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Commissioning of the DESIR High-Resolution mass Separator

J. Michaud^a, P. Alfaut^a, A. Balana^a, B. Blank^a, L. Daudin^a, T. Kurtukian Nieto^a, B. Lachacinski^a, L. Serani^a, J-C. Thomas^b, F. Varenne^b

^aUniv. Bordeaux, CNRS, LP2I Bordeaux, UMR 5797, F-33170 Gradignan, France,

^bGrand Accélérateur National d'Ions Lourds, CEA/DRF - CNRS/IN2P3, Bvd Henri Becquerel, BP 55027, F-14076 CAEN Cedex 5, France,

Abstract

DESIR is, together with S3-LEB, the low-energy part of the SPIRAL2 ISOL facility at GANIL. The High-Resolution mass Separator (HRS) included in DESIR is a 180° symmetric online separator with two 90° magnetic dipole sections arranged with electrostatic quadrupoles, sextupoles and a 48-pole electrostatic multipole on the mid plane. The HRS is now completely mounted at LP2i Bordeaux and under commissioning for the next years before its transfer to the entrance of the DESIR facility. Optical aberrations, mainly introduced by the dipoles, must be corrected up to the highest possible order to guarantee an optimal resolution of the separator. They are measured with a pepperpot-type emittance-meter, analysed then corrected with the multipole. Up to now, 2nd order (hexapolar) and part of 3rd order (octupolar) aberrations are under control and an optimal FWHM separation has been achieved for two identical beams with a relative energy difference of $\Delta E/E (\equiv \Delta M/M) = 1/23400$.

In this paper, we present the effects of optical aberrations on the beam and its emittance figure, as well as the effect of the associated corrections with the multipole. Finally, we will show the latest resolution measurements and associated methodology.

Keywords: Magnetic separator, Aberrations, Multipole

1. The DESIR HRS

The DESIR facility [1] (Désintégration, Excitation et Stockage d'Ions Radioactifs) under construction at GANIL (France) is a low energy facility for nuclear physics. The beams with masses up to $A = 240$ at energies up to 60 keV will be provided by the RFQ cooler SHIRaC [2] with a low energy spread ($< 4eV$) and a transverse emittance of less than $2.5 \pi \cdot \text{mm} \cdot \text{mrad}$ to the High Resolution Separator (HRS), before being sent to the DESIR facility. The HRS [3, 4] is a magnetic separator which will purify the beams with a design mass resolution of $R = M_0/\Delta M = 20000$.

Its design [4], whose synoptic scheme is shown in Figure 1, is mainly focused around the two 90° magnetic dipoles, responsible for the mass separation. It is completed with a set of fully electrostatic elements, such that their effect on the beam dynamics is independent of the mass of the particles. In order to get a better control on optical aberrations, a mirror symmetry has been imposed and a 48-pole

electrostatic multipole has been placed in the center of symmetry of the HRS.

All these HRS equipments are remotely controlled with an EPICS based control system. The HRS is now fully mounted at LP2i Bordeaux (former CENBG) and its commissioning started in July 2018.

2. Aberrations measurements and corrections

The mass or energy resolution of the HRS is given by Eq. 1:

$$R = \frac{D}{2x_{00}M + \delta} \quad (1)$$

where D is the dispersion of the HRS (31 cm/%), $2x_{00}$ the beam size at the entrance of the apparatus (typically 1mm), M the magnification of the system (equal to 1 by design) and δ an additional term including systematic errors and optical aberrations,

