RECENT STUDIES ON A 3-17MEV DTL FOR EUROTRANS WITH RESPECT TO RF STRUCTURES AND BEAM DYNAMICS*

Chuan Zhang#, Marco Busch, Florian Dziuba, Horst Klein, Holger Podlech, Ulrich Ratzinger
Institut für Angewandte Physik, Goethe-Universität, D-60438 Frankfurt a.M., Germany

Abstract

EUROTRANS is a EUROpean Research Programme for the TRANSmutation of High Level Nuclear Waste in an Accelerator-Driven System. Frankfurt University is responsible for the development of the 352MHz injector which mainly consists of a 3MeV RFQ and a 3-17MeV CH-DTL. Based on the beam dynamics design, the CH-cavities were designed with the concern to optimize the RF properties. In the cavity design, the tube-gap configurations were modified, so the beam dynamics has been adjusted to fit the new effective gap voltage profiles accordingly. A comparison of the beam dynamics results before and after the RF optimization is presented.

INTRODUCTION

EUROTRANS [1] is a European approach for nuclear waste transmutation using an Accelerator-Driven System (ADS). To achieve the extremely high reliability required by the ADS application, the design of the driver linac especially the 17MeV injector has been intensively studied. In the proposed injector, the beam acceleration will be completed in two steps: 1) a 4-vane RFQ bunches and pre-accelerates a 50keV proton beam to 3MeV; 2) then a CH-DTL continues the acceleration to 17MeV.

Excluding the two short rebuncher cavities, the CH-DTL layout (see Fig. 1) mainly consists of 6 CH-cavities, among which the first twos are coupled together and will be operated at room temperatures (RT), and the others sharing one cryo-module are superconducting (SC) cavities. For the required CW operation, the accelerating gradients of the SC CH-cavities have been conservatively chosen to ~4MV/m.

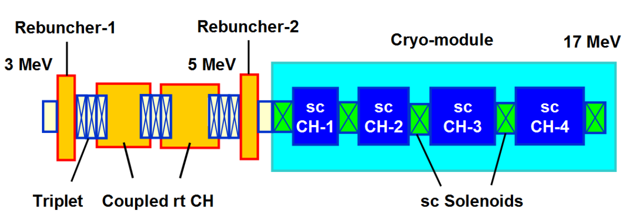

Figure 1: Actual layout of the 3-17MeV CH-DTL, where the warm triplets and cold solenoids are marked in yellow and green, respectively.

On the basis of the beam dynamics design [2, 3], the cavity design of the EUROTRANS CH-DTL was recently made. To optimize the RF properties, e.g. the quality factor Q and the electric-field flatness, as well as to meet the demands for high-power applications, not only the CH-cavity shape but also the tube geometries and the gap lengths given by the beam dynamics design have been modified, especially in the SC CH-cavities.

Fig. 2 makes a comparison between the prototype cavity (no β-profile) of the SC CH structure [4] and the 1st SC CH-cavity designed for EUROTRANS with a graded β-profile. The major improvements are: 1) the stems, whose elliptical bases have the long axes originally parallel to the beam axis, have been rotated by 90° in order to provide more space to contain larger RF power couplers; 2) the original major tuner system, which tunes the cavity by pushing on the end-cells, has been replaced by bellow tuner located between the stems, considerably reducing the space for end-cells; 3) shorter girders and inclined end-stems have been adopted to shorten the cavity by ~20% (also, the end-tubes have been further shortened) and to improve the E-field flatness [5].

As a result, the end-tube lengths of the 1st SC CH-cavity for EUROTRANS were reduced to 5.6cm and 6.2cm, respectively, from 13.1cm that had been applied to the prototype cavity.

