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Status report on the folded tandem ion accelerator at BARC

P SINGH, S K GUPTA, M J KANSARA, A AGARWAL, S SANTRA, RAJESH KUMAR, A BASU, P SAPNA, S P SARODE, N B V SUBRAHMANYAM, J P BHATT, P J RAUT, S S POL, P V BHAGWAT, S KAILAS and B K JAIN
Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai 400 085, India

Abstract. The folded tandem ion accelerator (FOTIA) facility set up at BARC has become operational. At present, it is used for elemental analysis studies using the Rutherford backscattering technique. The beams of ^{1}H, ^{7}Li,^{12}C, ^{16}O and ^{19}F have been accelerated up to terminal voltages of about 3 MV and are available for experiments. The terminal voltage is stable within ± 2 kV. In this paper, present status of the FOTIA and future plans are discussed.

Keywords. Folded tandem ion accelerator; charged particle beams; voltage stability; Rutherford backscattering; ion optics; beam lines.

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1. Introduction

An indigenously built folded tandem ion accelerator (FOTIA) facility [1–3] has recently been commissioned at BARC. It involved designing, fabrication, testing, installation and commissioning of a 6 MV folded tandem ion accelerator, by utilizing some of the components like the pressure tank, the storage tank, the equipotential rings, the high voltage dome and the accelerator room of the old 5.5 MV Van-de-Graaff accelerator at the Nuclear Physics Division, BARC.

The construction of the FOTIA involved development of technologies for several important components like dipole and quadrupole magnets, high voltage generator (figure 1), SF_6 gas handling system, PC-based control system, etc. The FOTIA has the capability of delivering accelerated light and heavy ion beams up to $A = 40$ and beam energy up to 66 MeV. These accelerated beams will be used for research both in basic and applied sciences. In this paper, present status of the FOTIA facility and future plans are discussed.

2. Details of the FOTIA facility

In the FOTIA, negative ion beams extracted from the SNICS-II source are pre-accelerated up to 150 keV and then injected into the low energy accelerating tube through a 70°-

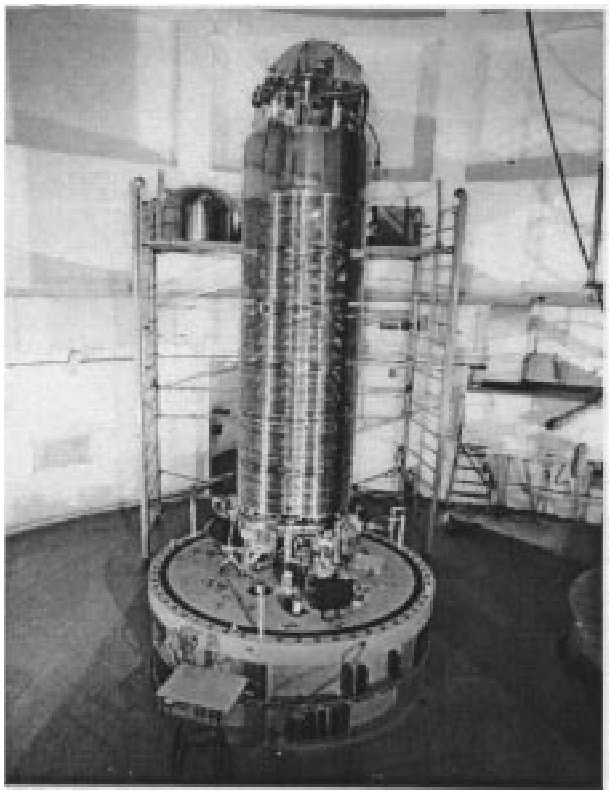

Figure 1. High voltage column section of the FOTIA. The 180°-magnet and other components inside the terminal can also be seen.

magnet and a 20°-electrostatic deflector. An electrostatic quadrupole triplet and an einzel lens focus and match the beam parameters to the acceptance of the low energy tube. The electrons of these accelerated negative ions get stripped off at the stripper and charge state of the positive ions thus produced is selected with the 180° magnet inside the high voltage terminal before being bent into the high energy accelerating tube. As at the exit of the 180° magnet the beam diverges, an electrostatic quadrupole doublet is used to focus the beam before it enters the high energy accelerating tube. The beams accelerated in the high energy accelerating tube are focussed using a magnetic quadrupole triplet before being analyzed by a 90°-magnet.

As mentioned above, three dipole magnets are used in FOTIA. They were developed indigenously. While two of these magnets (70°-injector, 90°-analyzing magnet) are at ground potential, the third, 180°-folding magnet, is located inside the high voltage terminal. The 70° magnet ($\mathrm{ME}/q^2 \leq 15$) has a bending radius of 40 cm and can provide a magnetic field of 14 kG in the pole gap of 4 cm with field uniformity of ±0.1%. The 180°-magnet ($\mathrm{ME}/q^2 = 10$, $R = 30.5$ cm) designed for 14 kG has field uniformity of ± 0.15%. The 90°-dipole magnet was designed for a magnetic field of 14 kG and $\mathrm{ME}/q^2 = 50$ with a radius of curvature of 75 cm. A magnetic field of 15.5 kG was measured at a coil current of 500 A.

