BEAM DYNAMICS LAYOUT OF H-TYPE DRIFT TUBE LINACS FOR INTENSE LIGHT ION BEAMS*

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Abstract

H-type cavities have been successfully developed during the last 30 years for a large variety of applications in the field of ion acceleration. Radio Frequency Quadrupole (RFQ) and Drift Tube Linac (DTL) versions were designed in the $H_{11(0)}$- and in the $H_{21(0)}$-mode. The Interdigital H-type (IH) drift tube structure is efficient for an energy range from 0.1 to 20 MeV/u, especially in combination with the KONUS beam dynamics layout. At higher beam velocities higher frequencies must be applied for efficient operation, which can be achieved with the CH-structure ($H_{21(1)}$-mode). Frequencies range from 150-800 MHz at beam energies from about 2 to 150 MeV/u. The CH-structure has small transverse dimensions and is mechanically robust using crossed stems. This opens the possibility to build superconducting (sc) cavities, which is advantageous for cw operation. In this paper we present two beam dynamics layouts for light ion accelerators with intense beams, using the KONUS beam dynamics design: a) For an International Fusion Material Irradiation Facility (IFMIF) the acceleration of a 125 mA Deuterium beam from 2.5-20 MeV/u is required in cw operation. A combination of one rt IH-tank followed by a 175 MHz sc CH-DTL has been considered. b) Several proposals deal with the acceleration of proton beams with currents ranging from a few mA up to 100 mA. Here the sc CH-DTL could cover the medium energy part of the linac from several MeV/u input energies up to about 150 MeV/u. For a 350/700 MHz frequency combination a layout is presented, which is oriented on the requirements to the linac of an Accelerator Driven System (ADS) for waste transmutation or/and energy production. Beam simulations show in all cases that the required intensities could be accelerated with good emittance preservation, high transmission and high efficiency.

1 INTRODUCTION

Various study groups have been working since more than 20 years already on the feasibility and technical layout of a new generation of high current, high duty factor linear accelerator facilities for protons, deuterons and H-ions. A combination of a RFQ-accelerator with a drift tube linac (DTL) and a Coupled Cavity Linac (CCL) design for the high ion energies has been chosen in all cases. For many years the Alvarez-type DTL has been the standard structure, while recently the H-type structures became an rf efficient and compact alternative. For higher ion energies the necessarily higher operation frequencies can be achieved with the CH-structure [5]. Fig. 1 gives a schematic view on a room temperature design.

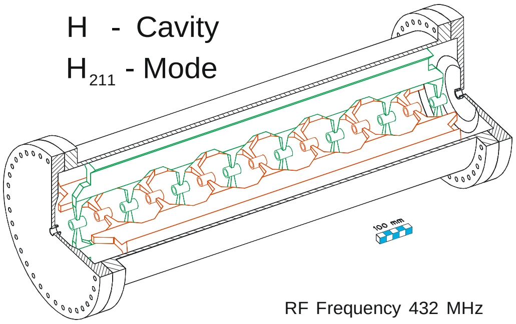

Fig. 1: Sketch of a room temperature CH-cavity.

The CH-structure is rather compact and very stable, due to the cross-bar stem array. Moreover this allows a superconducting approach. These multi-cell cavities will considerably reduce costs for investment, operating and maintenance when compared to existing sc solutions in that β-range. Transverse focusing can be accomplished in between the tanks with high adjustment precision. Therefore the sc CH-structure is an efficient alternative in all cases with a conventional fixed velocity profile along the linac, especially for high duty cycle operation.

2 SUPERCONDUCTING CH-DTL DESIGN FOR A PROTON LINAC

In the feasibility study of an accelerator driven system for waste transmutation the potential of a rf linac with 600 MeV end energy and beam currents up to 40 mA has to be evaluated in comparison to a cyclotron. For the medium energy part of the rf linac between RFQ and Coupled Cavity Linac the CH-structure could be applied. Fig. 2 gives a schematic view of a 350/700 MHz approach for the energy range from 5-100 MeV.

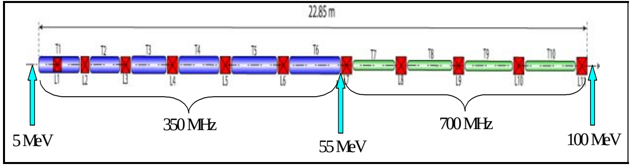

Fig. 1: Schematic layout of an 350/700 MHz sc CH-DTL for ADS.

