REVIEW of LARGE ELECTROSTATIC ACCELERATORS

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Abstract

A Review of the large tandem accelerators operating all around the world at terminal voltages larger than 12 MV is presented. Such former summary talk has been given by Hyder[1] for example. Their main characteristics are discussed and compared to the new technical solutions applied in the Vivitron[2] which enters now in operation for physics at terminal voltages limited in phase 1 to a 15 to 20 MV range.

1. INTRODUCTION

There are mainly two types of large tandems : (i) folded machines where the low energy and high energy sections stand parallely connected at the top of the machine in the terminal electrode where a 180° deviation and analysing magnet is located. The latter is in two 90° sections, the stripping system being in between. The Oak Ridge machine (see table) is the largest existing one of this type.

Machine	type	V(MV) nominal	Starting year	Operational max. voltage with beam
9 Up-graded Tandems	HVEC	13→15	1965 to 1973	15 (mean value)
Legnaro	HVEC	16	1982	16
Strasbourg	HVEC	18	1984	17
Catania	HVEC	13	1984	14
Yale	HVEC	20	1987	18.6
Canberra	NEC	14	1972	15.7
Tsukuba	NEC	12	1976	12
Rehovot	NEC	14	1977	14
JAERI	NEC	20	1981	16
Oak Ridge	NEC	30	1981	22
Daresbury	-	25	1983	20
Buenos- Aires	NEC	20	1984	15
Bombay(Tata)	NEC	14	1988	14
New Dehli	NEC	15	1992	15
Vivitron	(HVEC)	35	1993	18

*Brookhaven, Chalk River, Minesotta, Rochester, Heidelberg, Munich, Orsay, Pekin

(ii) Unfolded or straight accelerators where the terminal electrode separates the low and high energy sections. Such machines are either vertical such as in Daresbury or in Tsukuba or horizontal as the VIVITRON. For the latter it should be emphasized that it is mainly due to the large length of the machine (50m for the reservoir only) that the horizontal configuration has been chosen. It avoids the construction of a huge at least 80 m high building.

Today 13 High Voltage Engeneering Corporation (HVEC), 8 National Electrostatics Corporation (NEC) and 2 local designed electrostatic accelerators have been build. Their type, nominal voltage, starting year are indicated together with the so called operational max. voltages these machines are fluently operated are listed in table; of course this latter value can be discussed but it gives a general idea how close the normal operation is in comparison to the nominal announced performances.

In the next sections we will try to compare the new VIVITRON to all other existing machines. Before this the main advantages of these electrostatic accelerators should be emphasized :

- such machines are ideal for structure studies of course first in nuclear physics where high energy resolution beams better as 10^{-4} can easely be obtained ;
- all kind of beams out of noble gases can be accelerated at energies between typically the coulomb barrier on heavy mass targets up to at least 5 to 10 times this energy ;
- all changes of the nature of the beam or its energy are very fast and easy. To illustrate this, studies of excitation functions where small energy steps are done (100 keV typically) can be undertaken ;
- these machines are quite easy to operate at generally low operation and energy costs.
- these machines are the only one able to deliver continuous beams.

2. THE VIVITRON

Fig.1 shows the implantation of the accelerator together with the four physic equipments : DEMON, EUROGAM, ICARE and the Q3D. The three first ones are new equipments due to large european collaborations for neutron, gamma and charge particles detection respectively. An other large equipment, CHARISSA built in an english universities collaboration will also be installed.

