RECENT CHANGES IN THE 500 MeV CYCLOTRON'S CENTRAL CONTROL SYSTEM TO REDUCE BEAM DOWNTIME AND BEAM ON/OFF TRANSITIONS

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Abstract

Recently at TRIUMF there has been an effort to reduce the downtime of scheduled beam and to reduce the number of beam on/off transitions on the radioactive ion beam (RIB) targets. In these pursuits, the 500 MeV cyclotron's Controls Group identified and proposed certain areas of improvement. Working with the Beam Delivery and Operations Groups improvements have been developed and now run in production mode. This paper will detail the introduction of three software measures that resulted in beam delivery enhancements. Specifically, 1) a more stable beam current, 2) a more centered beam, and 3) a new concept called "soft trips". Together, these measures reduce the number of beam trips, shorten beam recovery times, reduce thermal shocks on the RIB target, and simplify accelerator operation.

INTRODUCTION

The 500 MeV cyclotron at TRIUMF [1] is a complex accelerator. Three beams of protons can be simultaneously extracted, at different energies, and different beam currents. The three beam facilities run with up to 50 kilowatts (100 uA) on beamline 2A, up to 50 kilowatts (100 uA) on beamline 2C, and up to 100 kilowatts (200 uA) on beamline 1A. The total extracted proton beam current does not exceed 250 microamps. Managing the complexity and power requires a variety of machine protection features. Many of these features are provided by the cyclotron's Central Control System (CCS).

In the last 10 years there has been a growing focus on the new Radioactive Ion Beam (RIB) facility, ISAC [2]. Protons are fed via the cyclotron's beamline 2A to one of two RIB targets in ISAC. As the understanding of the RIB targets has grown, there have been two primary focuses on proton beam delivery: Stable beam current and a minimum of beam on/off transitions. These requirements come from the specific target needs of optimum ion production and target lifetime. The RIB targets run at a high temperature and ion production is best when the temperature is close to but not exceeding a value where serious damage is done. The target heating is accomplished in large measure by the energy deposited by the incident proton beam (target heaters can also be used). If the proton beam fluctuates up in current, while maintaining a fixed energy, then the target's temperature rises and damage may occur. Stable beam current has become an important goal in establishing efficient RIB production and avoiding damage. Pre-existing experimental requirements on the other beamlines, for instance in meson production, did not have this delicate requirement.

In addition, it appears that RIB target production is negatively affected by thermal cycles. Because the proton beam is the primary source of target heating, the target gets cycled thermally when the proton beam goes off. Again, in the other beamlines, for example in the meson production and in the meson experiments, the beam on/off transitions are not a problem. These new RIB target requirements have led to a search for improved beam delivery characteristics and approaches. The CCS has been important in these improvements.

Three areas of improvement were developed and are now in production use. The first is beam current stability, which helps to maintain a constant energy deposition in the target and thus more constant target heating/temperature. The second is beam position stability (beam centering), which improves both temperature stability and thermal cycling. This improves target temperature stability by heating the target in a more consistent manner. If the beamspot drifts around in an uncontrolled fashion, the heat loss rate changes due to physical geometric differences in the target, which leads to changes in target temperature. In addition, if the beam moves very much then target protect diagnostics (a split plate monitor) detect the movement and action may be taken to protect equipment. If a serious misalignment is detected, the beam is turned off, and thermal cycling occurs. The third area concerns a broad array of interlock conditions, which previously resulted in beam off trips and thus thermal cycles. Where previously the other beamlines were not seriously affected by beam on/off transitions, the RIB targets want to avoid trips if possible. After closely examining a number of these trips it was determined that completely turning off the beam was often an unnecessary reaction to the machine protection requirements. In many cases it is sufficient to quickly reduce the beam current by a known amount to avoid the interlock condition but not to entirely remove the beam. This staged beam reduction, which we refer to as "soft trips", does not thermally cycle the RIB targets nearly as much as the earlier hard trips. Together these three enhancements are producing more stable target operation, less thermal cycling, less beam downtime, and improved cyclotron operation. Better beam delivery results in more and better physics output.

BEAM CURRENT STABILITY

Ion production in the RIB target increases, often exponentially, as the beam current applied to it increases.

Thus, it is preferable to run the current very close to the target's maximum rating. But running beam at the desirable level raises the likelihood of the current accidentally drifting above safe margins for too long and damaging the target. Existing safeguards would trip the beam before damage occurs, but the ensuing beam off would result in an undesirable thermal cycle on the target. The challenge is to deliver a constant and stable beam current as close as possible to the target's maximum rating.