The accelerated ions cover a distance of about 40 m while traveling from ion source to scattering chamber. The acceleration of heavy ions requires ultra high vacuum in the accelerating tubes and rest of the beam transport system, in order to avoid the loss of intensity and spread in energy of the ion beams. Also, the accelerating tubes which are subjected to very high voltage gradient of about 2 MV/m require clean vacuum for smooth operation of the accelerator. A distributed pumping system [4] having seven pumping stations maintains UHV in the entire system including the target chamber. The ion source section has a large gas load, which increases substantially whenever samples are changed in the ion source. A turbo-molecular pump, with the speed of 1600 l/s, maintains ultra high vacuum in this region. The other sections are pumped by a combination of titanium sublimation and sputter ion pumps or only by sputter ion pumps.

For controlling and monitoring the parameters of the FOTIA a PC-based control system [5] is used. The system is a network of PCs with a front-end interface using CAMAC instrumentation and uses QNX real time operating system.

3. High voltage generation, its measurement and stabilization

The high voltage column section consists of six modules; each designed for one million volt. A pellet chain system, made of metallic pellets and nylon links, is used for generating the voltage on the terminal. The electrical power, required in the terminal, for 180°-magnet, ion pump, etc., is generated by an alternator. The 5 KVA alternator, connected by a perspex shaft is driven by a 10 HP motor.

It was planned to test the high voltage column section initially with N_2+CO_2 and solve all the problems before filling the accelerator tank with SF_6 gas. The high voltage terminal could be raised to 3.4 MV using N_2+CO_2 mixture as an insulating gas at a pressure of 98 psig [6]. With SF_6 gas, which has a dielectric strength of approximately 2.2 times that of the N_2+CO_2 mixture at 98 psig, it will be easy to get a terminal voltage of 6 MV. Since hydrocarbon free environment is required inside the accelerator tank, a new gas handling system, which consists of an oil free compressor, a centrifugal blower, a heat exchanger, dust filters, dryers and a vacuum pump etc, has been used. The high voltage on the terminal is measured using a generating voltmeter (GVM). A terminal voltage stabilization system was developed [7] for obtaining a stable energy beam. The system consists of GVM pre-amplifier, slit amplifier, corona probe drive circuit and control and monitoring system. It is a closed loop control system involving generation of error signals derived from GVM or slit pick-ups and feeding it to the correcting circuitry. The circuit drives the corona probe system, acting like shunt regulator, thereby correcting the terminal voltage. The stabilization system was tested both in GVM control mode and in slit control mode with beam current as low as 2 nA and its performance is satisfactory. The voltage stability in GVM control mode was found to be about ± 2 kV.

4. Safety related interlocking in FOTIA

Like any other accelerator, FOTIA also involves various hazards like SF_6 leakage, high voltages, radiation, fire and vacuum failures. The low and high energy accelerating tubes maintaining high voltage gradients across them have to be protected against vacuum failures. Two fast acting valves are used to isolate the tubes against vacuum failure. Accelerator tank housing the high voltage column is to be filled with SF_6 to provide required breakdown strength.The tank needs to be evacuated before every opening and after every closing operation. During tank evacuation, ion pumps inside the tank should be OFF in order to avoid high voltage sparking on pump feedthroughs. Similarly chain charging power supplies, chain motor and shaft motor should not be ON when the tank is being evacuated. Any leakage of SF_6 can create oxygen deficiency which can cause problems in breathing for working personnel. The radiation levels inside the beam hall and control room areas are to be continuosly monitored for X-ray and neutron emission. Any increase, beyond the safe limit, in radiation levels should automatically stop the beam. Also, opening of doors to beam hall area should stop the beam in case of high radiation levels. Apart from this audio/visual alarms available on SF_6 leakage/radiation monitors/smoke detectors should also be available in the control room so that necessary action can be taken during any abnormal condition. The ion source deck floats at 150 kV. Opening of entry door should switch OFF the deck voltage. Similarly temperature rise inside high voltage terminal beyond 45° should switch OFF the 180° magnet power to avoid damage to its coils and surrounding electronics. All other magnets (70°, 90°, MQTs) using water cooling need to be protected against cooling failure and rise in temperatures beyond the safe limits. Considering all above requirements of machine as well as human safety, a PLC (programmable logic controller) based interlocking system has been designed and implemented. PLC is connected to windows based PC and is programmed in ladder language. All SF_6 leakage/oxygen deficiency/radiation monitors having local, audio/visual alarms have been wired to the PLC I/O to generate suitable status and alarm signals on PC as well as on the control panel. The status of all interlocks, motors (like compressor, blower, chain, shaft, turbomolecular and rotary pumps, etc.), isolation valves and fast acting valves are available on PC monitor. The PLC system works independent of the existing control system in order to achieve high reliability.