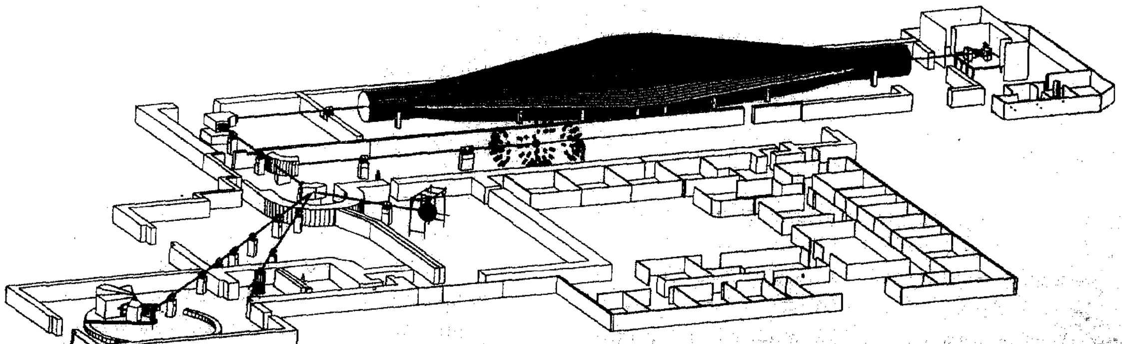

Fig. 1

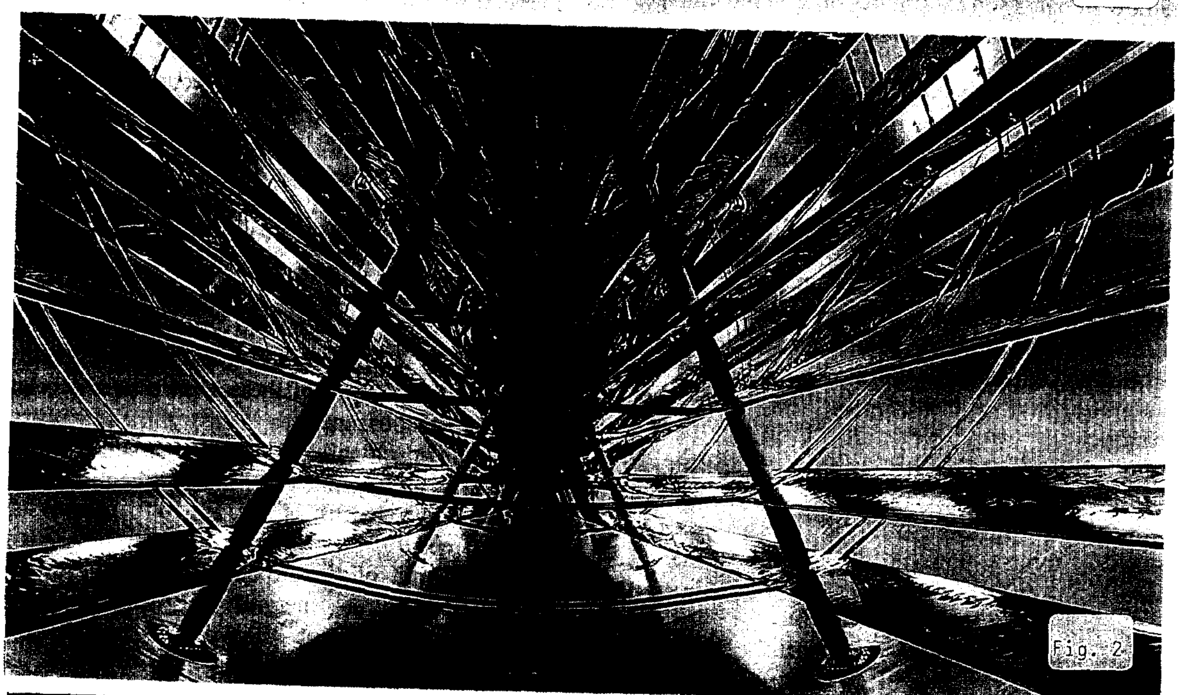

Fig. 2

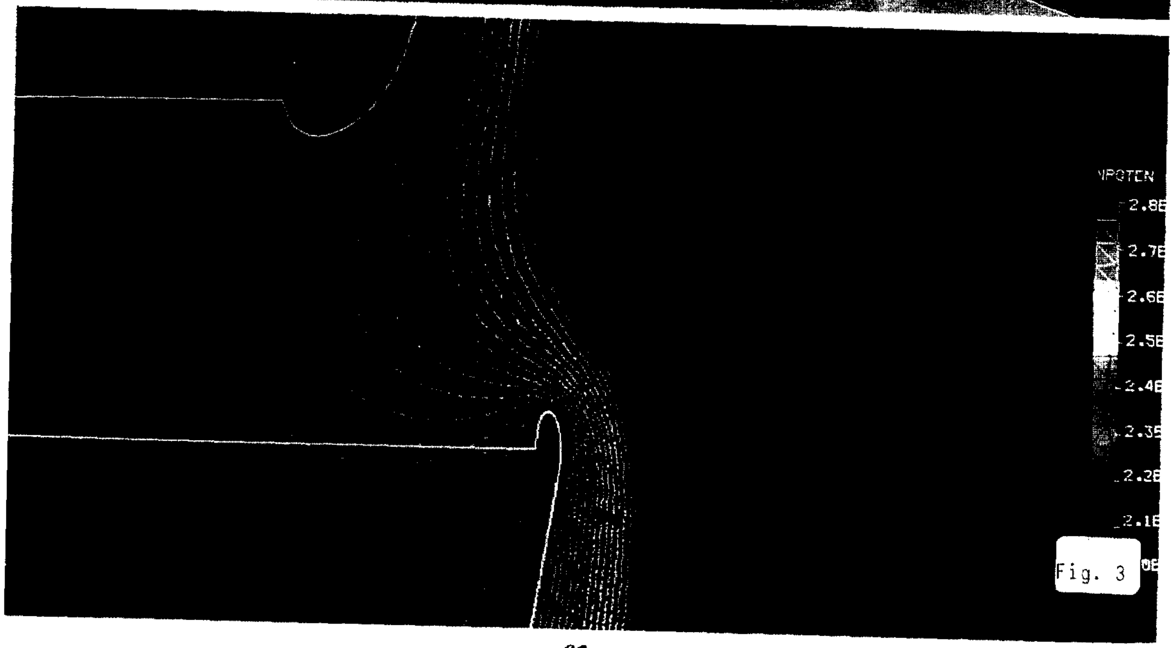

Fig. 3

During the test of the electrostatic generator the Vivitron could be operated at voltages between 21 and 22 MV. However we could identify a lot of problems during these runs, mainly related to the dynamical behaviour of the longitudinal isolating materials. A large number of damages obliged us to reconsider totaly the basic problems of their protection and the manner they were used in the Vivitron. Systematic tests have been done on a single stage machine as it is explained in section 5. Finally, after the monting of the accelerator tube during the year 1993 we could obtain a first ^{12}C beam in august 1993[3]. In december we could run different beams ^{12}C, ^{16}O, ^{28}Si at voltages between 15 and 18 MV. As an illustration we have accelerated a 600 nA injected ^{28}Si beam at 17.1 MV (17.5 MV without beam) to energies up to 188 MeV.

3. THE NEW CONCEPTS OF THE VIVITRON

The new ideas developped primarely in the old Strasbourg 18 MV tandem[4] have been directly applied or generalized in the construction of the Vivitron. The main progress are :

- to have radialy an uniform field in contrast to a 1/radius law in the tandems. This is realized by the installation of 7 discrete electrodes or porticos having each 7 arms. Fig. 2 illustrates how it looks like inside the machine which is seen here from the bottom.
- to use non subdivided horizontal insulating structure. Long bords (2,8m) of fiber glas and epoxy have been used ;
- to use radialy 5 stacks of post insulators in epoxy charged with alumine and silice. These posts, developped by C. Cooke from the MIT play an important mechanical role: they separate the porticos and held the machine to the tank (see fig. 2). Such structure is newer used in the other machines, either because they are much smaller (MP-tandems) or because they stand vertically.
- The shielding of the inner part of the accelerator is realized by the large column electrodes visible on fig. 2 and not the habitual rings used in the other machines.
- to use a 100m long belt for the charge system, running from one end to the other[5]. Today in nearly all machines one can find either pelletron (all NEC machines) or laddertron. The main advantages of our long belt is first related to mechanical considerations ; it rotation speed is half of the MP belts and we can use the four "arms" to load and equilibrate the charge system.

