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COMMISSIONING OF THE DESIR HIGH-RESOLUTION SEPARATOR AT CENBG

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Abstract

DESIR is the low-energy part of the SPIRAL2 ISOL facility under construction 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 multipole on the mid plane.

The HRS is now completely mounted at CENBG and under commissioning for the next 2 to 3 years before its transfer at the entrance of the DESIR facility. The objective is to test, characterise and correct all HRS elements contributing to the higher order aberration by performing experimental measurements and comparing them with the results from different simulation tools. The recently mounted pepperpot-type emittance-meter will allow us to observe the emittance figures and dynamically tune the multipole to improve the optical parameters of the HRS.

We will present the first results concerning the hexapolar correction with the multipole, the associated emittance measurements and the resolution currently achieved.

INTRODUCTION

The High-Resolution Separator (HRS) is a magnetic mass separator whose main objective is to separate isobars for high-intensity beams with a resolution R = 20000. In addition to this high resolution, the HRS should have a high transmission (ideally close to 100% for a 1 π mm mrad emittance), match the beam emittance from the RFQ cooler SHIRaC ($\epsilon < 3$ mm mrad , $\Delta E < 1$ eV at 60 keV) and have a compact configuration. The HRS will be located at the entrance of the DESIR hall and will purify the beams from the S3 and SPIRAL1 facilities to send it to the DESIR hall where it can be:

- sent directly to the experiments
- cooled and bunched by the GPIB
- further purified using Piperade (a double Penning trap system)

The design of the HRS has been described by T. Kurtukian Nieto *et al.* [1], inspired by the CARIBU HRS at Argonne National Laboratory and gives a maximal resolving power of 31000 for 1 π mm mrad emittance. By integrating the maximal tolerance on the misalignment of the different optics modules into the simulations, it has been shown that the mass resolution decreases to ≈ 20,000 for the worst case.

Figure 1 represents the HRS with its associated elements in the symmetric configuration MQ-MQ-FS-FQ-D-M-D-FQ-FS-MQ-MQ with:

- D : 90° magnetic dipoles with 36° entrance/exit angles. These elements provide the mass separation with an intrinsic mass dispersion of 31 cm/% for the HRS.
- MQ : matching quadrupoles. A pair of electrostatic quadrupoles with opposed polarity.
- FQ : focusing quadrupoles that makes the beam diverge horizontally and converge vertically. The beam envelope should occupy the entire dipole magnet acceptance to maximize mass dispersion.
- FS : electrostatic focusing sextupoles.
- M : electrostatic multipole. This is a 48 rods multipole placed in the mid-plane of the HRS that will be used to correct aberrations up to the 5^{th} order.

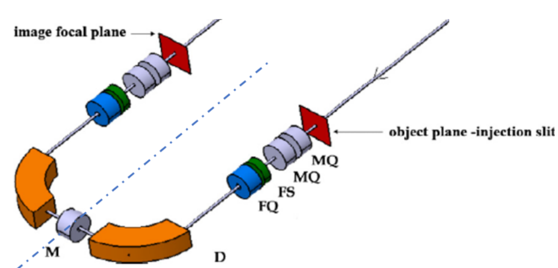

Figure 1: Optical layout of the HRS.

All the optical elements except the dipoles are fully electrostatic so that their effect is independant of the mass.

TOOLS CHARACTERISATION FOR COMMISSIONING

The HRS is now mounted and under commissioning at CENBG (Fig. 2).

A test bench has been built in 2020 in order to caracterise the principal tools that will be used for the commissioning: a ^{133}Cs ion source and a pepperpot-type emittance-meter.

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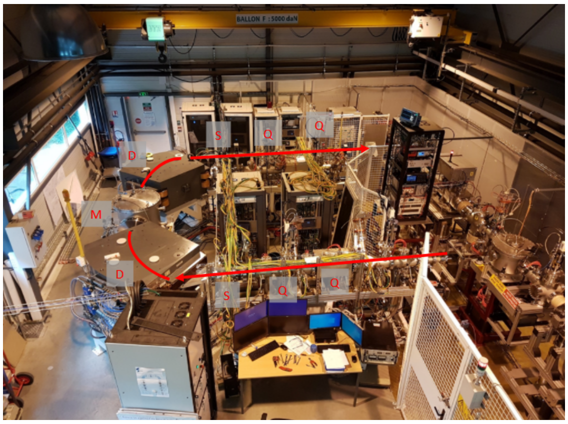

Figure 2: Picture of the HRS mounted at CENBG.

