STABILIZING THE BEAM CURRENT SPLIT RATIO IN TRIUMF'S 500 MeV CYCLOTRON WITH HIGH LEVEL, CLOSED-LOOP FEEDACK SOFTWARE

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Abstract

In the pursuit of progressively more stable beam currents at TRIUMF's 500 MeV cyclotron there was a proposal to regulate the beam current split ratio for two primary beamlines with closed-loop feedback. Initial runs have shown promising results and have justified further efforts in that direction. This paper describes the software to provide the closed-loop feedback, and future developments.

INTRODUCTION

Initially, TRIUMF's 500 MeV cyclotron extracted beams simultaneously into two primary beamlines, at variable energies and currents. Over time this was expanded to three and then four simultaneous beams. Only three beamlines are presently in use but there are plans for a new fourth beamline. Extracting multiple beams is relatively straight forward but stabilizing the beam currents in multiple beamlines is challenging.

One of the main requirements for stable beam current involves the production of rare isotopes for TRIUMF's ISAC Facility. This facility employs targets that run extremely hot and where the power on target is largely deposited by an incident beam of protons. Variations in the proton beam current changes the power deposited on the target. Running too cool reduces the output of ions, while running too hot can damage the target. A stable incident beam is important to optimize isotope production and target lifetime.

For a number of years closed-loop feedback software has been used on the extracted beams to stabilize beam current and beam position on target(s) [1]. The first of these loops started more than 8 years ago. Beam current stability using the existing electrostatic pulser in the low energy injection line has been applied to stabilize the current in the beamline for rare isotope production (Beamline 2A). This stabilization technique works as expected but results in greater beam instability on the other beamlines (Beamlines 1A and 2C). The greater instability was acceptable but not desirable. Subsequently, new ideas have been proposed with the goal of stabilizing beam currents on two beamlines [2][3].

One of these new proposals involves the introduction of additional closed-loop feedback software to stabilize the split ratio between two extracted beams (Beamlines 1A and 2A). The ratio of the two beam currents can be affected by using a local magnetic field to shift the beam orbit before extraction from one extraction foil to the other. An existing harmonic coil's Bz component is used to produce the local magnetic field to shift the beam orbit horizontally. Initial tests of this technique showed improved current stability simultaneously on the two beamlines.

Recently, better and additional power supplies were installed. These changes, combined with enhanced software, have provided better and finer control over the harmonic coils.

Initial software developments to monitor the beam currents and stabilize the split ratio using the harmonic coil have worked so well they have been left running. Enhancements are planned but limited resources have slowed progress.

BEAM CURRENT ADJUSTMENT BY HARMONIC COIL

The 500 MeV cyclotron accelerates H^- and uses stripping foil extraction to extract protons. A number of trim and harmonic coils exist to alter the beam path of the H^- as it spirals out toward the extraction foils. The coils can be used to provide radial (Br) and vertical (Bz) magnet field components, which move the beam vertically and radially (horizontally) respectively.

The ratio of the currents extracted from the two high energy, high current beamlines (Beamlines 1A and 2A) is determined by a number of factors. The primary factor is the relative position of the circulating/accelerating beam to the position of the two extraction foils. By moving the beam horizontally, current can quickly be re-positioned from one foil to the other. This re-positioning is done using a harmonic coil's Bz field to move the beam radially.

The harmonic coil in use is driven by six power supplies and has six windings on each of the top and bottom of the vacuum tank.

There is a process which monitors the adjusted, extracted currents for the two beamlines, calculates the split ratio and exports the value for use by other programs.

A closed-loop feedback software application running in a server monitors the split ratio and adjusts the position of the beam to stabilize the split ratio. Users interact with the feedback application via an X Window based user interface.

