RIA Diagnostics Development at Argonne

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Introduction

The Rare Isotope Accelerator(RIA) project proposes to enter new regimes of operation for heavy-ion beams in both current and power. On the driver side, previously unheard of levels of heavy-ion current is needed to deliver beams with power up to 400 kW, while on the secondary-beam side of the facility the accelerator must efficiently deliver beams with intensities of only a few (or less) ions per second. The driver linac must accelerate these high-power beams with losses less than 1W/m, especially in the high energy section, to allow hands-on maintenance and to efficiently use the beam current available from the ion sources. This is complicated by the plan to accelerate beams comprised of a variety of charge states to maximize the available beam current. The secondary-beam linac must also operate with extremely low losses to maximum beam intensity for research. In addition, many experiments will need beams of high quality, both in transverse and longitudinal phase space. Optimal design of the diagnostics system for both accelerators is crucial to achieve these beam property goals and to do so in a manner that maximizes available research hours.

The design of the diagnostics for RIA is further complicated by the requirements that for optimum beam optics, close spacing of the active elements (independently phased superconducting resonator and solenoids) is needed with minimum drift distances. This requirement is especially true in the low-velocity ($\beta<0.1$) accelerator region for heavy-ions with low charge-to-mass ratio (q/m), and so the pressure to minimize the space needed for diagnostics is intense. In existing heavy-ion linacs such as ATLAS, no space has been allocated for diagnostics over ten meter distances. Especially at low velocity, beam steering and focusing problems make tuning cumbersome when diagnostics are sparsely distributed. This problem will be even more acute for the RIA.

At Argonne, a number of projects have been undertaken to develop new diagnostic systems necessary for the RIA facility and are described in this document. The present ATLAS facility has immensely valuable in developing these devices and also benefits operationally for these developments by incorporating the equipment and techniques into current operations.

Beam phase detection with a SC resonator

ATLAS staff have demonstrated, for the first time, the use of a superconducting resonator (SCR), installed for beam acceleration, to detect the arrival time of a beam bunch at the detecting resonator[1]. This is accomplished when the resonator is operating, not as an accelerating cavity, but rather running with a very low field, comparable to, but larger than, the field induced by the beam pulses traversing the cavity. In this mode, the information obtained from the detecting resonator can be used to accurately determine the

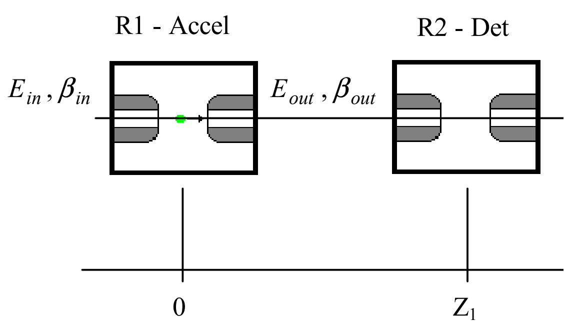

Figure 1 Schematic geometry for resonant beam phase detection.

beam-RF phase relationship in an upstream resonator and thereby correctly set that resonator for the proper accelerating mode.

Because of the extremely high Q of superconducting resonators, very narrow frequency bandwidth and microphonic effects do not allow direct use of the induced RF signal in the SCR for beam phase detection. As for normal SCR operation for ion acceleration, beam phase detection requires stabilization of the SCR resonant frequency, which is typically accomplished by means of RF feedback loops. To achieve normal operation of the feedback loops, some low level of resonator RF field is required. The level of the RF field must be comparable to the beam-induced RF field to maximize the sensitivity and to avoid any perturbation of the beam from the detecting resonator field. Therefore, unlike "normal" beam phase detectors, the RF field in an SCR is always a superposition of a reference RF and the beam-induced signal.

