TRIUMF ISAC RF SYSTEM IMPROVEMENTS AFTER 2 YEARS OF OPERATIONAL EXPERIENCE

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Abstract

The TRIUMF ISAC accelerator has been successfully operating since spring 2001 with very little downtime. The machine comprises 16 independent RF systems including a 35 MHz RFQ, a 106 MHz DTL and several sub-harmonic choppers and bunchers. The post stripper DTL enables fully variable output energy up to 1.5 MeV/u for rare isotopes with $A/q \leq 6$ in cw mode. This sets rather stringent requirements for the RF system as a whole and the RF controls in particular. A new RF phase measuring system has been commissioned, which together with other modifications has improved machine tunability. During initial operation the DTL frequency tuners and power couplers showed some problems, which could affect the machine reliability. Modifications to these components together with additional diagnostics have solved these problems. In this paper we will describe the overall operation of the RF system and present details of the modifications.

INTRODUCTION

The first stage of a radioactive beam facility at TRIUMF, ISAC-1, was commissioned in 2001 and is routinely producing a variety of beams to low and high energy experiments [1]. The accelerator consists of a 35.36 MHz RFQ, which accelerates beams of $A/q \leq 30$ from 2 keV/u to 153 keV/u, and a post stripper, 106 MHz variable energy drift tube linac (DTL) [2], comprising 5 interdigital-H accelerating and 3 split-ring bunching cavities to accelerate ions of $3 \leq A/q \leq 6$ to a final energy between 0.153 to 1.53 MeV/u. A multi harmonic pre-buncher is part of the low energy beam transport (LEBT) section. The 106 MHz bunch rotator used for focussing, the dual frequency (5.89 and 11.8 MHz) chopper for 85 ns and 170 ns pulse separation, and the 35 MHz rebuncher for DTL matching are the rf structures which constitute the medium energy beam transport (MEBT). The high energy beam transport (HEBT) section consists of 11.8 MHz, low-β and a 35 MHz, high-β bunchers, which are required to maintain a good longitudinal emittance. The rf structures' parameters and commissioning details are reported elsewhere [3].

RESONATORS

Most of the rf structures have been reliably operated since commission with minor maintenance interventions. For example, the RFQ structure required a high power pulse conditioning twice a year to reduce the build up of dark currents. At the same time a lot of effort was dedicated to the reliable operation of DTL rf amplifiers, couplers, tuners, problem troubleshooting and upgrades. Once a year all the DTL cavities were opened for inspection and assessed for problem. In the DTL tanks #3 and #4, soldering flux patches were observed around the nose cones (see Figure 1). This was traced to be a manufacturing defect, when the flux residuals were trapped in a pocket behind the nose cone and then came out during rf conditioning. Evaporating flux contaminated some critical rf surfaces, including rf coupler window, which eventually overheated and broke. A few attempts were required to clean off the flux residuals from the tank surface.

Figure 1. Soldering flux patch in DTL tank #4

In the beginning we also faced many interruptions caused by spurious vacuum interlock trips. Replacement of ion gauges, installation of screening grids and distancing the ion gauge from the cavity volume by means of extension pipes 200 mm long and 25 mm in diameter did not solve the problem. On the assumption that the problem was caused by a penetration of charged particles ionised and accelerated in the presence of an rf field, extension elbows were installed for all DTL ion gauges and the problem disappeared.

RF couplers

RFQ 150 kW coupler gave us troubles in the beginning due to uneven rf field gradient along a ceramic window, which eventually led to a ceramics overheating. Improved design incorporated cylindrical screening electrodes, which cured the problem. Smaller type (30kW) coupler, installed in most of the other rf cavities (11 units), did not suit such a modification. Over 2 years we had to replace 6

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of those. In DTL buncher #2 a silver alloy evaporated from the coupling loop soldering joint (see Figure 2) and coated all the surfaces around including the ceramics (see Figure 3). Three other couplers failed in DTL tank #5 due to overheating, showing darkened ceramics with dramatically degraded isolation properties (DC resistivity dropped from few MOhm down to ~ 30 kOhm).

Figure 2. Buncher #2 coupling loop with a failed soldering joint.

