PRESENT AND FUTURE OF ELECTROSTATIC ACCELERATORS

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Abstract

Electrostatic accelerator laboratories were the nurseries for the heavy ion physics research of today and the accelerators this research needed. The first conference, of what has evolved into the HIAT series, was the "International Conference on the Technology of Electrostatic Accelerators" hosted by the Daresbury Laboratory in 1973. While some of the founding labs of this series have ceased doing accelerator based physics, electrostatic accelerators still inject beams into present day heavy ion boosters. Electrostatic accelerators also continue to provide beams for nuclear and applied physics in laboratories with and without boosters.

The development of electrostatic accelerators remains active and will continue in the next few years. The improvements have been spurred by injection beam requirements of boosters as well as the special transmission and stability needs of accelerator mass spectrometry.

The survey of the electrostatic accelerator community presented here, has identified a broad range of improvements and uses as well as future technical directions for electrostatic accelerators.

INTRODUCTION

The present and future cannot be understood without at least a glance to the past. The evolutionary tree of nuclear physics separated into the electrostatic branch and the circular accelerator branch in the 1930s. Both branches nurtured nuclear physics research and developed their respective technologies right through the 1970s.

The first conference of the HIAT series was at Daresbury Laboratory and titled the "International Conference on the Technology of Electrostatic Accelerators". After a small alteration, the title "International Conference on Electrostatic Accelerator Technology" served for the next two conferences in Strasbourg in 1977 and Oak Ridge in 1981. These three conferences concentrated on the technology central to the new large machines in the three hosting laboratories: the Daresbury 20-30 MV machine, the 20-30 MV Vivitron and the Oak Ridge 25 URC. The maximum voltage aspired to became more conservative over time. Only the 25 URC still exists and now runs above 24 MV. None of the participants in the first conference is here today.

The striving for higher voltages in large machines went along with the development of booster RF machines. These developments were in response to the desire of nuclear physics researchers for ever higher energies to explore reactions with heavier targets well above the Coulomb barrier using light ions. This voltage push was soon subsumed into the budding of research with heavy ion beams. The booster efforts and successes lessened the impact on research of the failure of the electrostatic machines of the 1970s to reach the 20+ MV terminal voltages. The competition of the booster concept acted as a spur to Daresbury and Strasbourg but also contributed to their eclipse.

This eclipse was gradual as reflected in the evolution of the conference title to "International Conference on Electrostatic Accelerator Technology and Associated Boosters" for the next three conferences; the 1985 conference in Buenos Aires, the 1989 conference in Strasbourg-Heidelberg and the 1992 conference in Padua (Legnaro). Even at these transitional conferences, the boosters allowed were LINACs rather than the barely tolerated cyclotron booster at Munich. The linear-circular divide was alive but faltering.

Reality finally seeped into the title as the "International Conference on Heavy Ion Accelerator Technology" for the conferences in Canberra (1995), Argonne (1998), New Delhi (2002), Brookhaven (2005) (a combined conference with SNEAP), and now in Venice (2009) Legnaro. This change reflected proper focus on the broad topic of heavy ion accelerators and an open-minded acceptance of combined linear and circular machines. The linear and circular accelerator tree branches have now coalesced and are stronger for it.

Survey

Questions about their facilities were sent to staff at many laboratories with electrostatic accelerators and broadcast on the Symposium of North Eastern Accelerator Personnel bulletin board. I apologize to those at some facilities who have been inadvertently left out. The generous input of the colleagues who have contributed is gratefully acknowledged as the basis of this report. They represent the full gamut of electrostatic accelerators ranging from small ion implanters, neutron generators and ion beam analysis facilities to radioactive ion beam accelerators and injectors with straight nuclear physics and accelerator mass spectrometry machines in the middle.

Table 1 summarizes input. Labs are abbreviated by three letters so that the relative involvement in various areas is clearer in Table 2.

