First Coupled CH Power Cavity for the FAIR Proton Injector

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Abstract

For the research project on cooled antiprotons at FAIR a dedicated 70 MeV, 70 mA proton injector is required. The main acceleration of this room temperature linac will be provided by six CH cavities operated at 325 MHz. Each cavity will be powered by a 2.5 MW Klystron. For the second acceleration unit from 11.5 MeV to 24.2 MeV a 1:2 scaled model has been built. Low level RF measurements have been performed to determine the main parameters and to prove the concept of coupled CH cavities. In Summer 2012, the assembly and tuning of the first power prototype was finished. Until then, the cavity was equipped with a preliminary aluminum drift tube structure, which was used for precise frequency and field tuning. During Spring 2013 the final drift tube structure will be welded into the tank sections and the preparation for copper plating will take place. This paper reports on the main tuning and commissioning steps towards that novel type of DTL and it will show the latest results towards a fully operational CH proton cavity.

INTRODUCTION

The proton linac for FAIR is mechanically grouped in two tanks, each having a length of about 10m. Based on the actual design the first tank will consist of 3 coupled CH-cavities. Between both tanks there will be a diagnostics section with a rebuncher for longitudinal beam matching.

Further investigations have shown that a simplified layout of the 2nd section of the proton linac will be an improvement. In that case, three simple CH cavities without a coupling cell will be used, reducing the triplet lens number by three and simplifying the cavity layout a lot.

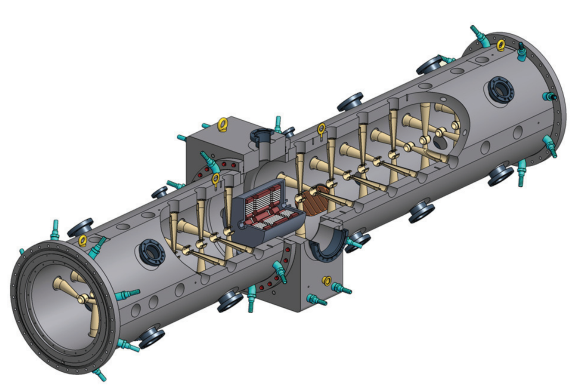

Figure 1: 3D-View of the coupled prototype cavity.

THE COUPLED PROTOTYPE CAVITY

Figure 1 shows the prototype cavity which corresponds to the second coupled cavity within the first tank. The low energy part consists of 13 gaps, followed by the coupling cell and by the 14 gap high energy part. The whole cavity has an inner length of about 2.8 m and an inner diameter of about 360 mm.

The coupling cell has a length of 2β and hosts the focusing triplet lens within one large drift tube. The inter cavity sections will also house triplet lenses and some beam diagnostics additionally (4 knob phase probes). They mechanically connect neighbored cavities.

Table 1: Parameters of the Coupled CH Prototype Cavity

No. of gaps	13 + 14 = 27
Frequency [MHz]	325.2
Energy range [MeV]	11.7 - 24.3
Beam loading [kW]	882.6
Heat loss [MW]	1.35
Total power [MW]	2.2
Q_0-value	15300
Eff. shunt impedance [MΩ/m]	60
Average E_0T [MV/m]	6.4 - 5.8
Kilpatrick factor	2.0
Coupling constant [%]	0.3
Aperture [mm]	20
Total inner length [mm]	2800
Inner diameter [mm]	180 / 217 / 182

MECHANICAL DESIGN

Intertank Unit and Cavity End Cell

The concept based on two 10m long tanks leads to very tight tolerances with respect to the surface finishing of the tank flanges as well as with respect to the transverse alignment against the beam axis. To control mechanical deformations by gravity or stress the linac will be mounted on a rail system - as practiced at the GSI Unilac. Alternatively, each tank could be mounted precisely on a robust support and then be aligned via a 3-point adjusting device with respect to the beam axis.

The neighbored cavities will be connected by an intertank unit consisting of a quadrupole triplet housed in a drift tube and mounted into a rectangular massive containment which provides the end flanges for the neighbored cavities at the same time. This concept allows to group an adequate number of CH cavities into one rigid tank and to do a precise alignment in the laboratory before final mounting on the beam line.

