KONUS BEAM DYNAMICS DESIGN OF A 70 mA, 70 MeV PROTON CH-DTL FOR GSI-SIS12*

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Abstract

The future scientific program at GSI needs a dedicated proton injector into the synchrotron SIS, in order to increase the proton intensity of the existing UNILAC/SIS12 combination by a factor of 70, resulting in 7×10^{12} protons in the synchrotron. A compact and efficient 352 MHz RFQ - CH-DTL combination based on novel structure developments for RFQ and DTL was worked out. For DTL's operated in an H-mode like CH-cavities (H210-mode), the shunt impedance is optimized by use of the KONUS beam dynamics. Beam dynamics simulation results of the CH-DTL section, covering the energy range from 3 to 70 MeV, with emphasis on the low energy front end are presented. Optimization aims are the reduction of emittance growth, of beam losses and of capital costs, by making use of the high acceleration gradients and shunt impedance values provided by the Crossbar H-Type (CH) structure. In addition, the beam dynamics design of the overall DTL layout has to be matched to the power limits of the available 352 MHz power klystrons. The aim is to power each cavity by one klystron with a peak rf power of around 1 MW.

DESIGN CRITERIA AND PARAMETERS

KONUS Beam Dynamics and H-Mode Cavities

First investigations on proton beam acceleration with a CH-DTL were presented in ref. [1].

For the proposed GSI Proton Injector the KONUS beam dynamics (“Kombinierte Null Grad Struktur” – Combined 0° Structure [2]), together with the use of H-mode structures (“Crossbar H-Type” - CH) are foreseen for the energy range from 3 to 70 MeV. The advantages of this concept are:

- High accel. gradients (up to 6 MV/m) due to the high shunt impedance of the CH-DTL and the KONUS beam dynamics concept (“slim” drift tubes without integrated quadrupole lenses housed in each multi-cell cavity).
- Simplified construction, maintenance and reduced number of components.
- Reduction of project costs and overall linac size.

Design Parameters

Compared with the initial layout presented in ref. [3] the following modifications were necessary, leading to an updated overall linac design:

- The optimum RFQ-DTL transition energy was investigated and finally fixed at 3 MeV. This opens the option to realize the RFQ as 352 MHz 4 rod-RFQ in one cavity [4].
- The linac output energy has been increased and fixed at 70 MeV.
- The design current has been increased from 50 to 90 mA (safety factor included): for operation a maximum linac output current of 70 mA is specified.
- The operating rf frequency of 352 MHz along the whole linac has been fixed now.

The latter decision was motivated by the manifold offer of rf hardware (power klystrons) at that frequency. The exit energy and beam current were chosen with regard to a 10 – 15 turn injection scheme into the horizontal acceptance (150 π mm mrad) of SIS.

Table 1 summarizes the CH-DTL relevant Proton Linac beam parameters:

Table 1: Basic beam parameters specified for the Proton CH-DTL section

General	
rf frequency	352 MHz
macro pulse length	0.1 ms
rep. rate	5 Hz
macro pulse current at linac exit	90 mA (design current; 70 mA spec. for operation)
RFQ exit	
beam energy	3 MeV
transverse beam emittance (norm.)	1.5 mm mrad
CH-DTL exit	
beam energy	70 MeV
transverse beam emittance (norm.)	2.8 mm mrad
beam momentum spread	$\pm 5 \times 10^{-4}$

Design Criteria and Restrictions

For the design of the 3-70 MeV CH-DTL section some constraints had to be taken into account:

- The choice of the RFQ-DTL transition energy is a trade-off between an adequate maximum output energy of the RFQ and the minimum input energy acceptable for the DTL. Covering a larger energy range by the RFQ reduces the acceleration efficiency and can lead to problems with respect to tank length, flatness and coupling between structure cells. In the DTL short period lengths

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lead to construction problems. Different layouts with DTL input energies from 2.5 to 4 MeV were investigated; finally 3 MeV were chosen as a good compromise at the specified beam intensity. In addition, the 3 MeV MEBT section has to be carefully designed at that low transition energy.

- For matching to commercial klystrons (352 MHz, 1.3 MW), the maximum total power consumption per cavity (rf + beam power) should not exceed 1.1 MW. Thus cavity shunt impedances have to be carefully optimized for the whole 3-70 MeV energy range. Effective shunt impedances ranging from about 100 MΩ/m at injection energy down to 40 MΩ/m at the linac exit seem feasible [5].

  To keep below the 1.1 MW rf power and according to the achievable shunt impedance, parameters like the max. cavity length, number of gaps and acceleration gradient have to be adapted (especially towards the high energy end) and are not solely defined by the KONUS beam dynamics.

