ROSE, MEASURING THE FULL 4D TRANSVERSE BEAM MATRIX OF ION BEAMS

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ABSTRACT

A ROtating System for Emittance measurements ROSE [1], to measure the full 4 dimensional transverse beam matrix of an ion beam has been developed and commissioned. Different ion beams behind the HLI at GSI have been used in two commissioning beam times. All technical aspects of ROSE have been tested, ROSE has been benchmarked against existing emittance scanners for horizontal and vertical projections, and the method, hard-, and software to measure the 4D beam matrix has been upgraded, refined, and successfully commissioned. The inter plane correlations of the HLI beam have been measured, yet as no significant initial correlations were found to be present, controlled coupling of the beam by using a skew triplet has been applied and confirmed with ROSE. The next step is to use ROSE to measure and remove the known inter plane correlations of a uranium beam before SIS18 injection.

MOTIVATION

Usually just separated measurements of two-dimensional x-x′ and y-y′ sub phase-spaces (planes) are measured, as for simplicity correlations between the two planes, i.e. x-y, x-y′, x′-y, and x′-y′ are often assumed as zero. However, such inter-plane correlations may be produced by non-linear fields such as dipole fringes, solenoids, and tilted magnets or just by beam losses. Figure shows the simulation of a coupled and an uncoupled beam with initially identical projected horizontal and vertical rms-emittances though a solenoid channel. This illustrates the fact that initial coupling influences the final horizontal and vertical beam size.

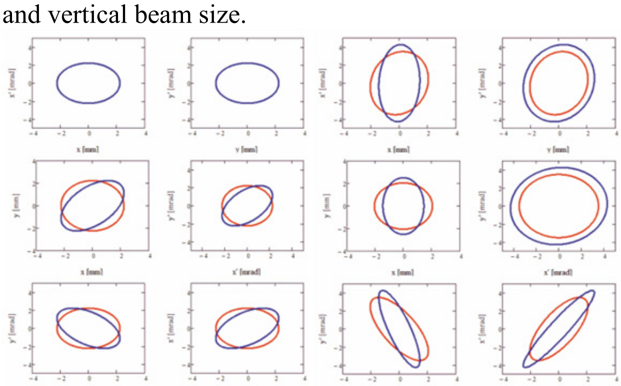

Figure 1: Simulation of an initially uncoupled (red) and coupled (blue) ion beam (left) through a solenoid channel (right).

For some applications, like to match the round transverse phase space of a Linac beam to the flat acceptance of a synchrotron [2], inter-plane correlations are a prerequisite. And in order to remove correlations that do increase the projected rms-emittance, they must be quantified by measurements. This applies especially if space charge effects are involved as they cannot be calculated analytically.

ROSE PRINCIPLE

ROSE is a standard slit grid emittance scanner using only one measuring plane which is rotatable around the beam axis. In combination with a magnetic doublet it allows to determine the full 4d beam matrix C Eq. (1) in approximately one hour with a minimum of four emittance measurements at three different angles [3].

$$C = \begin{bmatrix} XX & XX' & XY & XY' \\ X'X & X'X' & X'Y & X'Y' \\ YX & YX' & YY & YY' \\ Y'X & Y'X' & Y'Y & Y'Y' \end{bmatrix} \tag{1}$$

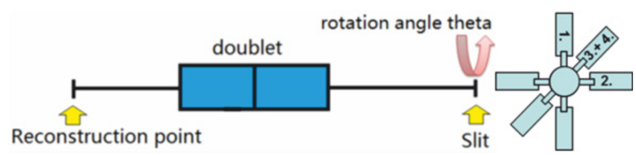

Figure 2: To obtain the beam matrix C at the reconstruction point all four emittance values are measured using ROSE behind a magnetic doublet.

As shown in Figure the emittance measurements are done using a magnetic setting a for the 0°, 45°, and 90° measurement and another magnet setting b for the 45° measurement. A minimum of four measurements is sufficient to measure the complete four-dimensional second-moments beam matrix.

1. 0° doublet setting a
2. 90° doublet setting a
3. + 4. 45° doublet setting a and b

The method of ROSE is described in detail in [3].

ROSE DETECTOR

A technical drawing of the ROSE detector is shown in Figure. The two ports to house the slit and grid mechanics are on opposite sides of the rotating chamber to minimize the torque. The turbo molecular pump is mounted on a separate vacuum chamber that does not rotate. Two gate valves are limiting the setup to easily separate ROSE from the accelerator vacuum for maintenance. The slit and grid geometry is shown in Figure 4. The spatial resolution is given by the slit width of 0.2 mm, while the angular resolution is 3 (0.3) mrad (with up to 9 intermediate grid steps). Figure shows the stepper motor used to rotate the chamber and an encoder to determine the rotation angle with a precision better than half a degree. The disc brake is used to stabilize the chamber during the emittance measurement. And a detailed view of the used rotation flanges.