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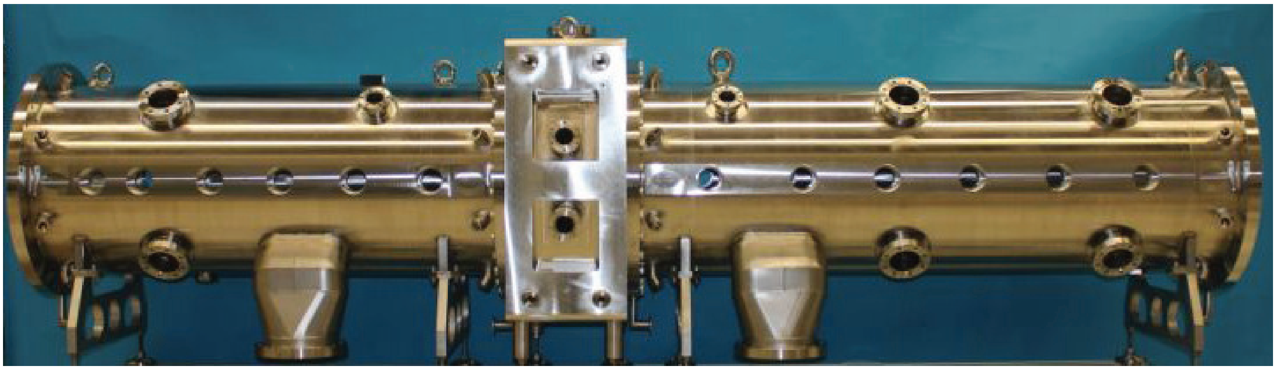

Figure 2: Side view of the proton linac power prototype after first assembly.

Within the intertank units space is narrow dictated by beam dynamics. Therefore, a special cavity end cell geometry was developed, that allows to mount diagnostics, such as beam position monitors, next to the quadrupole lense inside the RF free region.

To make this kind of layout possible several changes of the mechanical and RF design had to be performed. Of great importance were the inclined stems as well as a special end shape of the cavity wall to reach short distances finally between end gaps from neighboured cavities.

Drift Tube Sections

It has been demonstrated successfully by a 8-cell prototype cavity [1, 2, 3] that the drift tube stems can be welded into the tank wall at the inner surface. To avoid large holes in the outer tank, special techniques were developed to integrate long drift tubes with modest transverse stem diameters. Additional care must be taken to limit longitudinal stress along the stem caused by temperature differences between tank wall and drift tube structure. Therefore, a special end shape was developed which prevents the stems from rupturing in case of temperature variation.

With respect to the cooling system a stem and drift tube geometry was developed which allows to produce the stems in two single parts. The stems are produced hollow as a unibody piece in which only the drift tube has to be inserted. This technique makes it possible to stick to the very tight tolerances for the stem alignment.

New camera assisted welding techniques make it possible to weld the stems with very high precision into the outer wall.

MEASUREMENTS

Mode Spectrum

After production of the main parts the prototype was assembled at Frankfurt University using an aluminum dummy drift tube structure for tuning. First measurements took place in Dec. 2011 and were performed without any tuners. Table 1 shows that the simulated frequencies are very close to the measured frequencies. The failure is only about 1 percent.

Table 2: Comparison Between Simulated and Measured Frequencies of the First Two Resonant Modes

Simulated [MHz]	Measured [MHz]
324.4	323.7
325.3	324.6

Because the prototype is only equipped with inductive acting tuners the simulations were made for frequencies slightly lower than the final operational frequency. This gives extra safety for the tuning, even if inaccuracies wouldoccur during the manufacturing. In the next step all above mentioned tuners were installed and the frequency tuning was performed. The first resonant mode was step by step pushed up in frequency until the tolerable range was reached. The frequency of this mode is 324.9 MHz by now. Pushing the frequency further up is not necessary at this point, because by evacuating and copper plating the frequency will raise additionally. The difference between the first two resonating modes is acceptable. A difference of about 1 MHz gives a coupling constant of 0.3. This is of great importance when the effect on beam operation is estimated. One has to ensure that the klystron does not excite the adjacent mode during power ramping. this effect should be excluded by several precautions taken like a coupler position feeding the working mode only. The main tuner in the coupling cell acts in a way on the first two resonant modes, which should ensure the spacing of the modes even in case of temperature changes.

Field Distribution

Nearly all inductive tuners which were used to tune the frequency have an effect on the field distribution on the beam axis. Only one tuner in the coupling cell has no effect on the field within the accelerating sections.

