A NON-INTERCEPTING BEAM CURRENT MONITOR FOR THE ISAC-II SC-LINAC

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Abstract

A personnel protection system will monitor the ion beam current into the experimental hall from the ISAC-II SC-linac. It will have continuous self-test and redundancy and an accuracy of ±10% ±0.5 nA from 1 to 200 enA. The system, based on an Atlas design, will use capacitive pickups with RF resonators and buffer amplifiers. Ion charge, velocity and bunch width will affect the sensitivity so periodic calibration with dc Faraday cups will be needed. The signal from each 13 cm long, 5 cm diameter pickup tube will pass through a vacuum feedthrough to a helical resonator. An AD8075 IC with an input impedance of 40 kΩ at 35 MHz will allow a high coil tap. The ISAC beam, bunched at 11.8 MHz, is injected into the ISAC-II SC-linac via a 25 m long transfer line. The 35 MHz and 70 MHz coils (3rd and 6th harmonic) have loaded Q's of ~675. A test in the transfer line of the 35 MHz coil gave a sensitivity 93 μV/enA from the unity gain buffer using $^{20}Ne^{+5}$ ions at 1.5 MeV/u. Another test downstream of the linac before the experimental hall yielded a sensitivity of 60 μV/enA for a beam of $^{22}Ne^{+4}$ ions at 4.97 MeV/u. The backgrounds were equivalent to 1 enA or less. System design and test data will be presented.

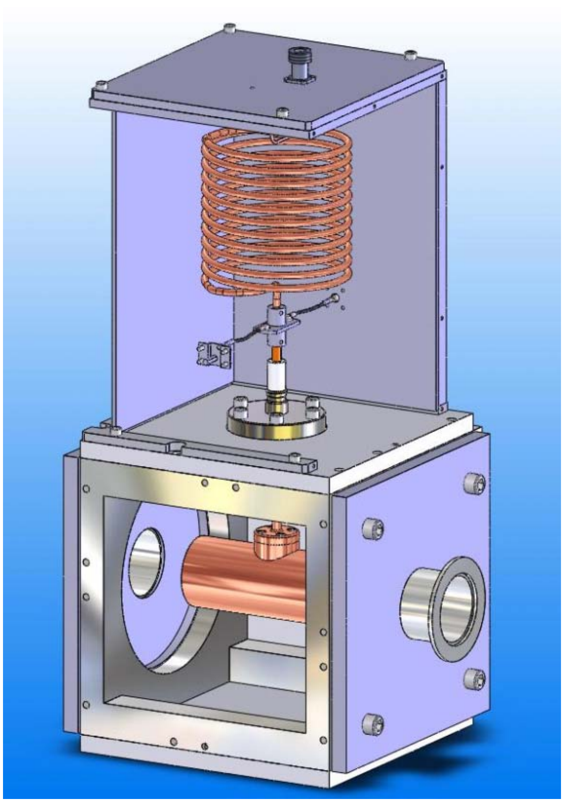

Figure 1: A SolidWorks drawing of the monitor showing the pickup tube and helical resonator.

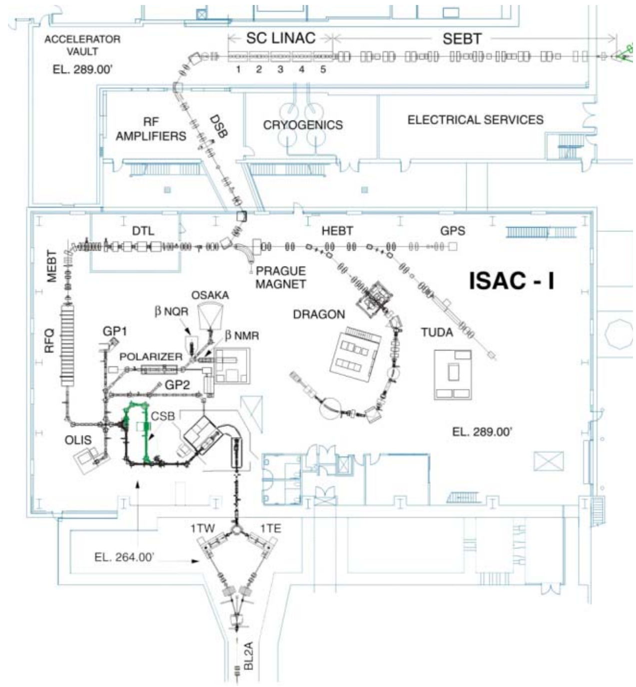

Figure 2: The beam exits to the ISAC-II experimental hall at the top right corner of the diagram.

