CONTROL OF THE ROTATING BEAM ON RIB TARGETS AT TRIUMF

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Abstract

Modelling of the radioactive ion beam (RIB) targets at TRIUMF has suggested that rotating the high energy proton beam in a circle on the face of the target may provide a greater source of radioactive ions than a static incident beam. To explore this idea a system has been configured to allow the beam of protons in the primary beamline to be steered in a circle and to permit various parameters to be changed. A description of the system and initial experience in operating the rotating beam are included.

INTRODUCTION

On August 8, 2009 TRIUMF [1] celebrated the 40th anniversary of the laboratory. Approximately 10 years earlier a major milestone in the expansion of the facility occurred when beam was first produced in ISAC [2] (Isotope Separator and Accelerator). ISAC is a radioactive ion beam (RIB) facility. TRIUMF's 500 MeV cyclotron is able to simultaneously extract three proton beams at variable energies and currents. One of these beams, in beamline 2A, provides protons for an ISAC target. 500 MeV protons are used to bombard the ISAC target and produce the RIB. The target is heated to a high temperature and the atoms liberated in this way are transported by diffusion and effusion to an ion source contiguous with the target. The quantity of RIB current produced is affected by many factors such as the size and the intensity of the incident proton beam, the geometric configuration of the target and the thermal fluctuation the target has experienced. Modelling has been applied to optimize the generation and the collection of the RIB. Some results have suggested that instead of applying the 500 MeV proton beam as a fixed spot on the target, rotating the beam in a circular pattern may increase the yield of the RIB [3]. To pursue this possible increase in yield, initial developments have taken place.

SYSTEM SETUP FOR THE ROTATING BEAM

Currently there are two switchable target stations for the RIB, namely 2A2 (west) and 2A3 (east) (see Fig. 1). They are named for the incident proton beam, which originates from the cyclotron's beamline 2A. Only one target station is in use at any time. For DC operation mode the proton beam is delivered as a defused, fixed spot on the target. To deliver a rotating beam, the beamline is re-tuned to have a smaller spot, in other words, more focused. The rotating beam configuration sweeps the beam on the target in a circular fashion at a fixed frequency. The modelling indicates a higher proton current may be delivered and that a better distribution of the thermal energy may be obtained. This is called the AC operation mode. Initial developments occurred with both the original "D" shaped target geometry and with a new, toroid shape. The new shape has been designed to be a ring shaped geometry to facilitate the collection of the radioactive atoms.

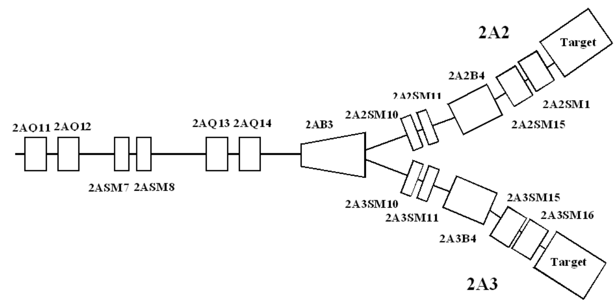

Figure 1: Beamline 2A magnets configuration.

To deliver the rotating beam, two new steering magnets, namely 2A2SM10 (2A3SM10) and 2A2SM11 (2A3SM11), were inserted in each leg of the 2A beam line. Each magnet provides horizontal deflection of the proton beam and vertical deflection. A single magnet of this design was unable to provide sufficient beam deflection so two magnets in series are used. To give the beam a circular pattern, each deflection has to follow the same sinusoidal amplitude and frequency, with a 90 degree phase difference between them (see Fig. 2). Calibration of the steering characteristics of the two magnets was carried out.

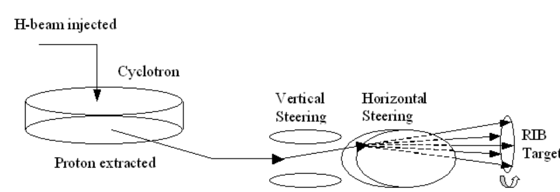

Figure 2: Magnet steering diagram.

