Transverse emittance measurement using a wire scanner in injector of RAON

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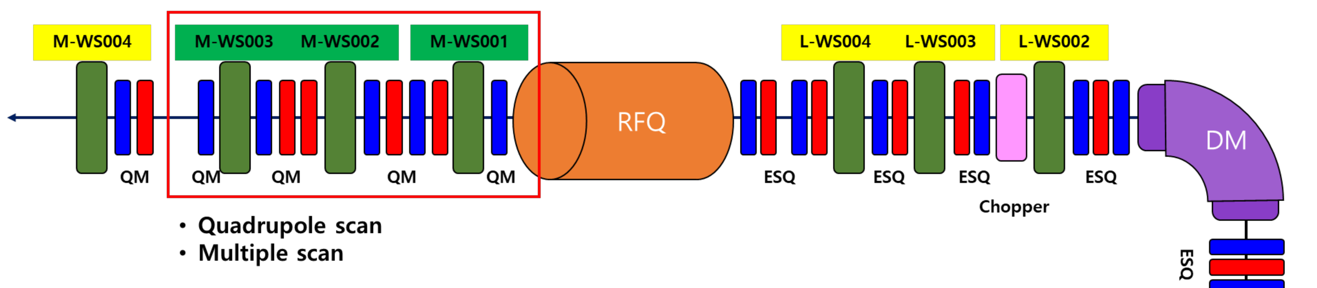
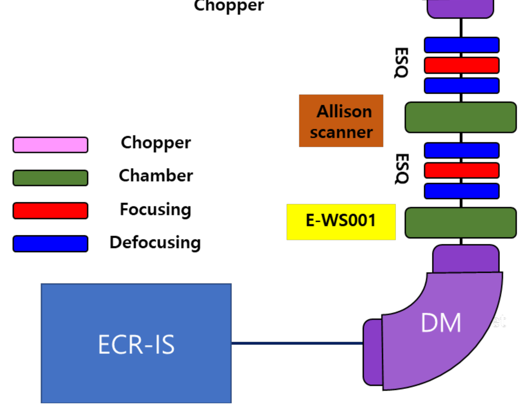
Abstract

The Rare Isotope Accelerator Complex for ON-line Experiments (RAON) is a facility designed to produce rare isotope beams using the ISOL and IF methods. RAON has a variety of diagnostic devices to measure beam characteristics. Among them, emittance is an important parameter in determining beam characteristics. RAON was applied the Multiple scan and Quadrupole scan methods to measure emittance using a wire scanner. These methods of measurement was confirmed through beam generation and transmission simulation at Python. Afterwards, in the beam commissioning, the beam size were measured by 3 wire scanners installed in the MEBT section and the emittance were calculated from the Multi-wire scan and Quadrupole scan methods. This paper presents simulation results and Argon beam emittance measurement results.

Overview



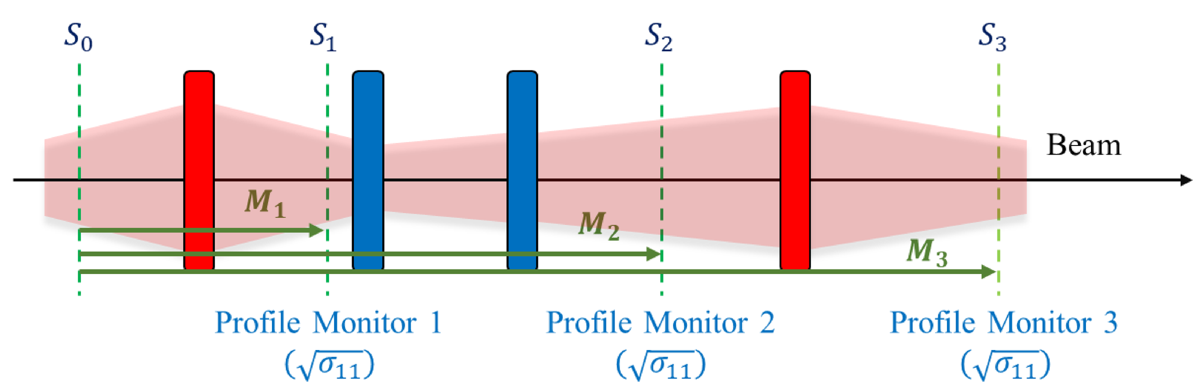
Ion	$^{40}Ar\ 8+$
Energy	500 KeV/u
Current	40 μA



The beam from ECR-IS with energy of 10 keV/u is separated according to A/Q in dipole magnet and emittance is measured at Allison scanner. Then, it passes through LEBT, accelerates to 500 keV/u in RFQ, and transmits through MEBT. There are 4 wire scanners installed in MEBT section, and 3 of them are used to measure emittance in quadrupole scan and multiple scan method.

