CONCEPTUAL STUDIES OF THE EUROTRANS FRONT-END*

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Abstract

EUROTRANS (EUROpean Research Programme for the TRANSmutation of High Level Nuclear Waste in an Accelerator Driven System) is calling for an efficient high-current CW front-end accelerator system. A combination of RFQ, normal conducting CH- (Crossbar H-mode) and super-conducting CH-DTL which aims to work at 352MHz and accelerate a 30mA proton beam to 17MeV has been studied as a promising candidate. The preliminary conceptual study results are reported with respect to beam dynamics design.

INTRODUCTION

Supported by European Union, the EUROTRANS project is proposed for the transmutation of high level nuclear waste using the ADS (Accelerator Driven System) concept. Fig. 1 shows a reference accelerator scheme for the EUROTRANS project. The linac front end which consists of two identical sets of ion sources, RFQs and CH DTLs is responsible for accelerating up to 4mA proton beam to 17MeV. Through other linear accelerating structures the beam energy will be increased to 600MeV before bombing the spallation target.

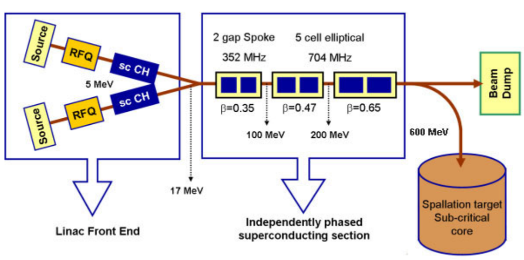

Figure 1: EUROTRANS Layout.

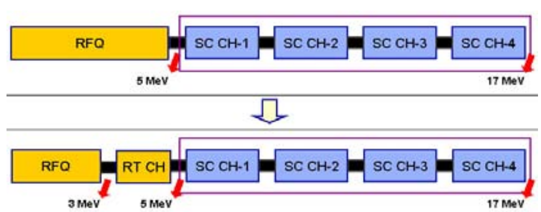

Figure 2: Linac Front End Proposed by IAP.

For each set of the linac front end, an old proposal offered by IAP of Frankfurt University is to use a combination of an RFQ and four superconducting CH-DTLs as shown in Fig. 2. A new one is planning to replace the 5MeV-RFQ with a 3MeV-RFQ and a room-temperature CH-DTL. There are two main reasons: 1) normally at the end of the RFQ there are some not-well-accelerated but transported particles which have high chances to be lost in the downstream linacs. Because for avoiding breakdown a superconducting linac just permits very low beam losses, a room-temperature CH-DTL could be a good "filter". 2) After 3MeV, an RFQ is not efficient as a DTL for acceleration. Therefore, the new proposal has the advantages of saving the total structure length as well as the costs.

The requirements from the planned CW and partly SC operations are the most critical limitations for the beam dynamics design. In order to leave safe margin, all conceptual studies use a 30mA of beam current to replace the nominated 4mA one. On the other hand, a future full intensity transmuter (EFIT) has to accelerate 25mA.

RFQ DESIGN

Besides the fixed frequency and beam current, other basic RFQ parameters have been chosen to meet the demands for achieving a transmission efficiency as high as possible in a compact structure as well as enough safety in CW operation. For example, a moderate inter-electrode voltage of 65kV is adopted as a trade-off between acceleration efficiency, RF power consumption and Kilpatrick factor. The input normalized rms transverse emittance is 0.2πmm-mrad, which is typical at 30mA.

Fig. 3 gives the main parameter evolutions along the designed 3MeV RFQ, where *a*, *m*, *V* are the electrode aperture, modulation and voltage, respectively, and *Ws* and *Phi* are the synchronous energy and phase, respectively. Obviously, all these parameters' variations are quite conservative and smooth.

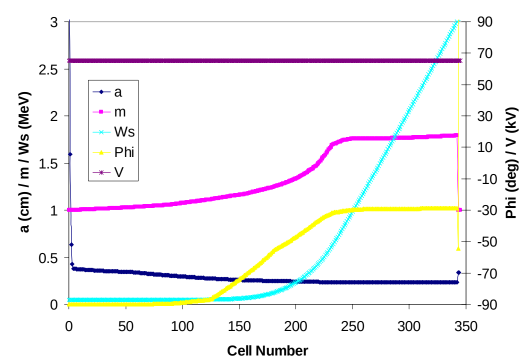

Figure 3: RFQ Parameters' Variations.

Using PARMTEQM [1] and 100,000 macroparticles, the beam transport simulation of the RFQ has been performed. The results are satisfying: the beam transmission efficiency is 99.9%, the total structure length is 4.3m and the Kilpatrick factor is 1.7 which is comfortable for CW operation.

The detailed parameters of the RFQ design are listed in Table 1.