CONTROL BY SOFTWARE

Initially during development there were a number of parameters the users wanted to vary, while noting the target yield. Parameters such as the rotation frequency (in this case between 1 Hz to 25 Hz), the radius of the circle (in millimeters), and the horizontal and vertical offset from the target's longitudinal center line could be varied. At the start, a software program was used to implement the AC-steering of the proton beam. The software application positions the proton beam sequentially at twenty equally spaced points on the circle to approximate a circular beam pattern. The application calculates the required currents for the horizontal and vertical steering magnets for each requested position and then sets the magnet power supplies appropriately. A power supply is controlled in this configuration by the software outputting a setpoint to a digital-to-analog converter (DAC). An X-window user interface was developed to display the status, enable/disable the AC steering, and to allow changes in the parameters (see Fig. 3). Since thermal fluctuation will decrease the target lifetime, parameter changes are carried out on the fly, without beam stoppage.

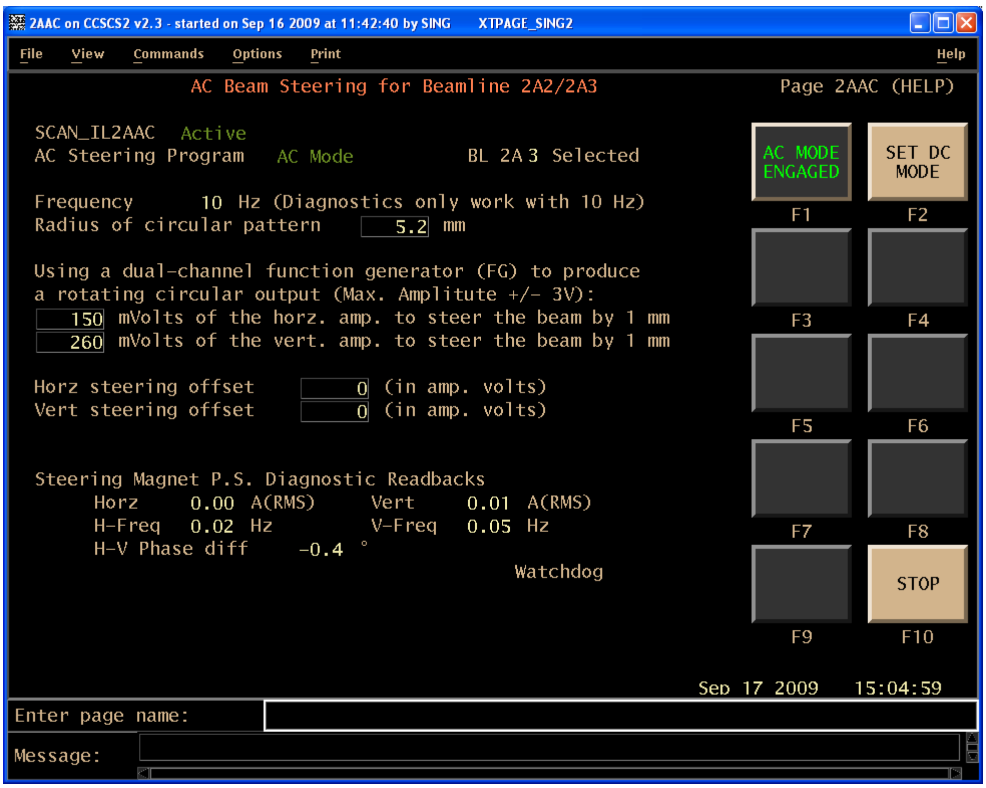

Figure 3: User interface for controlling the rotating beam.

DIAGNOSTICS AND INTERLOCKS

Damage to the target may occur if the AC steering stopped while the beamline was tuned to the small spot size. To avoid this damage, diagnostics and interlocks were developed to detect problems in the beam rotation and stop beam delivery when problems occur.

There is a split plate protect monitor with directional foils upstream of each target. The time response of the current amplifiers used was purposely lengthened in order to wash out the variation in signal currents due to the beam rotation. As an independent form of protection, the steering magnet currents as derived from current sensing resistors in the power supplies are monitored. Since the power supply setpoints were changing every 2 ms at the 25 hertz rotation rate, the conventional means to read back and verify the magnet currents was deemed inadequate. A hardware diagnostic module was designed to measure the rotation frequency, the horizontal and vertical AC current amplitudes (Root Mean Square) and the phase difference between the horizontal and vertical steering currents. These parameters are monitored by the computer system which will trigger termination of the proton beam delivery within 200 ms if the magnet currents are not varying as expected. After initial developments had occurred, a decision was made to fix the rotation rate at 10 Hz. The diagnostics were then set up to measure the amplitudes and phase of the 10 Hz component of the magnet currents (see Fig. 4).