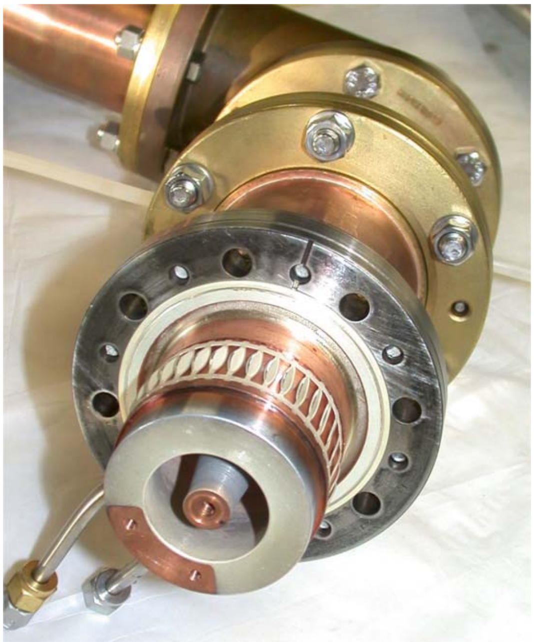

Figure 3. Buncher #2 coupler – silver spattered.

Test studies brought us to a conclusion that in most cases coupler coating is triggered by a secondary electron emission discharge (multipactoring). In DTL tank #5, for instance, it happened during abnormal operation of an automatic starting procedure. After its rf controls operational parameters were readjusted the failure never happened again. To reduce the coupler failure risk some other preventive measures were taken:

- All coupling loops were copper plated to eliminate the soldering alloy exposure to the rf field.
- All couplers were equipped with Omega OS36 infrared thermocouples, which are pointed on the ceramic window.
- High standing wave (VSWR) protection was introduced into rf controls .

An easy and economical restorative solution has been found for the degraded couplers. It involves an abrasive removal of the coating by means of a sand blaster. With this procedure 4 malfunctioning couplers were rebuilt to their original specifications. In future we plan to incorporate a multipactor sensor into coupler design.

Frequency tuners

All DTL systems use capacitive tuners driven by identical drives. The weakest point of this drive appeared to be the rf fingerstock contacts between the moving copper shaft and a ground housing. Inspection has shown almost all shafts being severely scratched with deep cuts. The most damaged MEBT rebuncher tuner shaft is shown in Figure 4.

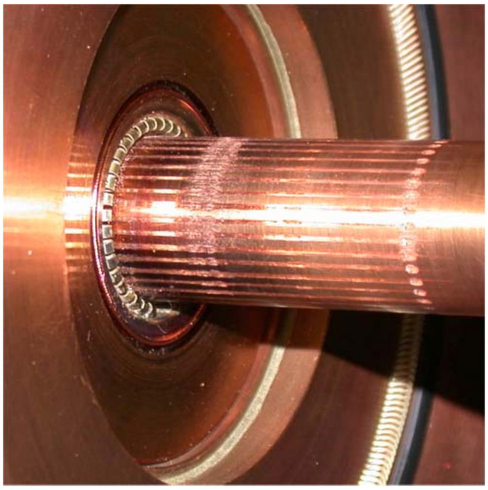

Figure 4. Damaged MEBT rebuncher tuner shaft

The reason for this failure is a constantly moving tuner, which operates in a feedback loop for frequency regulation. The fingerstock cannot stand that heavy load. Operating in vacuum without lubrication they get worn and start scratching the copper shaft. These contacts serve to shield a stainless steel bellow from rf currents, which could result in excessive heat on the bellow. An extensive design review and bench tests were undertaken, which led us to the conclusion that the fingerstock could be removed without causing excessive heat on the bellows. Bench tests showed that 25 W dissipated power caused a bellow temperature rise of up to 100°C without cooling, while application of air cooling allowed 100 W power dissipation with a moderate 40°C temperature rise. Full-scale test on DTL tank #5 confirmed our optimistic assumptions regarding operating the tuner without fingerstock. At a 20 kW power level the bellow temperature rose only by 6°C even without air-cooling. Following this positive outcome, we removed the fingerstocks from all DTL operational tuners.

Subsequently all the modified tuners were equipped with thermocouples to ensure our control over bellow temperature. A few months of operation didn't show any noticeable degradation in system performance.

