

STATUS REPORT AND NEW DEVELOPMENTS AT iThemba LABS

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Abstract

iThemba LABS is a multi-disciplinary research facility in the fields of nuclear physics research, neutron therapy, proton therapy and radionuclide production. Three long-running projects – the construction of a new electron cyclotron resonance ion source, a beam phase measuring system for the separated-sector cyclotron comprising 21 fixed probes and an RF amplitude and phase monitoring system for the 16 RF systems – have been completed. The first results will be reported. The status of the newly developed low-level RF control system will be discussed and an interactive magnetic field calculation method for an injector cyclotron, making use of a database compiled from calculations with the computer program TOSCA, will be presented. Plans to save on the power consumption of the accelerators will be reported on. The beam statistics and the progress with the planning of a radioactive ion beam facility will be discussed.

ELECTRON CYCLOTRON RESONANCE ION SOURCES (ECRIS)

iThemba LABS operates two electron cyclotron resonance ion sources. ECRIS4, which was originally built by GANIL for the Hahn Meitner Institute [1, 2], delivers ion beams from gases and fluids. Since 2011 a second ECRIS, the GTS2, which is based on the design of the Grenoble Test Source [3], has been installed.

In the frame of our collaboration with the ion source group at CERN, experiments for the production of intense argon beams were performed. The source was optimized for the 11+ charge state of argon ions, as it is required for direct injection into the CERN linear accelerator and booster ring. A current of 65 μA was obtained for the 11+ charge state in CW operation. For injection into the RF linear accelerator at CERN, pulses with a pulse length of 200 μs at a maximum repetition frequency of 5 Hz are required which can be produced from the source in the so-called afterglow regime. In this mode an intensity of 200 μA with oxygen support gas was achieved. The pulse is stable for more than 500 μs . Additional experiments at iThemba LABS are scheduled to further optimize the beam performance.

RF CONTROL SYSTEM

A modularized version of a digital low-level RF control system has been developed at iThemba LABS. The system is the evolution of the prototype that was reported on previously [4]. The system as illustrated in Fig. 1 utilizes a Xilinx Spartan 6 FPGA that is interfaced with two high-speed 16-bit 500 MHz DACs from Analog

Devices to synthesize the RF and local oscillator signals. The RF frequency is programmable in steps of 1 μHz between 5 and 100 MHz and the phase in steps of 0.0001° in the current configuration. High dynamic range of the main RF signal is maintained using a 23-dBm amplifier cascaded with three 32-dB, 0.5-dB digitally programmable step attenuators. The system uses 1 MHz intermediate frequency (IF). The five IF channels are sampled by five 16-bit 10-MHz SAR ADCs from Analog Devices. The dynamic range of each of the IF channels is maintained using 32-dB, 0.5-dB digital step attenuators as well. The amplitude and phase information is extracted from the signals using quadrature demodulation. A closed-loop controller within the FPGA is utilized to keep the phase and amplitude at an operating point and to reject system disturbances. The ARM CPU runs Ubuntu 13.04 and an EPICS IOC. Amplitude and phase information as well as system parameters can be streamed to an EPICS client via Ethernet allowing monitoring and diagnostics of the RF signal to be performed in real time. The system is now in the design verification stage.

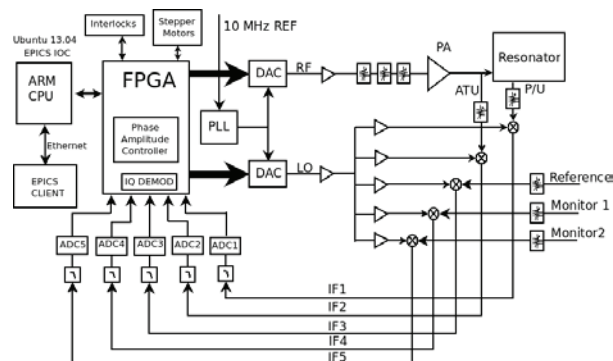


Figure 1: New digital low-level RF control system.

PHASE PROBES FOR THE SEPARATED-SECTOR CYCLOTRON (SSC)

Twenty-one non-destructive fixed phase probes have been installed in the SSC injection valley vacuum chamber. Each probe consists of two double-shielded electrodes symmetrically arranged with respect to the median plane. The upper and lower plates of each probe can be multiplexed to a single output port and are then combined. This reduces the unwanted RF pickup in the system. The second harmonic of the beam bunches is used to extract amplitude and phase information. Selectable 7th-order band-pass filters comprising thirteen 4-MHz band-pass filters, each with a 1-MHz overlap, are used to filter the second harmonic. The filters are designed to reject the fundamental and higher-order harmonics by 60

dB. The signal can then be amplified from 0–60 dB in steps of 20 dB. A Stanford Research Systems SR844 lock-in amplifier is used to extract the amplitude and phase information. A block diagram is shown in Fig. 2.

