STATUS OF THE SUPERCONDUCTING D^+-CH-DTL DESIGN FOR IFMIF*

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Abstract

Within the IFMIF project (**I**nternational **F**usion **M**aterials **I**rradiation **F**acility) a high current D^+-linac operated in cw mode has to be developed. The parallel acceleration of two 125 mA D^+-beams from 0.1 MeV up to 40 MeV must be performed at an extremely low loss rate (0.1 - 0.2 µA/m) to avoid an activation the linac structures and guarantee hands-on maintenance. One optional layout of the acceleration facility consists of a high current ion source, low energy beam transport (LEBT), room temperature Radio-Frequency-Quadrupol (RFQ) followed by a superconducting H-type DTL. A first 352 MHz prototype s.c. cavity is under construction at the ACCEL company, Germany. Actual beam dynamics simulations for such a linac design including parameter errors of components are reported. Consequences for the LEBT- and RFQ-section are discussed.

INTRODUCTION

Extended particle dynamics investigations of the reference IFMIF DTL layout (Four-Vane-RFQ+Alvarez-DTL) showed a very robust beam behaviour for the Alvarez-type DTL. This layout has an overall length of 46 m. The total rf power consumption per linac is estimated to around 7.5 MW.

The continuous wave (cw) operation mode of the IFMIF facility the combination of a short room temperature (r.t.) IH structure and a chain of sc CH resonators with inter tank focusing has also been made and is a promising option for an IFMIF injector. The sc CH DTL part provides very high rf and acceleration efficiency and due to its special cell geometry high mechanical robustness. The estimated total plug power (including all cryostat losses) per meter of this design study is ≈ 1.5 kW/m which demonstrates the high rf efficiency of the s.c. CH modules. In connection with large drift tube apertures the risk of particle losses in the s.c. part is minimized. Detailed simulations showed also a low sensitivity of the beam behaviour and beam quality against all combinations of statistically distributed rf, focussing and mechanical errors [1,3].

BEAM DYNAMICS DESIGN OF AN OPTIMIZED SC CH-DTL

In a first level design we assumed a chain of two rf couplers per sc CH cavity which leads to 12-gap sc CH resonators with a maximal tank power of ≈ 1.1 MW and a cavity length range between 1.2 m @β=0.1 and up to 2.4 m @β=0.2. These design assumptions are due to several reasons especially for superconducting resonators critical: a.) a cavity with a length over ≥ 1.5 m is more difficult to tune (frequency and field flatness) and have a lower mechanical rigidity than smaller ones b.) the probability of material defects is higher, c.) the needed rf power per cavity for high intensity beams are higher and d.) the beta-acceptance of the cavity is lower (a beta profile is needed) and at least e.) the fabrication and preparation of long cavities are more difficult [2].

In the previous design of the IFMIF IH sc CH-DTL two rf couplers per s.c. cavity were assumed [3]. But due to the small rf bandwidth of sc cavities (up to 10^{-6} smaller than r.t. cavities because of the high external quality Q_{ext} in the s.c. case) they are more sensitive to resonant frequency changes during cool down and operation. Therefore we changed the former design to a cavity chain, fed by one standard rf amplifier for IFMIF with an effective rf power of $P_{eff} \approx 0.71$ MW in cw mode. For this aim we divided the s.c. CH 2 up to CH 4 resonators of the previous design and used an intertank drift of one rf period between the subsequent cavities. This allows to have some additional space for tuner and cryostat endwall between the tanks. A further external quadrupole lens is not foreseen because with the demand of one rf period between the tanks the transverse and longitudinal focussing properties are not disturbed. This strategy results in phase and amplitude independent cavities after s.c. CH 1. The Figure 1 illustrates the layout, estimated length, the number of tanks and rf input of the actual s.c. CH-DTL. The following Figure 2 compares the total rf power supply of the old and new design [3].

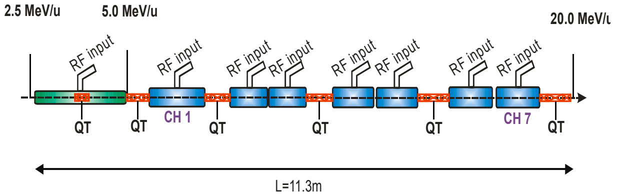

Fig. 1: Schematic layout of an optimized IH sc CH-DTL for IFMIF. The rf input and the quadrupole triplets (QT) are also indicated.

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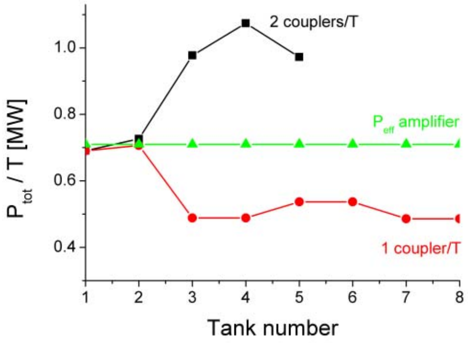

Fig. 2: Total rf power per tank of the old design (black line, 5 tanks) and the new one (red line, 8 tanks). The green line shows the effective power of one IFMIF standard rf amplifier.