Measurement Methods

- Multiple Scan



In the drift and quadrupole magnet sections, the transport matrix is:

$$M_L = \begin{pmatrix} 1 & L \\ 0 & 1 \end{pmatrix},\ M_F = \begin{pmatrix} 1 & 0 \\ -K & 1 \end{pmatrix},\ M_D = \begin{pmatrix} 1 & 0 \\ K & 1 \end{pmatrix}$$

L is the transport distance of the beam, and K is the magnet focal strength. At any position the beam matrix is

$$\sum = \begin{pmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{12} & \sigma_{22} \end{pmatrix} \qquad M = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix}, \qquad M^T = \begin{pmatrix} M_{11} & M_{21} \\ M_{12} & M_{22} \end{pmatrix}$$

When the transfer matrix from the measuring position to wire scanner is M, the relationship between beam matrix of wire scanner and measuring point,

$$\sum^{WS} = M \sum^{MP} M^T$$

Considering only the (1,1) term of beam matrix of wire scanner,

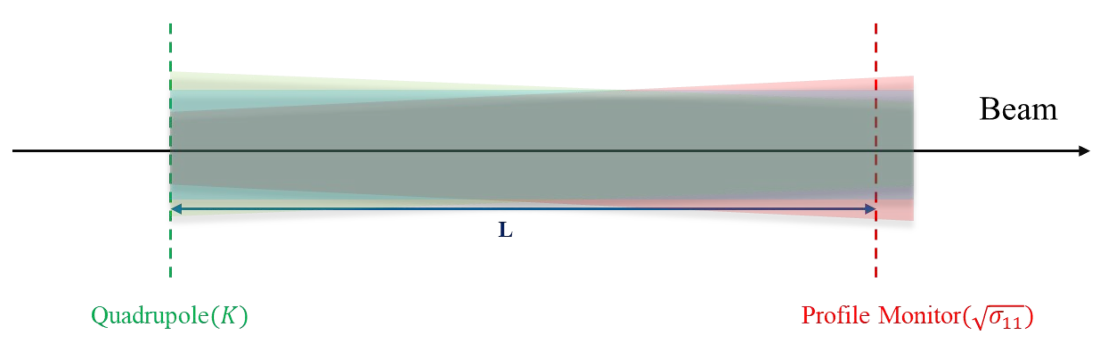
$$\sigma_{11}^{WS} = M_{11}^2 \sigma_{11}^{MP} + (2M_{11}M_{12})\sigma_{12}^{MP} + (M_{12}^2)\sigma_{22}^{MP}$$

By measuring the beam size from three or more wire scanners, a solution ($\sigma_{11}^{MP}, \sigma_{12}^{MP}, \sigma_{22}^{MP}$) can be found through a simultaneous equation system.

So, Emittance is obtained as,

$$\varepsilon = \sqrt{\sigma_{11}^{MP}\sigma_{22}^{MP} - (\sigma_{12}^{MP})^2}$$

- Quadrupole Scan



Considering the transfer matrix from quadrupole magnet to wire scanner,

$$M = M_L M_F = \begin{pmatrix} 1-LK & D \\ K & 1 \end{pmatrix} \qquad \begin{matrix} M_{11} = 1 - LK \\ M_{12} = L \end{matrix}$$

If we rewrite the (1,1) term of Σ^{ws} for K,

$$\sigma_{11}^{WS} = \overbrace{(\sigma_{11}^{QM}L^2)}^{A}K^2 + \overbrace{(2\sigma_{11}^{QM}L + 2\sigma_{12}^{QM}L^2)}^{B}K + \overbrace{(\sigma_{11}^{QM} + 2\sigma_{12}^{QM}L + \sigma_{22}^{QM}L^2)}^{C}$$

By measuring the beam size while changing the magnetic field strength K, we can obtain the coefficients. Then, we obtain the sigma value from the coefficients.

