A COUPLED RFQ-DRIFT TUBE COMBINATION FOR FRANZ

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Abstract

The Frankfurt Neutron Source at the Stern-Gerlach-Zentrum (FRANZ) [1] will comprise a short 175 MHz linac sequence consisting of a 1.75 m long 700 keV 4-rod type RFQ [2] followed by a 60 cm IH-DTL [3] for proton acceleration up to 2 MeV. The beam current is 200 mA at pulsed and up to 30 mA at c.w. operation. The aim is to have a very compact device driven by only one rf-amplifier to reduce costs and required installation space. A strong coupling between the RFQ and the IH resonators will be realized by a direct connection between the last stems of each resonator through the common end wall. The accelerators could also be driven separately by just removing the coupling. The distance between the end of the RFQ electrodes and the midplane of the first DTL gap is only 5 cm leaving some place for a x-y-steerer. Preliminary rf-simulations have been carried out together with accompanying measurements on rf-models.

INTRODUCTION

The coupling of different rf-components is very attractive for most recent accelerator development. It leads to more compact devices using a common rf-amplifier and control system. Thus the overall size and the costs of the set up can be reduced drastically.

Many examples are planned or already in existence. For instance a coupled RFQ-drifttube combination that has been developed for medical application at the HICAT (Heavy Ion Cancer Therapy) center in Heidelberg by the IAP, where a 4-rod-RFQ and a 2 gap rebuncher sequence are merged [4]. This concept has been applied recently to other treatment facilities by industry several times [5]. Coupled CH-DTL cavities are a major achievement in the development of the FAIR Proton Injector at GSI [6, 7].

Two coupled rf-systems with same resonance frequency can be driven in 0 or in π-mode, which can lead to very interesting applications. When they are excited both at the same time, the resulting beat resonance can be used to reduce thermal load where pulsed operation is not feasible like in the case of the former LEP normal conducting accelerator at CERN, where the accelerator cavity was coupled to a low loss spherical resonator [8].

Presently investigations on a resonant coupling between RFQ an IH-DTL for FRANZ are performed. Unlike the aforementioned medicine RFQ, both parts are tuned to the same resonance frequency and are clearly separated by means of a metallic wall.

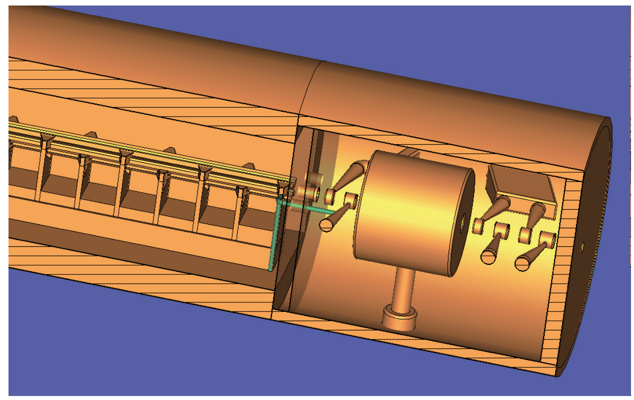

Figure 1: The coupled 4-rod-RFQ-IH-DTL structure. The coupling bridges are colored in green.

Table 1: Main Parameters

Operating frequency	175 MHz
Ion species	protons
Length of RFQ	1.75 m
Length of IH-DTL	0.6 m
Tank diameter IH	510 mm
Height of RFQ-Stems	145 mm
# of RFQ cells	97
# of matching in cells	4
# of IH-gaps	8
Input energy	120 keV
Input emittance (absolute) $\varepsilon_{x,y}$	150 π mm mrad
Electrode voltage (RFQ)	75 kV
Max. gap voltage of IH-DTL	300 kV
Exp. Power consumption RFQ	150 kW
Exp. Power consumption IH	45 kW
Current	max. 200 mA
Output energy RFQ	700 keV/u
Output energy IH-DTL	2 MeV
Coupling factor k	≈0.03

COUPLING

The distance between 0 and π-mode is given by $\Delta\omega = \omega_0 \cdot k$, where ω_0 is the uncoupled resonance frequency and k is the coupling strength. The coupling should be sufficiently strong ($k > 0.01$), to guarantee a good separation between the modes.