This means, that after frequency tuning one has to look at the field distribution in a second step. Using the same inductive tuners as with the frequency tuning it is possible to do a rough voltage tuning considering that the effect of

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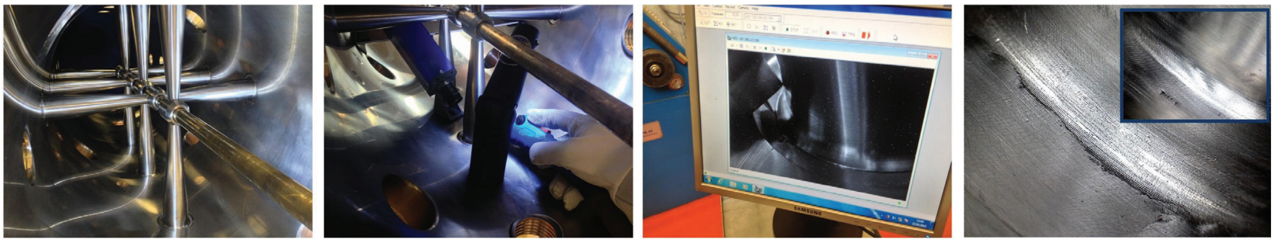

Figure 3: Pictures of the manufacturing process demonstarting the alignment and welding methods.

different tuners has to be inverse to each other in terms of frequency. The final position of these plungers are now very moderate: This means, that the plungers are leaping into the cavity between 50 and 150 mm.

Tuners always act on a large region within the cavity and are therefore not capable to reach high local precision. Final results were gained by manipulating the g/L ratio. This means, that the lengths of different drift tubes have to be changed. This was possible with the dummy drift tube structure that was installed in the beginning. With this technique the local gap voltages can be in general varied up to $\pm 20\%$ - towards the cavity ends.

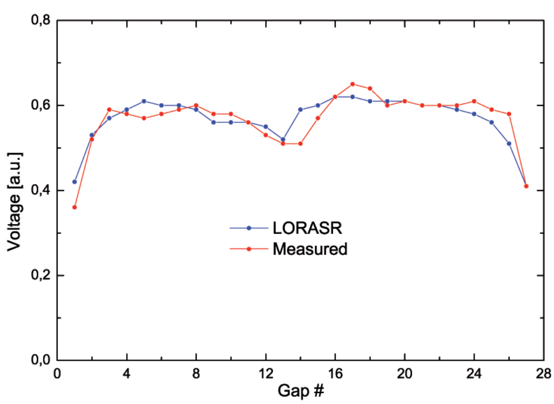

Figure 4: Comparison between measured and simulated voltage distribution of the CCH power prototype.

Figure 4 shows the latest measured and normalized voltage distribution in comparison to the target voltages which were calculated by the beam dynamics code LORASR. This distribution would be acceptable as it shows no changes in transmission according to the beam dynamics simulations. So, the tuning of a coupled CH cavity by that concept looks feasible.

MANUFACTURING

The two main outer cylinders and the intertank section have been already manufactured and tested in 2012. By this time a preliminary drift tube structure made from aluminum was used.

Using the dimensions of the aluminum structure the stainless steel structure was produced using a challenging design in which the stem is produced in one part and only the drifttube is welded in afterwards. It could be shown, that this technique gives very good results concerning the alignment and the vacuum properties.

The stems were then put into the cylindrical tanks as shown in Fig. 3 (left). The alignment within the cavity is done by a brass shaft and is lateron confirmed with optical targets and a telescope.

Figure 3 also shows the new camera assisted welding method which produces high quality welding seems, so only very little grinding and polishing has to be done afterwards. The surfaces are then well prepared for galvanic copper plating.

Vacuum testing of the stems is done in each case immediately after welding and again after polishing. This is quite important because due to the geometrical difficulties of the stem configuration it is only possible to weld the stems successively after finishing all steps at a given position moving from the centre to the outer regions. It is expected, that the welding of all stems will be finished by summer this year. This means that after the copper plating the final high power tests of the prototype might begin end of this year.

CONCLUSION

This paper has described the process of building and tuning a coupled CH - cavity according to a reliable RF design. It was proven that the applied techniques for manufacturing and tuning are capable of building up a 27 cell prototype cavity. Referring to the latest measurements that have been shown, this novel type of DTL has a potential to become an attractive alternative for future linac designs.

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