

PHY 542
COMPUTATIONAL EXERCISE #3 – QUADRUPOLE SCAN TECHNIQUE

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GENERAL INFORMATION

The quadrupole scan technique is a standard technique used in accelerator facilities to measure the transverse emittance. It is based on the fact that the squared rms beam radius (x_{rms}^2) is proportional to the quadrupole “strength” or inverse focal-length f squared, so

$$x_{rms}^2 = \langle x^2 \rangle = A \left(\frac{1}{f^2} \right) - 2AB \left(\frac{1}{f} \right) + (C + AB^2) \quad (1)$$

where A, B, C are constants and f is the focal length defined as

$$\frac{1}{f} = \kappa l, \quad (2)$$

here κ is the magnet focusing strength in units of 1 over length squared and l is the effective length of the magnet.

The emittance can be estimated according to

$$\varepsilon = \frac{\sqrt{AC}}{d^2} \quad (3)$$

where d is the distance from the magnet you scan to the point you calculate the beam rms radius.

OVERVIEW OF THE EXERCISE

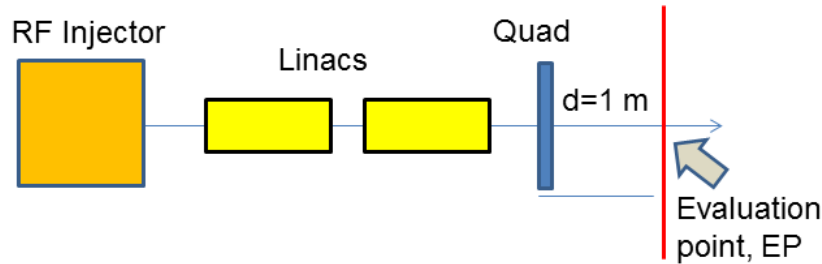


Figure 1: Simulation set-up

In the simulation you will vary the strength of the magnet and record the size of the beam on point EP. You will do it for several values of κ . Then, using excel you will fit the result into a polynomial fit and estimate the emittance from Eq. (3). You will compare the result with the emittance you obtain directly from ASTRA. In the exercise you will calculate the emittance on x axis, so you need to calculate only the x-beam size.

CAUTION: ASTRA is giving you the normalized emittance. Quad scan is giving you the unnormalized emittance. You need to do the conversion through the following relation:

$$\varepsilon_{x,norm} = \beta\gamma\varepsilon_{x,un} \quad (4)$$

here beta and gamma are the usual relativistic factors.

PROCEDURE

SUGGESTION: While not required, when you run the steps below you can use the lineplot program to look how different quantities (like beam emittance, size, energy) evolve with z.

1. Open HW3 folder on your desktop
2. Open the ASTRA file *ATF_LINAC.in*
3. Go to the Quadrupole section at the end of the program. Note that there are three quads and for each: Q_length is the effective length l in units of m, Q_K is the focusing strength κ in units of m^{-2} and, Q_pos is the longitudinal position of the magnet center in units of m .
4. Make sure that the second and third magnet are off. So the focusing strength is Q_K=0.

5. Now you will scan the first magnet at $z=7.1$ m and for each value you will calculate the beam rms radius at the EP at 8.1 m ($ZSTOP=8.10$ m)
6. Suggestion: Run simulations for the following values of focusing strength: $Q_k=2, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 19, 21, 23, 26 \text{ m}^{-2}$.
7. For each run, at the EP, record the beam rms radius x_{rms} . To do that, open ATF_LINAC.Xemit file and record the value on the fourth column in the last row. Please note that the rms radius is **in units of mm**.
8. Open an excel spreadsheet. Please create two columns: One with the rms size **squared** and the other with $1/f$ which can be calculated from Eq. (2). Hint: Check units for consistency. Now you need to do a second order polynomial fit.
9. Highlight the two columns. Then go to “insert” -> “scatter” -> “scatter with only markers”. You should see a parabola with scatters. Click first on the scatter plot and then on this icon:



10. You will see a linear fit. Right click on the black line, click on “Format Trendline” and check “Polynomial” (Order two). Make sure that “Display equation on chart” is checked. Click “close”.
11. Now you will see the equation and fit. How is the fit? Now you can extract quantities A, B and C.
12. Use Eq. (3) to estimate the emittance.
13. Estimate the emittance at EP directly from ASTRA (last row, column six on ATF_LINAC.Xemit file) or use lineplot. Set: $Q_K(1)=0.0$ when you run ASTRA. To find the value, please open the file ATF_LINAC.Xemit and look at the last row (column six). This is the **normalized emittance in units of microns!**
14. Hint: Recall Eq. (4) and note that the beam energy is 38.3 MeV.
15. What is the difference between the two emittances?
16. OPTIONAL: Can you repeat the same exercise for the emittance along y-direction?