UPGRADE OF THE BUCHAREST FN TANDEM ACCELERATOR

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Abstract

The Bucharest FN Tandem Accelerator was put in operation in 1973 and upgraded a first time in 1983 to 9 MV. In the period 2006-2009 a second program of the tandem upgrade was performed aiming to transform this accelerator in a modern and versatile facility for atomic and nuclear physics studies as well as for different applications using accelerated ion beams. The upgrade was achieved by replacing the main components of the tandem by new ones and by adding new components.

The old HVEC belt of the Van de Graaff generator was replaced by a "pelletron" system, the old inclined field stainless steel electrodes accelerator tubes were replaced by titanium spiral field tubes, the old HICONEX 834 sputter negative ion source was replaced by a new SNICS II sputter source and all old electronic equipment including NMR and Hall probe gauss meters as well as low voltage and high voltage power supplies for the magnets, lenses and ion sources were replaced by new ones.

The new equipment added to the tandem consists of a helium negative ion source, a new injector based on a multi-cathode ion source 40 MC-SNICS II for AMS applications, a new GVM, a new pulsing system in the millisecond range and a new chopper and bunching system for pulsing the ion beam in the nanosecond range. Now the tandem is currently operated in very stable conditions up to 9 MV on a basis of about 4000 hours/year accelerating a broad range of ion species.

INTRODUCTION

The Bucharest FN tandem accelerator (made by High Voltage Engineering Corp. – HVEC, USA) was commissioned in 1973 as a major Romanian facility for atomic and nuclear physics researches using accelerated ion beams. After a first upgrade in 1983 (installation of a sputter negative ion source [1] and increase of the terminal voltage from 7.5 MV to 9 MV by installing inclined field stainless steel tubes and adding SF_6 to the tank gas) the tandem delivered up to now in average 3500 hours/year a large range of accelerated ion species. This long period was marked in 1977 [2] and 1986 by two major damages of the tandem column due to strong earthquakes. In 1990 an original protection system of the tandem tank against earthquakes was installed [3, 4].

The main original tandem equipment still in use in 2006 was in very poor condition due to physical and moral wear and some of the necessary spare parts were no longer available on the market. After an analysis of the opportunity to invest in this old tandem accelerator, it was decided to change most of the equipment and to upgrade the tandem so that to convert the Bucharest tandem into a modern and versatile machine. The main motivations of this decision were: 1) such a facility is still important for specific atomic and nuclear physics researches; 2) a tandem accelerator is a very good tool for applications such as ion beam analysis – IBA (PIXE, RBS) and accelerator mass spectrometry – AMS; 3) a tandem accelerator laboratory is important for the education of young generations of physicists; 4) the preparation at the tandem accelerator of experiments at large scale facilities - LSF where the access is very limited is important; 5) last but not least, the Bucharest tandem accelerator is the single facility of this type not only in Romania but also in the south-east Europe, so that by its upgrade it may become a facility of regional importance.

Following this decision, a plan of upgrading the Bucharest tandem accelerator was started in 2006, the plan spreading over three and a half years. This long period is partially due to the limited and gradual financing but also to the decision to do the implementation of the new equipment with minimum interruptions of the tandem operation and delivery of accelerated ion beams.

The upgrade of the Bucharest tandem consisted of the following actions:

- modification of the Van de Graaff generator by installation of a "pelletron" system instead of the HVEC belt which is no more produced;
- installation of a new set of accelerator tubes in the tank;
- renewal and development of the tandem injector by installing a new SNICS II sputter negative ion source, development and installation of a new source for negative helium ions and installation of a dedicated injector for AMS based on a sputter negative ion source (MC-SNICS II);
- development and installation of a millisecond ion beam pulsing system;
- installation of a nanosecond pulsing system of the ion beam;
- replacement of all electrical equipment (low voltage and high voltage power supplies, fluxmeters, GVM) by new ones;
- refurbishment of the vacuum system by installing new vacuum pumps, new vacuum valves and a new vacuum measurement system.
- improvement of auxiliary equipment.