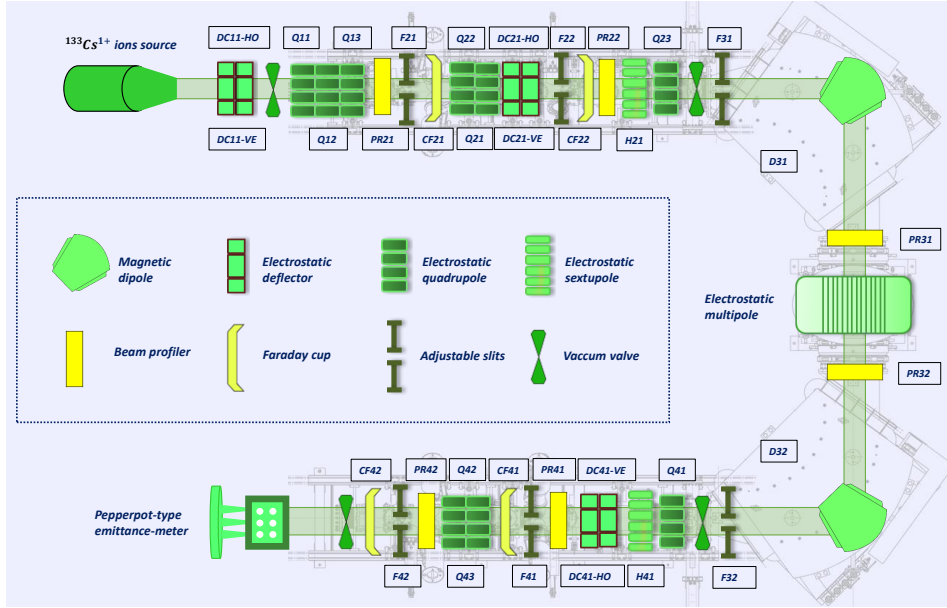


Figure 1: HRS synoptic scheme [3] as it is used for the commissioning. The picture is extracted from the HRS control system. For commissioning purposes, the entrance quadrupole triplet has been removed and replaced by a pair (vertical-horizontal) of steerers, named DC11. The ion source and the emittance-meter have been added to the scheme as they are used for the commissioning.

which tends to decrease the resolution. In a perfect case ($\delta = 0$), the HRS should reach an optimal resolution of $R = 31000$ for a 1 mm beam. Hence, a fine control of the optical aberrations is necessary to reach the best achievable resolution for the HRS.

One way to measure the aberrations of a beam is to use an emittance-meter. The HRS is equipped with a pepperpot-type emittance-meter, which allows to measure simultaneously the transverse 4-dimensional phase space of the beam (X : transverse horizontal position, X' : transverse horizontal angle, Y : transverse vertical position, Y' : transverse vertical angle). Horizontal aberrations, responsible of the decrease in the resolution and mainly introduced by the dipoles, can be observed through the XX' emittance figure as shown in Figure 2.

In the presence of hexapolar (2nd order) aberrations, a C-shaped emittance is generally observed while an octupolar (3rd order) aberration will generally lead to a S-shaped emittance.

Optical aberrations at different orders can be corrected with the application of the corresponding multipolar field on the beam. The HRS' 48-pole multipole has been designed to achieve such corrections up to the 5th order (duodecapole). Figure 3 shows the effect of hexapolar corrections of the multipole on the beam shape. A multipolar field is

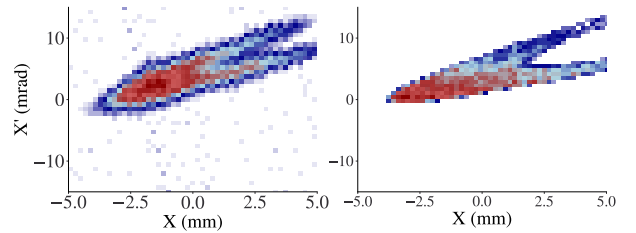


Figure 2: Measured (left) and simulated (right) emittance for a 15keV $^{133}\text{Cs}^{1+}$ beam at the exit of the HRS[3]. The presence of hexapolar aberrations leads to the appearance of a C-shaped emittance figure.

created by polarizing the 48 electrodes with a sine functions with the appropriate harmonics (see [3], Eq. 1 and Fig. 2 for more details). The associated voltage of correction is the amplitude of the sine function.

In the case of 2nd order aberrations, when no corrections are applied with the multipole, a tail can be observed on one side of the beam, while it disappears if the exact correction is applied. In the case of odd levels of aberrations (3rd order for example), tails tend to appear on both sides of the beam.

Up to now, 2nd order and 3rd order aberrations have been corrected on the HRS.

