BRIEF REVIEW OF THE DEVELOPMENT OF ELECTROSTATIC ACCELERATORS AND CONTINUING WORK AT STRASBOURG

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ABSTRACT :
The development of electrostatic accelerators follows the need of high energy charged particles. It has been a continuous increase in voltage from some MV in the 1930's, up to some 20 MV nowadays, and around 35 MV in a near future. That allows to accelerate and to make nuclear reactions for almost all stable nuclei existing in nature.

The need to accelerate charged particles for research in nuclear physics led to the develomment of high-voltage electrostatic accelerators in the early 1930's. The fundamental components, then as now, comprised a generator of high voltage electricity, a source of charged particles and an accelerator "tube" capable of sustaining internal vacuum conditions suitable for unimpeded particle transmission while withstanding high external voltages.

Today's large electrostatic accelerators are descendends of the pioneering work by R.J.Van de Graaff who succeeded in operating open-air generators at several millions of volts potential. The magnitude of that initial success can be appreciated if we consider that today, more than fifty years later, there are worldwide only two electrostatic accelerators capable of operating in excess of 20 millions volts, at Daresbury England (fig.1) and at Oak Ridge (fig.2).
At Yale University, an extended existing accelerator, the ESTU, is presently under beam tests in the same range of voltage (fig.3).

Of course, these are precision research instruments and there are hundreds of accelerators operating at lesser voltages ; nevertheless, it is fair to say that progress in electrostatic accelerator technology has been agonizingly slow by comparison, for example, to linacs and sunchrotrons where it has been possible to scale up proven designs to larger and larger dimensions. Indeed, serious difficulties of scale have been encountered in the field of electrostatic accelerator technology.

While Van de Graaff, working at M.I.T., quickly attained megavolt potentials, firm control took a little longer. However, by the late 1930's relatively compact, reliable, highly functional electrostatic accelerators were transforming research in nuclear physics. Many improvements, most notably installation of the voltage generator inside a pressure vessel for improved insulation, were contributed by R.G.Herb and colleagues at the University of Wisconsin. One of the severe problems to be overcome was (and still is) the tendency for electrical stress to concentrate near the ends of insulators causing local failure that could not be overcome simply by lenghthening the insulator. (Early machines have meters of insulator where we would substitute centimeters today). The solution to that particular problem was to subdivide the insulator into thin layers sandwiched between conductors that could be graded uniformly in potential throughout high stress regions. Once the major problems were "solved" the technology shifted from exploration to exploitation. In such a fractions technology, anything that works quickly becomes dogma ; consequently, many of these early technical "fixes" are still found in nearly all later electrostatic accelerators.

In the 1950's, following a suggestion by L.Alvarez, the tandem electrostatic accelerator was born. By injecting with negative ions and stripping to positive charge within the high voltage terminal, two stages of acceleration from one high voltage source became available. This doubled proton energies and permitted order-of-magnitude increases (depending on what positive charge states could be attained) for heavier ions. The tandem accelerator thus was able to keep pace with the demand for higher energies and became a workhorse of low-energy nuclear and atomic physics [1].

With a little imagination it is possible to extend the tandem concept to more than two stages. There exist a fair number of three-stage systems where negative ions are accelerated from negative high voltage in an injector terminal to positive high voltage in a tandem terminal before stripping. Secondary and tertiary stripping are used to increase charge states before the final stage acceleration is completed. A pair of tandems has been coupled in four stage accel/decel mode to produce low-energy, highly-stripped ions for atomic physics. Four-stage acceleration, with experiments to be performed inside a tandem terminal, was proposed by Van de Graaff and given serious study but never actually attempted.

Although there are a variety of ways to generate high voltages, including cascaded transformed and voltage-multiplier systems (R.D.I.), the largest generators continue the path set by Van de Graaff of mechanically transporting electrical charge to the inside of a high voltage terminal where if flows to the outside by electrostatic repulsion (Faraday effect) when released from the conveyor. Van de Graaff chose a continous conveyor belt for this purpose "spraying" charge of either polarity onto the belt surface by continuous corona discharge from a constant-current power supply (fig.4).

