TIME DOMAIN DIAGNOSTICS FOR THE ISAC-II SUPERCONDUCTING HEAVY ION LINAC

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Abstract

The medium beta section of the ISAC-II superconducting linac has 20 bulk niobium quarter wave resonators and adds up to 20 MeV of energy to the 1.5MeV/u and A/q≤ 6 ion beam injected from the ISAC-I accelerators A standard array of ISAC diagnostics were installed to commission and tune the transport beam line and linac optics. In addition two new devices were developed: a silicon detector measuring beam particles scattered from a gold foil and time-of-flight (TOF) monitors based on micro-channel plates. These are used both to tune the linac and characterize the accelerated beams in the longitudinal phase space. The TOF monitors reach a time resolution of < 100 ps, energy resolution of 0.1% and a dynamic range spanning seven orders of magnitudes.

INTRODUCTION

The ISAC accelerators produce stable and radioactive ion beams with A/q ≤ 6 and an energy of up to 1.5 MeV/u. An upgrade of the facility with an aim to further increase the final beam energy started in 2000. The first phase of the upgrade, the medium beta section of the ISAC-II superconducting linac, was completed in 2006 by commissioning started in April 2006 [1] and the first radioactive beam delivered to the experiment in January 2007. The linac comprises twenty bulk niobium quarter wave resonators grouped in five cryomodules. Operated at an average accelerating gradient in excess of 6 MV/m in an 18cm gap the medium beta section adds 20 MeV of energy to the injected beam. The linac is connected to the ISAC facility with a 25 m long S-bend achromatic transport line consisting of a transverse focusing structures and a 35 MHz rf buncher to match the input linac optics. Following the linac the beam is transported via a 27 m long straight FODO transport line to the experimental areas. Both transport lines and linac are equipped with standard diagnostics equipment: faraday cups, slits and wire scanners. In addition, two new time domain devices were added: a scattered particle monitor and time-of-flight monitors.

MONITOR DESIGN

The scattered particle and TOF monitors are intended primarily for beam energy and timing measurements delivering, however, different levels of accuracy. In both monitors, intrinsically intended for single particle detection, signal attenuation is achieved in different ways to make measurements possible with nA beams. The monitor design is similar to one developed at ANL [2].

Scattered Particle Monitor

As the monitor name suggests the beam particles are scattered in it from a thin, 40 nm, gold foil towards a Canberra, 50 mm^2 ion implanted, silicon detector with an improved time response placed at 30 degrees with respect to the incoming beam. The detector location is fixed but the scattering foil is mounted on a pneumatically driven actuator and retracts into a collar to protect it during pumping and venting. With this foil thickness and an angular acceptance of the detector of ~7°, the monitor can operate with beam currents from ~100 pA up to a few nA. Depending on the beam energy the count rate from the monitor varies from a few tens to a few hundred counts/sec. The design also incorporates a shutter to protect the silicon detector from a direct beam impact when the beam is tuned. An alpha source is available on the same shutter for test and calibration purposes. The monitor aims to provide beam energy and timing measurements with accuracies of 1-3% and ~200 ps, respectively.

The monitor has been operated for nearly one year with only small signs of radiation damage.

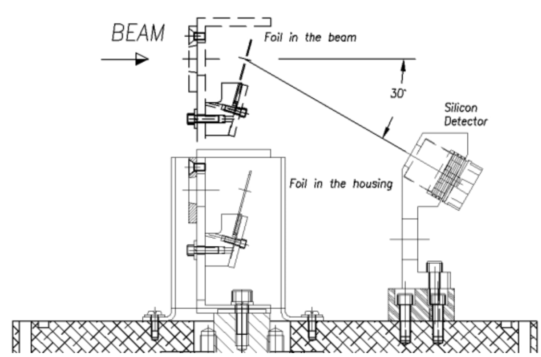

Figure 1: A sketch of the scattered particle monitor.

Time-of-Flight Monitors

The ISAC-II TOF monitors are designed for measurements of the beam velocity with an accuracy of better than 0.1% for v/c of 0.03 to 0.2. The system consists of three identical secondary electron emission (SEE) monitors spaced apart by 3 and 9 m. In each SEE monitor the beam strikes a 50 µm diameter tungsten wire stretched on the axis of a grounded metal cylinder and generates secondary electrons. The secondary electrons are accelerated in a radial electrostatic field when a potential of a few kV is applied to the wire. A small fraction of them, ~4%, passes through an 11 mm aperture in the cylinder and is detected by a fast micro-channel plate (MCP) Hamamatsu F4655-12. The metal cylinder is mounted on a pneumatic actuator and can be retracted from the beam. The MCP is mounted in the housing with a protection mesh of 500 lines per inch on the input aperture. It should be noted that a strong field emission was observed from a fresh tungsten wire at a voltage larger than 800V. Extended conditioning was required to bring the HV up to higher values.