The design and structure parameters are summarized in Table 1. They have been generated with the multi particle program LORASR©.

Table 1: Design parameter of a optimized 175 MHz sc IH/CH-DTL for IFMIF.

DTL parameters	SC CH-DTL	Units
A/q	2 (D^+)	
In-/out current	125.0 / 125.0	mA
Frequency	175.0	MHz
Number of tanks	8 (1NC+7SC)	
P_{tot}	4.44	MW
P_{max}/T / P_{min}/T	0.7 / 0.48	MW
W_{in} / W_{out}	5.0 / 40.1	MeV
Cells / Length	73 / 11.3	m
a_0 of DT rt / sc	1.5 / 2.4 - 4.0	cm
In- / Out rms ε^n_{trans}	0.035 / 0.091	cm×mrad
In- / Out rms ε^n_{long}	0.070 / 0.097	cm×mrad

Extended beam dynamics studies showed a smooth beam behaviour, no losses along the linac occurred and a good safety margin between beam size and structure wall could be reached in the s.c. linac against losses due to mismatch and standard DTL errors (quadrupole, phase and amplitude errors). In addition intensive electromagnetic simulations have been performed with Microwave Studio® to optimize the geometry parameters of both the first sc 12-gap CH tank at β(const) = 0.1 and the halved 6-gap CH-cavities up to the end energy of β(const) = 0.2. It was possible to further reduce the electric and magnetic peak fields to modest values which is important for reliable routine operation. Furthermore field flatness in the first and last two gaps of every resonator was improved considerably.

Table 2 gives the structure parameter of sc CH 1 and CH 7 and Fig. 3 shows 3D sketches of the actual 175 MHz sc CH tank 1 and 7 in the critical low energy part and at the high energy end of the DTL, simulated with Microwave Studio®.

Table 2: Cavity parameters of sc CH tank 1 and 7 calculated with MWS®.

Cavity parameters	CH 1	CH 7	Units
Beta	0.1	0.2	
Frequency	175.00	175.00	MHz
E_{acc}	4.00	3.44	MV/m
Gaps	12	6	
E_{peak}	18.64	17.89	MV/m
B_{peak}	35.56	31.98	mT
R_{eff}/Q	1.8	1.04	kΩ
G	55.14	67.61	Ω

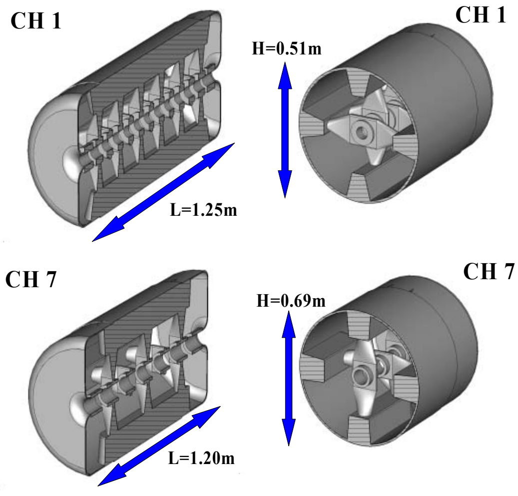

Fig. 3: 3D views of the first and last 175 MHz sc CH-cavities (tank 1 and 7) calculated with MWS®.

In Figure 4 are the field distributions of the resonators from Table 2 and Figure 3 plotted.

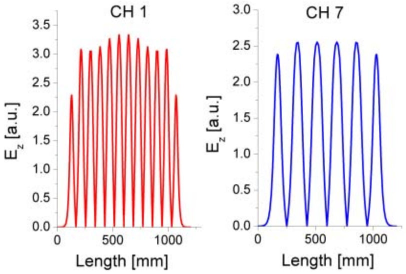

Fig. 4: Field distribution of sc CH 1 and CH 7 from Table 2 and Figure 3 calculated with MWS®.