Mechanical energy supplied by the belt drive motor raises this charge to the potential of the high voltage terminal. A belt has the advantages of large charge carrying capacity (on its large surface area) plus the ability to transmit substantial amounts of auxiliary mechanical energy to the terminal where an alternator converts this to electricity for powering equipment in this isolated environment. More recently, Herb developed a pellet-chain charging system (fig.5) wherein separately insulated metal links on a chain are inductively charged and discharged. The chain charging system delivers charge at a more uniform rate. Multiple chains are used to convey additional charge and, where required, any deficiency in mechanically transmitted power is easily made up by direct drive through insulated, rotating power shafts operating from ground to the terminal. A ladder arrangement of two interconnected pellet chains has been successfully developed at the Daresbury Laboratory in England (fig.6) [2].

At the heart of every electrostatic accelerator is an accelerator tube composed of many layers or "pitches" of alternating conducting and insulating materials. The metals aluminum, stainless steel and titanium are commonly used with a aluminium substantially less expensive but also less durable. Insulators are typically either glass (vacuum sealed to metal by a vinyl plastic) or ceramic (diffusion bonded by aluminum to titanium). To sustain extreme high voltages some means must be provided to interrupt the paths of electrons and ions liberated from surfaces within the tube. Magnetic suppression obtained from small permanent magnets mounted inside or outside the tube is effective for electrons (and can suppress x-ray production) but not for ions.

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Electrostatic suppression, in which the tube electrodes are configured to produce transverse electric field components that sweep secondary particles away from the main beam axis, has proved to be the most effective overall. There are two forms of electrostatic suppression : 1) transverse "inclined" fields from deformed electrodes (fig.7) and 2) radial fields from modulated axial gradients (fig.8).

It seems appropriate that pioneers Van de Graaff and Herb each contributed directly, and competitively, to these methods.

The forefront of this technology is not limited exclusively to attaining the highest possible voltages. For many applications such as ion implantation, irradiation, ion microscopy, accelerator mass spectroscopy, etc. the user would prefer to have compact accelerators of only moderate voltage, often in the range of 0.5 to 5 MV, with other special properties such as high current, high brightness, high stability or low cost.

At Strasbourg some of the old dogma is undergoing a new examination [3]. Under construction at present is the 35 MV Vivitron accelerator that combines a mixture of old and new concepts (fig.9). The pressure vessel is 50 m long, 8.4 maximum diameter, to be filled to 8 bar with pur SF_6 insulating gas. The terminal will be charged from a belt running longitudinally end to end through a graded column. This provides four charging runs (both upcharge and downcharge in each direction from the terminal). Accelerator tubes will be High Voltage Engineering Corporation (HVEC) inclined field type made of glass and stainless steel. Fourteen modular tube sections will each be 2.5 m insulated length ; half-length tube sections will be used in four locations. Ion beam injection, transport and extraction will be conventional, based on the successful HVEC Model MP tandem accelerator. In fact, all of these choices are conservative extrapolations from successful working systems, particularly the Strasbourg MP upgraded by steps from 13 MV up to 18 MV.

New in the Vivitron is the method of terminal and column support, the configuration of potential-defining electrodes and the choice of insulating materials in the voltage generator. The horizontal column and terminal are supported directly from the wall of the pressure vessel by high voltage support posts based on work by C.M. Cooke at M.I.T. (fig.10).

The largest supports contain eight post insulators each capable of sustaining the projected 4.4 MV working voltage and separately tested to 5 MV before installation. Supported by the insulator posts is a cage of seven layers of discrete electrode panels that surround the terminal and taper into the electrically graded column structure at locations that correspond to their proper operating potentials (fig.11).

These discrete electrodes redistribute the electric stress around the terminal, making the field more homogeneous (fig.12) and permitting about a factor of two reduction in the diameter of the pressure vessel. A single layer of discrete electrodes (named the "portico") has been in service for more than 3 years in the Strasbourg MP tandem accelerator.

Instead of the now "classical" conductor/insulator laminate, the Vivitron column frame members consist of continuous sheets of fiberglass - epoxy resin board material surrounded by large equipotential rings with 0.73 MV from ring to ring. A full scale model of column insulators and equipotential rings has been tested to 6 MV in the Strasbourg CN accelerator.

