Minimizing Energy Spread In The REX/HIE-ISOLDE Linac

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Abstract
This report tries to minimize the energy spread of the beam at the end of the REX-HIE-ISOLDE Linac using the last RF cavity as a buncher. Beams with very low energy spread are often required by the users of the facility. In addition, one of the main reasons to have minimum energy spread in longitudinal phase space is that higher beam energy spread translates into a position spread after interacting with target. This causes an overlap in the position of different particles that makes it difficult to distinguish them. Hence, in order to find the operation settings for minimum energy spread at the end of the REX-HIE-ISOLDE linac and to inspect the ongoing physics, several functions on Matlab were created that runs beam dynamics program called “TRACKV39” that provides some graphs and values as a result for analysis.
Acknowledgement

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Aims & Objectives

Firstly, aim of this project is to reduce energy spread in longitudinal phase space at the end of the linac for users to be used for precise research for instance in nuclear structure.

On the other hand, in order to achieve the stated aim, several functions on Matlab was created to run the Non-Linear beam dynamics program in a desired and faster way without needing a user to control it. Moreover, there are also other functions created on Matlab that is used to give either energy or field of last cavity interchangeably with each other.

Matlab Functions & Studies

First of all, 4 generic base functions were created to be used with other less generic functions and to complete some studies. In addition, these 4 generic functions are:

1. **InputFileGenerator** = To programatically replace the given field strengths, longitudinal emittance and RF cavity phases into the input file of beam dynamics program to run with.
2. **RunTrack** = To run the beam dynamics code at the background without user interface and close it when the simulation is complete.
3. **FreePlot** = To plot the results of beam dynamics program.
4. **Extract** = To extract the whole row of a single column of values given the filename and column number.

**Specific Higher Level Functions To Call Generic Functions For Studies**

- **Study 1** – Specific Function to Compute the Energy of the Beam at The End of the Last Cavity

- **Study 2** – Plotting Energy of the Beam at The End of the Last Cavity As a Function of Different Electric Field Strengths of RF Cavity

- **Study 3** – Function to Compute Required Field Strength of a Given Beam Energy at The End of The Last Cavity

Function of study 3 to compute the required field strength works using interpolation technique. In addition, it also possess optimization and convergence to increase the accuracy of the final result.

**Step 1:** Assume Energy at Minimum Field is “b₁” and Energy at Maximum Field is “b₂”. Moreover, Define Energy at Minimum (0) and Maximum Field (1). By initiating the beam dynamics program.

**Step 2:** Interpolate To calculate required Field Strength at Requested Energy.

**Step 3:** Narrowing down the initial lower and upper boundaries as close as possible to the middle desired field value with a given step size in order to re interpolate and optimize the final result. Furthermore, during optimization it also checks that input energy to the program is within the limits of “b₁” and “b₂”.

Mathematically, the function in study 3 can be shown as:

<table>
<thead>
<tr>
<th>Energy (MeV/n)</th>
<th>$b_1$</th>
<th>Defined Energy</th>
<th>$b_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field (Normalised)</td>
<td>0</td>
<td>$x$</td>
<td>1</td>
</tr>
</tbody>
</table>

From Interpolation, “$x$” can be written as:

$$x = \frac{(Field_{max} - Field_{min})(Defined\ Energy - b_1)}{(b_2 - b_1)} + Field_{min}$$

- **Study 4** – Function To Plot Energy Spread At the Last Cavity as a Function of Different Field Strengths at The Last Cavity
- **Study 5** – Function To 3D and Contour Plot the Energy Distribution of Particles For Different Field Strengths of Last RF Cavity
- **Study 6** – Function To Plot Energy Distribution of Particles For Different Longitudinal Emittances
- **Study 7** – Calculating Number of Cavities and Field Strength of Last Cavity to Give $^{30}\text{Mg}^{8+}$ Ion 7.5 MeV/n.
- **Study 8** – Computing Ion Energy Distribution of Mg30 at Different Longitudinal Emittances.

**Step 4:** Records the output of the final result into a vector after each iteration and checks if the last two values of the vector is same in order to decide that the final result has converged to a specific value.
Results

Study 2

Figure 1. Beam Energy For Different Final Cavity Strengths Normalised to 1.

Study 4

Figure 2. Energy Spread (Rel.u) For Different Final Cavity Field Strengths Normalised To 1

As it can be seen from figure 2, minimum energy spread occurs at 3.9 MV/m field strength setting at last RF cavity.
Study 5

Figure 3. Emittance of 1 – Default Beam of A/Q = 4.5

Study 6

Figure 4. Emittance of 4 – Default Beam of A/Q = 4.5
Study 7

By using the function created at study 3 which bases on Interpolation, it has been found that 14 RF cavities needs to be On out of 20 RF cavities in order to give $^{30}\text{Mg}^{8+}$ ion beam 7.5 MeV/n energy. In addition, electric field strength of 13 cavities were chosen to operate at 5.5 MV/m to be more realistic where the maximum is 6MV/m and last operating 14th cavity field was calculated to be 1.406 MV/m.

Study 8

Particles Energy Distribution is in MeV/u ($dW$)

In this study, longitudinal emittance was changed from by factor 1/4, 1/2, 2, and 4 with respect to default longitudinal emittance of 1 in order to see the effect of longitudinal emittance on energy distribution of particles.

On the other hand, before simulation in order to get more accurate result for the $^{30}\text{Mg}^{8+}$ beam Solenoid focusing magnetic field strengths were recalibrated to reduce the beam loss. By adjusting field strengths using equation 1, 83% transmission was acquired. Furthermore, by reducing the transverse emittance which is redundant in this study 100% transmission was acquired.

\[
B_{\text{Sol1}'} = \frac{\sqrt{E'_1} (1/4.5)^2 B_{\text{Sol1}}^2}{\sqrt{E_1} (1/3.75)^2} \tag{1}
\]

Where,

\[
E'_1 = \text{Energy of The Desired Beam at Solenoid 1}
\]

\[
E_1 = \text{Energy of The Reference Beam at Solenoid 1}
\]

\[
B_{\text{Sol1}'} = \text{Focusing Strength For Desired Beam at Solenoid 1}
\]

\[
B_{\text{Sol1}} = \text{Focusing Strength of Solenoid 1 at Reference Beam}
\]

\[
\left(\frac{1}{4.5}\right) \text{ and } \left(\frac{1}{3.75}\right) \text{ are the inverse}\frac{A(\text{atomic mass Number})}{Q(\text{Charge State})}
\]
Figure 5. Emittance 1

Figure 6. Emittance 2

Figure 7. Emittance 4

Figure 8. Emittance 0.25
Overall, as it can be seen from 2D contour plots increasing emittance in both default and $^{30}$Mg$^{8+}$ beam reduces the minimum of particles energy distribution.