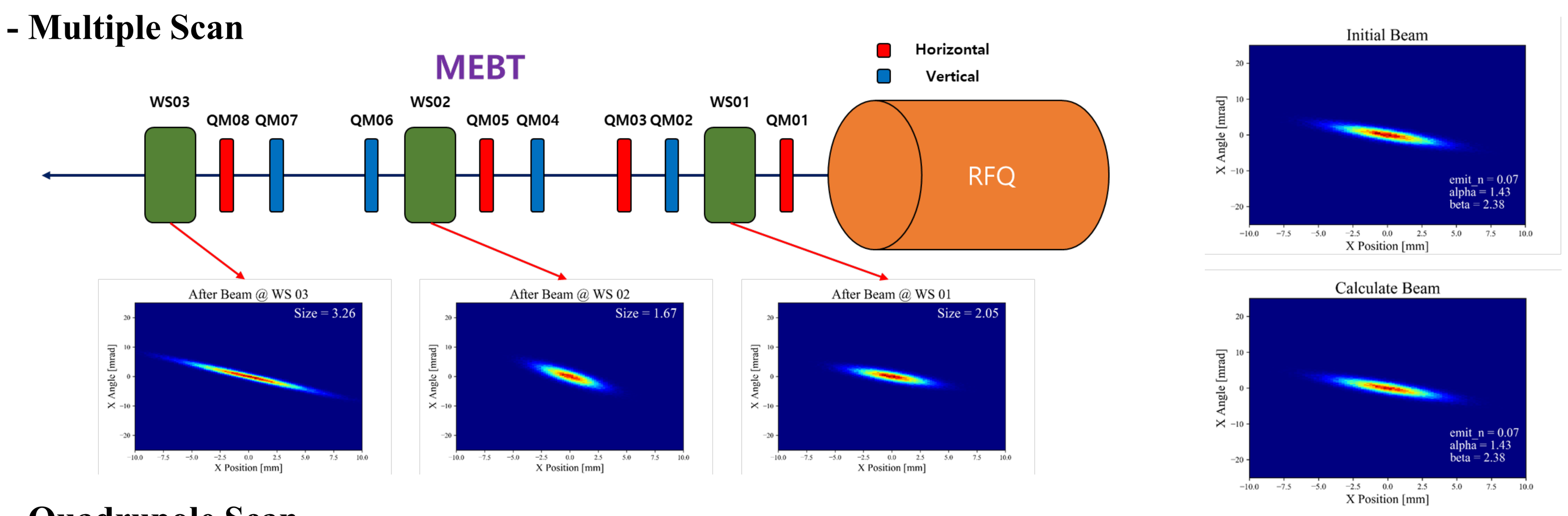
$$\sigma_{11}^{QM} = \frac{A}{L^2} \qquad \sigma_{12}^{QM} = -\frac{B + 2L^2\sigma_{11}^{QM}}{2L^2} \qquad \sigma_{22}^{QM} = \frac{C - \sigma_{11}^{QM} - 2\sigma_{12}^{QM}}{L^2}$$

So, Emittance is obtained as,

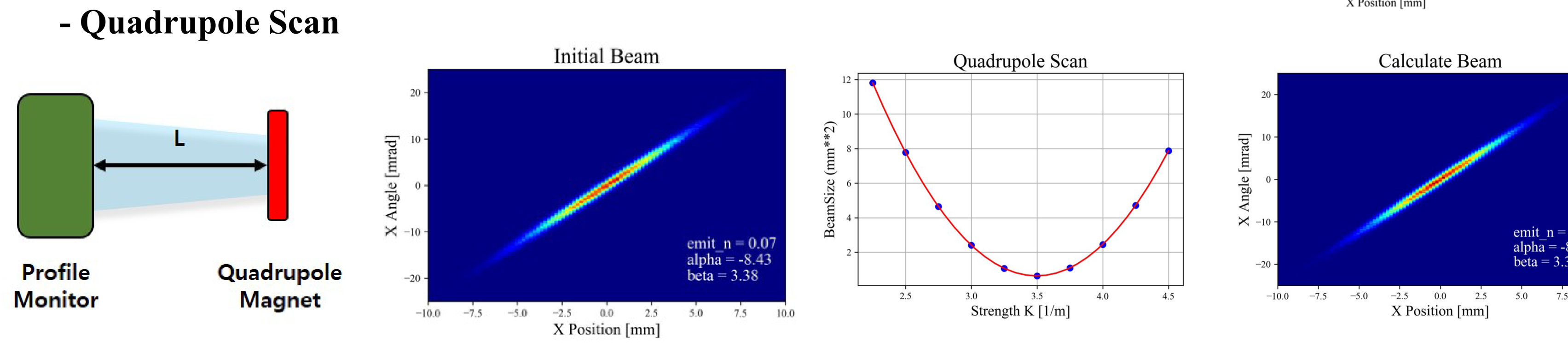
$$\varepsilon = \sqrt{\sigma_{11}^{QM}\sigma_{22}^{QM} - (\sigma_{12}^{QM})^2}$$