4. THE "CONSERVATIVE" CONCEPTS OF THE VIVITRON

Out of some quite obvious conservative ideas the most important item is related to the horizontal gradient of ≅ 20kV/cm one can achieve with the known HVEC accelerator tubes. This parameter determined the length of the Vivitron : For 18 100 inches tubes (in fact 14 and 4 half length tubes) one should go easily above 30 MV.The maximum possible voltage on one section is not limiting the machine. The other materials used in the Vivitron and which are also used in the machines listed in table 1 are :

- insulating pure SF_6 gaz operated at ≅ 8 bars. Today a mixture with Nitrogen + CO_2 is generally no longer used in these large tandems in contrast to some smaller tandems.
- negative in sources using sputtering and caesium charge exchange ;
- charge selector at the terminal using a triple quadrupole deflectors system[6] ;
- power in the dead sections and at the terminal by alternators drived by the belt. At other places rotating shafts are used ; first thought also to be used in the Vivitron we decide to eliminate this possibility up to now ;
- to pump the accelerator tube we use 2200 l/sec. turbo molecular pumps at both ends and cryopumps and ionique pumps inside the machine The mean vacuum is almost around 1 to 2 10^{-7} torr.

5. DEVELOPMENTS FOR BEAMS IN THE VIVITRON

It is to long to pinpoint all ameliorations we had to make after observing the behaviour and damages of the accelerator during the test runs as an electrostatic generator. We developped therefore 3D calculations[7] using the code COSMOS ; fig. 3 is an nice illustration of a situation where a too large field is simulated on the edge of a column electrode. By this means we could resolve and find out which kind of protection for the horizontal boards are sufficiently efficient[8]. Such calculation is shown on fig. 4 ; in this case we tried to lower the field at the fixing point of the board in the dead section by mounting a hand rail in front of the screws. The reduction of a factor 4 for the field at such triple points allows to accept transient phenomena without damages.
These all modifications have been installed at the end of 1993 in the Vivitron, together with 3 spark gaps per column electrode (total number near 300!). We could run the machine up to ≅ 18 MV with beam avoiding totally damages inside the machine. This success is surely due to the fact that all the modifications have been carrefully checked in a single stage machine (fig. 5) where a full and real Vivitron section has been