The upgrade program was started in order to diversify the available ion beam species, to enhance the quality of the accelerated beam and to make the accelerator much more reliable and stable, covering so the requirements of modern research and applications with ion beams delivered by an accelerator. The general configuration of the tandem was conserved. That means the HVEC 3 legs, 20^0 inflection magnet for the injector, the 90^0 analyzing magnet of the accelerated ion beam (1 m radius of beam curvature) and the 7 legs switching magnet that deflect the beam toward two experimental rooms remained in position.

Some of the works performed in the frame of this upgrade program were previously reported [5]. Here are outlined all the aspects of this program and are given more details.

DESCRIPTION OF THE MAIN WORKS FOR THE TANDEM UPGRADE

Pelletron System Installation

The "pelletron®" system made by National Electrostatic Corporation - NEC, USA for the Van de Graaff generator of an FN tandem accelerator consists of two chains installed on the left outer side of the column in the tank. On the right side of the column are installed the accelerator tubes. Pelletron chains are made of metal pellets connected by insulating nylon links and are charged by an induction scheme [6]. In order to be able to install the pelletron chains, a new location of the terminal voltage resistive divider installed since 1990 on the left outer side of the column had to be found keeping in the same time the advantages of the screwed system [7]. As the space between the two column sections became accessible by the removing of the old HVEC belt, the resistive divider was installed in this space. For this a set of 384 frames, one for each column plate, made of chromium plated 5 mm thick steel band were made, on each frame being mounted by screws the two Wellwin 300 MΩ resistors corresponding to a column gap (Fig. 1).

Figure 1: The new terminal voltage resistive divider installed between the column sections.

These frames with resistors were installed in the space between the column sections by securing them with screws on the upper side of the column steel plates. The pelletron system installed in 2007 proved so far to be reliable and to offer a stable operation of the tandem up to 9 MV. A further advantage offered by the pelletron system is that it uses electrical motors of lower power than the HVEC belt system. As a result we could remove from the tank the water cooled heat exchanger that had given us in time much trouble due to microscopic, undetectable water leaks. By renouncing to the heat exchanger the dryness of the tank gas (90% N_2 and 10% SF_6) was significantly improved. On the other hand, the tank gas has to be more frequently recirculated through the gas dryer with alumina in order to eliminate the fluorine compounds formed at surges in the tank. These compounds may drastically shorten the lifetime of the pelletron chains. The alumina in the dryer has to be changed yearly.

Installation of a New Set of Accelerator Tubes

Until 2008 the Bucharest tandem accelerator used a set of HVEC stainless steel, inclined field accelerator tubes. After more than 50,000 hours, the tubes began to produce high levels of X-radiation and prevented the raise of the voltage over 5 MV. It was decided to change them with a new set of titanium, spiral field accelerator tubes we had as spare parts since 1993. The new tubes, carefully conditioned mainly by monitoring the X-ray level of emission outside of the tank, behaved normally up to the maximum terminal voltage of 9 MV.

Renewal and Development of the Tandem Injector

The upgrade of the tandem injector consisted in the installation of three new negative ion sources:

- A new sputter negative ion source model SNICS II made by NEC [8], replacing the old HICONEX 834 source, was installed on one leg of the 20^0 inflection magnet. New power supplies and a computer control system with optical fibers using a Labview software were installed. The old preaccelerator tube is still in use allowing an input in the tandem of ion beams with energies up to 100 keV. This ion source proved to be stable and easy to operate. It produces ion beams for all elements which form a stable negative ion. The ion beams have a good match to the accelerator tube admittance.
- A helium negative ion beam source based on a duoplasmatron ion source followed by a lithium vapor charge exchange unit was developed in our laboratory and installed on the opposite 20^0 leg of the inflection magnet; it provides helium negative ion beams of intensities up to 5 μA at 80 keV.
- A dedicated injector for AMS based on a 40 cathode sputter negative ion source (model MC-SNICS II made by NEC [8]) followed by a 90^0 analyzing magnet and a short accelerator tube was installed on the 0^0 leg of the inflection magnet. This injector shares the high voltage platform and preacceleration power supply with the SNICS II ion source.