Fig.13 shows the performances of the Vivitron depending on the choice of stripper (gas, foil or a combinaison of the two of them), the energy goes from 15 to 20 MeV/A for the lightest ions and to 5 MeV/A for the heaviest. The expected intensity reaches 10^{12} pps for light ions but only a few 10^9 pps for the heavy ions. The beam properties are those usual with Tandems.

At the present time the activities of the Vivitron group has to do mainly with the construction of the accelerator and with the different technological aspects of this work. But we made also an important effort with more fundamental problems like those concerned with the particle beam. Most of the parts concerning the structure and necessary for the preliminary voltage tests are in place. The first beam can be expected for 1990.

Special attention has to be given to the computer control system, mainly concerning the equipment and data transmitting system located inside the tank. The problems have to do with the electromagnetic perturbations following eventual sparks and the very little space available.

An extensive series of measurements has been made to obtain better knowledge of the tank deformation under pressure and to determine the final design of the mechanical structure.

The Vivitron will use a belt as charging system. This device is very well known but will be used here with a greater length than usual. We built a mechanical test bench for the design of the mechanical aspects of the belt system.

We are making electrical and mechanical tests on all delivered insulating posts. These tests also allow us to understand better the behaviour of these insulators.

A few other original developments have to be reported. Concerning the beam we made emittance measurementds with the ion source injector of the MP. As an example (fig.14) we show here the experimental emittance picture obtained with a sputtering source (type 860). The beam was ^{16}O, the measured emittance was 3.4 π.mm.mrad $\sqrt{}$MeV.

On the other hand we performed non linear calculations for the negative ion sputter source. Space charge aberrations and general focusing properties were investigated. The comparison with experiment shows good agreement.

Extensive calculations were also made concerning the transmission of the beam through the accelerator tube, which is of the inclined field type with a special design for the first element. The knowledge of this part of the machine determines the final design of the injector and the charge selector situated at the high voltage terminal.

An other aspect of the transmission is the charge exchange and consecutive intensity loss in the residual gas of the machine tube. Extensive measurements have been made using the MP tandem accelerator. So we observed the excellent transmission of 97 % in the low energy tube for particles like H, C, S, Co, Br and I. The vacuum at the tube entrance was as good as $0.5.10^{-7}$. On the high energy side of the tube the transmission with the gas stripper was better than with the foil stripper. It has been shown, that with the foil stripper the transmission is limited by the angular straggling which enhanced the emittance of the beam. With the gas stripper the limitation comes mostly from the low energy tube where the less good vacuum leads to loss of particles.

Finally the overall transmission lies between 35 and 25 % (not corrected for the loss due to the gridded lens).

[1] D.A.Bromley, NIM 1974

[2] R.G.P.Voss, The Nuclear Structure Facility at Daresbury. Proceedings of the1st International Conference on the Technology of Electrostatic Accelerators, Daresbury 1973

[3] M.Letournel, The Vivitron New Design for an Electrostatic Accelerator. Proceedings of the 3rd International Conference on Electrostatic Accelerator Technology, Oak Ridge 1981

[4] Proceedings of the 2nd International Conference on Electrostatic Accelerators, Strasbourg 1977

[5] Proceedings of the 4th International Conference on Electrostatic Accelerators, Buenos Aires 1985

[6] Proceedings of the 7th Tandem Conference, Berlin 1987

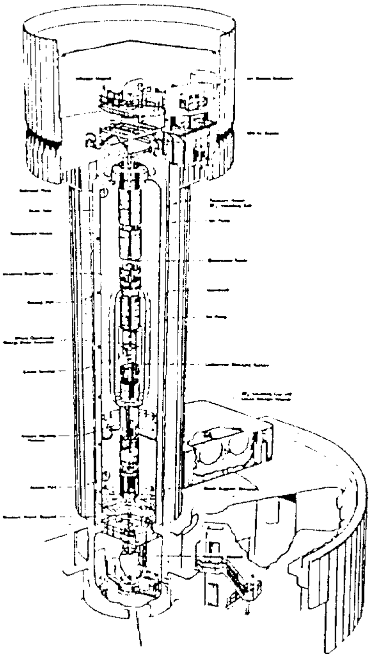


Fig.1 Cutaway drawing of the NSF.