RF CONTROLS

Linac variable energy capability requires an amplifier operational range of 5 - 100% of output power. The DTL amplifier's phase shift is dependant on the output power and exceeded 45° for the full dynamic range. Since the frequency tuning control is achieved by monitoring the tank rf phase, this phase deviation caused intolerable detuning with power variation. Implementing of a phase compensation circuit, which uses amplifier output sample voltage to modulate the input signal phase, reduced the phase shift down to 5°.

Upgrade work has been done on the input circuits of the control modules in order to increase stability and reduce rf interference between subsystems. We have also completed the installation of all VSWR protection circuits in all the control modules.

All rf control computers have been upgraded from embedded Intel-486 processors to rack-mounted AMD K-7 processors and VXI IEEE-1394 slot 0 controllers, with increased RAM and hard drive capacities. Their firmware and software were upgraded for better flexibility, performance, and reliability. The DSPs are fitted with flash EEPROMs that enable their firmware to be upgraded remotely. The ADCs in the VXI mainframes are now cycled by separate threads, with better performance in the rate of data update.

Phase measuring system

An auxiliary phase measuring system has been developed for the ISAC rf system. It provides precise phase difference measurements between the reference rf source and each individual rf device. The need for this system comes from the operation of a multi-cavity variable energy linear accelerator, which dictates very high tolerance (fraction of a degree) for rf phase stability and reproducibility. The setup includes a frequency synthesizer, an rf switcher and a Hewlett Packard vector voltmeter. The synthesizer is driven by a 5.89 MHz ISAC rf controls reference signal and provides all ISAC rf system harmonics: 5.89, 11.78, 23.57, 35.36, 106.08 MHz with a very good stability (0.2°) with respect to the reference signal. Rf MUX connects voltmeter to the desirable rf cavity and corresponding frequency multiple harmonics from the synthesizer. MACOM SW221 rf switches provide 100% reproducible connection and –75 dB isolation between channels. Vector voltmeter measures amplitudes and phase difference between 2 rf signals of the same frequency. Voltmeter phase resolution is about 0.1°. All the rf signals are canalized through semi-rigid phase stable cables in order to reduce temperature dependence and dielectric aging effect. All hardware was tested and calibrated. An EPICS based control system for this device is being commissioned. In the manual mode this system has already helped us in the troubleshooting of beam instabilities.

AMPLIFIERS

All the DTL rf systems are energized by identical 106 MHz amplifiers based on an EIMAC 4CW25000B tetrode as the final amplifier. Last year most of tubes had reached 10000 hours of operation and a substantial degradation in their performance was observed. One tube showed a grid to cathode short, a filament burnt in another one, and 4 more aged, providing low cathode emission. Five tubes out of 8 tubes in operation had to be replaced. This triggered a detailed investigation on the tube performance. Two major conclusions were derived as a result.

- Hairpin filament structure in a tube of different type 4CW25000A is almost insensitive to thermal deformation, while the tube is warming up, compared to the mesh filament structure (4CW25000B). So application of a type-A tube dramatically cuts down the downtime for system conditioning and reduces the probability of a thermal grid-to-filament short circuit.
- Most of the tubes were running at slightly increased filament voltage, which is good for tube conditioning but not for operation. The supplier claims a 15% reduction in filament voltage should double the tube lifetime.

Based on these findings we decided to gradually replace all B-type tubes in use to A-type tubes. Also, all filament transformers were replaced with new ones with proper voltage taps and all filament operational voltages were reduced by 15% from the nominal values.

Annoying problems were experienced with amplifier screen power supplies. These were commercial switching regulators and their designs were prone to RF interference and were unable to handle transient loads. These had resulted in many spurious amplifier trips. All these power supplies have been replaced with unregulated ones that are more immune to RF interference.

CONCLUSION

The extensive study and upgrade activities performed for the key rf system elements allowed high machine availability (above 90%) and ensure an improved reliability for the future.

REFERENCES

[1] R.E. Laxdal, "ISAC-I and ISAC-II at TRIUMF: Achieved Performance and New Construction", Proc. of the XXI-st Linac Conf. (LINAC2002), Gyeongju, Korea, Aug. 2002

[2] A. K. Mitra et al, "RF Measurement Summary of ISAC DTL Tanks and DTL Bunchers", Proc. of the 2001 Part. Acc. Conf., Chicago, 2001, p. 951.

[3] K. Fong et al, "Commissioning of the TRIUMF ISAC RF System", Proc. of the 2001 Part. Acc. Conf., Chicago, 2001, p. 945.