As a first approach two galvanic coupling bridges between IH-structure and 4-rod-RFQ were under investigation. They are connecting the last two RFQ stems to the first two DTL stems (fig. 1). Microwave Studio (MWS) [9] simulations resulted in a preliminary coupling factor of $k \approx 0.03$ depending on the exact geometry, which is not fixed in every detail yet. They have to be water cooled at c.w. operation, which could be done by a coaxial cooling system entering at the RFQ side or just by a simple tube geometry with a one way passage of the water. The cavities could also be operated separately by removing the bridges and a subsequent tuning of the RFQ. An alternative coupling over a short external power transition line could also be realized.

TUNING CONCEPT

One of the most challenging aspects is the tuning of the coupled system during operation. Not only the resonance frequency of the whole system has to be stabilized, the amplitude relation between the cavities has to be kept constant.

The voltage ratio between two coupled resonators can be controlled by a variation of their individual resonance frequency. If the intrinsic resonance frequency of one resonating cell is tuned down, the voltage will increase here and decrease in the other resonator at 0-mode and vice versa at π-mode. This can be shown by treating local frequency detuning within a chain of coupled resonators by means of perturbation theory, which results in field contributions from other unperturbed modes [10]. In the case of the 4-rod RFQ for instance, the field distribution is tuned by means of variable tuning plates. They increase the intrinsic resonant frequency of one cell, which decreases the voltage locally at 0-mode [11].

For the coupled RFQ-DTL combination frequency and amplitude control can be performed by rf-tuning devices (plungers), as illustrated in fig. 2. Both states of the system must be monitored and controlled in separated time slots to avoid instabilities.

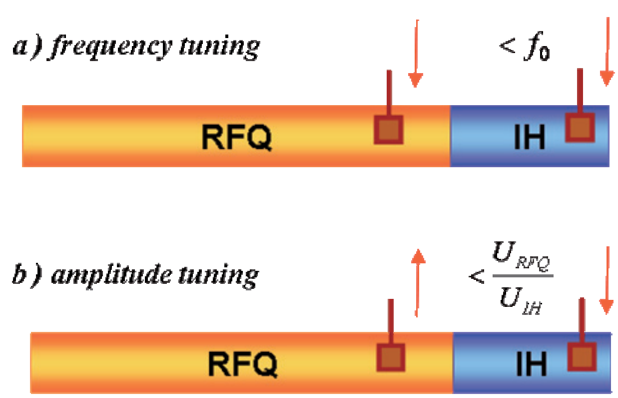

Figure 2: Tuning of frequency and amplitude during operation. Both tuners are acting inductively.

IMPACT ON RFQ DESIGN

The coupling will have a substantial effect on the field distribution within each cavity. For instance the electrode voltage within the RFQ increases towards the end where the IH-structure is connected to, which can be balanced by tuning plates. For this purpose detailed investigations with MWS have been performed to get information on how the range of the plates respectively the height of the stems has to be extended in comparison to the uncoupled case. To get reliable results it is important to include the aperture progression along the structure implying a sufficient mesh resolution to cover these details. A detailed investigation on the precision of MWS-simulations regarding RFQ-resonators can be found in reference number [12]. Since the exact RFQ beam dynamics is not yet fixed in detail, a reasonable aperture progression with an average of $\bar{a}$ = 5.44 mm for a 1.6 m structure with electrode voltage U_{el} = 85 kV is assumed for these calculations on the basis of a preliminary design proposal [13].

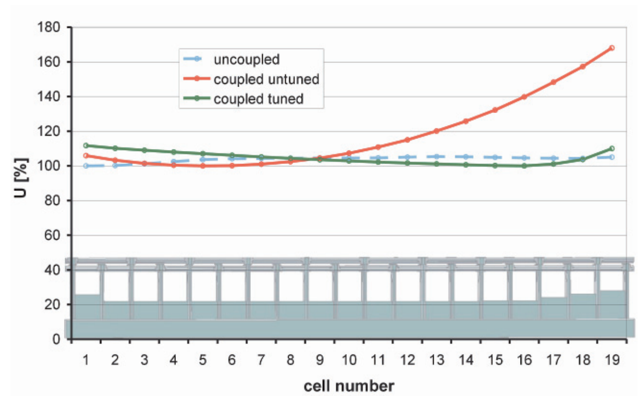

Figure 3: Simulation of the field distribution on RFQ-axis. The different height of tuning plates is indicated for the coupled and tuned case. The aperture is held constant here.