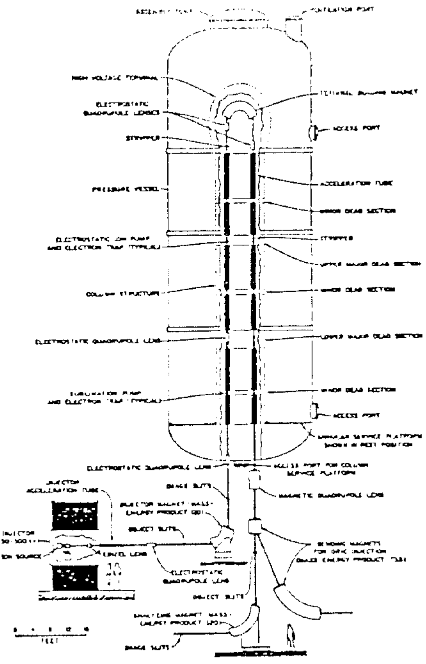


Fig.2 — A simplified schematic drawing of the Oak Ridge 25 MV NEC tandem accelerator.

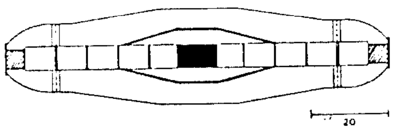


Fig. 3 Longitudinal section of the ESTU.

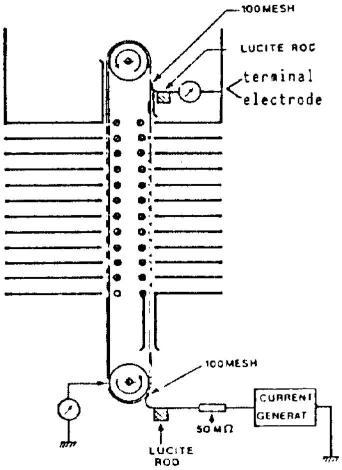


Fig.4 Belt charging system scheme

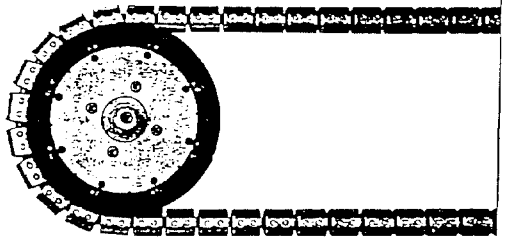


Fig.5

PELLETRON CHARGING CHAIN

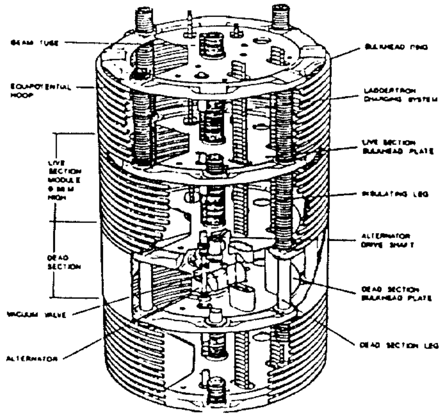
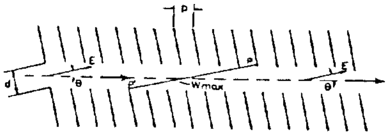


Fig. 6 Typical Stack section indicating main structural & Electrostatic elements.



a NEUTRAL BEAM TUBE

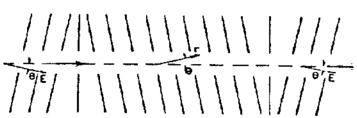


Fig.7 b CHARGED PARTICLE ACCELERATION TUBE

Principle of inclined-field accelerating tube
HVEC

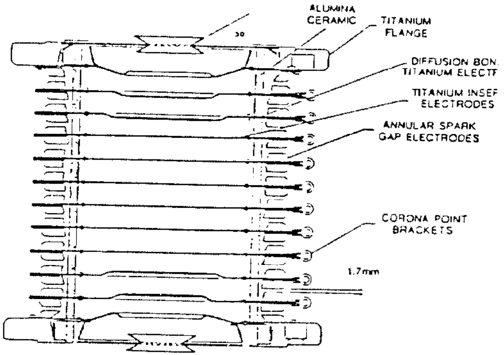


Fig. 8 Section view of compressed geometry NEC tube section with vee apertures.