The ion optics of the injector, of the low energy (LE) beam transport system and of the overall transmission through the tandem accelerator were checked with the SIMION code.

The Millisecond Beam Pulsing System

For some experiments a millisecond pulsing of the accelerated ion beam is necessary. This system was home developed and installed on the low energy (LE) beam transport line, just after the inflection magnet. The system consists of a chopper system fed with rectangular pulses by a pulse generator followed by a power amplifier. The pulse generator gives TTL-pulses with a period between 5 ms and 2x104 s (very long periods are required in some activation experiments). The power amplifier provides on the chopper plates pulses with an amplitude up to 1 kV and a rise-time less than 50 ns. The pulse duration may be changed between 3% and 50 % of the period. The two rectangular chopper plates are 500 mm long with a distance of 50 mm between them allowing to use a pulse amplitude limited between 100 V and 200 V for any particles accelerated by the Bucharest tandem accelerator.

The Nanosecond Beam Pulsing System

This system, made by NEC and recently installed, consists of a chopper system and a buncher. The 2.5 MHz sweep (chopper) system produces 5 MHz pulse rate and is combined with a countdown system allowing repetition rates of 5 MHz, 1.25 MHz, 625 kHz and down to 19.53 kHz. This system is installed right downstream the preacceleration tube of the negative ion beam delivered by the SNICS II sputter source. The chopper system is completed by a model 63-50 (63 mm aperture, 50 kV) Einzel lens for a better beam matching to the tandem. The buncher is installed just in front of the first tandem accelerator tube and consists of two tubes of different lengths to match injected ion beams from mass 1 (protons) up to mass 40 u. The beam pulse duration is in the range of 1-3 ns with a packing efficiency of 25% This system will be very soon tested and commissioned.

In Fig. 2 the layout of the injector and the LE beam transport of the tandem accelerator is given, including the three negative ion sources and both beam pulsing systems described above.

Fig. 3 is a picture of the millisecond beam pulsing system and of the buncher of the nanosecond beam pulsing system, which are installed in front of the tandem tank.

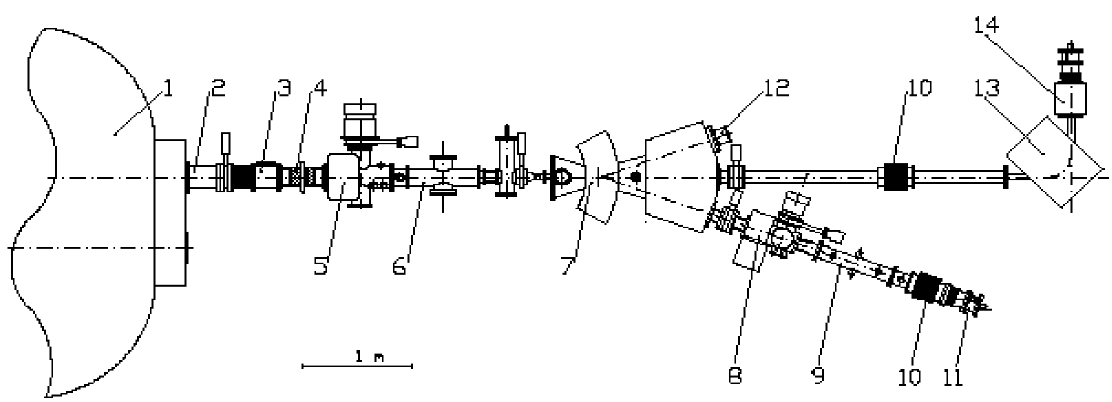

Figure 2: Layout of the tandem injector and of the LE beam transport line: 1 - Accelerator tank; 2 – LE steerer; 3 – Faraday cup; 4 – Einzel lens; 5 – Buncher of the ns pulsing system; 6 – ms pulsing system; 7 – 20^0 Inflection magnet; 8 – Einzel lens and chopper of the ns pulsing system; 9 – Steerer; 10 – Preaccelerator tube; 11 – Negative ion source (SNICS II); 12 – Duoplasmatron of the He negative ion source; 13 – 90^0 Analyzing magnet; 14 – Negative ion source (40MC-SNICS II) for AMS.