Python simulation

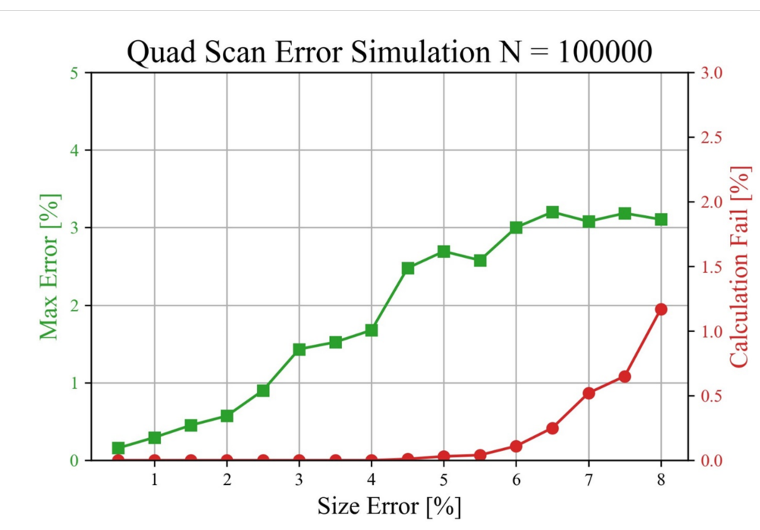
- Multiple Scan

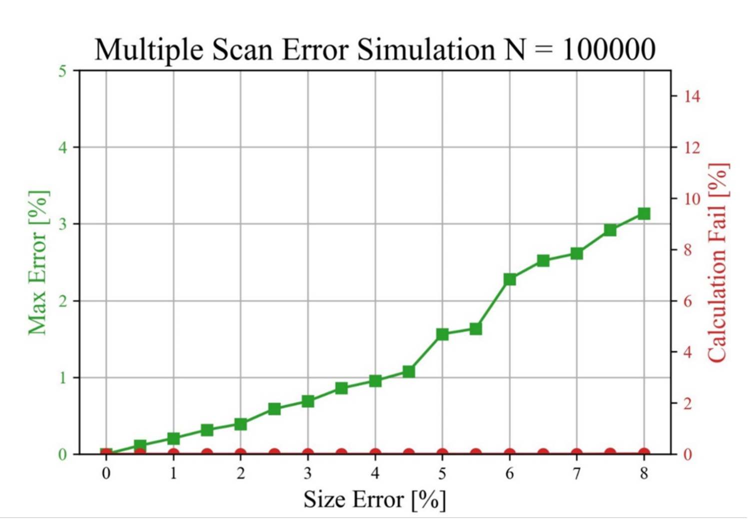


- Quadrupole Scan



To verify the formula in the measurement method, a simulation using Python was performed. After generating a beam distribution, the emittance was calculated using the results after beam transport and it was confirmed that both methods were calculated correctly.

