A SUPERCONDUCTING CH-LINAC FOR IFMIF

H. Podlech, A. Bechtold, M. Busch, H. Klein, U. Ratzinger, R. Tiede, C. Zhang
Institut für Angewandte Physik (IAP), Goethe Universität Frankfurt, Germany

Abstract

The IFMIF accelerator which has to provide a 40 MeV 250 mA Deuteron beam requires a duty cycle of 100% [1]. The IAP Frankfurt has proposed a 175 MHz H-type drift tube linac consisting of an IH-cavity and a chain of superconducting CH-cavities [2]. A superconducting CH-prototype cavity has been tested very successfully and has reached effective gradients of 7 MV/m [3]. Two rf power couplers are necessary to feed one CH-cavity in the IFMIF case. The maximum rf power per cavity is approximately 500 kW. As amplifiers the originally foreseen 1 MW units or 300 kW units can be used. The focusing scheme in the CH-linac is based on superconducting solenoids. Beam dynamics simulations have been performed with an error analysis using the LORASR code based on the KONUS dynamics. An updated and improved linac design will be presented. A contribution of IAP for the EVEDA phase could consist of the construction and the test of the room temperature IH-cavity and the first sc CH-cavity. A study together with industry has been already performed to solve the production process and the system integration of auxiliary equipment like couplers and tuners.

INTRODUCTION

The International Fusion Material Irradiation Facility (IFMIF) has to deliver a 250 mA D^+-beam in cw mode provided by two linacs. Due to the cw operation a superconducting solution of the drift tube linac seems to be attractive compared to conventional room temperature linacs because of the lower operational costs and the increased reliability. Because no energy variability is required it would be possible to use superconduting multi-cell cavities like CH-structures to minimize the number of subsystems like tuners and rf amplifers. The proposed CH-linac consists of one 4 MV rt H-mode cavity (IH- or CH-type) followed by 8 superconducting CH-cavities.

H-MODE LINAC

Room Temperature DTL

The room temperature H-mode cavity is necessary to increase the cell length at the entrance of the superconducting linac to simplify the cavity fabrication. Additionally, it can filter unaccelerated particles coming out of the RFQ.

The rt cavity has 20 accelerating gaps providing 4 MV effective voltage, the cavity length is about 2 m. As candidate for the rt drift tube cavity an IH- or CH-structure are suitable candidates. The effective shunt impedance of the IH-cavity (116 MΩ/m) is about 40% higher than of the CH-cavity (83 MΩ/m) in the IFMIF case. Therefore the required power to drive the cavity is lower, about 75 kW versus 120 kW. But the maximum surface power density is almost a factor of two lower in the case of the CH-cavity (see Fig. 1). With respect to the required cw operation the CH-cavity is maybe the preferred structure, in particular because of the good cooling capabilities. The total rf power including the beam power is 575 kW and 620 kW, respectively [4]. Table 1 summarizes the main parameters of the rt IH- and CH-cavity.

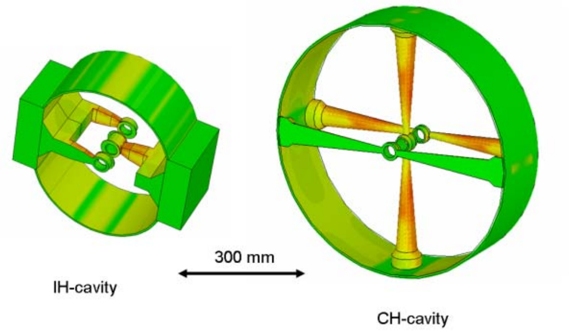

Figure 1: Power density of the rt IH (left) and the CH-cavity (right). Although the IH-cavity required less power, the power density ist larger by a factor of about two.

Table 1: Parameter comparison of a 4 MV rt IH- and CH-cavity

Parameter	**IH**	**CH**
f (MHz)	175	175
Energy range (MeV/u)	2.5-4.5	2.5-4.5
Tank diameter (mm)	400	600
Gaps	20	20
Aperture diameter (mm)	30	30
Z_{eff}, no lenses (MΩ/m)	116	83
U_a (MV)	4	4
P_c (kW)	75	120
ρ_{max} (W/cm^2)	20	11.5
P_{beam} (kW)	500	500
P_{tot} (kW)	575	620
Amplifier (kW)	2×400	2×400

Superconducting DTL

The main acceleration from 4.5 to 20 MeV/u takes place in the superconducting CH-linac consisting of 8 CH-cavities. The superconducting CH-cavity is the first low