Table 1 summarizes the main parameters for a sc CH-linac design with 6 cavities operated at 350 MHz and another 4 at 700 MHz. A modest accelerating field of 4.1 MV/m has been chosen to guarantee low electric and magnetic peak fields for sc operation. Particle dynamics simulations with 10,000 macroparticles show no losses and low emittance growth along the linac also in case of maximum current. In Figs. 4-6 the calculated output emittances are plotted for a homogenous elliptical 3d input

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space charge distribution. The emittances are well confined for the further acceleration in the high-beta linac part. Fig. 3 gives a sketch of the CH-structure calculated with the code Microwave-Studio [4], the structure parameters are given in Table 1, too. A drift tube aperture diameter of 4 cm results in a good safety factor against particle losses.

Table 1: Design parameters of a 350/700 MHz sc CH-DTL for ADS and cavity parameters of tank 2.

Design parameters	**SC CH-DTL**	**Units**
A/q	1 (H^+)	
Max current	40.0	mA
Frequency	350 / 700	MHz
Lattice	FDF - DFD	
Tank number	10 (SC)	
P_{tot} per tank	362.0	kW
W_{in} / W_{out}	5.0 / 100	MeV
Cells / Length	202 / 22.85	m
E_oT	4.10 – 4.92	MV/m
Bore radius	1.5 / 2.0	cm
Max quad gradient	6.15	kG/cm
Max quad field	1.23	T
Max Kilpatrick	0.80	
In- / Out RMS ε^n_{trans}	0.03 / 0.0385	cm×mrad
In- / Out RMS ε^n_{long}	0.53 / 0.97	keV/u×ns
Cavity parameters	**Tank 2**	**Units**
Beta	0.1	
Frequency	350.43	MHz
E_{acc}	5.29	MV/m
Tank length / diameter	0.936 / 0.268	m
Drift tube diameter	4.0	cm
Gaps	16	
E_{peak}/E_{acc}	4.75	
B_{peak}/E_{acc}	8.43	mT/MV/m

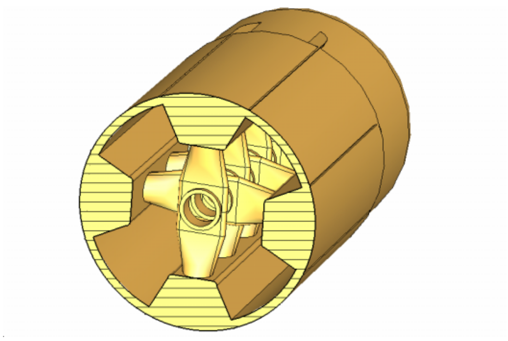

Fig. 3: Middle-cut of a 350 MHz 16 gap sc CH-cavity (tank 2) for ADS.

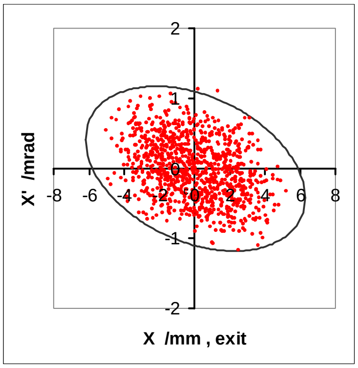

Fig. 4: Output distribution in the X-X' trace space of the sc CH-DTL for ADS with 99 % emittance ellipse.

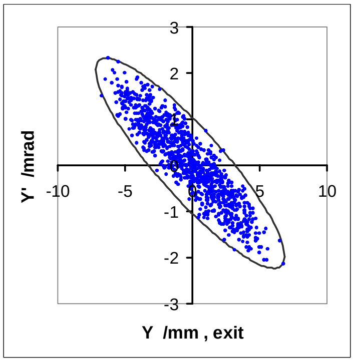

Fig. 5: Output distribution in the Y-Y' trace space.

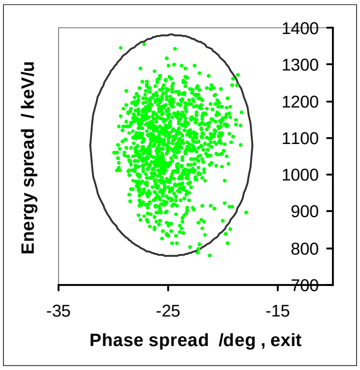

Fig. 6: Output distribution in the $\Delta\varphi$-ΔW trace space.

3 THE SC CH-DTL FOR IFMIF

Extended beam dynamics and structure studies have been done in the IFMIF collaboration for a 175 MHz, 40 MeV, 125 mA D^+ rf linac approach for cw operation. For the DTL part both a room temperature IH-design and a combination a rt IH tank with a sc CH-linac (scheme of Fig. 7) has been successfully investigated [1,2]. The sc CH-version (design and structure parameters of table 2) turned out to be superior to the rt IH-design with respect to the following critical issues: a) no cooling problems of the rf structure losses in cw operation b) smaller construction length and less tanks, i.e. higher efficiency c) larger drift tube diameters up to 8 cm. The beam behaviour is smooth, no losses along the linac occurred and good safety margin could be reached in the sc linac against losses. Figs. 9 shows the transverse beam envelopes, Fig. 10 the longitudinal output emittances at the linac end. Fig. 8 gives a first real sketch of the 175 MHz CH-tank 2 in the critical low energy part of the IFMIF-DTL, calculated with Microwave Studio. Again special attention was given to low peak fields and acceptable flatness of the accelerating field.