In a first step the positions of the tuning plates for a balanced field distribution were simulated for the uncoupled case assuming a 20 stem structure. Then the coupling was introduced, which gave a field distortion of +70% (fig. 3) towards the end of the RFQ, where it is connected to the IH-structure. To rebalance this disturbing effect, the tuning plates had to be moved up in that region to flatten the field distribution again. To compensate the consequent raise of the resonance frequency, the height of the stems had to be extended by Δs = 5 mm which results now in an upper limit for the distance between beam axis and tuning plates of 145 mm, giving some safety margin of 30 mm to cover both cases. It shall be emphasized again that these investigations have been carried out under the assumption of some reasonable but not yet exactly fixed design parameters (aperture progression, number of stems, electrode voltage etc.), which will have to be included successively in future simulations.

IH-DTL DESIGN

The IH-DTL will comprise eight accelerating gaps and one focussing triplet lens for an energy gain of 1.3 MeV within 60 cm. The structure has been optimized to get maximum field concentration on beam axis. The gap voltages are well tuned to the values given by beam dynamics simulations with LORASR (fig. 4). The field distortion of the IH-structure due to the coupling to the RFQ can be cancelled out by choosing the right position to where the bridges are connected to the IH-stem. The optimum close to the point the voltage corresponds to the voltage on top of the RFQ-stem.

The expected power consumption of the IH-DTL is 45 kW. For c.w. operation it is mandatory to do investigations on power dissipation and thermal load. Cooling of tank and drift tube stems of the IH structure are mandatory. A heating of less than $\Delta T = 20$ K is considered to be uncritical in terms of a stable operation. Thus the maximum acceptable power dissipation on the drift tube averages to $\overline{P}_{DT} = 1.5$ W/cm^2 if a direct water cooling of all stems is assumed. Calculations have been executed under the assumption of a linear progression of power dissipation from $P_{\mathrm{DT,max}} = 3$ W/cm^2 on bottom to zero on top of the Drifttube (fig.5).

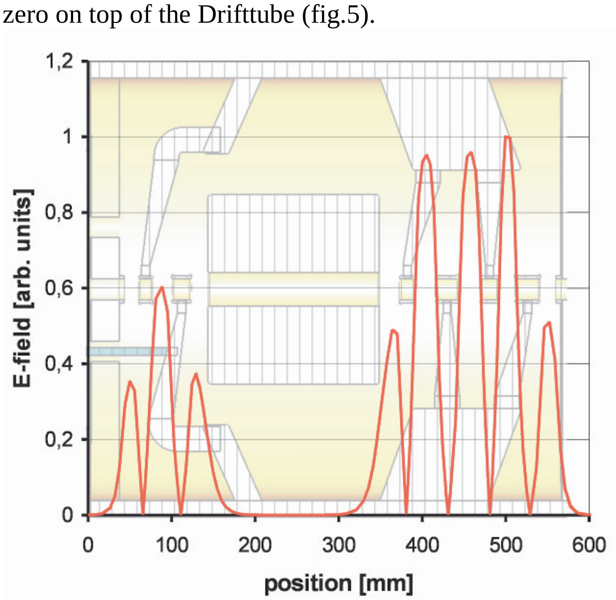

Figure4: Field distribution on beam axis along IH-DTL.

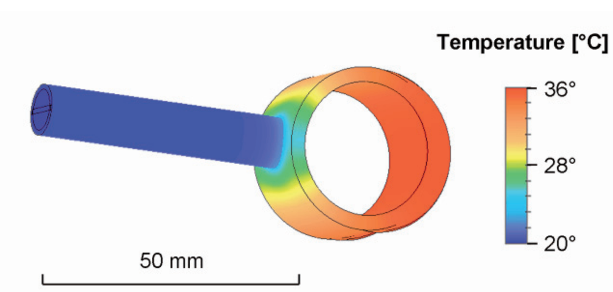

Figure 5: Simulation of thermal load on an IH-drifttube.

CONCLUSIONS

For the FRANZ project the technique of coupled rf-cavities yields very attractive applications options. Simulations on a coupled RFQ-DTL combination are rather promising. The tuning concept has been demonstrated by means of a "prove of principle" experiment on two coupled pillboxes. It is planned to build up a more sophisticated rf-model that reflects the design of the RFQ-IH-combination more in detail. In addition further investigations on thermal load on the rf-cavities are required. Next step will be the improvement of the coupling design with respect to more detailed beam dynamics simulation data.

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