Caracterisation of the Ion Source

The HRS ion source is a KIMBALL ^{133}Cs ion source (0-5 keV) coupled with a high-voltage supply (0-25 kV) and extraction electrodes providing a mono-isotopic stable beam.

As the aberrations of the HRS will modify the emittance figure of the beam, it is necessary to understand what is injected in the object plane of the HRS, in order to compare and correct the emittance figure and the aberrations.

We compared experimental emittances for different working points of the source to SIMION simulations and found a very good qualitative (shape of the emittance figure) and quantitative (value of the emittance area) agreement. Figure 3 shows the comparison between an experimental and a simulated emittance as well as the simulated ion source image.

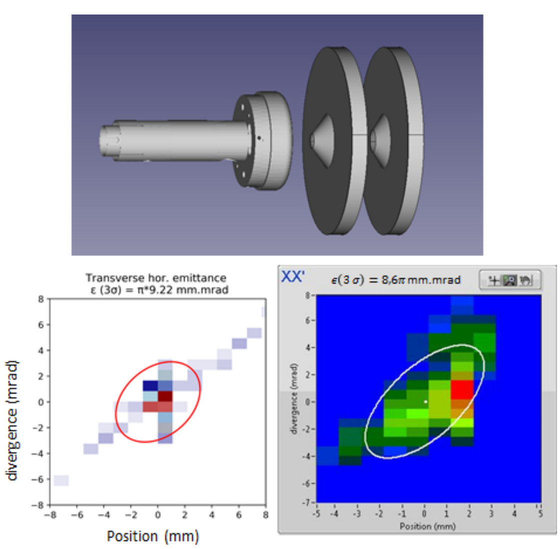

Figure 3: Comparison between simulated and measured beam XX' emittance. Bottom-left: simulated XX' emittance with SIMION. Bottom-right: measured beam XX' emittance. Top: picture of the simulated source.

We measured a few working points of the source for reference and validated our SIMION model before installing the source on the HRS.

Emittance-meter

The emittance-meter that has been choosen for the commissioning of the HRS is a Pantechnik pepperpot-type emittance-meter with a 1 mm step and 20 µm holes. Its mask is a 40 holes vertical band that can be moved in the horizontal direction to scan the beam emittance horizontally. In that way, horizontal pile-up can be avoided, even with a highly-diverging beam.

We implemented with success an emittance reconstruction and analysing software and used the Pantechnik integrated software for benchmark. Doing so, we caracterised the emmitance-meter by understanding and correcting all its hardware parameters (holes size, spacing, MCP distance to mask...) and reconstruction parameters (angle reconstruction, pile-up, image treatment...).

This implementation now allows us to directly work on the raw emittance data and proceed to more advanced analyses such as multi-order aberrations detection in emittance figures and potentially tune the multipole in a dynamic way.

BEAM TRANSPORTATON AND CORRECTION

0th and 1st Orders Transport

As an online separator, the HRS should have a high beam transmission (ideally close to 100%). The first orders of beam transport are now validated. The calibration of the dipoles with RMN probes now allows us to transport the beam at 0th order and their control command is now complete. The quadrupoles of the line have been wired and checked. The new pair of profilers in the multipole chamber will allow us to monitor the effect of the two focusing quadrupoles to maximize the beam size in the dipoles, and assure a good 1st order transport. The simulated values for the quadrupoles gives a maximal 1st order transmission in the HRS.

2nd Order Aberrations

Still, the 1:1 transmission in the HRS is not achieved and higher-order aberrations (mainly hexapolar) lead to a higher beam size on the final slits. Figure 4 shows a comparison between the simulated (COSY [2] and Zgoubi [3]) and measured 2nd order aberrations on the XX' emittance figure at the end of the HRS.

We can observe a "boomerang-shape"on the XX' emittance figure that might come from the hexapolar aberration of the dipoles. The agreement with the simulation confirms this hypothesis. This aberration shape can be corrected to a more elliptical shape by applying an hexapolar correction in the multipole, hence reducing the final beam size and increasing the resolution. This correction can be quantified by observing the diminution of the ellipse-fitted area in

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the emittance figure, that is no more over-estimated by the aberration tails.

