IMPROVEMENTS TO THE ITHEMBA LABS CYCLOTRON FACILITIES

J.L. Conradie, P.J. Celliers, J.G. de Villiers, J.L.G. Delsink, H. du Plessis, J.H. du Toit, R.E.F. Fenemore, D.T. Fourie, I.H. Kohler, C. Lussi, P.T. Mansfield, H. Mostert, G.S. Muller, G.S.Price, P.F. Rohwer, M. Sakildien, R.W. Thomae, M.J. van Niekerk, P.A. van Schalkwyk, iThemba LABS, P.O. Box 722, Somerset West 7130, South Africa
Z. Kormány, ATOMKI, P.O. Box 51, H-4001 Debrecen, Hungary
J. Dietrich, T. Weis, Fachbereich Physik, University Dortmund, D-44221 Dortmund, Germany
S. Adam, D. Goetz, P.A. Schmelzbach, Paul Scherrer Institut, CH-5232 Villigen, Switzerland

Abstract

At iThemba LABS a K200 separated-sector cyclotron and its two K8 injector cyclotrons accelerate beams of light and heavy ions as well as polarized hydrogen ions to variable energies for nuclear physics research. For proton therapy a 200 MeV proton beam is used. For neutron therapy and radioisotope production a 66 MeV proton beam is available. The latest development work concentrated on increasing the intensity of the 66 MeV proton beam and extension of the facilities for radioisotope production.

INTRODUCTION

In recent years several projects aimed at increasing the intensity of the 66 MeV proton beam and extending the facilities for radioisotope production have been worked on [1]. Flat-topping systems were installed in the light-ion injector cyclotron (SPC1). A flat-topping resonator [2] was built for the separated-sector cyclotron (SSC) and inserted through a port in a valley vacuum chamber. An additional rebuncher, operating at twice the frequency of the main rebuncher, was installed in the transfer beam line between the light-ion injector and the separated-sector cyclotron. A vertical beam line for radioisotope production was commissioned and a new beam line that will allow operation with split beams is under construction [3]. Additional non-destructive diagnostic beam position monitors [4] were installed and new equipment for beam phase measurement [5] in the separated-sector cyclotron is being designed. To improve the reliability of beam delivery new RF power amplifiers for the separated-sector cyclotron are under construction. For acceleration of heavy ions to higher beam energies two additional ECR ion sources and beam lines for injection into the heavy ion injector cyclotron (SPC2) are being constructed.

INCREASE IN BEAM INTENSITY

External proton beam intensities of up to 300 μA could be obtained with SPC1 at the injection energy of 3.14 MeV for the 66 MeV proton beam that is used for radioisotope production. With the two flat-topping systems now in routine operation the external beam intensity increased to 600 μA, since longer beam pulses are extracted from the ion source and accelerated with low energy spread up to extraction. A fifth harmonic dee voltage of 2 kV is superimposed on the main dee voltages with a harmonic power dissipation of 700 W per resonator. The beam intensity was further increased to 800 μA by using a 2 mm wide and 4 mm high aperture in the anode of the internal PIG ion source instead of a circular aperture with a diameter of 2 mm.

The double-gap additional rebuncher in the transfer beam line operates at double the main rebuncher frequency and four times the cyclotron RF frequency. It was designed for operation at 14 kV with a power dissipation of 300 W and has been installed upstream of the main rebuncher. The amplitude and phase stabilization of the dee voltage is done by using a direct digital synthesizer chip AD9952 [6]. The optimum operating conditions for minimum beam loss in the SSC still have to be determined experimentally.

The 3rd harmonic flat-topping resonator in the SSC is in routine operation. At a dee voltage of 62 kV the power dissipation without beam is 7 kW and decreases as the beam intensity increases. A 66 MeV proton beam with an intensity of 250 μA with an extraction efficiency of 99.8% is regularly used for radioisotope production.