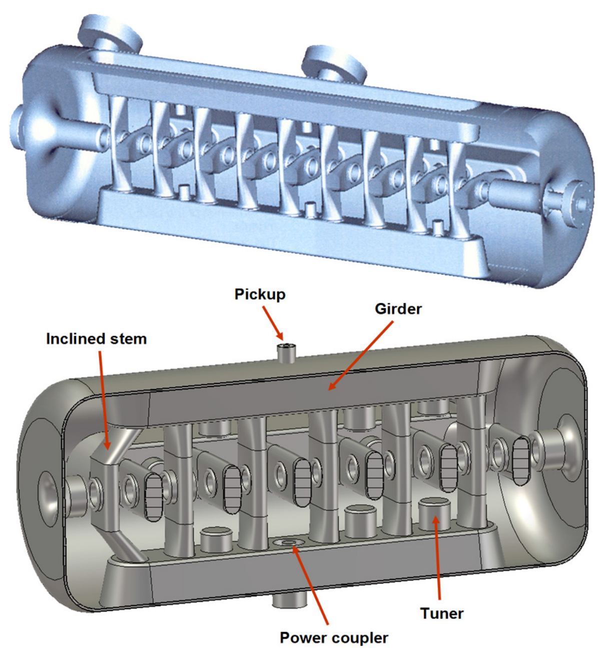

Figure 2: Prototype cavity of the SC CH structure (top) and the 1st SC CH-cavity for EUROTRANS (bottom) [6].

The structure and RF parameters of the EUROTRANS CH-cavities designed using the Microwave Studio [7] (MWS) software are given in Table 1, where: 1) the inside radii of middle drift tubes in the 1st RT and 1st SC CH-cavities were reduced due to the flatness optimization; 2) the total effective gap voltage $\Sigma V_{\rm eff}$ was kept constant; 3) the Q_0 values of the SC CH-cavities are the BCS values, and the corresponding RF power consumption of these cavities P_c were calculated for the goal Q_0 value, 2×10^8.

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# zhang@iap.uni-frankfurt.de

Table 1: Summary of the EUROTRANS CH-Cavities [6]

Parameter	RT-1	RT-2	SC-1	SC-2	SC-3	SC-4
L_{total} [m]	0.49	0.59	0.70	0.86	1.01	1.12
Φ_{bore} [mm]	18-20	20	25-30	30	40	40
N_{gap}	11	12	13	14	14	14
Q_0	1.2×10^4	1.2×10^4	1.4×10^9	1.5×10^9	1.5×10^9	1.6×10^9
E_a [MV/m]	2.9	2.6	3.9	3.9	3.9	3.6
E_p / E_a	6.9	5.3	6.8	7.2	7.3	7.6
ΣV_{eff} [MV]	1.2	1.3	2.5	3.2	3.7	3.8
P_c [W]	35000	37000	18	24	37	36

RECENT STUDIES

The cavity design has tried to achieve a homogeneous on-axis E-field distribution for minimizing the peak field. It is especially essential to ensure a reliable operation of SC cavities. The lengths of the accelerating cells i.e. the gap-center distances are frozen by beam dynamics, so the flatness optimization of the EUROTRANS CH-cavities has been achieved by adjusting the tube geometries and the gap lengths. As an example, the E-field profile and the corresponding tube-gap configuration of the 1st SC cavity is shown in Fig. 3, where the very long Tube-3 is the result of a synchronous-phase jump from -40° to 0°.