Each SEE monitor detects the time when the beam passes through. Measuring the beam transit time between the monitors, the ion velocity and, thus, the beam energy can be computed.

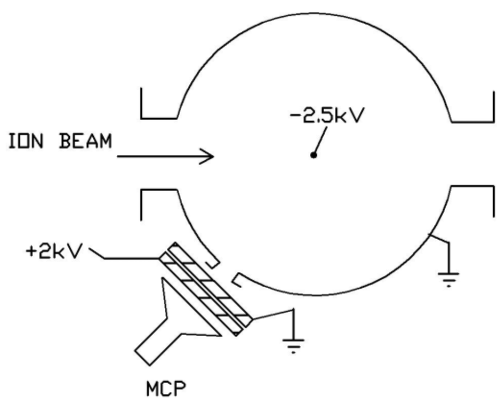

Figure 2: A time-of-flight monitor schematic view. Secondary electrons are extracted by the beam from a wire, accelerated in the electrostatic field and detected by a microchannel plate.

To get the desired resolution at the high energy end of the range, the monitors should be separated by a substantial distance of ~10 m. This introduces an element of ambiguity in the data analysis since the beam transit time between the monitors is significantly longer than the bunch separation of 85 ns. Generally, signals in different TOF monitors are generated by different bunches and the beam transit time is measured with an uncertainty of an integer number of bunch periods. To determine that integer an energy estimate with accuracy of better than 10% is required which is provided by the scattered particle monitor or determined from the accelerating fields in the cavities.

The performance of the system was initially estimated by means of computer simulations. They confirmed that a time resolution in the range of 50 to 70 ps can be achieved. The monitors typically intercept less than 5% of the beam and, thus, can be considered nearly non-intercepting. The monitors are capable of operating with beam intensities from ~10 nA down to 1 fA, thus spanning seven orders of magnitude with a little adjustment of the MCP bias.

The monitors were tested in the lab with a short pulse UV laser. The laser beam was split in two and sent simultaneously to a fast UV silicon photodiode and to a FTM monitor. The pulse shape of the photodiode signal was measured with a 6 GHz Tektronix TDS820 sampling scope. It was in a very good agreement with the FTM time spectra. Both measured a pulse width of ~500 ps.

The low loss phase stable signal cables for the FTM monitors were cut to have equal electrical lengths of within a few tens of ps. The overall signal transit time variation for the different FTM monitors was measured to be less than 100 ps. Later in 2007 it is planned to equip the TOF monitors with a calibration UV laser that will make possible periodic corrections of electronic and other drifts in the system.

Data Acquisition and Processing

The data acquisition system is built on the basis of commercial NIM and VME modules. Signals from the silicon detector, following a charge preamplifier, are sent for pulse height and timing analysis. In the later case they are discriminated and compared by a TDC with a reference 11.8 MHz bunch repetition frequency. Signals from TOF monitors are amplified and sent to low jitter CFDs. The CFD outputs are connected to a 25 ps resolution multihit TDC operating in trigger mode and a logical OR unit generating a common trigger for all three monitors. The TDC calculates the deviation of TOF signals w.r.t. the same 11.8 MHz reference. The modules are controlled by a VME CPU running Linux.

The same CPU provides the interface to the EPICS based ISAC control system. The fast data acquisition is performed by a set of applications communicating with the EPICS soft IO channel by means of a run-time database resident in a segment of the OS supported shared memory. The on-line data processing is done by a number of Matlab applications run on a remote host. Peak fitting, peak position and widths, energy computations and automatic phase scanning of the RF cavities is done in this way. The system is highly automated and transparent to the users.

MEASUREMENT RESULTS

During the linac commissioning the scattered particle and TOF monitors were used both to tune the linac and to characterize the accelerated beams in the longitudinal phase space.

Six different beams from ^{4}He to ^{40}Ca with A/q ratios of 2, 4 and 5.5 were successfully accelerated. Beams from ISAC at two different reference energies were delivered and coasted through the linac to calibrate the scattered particle monitor. The energy losses in the foil and detector window and energy transfer occurring in the scattering from the gold foil vary with the ion mass and charge and require monitor calibration for every ion species being accelerated. This rather time demanding procedure limits the use of the monitor for absolute energy measurements. It proved very useful for the phasing of the buncher and cavities, however.

Following the S-bend buncher, each linac cavity was turned on starting from the upstream end. The cavities were phased by measuring the beam energy for four different phases and fitting the data to a cosine profile to find 0°. After that all cavities were set to a synchronous phase of -25° for acceleration.

Using the monitor we were able to observe components a “cocktail” beam of $^{20}Ne^{5+}$ and $^{40}Ca^{10+}$ accelerated at the same time. Both ions have the same velocity and A/q and would be indistinguishable by the ISAC PRAGUE magnetic energy spectrometer and by the TOF monitors.

