

UPDATED CAVITIES DESIGN FOR THE FAIR p-LINAC

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Abstract

The research program of antiproton beams for the FAIR facility requires a dedicated 68 MeV, 70 mA proton injector. This injector will consist of an RFQ followed by six room temperature "Crossbar H-type" CH-cavities operated at 325 MHz. The beam dynamics had been revised by IAP Frankfurt in collaboration with GSI-FAIR in Darmstadt to further optimize the design. This step was followed by cavity RF design. The detailed mechanical cavity design will begin in 2017, while the quadrupole lenses are under production already. In this paper, besides an overview the RF design of the coupled cavities with integrated focusing triplets will be a main focus.

INTRODUCTION

The antiproton program at FAIR (Facility for Antiprotons and Ions Research) aims on producing 7×10^{10} cooled antiprotons per hour which requires a primary proton beam of about 2×10^{16} protons from the synchrotron SIS100 per hour [1-3]. The needed proton intensity from the injector linac is far beyond the capabilities of the GSI-UNILAC, therefore a high current proton linac is needed.

This new linac serves as a new injector for the SIS18 synchrotron, where the proton beams will be accelerated to the final energy of 68 MeV. Beyond this linac energy, the antiproton production and cooling chain will not profit substantially in a higher production rate [3].

It is very important to have a robust design with respect to operation at different current levels from 0 mA up to the design level of 75 mA. From beam simulations and experience with heavy ion beams from the UNILAC it was concluded that a beam current around 35 mA and within a normalized horizontal brilliance of $16.5 \text{ mA}/\mu\text{m}$ should be well suited to fill the synchrotron SIS 18 up to the space charge limit [1]. The best linac current operation point will be determined during beam commissioning and injection into SIS 18.

FAIR PROTON LINAC

An ECR ion source will deliver protons with an energy of 95 keV [4]. After that, an RFQ structure will be used to accelerate the proton beam up to 3 MeV [5].

The main accelerator section in the proton linac consists of six room temperature "Crossbar H-type" CH – cavities operated at 325 MHz. Figure 1 shows an overview of the proton linac from the RFQ exit down to the end of the last CH cavity.

The CH-cavities consist of two sections: the first one is composed of three coupled CH – cavities (CCH1, CCH2 and CCH3) that will accelerate the beam from 3.0–33 MeV.

At 33 MeV, the space charge effects and rf defocusing are reduced. This will allow for longer lens-free sections in KONUS beam dynamics. Consequently, the high energy section-consists of three lens-free CH – cavities. This helps to simplify the mechanical design and to tune the cavities besides reducing the total cost.

The main parameters of the CH – cavities are summarized in Table 1.

All cavities have been designed in order to fulfill the revised beam dynamics [6]. This includes the number of gaps, voltage distribution, coupling cell lengths, additional spaces for diagnostic and vacuum elements and the total length.

Table 1: Main Parameters for the FAIR Proton Linac CH – Cavities at 75 mA Operation

Cavity	L (m)	P _{tot} (MW)	Z _{eff} (MΩ/m)	Energy (MeV)	Gaps No.
CCH1	1.44	1.33	53.5	3.0 - 9.9	21
CCH2	2.56	1.87	53.2	9.9 - 21.1	27
CCH3	3.66	1.92	44.6	21.1 – 33.0	30
CH4	2.67	2.14	42.4	33.0 - 44.6	20
CH5	3.02	2.12	38.5	44.6 - 56.3	20
CH6	3.31	2.06	36.7	56.3 – 68.0	20
Magnetic Quadrupole Triplets					
Effective Length (mm): 2x				38, 60, 38	
10x				52, 95, 52	
Effective Gradients (T/m)				45 – 62	
Aperture Diameter (mm)				30	
Yoke Material				Cobalt Iron (Vacoflux50), laminated	
Beam Parameter					
Beam Current (mA)				75	
Emittance				input	Output
ε _{n, 95% trans.} (mm·mrad)				1.35	2.6
ε _{rms, 95% trans.} (mm·mrad)				0.266	0.455
ε _{n, 95% long.} (keV·ns)				12.0	15.6
ε _{rms, 95% long.} (keV·ns)				2.4	2.9

THE COUPLED CH – CAVITY CCH2

The revised beam dynamics for the FAIR proton linac [6] was used to fix all relevant cavity parameters and to be able to start the cavity rf design and later on the construction.