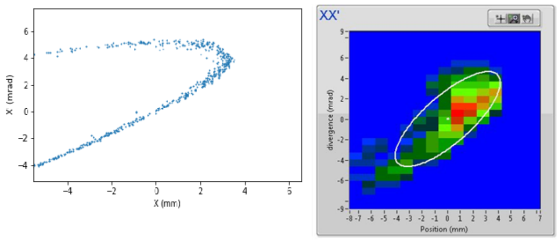

Figure 4: Comparison of the simulated (left) and measured (right) beam emittance at the end of the HRS. This have been simulated with COSY and confirmed by Zgoubi. This figure has been obtained by turning off the last doublet of quads in the beamline so that the beam is large enough to be measured. The tail on the left of the simulated emittance also disappears when a binning and a threshold are applied on the simulated data as for the experimental data.

PRELIMINARY : RESOLUTION MEASUREMENTS

In parallel to the aberration correction, we managed to run a few resolution tests. As the source is mono-isotopic, we can not measure two beams with close masses. However, the transfer functions of the spectrometer are identical for the $\frac{\Delta M}{M}$ term and the $\frac{\Delta E}{E}$ term, so we can estimate the resolution of the HRS by measuring two beams with close energies.

Figure 5 shows the separation of two beams with a $\frac{\Delta E}{E} = 1/5000$ separation in energy.

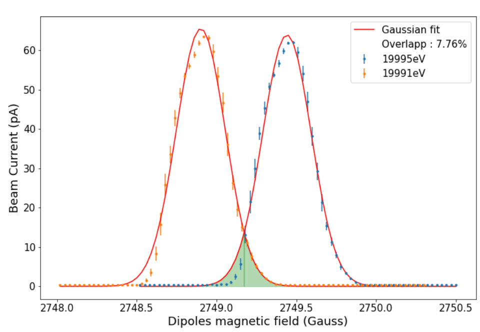

Figure 5: Separation of two beams with a close energy ($\frac{\Delta E}{E} = 1/5000$). The beams have been separately scanned with the dipoles through the final slits of the HRS, and their intensity monitored with the Faraday cup right after the slits. A Gaussian fit of the beams gives the beam separations and their respective standard deviation, leading to an estimation of the resolution.

From this separation ($\Delta\mu = 0.54$) and the associated standard deviations ($\sigma = 0.15$), we deduced a (*preliminary*) resolution for the HRS of $R \approx 7516$ FWHM or ≈ 7225 at 95% confidence level (2.45σ).

This resolution has been obtained for a preliminary hexapolar correction but no other higher order corrections. In the near futur, we will use the analysing software developed at CENBG to optimize the hexapolar correction of the HRS with the multipole and also include higher order corrections such as octupolar, decapolar and duodecapolar corrections.

We also showed recently that the high-voltage plateform oscillations add a non negligible value of $\frac{\Delta E}{E}$ to the beam, hence reducing the measured resolution of the HRS. A new high-voltage supply recently added to the source should help to increase the resolution of the HRS in the near future.

CONCLUSION

Through the development of a test bench, we managed to characterise both the ion source and the emittance-meter that should be used for the commissioning of the HRS. We now have a few known working points for the ion source and the tools to reconstruct and analyse emittance data from the emittance-meter. The commissioning of the HRS itself started one year ago. Many instruments and diagnostics (RMN probes, profilers, slits, multipole...) have been calibrated, realigned and implemented in the control system. Emittance measurements were done through the entire commissioning process and showed a real improvement in our understanding of the machine and the beam. The hexapolar aberration of the line has been measured and confirmed by simulations and its correction with the multipole is under study at the moment. Also, a first estimation of the resolution of the machine (1 mm beam, emittance of few mm mrad) leads to a resolving power (FWHM) of $R \approx 7500$. This resolution is preliminary and can be improved by applying additional correction (octupole, decapole... up to the 5^{th} order) and reducing the initial $\Delta E/E$ of the beam.

In the near future, it is planned to reshape the entrance poles of the dipoles to naturally correct the main part of the hexapolar aberration introduced by the dipoles.

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