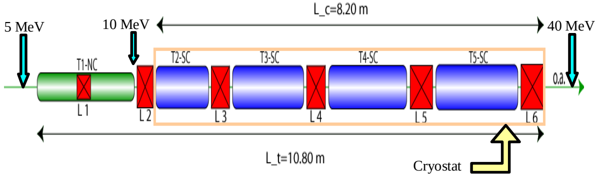

Fig. 7: Scheme of an 175 MHz sc IFMIF CH-DTL.

Table 2: Design parameter of a 175 MHz sc CH-DTL for IFMIF + Cavity parameter of tank 2.

Design parameters	**SC CH-DTL**	**Units**
A/q	2 (D^+)	
Design current	125.0	mA
Frequency	175.0	MHz
Lattice	FDF - DFD	
Number of tanks	5 (1NC+4SC)	
P_{tot} per tank	NC:690.0 SC:740.0	kW
W_{in} / W_{out}	5.0 / 40	MeV
Cells / Length	73 / 10.8	m
E_oT: NC/SC	1.95 / 4.1	MV/m
Bore radius of DT	NC:1.5 SC:2.4 - 4.0	cm
Max quad gradient	6.40	kG/cm
Max quad field	1.28	T
Max Kilpatrick	1.00	
In-/ Out RMS ε^n_{trans}	0.035 / 0.091	cm×mrad
In-/ Out RMS ε^n_{long}	0.070 / 0.097	cm×mrad
Cavity parameters	**Tank 2**	**Units**
Beta	0.1	
Frequency	174.86	MHz
E_{acc}	5.35	MV/m
Tank length	1.52	m
Drift tube diameter	5.0	cm
Tank diameter	58.0	cm
Gaps	12	
E_{peak}/E_{acc}	7.23	
B_{peak}/E_{acc}	9.17	mT/MV/m

4 CONCLUSION

The superconducting CH-structure in combination with the KONUS [3] beam dynamics layout is well suited for the efficient acceleration of intense light ion beams. Beam dynamics simulations gave high transmission, also in case of statistical and matching errors. A first superconducting prototype structure will be constructed and tested within the next year to ensure the mechanical and superconducting properties.

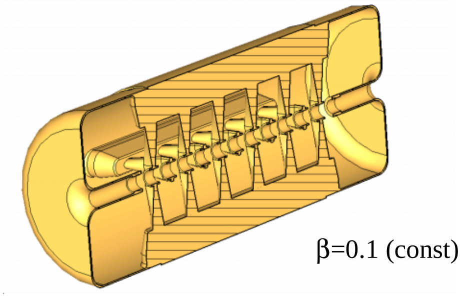

Fig 8: View of a 175 MHz sc CH-cavity (tank 2).

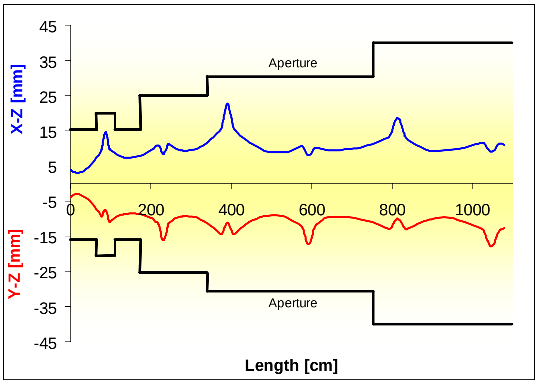

Fig. 9: 100 % beam envelopes along the linac.

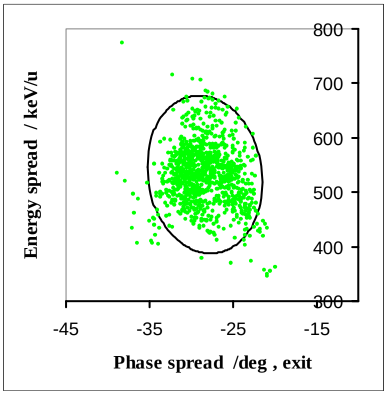

Fig. 10: Output distribution in the Δφ-ΔW trace space The 95 % emittance ellipse is drawn.

5 REFERENCES

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