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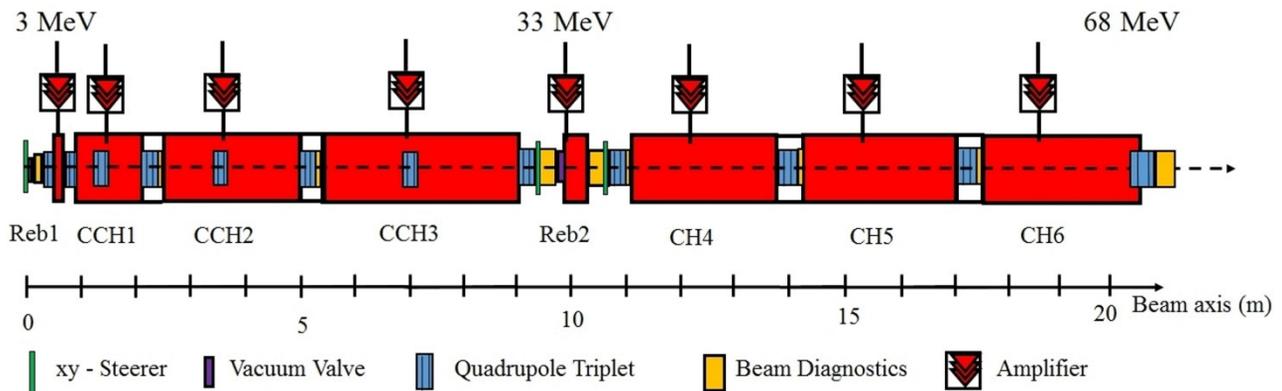


Figure 1: An overview of the FAIR proton linac from the RFQ exit down to the last CH cavity including the positions of the triplet quadrupoles, diagnostics and vacuum elements.

As an example for the cavity RF design, the final layout of the second coupled cavity (CCH2) will be presented in this section. Figure 2 shows a 3D – view of the cavity, where the two drift tube sections (low and high energy parts) are coupled by the central element that houses the quadrupole triplet. The concept of coupling two CH – sections and the physics of this kind of cavities has been discussed in detail before [2, 7].

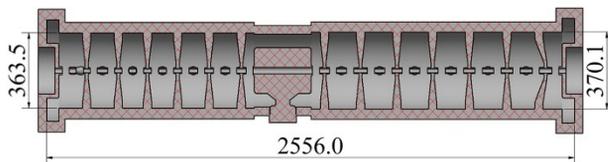


Figure 2: A cross sectional view of the second coupled CH – Cavity.

This cavity consists of 27 gaps and will accelerate the proton beam from 9.9 – 21.1 MeV within about 2.6 m. The coupling cell has a length of about $2\beta\lambda$. The rf simulations have shown that an effective coupling is achieved with this geometry as shown in Figure 3.

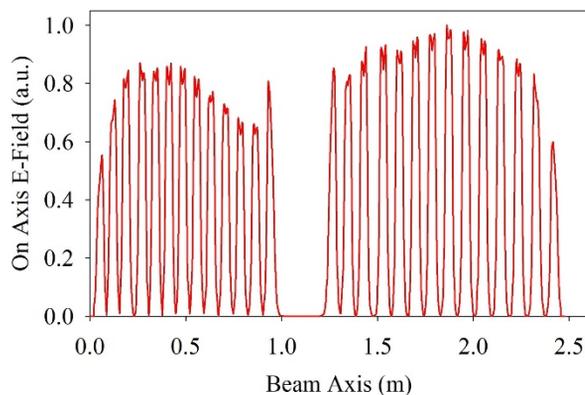


Figure 3: On axis electric field for the second coupled cavity.

The special shape at the cavity ends was needed to increase the effective voltage for the end gaps and to optimize the RF efficiency by improving the effective shunt

impedance value Z_{eff} . By that method, the matched cavity ends become short allowing for an improved mechanical integration of the inter-tank quadrupole triplets.

The effective gap voltage was calculated from the longitudinal electric field integration (Fig. 3), and including the particle velocity dependence (transit time factor). These values were controlled and compared to the expected effective voltage from the beam dynamics calculation (using LORASR code). This comparison can be seen in Figure 4.

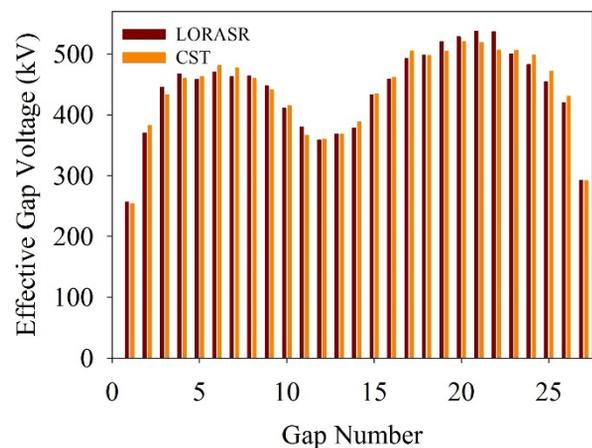


Figure 4: The calculated effective gap voltage from CST-MWS [8] simulation versus the design gap voltage from the beam dynamics with the LORASR code.