Table 1: Survey of Electrostatic Accelerators

Lab	Abbreviation	Respondents	e-mail address
Albuquerque	San	Barney Doyle	"Doyle, Barney L" <bldoyle@sandia.gov>
Argonne	ANL	Richard Pardo	Richard pardo <pardo@phy.anl.gov>
Beijing	CIA	Guan Xia Ling	Guan XiaLing <guanxl@ihep.ac.cn>
Brookhaven	BNL	Dannie Streski, Chuck Carlson	Dannie Steski <steski@bnl.gov> Charles Carlson <ccarlson@bnl.gov>
Catania	LNS	Danilo Rifuggiato	Danilo Rifuggiato <rifuggiato@lns.infn.it>
Geel	IRM	Göran Lövestam	Goeran.LOEVESTAM@ec.europa.eu
Heidelberg	MPI	Roland Repnow	repnow <repnow@mpi-hd.mpg.de>
Legnaro	LNL	Davide Carlucci	davide.carlucci@lnl.infn.it
Lucas Heights	ANS	David Garton	"GARTON,David" <dbg@ansto.gov.au>
Melbourne	Mel	Roland Szymanski	Roland Szymanski <ras@unimelb.edu.au>
Michigan	Mic	Ovidiu Toader	"Toader, Ovidiu" <ovidiu@umich.edu>
Middleton	NEC	Greg Norton	NEC <nec@pelletron.com>
Mumbai	TIF	Raj Pillay	Raj Pillay <pillay@tifr.res.in>
Munich	MLL	Ludvig Beck	Ludwig.Beck@physik.uni-muenchen.de
New Delhi	IUA	Amit Roy	Amit Roy <roy@iuac.res.in>
Oak Ridge	ORN	Martha Meigs	Martha Meigs <meigsmj@ornl.gov>
Purdue	Pur	Tom Miller	"Miller, Thomas Edward" <millerte@purdue.edu>
São Paulo	USP	Alinka Lépine-Szily	alinka.lepine@dfn.if.usp.br
Strasbourg	VIV	Michel Letournel	Michel LETOURNEL <mletournel@vivirad.fr>
Tallahassee	FSU	Ingo Wiedenhoever	Ingo Wiedenhoeve<ingo@nucmar.physics.fsu.edu>
Tel Aviv	Wei	Yourm Lasser	Yoram Lasser <yoraml@ariel.ac.il>
Tokai	JAE	Matsuda Makoto	Matsuda Makoto <matsuda.makoto@jaea.go.jp>
Tokyo	HFI	Todoa Iwai	Takeo Iwai <iwai@nuclear.jp>
Woods Hole	NOS	Karl von Reden	Karl von Reden <kvonreden@whoi.edu>
Yale	Yal	Jeff Ashenfelter	Jeff Ashenfelter <ash@riviera.physics.yale.edu>
Zurich	ETH	Lukas Wacker	Lukas Wacker <wacker@phys.ethz.ch>

THE PRESENT

The members of the electrostatic accelerator family share many traits but display interesting differences in the same way as siblings and cousins do. They each have started with a technical inheritance from either High Voltage Engineering Corporation, HVEC, or from National Electrostatics Corporation, NEC. Each suite of stating equipment was somewhat different and each evolved in response to the strengths of their individual staffs, host laboratories and scientific-political environment.

Keys to Success

In my view, all successful labs have in common three essential traits. First is the excellence of their technical staff characterized by their competence, commitment and innovative spirit. The second is the quality of the scientific staff. Their status in the international physics community is based on productivity built upon the competence of their home accelerator facilities. They are also notable for nimble response to changing science priorities and clever exploitation of the strengths in local equipment and personnel. This scientific competence provides the political strength that protects and nurtures their home accelerators. Thirdly, the best labs profit from close collaboration between the scientific and technical staff.

Table 2: Activities and Plans

Category	Past	Next	Wish
Power supplies & Vac Eq	Yal, MPI, ANS, TIF, BNL, ANU, ORN, FSU, MLL	Yal, ANS	Yal, MPI, ANS
Accel Tubes HVEC VIVIRAD	FSU, IRM, Mic		LNS, LNL
Accel Tubes NEC	JAE, MPI		ORN
Voltage grading	LNL, MPI, TIF, San	USP, IUA	MPI, TIF, IUA
Computer control upg	ANS, MLL, MPI, ANS, TIF	FSU, ANU, IRM, Pur	BNL
Beam pulsing	IUA	TIF, FSU, USP, ANU, Yal	
Positive ion source	ANL, LNL, BNL	ANL, LNL, BNL	
ECR Terminal	JAE	JAE, IRM,	Yal, Mel, HFI
High vlotage deck	HMI, CIA, ANS, MPI	HMI, CIA	
LINAC expand	CIA	CIA	FSU, San, JAE
Replace/Add El Accel		ANS	Mel, Mic, NOS, IRM
Pellet chains	San, Yal		Wei, IUA
RIB accelerator	LNS, ORN, CIA	LNS, ORN, CIA	Yal, JAE
RIB recoil	FSU, Pur	FSU, Pur, ANU	Yal

Consolidation

The present focus of most labs is on consolidation of existing facilities exemplified by the replacement of old electronic control and vacuum equipment. This has the largest numbers of entries in Table 2. Effort also is directed at improving reliability of control equipment and power supplies.

