REBUNCHER CAVITIES FOR THE FRANZ BUNCH COMPRESSOR†

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Abstract

The Frankfurt Neutron Source (FRANZ) currently under construction at IAP is designed to produce short neutron pulses at high intensity and repetition rates [1, 2]. To achieve a bunch length of one nanosecond despite the high space charge forces, a bunch compressor of the Mobley type [3] using four dipole magnets and two rebunchers has been developed [4]. The first rebuncher cavity, a quarter-wave resonator operating at 87.5 MHz, has to offer nine apertures due to the multi-trajectory system. Additionally the gaps have to be adjusted longitudinally so that all bunches arrive at the correct rf phase. The second rebunching cavity will provide final focusing as well as an energy variation of ± 0.2 MeV in front of the target and will be operating at 175 MHz. This paper presents the design of these novel cavities as well as the simulated beam dynamic characteristics.

INTRODUCTION

At the FRANZ facility a 175 MHz proton linac will deliver 100 ns long macrobunches with a repetition rate of 250 kHz into a bunch compressor. The machine is designed to deliver an average 200 mA beam current within these macrobunches. The compressor will merge nine microbunches into a one nanosecond long pulse. On the target, neutrons are produced via the $^7\mathrm{Li(p,n)}^7\mathrm{Be}$ reaction. High intensity neutron pulses are especially interesting for astrophysical measurements [5].

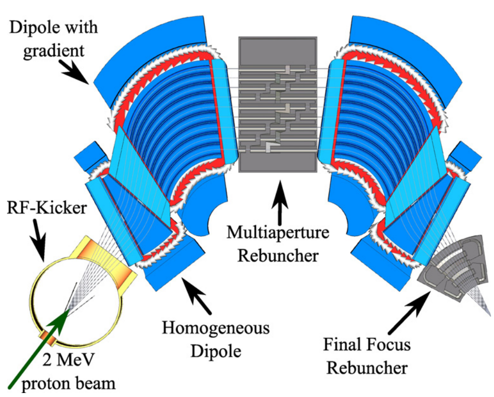

Figure 1: Current design of the bunch compressor.

The bunch compressor ARMADILLO (shown in figure 1) consists of a magnetic bending system which guides nine microbunches deflected by a kicker on different paths. The compression is achieved by transit time difference. More information on the general design of the system and the layout of the dipoles can be found in another contribution to this conference [4].

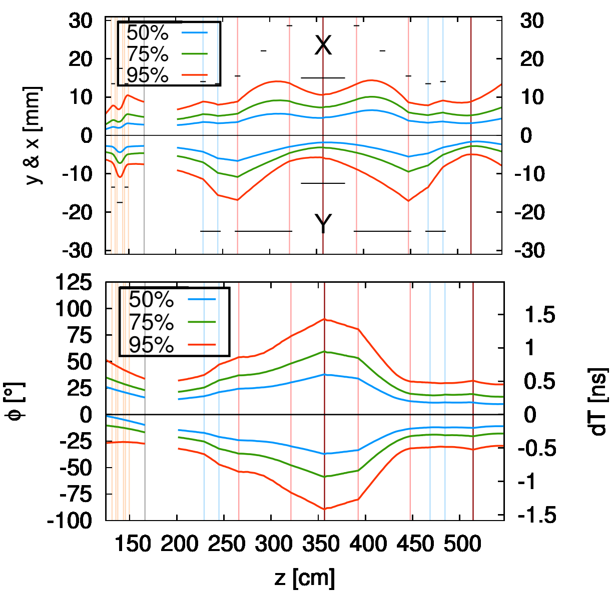

Figure 2: Transversal and longitudinal beam dynamics for the central trajectory in the bunch compressor.

Transversally the beam can be transported with less than 5% loss by utilizing weak and edge focusing (figure 2). Longitudinally however, the beam effectively drifts freely in the first half of the system. Due to the high space charge forces this leads to a phase spread in the range of $\pm 90°$* at the symmetry axis of the system. Thus at this point a rebuncher with a lower frequency than 175 MHz is needed to avoid major aberration in the longitudinal phase space. We have chosen the half harmonic, 87.5 MHz. The required voltage is around 140 kV. About 35 cm in front of the neutron production target a second rebuncher is placed, providing final focusing with a voltage around 100 kV. Additionally an energy variation of ± 200 keV will be possible.