The electric field distribution along the yz - symmetry plane is shown in Figure 5. The magnetic field distribution in a xz - plane above the beam axis as indicated by Fig. 5 shows that the coupling section oscillates along the central tube approximately in a 0 – mode (see Figures 6-7). The given maximum field values (as indicated in Figures 5–7) refer to the design operation level, as deduced from CST-MWS simulations.

The first and third coupled CH – cavities have been designed in a similar way to the CCH2 and all the numerical results from all cavities (including the uncoupled CH-DTL's) will be used for a final beam dynamics cross check.

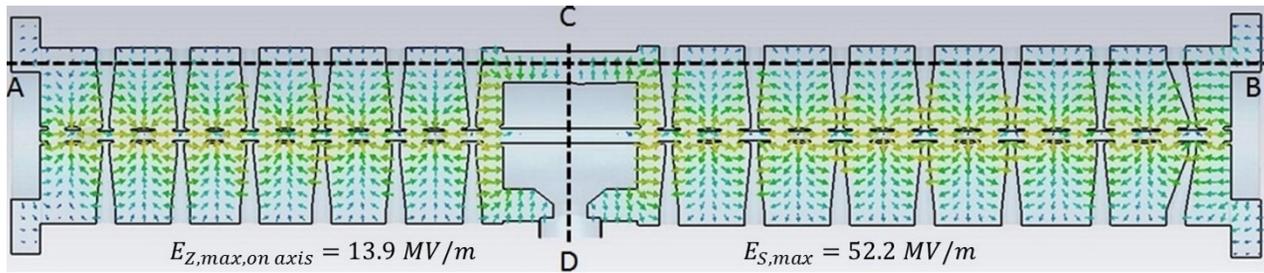


Figure 5: The electric field distribution along the xz – plane for the second coupled CH – cavity.

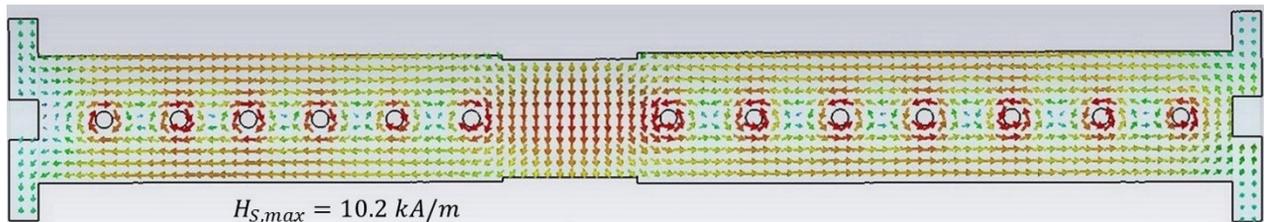


Figure 6: The magnetic field distribution along the plane A-B.

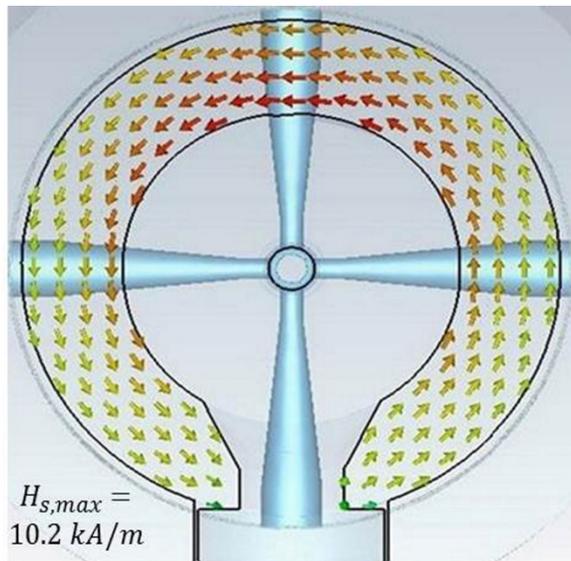


Figure 7: The magnetic field distribution in the middle plane of the central part along the plane C-D.

CONCLUSION

The proton linac for the FAIR facility will be the first one based on CH – DTL’s and applying the KONUS beam dynamics.

The final layout for the cavities has almost been finished and the results will be used as the basis for the mechanical layout and cavity construction.

Besides the cavities design, the magnetic quadrupole triplets have been defined as shown by Table 1 and their integration either in the coupling cell (for the coupled cavities) or in the inter-tank section (between the cavities) are currently done in collaboration with GSI – FAIR. The quadrupole lenses are under production.

The good results from the RF power tests of the full scale CCH2 prototype cavity [9] are giving confidence to this novel linac approach and give inspiration for further improvements in the final design.

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