Other important areas for attention to shortcomings are in voltage grading systems in the Sao Paulo 8UD and the replacement of accelerator tubes in the Florida State FN. Computer control systems are being modernized in several labs reflecting the normal life trajectory of computer equipment.

Reliability at the Brookhaven MPs has been greatly improved by the adoption of laser ablated carbon stripper foils bought from Peter Maier-Komor in Munich. Since these foils last about three times longer than the locally made arc discharge foils, the frequency of tank openings has decreased and the beam is more consistent in intensity as the foil ages. Laser ablated foils from Peter Maier-Komor, are also in use for heavy beams at ANU and New Delhi.

The change of role for large electrostatic machines to injecting boosters has lessened the need to achieve the highest possible terminal voltage which results in much more reliable operation at Heidelberg and Brookhaven. Facility reliability is enhanced by the redundancy of having two MPs at Brookhaven and the choice of injectors at ANL and Heidelberg.

The successful marriage of DC electrostatic machines to RF boosters depends upon efficient beam pulsing systems. This is a center of current interest in Mumbai, Sao Paulo and Florida State. Competent pulsing systems are also a valuable tools for the basic nuclear physics tasks of measuring nuclear lifetimes and time of flight particle identification. Beam pulsing is convenient for AMS facilities providing flexibility to reduce the intensity stable beams.

Areas of Use

The range of science being performed is still dominated by nuclear physics in many labs but is no longer done at facilities concentrating on ion beam analysis like the labs at Michigan, Tel Aviv, Tokai-Mura and Sandia. Dedicated AMS facilities like Lucas Heights, Woods Hole and Purdue also do no nuclear physics. There is a nuclear physics component for the MPs at Brookhaven serving as injectors for the Relativistic Heavy Ion Collider, RHIC, or for the NASA Space Radiation Laboratory, NSRL, as well as providing for some stand alone users. The Heidelberg MP, on the other hand, is an injector for the heavy ion storage ring and other facilities dedicated to atomic physics research..

Many labs spend 75% or more of their effort on nuclear physics. These include Florida State, Geel, Oak Ridge, Legnaro, Catania, Yale and Canberra. The competing uses include AMS, single event upset of electronic devices, materials analysis and atomic physics. This is the case for JAERI, Brookhaven, New Delhi and Munich.

Innovation

The focus of development has shifted in several labs from the accelerator to novel and demanding experimental equipment. The introduction of light radioactive ion beams at Florida State, Notre Dame, Sao Paulo and Canberra has driven work on high intensity lithium beams used to bombard beryllium targets. The later three labs are exploiting superconducting solenoids to filter and focus the radioactive beam on secondary targets. While at FSU, a superconducting resonator homogenizes the energy of the radioactive beam impinging on the secondary target. The resulting small energy spread facilitates analysis of the reaction.

AMS continues to be an incubator for novel electrostatic accelerator development. NEC has developed a new type of "accelerator" that exploits their realization that the molecules of $^{12}CH_2$ and ^{13}CH, which would interfere with ^{14}C detection, can be dissociated in stripper gas at only 250 keV and not requiring the MeV terminals of the past. They are now building 500 kV tandems that are small versions of the standard 1.7 MV machines. But they have also taken the audacious step of eliminating the accelerator tank completely. This is accomplished in the Single Stage AMS facilities. [1] in which the ion source is near ground potential with the analysis devices and detectors on a 200 kV voltage deck. Since an accelerator tube is still used, this still qualifies as an electrostatic accelerator.

