TRANSVERSE EMITTANCE MEASUREMENTS OF THE REX-ISOLDE BEAMS IN PREPARATION FOR THE HIE-ISOLDE COMMISSIONING

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Abstract

The transverse emittance at the output of the REX-ISOLDE normal conducting linac has been measured at different energies in order to characterise the beam at injection to the future HIE-ISOLDE superconducting linac. The measurements were done with low intensity stable beams in order to avoid compensation effects in the electron beam ion source (EBIS) and obtain representative measurements of the radioactive ion beam emittance. Emittances were measured using a slit-grid emittance meter and compared with results obtained with a quadrupole-scan (three-gradient) method. An analysis of the background suppression is presented and possible source of errors for both type of measurements are discussed.

INTRODUCTION

REX-ISOLDE is operational since 2001 and has been delivering radioactive ion beams (RIB) at energies up to 3 MeV/u for a large physics programme [1]. With the extension of the charge-breeding performance for ions with large A and the increasing number of isotopes available at ISOLDE, an energy upgrade was necessary to make full use of the available beams. The new High Intensity and Energy (HIE-ISOLDE) superconducting linac will be installed downstream the existing linac and extend the energy range to 5.5 and eventually 10 MeV/u for ions with mass-to-charge ratios below 4.5 keeping full flexibility and improving the beam quality [2] [3]. The accurate measurement of the transverse emittance of the accelerated beams is essential to assess the performance of the linac and the quality of the delivered beams. It is also a key parameter for the design of the HIE-ISOLDE linac.

Due to the low intensity nature of the RIBs typically accelerated at REX-ISOLDE, a stable pilot beam extracted from the rest gas of the EBIS charge breeder is normally used to set-up the linac. These beams have a typical intensity of 10-100 epA and should represent well the beam characteristics of the charge-bred beams. The stable beam intensity can be increased by injecting gas directly in the electron beam region of the source but this has the disadvantage of degrading the EBIS beam emittance through electron beam compensation. For this reason the beam intensity was practically limited to 500 epA – 1000 epA which is very challenging for the classical slit-grid emittancemeter employed here. For this reason a number of steps were taken to ensure that the effect of background data point and offsets were appropriately treated. The results were also compared with emittance measurements obtained with alternative methods in particular a quadrupole scan method.

MEASUREMENTS AND DATA TREATMENT

The transverse emittances were measured with a commercial slit-grid emittance-meter (NTG Neue Technologien GmbH, Germany) with a slit of 0.2 mm width separated from the grid by a 1 m drift distance. The grid is made of two sets (X and Y) of 30 wires 0.2 mm in diameter with 2 mm spacing. The minimum step size of the slit is 10 µm and the grids can be moved in steps of 250 µm to improve the angular resolution.

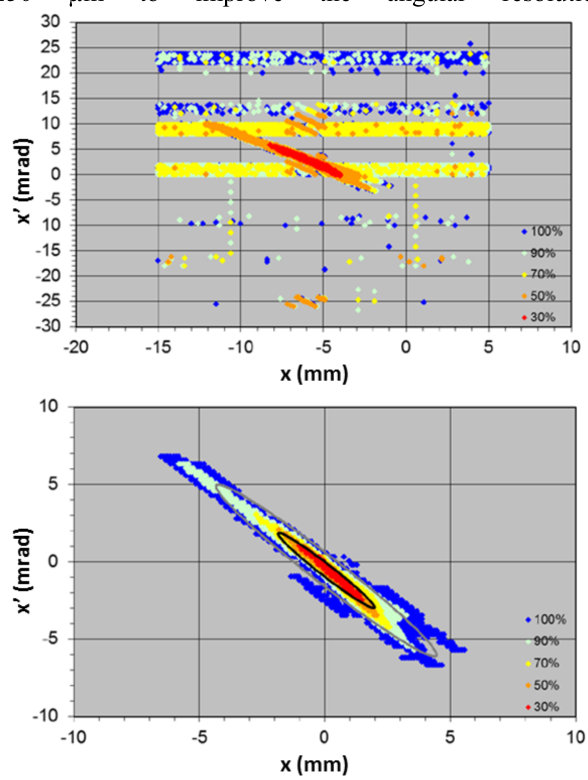

Figure 1: Emittance scan of a 2.85 MeV/u beam of Ne5+, raw data (top), emittance plot after background suppression (bottom)

The emittance-meter was placed downstream the normal conducting linac. Beams of mass to charge ratio equal to 4*, either Ne5+ from the EBIS rest gas or He+ from gas injection, were used. The beams had a repetition

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* The REX-ISOLDE linac can accelerate beams with A/q in the range 2-4.5

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rate of 20 Hz with a pulse length of typically 100 µs. Emittances were measured at different energies between 0.3 and 2.85 MeV/u.

Even with 1 enA of beam intensity, the maximum intensity collected by a single wire after the slit was of the order of 1 epA. For this reason the signal-to-noise ratio was poor outside the core of the beam. A plot of the raw data is shown in Figure 1, the different offsets of individual wires appears as horizontal bands and due to some software limitations some of the less significant data points are deleted.

