Online retuning of ISAC linac beam with quadrupole scan tomography

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Abstract

The method of tomographic reconstruction has been in use at TRIUMF and elsewhere for several years, allowing for the diagnostic extraction of elements of the beam matrix on-line. One of the more recent applications of the technique at TRIUMF-ISAC consists of using the measured density distribution as the input for a real-time tune re-computation. This technique is advantageous since it does not require installation of dedicated emittance meters but can instead be carried out with existing position monitors. Instead of requiring an operator to manually re-tune quadrupoles in a matching section, which can be time consuming, the method allows for a fast and reproducible means to precisely control the beam and can be proceduralized for use by operators tuning the machine.

Maximum Entropy Tomography

The phase space distribution is assumed to be positive:

$$f(x,y) \geq 0$$

$$\int\int_{\mathcal{D}} f(x,y)dxdy = 1,$$

Projections G_{jm}, acquired by the RPM, provide constraints for the distribution:

$$G_{jm} = \int_{s_0}^{s_1}\int_{t_0}^{t_1} f(s,t)\,ds\,dt,$$

The variables (s,t) are related to (x,y) by a rotation angle:

$$x(s,t) = s\cos\theta_j - t\sin\theta_j$$

$$y(s,t) = s\sin\theta_j + t\cos\theta_j.$$

The entropy of the distribution is:

$$\eta(f) = -\int\int_{\mathcal{D}} f(x,y)\ln[f(x,y)A]\,dx\,dy,$$

The Maximum Entropy Tomography (MENT) algorithm iteratively finds the distribution f(x,y) subject to the constraints G_{jm} imposed by the measured RPM intensity profiles. MENT "yields the image with the lowest information content" and "avoids introducing extraneous information or artificial structure." [1] This method has been used elsewhere at TRIUMF, previously. [2]

Quadrupole Scanning on a Diagnostic

A quadrupole field (electric or magnetic) acting on an ellipsoidal particle distribution in position-momentum phase space is represented by a point-to-point transformation which is area preserving.

A downstream position-intensity diagnostic (RPM, Fig.1) is used to record the beam intensity distribution at a given quadrupole setting.

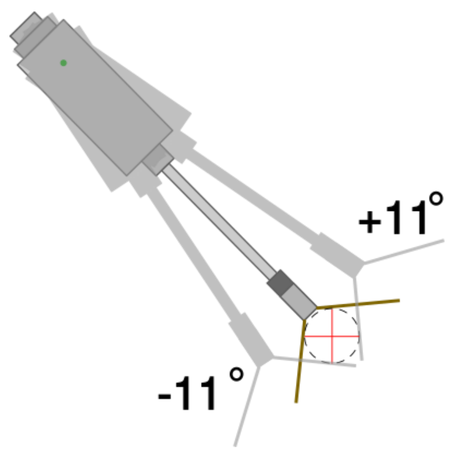

Figure 1: schematic representation of a rotary position monitor (RPM), in use at ISAC. The device record the beam intensity by sweeping back and forth 11° .

Retuning of ISAC-Linac beam

Quadrupole scans performed in the MEBT section [3] of the ISAC linac are used to extract the transverse distribution, without resorting to dedicated emittance meters.

This distribution is in turn fed into the envelope model of the machine, which is used to recompute the tune, whose computed settings are then loaded to the control system [4].