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Table 1: RFQ Parameter List

Parameters	Values
Beam Current [mA]	30
Frequency [MHz]	352
Input Energy [keV]	50
Output Energy [MeV]	3.0
Inter-Electrode Voltage [kV]	65
Kilpatrick Factor	1.69
$\varepsilon_{in}^{trans., n., rms}$ [π mm-mrad]	0.20
Output Synchronous Phase [°]	-28.8
Minimum Aperture [cm]	0.23
Maximum Modulation	1.79
$\varepsilon_{out}^{x., n., rms}$ [π mm-mrad]	0.21
$\varepsilon_{out}^{y., n., rms}$ [π mm-mrad]	0.20
$\varepsilon_{out}^{z., rms}$ [MeV-deg]	0.09
Electrode Length [cm]	431.8
Beam Transmission [%]	99.9

The emittance evolutions along the RFQ are shown in Fig. 4. Firstly, both transverse normalized rms emittances for 100% of good particles, which are nearly constant throughout the RFQ, are well controlled. Secondly, though the 100% longitudinal curve has a steep peak at the downstream, according to the 99% curve we know that it is just because of less than 1% of unstable particles.

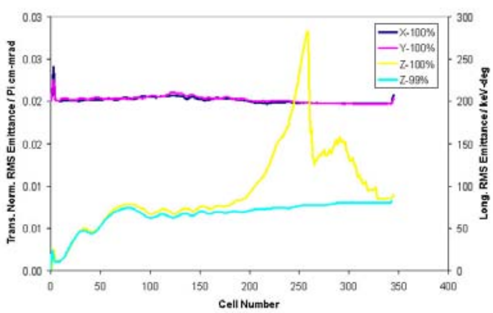

Figure 4: RFQ Emittance Growths.

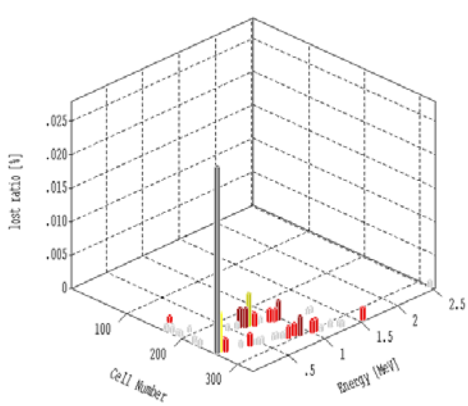

Figure 5: RFQ Beam Losses.

The positions and energies of the lost particles are plotted in Fig. 5. It is clear that most of them have the energies less than 1MeV. Also, the output particle distributions are shown in Fig. 6. The green and red ellipses, which shapes and orientations are referenced to the rms ellipse, contain 100% and 99% of transported particles respectively. The output particles are horizontal and concentred transversely with small energy spread, which offers a good start point for the design of the following DTLs.

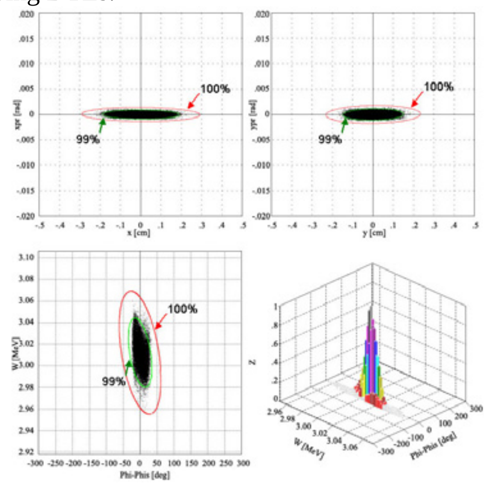

Figure 6: RFQ Output Distributions.

DTL DESIGN

The DTL design is based on the KONUS (Kombinierte Null Grad Struktur – Combined 0° Structure [2]) beam dynamics, which is a kind of separated function concept: 1) the main beam accelerations are achieved by 0° synchronous phase sections which have maximum energy gain efficiency and relatively low transverse defocusing, so using lens-free drift tubes is possible; 2) Only some short traditional rebunching sections and independent lenses are needed to compensate the accumulated longitudinal instability and transverse defocusing.

The whole DTL will use the CH type structures and it can be divided into two parts: 1) RT (Room-Temperature) part which includes two 2-gap rebunchers and one KONUS cavity; 2) SC (Super-Conducting) part which consists of four KONUS cavities.

Fig. 7 and Fig. 8 are the schematic layouts for the RT part and the first SC-CH cavity (in the same cryomodule the other three cavities have similar layouts) respectively, where rebunching sections are marked in green, 0° sections in sky-blue and lenses in yellow. Between the rebuncher II and the SC-CH I as well as between SC-CH cavities, quite long pure drift spaces are required for placing steerers, diagnostic devices, cryomodule, tuners and He vessel etc. This makes the beam dynamics unusually difficult.

Table 2 gives the main parameters for the DTL cavities in detail.

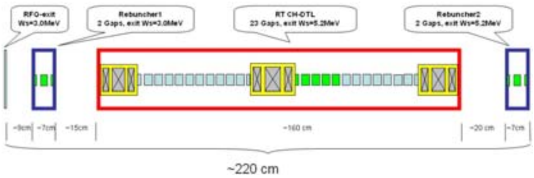

Figure 7: Schematic Plot for RT Part.