Before determining the emittance the background around the beam was clipped and the offset adjusted. To verify the validity of this step some systematic tests were done on the raw data following a similar approach to the one proposed in [4].

In Figure 2 the RMS emittance as a function of bias (fixed offset applied to the full data set) and threshold (values below which data points are ignored) is shown. In all cases the variation of the normalised RMS emittance shows a clear change of slope around 0.04-0.05 mm.mrad which can be interpreted as the point where the effect of the background is correctly cancelled. This value is in good agreement with the value of 0.049 mm.mrad obtained after arbitrarily clipping the phase space area outside of the beam.

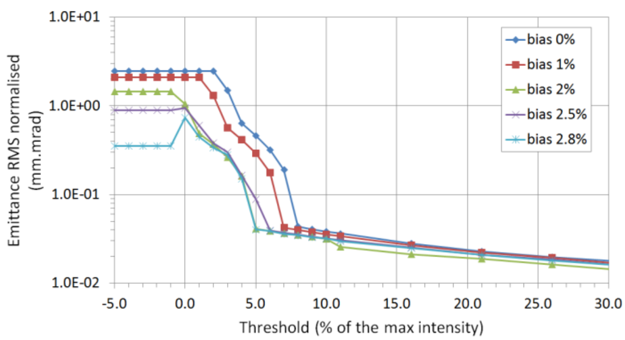

Figure 2: Emittance value calculated with the full data set for varying bias and threshold

QUADRUPOLE SCAN METHOD

In order to verify the results a measurement with an independent method - quadrupole-scan method - was attempted. This has the advantage of not requiring the use of a slit, which is advantageous for low intensity beams, and is also much faster which makes it attractive for online measurements. The quadrupole-scan method is described in [5] and the measurement principle is outlined below.

The beam can be represented by the σ-matrix:

$$\sigma = \begin{pmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{pmatrix} = \begin{pmatrix} \beta\epsilon & -\alpha\varepsilon \\ -\alpha\varepsilon & \gamma\epsilon \end{pmatrix}$$

where $\det(\sigma) = \epsilon^2$. The beam downstream a beam line can be calculated from the R-matrix representing this beam line and the σ-matrix representing the input beam: $\sigma^{(2)} = R\sigma^{(1)}R^T$. For a thin lens followed by a drift d the R-matrix will be:

$$R = \begin{pmatrix} 1 & d \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ -1/f & 1 \end{pmatrix} = \begin{pmatrix} 1-d/f & d \\ -1/f & 1 \end{pmatrix}$$

and the σ_{11} element can be written explicitly taking $f = 1/kl$ where l is the quadrupole length:

$$\sigma_{11}{}^{(2)}(k) = \left(d^2 l^2 \sigma_{11}{}^{(1)}\right)k^2 - 2\left(dl\sigma_{11}{}^{(1)} + d^2 l\sigma_{12}{}^{(1)}\right)k + \left(\sigma_{11}{}^{(1)} + 2d\sigma_{12}{}^{(1)} + d^2\sigma_{22}{}^{(1)}\right)$$

This yields a second order equation in k: $\sigma_{11}{}^{(2)}(k) = ak^2 + bk + c$.

The σ-matrix element can be calculated for the RMS ellipse from the distribution's second moments and in particular we have: $\sigma_{11} = \langle x^2 \rangle$. Thus from a set of beam profile downstream the quadrupole, recorded for different focussing strength k, one can calculate the σ-matrix element and emittance of the RMS beam at the entrance of the quadrupole by fitting $\sigma_{11}{}^{(2)}(k)$ with a parabola.

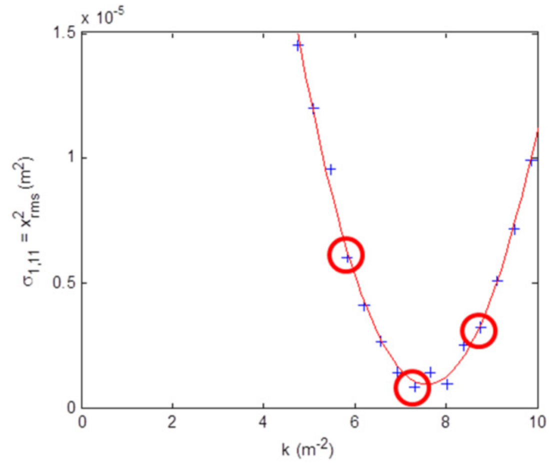

Figure 3: $\boldsymbol{\sigma_{11}}$ as a function of normalised quadrupole gradient $\boldsymbol{k}$

In Figure 3 $< x^2 >$ is plotted as a function of the normalised quadrupole gradient k and fitted with a parabola. For optimal resolution, the measurement should sample points around the beam waist, close to the minimum of the parabola. Three points for which an emittance scan was taken are marked with circles. Figure 4 shows the corresponding emittance scans drifted 1 m to the position of the grid, which clearly illustrate the bunch rotation as the beam goes through the waist.