Exploitation of hundreds of kilovolts rather than millions of volts for molecule dissociation also features in an extremely novel ^{14}C AMS device from ETH Zurich [2]. This machine does away with gas insulation and uses high vacuum insulation instead. It also does away with graded accelerator tubes and replaces them with gap lenses. Basically, it resembles a 200 kV Einzel lens in which the central electrode contains a differentially pumped gas stripper canal. The hollow ceramic insulator supporting the electrode is connected to a turbo pump at ground potential. The stripper gas that escapes through a pair of pumping impedances, at the entrance and exit of the electrode, is pumped by another pair of turbo pumps. The high voltage comes from an external commercial high voltage power supply through another vacuum feed through. This accelerator confronts most of the challenges of electrostatic accelerator technology. These features include conditioning electrodes at extremely high surface electric fields in vacuum. A special challenge is maintaining vacuum good enough for insulation which is in conflict with the flow of stripper gas through pumping impedances. These need to be small to ensure good vacuum but large to allow 100% beam transmission. Careful beam optics is demanded to ensure excellent transmission through small stripper assemblies. As well, there are the usual problems with 200 kV across ungraded ceramic insulators and the x-rays inherent in such equipment.

THE FUTURE

Research topics, at most facilities, for the next two years or so are expected to be more of the same with marginal shifts in emphasis. This is less the case where the electrostatic machines are in competition with positive ion injectors especially at Legnaro and Brookhaven. Although the Argonne FN injector, has been expected to be displaced by the positive ion injectors for the last ten years, it continues to be relied on for light ion beams and providing respite time for work on the other injectors. It is likely, that this strength-through-diversity will also keep the electrostatic injectors operating at Legnaro and Brookhaven longer than now anticipated.

Just about the full gamut of accelerator devices are on the agenda in Beijing. This lab stands out for vigorous expansion of its accelerator facility to cater for radioactive ion beam work as well as AMS. The Beijing Radioactive Ion-beam Facilities, BRIF, will have a 100 MeV, 200μA proton cyclotron coupled to isotope separator. The MP will accelerate the radioactive ion beam and be coupled to a superconducting LINAC using quarter wave resonators.

The development of reliable electron cyclotron resonance, ECR, ion sources along with the improvement in spark protection in the terminals of machines, has enabled the return of terminal ion sources as important capabilities. This is being pursued in JAERI, a long exploiter of a terminal ECR ion source and in Geel. Reliable terminal ion sources avoid the limitations of terminal stripper foils with their limited lifetime to say nothing of the potential for increased beam intensity that positive ion sources offer. There is interest in terminal ECR sources from other facilities with single ended machines such as the 5U in Melbourne.

SUMMARY

The future of electrostatic accelerators lies in their continued use as flexible, reliable injectors, as stand alone nuclear physics facilities and in applied accelerator technology.

It is somewhat ironic that electrostatic accelerator technology is returning to terminal ion sources. Their displacement by the tandem concept was one of the tandem's great selling points. The solution of spark protection in large machines has been essential in allowing terminal ion sources to provide reliably the advantages of high intensity and noble element beams.

Large tandems were also the foundation facilities at which AMS was established. The electrostatic technology developed there informs the extrapolation to lower terminal voltage of the new compact AMS machines. The cross fertilization of technical ideas in AMS is evident in the careful beam optics needed for 100% beam transmission, beam chopping systems, differentially pumped strippers and electrostatic design.

The menu of possible improvements to electrostatic machines is now quite bare. Even the most exciting innovation in cleaning the inside of NEC accelerator tubes with high pressure water by Takeuchi [3], is from 2003. NEC has now adopted high pressure cleaning to deal with alumina particulates during the manufacturing process. The cross fertilization from superconducting

LINAC technology to electrostatics, exemplified by the high pressure cleaning, has not been able to be more thoroughly exploited because of the difficulty in maintaining class 10 cleanliness in large electrostatic machines during tube installation, alignment and maintenance. Thus the Takeuchi's tactic of cleaning the inside of the tube after assembly is superior to the pre-cleaning adopted by NEC.

The high gradient tubes from NEC still maintain the historic 30 kV per 1.25 cm insulation gap and achieve total voltage increase by extending into the dead sections. Extended tubes were introduced many years ago by Michel Letournel in Strasbourg and have long been standard in large HVEC machines.

The aspirations of some leading edge electrostatic accelerator laboratories are moderated by the completion for resources from LINACs and positive ion injectors. The resources are not only financial but the interest and enthusiasm of young accelerator personnel. The strong interest shown in HIAT 2009 suggests that these essential ingredients to accelerator technology are still vibrant and perhaps sufficiently widespread to nurture our diverse technologies.

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