DEVICE IMPLEMENTATION

The TRIUMF cyclotron has thirteen harmonic coils, each at a different radius. Each harmonic coil comprises six pairs of windings located in a 6-fold symmetrical manner on the cyclotron tank. They are used to adjust the local magnetic field at a particular radius. The Bz mode is used for orbit centering and Br mode for median plane tilt. Harmonic coil 13 is the outermost and was chosen for use in the split ratio stability program. There are six parameters for this harmonic coil: the 1st harmonic amplitude, the 1st harmonic

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phase and the 3rd harmonic amplitude for both the Br mode and the Bz mode. Each parameter is implemented as a virtual device. Routines are in place so users can adjust each parameter independently without affecting the other five, even though all parameters control the same six power supplies for the coil. In practice, since all six power supplies are controlled by 10-bit DACs (digital to analogue converter), true independency of the parameters is an ideal case. Most of the time, when changing one parameter, there are minute but acceptable changes in the other five parameters. Low level routines calculate currents for the six power supplies and apply polarity change when needed as well as check if any of the power supplies has reached the high or low current limits.

Besides setting an individual parameter, users can also set all six parameters at one time using an X Window interface program, XTpage (page 3HC), which will be described in the next section.

APPLICATION PROGRAM FEATURES/USER INTERFACE

The feedback loop program periodically reads the present value of the beam split ratio and if there is enough variation from the desired ratio it adjusts the harmonic coil's Bz field to radially move the beam from one extraction foil to the other.

The primary graphical user interface in the Cyclotron's Central Control System is an X Window application called XTpage. Within XTpage there are 2 display pages associated with the control and monitoring of the harmonic coils. Page 3HC has both virtual and real signal values including power supply setpoints and readbacks, and 1st amplitude/1st phase/3rd amplitude for both Br and Bz (mostly for diagnostic use). Power supply, Bz, and Br values are logged. These six virtual devices provide a mean for the users to manipulate the harmonic coil at an abstract level. It allows beam physicists and cyclotron operators to carry out tests with ease.

The other XTpage display (page 3HS) is the user interface for the split ratio stability program (see Fig. 1). Via this display various parameters for the stability program can be changed:

- Enable/Disable: Manual enable or disable of the loop program.
- Number of samples and sampling rate: The loop program works with a calculated average of the split ratio. Operators can change the number of samples and time between samples.
- Multiplier: Operators can scale the magnitude of the change to the DAC setpoint for the harmonic coil's Bz field.
- Active zone: Operators can specify the minimum and maximum values of the split ratio where the loop program is engaged. If the split ratio drifts outside the active zone the loop program pauses.
- Dead zone: This is a small band/channel (with an upper and lower range) inside the active zone where fluctuations in the split ratio are acceptable. If the split ratio is inside the dead zone the loop program makes no change.

Some components of the control and readback have also been integrated into the main console for the convenience of Operations. State changes and user changes to parameters are automatically recorded in the master log.

Under certain conditions the feedback loop program is automatically disabled or paused while the condition exists. For example, if there is no current in either beamline then the process is disabled automatically. In other situations the feedback program automatically pauses momentarily so as not to interfere with normal beam activities. For example, the program auto-pauses when the pulser is ramping, when operators are adjusting the RF frequency, or when the RF booster is being turned ON/OFF.

Figure 1: XTpage - Control and monitoring of the split ratio stability program.

OPERATIONAL EXPERIENCE

For almost one year, when both of the high energy beamlines are running, it has become normal operation to enable the split ratio stability software. The increased stability permits less hands-on adjustment. In addition, increased beam current stability in Beamline 1A, although not a strict requirement, has been welcomed by experimenters.

The increased stability has also helped to reduce the number of beam trips. This metric of beam trips is now watched closely, as the thermal cycles on the rare isotope targets are minimized where possible.

Fig. 2 shows plots of data from before split ratio stability (2012 - June 19 to 23) compared to the data when split ratio stability is running (2013 - July 19 to 23) [4]. A noticeable improvement in Beamline 1A current stability is apparent.

