TRIUMF 500 MEV CYCLOTRON REFURBISHMENT

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Abstract

The TRIUMF cyclotron has successfully operated for more then 30 years at beam intensities well above the original goal of 100 µA at 500 MeV. Presently, it delivers proton beams (up to 300 µA) simultaneously to multiple users with 90 % availability for about 6000 hours annually. One of its current primary functions is to serve as a high power driver for ISAC, TRIUMF's radioactive beam facility. Most of the cyclotron's systems and components exhibit reliable and stable performance despite their age; others have been replaced or upgraded over the years. The Operations Group maintains downtime and component failure statistics; the analysis of these data leads to preventative actions to improve the machine reliability. Items which may have potentially significant downtime or dose implications are the first candidates for upgrade. At ISAC startup in the year 2000, the cyclotron's needs were reviewed and a dedicated refurbishing program was established. The aim is to ensure that TRIUMF's scientific goals can be achieved for the next 15-20 years. This paper describes recent and current refurbishing activities as well as plans for future major renovations.

INTRODUCTION

In 1995-2000 TRIUMF put tremendous effort into the development of a new ISAC radioactive beam facility. At the same time cyclotron needs were compromised in some areas due to limited resources and tight ISAC construction schedules. To ensure reliable operation and high beam availability a cyclotron refurbishing program was initiated covering most of the old facilities: ion source with injection line, all cyclotron subsystems, primary proton beamlines, meson production targets, beam dumps, and irradiation facilities. A majority of the cyclotron components date from the original installation and have seen more then 30 years of service. Therefore the cyclotron refurbishing needs were carefully analyzed and the upgrades were thoroughly planned in conjunction with TRIUMF's immediate and long term goals. The refurbishing program is quite diverse and here we present only major achievements and milestones.

RF SYSTEM

The RF system refurbishing program has already demonstrated a significant reliability improvement, reducing by a factor of 3 the machine downtime due to RF failures and sparks in the cyclotron [1]. This success has been demonstrated repeatedly over the last 3 years.

One of recent major upgrades was a high power switch installation into the RF distribution system. The RF coaxial switch allows a rapid connection of the 1 MW RF amplifier output to either the cyclotron or a 800 kW dummy load (See Fig.1). It enables amplifier stand alone tests and simplifies troubleshooting. This motorized coaxial 4-port switch manufactured by Dielectric Communications was rated to 600 kW of transmitted power. Extensive modifications were carried out before the switch installation. Water and air cooling were provided to the critical rf contacts. This resulted in a very comfortable 47º C temperature at the RF contacts at 1 MW compared to the original marginal 75º C at 600 kW.

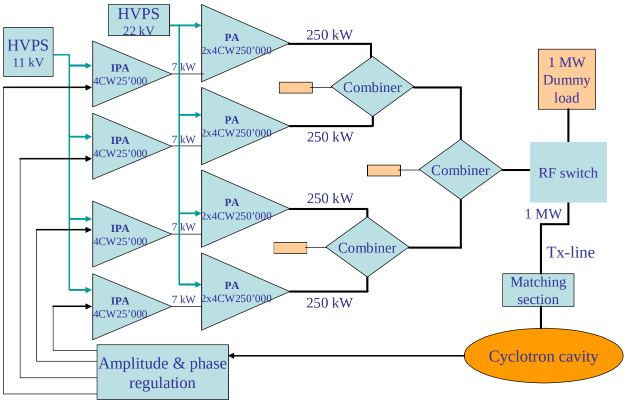

Figure 1: RF System diagram projected for modifications.

At present, a prototype of an intermediate power amplifier (IPA) is being developed, which should be eventually incorporated into the system, replacing the existing IPA and power splitter/phasor configuration, which is difficult to tune and troubleshoot. Four 25 kW amplifiers are envisaged to replace one 100 kW amplifier, each of which will drive one of the final power amplifiers (See Fig.1). Both cavity design and lumped component design of the output resonator are under study.

A number of upgrades to the cyclotron main RF, booster, and buncher low level RF controls have been implemented over the past several years. All of the above systems have had their obsolete control computers replaced with firewire-based interfaces and standard industrial rack-mount PCs. Most of the original control wiring has been replaced with semi-rigid phase-stable cable. The RF booster conventional I/Q control system had to be redesigned to use amplitude/phase control due to the nonlinearity of the power amplifier. The original DOS-based control software was recently replaced with a newer MS Windows® version. Spark detection and recovery algorithms have been improved to the point that little or no operator intervention is normally required to restore RF. Apache web servers enable the status of the cyclotron RF systems to be monitored any time from anywhere.