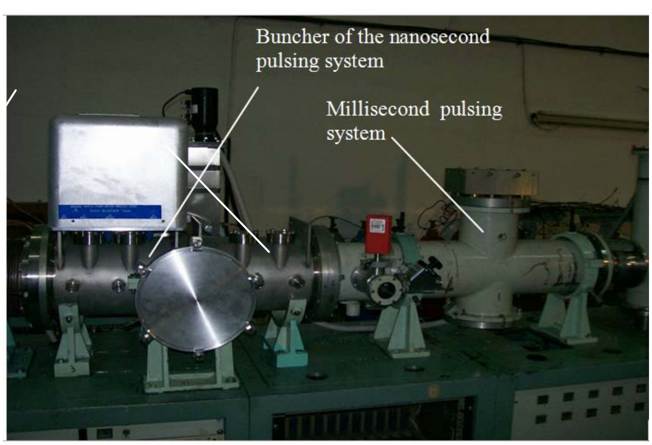

Figure 3: Beam pulsing systems installed on the LE beam transport line.

The replacement of the electrical equipment of the Bucharest tandem accelerator was a must of the upgrade program because it was very old, obsolete and unstable if not defective. This situation was due to the fact that for many years no funds were available for renewing the tandem equipment. Now most of the very old electrical devices were replaced by new ones, reliable and capable to support a computer control system. Several categories of devices were replaced:

- The old HVEC power supplies of low voltage and high power for the three beam deflection magnets: inflection magnet (1 kW), analyzing magnet (12 kW) and switching magnet (20 kW) were replaced by new Danfysik power supplies having a long term current stability of 10 ppm; these power supplies significantly contributed to improve the ion beam stability.
- The old power supplies for the magnetic quadrupole doublet lenses that focus the ion beam on the HE line and in front of experiments were replaced by Sorensen, USA power supplies which have a long term current stability of 100 ppm and contribute also to improve the ion beam stability.
- The high voltage power supplies for the ion injectors and for the Einzel lens on the LE ion beam line were replaced by Glassman, USA power supplies that proved to be reliable and stable in operation.
- The fluxmeters for measuring the magnetic field in the inflection magnet gap and in the analyzing magnet gap were replaced by a Hall probe fluxmeter made by Group3, New Zeeland and respectively by a NMR fluxmeter made by Metrolab, Switzerland; these flux meters proved to be accurate, reliable and easy to use.
- The instability of the old HVEC generating voltmeter (GVM) led us first to decide its replacement with a new one. But after a careful inspection, we observed some misalignment between the fixed and the rotating disks of the old GVM as the major cause of this instability. After fixing this misalignment the old GVM output allowed a much improved stability of the terminal voltage, in the range of 4 kV at 9 MV, so it was decided to keep it in operation. This accuracy combined with the terminal voltage low ripple given by the pelletron charging system is enough to maintain a stable ion beam spot on target even in the absence of the slit stabilization for most experiments at terminal voltages over 5 MV. At lower terminal voltages the GVM output is too small and the noise is affecting the beam stability, so the slit stabilization has to be used. Nevertheless, in some experiments, as is the AMS application, the terminal voltage must be stabilized even in the absence of a measurable beam that usually allows to use the slit stabilization. Such applications require a very accurate GVM. For this purpose a new GVM developed at the Technical University Munich, Germany was installed on an available port of the tandem tank beside the old GVM (Fig. 4). The tandem may work with either of the two GVM's, the change consisting only in the change of the signal cables to the common amplifier. The new GVM has definite geometrical and technical improvements, described in [9], that determine higher performances (terminal voltage stability of 1 kV or even better at a terminal voltage of 9 MV with GVM stabilization).