BEAM DYNAMICS DESIGN OF A 4-70 MeV CH-DTL SECTION

The beam dynamics design of the CH-DTL is still under development. Different schemes have been worked out for different injection energies and beam currents.

The results presented in Figures 1 and 2 show one intermediate step achieved for an input energy of 4 MeV and a beam current of 70 mA. Calculations were performed by using RFQ output distribution data (the "core" out of 20000 particles was used).

The final layout will basically depend on the DTL frontend design (MEBT and first CH-DTL tank, see next chapter).

Nevertheless these intermediate results give a realistic view on the expected CH-DTL layout parameters, e.g. overall length, number of tanks, acceleration gradients, quadrupole lens strengths. Furthermore it is shown that the beam requirements at the linac exit, as mentioned in Table 1, can be achieved.

The parameters of the CH-DTL section design presented here are summarized in Table 2, together with the resulting beam parameters.

Table 2: Proton Linac CH-DTL structure parameters (4-70 MeV, 70 mA intermediate design)

Cavity parameters		
total CH-DTL section length	21 m	
cavity lengths	0.6 – 2.2 m	
number of gaps	12 - 17	
accel. gradient	6.3 – 2.7 MV/m	
total rf input power	500 – 1100 kW	
Beam parameters	**Input**	**Exit**
ε_{tr} (99%,norm.)	1.5	1.9 mm mrad
ε_{tr} (rms)	0.31	0.35 mm mrad
ε_{long} (99%)	0.2	0.45 MeV deg
ε_{long} (rms)	0.044	0.075 MeV deg
transmission	100 %	

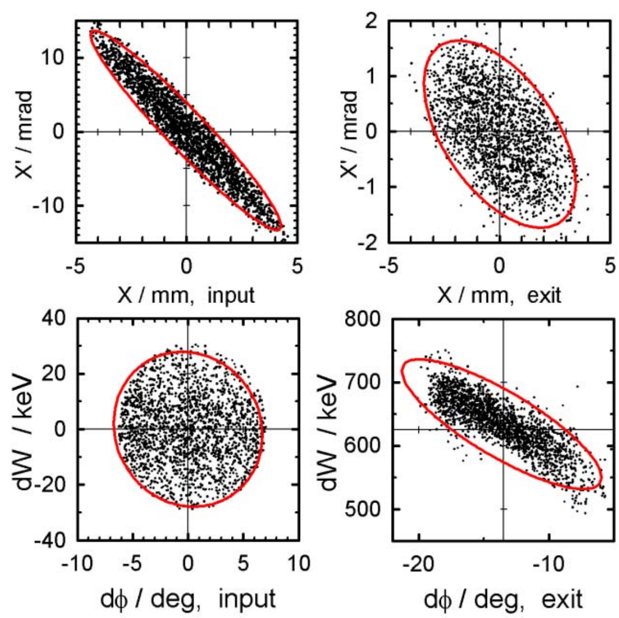

Figure 2: Transverse and long. particle distributions at entrance and exit of the CH-DTL section.

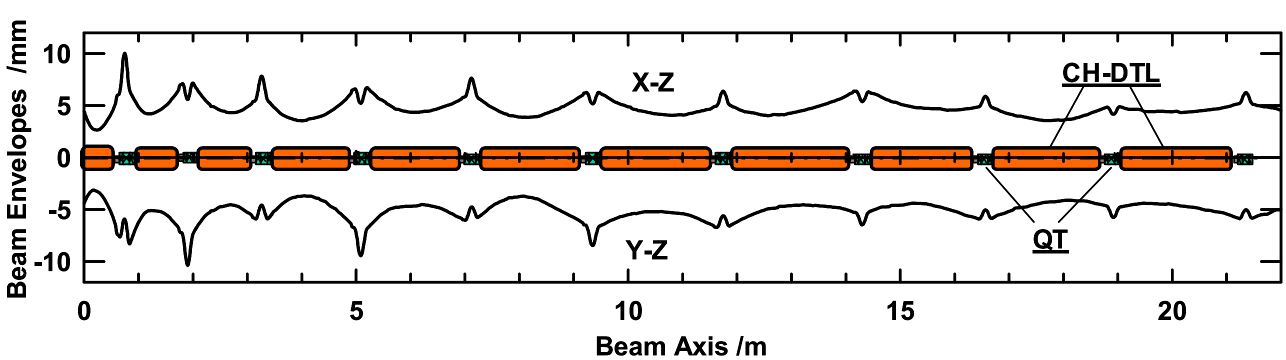

Figure 1: Schematic layout of the proposed GSI Proton Linac CH-DTL section, together with calculated transverse 99% beam envelopes (CH-DTL : Crossbar H-type Structure ; QT : magnetic quadrupole triplet lens).