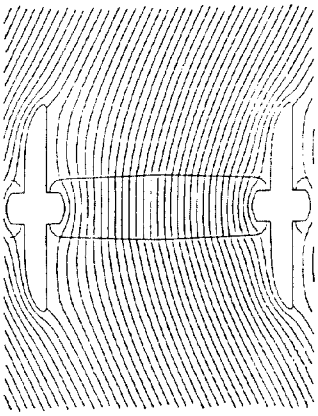


Fig. 10 Field mapping, across an insulator.

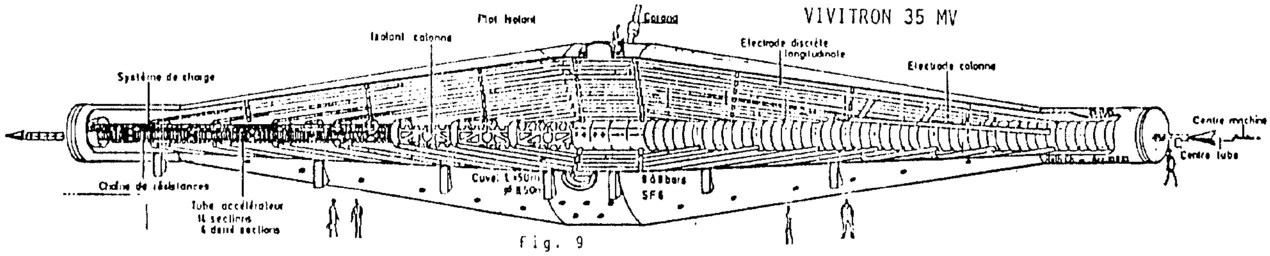


fig. 9

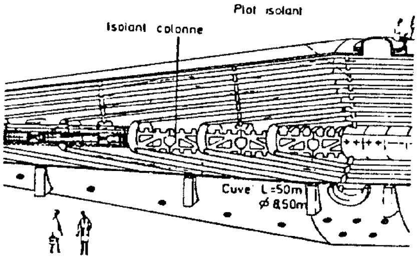


Fig. 11 The 35 MV Vivitron components.

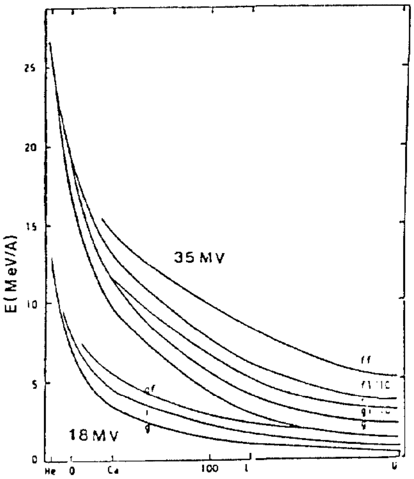


Fig. 13 Performance of the Vivitron tandem

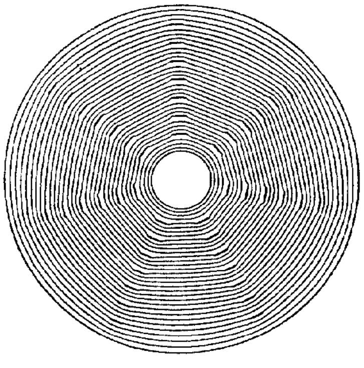


Fig. 12 Field mapping across a section of the Vivitron terminal area.

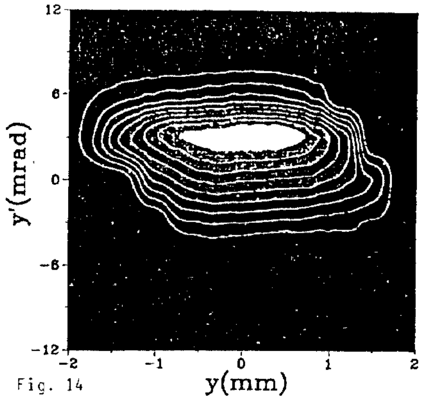


Fig. 14