BEAM SPLITTING

The beam lines to the two vaults for the production of radioisotopes at iThemba LABS are being modified to allow simultaneous irradition of targets in the two vaults by using an electrostatic channel and a septum magnet, similar to those in use at the Paul Scherrer Institut (PSI), to obtain separate beams. Experience at the PSI has shown that horizontal movement of the beam increases the losses in the septum of the electrostatic channel. Since the beam from the cyclotron at iThemba LABS is more stable in the vertical direction than in the horizontal direction it was decided to rotate the beam in the high-energy beam lines through 90° with five quadrupole magnets turned through 45° with respect to the orientation that is normally used [7]. Fig. 1 shows the layout of the beam line with electrostatic channel, that will operate at a voltage of 100 kV across a gap of 30 mm, and septum magnet that deflects the beam through 16 degrees. The quadrupole currents have been calculated with the program TRANSPORT [8]. Calculations with the program TURTLE [9] have shown that the losses on the electrostatic channel will be approximately 0.3% of the total beam current of 350 μA.

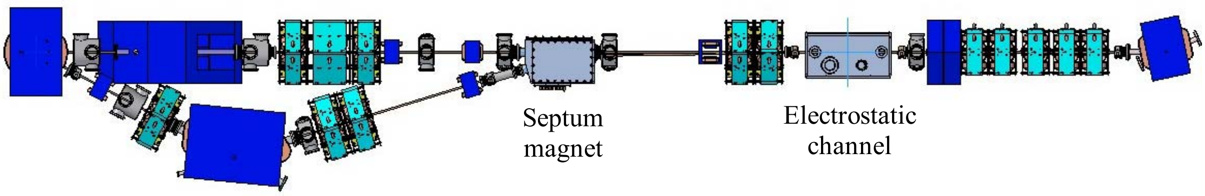

Figure 1: Layout of the 15.4 m long beam line for beam splitting.

DIAGNOSTIC EQUIPMENT

Up to now beam phase measurements was done by displaying the amplified beam signal from a phase probe from one of the two multi-head probes on an oscilloscope, triggered by a signal derived from the dee voltage, and noting the time while the probe is driven from the injection to the extraction radius. Although the accuracy of the method is sufficient it is time consuming and the probe support also intercepts beam, which means that the beam phase in the cyclotron is not known during operation. New, non-interceptive phase probes with greater sensitivity are therefore planned.

The combined signals from the top and bottom plates of a phase probe are amplified and filtered before addition to a harmonic of the dee voltage generated by an Analog Devices direct digital synthesizer chip AD9952 mounted on a development board. Two signals with independent phase and amplitude adjustment by computer control are available from the synthesizer. One signal is used as a reference for the lock-in amplifier, and the other for cancellation of the pick-up signal, by adjustment of the amplitude and phase, to minimize the voltage displayed on the lock-in amplifier, without beam. Accurate phase and amplitude measurements are therefore not required for cancellation of the pick-up signal, except that such measurements are useful to calculate the approximate phase and amplitude settings of the AD9952 synthesizer before final adjustment, in order to speed up the cancellation process. Measurements on a test set-up showed that phase measurements at a beam intensity of 10 nA is possible.

Air-filled ionization chambers, similar to those in use at the PSI, were installed at 2 meter intervals in the high-energy beam lines leading to the radioisotope production vaults to detect stray-beam leaving the beam pipe. Each detector consists of two printed-circuit boards separated by a distance of 10 mm and with facing surfaces copper-plated. The ring-shaped copper surfaces have inner and outer radius of 55.8 mm and 85.8 mm, respectively. On the one board the copper ring is divided in quadrants to indicate the position of the stray beam. The boards have been designed in such a way that they can be clamped onto the outside of the beam pipes without removing a pipe section. To detect stray particles the quadrant currents, using a 1 kV bias voltage, are measured, using integration techniques, and displayed with a computer program Halo. The system can measure 48 channels concurrently with an accuracy of a few pA. Central to the electronic system is a rabbit microprocessor. The computer program connects to the microprocessor over the network using TCP/IP. The program displays the data graphically and controls the current range. The colour of the graphs change when certain important conditions are met. Data from 8 stray-beam detectors are displayed. Using a client program the visual interface can be seen from any computer on the network. The stray-beam detectors now form part of the safety-interlocking system for protection of beam pipes and peripheral equipment. Stray-beam detectors, using PIN diodes, have been installed in the beam lines leading to the experimental areas.

