass through slots (we simply require that none of the conductors completely encircle the axis, nearly complete encirclement is allowable).
- o An insulated rotating shaft with mechanical to electric generators placed inside each shell.
- o Batteries which are used to power high voltage generators inside each shell. The batteries can be recharged via the particle egress hole when the generator is not in use.
- o Thermoelectric converters where the system is hot.
- o Cascade generators

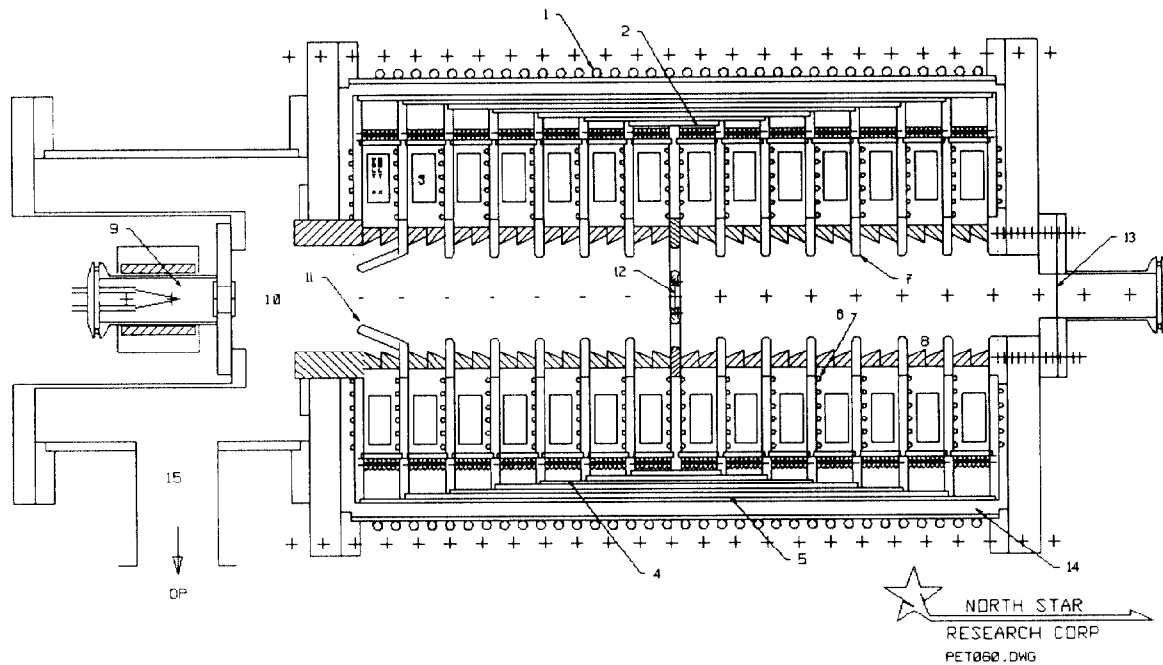


Figure 1. Detailed schematic of the PET NHVG negative ions. 1)Primary winding 2)Secondary winding 3)Voltage multiplier 4)Conducting shell 4)Insulator 6)Conductor 7)Grading ring 8)Vacuum insulators 9)Ion Source 12)Stripping foil.

A number of practical questions are not addressed in the discussion above. The exact design of the ubiquitous interfaces between different types of insulators is not discussed. The exact geometries of the conductors for transformer coupling are also not discussed.

We believe that transformer coupling is the most effective means of providing the energy for the NHVG, and so limit the discussion to this technique, and this is the embodiment of the device shown in Figure 1. The transformer configuration consists of secondary high voltage multi-turn windings, diode/capacitor voltage multipliers. A high voltage vacuum insulator and an evacuated acceleration well through the insulator stack allows the particle beam to move from the source region at the inner most cell toward ground potential. A nearly complete conducting casing separates each pair of voltage sources. Power is supplied through an air core transformer and magnetic induction from an external oscillating field coil using a resonant circuit.

Referring also to Figure 1, the common wall between adjoining generators is arranged to be a nearly complete conductor with relatively few openings. The complete conductors are separated by oil, solid, or vacuum insulators. Openings of note are slots which allow penetration of magnetic flux without compromising the electrostatic shielding provided by the metal foil. The

winding acts as a transformer secondary and converts the magnetic flux provided by the external generator into alternating electric currents which transmit power to power supplies. The power supplies, which may be as simple as capacitor --diode combinations provide a high voltage potential difference across the insulator. This insulator, which may be made of dielectric film or an insulating liquid is designed to hold-off the voltage across the module. The complete insulation afforded by the insulator is terminated by the vacuum interface which provides a separation between the insulation required for the power supply and the vacuum required for particle beam acceleration.