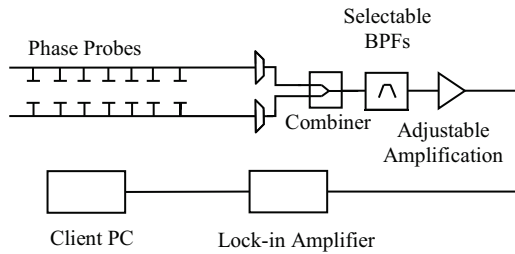


Figure 2: Block diagram of the non-destructive beam phase measurement system for the SSC.

An interface for phase measurement was developed using LabVIEW. The different hardware sections, i.e. the multiplexer controller, the lock-in amplifier, adjustable amplifier and filter controller are running as separate services connecting the different control bus interfaces together in centralised global variables. These global variables are controlled by National Instruments Shared Variables from any TCP/IP remote client. The LabVIEW client scans through the 21 probes and plots the amplitude and phase. The phase information is used to isochronize the magnetic field of the SSC.

BEAM STATISTICS

The beam statistics for the past five years are shown in Table 1 below. Since 2009 the beam time lost as a result of interruptions has been well under control: e.g. only 4.8% of scheduled time during 2011. Also shown in Table 1 below is a steady increase in time lost due to energy changes. This could be accounted for by the increased beam current delivered to the various radionuclide target stations. Delivering more current on the target stations requires more time to optimise beam transmission.

Table 1: Operational Statistics of the SSC for the Past 5 Years

Year	Beam supplied as:		% of scheduled beam time for:	
	% of total time	% of scheduled time	Energy changes	Interruptions
2008	62.0	75.17	4.0	14.3
2009	70.5	82.45	5.7	6.6
2010	67.6	82.18	5.2	7.3
2011	68.9	85.91	5.4	4.8
2012	69.9	82.04	6.1	7.9

MAGNETIC FIELD CALCULATION FOR INJECTOR CYCLOTRON 2 (SPC2)

A finite-element TOSCA-simulation [5] of the complete SPC2 cyclotron magnet was used to compile a database of magnetic field contributions for each coil over the full range of their respective power supplies.

Interactive use of an MS-Excel spreadsheet program and the database, together with graphical displays,

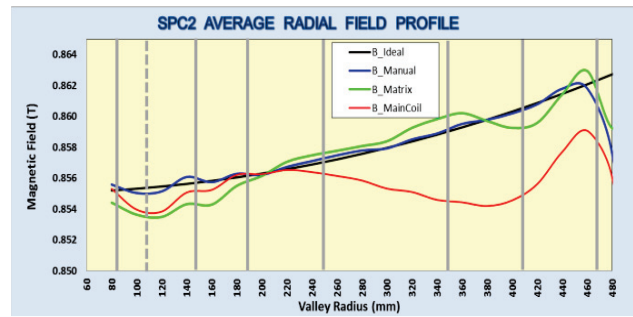


Figure 3: The average radial field profiles of SPC2, calculated with the two methods (in green and blue), are compared to the ideal field (black). The field of the main coil only is shown in red and the vertical grey lines represent the radial positions of the 8 correction coils.

provides an instantaneous prediction of current settings and quality of the isochronous field. A matrix solution gives an immediate prediction of the main coil and 8 correction coil currents to match an ideal isochronous field for the selected particle rigidity. The operator may further adjust the main coil current, which will immediately update the matrix solutions and graphical display. The spreadsheet program also provides another method for the operator to interactively adjust any of the nine coils to match the predicted field with the ideal field, also with an immediate graphical display of the fields. The latter method so far can provide the better solution to obtain the isochronous field, as shown in Fig. 3, and has also proved to be a good training tool for a better understanding of the contribution of any coil on the total field distribution of SPC2.

GREEN INITIATIVES AND ALTERNATIVE ENERGY SOLUTIONS

In realizing the benefits of Resource Efficient and Cleaner Production (RECP) initiatives, iThemba LABS endeavours to reduce its carbon footprint.

The first initiative was to improve the power factor of the incoming power from 0.86 to 0.99 resulting in a sustainable energy and cost saving.

The central cooling plant is the item with the single highest electrical demand (1.5 MW at maximum demand). The local electricity tariff structure can be exploited with the introduction of a Thermal Storage System to produce ice during the cooler night temperatures when the cost of electricity is the lowest and then melting the ice to assist the cooling processes during hotter daytime periods when electricity costs are significantly higher.

At iThemba LABS the electrical supply from the UPS (4 MVA) is isolated from the national grid, which provides an ideal interface for feeding solar energy into the local grid. This eliminates the need for a solar grid inverter. The solar support can be made very modular and, to prove the principle, a pilot plant of 34 × 80 W photovoltaic panels is under construction.