RF POWER AMPLIFIERS

The 24-year old power amplifiers of the SSC are progressively becoming more difficult to maintain as mechanical and electrical systems age and parts become obsolete. Failures regularly occur during energy changes, when the systems are more highly stressed, causing delays in beam delivery. To alleviate this problem it was decided to build simplified replacements for these 150 kW amplifiers, which are designed to operate only at the frequencies that are most often required. In restricting the operating range of the amplifiers, a huge cost saving is achieved. The existing amplifiers will be retained for use at all other frequencies. This will allow the operators to set up the amplifiers well in time for scheduled energy changes and will also allow servicing of the amplifiers not in use at the time. Models of sub-sections of the power amplifier have been built and preliminary tests and measurements were carried out. Mechanical parts are being machined, while some components are still being designed. The power-amplifier cabinet itself houses a 2-stage power amplifier using an Eimac 4CW100000E output tube and a 4CW25000A driver tube. The final anode circuit is a quarter-wave arrangement with fixed dimensions using a single variable vacuum capacitor for tuning. A fixed tapping on the transmission line acts as a fully-coupled loop to extract the output. A penalty for this arrangement is that the circulating current rises, as a function of falling frequency, faster than the surface resistivity decreases, resulting in a net reduction of resonant anode-impedance at the tube at the lower frequencies. A later refinement may be to add a series capacitor to the output coupling, to provide some adjustment for this impedance. The interstage tuned circuit uses a fixed inductor and yet again a single variable vacuum capacitor. These choices allow for a tuning range of about 2:1, which includes the two main frequencies for which the amplifier is intended, namely

26 and 16,373 MHz. Driver grid-tuning and matching to the 50 ohm input connector uses fixed capacitors and a single roller-type variable inductor in a parallel tuned circuit, together with a 4:1 broadband transformer. Resonant resistance levels have been kept moderate, so that Q-values are reasonable, in order to enhance stability. Neutralising circuits for both tubes and damping for the more obvious parasitic resonances have been included in the initial design. The input power for the amplifier will come from a 300W wideband solid-state unit. Preliminary impedance measurements on a partial trial-assembly of the amplifier confirm the calculations.

HEAVY-ION BEAMS

Since 1994 a 10 GHz Minimafios ion source, built by the CEA in Grenoble, has been used for the acceleration of heavy ions at iThemba LABS. The 14.5 GHz ion source, ECR4 [10], that was originally built by GANIL for the Hahn Meitner Institute (HMI), and its beam line have recently been installed at iThemba LABS. Beams from the source for acceleration with the separated-sector cyclotron will be available by the end of 2007. With the ECR4 source the maximum beam energy for xenon ions will be about 40% higher than at present and beam currents at lower energies will increase dramatically.

A new source, based on the design of the Grenoble Test Source (GTS) [11], is under construction. It is a room temperature source that uses two microwave frequencies, 14 GHz and 18 GHz, to deliver $^{129}Xe^{37+}$-ions of sufficient intensity to be accelerated in the separated-sector cyclotron to an energy of 2.2 GeV. Two ovens for ionization of metals and non-volatile elements will be used. Modifications to the buildings, cooling system and mains power switchgear are in progress. First operation of the source is scheduled for December 2008. With two sources for heavy ions it will be possible to do development work on new ion species while beam is being prepared and delivered for nuclear physics research. Fig. 2 shows the layout of the sources and beam lines in the basement area of the second injector cyclotron.

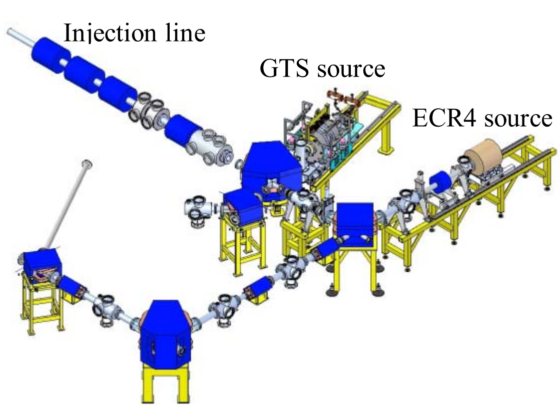

Figure 2: Layout of the ECR sources and beam lines.

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