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

(M. Letournel, Centre de Recherches Nucléaires Strasbourg
Louis Pasteur University)

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 development of high-voltage electrostatic accelerators in the early 1930's. The fundamental compenents, 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 millionsvolts, at Daresbury England (fig. 1)

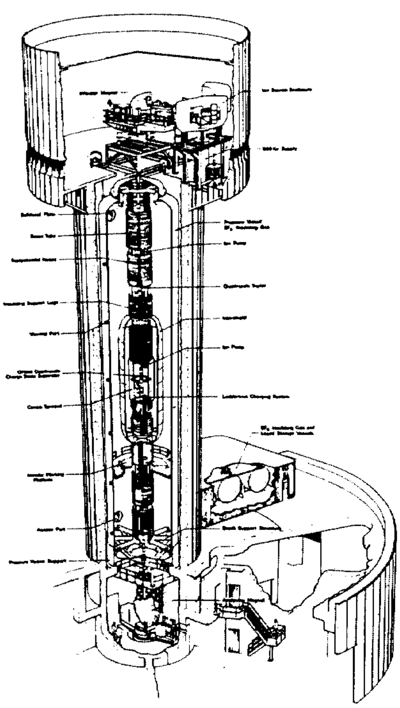

Fig.1 Cutaway drawing of the NSF.

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).

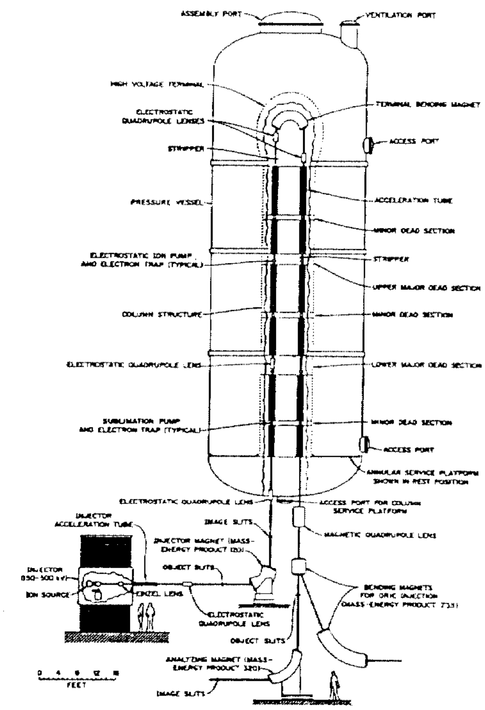

Fig.2 — A simplified schematic drawing of the Oak Ridge 25 MV NEC tandem accelerator.

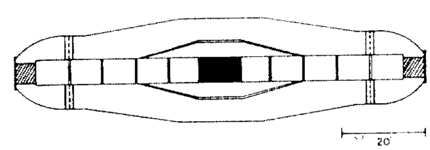

Fig. 3 Longitudinal section of the ESTU.

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 synchrotrons 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 lengthening 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 d'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 transformer 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 it flows to the outside by electrostatic repulsion (Faraday effect) when released from the conveyor. Van de Graaff chose a continuous 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).

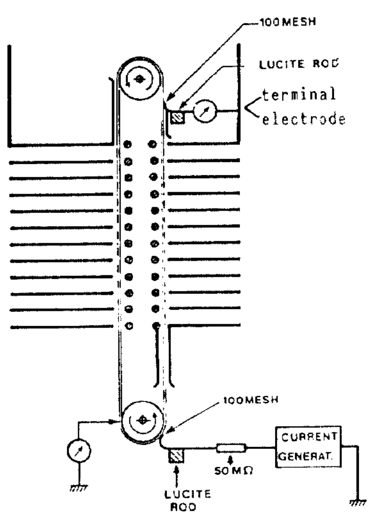

Fig.4 Belt charging system scheme

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].