With this objective in mind, the Controls Group proposed a closed-loop feedback program to automatically regulate beam current by manipulating the pulser DAC. The 500 MeV pulser DAC (setpoint) adjusts the amount of current delivered into the cyclotron by electrostatically discarding beam in the ion source. In the past, the pulser DAC was set at some optimum duty cycle level during tuning and then left alone. It was up to the operators to keep an eye on fluctuations in beam current and make corrections from time to time.

Presently, there is a software program called BL2A_STAB (for beamline 2A stability) that actively increments and decrements the pulser DAC to stabilize beam current at a designated level. The program calculates and works with a rolling average current. There is a user interface to allow operators to set program parameters and en/disable the program. En/disabling the program can also be done by a button push on the main Operations control console.

The introduction of BL2A_STAB has resulted in a more stable current on beamline 2A allowing operation of the RIB target at higher current levels without increasing the risk of overcurrents. In Figure 1 the current stabilization was disabled, as seen by the constant pulser DAC value and the varying beam current versus time. In Figure 2 the current stabilization was enabled and the pulser DAC is seen to vary while the proton beam current remains constant. However, it should be noted that the incidental cost of stabilizing beamline 2A is that the other two concurrent beamlines experience more variability. Adjustments in the pulser DAC affect all three beamlines, not just beamline 2A. Since the other beamlines are more resilient to variations in the current, this negative side effect is deemed an acceptable trade-off.

BEAM POSITION STABILITY

There was a time on TRIUMF's 500 MeV cyclotron when the normal practice of providing machine protection resulted in tripping the beam. Beam on/off transitions were tolerated as a minor inconvenience and accepted as part of a normal course of beam delivery. Since the commissioning of the RIB facility, the CCS has become aware that beam trips do not necessarily protect the RIB target and are in part detrimental. Good running conditions for the RIB target are for beamline 2A to deliver a stable current and with the least amount of interruptions in order to maintain an optimal target temperature. In other words, the beam trips that supposedly exist to protect equipment from damage may reduce the efficiency and life expectancy of the RIB targets. The problem is compounded by the fact that TRIUMF can run three beamlines simultaneously and a trip due to one beamline interrupts the others as well.

For reasons beyond the scope of this paper, the beam randomly drifts off the target from time to time. If left unchecked, the beam can drift away from the target enough to cause a misalignment trip. Thus, it is necessary to keep the beam stably positioned (usually centered) on the target. In addition, a misaligned beam is less efficient as the target is not kept at its optimum temperature.

Upstream of the target are four protect plates which detect the beam's halo current. The position of the beam can be inferred from these protect plates as long as the beamspot is sufficiently big. An abnormal halo current (too high, too low, too far left, too far right) is an indication that the beamspot is drifting and in extreme cases may cause a trip condition. In the past, operators manipulated the proper steering magnets to correct for horizontal and vertical drifts numerous times a day. It was a simple, mundane task that took the operator's attention away from more challenging duties.

Recently, the CCS introduced a closed-loop feedback program named BL2A_POS_STAB (for beamline 2A

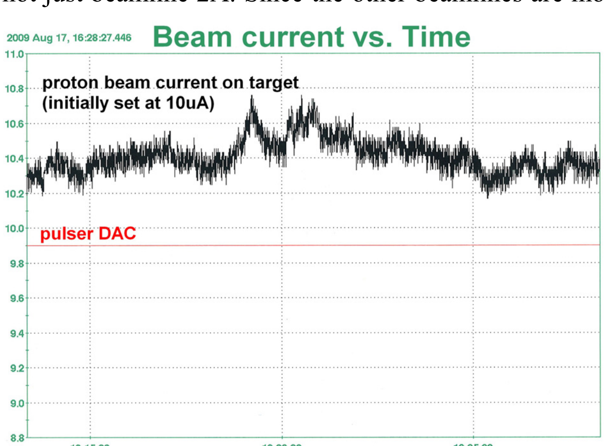

Figure 1: Current stability DISABLED.