The emittances measured with the quadrupole-scan method were found to be three to four times larger than the ones measured with the slit-grid method; this is true for both energies and for the two planes. See Table 1. The discrepancy can be explained either by an error on the profile measurement or due to the intensity limitation of the slit-grid method which could lead to an underestimation of the beam intensity in the tails of the distribution where the background is significant. A comparison of the profile reconstructed from the emittance data and the profile measurement seems to contradict this hypothesis. This should be confirmed by an independent measurement of the beam profile which unfortunately was not available at the time.

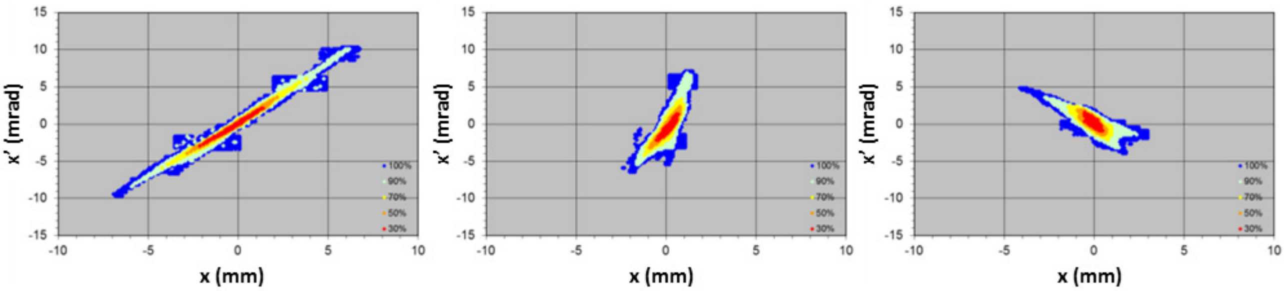

Figure 4: Horizontal beam portraits for different quadrupole magnet settings

Table 1: Summary of the results obtained with both methods

Energy (MeV/u)	Plane	Method	ε^n_{RMS} (mm.mrad)	Ratio
2.85	X	Quad-scan	0.210	4.1
		Slit-grid	0.052	
	Y	Quad-scan	0.230	4.2
		Slit-grid	0.055	
0.30	X	Quad-scan	0.140	4.4
		Slit-grid	0.032	
	Y	Quad-scan	0.060	3.0
		Slit-grid	0.020	

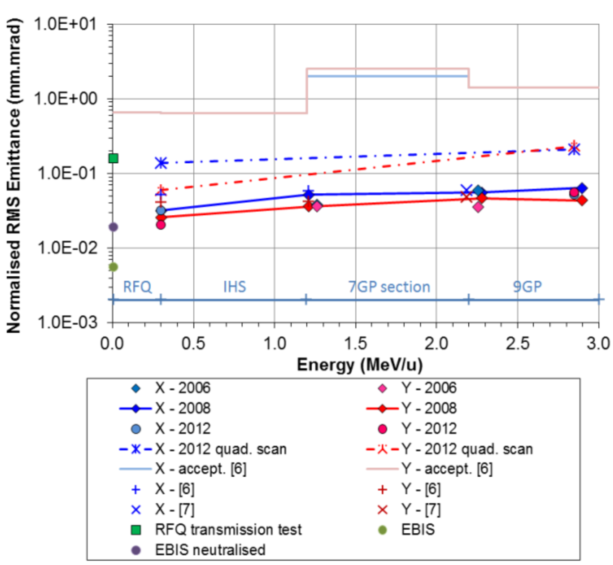

Figure 5: Summary of transverse emittance measurements at REX-ISOLDE. Design emittance and measurements from the REX-ISOLDE commissioning are shown for comparison **[6]** **[7]**. The geometrical acceptance is also indicated.

CONCLUSION

The transverse emittance measurements obtained at REX-ISOLDE are plotted together in Figure 5 with some of the values used in the REX-ISOLDE design studies. The linac acceptance and the energy after each section are also indicated. The data obtained with the slit-grid emittance-meter are fairly consistent and in good agreement with the values used in the REX-ISOLDE linac design studies. As discussed above the values obtained with the quadrupole-scan method are two to three times larger. The expected emittance from REXEBIS simulations is almost one order of magnitude lower; however this can be partly explained by the EBIS electron beam neutralisation which occurs when large intensities are extracted. An upper limit for the linac input emittance based on RFQ transmission test is also indicated. From this work two conclusions can be drawn,
1. The emittance values obtained with the 'empirical' background deletion method are in reasonable agreement with values obtained through a more systematic approach,
2. Although the results obtained with the quadrupole-scan method are in disagreement with the ones obtained with the slit-grid emittance meter, it is a promising technique for future emittance measurements at HIE-ISOLDE as it can be used with lower intensity beams which are more representative of the RIB emittance.

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