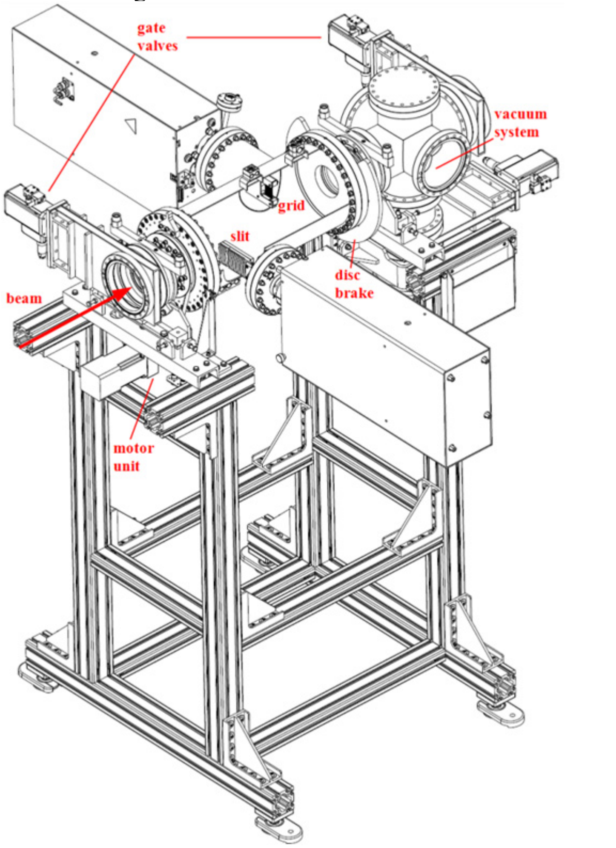

Figure 3: The ROSE detector system

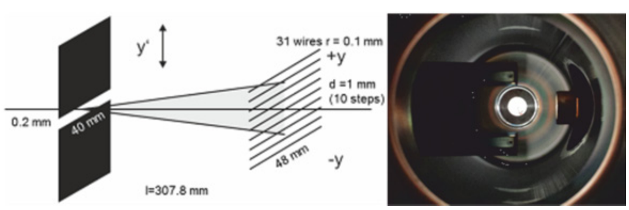

Figure 4: Schematic figure and photo of the slit and grid.

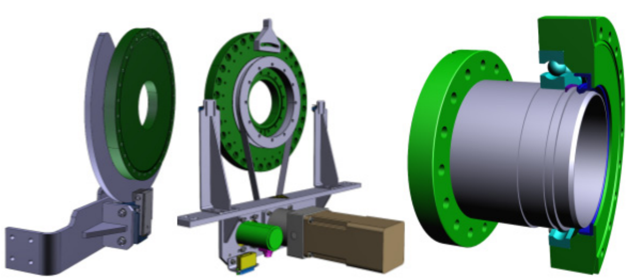

Figure 5: Technical drawing of the disc brake, motor unit and rotation flanges (left to right).

OFFLINE COMMISSIONING

At first the hardware, the control system, and the evaluation software have been tested without beam. Yet commissioning of the vacuum system was of main concern as rotary shaft seals have been used instead of commercially available rotation flanges with differential pumping stages. In a first attempt dry seals have been used. But already after some tens of rotations a strong degradation effect on the seals, as visible in Figure, has been observed. Thus the surface of the rotary shaft has been polished and vacuum grease is now used to minimize friction and to prevent dust from getting between the surfaces.

Figure 6: Damaged seal after some tens of dry turns.

A stationary pressure of 5*10-8 mbar and 1*10-7 mbar during rotation is now routinely reached and no degradation effect has been observed since then.

EXPERIMENTAL SETUP

The beam times used 1.4 MeV/u Ar^{9+} and Xe^{19+} beams from the high charge state injector HLI at GSI served to commission the hard- and software of ROSE, to benchmark it against existing emittance scanners and to proof its capability to measure the 4d beam matrix. To achieve this, an emittance scanner park shown in Figure has been used. It comprises a skew tripled to modify the coupling, a doublet to achieve the different magnetic settings that are required for the measurement, two existing standard emittance scanners Mob-Emi, Mob-Emi extended, and ROSE. Throughout the beamline three current transformers and one end cup are used to measure the transmission.

COMMISSIONG RESULTS

To benchmark ROSE the measured emittance data of the three different devices have been compared by back transformation in front of the doublet for different magnetic settings as shown in Figure.

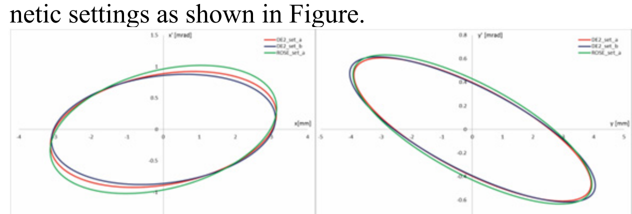

Figure 7: Comparing the horizontal and vertical emittance of a 1.4 MeV/u Ar^{9+} beam in front of the doublet measured with ROSE and existing scanners for different quadrupole settings.