VACUUM SYSTEM

The decreasing reliability of the Stirling cryogenerator B-20 (the main cyclotron cryopump) and demanding maintenance requirements triggered the decision to completely overhaul or replace this 30-year old machine. The replacement with the LINDE-1630 helium refrigerator was proposed, and recognized to be a very efficient solution both technically and economically. The nitrogen part of the system was successfully modified in September 2006 to apply liquid nitrogen instead of cold gas for thermal shielding of the 20ºK helium cryopanels. In the new configuration the old scheme of nitrogen gas venting inside the building has been eliminated. All components required for operation of the new refrigerator (cold box, compressor, helium buffer tank, room temperature piping, helium dewar, helium transfer lines and services) have been recently installed. The cold box was tested at the factory before shipment to TRIUMF and is being commissioned. Initial pumping tests with the new machine are very promising and the validity of the upgrade is about to be confirmed.

INTENSITY STABILIZATION

ISAC target yields increase with incident proton beam intensity very rapidly [2,4]. To achieve the highest possible isotope fluxes it is desirable to operate the primary beam current very close to the target power limit. But then even small changes in the beam current may cause a target protection system trip and associated downtime. To reduce the number of over current trips, while maximizing isotope production, special software was developed.

This new software application monitors the beam current and stabilizes it adjusting the duty cycle within 85–95% by means of 1 kHz beam pulser installed in the injection line. The stability system's parameters are adjustable by Operations via a graphical user interface. The nominal settings provide a 0.5 Hz feedback. The target protection system is also adjusted to ignore spurious intensity variations shorter then 0.5 seconds. This configuration gives an overall beam stability better then 1% with very few over current protection trips.

TRIUMF routinely runs 3 simultaneously extracted beams from the cyclotron. Therefore the intensity stabilization in the ISAC beamline is achieved at the expense of beam stability delivered to the other users. Fortunately they are usually tolerant to the minor beam current fluctuations, and the increased intensity variability there has not been a problem.

CYCLOTRON PROBES

After many years of service in the cyclotron, the two beam probes spanning the high energy region (HE1 and HE2) were selected for replacement. A new design was developed to provide the same radial coverage with improved signal capacity and drive mechanics. The original probes utilized ball-screw drives with cable-driven doubling of radial motion along a track that was raised and lowered to retract and insert the probe head into the cyclotron median plane. The replacement HE probe design utilizes a rack and pinion drive with cable-driven doubling to move along a vertically stationary track. Using a differential drive on a dual cable system, the probe head alone is raised or lowered into the beam plane along a wide radial range of probe motion. HE1 has 7 vertical fingers as opposed to the old probe head that had 5 signals and is used to measure the vertical position of the beam. HE2 has a differential head with six radial fingers whereas the old probe had only two differential fingers. Both probes can withstand currents up to 1 µA.

BEAMLINE DIAGNOSTICS

Proton beamlines transport beams, with intensities ranging from a few nA up to 200 µA, to a variety of destinations where beam current and position must be carefully monitored (to optimize for example the exotic ions production and target life time in ISAC). To improve the existing diagnostics we have developed wide dynamic range electronics for available non-intercepting beam monitors. An Analog Devices log detector, AD8306, and a Digital Signal Processor (DSP), ADSP-21992 measure and process the RF signals from the second harmonic (46.11 MHz) capacitive pickup. The log detector has a useful dynamic range of over 100 dB and allows beam intensity measurement from 10 nA to 200 µA. Figure 2 represents the measured beam intensity with respect to the peak beam current and 1 kHz beam pulser duty cycle. Alternative monitors (beam toroid and extraction foil current monitor) responses are also given here for comparison.

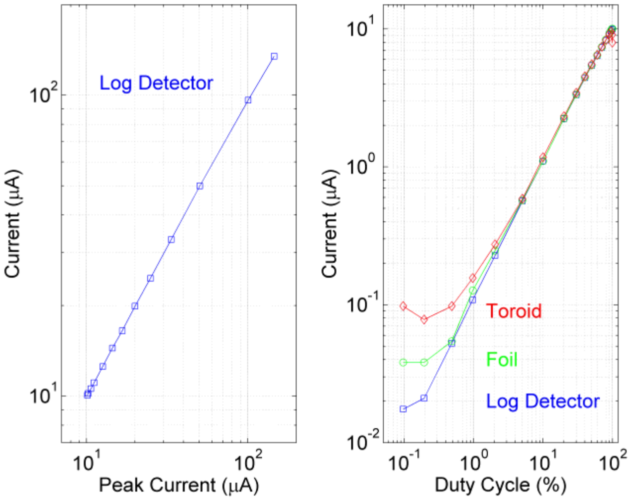

Figure 2: The log detector response vs beam peakcurrent and duty cycle.

