KONUS DYNAMICS AND H-MODE DTL STRUCTURES FOR EUROTRANS AND IFMIF*

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Abstract

During the last two decades, the combination of the KONUS beam dynamics and H-mode DTL structures has been developed as an efficient solution for accelerating low- and medium-energy proton and ion beams. EUROTRANS is a EUROpean Research Programme for the TRANSmutation of High Level Nuclear Waste in an Accelerator Driven System. IFMIF is a planned International Fusion Material Irradiation Facility to test materials for fusion reactors. For the driver linacs of both projects, two H-DTLs have been proposed to cover the energy ranges of 3–17MeV and 5–40MeV, respectively. The beam dynamics designs as well as the error studies of the H-DTLs are presented in this paper.

INTRODUCTION

With the rapid industrial and economic development, nuclear energy is one of the potential substitutes for the traditional fossil energy, which is limited by shrunk deposits, air pollution and the greenhouse effect. However, a problem for the present fission-driven nuclear power stations is that the long half-life nuclear wastes will remain dangerous for hundred thousands of years if they are directly stored underground. The fusion reactor can be a solution for clean and safe nuclear power production, but so far, there are still lots of construction difficulties.

EUROTRANS [1] which will be realized in two steps – XT-ADS and EFIT – is aiming to demonstrate the transmutation of nuclear waste in a way that the remaining radiotoxicity will decline within some hundred years. On the other hand, the mission of IFMIF [2] is to test materials for constructing fusion reactors. Both of them will promote the wide use of nuclear energy.

A common point of the two projects is that each of them will use an accelerator-driven intense neuton source. For EUROTRANS, the required intensity and energy of the proton beam hiting on the spallation target are 2.5 – 4mA, 600MeV for XT-ADS or 20mA, 800MeV for EFIT. For IFMIF, the required 250mA, 40MeV deuteron beam will be achieved by two 125mA accelerator modules working in parallel. Proposed by Frankfurt University, two H-mode DTLs based on the KONUS (Kombinierte Null Grad Struktur – Combined 0° Structure) dynamics [3] will be used to cover the 3–17MeV and 5–40MeV sections for the driver linacs of EUROTRANS and IFMIF, respectively. The main specifications of both H-DTLs are listed in Table 1, where the intensities for EUROTRANS are the design values with some safety margins included.

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One highlighted feature of the KONUS dynamics is that using “slim” drift tubes without integrated focusing elements is feasible. Together with the high mechanical rigidity from the CH (Cross-bar H-mode) DTL strucuture, the first multi-cell SC (superconducting) accelerator for low- and medium-energy beams has been prototyped [4], which is attractive for the high power, CW driver linacs of EUROTRANS and IFMIF.

Table 1: Main Specifications of the Two H-DTLs

Parameter	**EUROTRANS**	**IFMIF**
Particle	H^+	D^+
f [MHz]	352	175
W_{in} / W_{out} [MeV]	3 / 17	5 / 40
I [mA]	XT-ADS: 5; EFIT: 30	125
Duty cycle	CW	CW

LORASR [5] is a dedicated beam transport simulation tool for the KONUS-based H-mode DTLs. The newly implemented error study subroutines [6, 7] are able to examine 4 kinds of errors: 1) transverse translations of focusing elements (QMIS); 2) rotations of focusing elements (QROT); 3) gap and tank voltage amplitude errors (VERR); 4) tank phase error (PERR). In LORASR, manual or statistical error settings are both possible. For statistically generated settings, the errors are Gaussian-distributed and truncated at the maximum A=±2σ.

Table 2: Error Types and Settings

Type	**Setting1**	**Setting2**
QMIS [mm]	ΔX, ΔY =±0.1	ΔX, ΔY =±0.2
QROT [mrad]	$\Delta\varphi_{x,\,y}$=±1.5, φ_z=±2.5	$\Delta\varphi_{x,\,y}$=±3.0, φ_z=±5.0
VERR [%]	ΔU_{gap}=±5.0 ΔU_{tank}=±1.0	ΔU_{gap}=±5.0 ΔU_{tank}=±1.0
PERR [°]	$\Delta\Phi_{tank}$=±1.0	$\Delta\Phi_{tank}$=±1.0

The practical experience at Frankfurt University shows the typical values for the errors are: 1) QMIS: ΔX & ΔY ≤0.1mm; 2) QROT: the corresponding length displacements caused by the rotations along x and y axes are ≤0.1mm, while that around the beam axis is ≤0.3mm; 3) VERR: ΔU_{gap}≤5% & ΔU_{tank}≤1%; 4) PERR: $\Delta\Phi_{tank}$≤1°. In Table 2, two groups of error settings applied to the two DTLs are listed. The Setting1 errors are around the upper limits of the typical values. The QMIS and QROT errors of the Setting2 are twice as large as those of the Setting1.

H-MODE DTL FOR EUROTRANS

The main constraints for the dynamics design of the EUROTRANS H-DTL are extremly high reliability (due to ADS) and upgradeability (from XT-ADS to EFIT).