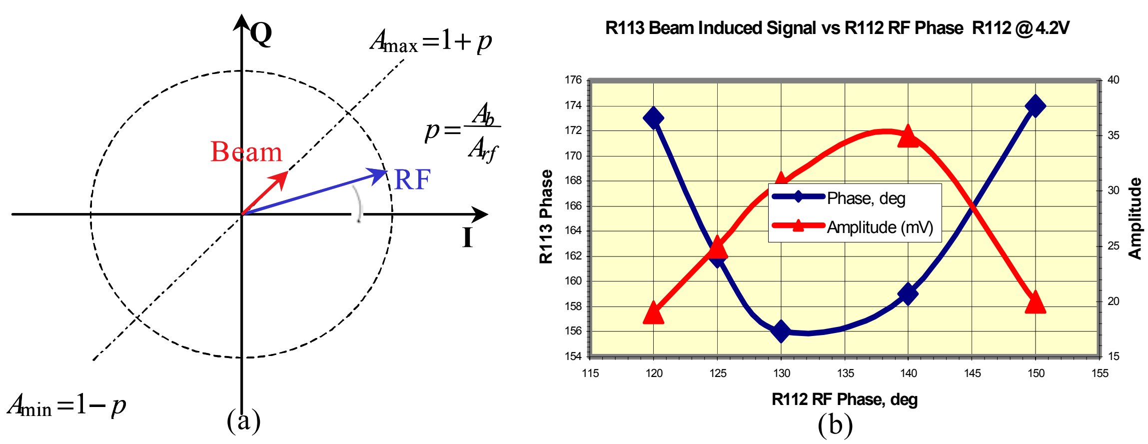

Figure 2 (a) Vector relationship between the reference RF and beam induced RF. (b) Beam-induced phase and amplitude vs last accelerating resonator phase for a 1 eμA $^{40}Ar^{7+}$ beam at ATLAS.

In this case, neither amplitude nor phase of the resonator RF field can give unambiguous information about beam phase, because both amplitude and phase of the resultant RF field are functions of the reference RF field amplitude and phase. Nevertheless, there is a simple way to extract beam phase information from the resultant RF field. By applying a linear circular phase modulation to the reference RF field, the magnitude of the resultant RF field will be amplitude modulated with the same frequency and, relative to the reference signal, will be shifted in phase by an angle exactly equal to the beam phase.

This system is fully implemented and in regular use for the lowest velocity portion of ATLAS[2]. The data in fig 2 is from an operational tune of one ATLAS resonator.

Bunch Length Measurement

An accurate longitudinal bunch shape measurement is one of the most important tasks during the fine tuning of multi-cavity accelerators. A device for the measurement of bunch time structure of cw heavy-ion beams with time resolution ~20 picoseconds was developed, constructed and commissioned at ATLAS[3]. The Bunch Length Monitor (BLM) is based on the analysis of secondary electrons produced by a primary beam hitting a tungsten wire biased by a -10 kV potential. In a BLM, the longitudinal distribution of charge of the primary beam is coherently transformed into a spatial distribution of low-energy secondary electrons through transverse rf modulation. The distribution of secondary electrons is detected by a chevron MCP coupled to a phosphor screen. The signal image on the screen is measured by use of a CCD camera connected to a PC.