THE MULTI-APERTURE REBUNCHER

The rebuncher on the symmetry axis needs to act on each beam path separately, therefore multiple apertures are necessary. The bunches reach the compressor with a time difference of $5.7\,\mathrm{ns} = (175\,\mathrm{MHz})^{-1}$ each. On the symmetry plane only half of this difference remains. With the

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*Defined with respect to 175 MHz.

Table 1: Parameters of the Multiaperture Rebuncher

Frequency	87.5 MHz
Dimensions ($w \times h \times d$)	70 cm×35.4 cm×42.5 cm
Drift tube geometry ($w \times h$)	30×25 mm (rounded with $r = 12.5$ mm)
Transverse distance between drifttubes	12.5 . . . 23.56 mm

rebuncher gaps operating at 87.5 MHz only two or three bunches out of one macropulse would arrive at the same rf phase. This can be amended by offsetting the gaps on adjacent beam paths by $\beta\lambda_{87.5\,\mathrm{MHz}}/4$ in longitudinal direction respectively. As it is not neccessary that the bunches on all trajectories are rebunched within the same rf period, it is already sufficient to offset the gaps in groups of four.

As an additional requirement it is necessary to increase the voltage from approximately 110 kV on the longest to 165 kV on the shortest trajectory to provide different focal lengths. To achieve an effective voltage of 140 kV with the ordered 18 kW transmitter, a shunt impedance of about 1.1 MΩ is required.

Cavity Design

The current design of the multiaperture rebuncher is a quarter-wave resonator with two gaps. The model simulated with CST Microwave Studio is shown in figure 3. The geometric parameters can be found in table 1. The aforementioned variation of the voltage distribution is achieved by shifting the stem to the side of the cavity.

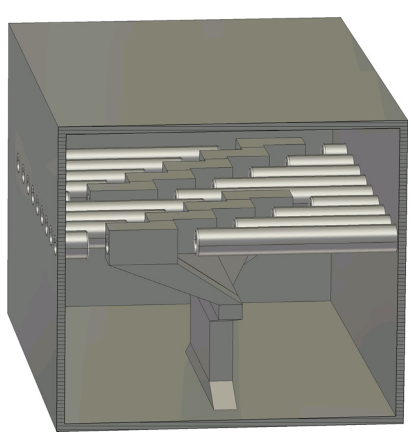

Figure 3: Quarter-wave resonator providing nine beam paths.

Especially challenging are the small distances between the trajectories. Due to the displacement of the gaps, drift tubes on different potentials are close to each other, in parts within distances smaller than the gap lengths. This leads to a decrease in shunt impedance and to significant electric fields between the drift tubes on neighbouring beam paths. These fields are particularly distinctive between the fourth and the fifth trajectory, where differently charged drift tubes sit side by side. To avoid another of these sections the drift tubes are grouped in four and five (instead of two groups of 4 with the gaps on the first trajectory shifted by an entire period once again), trading an increase in length of 56 mm for an increase in shunt impedance by approximately 250 kΩ (∼10 %).

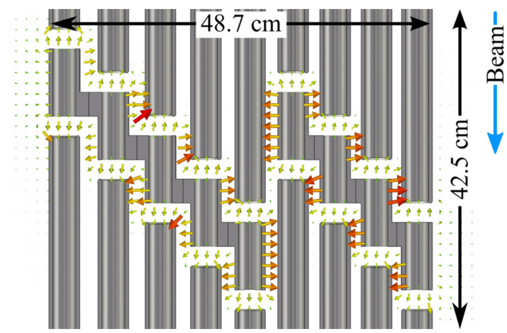

Figure 4: Electric field distribution at the drift tubes. The electric field in the gaps and between the drift tubes in transverse direction is in the same order of magnitude. One can also see the transverse electric field component within the gaps.

Attention should be paid to the transverse fields within the gaps. The displaced gaps lead to an electric field component in the x-direction, a vertical component is added by the supports of the central drifttubes. These dipole fields have to be kept tolerably small by the choice of moderate gap lengths, to avoid an unwanted deflection of the beam. In terms of rf power loss however a large gap length is preferable, as can be seen in figure 5.

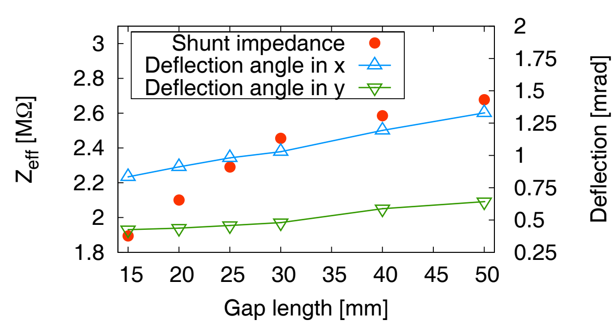

Figure 5: Effective shunt impedance Z_{eff} of the multiaperture rebuncher as well as the *total* bunch deflection due to the transverse fields. The shunt impedance for all gap sizes is larger than the required value of 1.1 MΩ.