The first ~2MeV energy gain will be provided by a RT (Room Temperature) CH cavity, a "filter" for potentially unstable particles from the RFQ. The main acceleration will be done by four SC-CH cavities. Though the latest measurement results of the first SC-CH prototype have shown that an effective accelerating gradient of 7MV/m is achievable [8], a modest value of 4MV/m has been adopted for reliability.

Two difficult areas for the DTL design are: 1) between the RFQ and the RT-CH, ~0.5m long for placing steerers, diagnostic devices and quadrupoles; 2) between the RT-CH and the1st SC-CH, ~1m long for placing cryo-module, tuners, helium vessel and focusing elements. Therefore, two short rebunchers operating at -90° are introduced to improve the longitudinal beam dynamics. By properly adjusting the rf level, they can also adapt the DTL to two intensities without changing the structure.

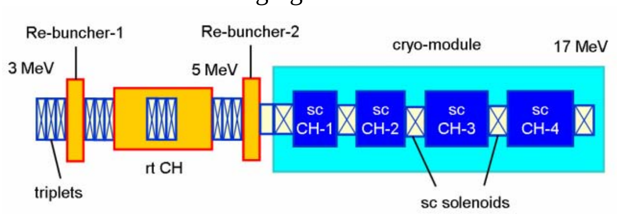

Figure 1: Schematic layout of the EUROTRANS H-DTL.

Shown in Fig. 1, the designed EUROTRANS H-DTL consists of 7 cavities, in which 3 are r. t. and 4 are cold and implemented in 1 cryo-module. Between the cavities, 3 triplets and 5 solenoids are used.

Based on the RFQ output particle distributions [9], the DTL has been simulated with LORASR. With the identical structure but different gap voltages of the rebunchers, the simulation shows that the transmission efficiencies are 100% at both 5mA and 30mA. For 5mA, the transverse and longitudinal emittance growths are all ≤10%. For 30mA, they are between 30–36%.

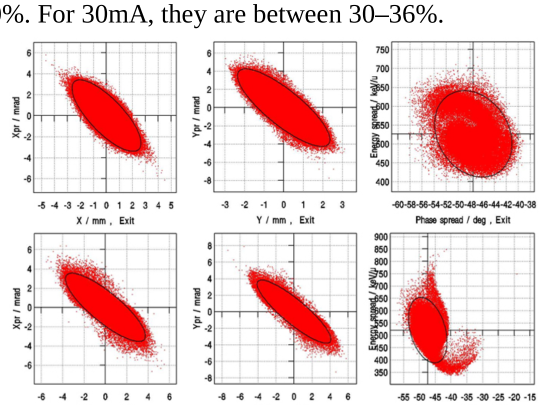

Figure 2: Output phase spaces (T: 5mA, B: 30mA).

The output particle distributions are given in Fig. 2, where each ellipse covers 95% of the particles. In case of 5mA, all distributions are concentrated and favourable for the further acceleration. In case of 30mA, the transverse output distributions are similar to the 5mA design; the longitudinal one has a "tail", because the strengths of the focusing elements are designed for 5mA, but it can be improved by optimizing the focusing strengths.

For each error setting, 100 random runs have been executed to evaluate the tolerances. In case of 30mA, the common maximum transverse beam envelopes for each batch simulation together with the 100% transverse envelopes for the reference design are shown in Fig. 3 for comparison, where the black curves are for the beamline apertures. The situation for the 5mA case is similar but better because of weaker space-charge effects. Obviously, with the Setting1, no particle touches the hard boundaries. Some beam losses happen with the Setting2, but the minimum beam transmission is still 99.9%.

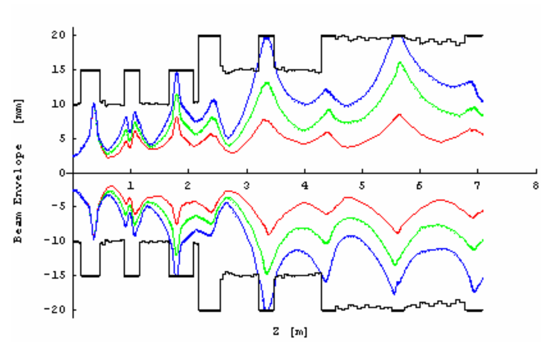

Figure 3: Transverse beam envelops for the 30mA case (red: reference design, green: Setting1, blue: Setting2).

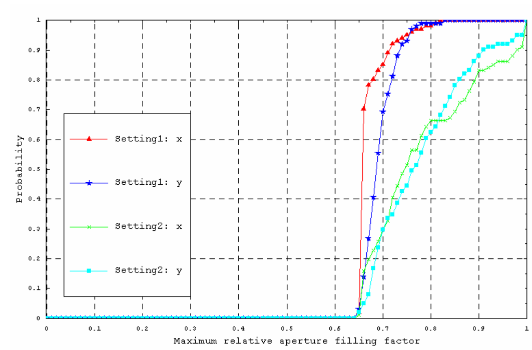

Figure 4: Probability vs. maximum relative aperture filling factor for the 30mA case.

