RF TUNING TESTS ON THE COUPLED FRANZ RFQ-IH-DTL

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Abstract

The neutron beam at the FRANZ facility will be produced by the $^{7}Li(p,n)^{7}Be$ reaction using an intense 2 MeV proton beam. These protons will be accelerated from 120 keV to 2 MeV by a coupled 4-Rod-type RFQ and a 8 gap interdigital H-type structure (IH-DTL). This coupled RFQ-IH-cavity will be operated at 175 MHz in cw mode and it has a total length of about 2.3 m. The two structures (RFQ, IH-DTL) are internally coupled inductively, and consequently, only one RF-amplifier providing a total power up to 250 kW is needed for operation. The IH-DTL was RF tuned while coupled with an Al-RFQ model, before final IH-DTL installation in the FRANZ cave, while the original RFQ was already installed in the beam line. After RF power and beam tests, the coupled structure will be installed to continue with RF and beam tests. This paper will focus on the RF tuning process and the main results will be presented.

INTRODUCTION

The Frankfurt Neutron Facility (FRANZ) is a project located on the Campus of Frankfurt University – Physics Faculty [1,2]. It aims at producing a high intensity neutron beam with an energy range of 1 to 200 keV using a 2 MeV primary proton beam. The production process is the $^{7}Li(p,n)^{7}Be$ reaction with an approximatly thermal energy spectrum of the neutron of about 30 keV [2]. These neutrons will be used to perform nuclear astrophysics experiments [3].

Within this project a high intensity proton beam of up to 200 mA will be accelerated from 120 keV to 2.0 ± 0.2 MeV [2]. This acceleration will be performed by a linac that consists of a coupled 4-Rod-RFQ and IH-DTL [2,4-6]. Figure 1 shows a scheme of the coupled cavity [2].

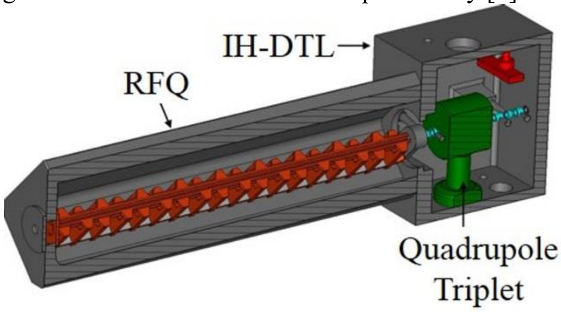

Figure 1: A 3D model for the coupled RFQ-IH-DTL cavity.

The main parameters fro both RFQ and IH-DTL are summarized in Table 1 [2].

This paper will focus on the new measurements and the tuning process for the coupled cavities.

Table 1: Main Parameters for the Coupled RFQ-IH-DTL

Parameter	Value	
Freuency (MHz)	175	
Beam Current (mA)	50 (140)	
Coupling Factor k	0.005	
	4-Rod-RFQ	**IH-DTL**
Energy Range (MeV)	0.12 – 0.7	0.7 – 2.0
Total Length (m)	1.7	0.6
RF Losses (kW)	95 (140)	60 (60)
4-Rod-RFQ		
Electrode Voltage (kV)	62 (75)	
R_p (kΩm)	70	
Number of Stems	18	
IH-DTL		
Effective gap Voltage (kV)	80 - 350	
$Z_{shunt,eff}$ (MΩ/m)	62	
Number of Gaps	8	

INDUCTIVE COUPLING CONCEPT

The coupling between RFQ and IH-DTL will help to reduce the rf amplifier costs and utility space, Moreover, this coupling option will minimize the length of the inter-tank section between RFQ and IH-DTL, which is in favour of the beam dynamics properties.

The inductive internal coupling option has been selected for the FRANZ linac case against other options like power splitter, phase shifter and galvanic internal coupling [2].

The inductive coupling is done by just opening the connection wall between both structures and placing it the steerer between the RFQ electrodes and the first IH-drift tube (Figure). The magnetic field penetrates through the coupling cell inducing the coupling between the last RFQ stem and the first stem of the IH-cavity. The setup allows for a flexible tuning in frequency as well as in the voltage ratio [2]. The main challenge of the inductive coupling is the matching of resonance frequency, field flatness, and the voltage amplitude ratio between RFQ and IH-DTL simultaneously [6].

Figure 2 shows the detail of the coupling geometry and the magnetic field path between both structures.

CAVITY TUNING

For two coupled resenators like RFQ and IH-DTL, one can solve the problem by assuming that the independent cavities have the same resonace frequency ω_0 before coupling.