INTRODUCTION

Specifications

A non-intercepting beam current monitor system is a licensing requirement for continued delivery of beam into the ISAC-II experimental hall. The primary purpose of the system will be personnel protection. It will work in conjunction with the existing prompt radiation protection system. The system should be operational by October 2007.

The system's current monitors, Fig. 1, should be sensitive in the range of 1 to 200 enA. Absolute accuracy within ±10% and ±0.5 nA should be possible after calibration with dc Faraday cups. Two monitors will be used for redundancy and their measurements will be compared. Each monitor and its electronics will have built in continuous self-test.

Beam Properties

A 500 MeV proton beam of up to 100 μA is used to produce radioactive beams from a thick solid target, ITW or ITE in Fig. 2. Ions released from the 60 keV target pass through a high resolution mass spectrometer. Alternatively, non-radioactive pilot beam from an off-line ion source (OLIS) may be selected. The beam is bunched by a three harmonic buncher at 11.79 MHz. The post-

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accelerators for ISAC include a 35.36 MHz RF Quadrupole (RFQ) to accelerate beams of $A/q \leq 30$ from 2 to 153 keV/u and a post-stripper and a 106 MHz variable energy drift tube linac (DTL) to accelerate ions of $3 \leq A/q \leq 6$ to a final energy from 0.153 to 1.53 MeV/u. These ions pass through a double s-bend (DSB) transport line which includes a 35 MHz buncher to the super conducting (SC) linac. Eventually, the linac will permit acceleration up to energies of at least 6.5 MeV/u for masses up to 150. Currently only the medium energy cavities are in place. In the SEBT beamline following the linac the energy ranges from 1.53 to 10 MeV/u and the beta from 0.057 to 0.145.

The signal induced in the pickup by the beam will consist of 11.79 MHz and its harmonics, however, if the first buncher were to fail, the fundamental would disappear. The transmission through the RFQ would fall from 75% to 25% but the beam would have a 35.36 MHz RF structure which could still be detected.

A kicker is present in the mass separator. It may be used to add a near dc to 10 Hz macrostructure to the beam. In addition, there is a chopper in the MEBT section which can remove every second beam bunch, resulting in a 5.9 MHz bunch repetition rate.

CAPACITIVE PROBE

Monitor

Our system will be based on a design used at ATLAS [1, 2]. The pickup consists of a 12.7 cm long, 4.76 cm inner diameter copper plated aluminum tube through which the beam passes. The tube is housed in an 8 inch vacuum box and has a capacitance to ground of ~5 pF. The signal is brought out through a robust vacuum feedthrough, a Ceramaseal 16941-01-CF, with a capacitance of 8.5 pF to a helical resonator [3]. A variety of coils were constructed with resonant frequencies at the first, third and sixth harmonic of the 11.79 MHz bunch repetition rate. An air spaced capacitor is used for tuning. The coils were tapped to match the high input impedance

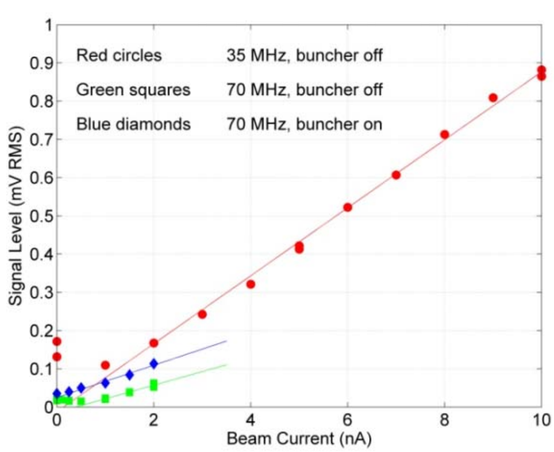

Figure 3: The sensitivity tested in the double s-bend transfer line, with straight line fits.