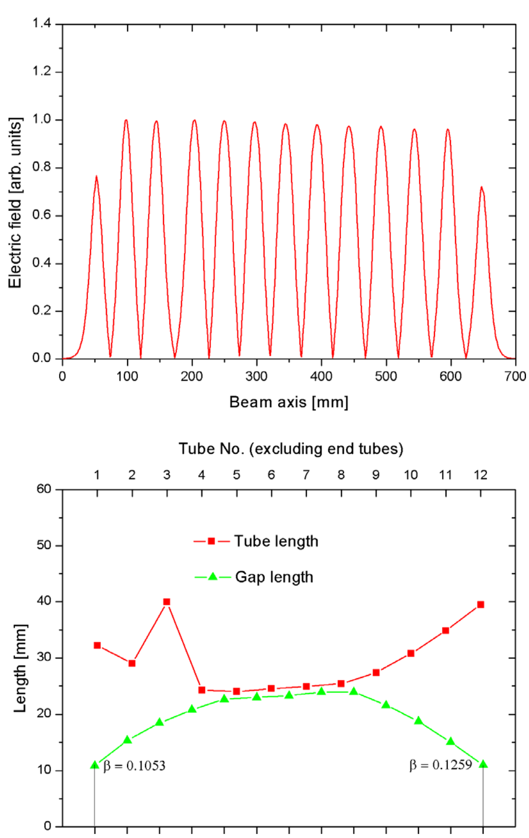

Figure 3: The E-field profile (top) and the corresponding tube-gap configuration (bottom) of the 1st SC CH-cavity.

Due to the above-mentioned adjustments, the effective gap voltage along the CH-DTL has been redistributed, though the ΣV_{eff} is unchanged. Fig. 4 shows the new V_{eff} profile of the 1st SC CH-cavity, and the previous one is also presented for comparison.

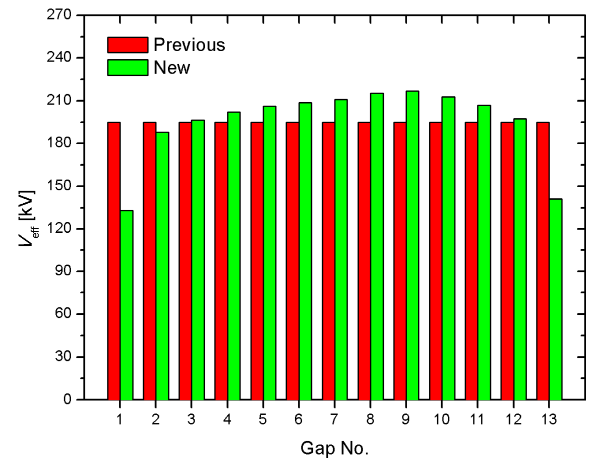

Figure 4: The V_{eff} profiles in the 1st SC CH-cavity [6].

Now, the cell lengths and the bunching strengths are different than the first design values, so the beam dynamics design has to be adjusted in order to fit the new energy-gain configuration and to improve the beam quality, especially in the longitudinal direction.

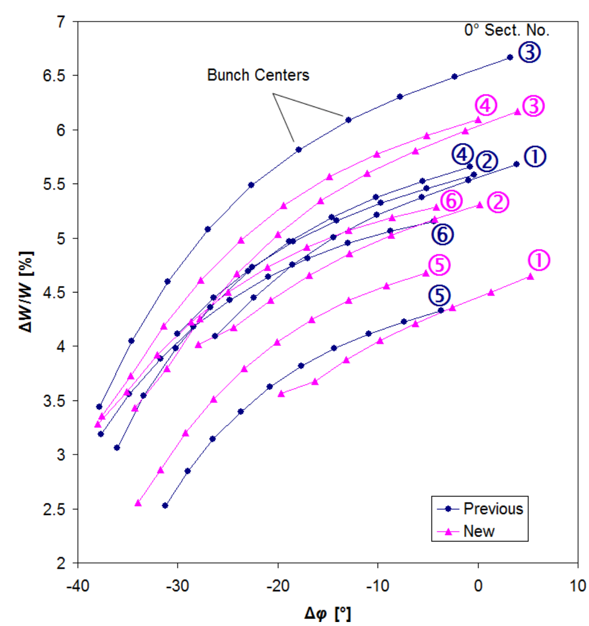

Figure 5: Bunch-center motions in the 0°-sections, which are marked with the section numbers at the beginning.