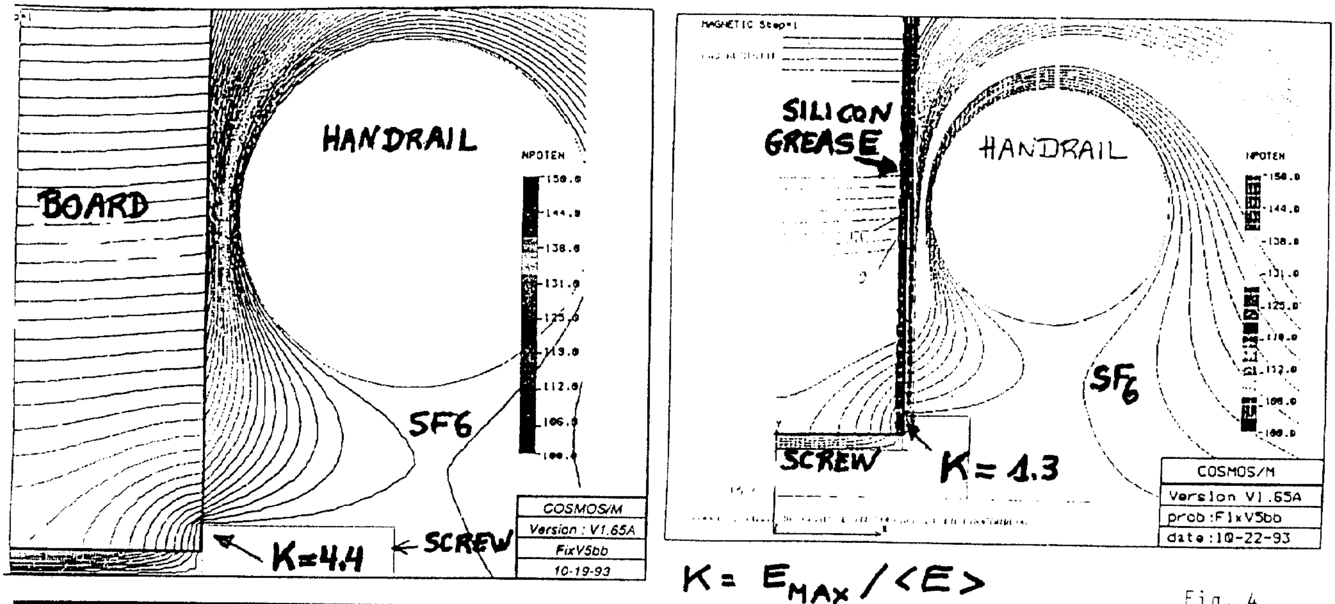

Fig. 4

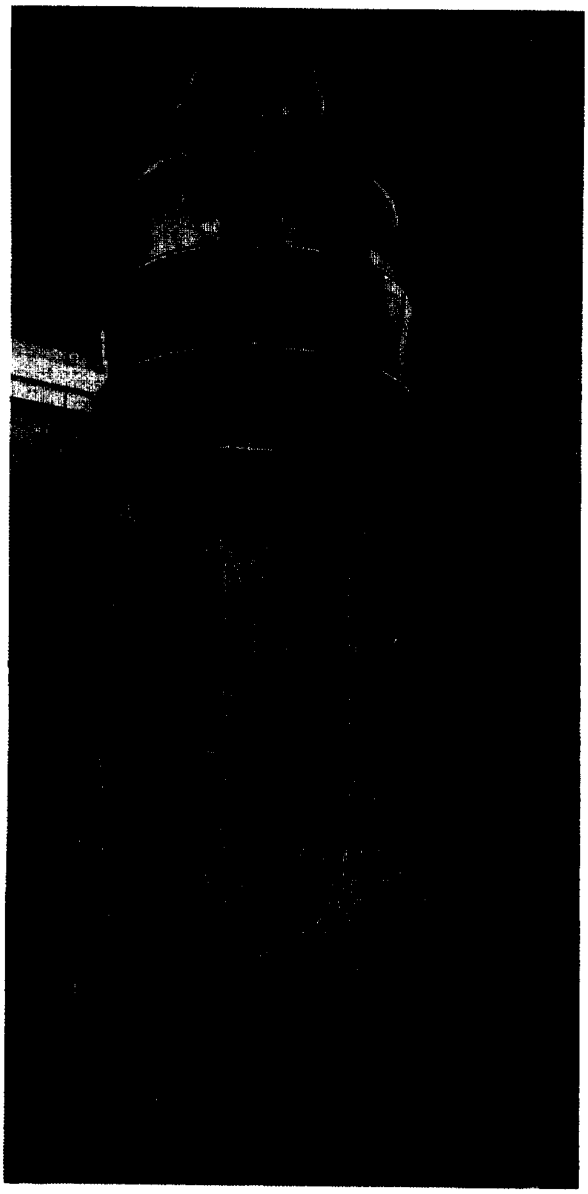

Fig. 5

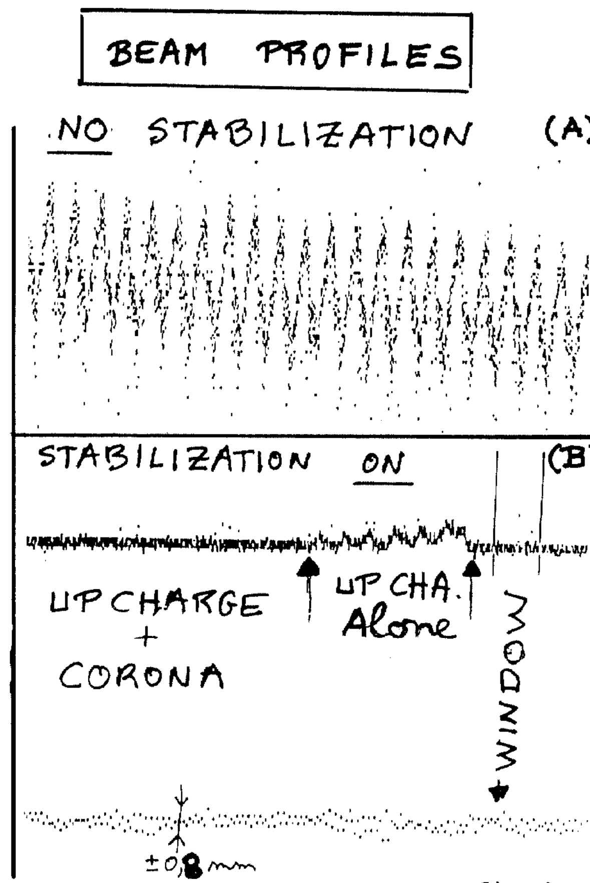

Fig. 6

(A) : 84 MeV ^{16}O beam

(B) : 140 MeV ^{28}Si beam

mounted. At the beginning of these tests we were only able to run such a section up to 3.5 MV with severe and unrepairable damages on the boards. After installing the protections we could run the same test up to 6 MV without any problem. This nearly doubling of the possible performances of the insulating materials was necessary to accept the high stress if a transient occurs.
Today beams of ^{12}C, ^{16}O, $^{28,30}Si$ mainly have been tested at voltages up to ≅ 18 MV. We used the first months of 1994 to stabilize at a high level these beams. This is necessary because the first experiments will be done using EUROGAM equipment where high order coïncidence measurements need a very stable beam. The natural beam without any stabilization system after the analysing magnet is shown on fig. 6 : for this ^{16}O beam the typical "wiggling" of the beam (1.6) is related to the periodicity of 10 sec. for one full turn of the belt. The natural width is ± 8mm in the horizontal plane, corresponding to an energy resolution of $2. 10^{-3}$. We developped at first a stabilization system acting simultaneously on both up-charge system (see fig. 6). It should be noticed that the initial system presented in ref. 5 was not able to ameliorate the beam stability and had to be given up. In fact all systems based on a down charge modulation (which was operated successfully in Daresbury) are faced to time constant problems and dynamical effects due to the "comeback" of the belt 5 sec