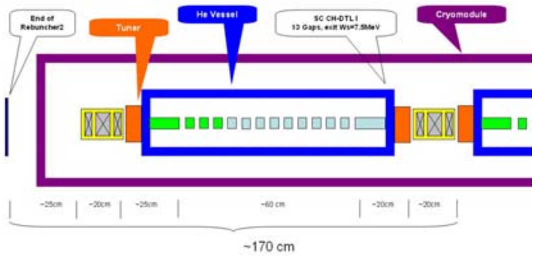

Figure 8: Schematic Plot for Beginning of SC Part.

Table 2: DTL Cavity List

Cavity	Gaps (φ_s [°])	Length [cm]	$W_{s,out}$ [MeV]	Eacc* [MV/m]
Rebuncher I	2 (-90°)	~7	3.0	2.79
RT-CH	11 (0°) 4 (-40°) 8 (0°)	~160	5.2	2.72
Rebuncher II	2 (-90°)	~7	5.2	5.11
SC-CH I	3 (-40°) 10 (0°)	~90	7.5	3.99
SC-CH II	4 (-40°) 10 (0°)	~105	10.4	3.97
SC-CH III	4 (-40°) 12 (0°)	~130	14.3	3.98
SC-CH IV	4 (-40°) 12 (0°)	~145	18.3	3.96

* Eacc: active acceleration gradient.

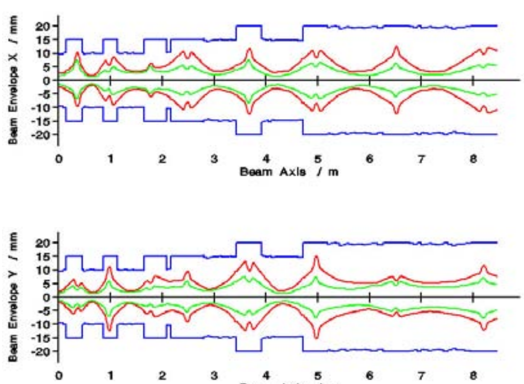

Figure 9: DTL Transverse Envelops.

Using the RFQ output particle distribution as input, the DTL beam dynamics is checked with the LORASR [3] code. The whole DTL is about 8.5m long and the beam transmission is 100%.

Fig. 9 shows the transverse envelops, where red and green curves for 100% and 99% of particles and blue ones for the apertures of drift tubes and lenses. In Fig. 10, both transverse and longitudinal emittances have quite similar and slow growths up to 35% along the whole DTL. Like the RFQ design, the DTL output particle distributions are demonstrated in Fig. 11. Clearly, the particles are still quite concentred, which is favourable for the design of the next linac structure.

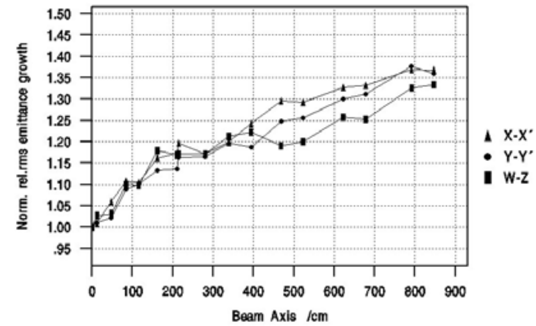

Figure 10: DTL Emittance Growths.

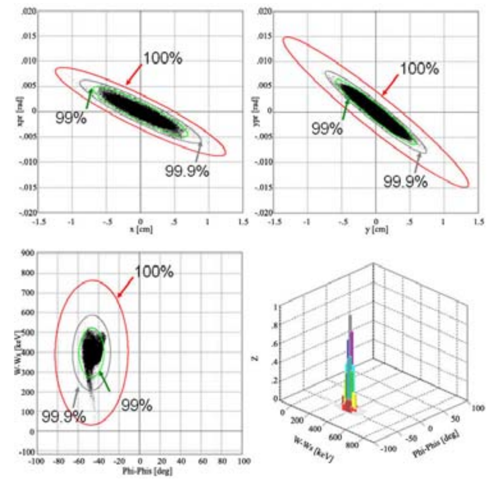

Figure 11: DTL Output Distributions.

CONCLUSIONS

In conclusion, the conceptual study results show the primary design of the EUROTRANS linac front end is feasible. The highlights are: 1) the total geometric length is less than 12m; 2) the total transmission is 99.9% with less than 40% of emittance growths.

Further optimization work and error studies will be performed in the near future.

ACKNOWLEDGEMENTS

Many thanks go to Mr. R. Tiede and Dr. A. Sauer for their valuable discussions on KONUS beam dynamics and LORASR simulation, also to Mr. J. Maus for helping prepare some plots.

REFERENCES

[1] Manual of RFQ Design Codes, LANL.
[2] U. Ratzinger and R. Tiede, “Status of the HIIF RF linac study based on H-mode cavities”, Nucl. Instr and Meth. in Phys. Res. A 415 (1998), pp. 229-235.
[3] U.Ratzinger, et al, LORASR – A computer code to calculate the longitudinal and Radial beam dynamics of a drift tube accelerator, GSI internal report0791.