Based on the new V_{eff} profile along the CH-DTL, the beam dynamics optimization has been firstly performed for the 5mA case. Because of the adopted KONUS (Combined 0° Structure) beam dynamics concept [8], main adjustments have been done with respect to the synchronous energy at the beginning of every 0°-synchronous-phase section. From Fig. 5, it can be seen that after adjustments the bunch-center motions in almost all the 0°-sections are bearing a general resemblance to the corresponding ones in the previous design, except a little large difference appears in the 1st 0°-section. This indicates that the beam dynamics simulation results will be similar to each other too.

COMPARISON ANALYSES

To evaluate the difference in beam performance of the CH-DTL before and after adjustments, some comparison analyses have been done.

Simulated with the LORASR [9] code, 100% transverse and longitudinal beam envelopes along the 3-17MeV CH-DTL are plotted in Fig. 6 and Fig. 7, respectively, where the green and red curves are representing the "before adjustments" and "after adjustments" cases, respectively. It is seen that the evolutions of the beam bunches are almost identical throughout the CH-DTL.

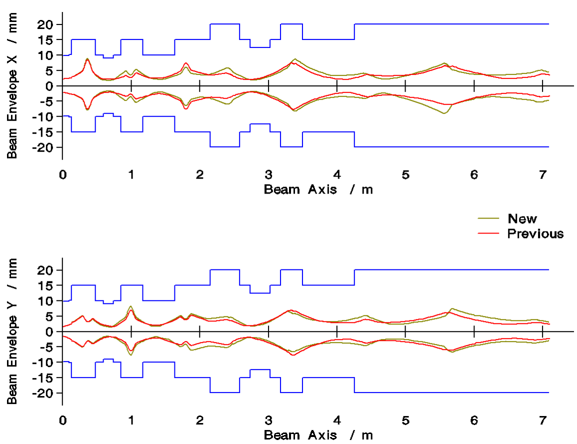

Figure 6: 100% transverse beam envelopes.

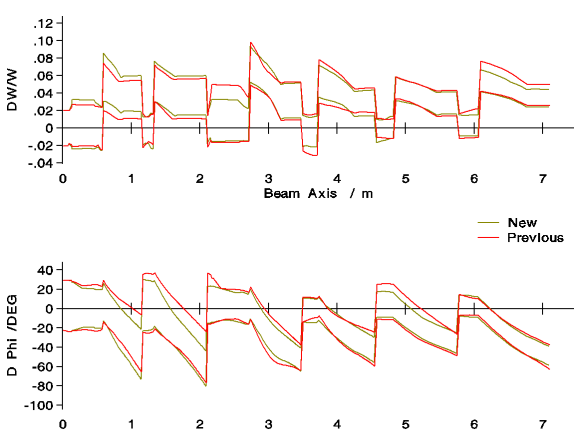

Figure 7: End-to-end 100% longitudinal beam envelopes.

In Table 2, some concrete data obtained from the beam dynamics simulations for the new and previous designs are listed together. Obviously, though the effective voltage profiles have been modified, the layout length, the beam quality, and the beam transmission efficiency of the previous design have been well kept.

Table 2: Comparison of the simulation results

Parameter	Previous	New
Layout length [cm]	708.86	709.93
Emittance growth (x) [%]	10.8	10.9
Emittance growth (y) [%]	11.0	10.8
Emittance growth (z) [%]	10.9	11.2
Beam transmission [%]	100	100

CONCLUSIONS

Recent studies on the 3-17MeV EUROTRANS CH-DTL with respect to RF structures and beam dynamics have been performed.

The results show that a compact layout and good beam quality can still be achieved with the new effective voltage profiles in case of 5mA.

The work will be continued to improve the beam dynamics by taking advantage of the shortened end-cell lengths (so far, the drift space between the CH-cavities is not changed), and to further optimize the cavity design as well. In addition, the possibility of an upgrade of the CH-DTL for higher currents (up to 30mA) will be studied.

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