MULTIPARTICLE SIMULATIONS OF AN IFMIF INJECTOR

As a very efficient method to test the global stability of the complete injector facility against particle losses, integrated overall multiparticle simulation studies at full space charge of an IFMIF injector were performed. The injector consists of a LEBT (two solenoids and 85 % space charge compensation for matching into the RFQ), a 13 m long Four-Vane-RFQ with a Kilpatrick value of 1.7, a compact MEBT (one quadrupole doublet, one λ/4-4-gap buncher and a quadrupole triplet for matching into the

DTL) and the optimized IH sc CH-linac from Table 1 [1,3,4]. The multi particle simulations were performed with 10,000 macro particles which leads to a maximum loss rate of 0.54 µA/m. The programs LINTRA® for the LEBT, PARMTEQC® for the RFQ and LORASR© for the DTL were used. The output beam distribution of every section was used as an input for the following one. For the LEBT calculation an ion source input emittance of the IAP Frankfurt high current proton volume source was used [5]. The matching into the RFQ was done by adjusting the solenoidal fields. Fig. 5 shows the phase space distribution at the exit of the LEBT at 0.1 MeV, 140 mA beam current and 85 % space charge compensation. There are no filamentations and the beam is well confined. Fig. 6 displays the phase space distribution at the exit of the RFQ at 5.0 MeV. The beam size in phase space is smooth, no halo but a 3 % lower transmission was seen. No additional particle loss over 2.0 MeV inside the RFQ.

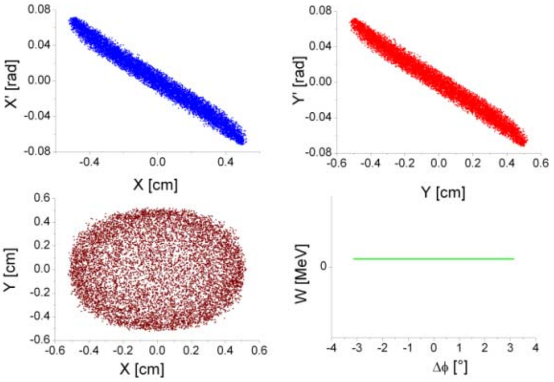

Fig. 5: Output phase space distribution of the LEBT at 0.1 MeV with 85 % space charge compensation and real solenoide fields, 10,000 macro particles used.

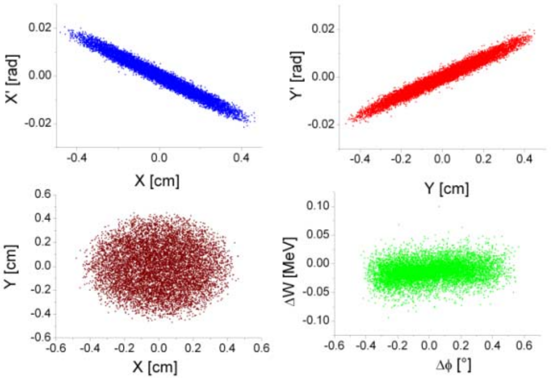

Fig. 6: Output distribution of the RFQ at 5.0 MeV with LEBT output as input, 9170 macro particles used.

Finally in Fig. 7 we can see the phase space projections at 40.1 MeV at the exit of the H-DTL. For the MEBT and DTL we assumed statistically distributed combined standard quadrupole errors for each quad. No further losses occurred in the transport section and along the DTL. The output distribution is slightly distorted form the focussing errors of the quadrupoles but this is uncritical and the aperture factor in the s.c. part is still ≥ 2. The emittance growth was modest and maybe will be further reduced.

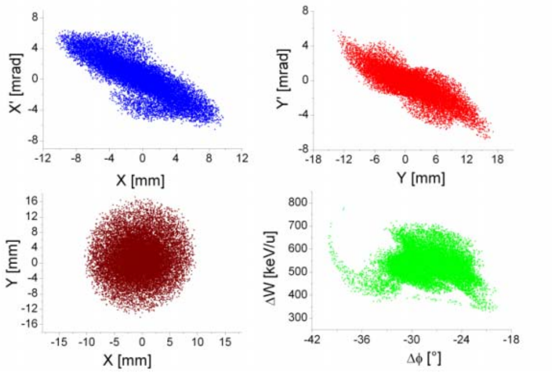

Fig. 7: Output distribution of the CH-DTL at 40.1 MeV with combined quadrupole errors and RFQ output as input, 9170 macro particles used.

CONCLUSION

The superconducting 12-gap and 6-gap CH-structure in combination with the KONUS beam dynamics layout seems to be suited for the efficient acceleration of intense light ion beams [1,6]. Also integrated overall simulations of a complete injector with a magnetic LEBT, a RFQ, a compact MEBT and a sc H-DTL even with standard quadrupole tolerances of the MEBT and a s.c. H-DTL showed a smooth beam behaviour, modest emittance growth and no particle losses after the RFQ. The matching was successfully performed with two short external transport sections. Extended electrodynamic studies of the modified 12-gap and 6-gap sc 175 MHz CH cavities with MWS® resulted in low peak fields and good field flatness. The fabrication, preparation and delivering of a downscaled 352 MHz s.c. 19-gap CH-prototype of bulk niobium is expected for the end of July 2004. The prototype will be tested in the fully equipped cryo lab at the IAP Frankfurt, where to this time a cold test of a 176 MHz half wave resonator at 4.2 K is being performed. The results from the CH-cavity tests will influence the design parameters of the layout of a s.c. CH-DTL for IFMIF.

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