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DESIGN STUDIES FOR THE PROTON-LINAC RFQ FOR FAIR

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Abstract

The planned 27 m long Proton-Linac (p-Linac) for FAIR (Facility for Antiproton and Ion Research) comprises a RFQ (Radio-Frequency Quadrupole) and six crossbar H-Mode cavities to accelerate a 70 mA proton beam up to 70 MeV. The FAIR Proton-Linac starts with a 325.2 MHz, from 95 keV to 3 MeV RFQ accelerator. The main RFQ for this Proton-Linac will be a 4-Vane type RFQ. RF analytics with varying and constant transverse focusing strength for the electrode parameters will be used. CST MWS (Microwave Studio) [1] simulations will help to find cavity parameters for the working frequency. This paper presents the main cavity design concepts and simulation results.

INTRODUCTION

A new international accelerator-based science center (FAIR) will be built in the near future at GSI, Germany [2, 3]. The FAIR facility is designed to provide antiproton and ion beams of worldwide unique intensity and quality for fundamental physics research.

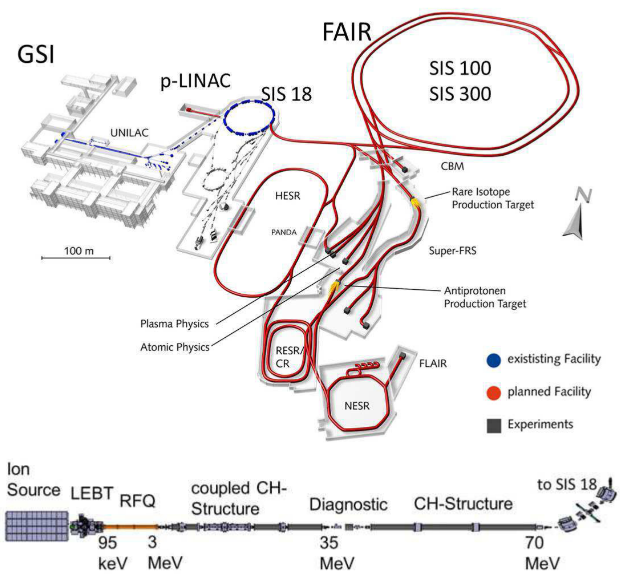

Figure 1: Layout of the FAIR facility and overview of the Proton-Linac.

Fig. 1 shows the planned Proton-Linac which is adjacent to the existing UNILAC. Both Linacs are injectors of the SIS 18 synchrotron, which delivers the SIS 100, the central accelerator component of FAIR. The Proton-Linac will mainly consist of an RFQ accelerator and two 9 m sections of Cross Bar H-Mode accelerators (CH structures) working at a frequency of 325.224 MHz. In the first section, there will be six CH cavities, which are pairwise RF-coupled. The second section consists of three separate long CH cavities. Each of those six cavities has its own klystron. It is required to provide a 70 MeV proton beam with a beam current up to 70 mA at a macro pulse length of 36 µs and a bunch length of 100 ps [4, 5]. The planned RFQ is between 3.2 m and 3.5 m long and will have an input energy W_{in} of 95 keV. After the acceleration in the RFQ the output energy W_{out} will be 3 MeV.

RFQ DESIGN STUDIES

One of the most important parameter for an RFQ design is the maximum electric field on the RFQ electrode surface. A high field is necessary for a reasonable and improved performance of the structure, but also a reliable and stable operation of the machine has a high priority [6]. The ongoing GSI Proton-Linac project requires such calculations for increased reliability.

Table 1: Design Requirements for the Proton-Linac RFQ for FAIR

Particle	proton (H^+)
Frequency	325.224 MHz
Input energy W_{in}	95 keV
Output energy W_{out}	3.0 MeV
Beam current (design)	70 mA
Length	> 3.2 m < 3.5 m
Kilpatrick factor	≤ 1.87
Rep. rate	≤ 4 Hz
Aperture (min)	≈ 2.2 mm
Modulation (max)	≈ 2
Average distance to beam	≈ 3.3 mm

The current design parameters for the Proton-Linac RFQ are listed in Table 1 [10]. These parameters are necessary for the beam dynamics design. For the RF-structure, a 4-Vane-RFQ is chosen [3]. The cavity geometry will be designed with the main parameters like aperture, modulation, frequency and the length of this cavity.