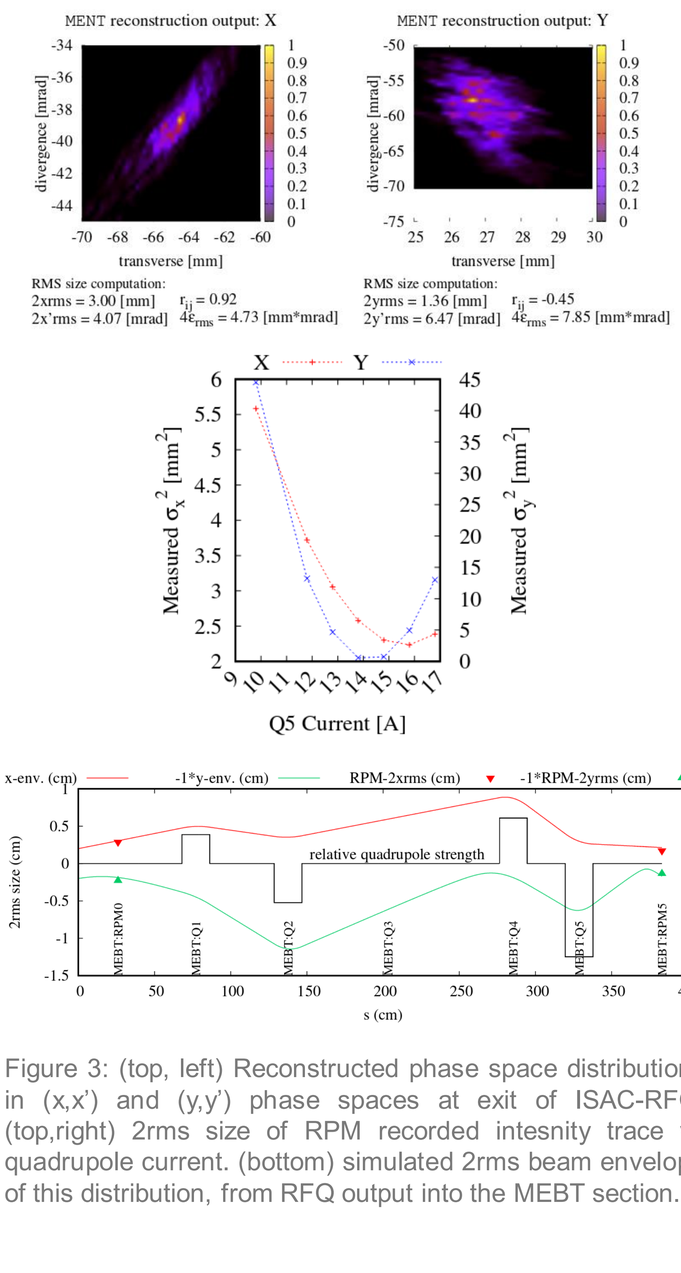

Figure 3: (top, left) Reconstructed phase space distributions in (x,x') and (y,y') phase spaces at exit of ISAC-RFQ. (top,right) 2rms size of RPM recorded intesnity trace vs quadrupole current. (bottom) simulated 2rms beam envelope of this distribution, from RFQ output into the MEBT section.

Since the quadrupole-drift transformation is known, so is its inverse. This connects the measured projections of the distribution to the a priori unknown phase space distribution, at the entrance of the quadrupole.

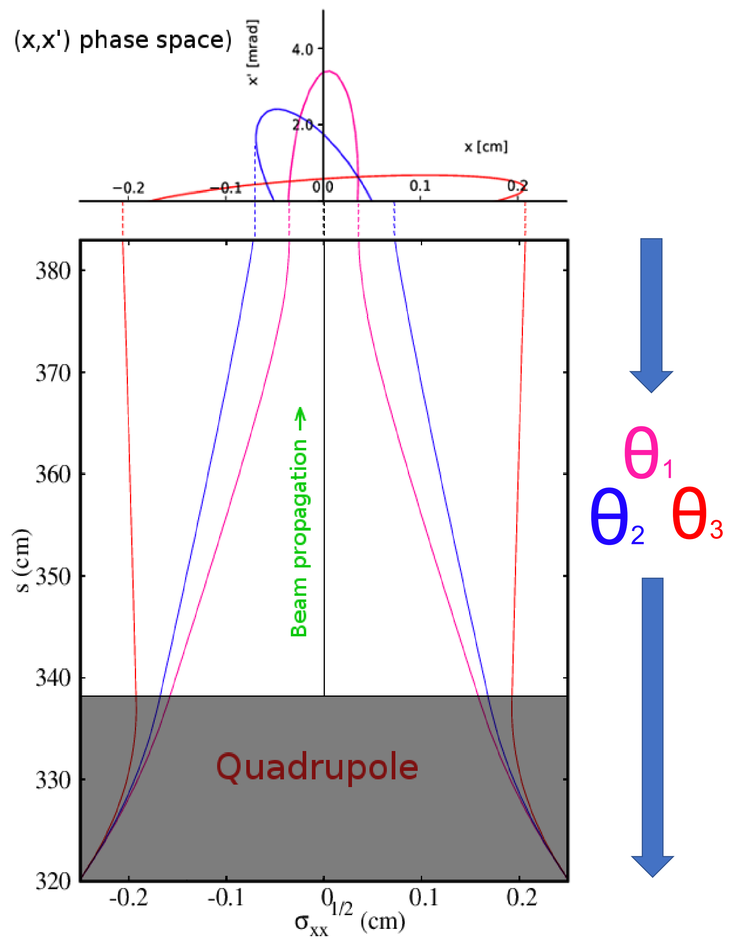

Figure 2: (bottom) transverse 2rms beam containment envelope through a quadrupole + drift. (top) Measured position-intensity distributions at a downstream RPM correspond to the physical length axis projection of the phase space distribution. Each intensity trace has an associated projection angle (θ) connected to the initial distribution.

Conclusion

The method of quadrupole scan tomography provides the means to measure phase space distributions in the ISAC accelerator. This is not only an important tool for machine study, but also for beam investigations related to operation and beam delivery to experiments.

This technique is now in use, along with other measurements, to develop model coupled accelerator tuning (MCAT), which aims to pair the use of an envelope code with on-line measurements.

Bibliography

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[4] – Shelbaya O. Maximum Entropy Tomomgraphy at the ISAC-RFQ, TRIUMF Tech. Rep. TRI-BN-20-12, 2020..