Fig. 4 plots the probability as a function of the maximum relative aperture filling factor ff_{max} – the max. ratio between the beam size at a certain position and the corresponding beamline aperture – for the 30mA case. With the Setting1, the beam envelopes from all runs stay within ~80% of the aperture. With the Setting2, only in <5% of runs the boundaries have been touched. The results are also similar but better in case of 5mA.

H-MODE DTL FOR IFMIF

The main limitation on the DTL design is that the beam losses must be below 1nA/m to avoid structure activation.

The number of the SC cavities is mainly decided by the required maximum total average rf power for each tank, which should be below 600kW because of the power feeder limits. As shown in Fig. 5, therefore, 8 SC cavities are designed. Similar to the EUROTRANS case, a rebuncher and a RT-CH are necessary before the SC part.

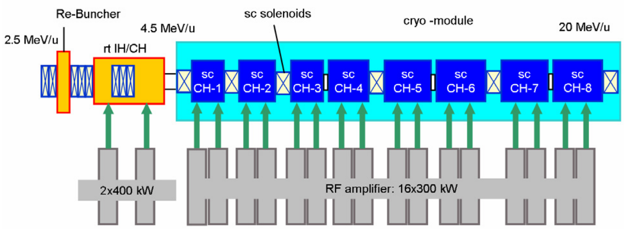

Figure 5: Schematic layout of the IFMIF H-DTL.

Due to the serious space-charge effects at 125mA, relatively large apertures and strong focusing elements are required against possible particle losses. The RFQ output distribution [10] has been used as the input distribution, and no beam losses have been observed in the simulation. The transverse emittance growths are 60% and 66%, respectively, and the longitudinal one is 32%.

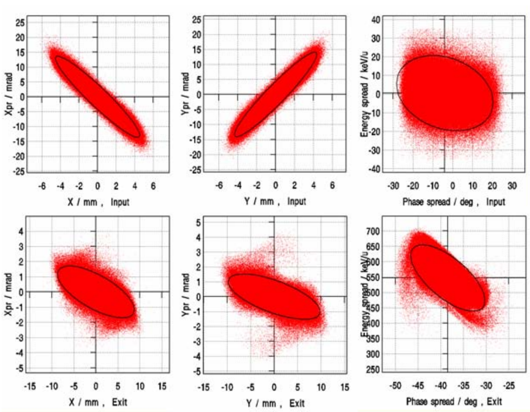

Figure 6: Input / output particle distributions.

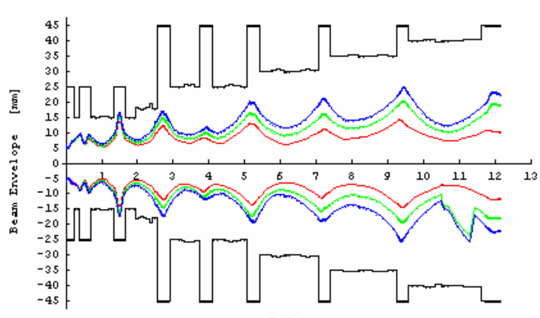

Figure 7: Transverse beam envelops (red: reference design, green: Setting1, blue: Setting2).

Some haloes appear in the output particle distributions (Fig. 6), but they are not dangerous because the beam has already arrived on the lithium target, and moreover, the 95% ellipses show the beam is still concentrated.

Similar error studies are made. Both the transverse beam envelops (Fig. 7) and the probability vs. ff_{max} plot (Fig. 8) indicate that there are no transverse beam losses. In each batch simulation, only 3 runs have ~0.003% of longitudinal losses down along the DTL.

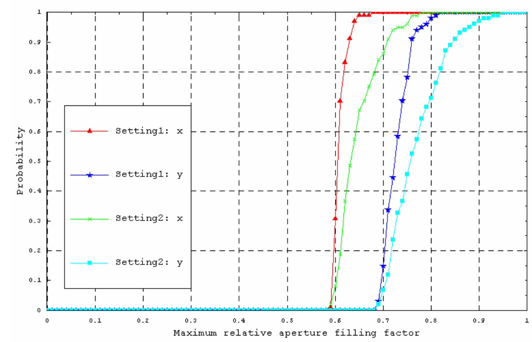

Figure 8: Probability vs. ff_{max}.

CONCLUSIONS

The main parameters for both H-DTLs are summarized in Table 3. The multi-particle simulation results as well as the error study results have proven: 1) the EUROTRANS H-DTL design is reliable and upgradeable; 2) the IFMIF H-DTL design is robust enough without any transverse beam losses even in case of relatively large errors.

Table 3: Summary of the Two H-DTLs

Parameter	EUROTRANS	IFMIF
Cavities	7 (3: RT, 4: SC)	10 (2: RT, 8: SC)
Focusing elements	3 triplets (RT) 5 solenoids (SC)	1 doublet (RT) 2 triplets (RT) 6 solenoids (SC)
B_{max} [T]	1.2 (quad.), 4.8 (sol.)	1.2 (quad.), 6.5 (sol.)
a [mm]	15 (quad.), 20 (sol.), 10-20 (tubes)	25 (quad.), 45 (sol.), 15-45 (tubes)
L [m]	7.09	12.15
T [%]	100	100

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