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COMPARISON BETWEEN MEASUREMENT AND SIMULATION OF A FULL SCALE PROTOTYPE FOR THE PROTON INJECTOR AT FAIR

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Abstract

A dedicated 68 MeV, 70 mA proton injector is required for the research program at FAIR (Facility for Antiproton and Ion Research). This 325 MHz linear injector contains a RFQ and six CH structures. The CH (Crossbar H-mode) structures are working in the H210 mode. The main acceleration of this room temperature linac will be provided by the CH structures. For the second acceleration from 11.5 MeV to 24.2 MeV a full scale prototype has been built. This structure consists of two individual CH resona-tors and a coupling cell. Inside the structure there are 17 tuners, they have an impact on the electric field and the fre-quency. For operation a flat field is required, therefore this tuners must be correctly positioned. Some series of low level tuning and frequency measurements were done to de-termine the size of the tuners. Low level measurements and simulations will be compared and presented.

INTRODUCTION

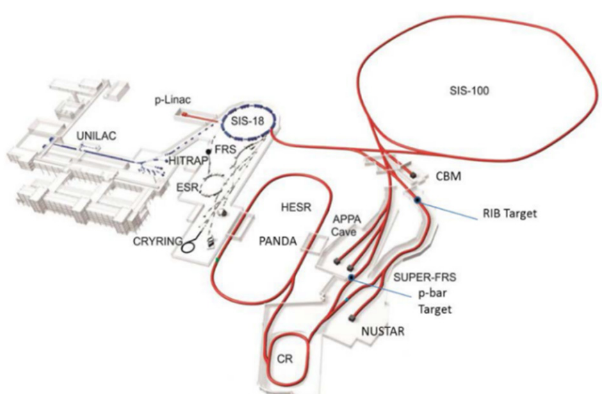

Figure 1: The FAIR facility in the full version [1].

The FAIR project (Fig. 1) will be a new international particle accelerator facility for antiprotons and heavy ions which is currently under construction [1]. This project will provide knowledge of still unknown subatomic components of matter in the Universe. In parallel the existing GSI facility is upgraded together with a new proton linear accelerator and will serve as pre-accelerator and injector for the new heavy ion synchrotron SIS100. The SIS100 beams are delivered to a complex of storage rings [2] and experimental stations reaching energies and intensities as required for FAIR [1].

As shown in Fig. 2, the main acceleration from 3 MeV up to 68 MeV will be realized with six CH-cavities mechanically grouped in two sections, each having a length of about 9 m. Between both sections there will be a diagnostics area at 33 MeV with a re-buncher for longitudinal beam matching and beam diagnostic chambers. The first DTL section will consist of three coupled CH-cavities (CCH). Each CCH-Cavity comprises two to four RF-coupled cavities connected by a transition tank called coupling tank housing a focusing magnetic quadrupole triplet lens within the vacuum and rf penetrated area. The second group consists of single CH-modules, each of them divided into three cylindrical pipe sections as well but flanged together directly without any inter tank section. These cavities have only quadrupole triplets in between. The DTL-cavities operate at a resonance frequency of 325.224 MHz. It is required to provide a 68 MeV proton beam with a beam current up to 70 mA at a rf pulse length of 200 µs and a beam pulse length of ≤ 36 µs. The estimated rf power requirement (power loss) of the cavities is max. 1.3 MW. The thermal energy thus released into the tank must be removed by efficient water-cooling.

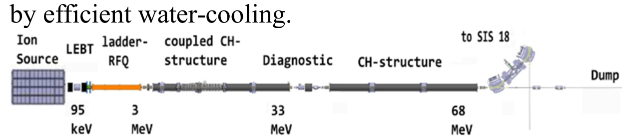

Figure 2: Overview of the proton linac.

THE COUPLED PROTOTYPE CAVITY

Figure 3 shows a prototype cavity of a coupled CH-DTL cavity developed by IAP University of Frankfurt [3]. This cavity corresponds to the second cavity within the first section. The low energy part consists of 13 gaps, followed by the coupling cell (housing the dummy triplet lens within one large drift tube) and by the 14 gap high energy part. The whole cavity has an inner length of about 2.8 m and the cylindrical tanks have an inner diameter of about 360 mm. The coupling cell has a length of about 2βλ. Fourteen fixed (five in tank one and nine in tank two) and three mov-able tuners (located at each cavity and at the coupling cell) are foreseen.

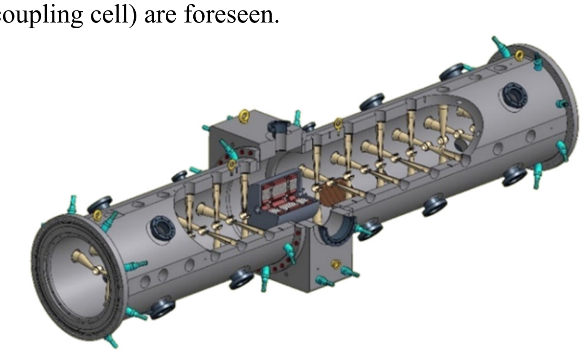

Figure 3: 3D-model of the coupled CH-prototype cavity [4].