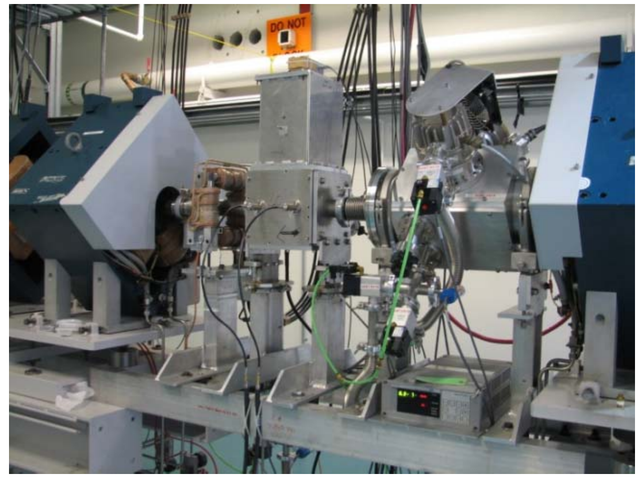

Figure 4: The monitor installed in the beamline downstream of the SC-linac at SEBT:DB18B.

of a buffer amplifier mounted on the monitor frame. The loaded Q's were ~675. Two small disk antennas loosely coupled to the pickup tube were used for tuning with a network analyzer and will be used to inject the self-test signal later.

Buffer Amplifier

The buffer amplifier uses an Analog Devices AD8075. The magnitude and phase of the input impedance of the buffer were measured with a HP 4193A vector impedance meter. From these parameters, the parallel input resistance and capacitance were calculated, eqns. 1.

$$R = \frac{|V|}{|I|}\sqrt{1+tan^2\theta} \qquad C = -\frac{|I|}{|V|}\frac{tan\theta}{2\pi f\sqrt{1+tan^2\theta}} \qquad (1)$$

The capacitance was 2.7 pF and the impedance was 109 kΩ at 11.8 MHz, 40 kΩ at 35 MHz and 16 kΩ at 70 MHz. The buffer has a voltage gain of 1. The signal is brought out of the SC-linac vault on 130 feet of Times LMR-400 coaxial cable to the electronics racks.

BEAM MEASUREMENTS

Double S-bend

The monitor was first tested in the double s-bend to which there is easy access. The monitor was located at DB12 where there is a double waist with a 2σ (90%) diameter of 4 mm. An Agilent E4402B spectrum analyzer was used to measure the signal amplitude with a bandwidth setting of 100 Hz. A sensitivity of 93 μV/nA using a 35 MHz resonator was measured for a 1.5 MeV/u $^{20}Ne^{+5}$ beam, Fig. 3. Interference from RF sources, including the RFQ, MEBT bunch rotator and s-bend buncher leaked into the monitor from wiring on a nearby beam profile monitor and Faraday cup. This gave a signal floor equivalent to about 1 nA of beam current. A measurement using $^{22}Ne^{+4}$ with a 70 MHz resonator yielded less sensitivity, 42 μV/nA, but a background floor equivalent to <0.5 nA. During beam start up, an unstable beam, due to plasma oscillations in the ion source, was

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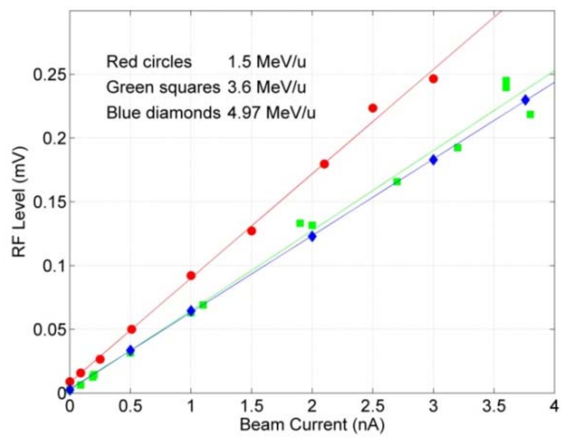

Figure 5: The sensitivity of the monitor decreased slowly with the beam energy.

measured using an Agilent 8508A vector voltmeter. The voltmeter measurement was much noisier than the signal from a downstream dc Faraday cup under these conditions, however.