Then, the coupled structue will show the following frequencies [7]:

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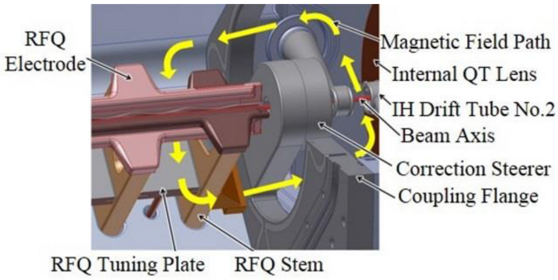

Figure 2: Detailed view for the inductive coupling between RFQ and IH-DTL including the correction steerer.

$$\omega_1 = \omega_0 \cdot \frac{1}{\sqrt{1+k}} \qquad \text{“}0-mode\text{”} \qquad (1a)$$

$$\omega_2 = \omega_0 \cdot \frac{1}{\sqrt{1-k}} \qquad \text{“}\pi-mode\text{”} \qquad (1b)$$

With k being the coupling factor as defiend by the means of the frequency splitting:

$$\delta\omega = \omega_2 - \omega_1 \cong \omega_0 \cdot k \qquad (1c)$$

The tuning process will be performed as follows:

- Both cavities (RFQ, IH) will be tuned to the same frequency by using the tuning plates for the RFQ (Figure 3) and static and movable tuning for the IH-DTL (Figure 4).
- The next step is to tune the voltage ratio U_{IH}/U_{RFQ} and the field distribution close to the target values. Figure 5 shows the RFQ frequency dependence on the tuner plate height.
- Finally, the resonance frequency of 175 MHz has to be adjusted.

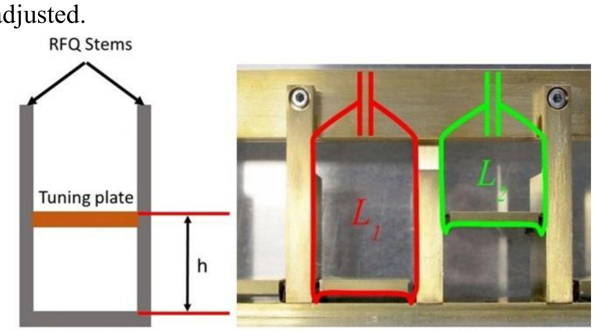

Figure 3: The tuning plate concept for RFQ tuning.

The tuning plates and static tuners give a tuning range of ±25 MHz (RFQ) and ±2 MHz (IH-DTL).

Figure 6 shows the resonance and plunger frequencies dependent on the tuner height for the IH-DTL.

CAVITY MEASUREMENTS

After the tuning of the coupled RFQ-IH-DTL structure to the operating frequency 175 MHz (Figure 7), the on axis electric field was measured using the bead-perturbation measurement techniques (Figure 8).

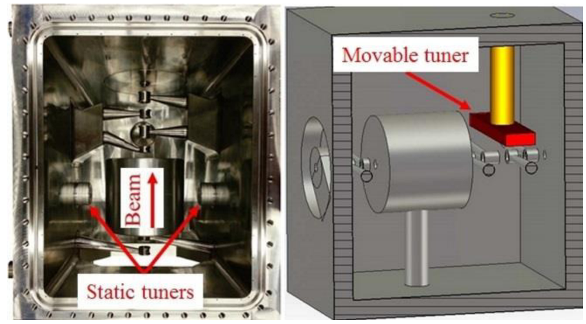

Figure 4: The position of the static and movable tuners for the IH-DTL cavity.

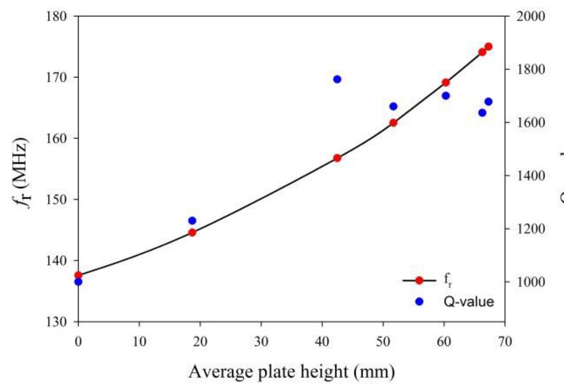

Figure 5: The resonance frequency and the quality factor versus the average height of the tuning plate for the RFQ.

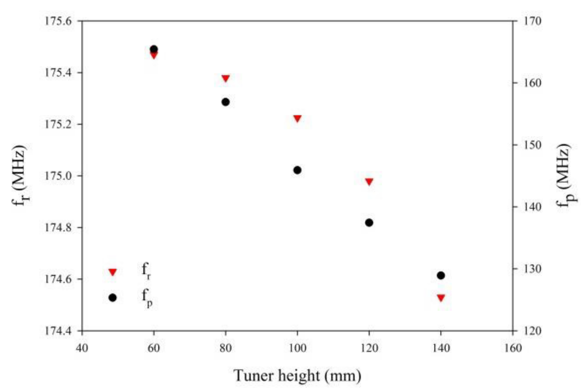

Figure 6: The resonance and plunger frequency in case of IH-DTL versus the movable tuner height and at an optimized static tuners shape.