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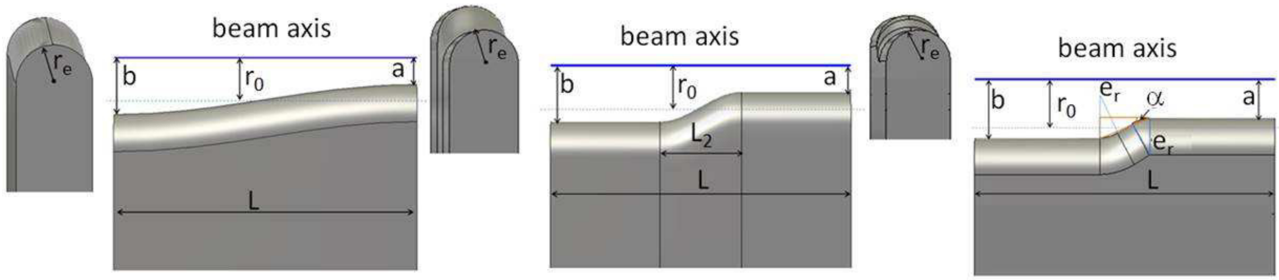

Figure 2: Layout of the three different models used for the CST MWS simulations. The main parameters are aperture (a), average distance to beam axis (r_0), modulation (m=b/a), cell length (L), lenght of the sinusoidal part (L_2) and electrode radius (r_e). For the trapezoidal design other parameters like edge rounding (e_r) and an angle (α) are required.

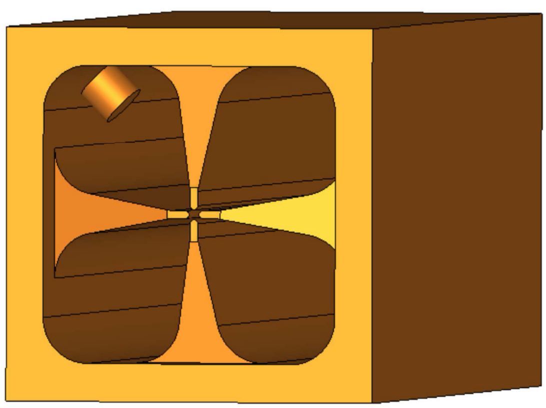

Figure 3: CST MWS model of a possible RFQ structure for the cavity design simulation.

RFQ CELL DESIGN

For the final modulation design of the GSI Proton-Linac RFQ three different single cell models were studied with CST MWS. As shown in Figure 2, the first model is a cell with a sinusoidal modulation, the second model consists of a trapezoidal shape having a sinusoidal modulation in the middle and the third model has a trapezoidal shape with rounded edges [7]. The simulations should show a higher accelerating efficiency but only a relatively low increase of the maximum E-fields on the surfaces. Reasonable mesh density was chosen on the base of previous studies for CST MWS accuracy and reliability. The main design values for the shape of the first two models are the aperture, the modulation and the cell length. The third model uses also variables such as edge rounding and trapezium angle. For this purpose, firstly a general CST MWS electrode model was developed (See Fig. 3). An optimum for the cell geometry could be found by using these simulations [8,9].

In Figure 4 the electric field distribution on the surface of the different cells are shown. The maximum electric field in the trapezoidal shape is higher than in the sinusoidal structure and should be optimized. By changing the parameters (α and e_r) for the trapezoidal cell design also the electric field distribution is changed.

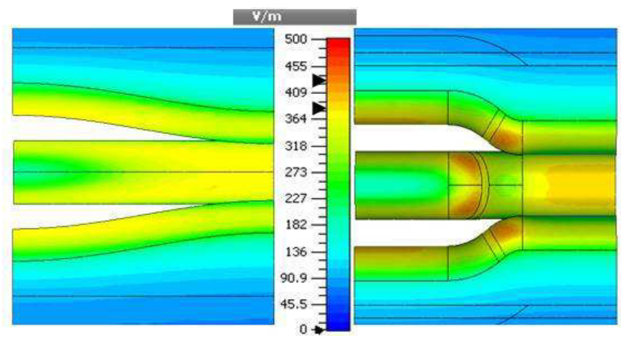

Figure 4: E-field on the CST MWS model surfaces for the sinusoidal (left) and the trapezoidal cell (right).

The effective longitudinal field E_Z along the z-axis is shown in Figure 5. A synchronous phase of -30° is assumed. The coloured lines correspond to different designs. Additionally an integrated field is calculated. A higher energy gain for Model 2 and Model 3 is illustrated. An optimal field should be found by changing the values of the edge rounding and the angle in the trapezoidal design.