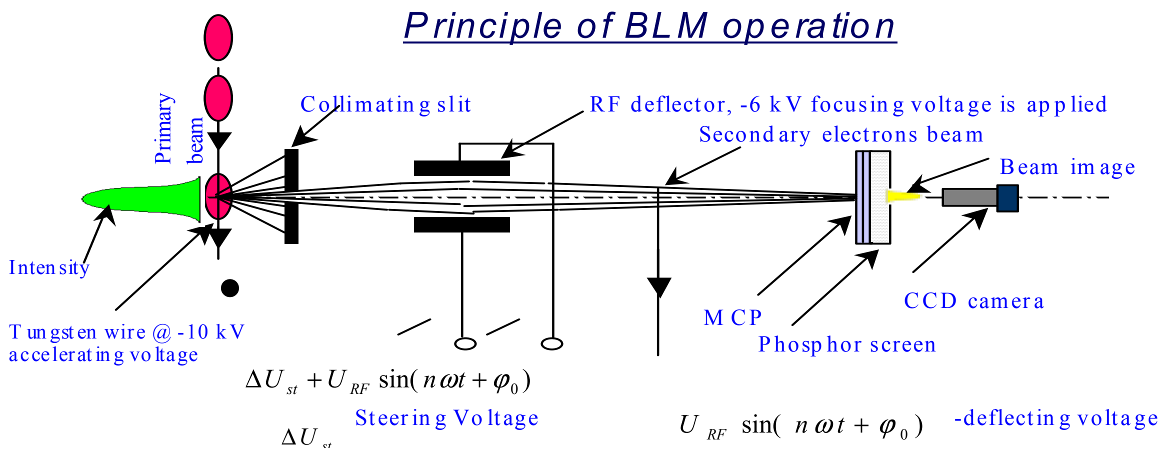

Figure 3 Schematic of Bunch Length Measurement System

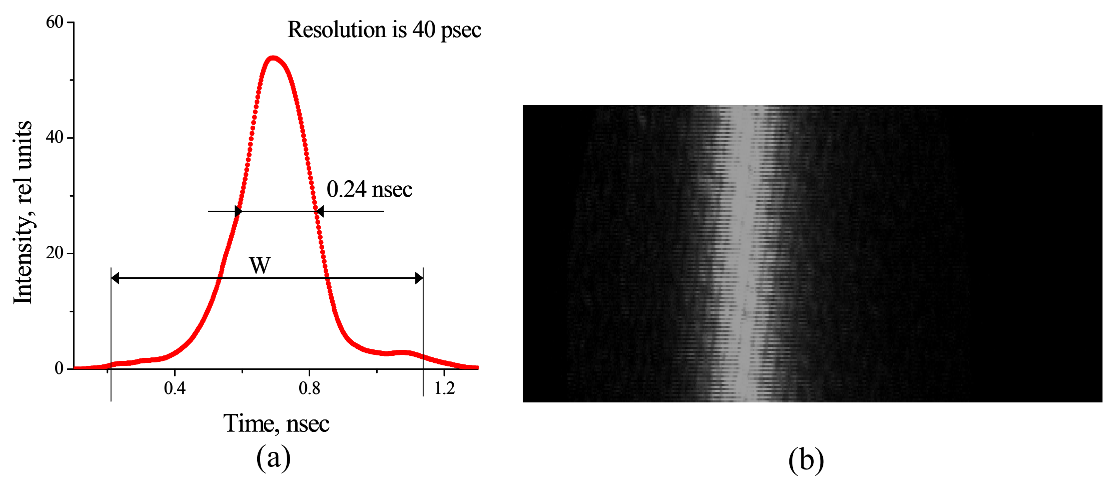

Figure 4. ^{58}Ni bunch profile (a) inferred from scintillator signal (b).

The general layout of the BLM developed for a cw heavy-ion linac is shown in figure 3. The secondary electrons produced when a primary beam hits a –10kV biased tungsten wire are collimated and pass through the rf field of the deflector. The quarter-wave resonant deflector operates at 97.0 MHz and is synchronized with the linac master oscillator. The detection of the secondary electron beam is done with the combination of a phosphor screen and a light sensitive detector. A monochromatic CCD (charge coupled device) is sufficient for detecting the light signal. A dual multi-channel plate (MCP) detection system was used to obtain a high gain.

Tests of the BLM done with $^{59}Ni^{15+}$ ions from the Booster section of ATLAS are shown in figure 4. The beam energy range was 6.5-7.2 MeV/u while the beam intensity was in the range 10 -100 pnA. The figure below shows a typical swept beam image and extracted bunch shape of the $^{59}Ni^{15+}$ beam accelerated to 7.0 MeV/u in the Booster. The time resolution for this particular measurements was 40 ps which was set in order to observe the full bunch on the screen.

Beam Image Monitor for Weak Beams

Intensity profiles and emittance analyses are among the most critical tools used for optimizing beam transport through accelerators. Development efforts have gone into the construction and performance testing of a beam image monitor (BIM) that can be used to provide snap shot images of the beam profile at very low ion beam intensities. The device is sensitive over a wide range of beam intensity from $\sim 10^2$ to $\sim 10^{12}$ pps. In conjunction with double-plane slits or a pepper pot plate, this system can be also be used to scan transverse emittance profiles in both the x-x′ and y-y′ phase space planes.

A layout of the BIM is shown in figure 5. Beam ions strike a flat aluminum surface that is oriented at 45° relative to the beam direction. The plate serves as a dynode since the ion signal is converted to a burst of secondary electrons (SE). These secondaries are promptly accelerated by a 5-15 kV potential imposed by a grid parallel to and 5 mm from the surface. Motion feed-throughs are used to insert the aluminum foil dynode and a dual slit plate upstream. Note that the beam cross section in the horizontal plane will appear √2 times large due to the 45º tilt relative to the beam coordinate system of the beam which shown in the diagram.