CONTROL BY ARBITRARY FUNCTION GENERATOR

The use of a software program to control the steering of the beam has been a success. It allowed quick prototyping to happen. However, due to the stringent time requirement (initially up to 25 Hz for rotation frequency) of the system, a decision was made that the computer that runs the steering program would not take on other tasks. Another approach which does not tie up an entire computer and which should provide better waveform control of the power supply outputs is being pursued. This second approach involves introducing a function generator. A Tektronix AFG 3022B Arbitrary/Function Generator (AFG) was purchased. It is capable of generating two sine waves with a 90 degree phase difference, and has two output ports that can be connected to the horizontal and vertical power supplies for the steering magnets. The AFG can provide its outputs at up to 250 MS/s and at a 14 bit resolution. The AFG comes with a LAN port that can be connected for use with either 10 Mb/s or 100 Mb/s communications. Software applications can employ the VXI-11 communication protocol to control the function generator via the network. A new software application and user interface have been developed to supplement the previous ones. In this new configuration the approximation of the circle is very good. The incremental change in the power supply outputs are extremely small and this reduces the ringing in the output current which occurred previously. This ringing resulted when then power supply output was stepped to the new value while attached to the magnet, which is an inductive load. More frequent, smaller steps leads to less ringing.

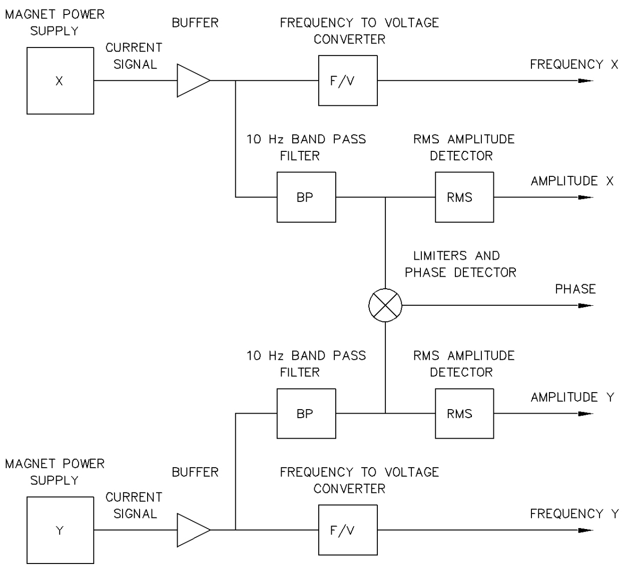

Figure 4: Block diagram of magnet current test circuits.

Development on the AFG was originally done on the bench and problems with network communications were encountered. Two changes were made and the network connection now works robustly. The first change involved a firmware upgrade. The second change involved moving the device onto a virtual private network (VPN), which can dramatically reduce the ambient broadcast activity.

The AFG has been connected to the power supplies and tested successfully. This configuration is now waiting for a Development Shift and access to a suitable RIB target for further commissioning.

SUMMARY

Modelling indicates rotating the proton beam on a radioactive ion beam target may increase the production of extracted radionuclides. Two techniques for controlling the rotation of a TRIUMF 500 MeV proton beam on an ISAC RIB target have been developed. These techniques both paint the high energy protons on the RIB target in a circle. Both configurations use horizontal and vertical steering magnets, with the associated power supplies varying according to the same frequency sine wave (10 Hz) but 90 degrees out of phase. The first approach uses a software application discretely controlling digital-to-analog converters, which are connected to the steering magnet power supplies. The second approach uses an Arbitrary Function Generator with its two outputs connected to the steering magnet power supplies. The former setup has been used in production running and the latter configuration is waiting for more development time to explore its robustness. Diagnostic hardware was developed and is used to monitor the power supply outputs to ensure the magnet currents (steering) are changing as expected. Interlock software monitors the diagnostic hardware and stops beam delivery if the frequency or phase angle of the power supply outputs is incorrect.

ACKNOWLEDGMENTS

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