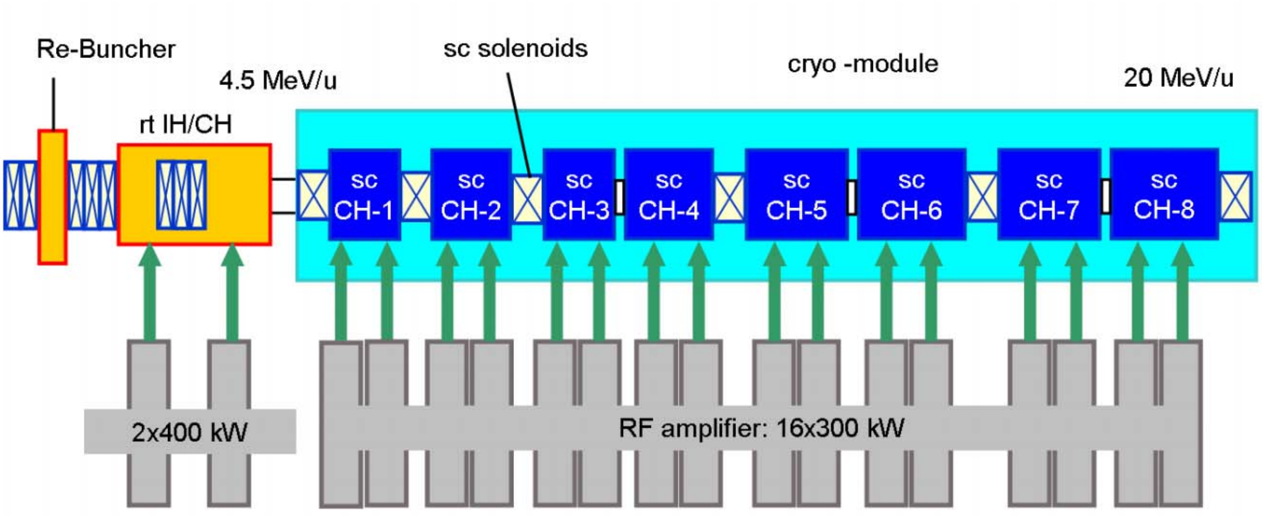

Figure 2: Layout of the H-mode-linac for IFMIF proposed by IAP. The linac consits of one rt H-mode cavity and a chain of 8 superconducting CH-cavities. Each cavity is fed by two amplifiers and two power couplers.

energy multi-cell rf structure providing efficient acceleration with high real estate gradients [5]. This type of drift tube structure has been developed at IAP Frankfurt. A prototype cavity has been tested with a maximum gradient of 7 MV/m, corresponding to an effective voltage of 5.6 MV.

The average rf power per sc CH-cavity is around 500 kW. For each cavity two 300 kW amplifiers and two power couplers are foreseen. The transverse focusing is provided by superconducting solenoids. The total length of the DTL is around 12 m. Fig. 2 shows the schematic layout of the proposed H-type linac and Fig. 3 shows the superconducting CH-linac. The design of the CH-cavities has been optimized towards high rf power and maximum compactness to avoid undesired drift section which can result in a detoriation of the beam quality [6].

To minimize the risk of beam losses and resulting activation the aperture diameter is increasing with the beam energy. In the superconducting part the aperture has been set to values between 50 and 80 mm.

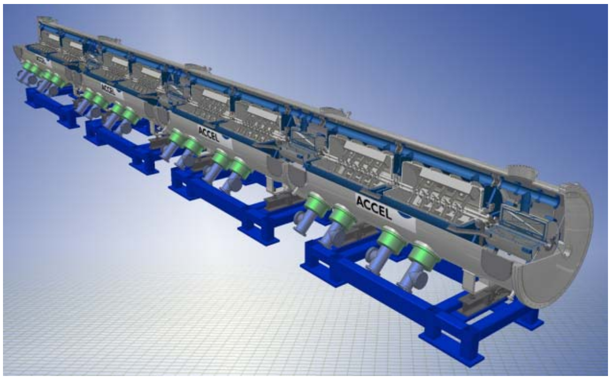

Figure 3: Layout of the superconducting part of the DTL.