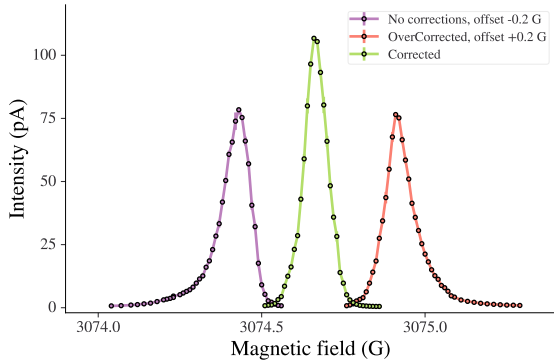


Figure 3: Experimental beam intensity profiles acquired by scanning the beam with the dipoles through slits F42 and monitoring its intensity on CF42 (see Fig. 1)[3]. Distributions are shifted for more visibility. With no correction (0V), the second order aberration tail extends toward smaller field values. With a correct level of correction (150V), the aberration tail disappears. If overly corrected (300V), the aberration tail extends towards larger field values.

3. Determination of the HRS resolution

The ion source available for the commissioning at LP2i Bordeaux is a $^{133}\text{Cs}^{1+}$ stable ion source, able to deliver a continuous beam of low emittance ($2\pi\text{.mm.mrad}$ at 25keV), low energy spread ($<1\text{eV}$) and a beam intensity between 1pA and 10nA. Even though some traces of other species have been found in the source (mostly alkalines), their masses are not close enough to test the resolution of the HRS.

Another way to characterize a magnetic spectrometer is to look at its energy resolution, which is the same as the mass resolution. By measuring the sizes and separation of two beams with close energies, we can estimate the resolution of the HRS. Figure 4 shows a beam separation for two beams with a relative energy difference of $1/20000$, at 25keV, with a low energy dispersion ($<1\text{eV}$), a 1mm beam (F21 entrance slits aperture) and a measured emittance of $2\pi\text{.mm.mrad}$.

An analysis of this experiment showed that two beams with the above parameters can be separated at their FWHM for $\Delta E/E_0 = 1/23400$ or at 10% height for $\Delta E/E_0 = 1/13500$.

As the final resolution strongly depends on the initial size of the beam (see Eq. 1), we used this measurement method to characterize the HRS resolution for different beam sizes, for a fixed set of parameters (mentioned above). The dependance of the HRS resolution on the entrance (located at F21 in Fig. 1) beam size is shown in Figure 5.

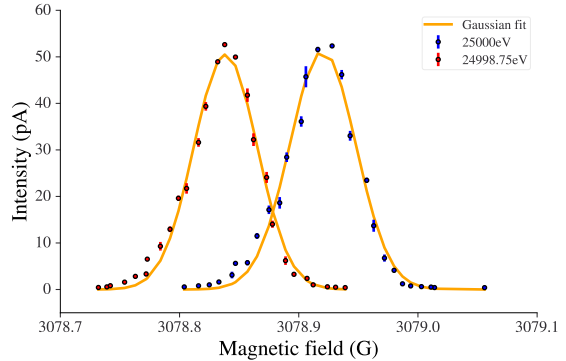


Figure 4: Separation of two beams with close energies ($\Delta E/E_0 = 1/20000$), with the best achieved aberration correction level, for a $2\pi\text{.mm.mrad}$ and 1mm beam, and a low energy dispersion ($<1\text{eV}$).[3]

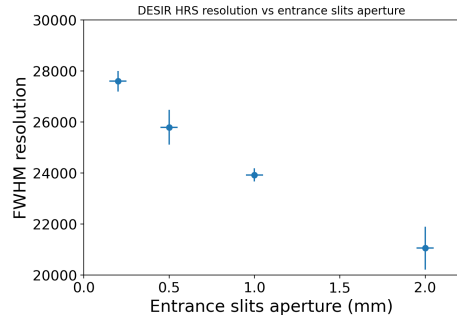


Figure 5: Resolution of the HRS measured as a function of the initial slits aperture, at 25keV, for a low energy dispersion ($<1\text{eV}$) and a beam transverse horizontal emittance of $2\pi\text{.mm.mrad}$ (for 1 mm slits aperture).