later (half a full turn). In the actual system, the charge currents are read at the terminal and the corresponding digitalized information acts by a modulation of the HE and BE positive upcharge systems. The result of it is obvious on fig. 6 where the stability of a 150 MeV ^{28}Si is better by a factor of nearly 3.
The final stabilization is obtained by a superimposed CORONA effect device. Its operation is the same as in all other machines but the difficulty here was related to the presence of the 7 intermediate porticos. A full study of its best localization has been done. The final result is shown on fig. 6 in the case of the ^{28}Si beam. This final stability allows us now to declare the VIVITRON ready to deliver excellent beams of high quality on targets.

6. SUMMARY

Among the 23 large electrostatic accelerators constructed all around the wold, only 4 of them give beam energies corresponding to terminal voltages above 17 MV : Daresbury, Oak Ridge, Yale and Strasbourg. Unfortunately today 3 of them and in a near future only Oak Ridge and the Strasbourg Vivitron machines will survive the difficult financial situation encountered in many countries.
The VIVITRON represents surely the actual ultimate evolution of such machine technologies in contrast to OACK RIDGE which is the largest "conventional" machine and which could be operated as high as 26 MV. Today, after the good results obtained recently, it is reasonable to think that the phase 2 of the Vivitron, where the terminal voltage should be rised in the 30 MV range, should bring this machine at the highest performances in the world.

7. REFERENCES

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