STATUS REPORT ON THE NSCL RF FRAGMENT SEPARATOR*

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Abstract

The Radio Frequency Fragment Separator (RFFS) proposed in [1] is now operational at the National Superconducting Cyclotron Laboratory (NSCL). The RFFS is an additional purification system for secondary beams at the NSCL after the existing A1900 fragment separator and will primarily be used to purify beams of rare neutron deficient isotopes. A similar device is already in use at RIKEN [2]. The RFFS uses an rf kicker to angularly separate unwanted particles from the desired ion beam, a π/2 phase advance cell to rotate the beam in phase space before the beam reaches a collimating aperture for purification, and a final π phase advance cell to transport the desired beam to the experiment. The final design for the rf kicker and the focusing system is presented and a status report on the building and commissioning effort is given.

INTRODUCTION

The NSCL Coupled Cyclotron Facility produces some of the most intense beams of neutron deficient nuclei such as ^{100}Sn available worldwide. Previous attempts to perform experiments with these neutron-deficient beams met with serious challenges due to large contamination and overpowering background from other undesired ions that cannot be separated with the existing A1900 fragment separator. The RFFS adds another criterion to the selection of rare isotopes by rejecting unwanted particles according to their velocities. The enhanced signal to background ratio for the typically weak rare isotope beams translates directly into enhancements in the discovery potential and into at least a factor of ten in efficiency for many experiments limited by detectors being overwhelmed with the background from unwanted particles. These experiments will address a wide range of important science ranging from astrophysical X-ray bursts to experiments relating to precision tests of the Standard Model. Four experiments using the RFFS have recently been approved by the NSCL Program Advisory Committee [3].

RFFS BEAM OPTICS

Secondary beams at NSCL are purified in the A1900 fragment separator based on their magnetic rigidity and can now be further purified in the RFFS based on their velocity. The layout for the RFFS is illustrated in Fig. 1. The central device in the RFFS is an rf kicker which exposes the beam to an rf transverse electric field. It is located 52 meters away from the A1900 production target and operated at the cyclotron frequency with an adjustable phase difference. Ions in the beam that differ in velocities and therefore in time of flight arrive at the rf kicker with different rf phases and experience different transverse deflections. The deflection is vertical and given by

$$\delta y' = c_1 \frac{V}{B\rho\ f} \left| \mathrm{Sin}\left(c_2 \frac{f}{\beta} \right) \right| \mathrm{Cos}\varphi$$

where δy' is in mrad, β and Bρ[T.m] are the reduced velocity (v/c) and the magnetic rigidity of the particle, f[MHz] and V[kV] are the frequency and the voltage between the deflecting plates of the rf kicker and φ is the average phase of the beam with φ=0 corresponding to the largest deflection. Also, c_1=6.37 and c_2=0.0157 are constants related to the geometry of the rf kicker. The sine term is related to the transit time factor and depends on the resonator's frequency and on the particle's velocity. As a numerical example, a $^{100}\mathrm{Sn}^{50+}$ beam with 100 MeV/u kinetic energy (Bρ=2.956 T.m and β=0.43) going through the rf kicker with f=23 MHz and V=100 kV is deflected by 7 mrad on crest.

The beam optics after the rf kicker was modified

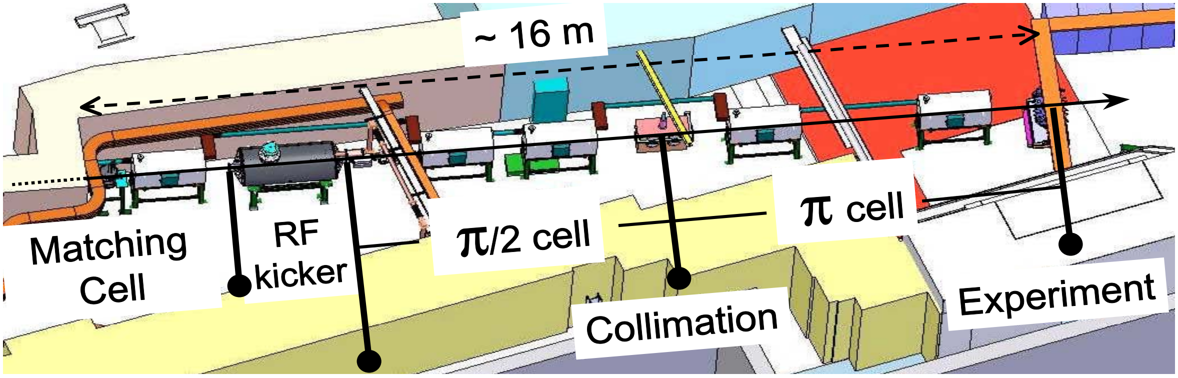

Figure 1: Layout of the RFFS. All the white boxes are quadrupole doublets (see text for details).