Beam Dynamics

To examine the effects of the transverse fields, a new particle tracking code for non-relativistic beams has been developed. The electromagnetic fields are imported directly from Microwave Studio. The space charge forces are calculated internally via the particle-in-cell method, offering a

Multigrid and a Biconjugate Gradient Stabilized algorithm as solvers for Poisson's equation.

The simulations were only done for the central trajectory so far, with the electric field calculated at one millimeter stepsize within the gaps. The total deflection of the bunch is within a negligible range (see figure 5). However due to the time varying fields particles with larger phase $\Delta\phi$ get a larger transverse kick. This can be seen in the $\Delta\phi$-$\Delta x'$-projection in figure 6, where a string of particles with no transversal offset and angle was transported through the rebuncher. There is a deflection in the vertical plane as well, as large as 5 mrad for a gap length of 50 mm. The influences of the aberration have to be studied in detail to choose an appropriate gap size.

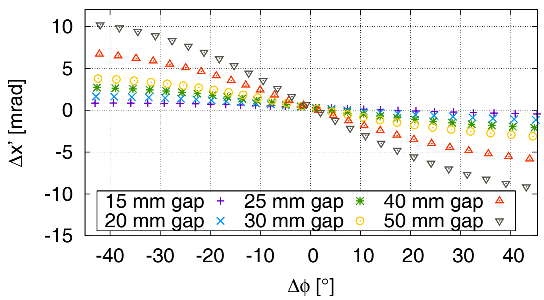

Figure 6: $\Delta\phi$-$\Delta x'$-projection in the relevant range, of a bunch consisting of a string of protons 5° apart after transport through the multiaperture rebuncher.

THE FINAL FOCUS REBUNCHER

At the location of the second rebuncher the bunches have compensated their transit time difference and approach the target within an opening angle of about 20°. Because of the low transversal distance, separate drift tubes are not possible. For this reason a geometry with curved drift tubes is necessary.

Table 2: Characteristics of the Final Focus Rebuncher

Frequency	175 MHz
$\beta\lambda$	11.25 cm
Gap size	25 mm
Vertical aperture	30 mm
Arc length in the center of the gaps	19.8 cm, 17.8 cm, 15.8 cm, 13.8 cm
Opening angle of the cavity	55°
Cavity length	25 cm
Cavity height	37.3 cm
Quality factor	10200
Shunt impedance	5.7 MΩ (22.8 MΩ/m)
Power loss at 230 kV	9.3 kW
Available transmitter power	12 kW

A number of different resonator types were examined: two-gap quarter-wave and spoke resonators, a four-gap quarter-wave resonator with an additional drift tube suspended from the top as well as a quarter-wave/halfwave-hybrid. Although the last two options are on par in terms of shunt impedance, the last option is currently preferred because the field-free upper half of the resonator provides enough space for a large tuner. The model can be seen in figure 7, the geometric parameters as well as the simulated characteristics can be found in table 2.

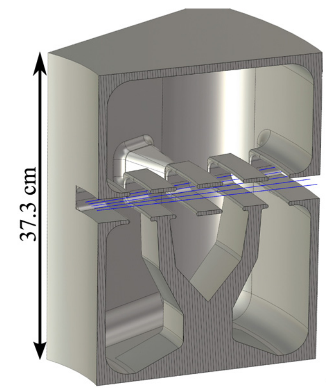

Figure 7: Four gap final focus rebuncher.

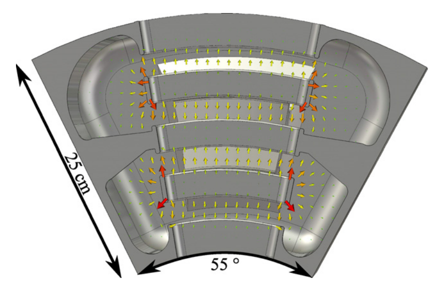

Figure 8: Electric field in the final focus rebuncher.

CONCLUSION

Two rebuncher cavities for the bunch compressor at FRANZ have been designed. From an rf point of view both designs fulfill their requirements. The beam dynamics within the multiaperture rebuncher is challenging due to transverse fields and has to be studied further on in detail.

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