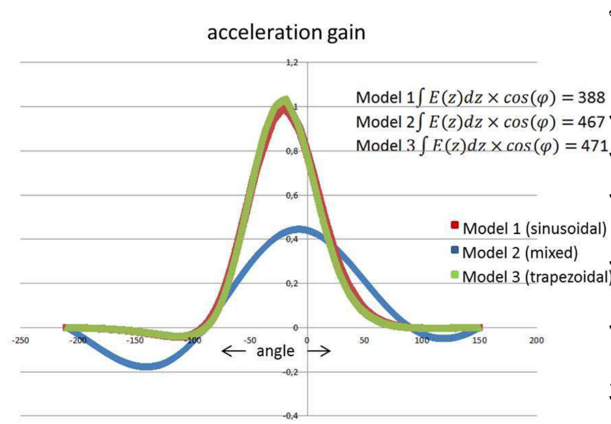

Figure 5: Effective longitudinal electric field along the Z-axis for the different models.

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Table 2: Simulation Results for Acceleration Gain and Max Surface Field Gain by Using Different Parameters

cell typ	a [mm]	m	re [mm]	α angle [°]	er [mm]	acceleration gain	max field gain
sinus	1,99	2,1	2.768	-	-		
mixed	1,99	2,1	2,768	45		24,7%	73,5%
	1,99	2,1	2,768	40		24,7%	58,8%
	1,99	2,1	2,768	35		23,7%	45,3%
	1,99	2,1	2,768	30		22,9%	32,3%
trapezoidal	1,99	2,1	2.768	45	3	22,4%	22,8%
	1,99	2,1	2.768	45	3,25	22,2%	20,5%
	1,99	2,1	2.768	45	3,5	22,2%	19,1%
	1,99	2,1	2.768	45	3,7	21,9%	17,9%
	1,99	2,1	2.768	30	2,77	20,9%	17,0%
	1,99	2,1	2.768	30	3	20,9%	15,8%
	1,99	2,1	2.768	30	4	20,6%	12,1%
	1,99	2,1	2.768	30	5	20,1%	8,4%
	1,99	2,1	2.768	30	6	19,3%	7,0%
	1,99	2,1	2.768	30	7	18,6%	6,7%
	1,99	2,1	2.768	30	8	17,8%	5,8%
	1,99	2,1	2.768	37,5	2,77	21,9%	20,2%
	1,99	2,1	2.768	37,5	3	21,9%	20,0%
	1,99	2,1	2.768	37,5	3,5	21,9%	17,4%
	1,99	2,1	2.768	37,5	4	21,4%	15,3%
	1,99	2,1	2.768	37,5	4,5	21,9%	12,8%
	1,99	2,1	2.768	37,5	5	20,4%	12,1%

The simulation results for the acceleration gain and for the maximum field gain on surface by changing the parameters for electrode radius and angle are shown in Table 2. The simulations with bigger edge rounding and a smaller angle shows a strongly reduced maximum field on the surface, while the acceleration field is still higher than for the sinusoidal modulation. The results for an angle of 30° and an edge rounding radius between 6 mm and 8 mm shows good results. The same check has been done with different cell modulation and aperture. The result for the mixed cell also shows a higher acceleration gain, but the maximum field gain is too high.

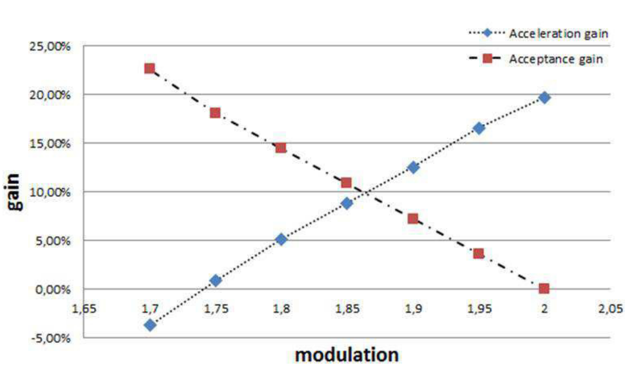

Figure 6: Acceleration and acceptance gain in dependence of the electrode cell modulation.

By decreasing the modulation of the trapezoidal shape the same accelerating efficiency was found as in the unchanged sinusoidal shape. All variables were kept constant, and only the modulation is changed. The goal is to achieve bigger acceptance at the same acceleration efficiency for the RFQ. Figure 6 shows that the acceleration gain is the same as in the sinusoidal shape for a decreased modulation of 1.73. Then it is also possible to build cells with the same acceleration efficiency but with higher acceptance.

CONCLUSION

Using a trapezoidal modulation of an RFQ cell has a significant advantage compared to a sinusoidal one. With the proper definition of the cell topology, the acceleration gain could be increased by using the same modulation (acceptance) and with almost the same maximum strength of the electric field on the surface of the vanes. Alternatively it is possible to design a channel with an increased acceptance but keeping acceleration efficiency, RF voltage and RF power. It is also possible to decrease the maximum strength of the electric fields have a stable routine operation, but with an acceptable acceleration efficiency, particle transmission and beam quality behind the RFQ.

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