Preliminary measurements with the contaminant creation technique

We recently developed a contaminant creation technique (see [5]) that consists in using an arbitrary waveform generator to create energy patterns within the same beam, by changing the acceleration potential of the ion source. We showed that the use of square signals allows to populate discrete energies (i.e. masses) in the same beam, with custom energy and intensity ratios. By applying an arbitrary noise to the voltage steps of the signal, one can control the energy spread of the sub-beams. Figure 6 shows the evolution of the HRS resolution as a function of the beam energy spread, within the range expected for the DESIR facility (1-3 eV at 30keV).

We observe a fast decrease of the resolution when increasing the energy spread, but no particular in-

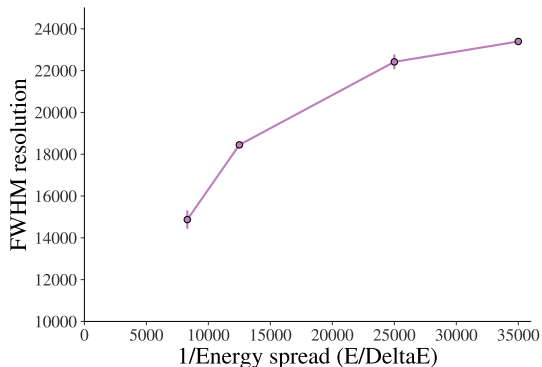


Figure 6: HRS FWHM resolution as a function of the beam energy spread. The energy spread was introduced by adding a noise on the acceleration voltage by means of an arbitrary waveform generator in the acceleration chain.

crease of the resolution when lowering the energy spread, leading to an asymptotic behavior towards the maximal HRS resolution.

This recent contaminant creation system opened the way to many possible studies, and the possibility to test the HRS in (almost) real DESIR operating conditions, but with a stable beam and relatively high intensities. One interesting case of DESIR-like beam purification is the separation of the ^{100}Sn and the ^{100}In singly-charged ions, whose mass difference is equal to $\Delta M/M_0 = 1/13157$. Figure 7 shows the measured beam separation of two beams with $\Delta E/E_0 = 1/13157$ and a relative intensity of 1/200 obtained by adapting the duty factor of the square signal.

This preliminary measurement shows that even if the HRS has the resolving power to separate such isobars, high intensity differences will make their separation more complicated. Even though, part of the beam of interest can be sacrificed with the exit slits to remove the majority of the contaminant, and the beam sent toward a higher-level purification device such as the PIPERADE [6] double Penning trap device of the DESIR facility.

Summary

We show in this paper the behavior of hexapolar and octupolar aberrations on the beam shape, and their consequences on the final resolution of the HRS. By means of a 48-pole electrostatic multipole located in the center of symmetry of the spectrometer, we are able to correct such aberrations and obtain near-Gaussian final beams. We also show a

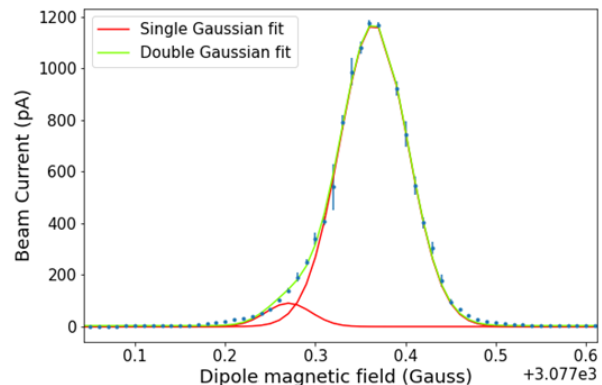


Figure 7: Experiment aiming to separate ^{100}Sn from its energy-equivalent contaminant ^{100}In . Instead of a mass difference, the equivalent energy difference was created by slightly changing the acceleration potential of the ions with an arbitrary waveform generator.

measurement of a beam emittance in the presence of hexapolar aberrations. The second part of the paper is dedicated to resolution measurements. We show the best achieved beam separation alongside with a preliminary test of a difficult separation expected for DESIR. The effect of an energy spread of the beam, and the effect of the entrance beam size on the resolution are also investigated.

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