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compared to its initial design [1] to accommodate experiments with various beam requirements. The beam horizontal and vertical envelopes along the RFFS are shown in Fig. 2 and sketches of the vertical phase space are given at a few locations. In this example, the red ellipses correspond to a contaminant beam having $\varphi=\pi/2$ (i.e. no deflection in the rf kicker) whereas the green ellipses correspond to the beam of interest having $\varphi=0$ (i.e. maximum deflection in the rf kicker).

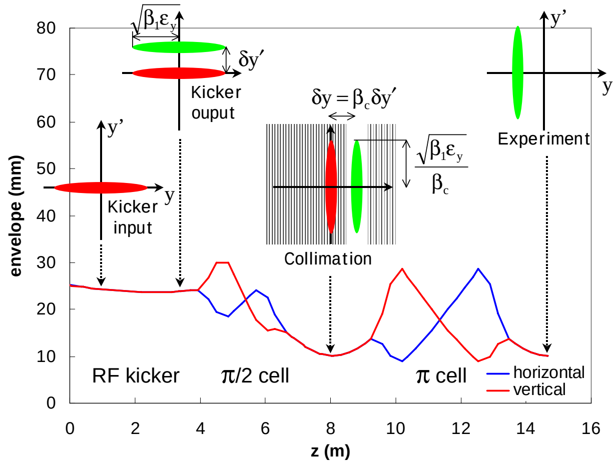

Figure 2: Horizontal and vertical beam envelopes along the RFFS for a beam with a transverse emittance of 80 π.mm.mrad. The beam vertical phase space is sketched at a few locations along the RFFS (see text for details).

The two beams are superimposed in phase space before the kicker. After the kicker, the red (contaminant) beam remains centered on the beam axis whereas the green (target) beam is kicked upward in phase space. Optimum angular separation between the ion of interest and the contaminants is achieved when the vertical beam size is equal to the resonator aperture so that the width of the beam divergence is a minimum. The corresponding Twiss parameter is

$$\beta_1 = g^2/4\varepsilon_y$$

where g is the gap between the deflecting plates (g=50 mm) and ε_y the vertical emittance of the beam. The two beams are then rotated through the π/2 cell and the angular separation between the beams is translated into a spatial separation. Because of the 90-degree rotation in this cell, it is important to have the ellipse upright in phase space (i.e. $\alpha_1=0$) at the kicker exit. After the π/2 cell, the contaminants are removed by collimation. In Fig. 2 for example, the red beam is removed by collimation and only the green beam is transported to the experiment through the π phase advance cell. In the RFFS, magnetic steerers are also available to put the beam of interest back on axis.

The π/2 cell is designed to have $\alpha_c=0$ and β_c~3m as eigen-Twiss parameters in both transverse phase spaces. Because of the π/2 phase advance through this cell, the beam envelope at the collimation point is equal to β_c times the divergence of the beam at the kicker exit or equivalently

$$\beta_2 = \beta_c^{\,2}/\beta_1$$

Using the previous beam conditions and for a beam with a transverse emittance of 80 π.mm.mrad, one finds β_1=7.8 m and β_2=1.2 m with corresponding beam envelopes (i.e. $\sqrt{\beta\varepsilon}$) of 25 mm and ~10 mm as illustrated in Fig. 2. The optics in the RFFS is in good approximation linear and the Bρ of all the ions nearly identical after the A1900 fragment separator. Thus, in the beam line after the rf kicker, all the particles transform similarly in phase space. This is true in particular for the beam centroids and two beams angularly separated at the entrance of the π/2 cell by δy' will be spatially separated at its exit by δy with

$$\delta y = \beta_c\ \delta y'$$

Assuming the beams are separated by 7 mrad after the rf kicker, the beam centroids will be distant by ~21 mm at the collimation point.

Some experiments (e.g. experiments using a beam scattering chamber) will require a beam spot and divergence at the experiment compatible with a transverse emittance of 10 π.mm.mrad whereas secondary beams can have up to 80 π.mm.mrad. At the expense of beam intensity, collimation can be used to satisfy such stringent beam requirements. For this reason, the π/2 cell is designed to identically rotate both the horizontal and the vertical phase space and to allow emittance collimation in both transverse directions using two sets of 4-jaw collimators. The first set is located at the entrance of the π/2 cell and effectively provides the angular cut. The second set is located at the end of the π/2 cell and provides the position cut.

MECHANICAL DESIGN OF THE RF KICKER

The rf kicker is a split-coaxial type resonant structure. A mechanical drawing of the rf kicker is shown in Fig. 3. In the figure, the deflecting plates, the coarse tuners, the fine tuner and the rf coupler are shown. Since the cyclotron frequency is variable, the frequency of the kicker is also adjustable. Two capacitive tuners (coarse tuners) provide the tuning of the resonant frequency anywhere between 17 and 27 MHz. To vary the frequency from the lowest to the highest value, the coarse tuning plates are moved and their distance to the deflecting plates increased from 2 to 12 cm. The design of the fingers that provide the electrical contact to the movable tuning plates was carefully done to limit the current density below 10A/finger. This limit was chosen for reliable operation based on past experience. The coarse tuners are used to bring the rf kicker close to the desired frequency, the exact frequency of the kicker is achieved using the fine tuner which provides a tuning range of 60 kHz. As reported in [1], the Q of the resonator depends on its operating frequency. To reach the 100 kV design deflecting voltage, the amplifier must provide 9 kW of rf power at 27 MHz and 19 kW at 17 MHz. The rf coupler is a movable inductive loop allowing critical coupling at any operating frequency.