The prototype arrived at GSI in late 2013 and Fig. 4 shows the final result after galvanic copper plating and polishing. A test stand was assembled for low power rf meaurements with a 4-port network analyser (bead pull

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measurement, tuning and rf-coupling investigations by an inductive loop [5]) and high power rf tests [6]. After several iterations the design of the six cavities changed to get better beam dynamic results, that's why this prototype is no longer part of the real linac. To see how tuning is ongoing and simulation and measurement results match, new series of analysis are done.

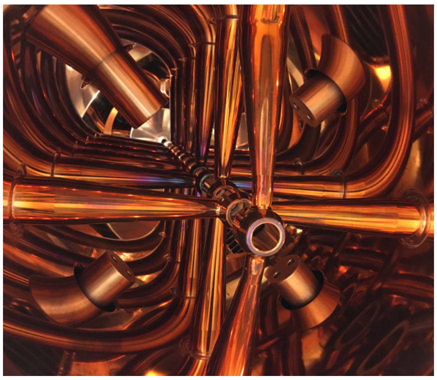

Figure 4: Copper plated inner surface of the coupled CH-prototype cavity [3].

MEASUREMENTS

The first measurement was done in 2013 without any tuning body inside the cavity. The resonance frequency is 323.5 MHz. The electrical field distribution in beam direction is shown in Fig. 5. The field distribution is tilt so there are tuning bodies needed (as well as for reaching the right operating frequency of 325.224 MHz). After a series of round about 200 measurements (changing the tuner high), the field is as flat as it could be with the right resonance frequency of 325.224 MHz (Fig. 6). The voltage distribution along the beam line shows a good comparison between measurement and LORASR (Fig. 7).

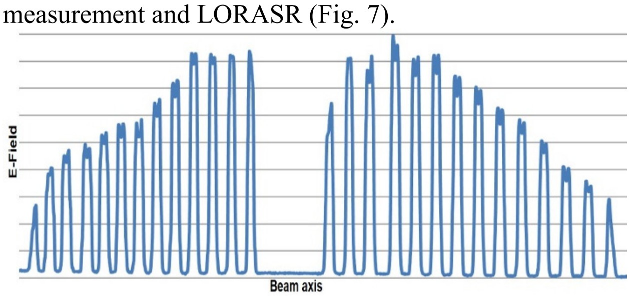

Figure 5: Measured electrical field distribution along the beam line (done in 2015 by M. Vossberg).

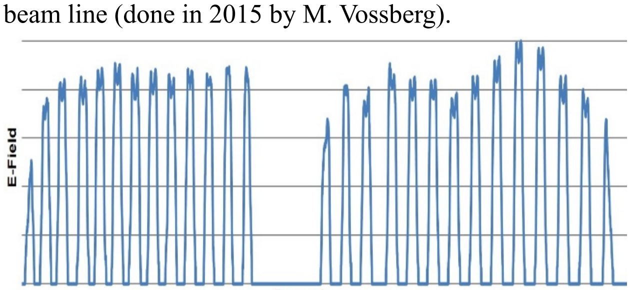

Figure 6: Best measured electrical field distribution along the beam line with tuning bodies (done in 2015 by M. Vossberg).

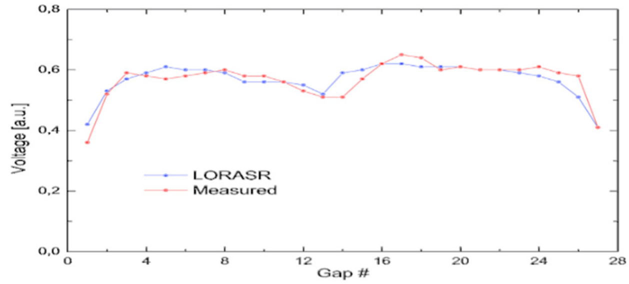

Figure 7: Voltage distribution along the beam line (blue: LORASR and red: Measurement) (done in 2015 by M. Vossberg).

SIMULATIONS

Simulations are done with CST MicroWave Studio [7]. The 3D model was added to the simulation program via measurement of the real geometry of the prototype, since no detailed drawings of the manufacturing could be found. Therefore, the simulation results have bigger errors and should be taken with care. First tests are done without tuning body inside. The resonance frequency is 324 2 MHz and the calculated electrical field distribution is shown in Fig. 8. The field distribution in the first tank section shows a good flatness, in tank two it is tilted because of bigger errors in measuring the geometry (longer drift tubes and gaps makes it more complicated to measure in the right way). Tuning bodies are installed inside the cavity (same position and length as in the real prototype). The resonance frequency becomes a value of 325.6 MHz and the field distribution is tilted (Fig. 9). This tilted field can also be seen in the voltage distribution between CST and LORASR (Fig. 10).