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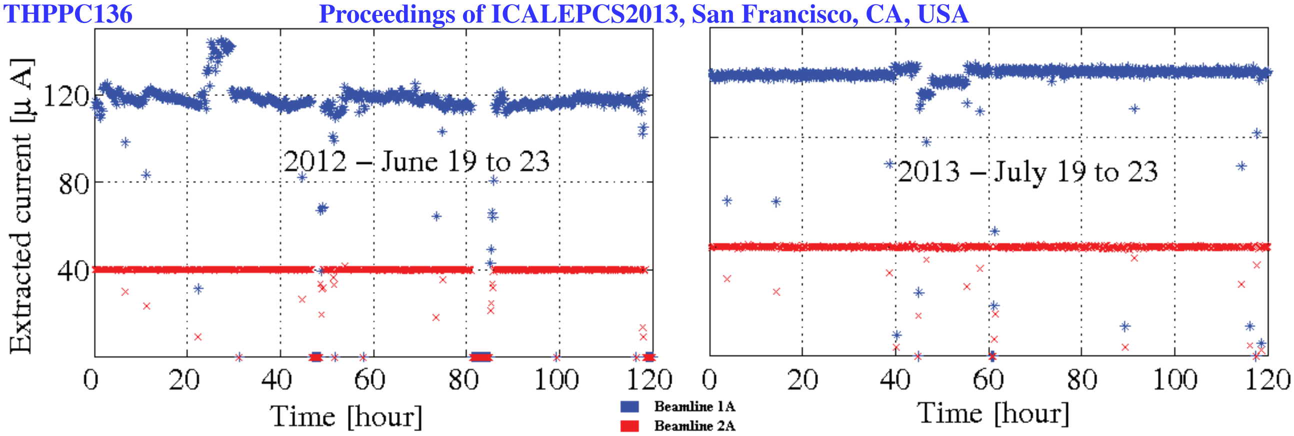

Figure 2: Beam current stability in beamlines 1A and 2A; without feedback (left plot), with feedback (right plot).

PLANS FOR ENHANCEMENTS

There are a number of areas where beam current stability improvements are anticipated. In one area, DAC resolution is felt to limit the ability to smoothly control the Bz amplitude. To improve this situation, plans to install higher resolution DACs are being considered. Improvements to the software algorithms are also planned. In still another area, the general approach of using the pulser to stabilize beamline 2A's extracted current may be changed to use the pulser to stabilize the injected current.

SUMMARY

Increased beam current stability has been achieved with the enhancement of harmonic coil power supplies and software to provide closed-loop feedback. This software, which runs in a high level server, is now used in normal operation of the beamlines. The user interface and closed-loop application are well accepted by Operations. Reliable operation of the software has been demonstrated over the last year. Operation of the cyclotron is easier for the Operations Group because less hands-on adjustments are needed. The empirical results of the closed-loop feedback software and other improvements on the harmonic coil have been published at IPAC2012 [3] and CYC13 [4].

A number of enhancements are anticipated, including increasing power supply DAC resolution, improving software algorithms, and possibly altering another feedback loop associated with the pulser.

REFERENCES

[1] J.J. Pon et al., "Recent Changes in the 500 MeV Cyclotron's Central Control System to Reduce Beam Downtime and Beam On/Off Transitions", ICALEPCS 2009, Kobe, Japan, Oct. 2009, TUP043, p. 179 (2009); http://www.JACoW.org/

[2] I. Bylinskii et al., "TRIUMF Cyclotron Beam Quality Improvement", PAC2011, NY, USA, 28 Mar-01 Apr 2011, WEP231; www.JACoW.org

[3] T. Planche, Y.-N. Rao, R. Baartman, "Correction of ν_r=3/2 Resonance in TRIUMF Cyclotron", IPAC2012, New Orleans, USA, 20-25 May 2012, MOPPD023; www.JACoW.org

[4] T. Planche, Y.-N. Rao, R. Baartman, "Improvement of the Current Stability from the TRIUMF Cyclotron", CYC13, Vancouver, Canada, 16-20 Sep 2013.

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