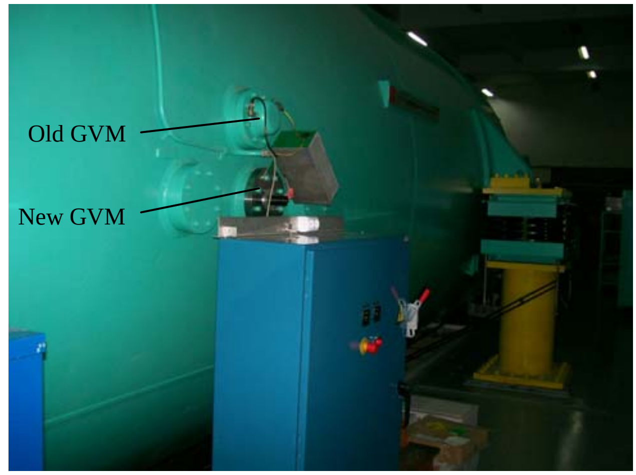

Figure 4: The two generating voltmeters installed on two neighbor ports of the tandem tank.

Refurbishment of the Vacuum System

Until recently the Bucharest tandem accelerator was still using the original vacuum equipment supplied by HVEC in 1973, mainly based on diffusion oil pumps using SANTOVAC 5 oil. The vacuum was in the range of 1-4x10^{-6} mbar. The actual requirements for a clean vacuum in the range of 10^{-7} mbar determined us to replace all the oil diffusion pumps by turbomolecular pumps and all the fore vacuum pumps by modern ones provided with oil sucking back protection and filters. Some of the gate valves were also changed with new ones. The old vacuum measuring system was doubled by a new one more accurate and that give the possibility to automatically record the readings.

Improvement of Auxiliary Equipment

The main improvement consisted in the installation of a high power (250 kVA) on-line, dual UPS (Uninterruptible Power Supply) providing to the entire building that houses the tandem accelerator electrical power of 3x400 V, 50 Hz. The UPS was necessary due to the very frequent interruptions, in general of short duration, of the electricity that caused the general shutdown of the accelerator and incidentally damage of the equipment. The stable and uninterrupted feed with electrical power had a benefic effect on the tandem operation. Other improvements consisted in the increase of the thermal capacity of the refrigeration system that cools down the distilled water used as cooling agent by the tandem accelerator and the installation of new distilled water pumps and air compressors.

CONCLUSIONS

The upgrade program of the Bucharest FN tandem accelerator developed in the period 2006-2009 had as a main result the transformation of this 36 years old accelerator into a modern, performing and reliable facility, offering stable beams of a large range of ion species: protons (2-18 MeV), helium (3-27 MeV) and a broad range of heavy ions that may be produced by the SNICS II sputter negative ion source (energies up to 100 keV or even somewhat higher depending on the ion atomic number). The beam intensities range from nA to μA depending on the electron affinity of the elements, parameter which determines the ion source efficiency to producing negative ions. The accelerated beam may be pulsed in the millisecond range (pulse period adjustable between 5 ms and $2x10^4$ s, pulse duration adjustable between 3% and 50% of the period) and in the nanosecond range (pulse duration in the range of 1-3 ns and repetition rates of 5 MHz, 1.25 MHz, 625 kHz and down to 19.53 kHz). The tandem is currently operated in very stable conditions up to 9 MV on a basis of about 4000 hours/year.

The performances and versatility of the upgraded Bucharest FN tandem accelerator combined with a strong scientific research program [10] and with high level results show the possibility for this facility to become an active part of the European Infrastructure in Nuclear Physics.

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