Table 2: Parameter of the first sc CH-cavity

f (MHz)	175
L (cm)	87
Gaps	9
Aperture diameter (mm)	50
$\overline{\beta}$	0.105
G (Ω)	62
R_a/Q_0 (Ω)	1962
R_aR_s ($k\Omega^2$)	173
Q_0 (BCS)	$5.2 \cdot 10^9$
Q_0 (Design)	$5 \cdot 10^8$
E_p/E_a	5.2
B_p/E_a [mT/(MV/m)]	9.3
E_p (MV/m)	22
B_p (mT)	39
U_a (MV)	3.6
P_c (W)	13
P_b (kW)	437
W (J)	5.3
Q_e	13000

A detailed beam dynamics study has been performed to optimize the linac layout with the goal to avoid particle losses and to optimize the beam quality. Fig. 4 shows the phase space after the RFQ and after the H-mode linac. The emittance growth without errors is moderate. It is about 60% for the transverse and 30% for the longitudinal phase space (see Fig. 5). Fig. 6 shows the transverse beam envelopes (100%) along the whole H-mode DTL.

Additionally, an error analysis has been performed. Different kinds of errors like misalignment and field errors as well as rf errors have been used. 100 runs with 10^5 particles each and randomly distributed errors have been performed. There was no case with transversaly lost particles. The detailed beam dynamics study with errors can be found in [7].

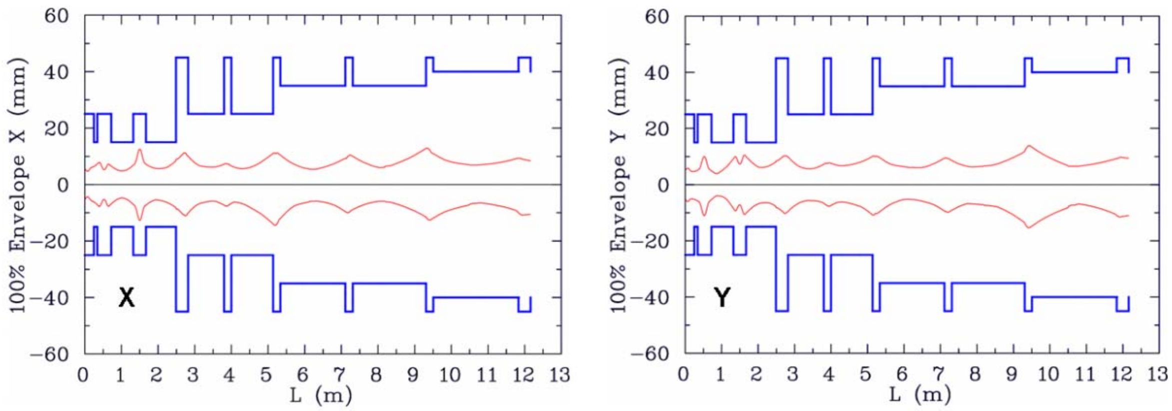

Figure 6: 100% transverse beam envelopes in both directions without errors. The blue lines correspond to the aperture.

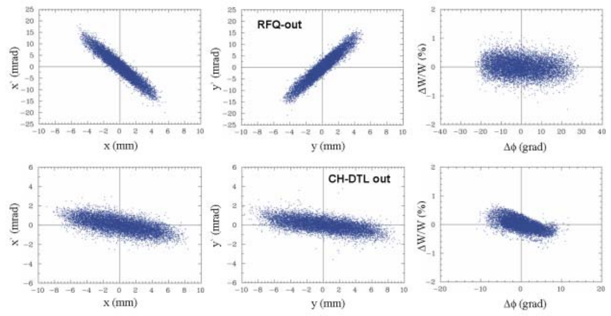

Figure 4: Phase space distribution after the RFQ (top) and after the DTL (bottom).

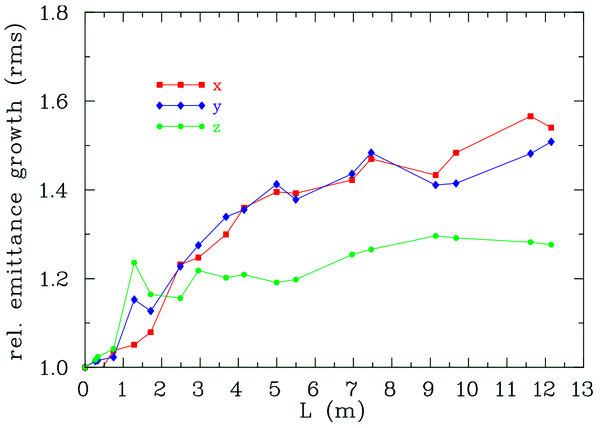

Figure 5: Emittancs growth along the H-mode-DTL.

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