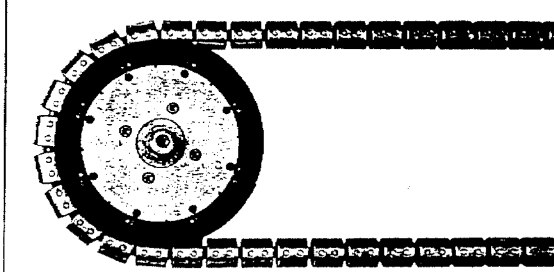

Fig.5
PELLETRON CHARGING CHAIN

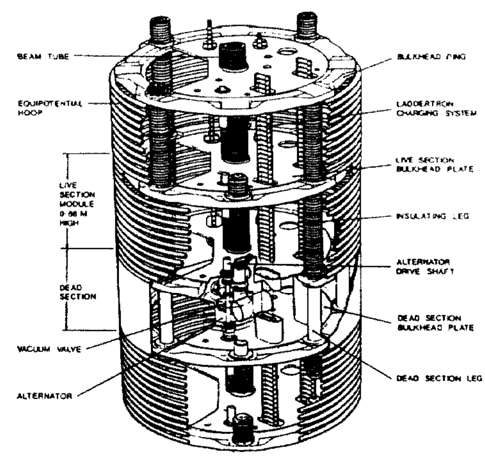

Fig. 6 Typical Stack section irdicating main structural & Electrostatic elements.

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 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.

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).

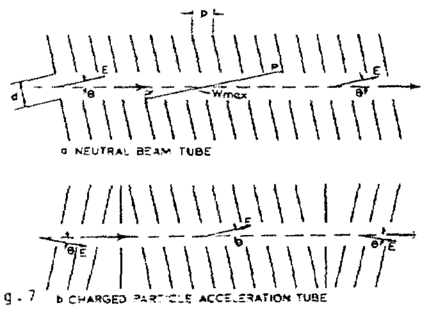

Fig.7
Principle of inclined-field accelerating tube
HVEC

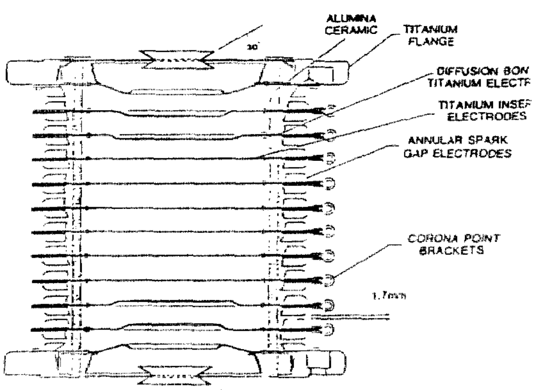

Fig. 8 Section view of compressed geometry tube section with vee apertures.
NEC

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 m maximum diameter, to be filled to 8 bar with pure 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 2.5m 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).

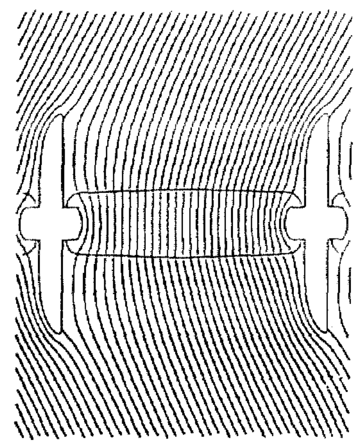

Fig.10 Field mapping, across an insulator.

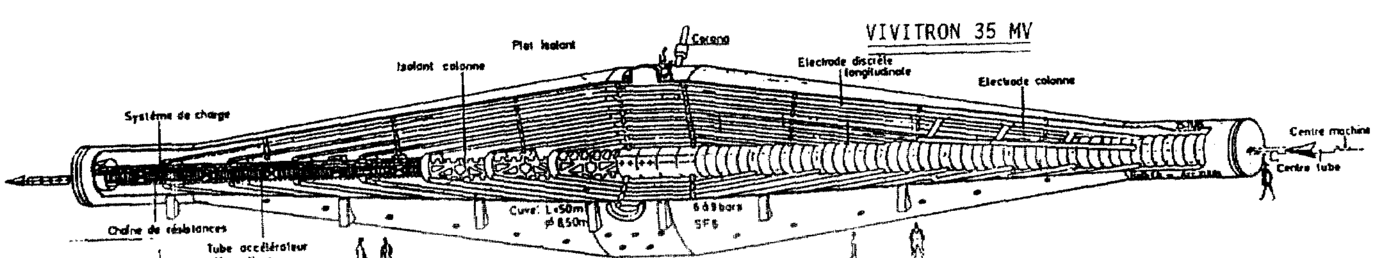

Fig. 9

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).