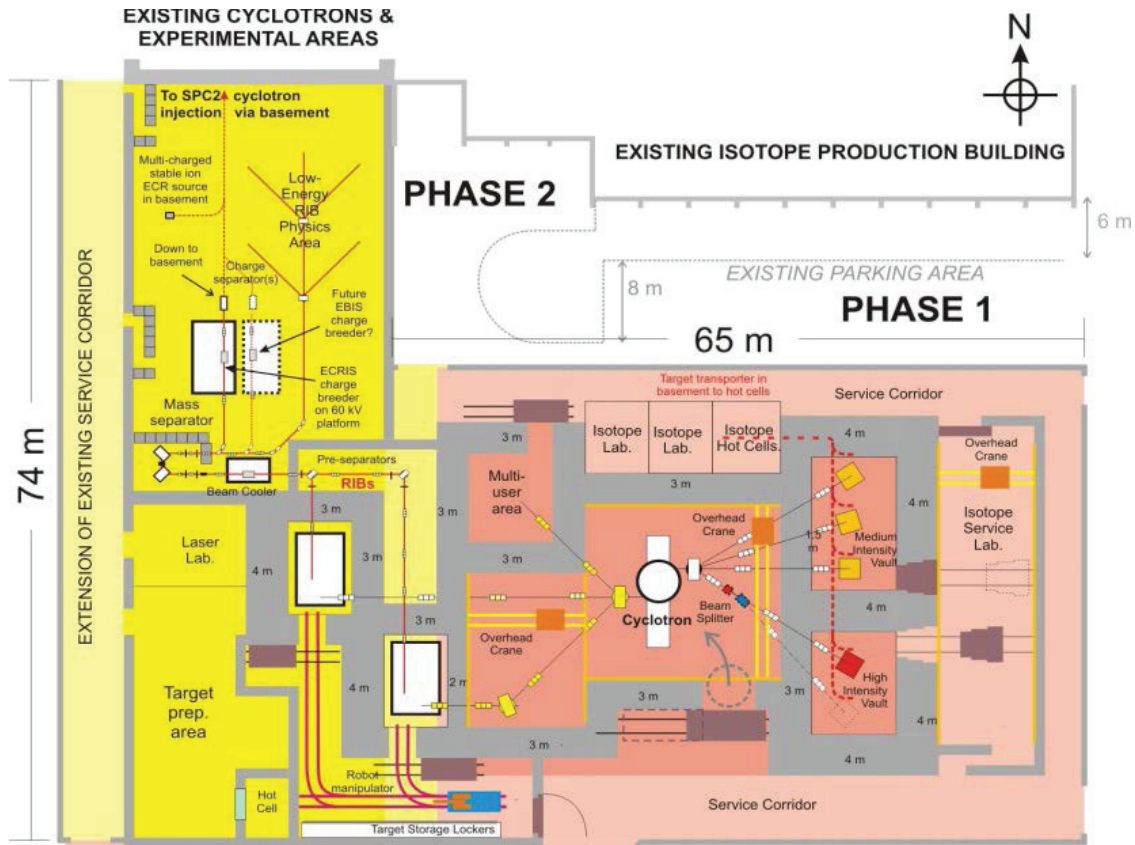


Figure 4: Diagram of the iThemba LABS proposed 70-MeV cyclotron installation for production of radioisotopes and radioactive-ion beams, showing phase 1 (pink) and phase (2) yellow. Radioactive-ion beams will also be post-accelerated via the SPC2 injector and the SSC (not shown).

RF DIAGNOSTIC SYSTEM

An independent eight-channel RF diagnostic system has been developed to monitor the phase and amplitude stability of the different RF systems. LabVIEW software is used to capture and display the information. The system can be programmed to select any RF installation at iThemba LABS. Figure 5 shows a block diagram of the system. It is an extremely valuable diagnostic tool to trace instabilities in the RF systems.

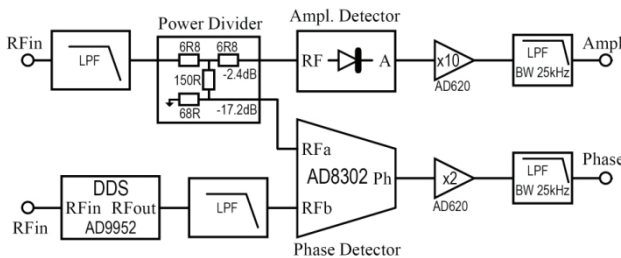


Figure 5: Block diagram of one channel of the RF diagnostic system.

RADIOACTIVE ION BEAM PROJECT

A proposal has been made for the acquisition of a commercial 70-MeV H^- cyclotron for the production of radioactive-ion beams for nuclear and materials research. With two exit ports, such a machine will also deliver

proton beams for the production of medical and industrial radioisotopes for the local and overseas markets. Collaboration with the SPES group at INFN Legnaro has already commenced, and it is envisaged that a target/ion-source system similar to the SPES version – based on a CERN design – would be used at iThemba LABS

Two production vaults are proposed and low-energy beams would initially become available, mostly for materials science and decay studies. Later, beams would be cooled, mass-analysed, charge-bred and then accelerated via the existing chain of cyclotrons (SPC2 injector and the SSC) for nuclear physics research with radioactive ion beams. The layout of the proposed facility is shown in Fig. 4.

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