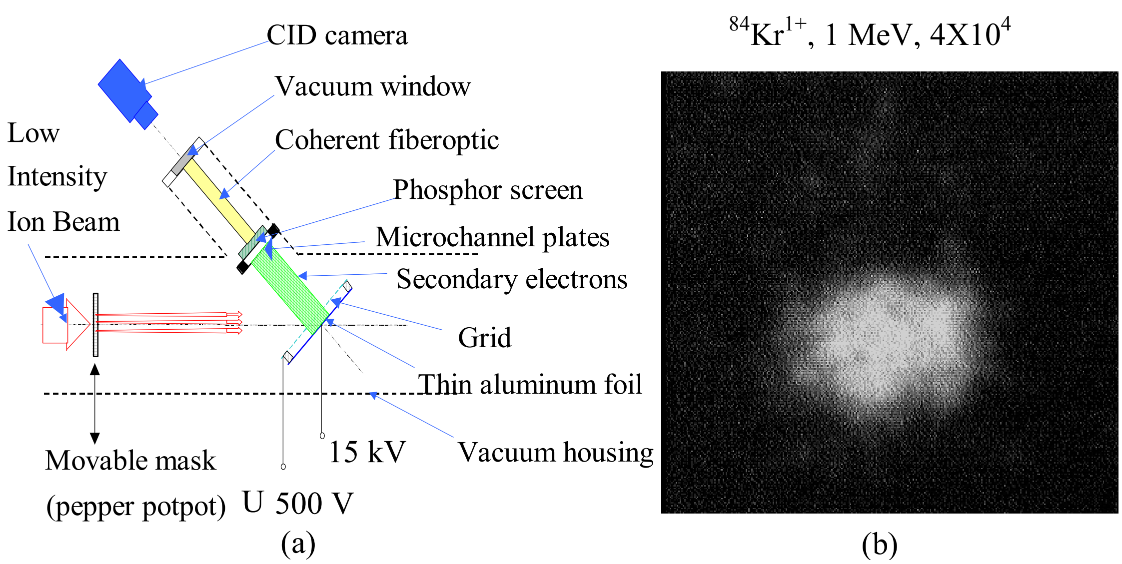

Figure 5 (a) Schematic of beam intensity monitor. (b) Digitized image of low intensity ^{84}Kr beam.

A dual position-sensitive microchannel plate (MCP) is excited by the secondary electrons and further amplifies the signal with a gain of $\sim 4X10^7$. The accelerating potential is distributed evenly enough such that the electrons are accelerated perpendicular to the conversion surface, thus the system may be used to map the ion beam intensity along the transverse plane. The actual detection of the signal is done with the combination of a type P-20 phosphor screen coupled to a light sensitive detector by a fiber optic (FO) transport system and demagnifier. We chose a CID (charge integrating device) since it has less cross sensor-induced noise as well as less thermal induced noise. The spatial resolution for a single particle exciting the MCP surface is better than 0.15 mm.

The BIM was tested using $^{84}Kr^{+1}$ beams at energies ranging from 3.6 keV/u to 18 keV/u. The BIM performance was measured for intensities for $4X10^2$ to 10^{12} pps. Using a dual slit system, beam emittances have also been measured with the system. The spatial resolution was characterized by comparing the emittance profile with that obtained by a wire scanning device which had better resolution but sensitive only to intensities above 10^{11} pps. The BIM has also been used to aid in the transport of ~6 MeV/u radioactive beams, such as ^{17}F, produced by pick-up reactions with a gas cell target at the ATLAS accelerator facility.

Additional R&D Diagnostics Needs

Although much work to develop the necessary diagnostics for RIA has been performed at Argonne and other laboratories, there remain significant diagnostics issues that must be addressed in order to insure the successful operation of the RIA facility. Some of the most important outstanding issues are:

1. The development and demonstration of beam position monitors (BPM) for the driver linac. A joint project with LANL and ANL is under discussion in this area.
2. Design and test a compact diagnostic assembly to be mounted in the very limited space between cryostats and containing a BPM, phase detector, current toroid, and wire scanner.
3. Develop a beam halo detector for the driver linac.
4. Develop high precision beam energy measurement system for secondary beams. A microchannel-plate time-of-flight system is a possible example. Absolute energy determination diagnostics (such as diode detectors) are also necessary to provide unambiguous beam determination. This information may also be used for feedback stabilization.

References

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