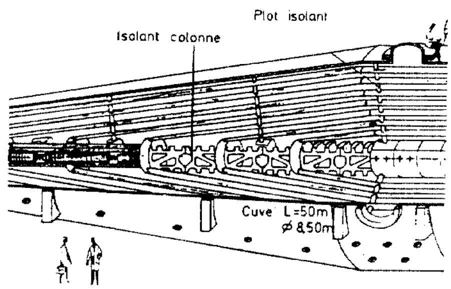

Fig. 11 The 35 MV Vivitron components.

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.

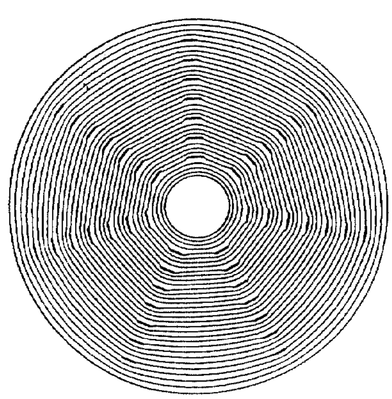

Fig. 12 Field mapping across a section of the Vivitron terminal area.

The 35 MV Vivitron will be voltage tested next spring 1989 and with beams in 1990 for nuclear research (Fig.13).

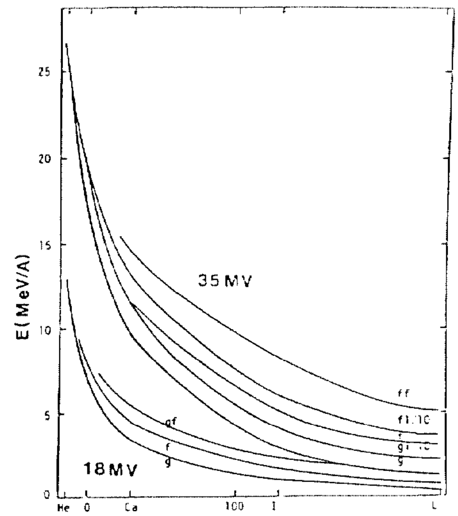

Fig. 13 Performance of the vivitron tandem.

In paralell to the development of the electrostatic accelerator itself, positive ion sources of different kinds but mainly negative ion sources coupled to tandems have considerably enlarged the possibilities of nuclear research. Particularly at the University of Philadelphia in the 1970's, R. Middleton pioneer in the field of negative sputtering ion sources obtained very large beams of a wide variety of ion species. Since then the negative ion sources have been largely developped in different laboratories. The beam quality and versatility, the reliability of these electrostatic equipments have even permitted to the Brookhaven MP tandem to serve as an heavy ion injector in the AGS.

The up to date developments of electrostatic accelerator technology can be found in the following proceedings referred [4] [5] [6].

References

[1] : D. ALLAN BROMLEY NIM 1974, 122

[2] : R.G.P. VOSS - The Nuclear Structure Facility at Daresbury. 1st International Conference on the Technology of Electrostatic Accelerators - Daresbury. 1973 - Proceedings.

[3] : M. Letournel : "The Vivitron New Design for an Electrostatic Accelerator". Proceedings of the 3rd Intern. Confer. on Electrostatic Accelerator technology 1981 - Oak-Ridge.

[4] : Proceedings of the 2d International Confer. on Electrostatic Accelerators - 1977 - Strasbourg.

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[6] : Proceeding of the 7th Tandem Conference - 1987 - Berlin.