A new beam position monitor accommodating this electronics has been also developed and installed in the 2A beamline. It consists of four orthogonal inductive loop pickups sensing the azimuthal component of the magnetic field induced by bunched beam. New device features 100 µm spatial resolution for beam currents of 1– 200 µA.

ISOTOPE PRODUCTION FACILITY

The Beamline 2C4 Solid Target Facility (STF) was first constructed in 1989 to produce radioisotopes from solid targets, and has been in operation since 1993. A major upgrade was recently completed in all systems aiming to reduce dose to personnel by improving the reliability and maintainability. The target handling mechanism is a positive drive system with modular components that allow for removal from a low radiation area if servicing is required. The target handling vessel and the beam pipe are no longer connected. A water cooled window terminates the beampipe (see Fig.3). The ventilation and the target transfer components in the hot cell and the water cooling package have been updated to improve diagnostics and maintainability. The beamline diagnostics have been modified to allow for quick removal in the vault and the vault lead shielding has been improved. The STF controls was also upgraded: software has been adapted to the Central Control System (CCS) protocol, and all interlocks were implemented in a site standard programmable logic controller (PLC). The STF was commissioned at low beam currents, then up to 80μA, and finally at 80μA with a rubidium target. Measured isotope yields indicate that 100MeV is the optimum extraction energy. Routine production of ^{82}Sr is scheduled to resume in the 2007 fall.

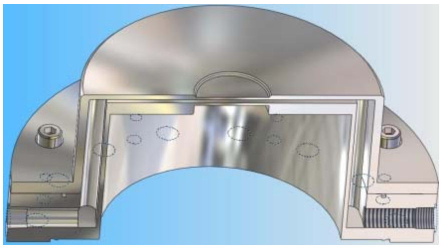

Figure 3: STF aluminum water cooled double window.

INJECTION LINE

The 300 keV beamline that feeds the 500 MeV cyclotron is roughly 35 m in length and consists of 80 electrostatic quadrupoles and 4 electrostatic 45 degree bends. There is one first harmonic (23 MHz) and one second harmonic buncher. Typically, it transports 0.36 mA of cw H-. The peak current in the bunch centre rises approximately linearly from the DC value of 0.36 mA to 2 mA through the inflector. The final 12 m section before the inflector is vertical, and of this only a small portion is easily accessible. It needs now an extensive servicing because of accumulated carbon deposits on the quadrupole insulators. The plan is to redesign and rebuild the vertical section. The goal is twofold: provide more diagnostics and upgraded optics for the future operation at 1 mA cw (>5 mA peak), and provide easier maintainability for the system. Optics will be simplified since the existing 11.5 MHz chopper near the inflector is no longer needed. A buncher will be added at the midway point to re-bunch the beam under the larger space charge conditions. Slits will be used to ensure better matching to the periodic section and also trim the emittance to protect the electrostatic inflector.

INFRASTRUCTURE

Radiation damage to existing Cyclotron Vault cabling is having an impact on cyclotron operation. Individual cable replacement has been done over the years however the brittleness of cables in existing trays results in other cables being damaged in the process. The cable trays are populated with wiring, which has accumulated over more than 34 years, not all of it well documented. It has been decided to replace all of the wiring in the vault (~1200 cables). The original design does not accommodate this eventuality without first stripping out all cabling and starting over. This method would result in a major interruption in operation of the cyclotron. Alternatively, a parallel system of new cable routing and trays was devised, and the first stage of installation of trays is nearing completion. The project will continue over several years during shutdowns.

Three 30 year old 1.2 MVA Askarel (PCB) transformers critical to the operation of the cyclotron were replaced with R-Temp Cooled transformers. The motivation was to dispose off old units that were approaching end-of-useful life and to remove from the site a sizable liability in the PCB filled unit.

MAJOR GOALS

ISAC physics demands for the isotope beams are presently much higher than what can be delivered in terms of beam time and variety of particles. A major limiting factor here is a single user configuration of the facility, where beam time has to be shared between multiple user stations and the target group, which has to develop new beams [2]. The proposed solution is to build another proton beamline equipped with two target stations: one for production and another for development [3]. To fulfill that the cyclotron will need to deliver higher intensity extracted beams. That requires the reviving of BL4 extraction and construction of a high power (200 μA) beam dump. The beam development group has been working towards this high intensity goal over the last few years. We have demonstrated 400 μA at low duty cycle and a stable 300 μA cw compared to the present 250 μA nominal [4]. Full current operation will also require a better ion source and significant enhancement of the RF system.

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