BEAM DYNAMICS DESIGN OF THE MEBT AND CH-DTL FRONTEND

Compared to the initial design of the overall (up to 70 mA) CH-DTL section presented in the previous chapter, the DTL frontend including the beam transport section behind of the RFQ had to be carefully redesigned with respect to the following issues:

- A transition energy of 3 MeV was chosen as mentioned before. In this case the period lengths are quite short (34 mm at 3 MeV) and transverse focusing is necessary after about 10 periods. The question is then, whether internal quadrupole lenses are needed in the first CH-DTL tank or not. Several layouts were investigated, and finally a solution without internal lenses was favoured. This makes the CH cavity construction simpler and gives more flexibility for matching the beam out of the RFQ. Additionally, a 2 gap rebuncher is foreseen for longitudinal matching.
- The design current was set to 90 mA out of the RFQ (and for the CH-DTL section as well), which implies a complete redesign of the 3-70 MeV CH-DTL section. However, 70 mA have to be provided at SIS injection in operation, which gives a safety factor.

The status of the CH-DTL frontend design is summarized in Figures 3 and 4 and in Table 3.

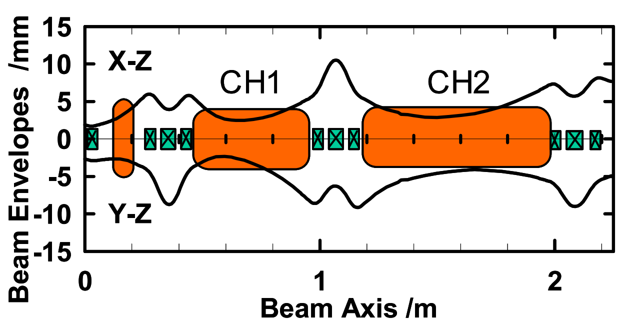

Figure 3: Scheme of the MEBT section and the first CH-DTL tanks, together with transverse beam envelopes.

Table 3: 10 MeV CH-DTL frontend parameters

Cavity parameters		
energy range	3 - 10.4 MeV	
beam current	90 mA	
total length	1.9 m (exit tank 2)	
max. on axis field	17 MV/m	
Beam parameters	**Input**	**Exit**
ε_{tr} (97%,norm.)	1.5	2.5 mm mrad
ε_{tr} (rms)	0.32	0.42 mm mrad
ε_{long} (97%)	0.3	0.56 MeV deg
ε_{long} (rms)	0.070	0.097 MeV deg

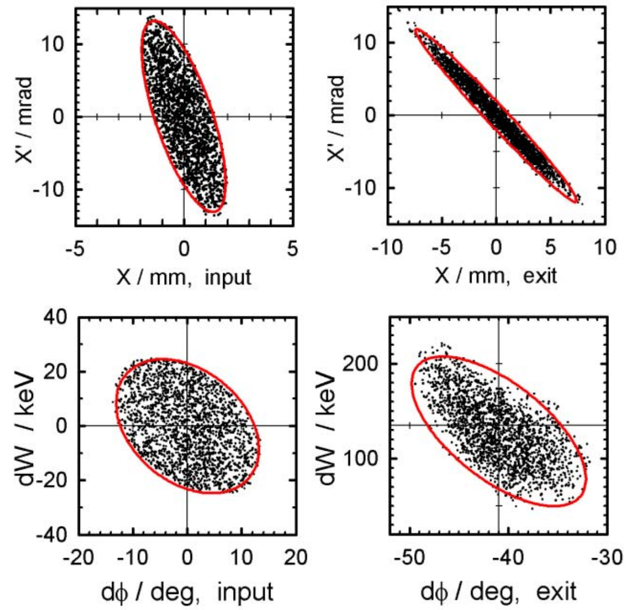

Figure 4: Transverse and long. particle distributions at RFQ exit and after second CH-DTL tank.

CONCLUSIONS

Beam acceleration by 12 to 17 cell CH-cavities and with intertank sections forming a quadrupole triplet channel seem well suited for high current proton beams. The design work is progressing, with special emphasis put on the RFQ-DTL transition.

The beam dynamics design goes hand in hand with the CH cavity development [5]. As a short term objective, a design report of the Proton Linac CH-DTL section is scheduled for the end of 2004.

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