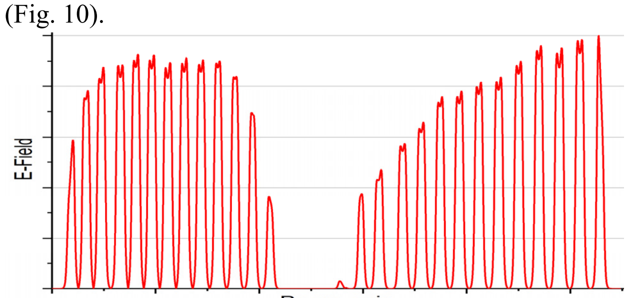

Figure 8: Simulated electrical field distribution along the beam line.

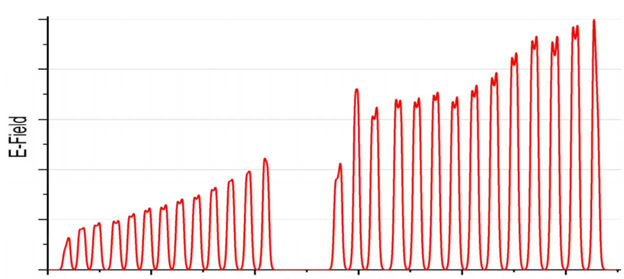

Figure 9: Simulated electrical field distribution along the beam line with tuning bodies.

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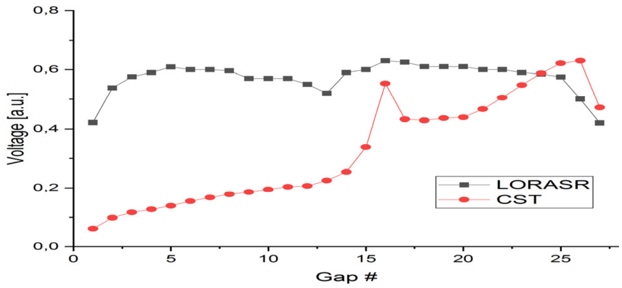

Figure 10: Voltage distribution along the beam line (blue: LORASR and red: CST).

By changing the tuner position in the simulations (beginning of section one tuners out; end of section two tuners in), it was possible to reach the right field distribution (Fig. 11) and set the resonance frequency down to 325.5 MHz. The voltage distribution shows a better comparison between LORASR and CST (Fig. 12).

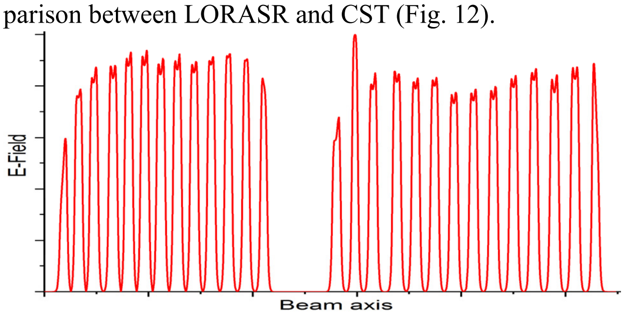

Figure 11: Simulated electrical field distribution along the beam line after changing the tuner positions.

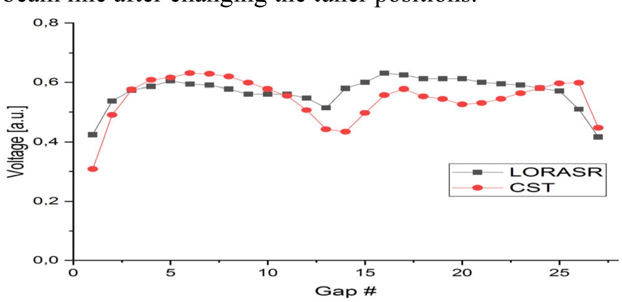

Figure 12: Voltage distribution along the beam line after changing the tuner positions (blue: LORASR and red: CST).

COMPARISON BETWEEN SIMULATION AND MEASUREMENT

The resonance frequency compare really good between measurement and simulation. The value of the frequency in the simulations is round about 500 kHz higher than in the measurements, which is due to the manufacturing tolerances and the imperfect geometry as it is the case in the simulations. A big error in the simulation results are due to the missing manufacturing drawings. Input values in CST measured by hand make a larger inaccuracy in the sum and thus a larger deviation in the field distribution / tilting.

CONCLUSION

This paper showed how simulation and measurement compare for a coupled CH-prototype cavity for the p-Linac project at GSI. Due to the difficulty of finding the design drawings, it is hardly possible to reach a direct comparison between measurement and simulation, since the measurement of the geometry of the prototype is fraught with great errors. Only by changing the plunger position, the tilting of the field can be minimized.

OUTLOOK

After some design changes, because of better beam dynamics and better mode separations, a new cavity design for all six cavities is planned. Therefore a prototype of the first coupled CH-DTL should be realized. This will be the most complex cavity for welding and copper plating. To reach the design rf-parameters it is planned to fabricate at first a stainless steel tank (which is fully prepared for vacuum and water-cooling usage) and stick aluminum stems inside. Tuning can be tested and a better comparison between simulations and measurements should be done. Afterwards it is planned to replace the aluminum stems by stainless steel stems and weld them inside the cavity. This could be the first of series with can be tested after copper plating with high power. Several tests are right now ongoing at GSI for welding techniques from outside the cavity (because of the small aperture it is not possible to weld inside the cavity) as well as copper plating tests for different welding lines.

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