Currently, there is no bunching cavity present downstream of the linac, however, it was possible to use one of the linac cavities to focus the beam in time or energy. Thus, by using the second cavity of the fifth cryomodule we could bunch the beam accelerated in the first two cryomodules The scattered particle monitor conveniently allows us to observe the energy and time spectra at the same time (Fig.3). The smallest beam energy and time spreads observed with the monitor were 0.5% and 0.6ns (FWHM), respectively. Both values are very close to and possibly limited by the monitor resolution.

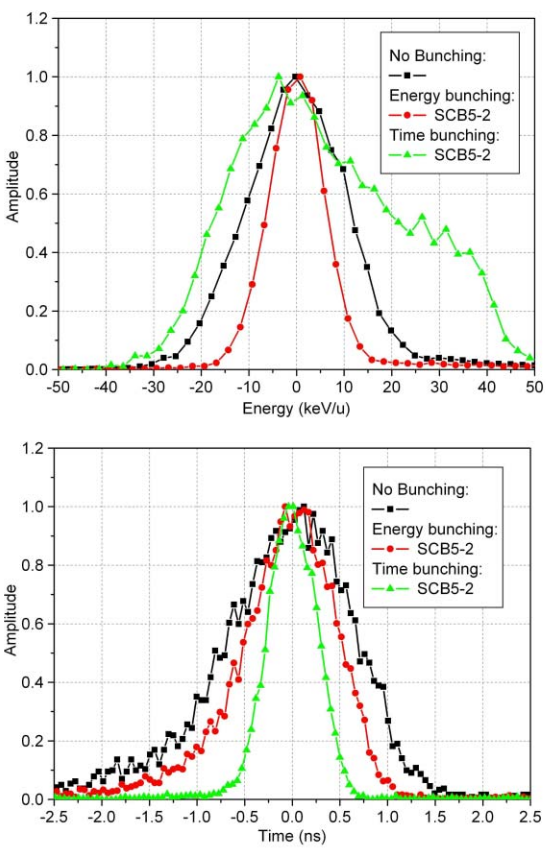

Figure 3: The beam energy (upper) and time (lower) distributions of a beam bunched in energy or in time compared to the non bunched beam at the location of the scattered particle monitor.

Accurate energy measurements were done with the TOF monitors. At the moment of commissioning two of three TOF monitors were in operation. The accuracy of the monitors was initially evaluated by comparing the TOF data with the measurement of the PRAGUE magnet when the beam was brought through the linac without acceleration. An agreement of better than 0.1% was observed in this case. Care, however, must be taken to center the beam on the TOF monitors since they are sensitive to ionization of the residual gas by the beam.

The measured energy for three accelerated beams versus the number of cavities in operation is shown in the Fig.4. Final energies of 10.8, 6.8 and 5.5 Mev/u were reached for beams with A/q values of 2, 4, and 5.5, respectively. The accelerating gradient calculated from these measurements had a very good consistency for all three beams. The average gradient in each case was 7.2 MeV/m corresponding to an average voltage gain of 1.3 MeV/cavity.

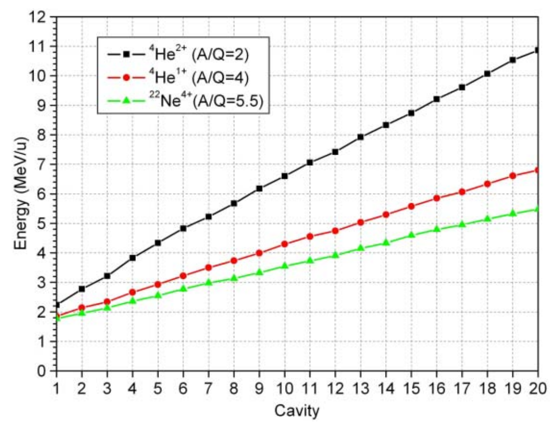

Figure 4: The full beam energy as a function of the number of cavities turned on for three different accelerated ions. Synchronous phase is -25°.

An attempt to determine the beam longitudinal emittance was undertaken taking advantage of three time domain devices available after the linac. The parameters of the beam ellipse in the longitudinal phase space can be calculated on the basis of measuring the time spread at three different locations along the transfer line where no acceleration fields are present. Using this method with a $^{20}Ne^{5+}$ beam a 1σ longitudinal emittance between 0.8 and 1.2 keV/u ns was obtained which can be compared with the theoretical value of 1.5 keV/u ns obtained from computer simulations.

CONCLUSION

Two new devices: scattered particle monitor and TOF monitors add to the ISAC-II superconducting linac time domain diagnostics. Both devices were successfully used in the linac commissioning for cavity phasing and energy measurements, energy and time spread and longitudinal emittance measurements.

REFERENCES

[1] R.E.Laxdal, et al., “Commissioning of the ISAC-II superconducting linac at TRIUMF”, EPAC’06, Edinburgh, June, 2006, p. 1556.

[2] P.K. Den Hartog et al., “The beam bunching and transport system of the Argon positive ion injector”, PAC’89, Chicago, IL, March 1989, p. 545.