We outline critical issues in NHVG design below.

A) *Solid Insulation*

The type and voltage withstand capability of the solid insulation is critical to the design and fabrication of these devices. A slot pattern must be developed which allows flux penetration without unacceptably compromising the axial insulation. The gap between the slots should be minimized. The radius of curvature at the slot edges should be sufficiently large so that the field enhancements at the slots do not increase the field to an unacceptable degree.

B) *Vacuum Insulation*

The vacuum insulation issues in this accelerator are the same as those in any DC electrostatic accelerator. The design must avoid charged particle impact on insulators, and minimize accelerator length. Ion transport must be minimized since this can lead to breakdown in the accelerator. We will not elaborate on this point in this section since we did not address this problem in detail in Phase I.

C) Transformer Coupling

An external circuit is required to supply the magnetic flux which powers the modules. DC power is converted, by means of a switch (such as the power MOSFET) into a high frequency oscillating voltage. The coupling of an air core transformer depends on the relative primary/secondary cross-sectional area. For this reason, the coupling coefficient is small in an NHVG. The effective coupling coefficient can be increased by making the primary circuit a resonant circuit. This resonant circuit can be configured in several ways, but the simplest is to make this resonant circuit consist of the primary transformer winding and a capacitance chosen to give the desired frequency. The effective coupling coefficient is then the product of the 'Q' of the circuit, and the conventional coupling coefficient. This number can easily exceed 1. A coupling coefficient greater than 1 implies that the ratio of the output voltage to the switch voltage is greater than 1. This is a practical solution to the coupling coefficient problem.

We note that while we specify power MOSFETs in the discussion above, power grid tubes are probably the modulation technique of choice for output powers above a few kW, particularly if weight is more important than efficiency.

III. 150 KV NHVG ACCELERATOR PROTOTYPE

In order to demonstrate the fundamental principles of operation, a six module, 150 kV, 150 μ A, CW/pulsed electron accelerator was constructed during an intensive 6 month effort. The resonant transformer circuit was used to inductively couple energy to step-up nested secondary coil and voltage multiplying circuits through a conductor geometry which shields electrostatic fields while it allows magnetic field penetration. Proof-of-principle experiments were conducted with a heated tantalum filament at ground potential to verify beam parameters and electron extraction.

Results obtained from the prototype device were very encouraging and verified the merits of the concept and scaling. We found no fundamental obstacles to scaling this concept to higher energies, powers, or gradients. The Phase

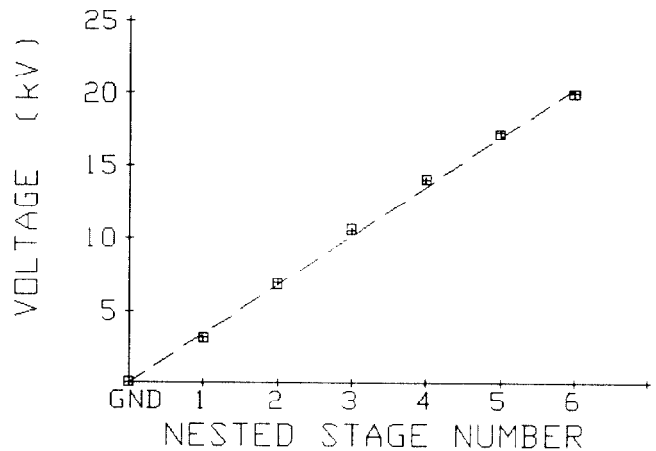


Figure 2. Accelerator voltage division. Measured across the vacuum diode and ground referenced.

I prototype device was still in working order when it was disassembled to assess whether any breakdowns had occurred. We anticipate that it is ultimately capable of at least 300 kV if a higher power drive system is utilized. The voltage grading achieved in the device is shown in Figure 2. We also note that one of the six sections was operated at 70 kV.

The overall capacitance of this device was approximately 5 nF., and we operated the accelerator in pulsed mode by changing to a flashboard plasma electron source.

IV. TANDEM NHVG ACCELERATOR

A tandem NHVG accelerator for proton/deuteron acceleration was constructed, and reached voltages at the terminal of 215 kV (particle energies of approximately 430 kV minus the stripping cell energy, and it is still in operation. This device is 30 inches long, and approximately 1 ft. in diameter. It is capable of being considerably reduced in size.

V. CONCLUSIONS

The NHVG principle has been used to build two particle accelerators. The principle limitation to the accelerator voltage is the size of the accelerators which have been built to date, and the power available from the MOSFET based accelerators which have been used so far. This work was supported by SDIO under contract DNA001-89-C-0114 and by DOE under grant DE-FG05-90ER80954.