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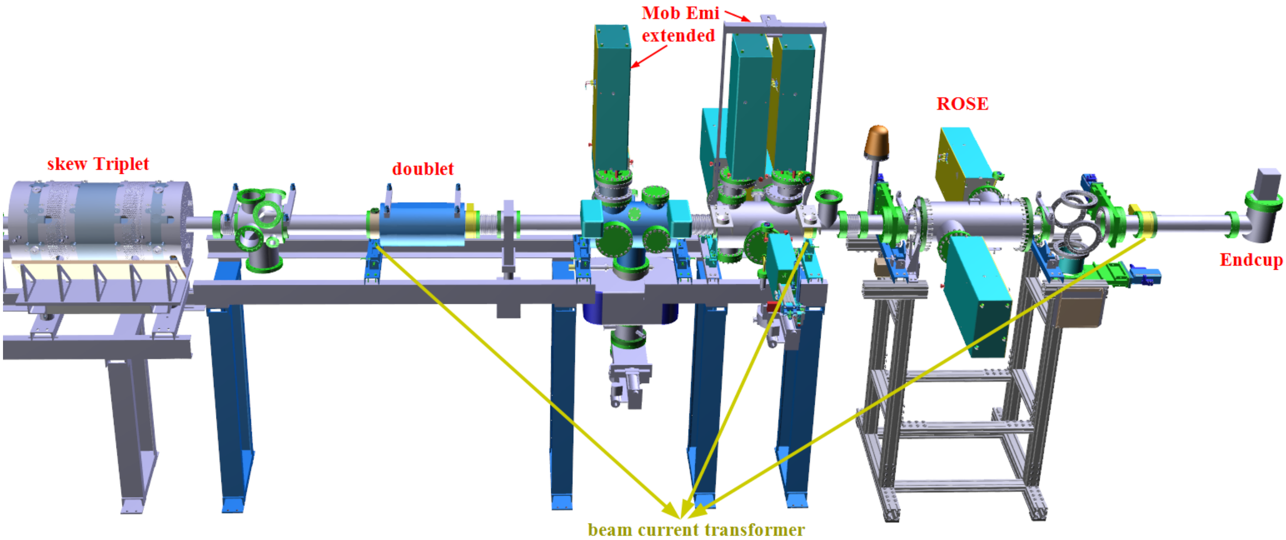

Figure 8: Experimental setup used for the ROSE commissioning.

The measured emittances at 0°≙ vertical and 90°≙ horizontal shown in Figure are in good agreement for all three emittance scanner set-ups. To experimentally prove ROSE's capability to measure the 4d transverse beam matrix the inter plane correlations of the HLI beam have been measured. As no significant initial correlations were found to be present in the HLI beam, controlled coupling of the planes by using the skew triplet has been applied and compared to the uncorrelated beam. Figure shows that the expected effect of the skew triplet has been confirmed with ROSE. As the beam parameters transformed back in front of the skew triplet shown on the left side of the plot match very well, the reliability of the ROSE measurements is experimentally proven.

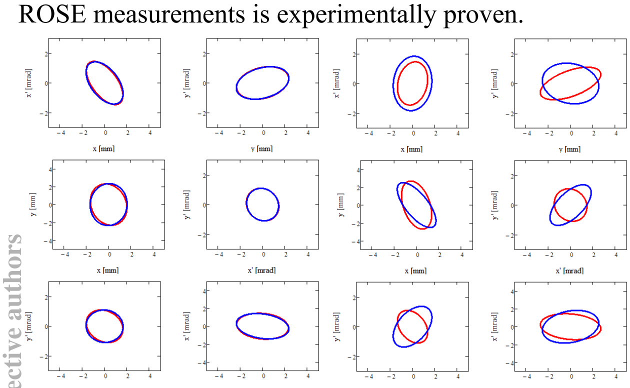

Figure 9: Experimental proof for ROSE capability to measure the 4d beam matrix.

CONCLUSION

ROSE has been commissioned successfully. To our knowledge this is the only device that can measure full 4d ion beam parameters at kinetic energies above 150 keV/u.

OUTLOOK

The next step is to use ROSE to measure inter-plane correlations of a uranium beam before SIS18 injection. In October 2014 emittance scans using the skew triplet [4] have shown an brilliance loss of 75% due to inter plane correlations of the uranium high current beam. With the availability of the 4d detector ROSE the skew triplet shall be used to remove the correlations. ROSE has been set up at the transfer channel and commissioned with He^{1+} beam. Just after this conference the uranium beam time will start.

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