SEBT Beamline

The monitor was installed in the SEBT beamline downstream from the SC-linac at DB18B, Fig. 4. Here the beam has a 2σ diameter of ~14 mm. Though the vacuum box did not have its own turbo pump, its ion gauge indicated that an acceptable pressure of $6{\cdot}10^{-7}$ Torr was attained.

The sensitivity was measured using a 35 MHz resonator. Sensitivities of 82, 63 and 60 μV/nA were measured for $^{22}Ne^{+4}$ beams of 1.5, 3.6 and 4.97 MeV/u, respectively, indicating that the sensitivity decreases slowly with the energy, Fig. 5. The vector voltmeter confirmed the spectrum analyzer measurements well for the 4.97 MeV beam as the ion source was stable.

Fig. 6 shows the spectrum of a 3.5 nA $^{22}Ne^{+4}$ beam at 3.6 MeV/u from the SC-linac. Though the central peak is less than a few Hz wide, there are sidebands extending out a few hundred Hz which reveal modulations due to ac ripple and mechanical vibrations of the accelerating structures. A known ~80 Hz mechanical resonance can be seen.

CONTROLS

TRIUMF already has personnel protection systems for prompt radiation in place. One such system has sensors in the ISAC-II experimental hall near the entrance of the beam from the SC-linac vault, placed outside of the vault shielding. The sensors consist of a moderator and pressurized ^{3}He tube to detect neutrons and a scintillator and photomultiplier to detect gamma rays. The presence of background pulses from the detectors is checked periodically to assure their operation.

Our ISAC EPICS based control system will be used for display and logging of the beam current measurement from the capacitive probes. In addition, it will allow the operators to pass calibration and trip set points to the local electronics. Over current or system malfunction trips will be passed from the capacitive probe electronics to the ISAC Safety system as simple go/no-go conditions. The Safety system is independent of the EPICS system and is based on a PLC with distributed drop points. It can drive in a beam blocker to prevent beam from exiting the SC-linac vault. Though the Cyclotron Safety system uses similar radiation monitors for personnel protection, the maximum plausible dose rate due to a beam excursion there is 1 Sv/h, much greater than the 25 mSv/h calculated for ISAC.

CONCLUSION

Tests of the non-intercepting beam current monitor indicate that it will be useful as an over current protection device for ISAC-II. The local electronics and the interface to the EPICS and Safety control systems remains to be designed and implemented. A second monitor will be constructed and installed in a vacuum box closer to the SC-linac during the September shutdown.

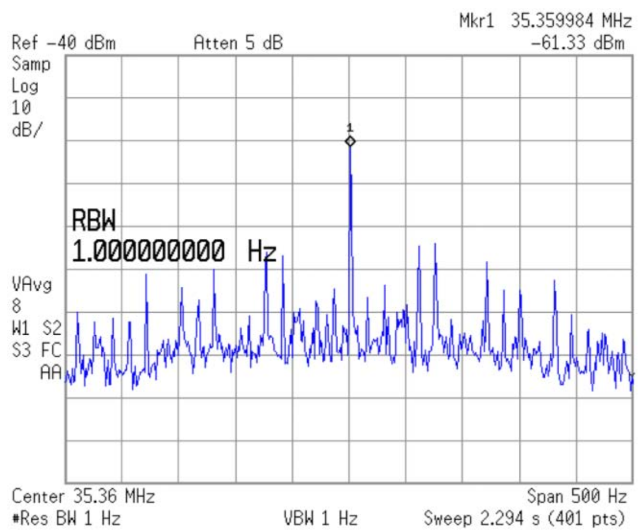

Figure 6: The spectrum of a 3.5 nA $^{22}Ne^{+4}$ beam at 3.6 MeV/u.

REFERENCES

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