5. Beam energy calibration

After high voltage tests, the beams of ^{1}H, ^{7}Li,^{12}C, ^{16}O and ^{19}F have been accelerated up to terminal voltages of about 3 MV. The 90°-analyzing magnet which is used for energy determination has been characterized by using RBS technique. A typical RBS spectrum of ^{7}Li+^{197}Au measured using 80 cm diameter scattering chamber [8] (figure 2) is shown in figure 3. The magnetic field B used for analyzing the beam with energy E, mass number A and charge state q is given by

$$B = \frac{K}{q}\sqrt{AE\left(1+\frac{E}{2Am_u c^2}\right)} \tag{1}$$

where m_u is the mass of one a.m.u. and K is the calibration constant for the analyzing magnet. From the beam energy determined using RBS and corresponding magnetic field measured by a hall probe mounted in the air gap of the analyzing magnet the K-value of the magnet was determined to be 0.1805$\pm$0.0002 Tesla/MeV$^{1/2}$/a.m.u.$^{1/2}$ [9].

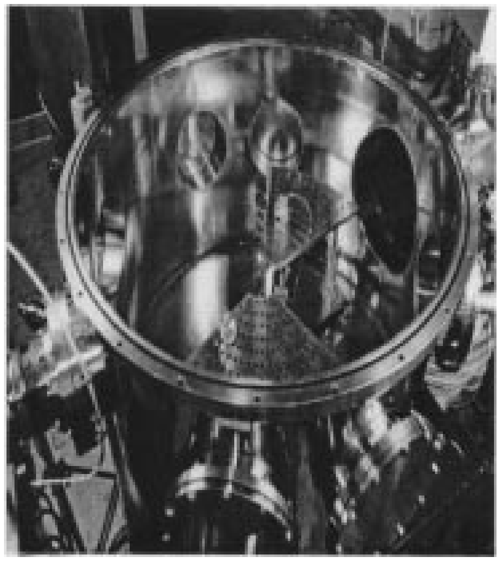

Figure 2. Scattering chamber used for RBS measurements.

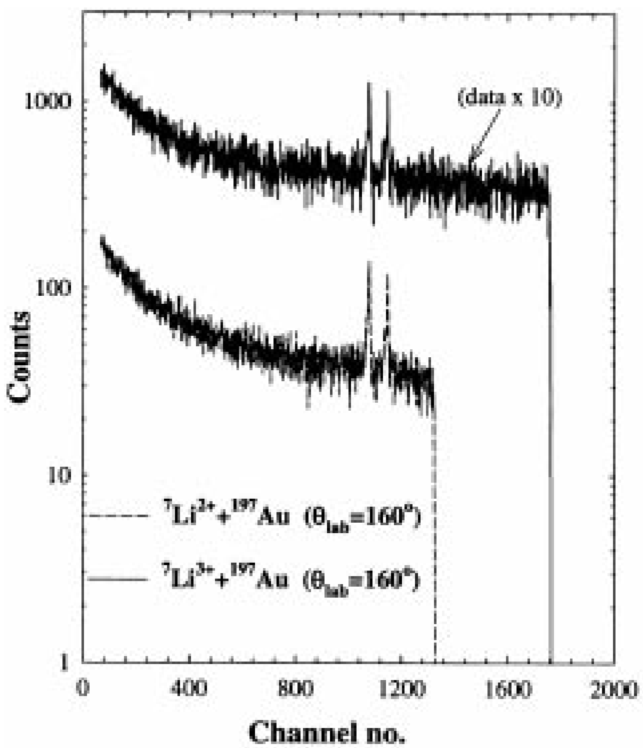

Figure 3. RBS spectrum for ^{7}Li+^{197}Au measured at $\theta_{\mathrm{lab}} = 160^\circ$ for characterization of the 90°-analyzing magnet. Two alpha peaks coming from an Am-Pu source mounted on one of the target positions can also be seen in the spectrum.

6. Summary and conclusions

The FOTIA facility at BARC has been commissioned recently. Several beams have been accelerated up to a terminal voltage of 3 MV and are characterized by RBS technique. The voltage stability of less than ± 2 kV has been achieved using the voltage sabilization system developed in the laboratory. A PLC based interlock system is being incorporated for the safety of the machine components and the accelerator personnel. A new beam hall has been constructed in order to set up five beam lines for various experiments in the fields of nuclear physics, material sciences, AMS, beam foil spectroscopy, etc. Details of the beam optics studies have been completed for the above beam lines and exact locations of various beam handling components have been finalized.

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