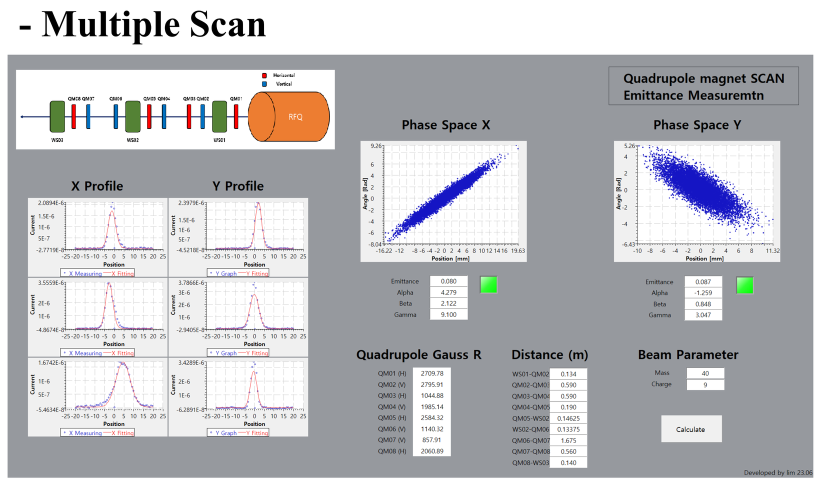




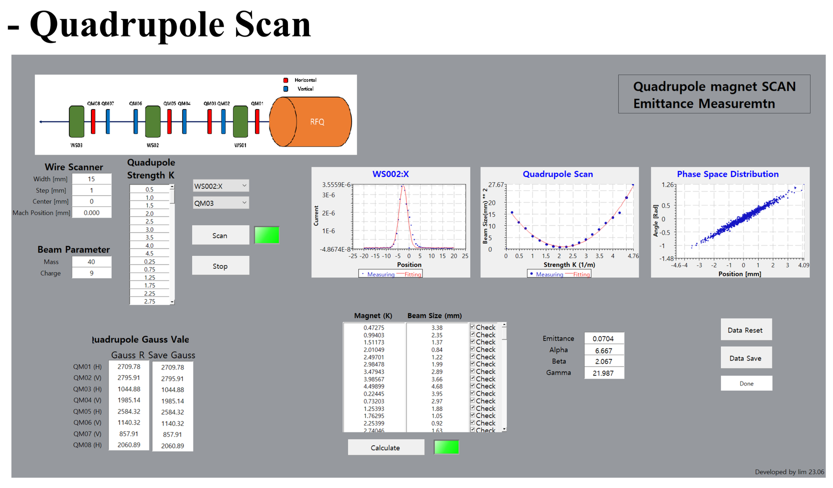
We tested the emittance calculation results according to the beam size measurement error in the wire scanner. This is the result of giving a random error value to wire scanner measurement and repeating it N times. In the quadrupole scan, as the measurement error increases, the emittance calculation error also increases, and when it exceeds 4.5%, calculation failure occurs. In the case of the multiple scan, the emittance calculation error increases according to the size, but no calculation failure is observed.

Emittance Measurement

- Multiple Scan



- Quadrupole Scan



The figure above shows the control GUI for measuring with each method. In the case of multiple scan calculation is performed after measuring three wire scanners and quadrupole scan calculates emittance after repeating wire scanner measurements according to the set K value.

Device	Emittance	Alpha	Beta	Gamma
Lattice1 – X	0.08	4.279	2.122	9.1
Lattice2 - X	0.088	3.975	1.768	9.5
Lattice1 – Y	0.087	-1.259	0.848	3.047
Lattice2 - Y	0.075	--3.11	0.652	16.365

Device	Emittance	Alpha	Beta	Gamma
QM01-WS002X	0.0570	-6.523	2.463	17.685
QM05-WS003X	0.0570	-6.819	2.656	17.888
QM02-WS002Y	0.0644	-7.365	2.134	25.891
QM07-WS003Y	0.0652	-11.259	3.37	37.909

The table shows the emittance and twiss parameter values measured by two methods in MEBT. The values measured by each method are similar, but the emittance measured by the multiple scan method is larger than that measured by the quadrupole scan method.

Conclusion

In order to measure emittance in the MEBT section of RAON, two methods using a wire scanner were performed. First, the validity of the two methods was verified through Python and errors that could occur due to beam size measurement errors were verified. After that, measurements were performed using the beam, and differences in measurement results occurred depending on the method. The emittance of the multi-scan method is larger than that of the quadrupole scan, which is thought to be due to greater influence of element alignment and magnet K measurement errors. It is necessary to compensate for these imperfections and reduce the measurement errors of both methods.

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IBIC2024