The measurements were done by running a small Teflon ball on axis through both structures.

Due to the specialty of this structure, one needs to perform extra measurements for the transverse RFQ electric field (Figure 9) which helps to make a gauging between the measured gap voltages and the RFQ vane-vane voltage.

To achieve this, the bead was moved transversally across extensions on the top of the upper two mini-vanes (see Fig. 9), which gives an electric field curve like indicated in blue in Figure 8, and a direct comparison with the on axis measurement in red.

Due to the inhomogeneous quadrupole field along the RFQ axis it is important to keep the bead very well centered to get the voltage distribution along the vanes.

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The effective gap voltage was calculated from the measured longitudinal electric field integration (Figure 8), and including the particle velocity dependence (transit time factor).

These values were controlled and compared to he expected effective voltage from the beam dynamics calculations. This comparison can be seen in Figure 10.

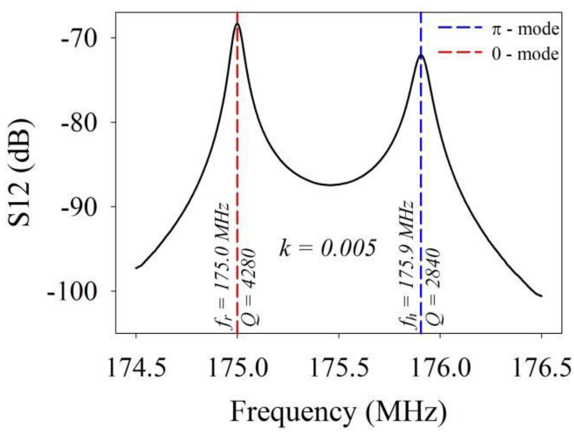

Figure 7: The 0 – and π – mode resonances for the coupled RFQ-IH-DTL structure.

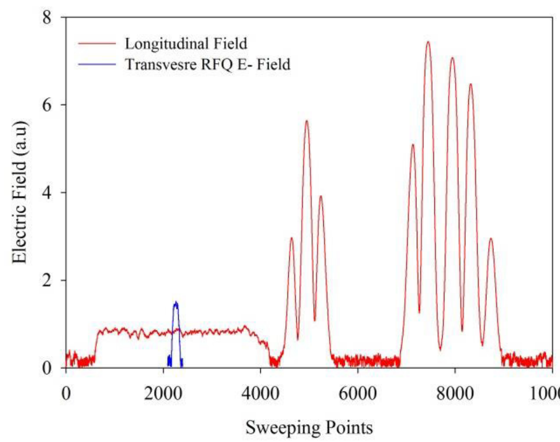

Figure 8: The on axis longitudinal electric field for the RFQ and IH-DTL (red) and the transverse RFQ electric field as measured in Figure 9.

CONCLUSION

The coupling between RFQ and IH-DTL has been successfully demonstrated.

The tuning concept for both RFQ model and IH-DTL has been tested using the tuning plates for the RFQ, and the static and the movable tuners for the IH-DTL.

The voltage ratio can be matched most effectively by only shifting the position of the last RFQ tuning plate. The measurements show that 1 mm plate shift makes about 5% voltage ratio shift between RFQ and IH – DTL, this is regarded as an acceptable tuning sensitivity.

The next step will be the installation of both structures in the FRANZ cave followed by the first test with a 2 MeV beam.

Figure 9: The bead- perturbation measurement for the RFQ transverse electric field and vane-vane voltage.

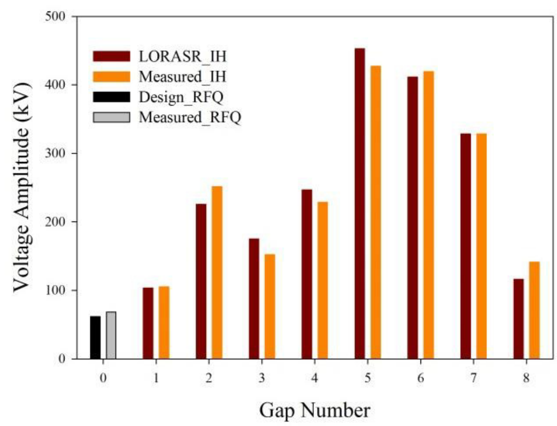

Figure 10: The measured effective gap voltage from bead-ball measurements versus the design gap voltage from the beam dynamcis.

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