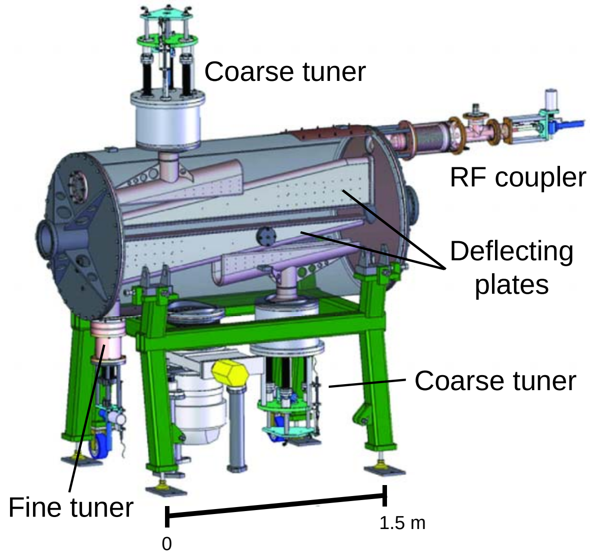

Figure 3: Mechanical drawing of the rf kicker for the RFFS at the NSCL. The ions experience a transverse rf electric field between the two plates held by the resonator wedges centered in the tank. The two coarse tuners, the fine tuner and the rf coupler are also shown.

Though the resonator is operated at room temperature, microphonics issues related to the coarse tuners were considered during the design. The unloaded Q of the resonator is approximately 7500 at 23 MHz giving a half-bandwidth (f/2Q) of 1.5 kHz. Each coarse tuner provides a 5 MHz change in frequency for a 10 cm travel or equivalently a detuning by a half-bandwidth for a 30 microns displacement. Such a sensitivity of the resonant frequency to small displacements is typical for superconducting resonators with high quality factors [4] but unusual for room temperature resonators. As a preventive measure, the deflecting plates were designed as hollow structures with reinforcing ribs to move the frequency of a mechanical resonance from 60 Hz to about 90 Hz. Also, the motion of the fine tuner is integrated into the rf control system to dynamically keep the rf kicker locked on resonance with the K1200 cyclotron frequency.

RFFS COMISSIONING WITHOUT BEAM

The main components of the RFFS were installed and commissioned without beam in April 2007. The movable 4-jaw collimating systems and the final amplifier were not yet available. Instead, a fixed slit was installed after the $\pi/2$ cell and a 6 kW rf plate amplifier was used for the commissioning with beam. During conditioning of the rf kicker, glowing discharges and soft multipacting barriers were observed. Design studies had shown that one-point multipacting between the deflecting and tuning plates was possible at very low fields but, as anticipated, easy to overcome in practice. The tuning ranges of the movable coarse tuners and fine tuner were measured and found in good agreement with their design specifications.

Figure 4: RF kicker for the RFFS installed and successfully commissioned at the NSCL in April 2007.

RFFS COMISSIONING WITH BEAM

The RFFS was commissioned with beam in early May 2007. The coupled cyclotrons produced 900 enA of $^{124}\mathrm{Xe}^{48+}$ at 140 MeV/u. This primary beam was used on a beryllium target for production of $^{100}\mathrm{Sn}^{50+}$ by fragmentation. The 6 kW of rf power from the amplifier generated a 55 kV deflecting voltage in the rf kicker. Because of the purification from the RFFS, the large background from the contaminants was significantly reduced and detection of neutron deficient isotopes possible. A detailed report on the results from the commissioning run will be given in [5].

SUMMARY

The RFFS was successfully built, installed and commissioned. Four experiments using this new purification capability for secondary beams are planned during the next year of operation at the NSCL coupled cyclotron facility.

REFERENCES

[1] D. Gorelov et al., "RF-Kicker System for Secondary Beams at NSCL/MSU" Proceedings of PAC05
[2] K. Yamada et al., Nucl. Phys. A 746 (2004) 156c-160c
[3] NSCL Program Advisory Committee (PAC31) http://www.nscl.msu.edu/aud/exp/approvedexp/
[4] T. Grimm et al., "Measurement and Control of Microphonics in High-loaded-Q Superconducting rf Cavities" Proceedings of LINAC2004
[5] J. Stoker et al., "Commissioning Report on the NSCL RF Fragment Separator" future presentation at the 234th ACS National Meeting.

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