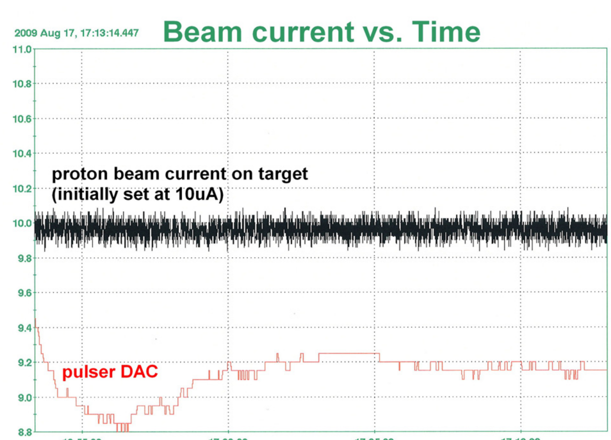

Figure 2: Current stability ENABLED.

position stability) to actively keep the beam centered on the target (or at an offset if so desired). The algorithm is straightforward and mimics the actions of the operators. The program calculates a rolling average of each protect plate to smooth out the noise in the signal. Then it makes adjustments to the horizontal and vertical steering magnets as needed to keep the beam centered on the target. There is a user interface to BL2A_POS_STAB to set program parameters such as the number of samples, inter-sample time (for the rolling average), and magnitude of a single corrective action, among other parameters. This capability for position stability has been expanded to cover beamline 1A's two targets and its beam dump.

The beam position stability programs have been well received by the operators. Of the three simultaneously extracted beams from the cyclotron, two of them (beamline 2A and beamline 1A) presently have the beam centered on target by software. In the fullness of time beamline 2C, the third beamline, will also be automatically centered.

But there are some limitations in the software and beam centering still requires the attention of the operators under some circumstances. First, some steering magnets need bipolar powering but the bipolar characteristic is accomplished using a polarity switch (for monetary reasons). When the steering magnet is run down to zero, the position stability program for the specific beamline stops working and issues a warning message. An operator has to manually change the polarity of the magnet before the program can resume auto-centering. The magnets support group is reluctant to allow software to automatically change polarities because the switch is mechanical and not designed to be exercised frequently. Normally Operations sets up the beamline tune so that these steering magnets are not near zero output on the power supply and this issue is avoided.

A second important limitation to note is that the programs only correct for slow drifts. Although the system could be set up to correct the beam position at tens of hertz (signal noise reduction would be needed), the algorithm is not designed to correct for singular events caused by, for example, sparks in the RF or the ion source, which can be as short as a few milliseconds. These singular events are averaged out during the calculation of the rolling averages.

SOFT TRIPS

There are many situations where tripping the beam is desirable and unavoidable. But there are also many previously considered "trip" conditions, which on closer examination do not require turning the beam off as a first course of action. The CCS introduced the idea of a staged intervention or as it is now called, a "soft trip". The first implementation of the soft trip was in response to target overcurrent conditions. In this case, a soft trip is defined as a temporary reduction in beam current to alleviate the trip condition. Only when soft trips fail to correct the situation does the system resort to a full beam off interruption.

Equipment damage could occur if beam current lingers above a target's maximum rating for even a few seconds. It has been observed that most of these encroachments are transient. If an overcurrent condition occurs, a soft trip quickly steps in to reduce beam current (by lowering the pulser DAC a few percentage points). If the event is in fact transient, the reduction in beam takes the situation out of the danger area and a full beam trip is averted. Compared to a beam off, a soft trip results in a faster resumption of full beam and a more tolerable thermal shock on the RIB target.

At present, the CCS has implemented soft trips on overcurrent trips for all three beamlines. As expected, most overcurrent conditions were transient and the soft trips have been sufficient to protect the machine. Accordingly, there has been a noticeable reduction in the number of overcurrent trips and in the recovery times [3], with no adverse effects.

SUMMARY

To improve RIB target performance three software applications have been developed and successfully deployed. The first is BL2A_STAB and it provides closed-loop current stabilization on the incident proton beam. The second is BL2A_POS_STAB and is a closed-loop beam position (centering) program that maintains the incident proton beam's position in a desired location on the target. The third is a machine protection interlock program that provides "soft trips". This is a novel concept in which beam current is not fully interrupted but simply reduced to a safer level. A reduction in current results in a less damaging thermal cycle on the RIB target and allows for faster recovery to full beam. Overcurrent trips were the first to benefit from soft trips.

Operations and other groups directly affected are pleased with the new functionality. These improvements have produced a noticeable reduction in beam downtime and beam on/off cycles.

ACKNOWLEDGMENTS

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