

Development of Superconducting CH-Cavities for the EUROTRANS and IFMIF Project ¹

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Abstract. The superconducting CH-cavity is an excellent candidate for the efficient acceleration in high power proton and ion drivers like EUROTRANS (**EURO**pean Research Programme for the **TRANS**mutation of High Level Nuclear Waste in an Accelerator Driven System, 600 MeV 352 MHz) and IFMIF (**I**nternational **F**usion **M**aterial **I**rradiation **F**acility, 40 MeV 175 MHz). The CH-structure is a superconducting cavity for the low and medium energy range operated in the H_{21} -mode. A prototype cavity has been developed and tested successfully with a gradient of 7 MV/m. Presently a new superconducting CH-cavity with improved geometry for high power applications is under construction. The status of the cavity development related to EUROTRANS and IFMIF is presented.

1. Superconducting CH-Cavities in High Power Applications

Superconducting Crossbar-H-mode (CH)-cavities are particularly suitable for high power applications with high beam currents like EUROTRANS or IFMIF because their well designed geometry reduces the number of drift spaces between the cavities significantly compared to conventional low- β ion linacs. Furthermore they deliver a better efficiency at high duty cycles in comparison with room temperature linacs. The special KONUS beam dynamics decreases the transverse rf defocusing and provides long lens free sections inside the cavities. All these components together lead to high real estate gradients with moderate peak fields [1].

1.1. EUROTRANS

The EUROTRANS project, supported by European Union, is proposed for the transmutation of high level nuclear waste using an accelerator driven system (ADS) with an efficient high-current cw-linac [2].

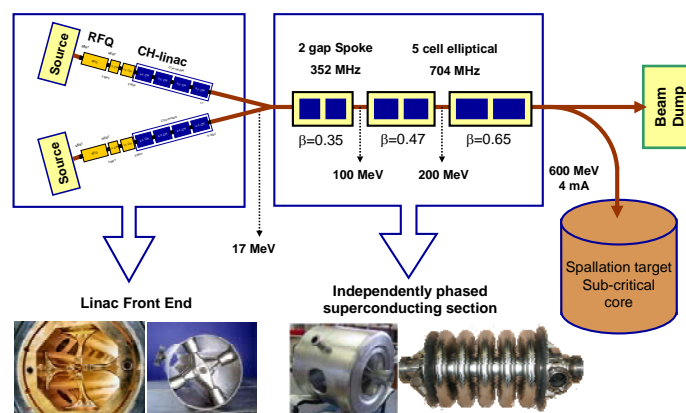


FIG. 1. Schematic overview of the EUROTRANS proton driver linac.

¹ Work supported by EU

Therefore protons will be accelerated up to 600 MeV with a beam current of 2.5 mA which can be increased to 4 mA during the burning process of the fuel. The beam is transported to a spallation target consisting of liquid metal with a power between 1.5 MW and 2.4 MW depending on the beam current. Figure 1 shows a reference linac scheme for the EUROTRANS project. The linac front end, shown in fig. 2, is a proposal offered by IAP of Frankfurt University. In order to assure the extreme high integrity of operation (less than 3-10 beam trips with $t > 1$ s per year) the EUROTRANS injector consists of two identical front ends. Both front ends are in operation but only one injector delivers the beam to the main linac. In case of a beam trip which is unfixable within a short time ($t < 1$ s) the second injector will deliver the beam. Each front end consists of an ECR ion source, a 4-vane-RFQ up to 3 MeV, two room temperature CH-cavities up to 5 MeV and four superconducting CH-DTL which accelerate the beam up to 17 MeV. All listed components will be operated at 352 MHz. Followed by other linear accelerating structures the beam energy will be increased to 600 MeV. The rt CH-DTL are foreseen to prepare the beam for the following superconducting CH-cavities. They are acting as beamloss filters and avoid a superconducting breakdown.

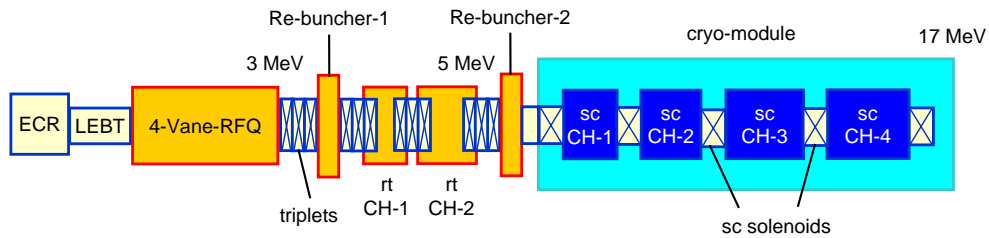


FIG. 2. Layout of the 17 MeV EUROTRANS front end.

1.2. IFMIF

Another high power application for superconducting CH-cavities is the IFMIF project. IFMIF is proposed for the research of new fusion reactor materials. A 250 mA D^+ -beam with 40 MeV will be provided by two identical linacs working in cw mode [3]. By hitting a liquid Li-target with a 10 MW beam fast neutrons will be produced. Behind the target are different modules containing analyzing samples. Regarding to the cw operation mode a superconducting drift tube linac composed of CH-structures seems to be an attractive solution compared to conventional room temperature linacs whose operational costs are much higher while reliability decreases. The proposed IFMIF front end, shown in fig. 3, consists of one room temperature CH-structure which accelerates the beam up to 4.5 MeV followed by eight superconducting CH-cavities leading up to 20 MeV. These eight cavities are supposed to be combined into four superconducting doublet structures using a special designed CH-cryo-module. The linac operation frequency will be 175 MHz.

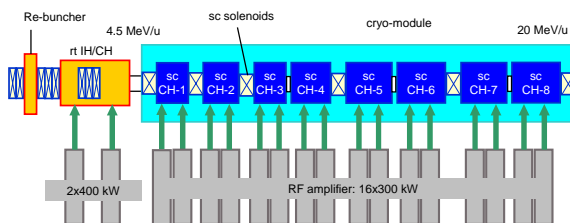


FIG. 3. Layout of the CH-linac for IFMIF proposed by IAP. The linac consists of one rt CH-cavity and a chain of eight superconducting CH-cavities. The cavities are fed by two amplifiers and two power couplers.

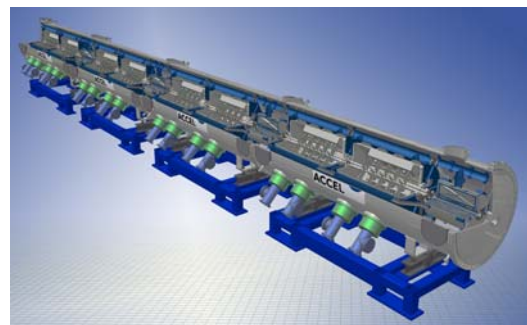


FIG. 4. Layout of the superconducting cryo-module of the IFMIF-DTL.

2. Status of the Superconducting CH-Development

In context of high power applications like EUROTRANS or IFMIF the girder and stem geometry of the superconducting CH-cavity has been optimized to accommodate large power couplers up to 250 kW between the stems (see fig. 5). Via integration of inclined stems the end cell length and unwanted drift sections could be reduced significantly while reaching a high beam quality. The minimization of unnecessary drift sections reduces the total cavity length by about 20% without changing the voltage and peak fields [4]. A high beam quality is necessary to avoid beam losses and activation of accelerator components.

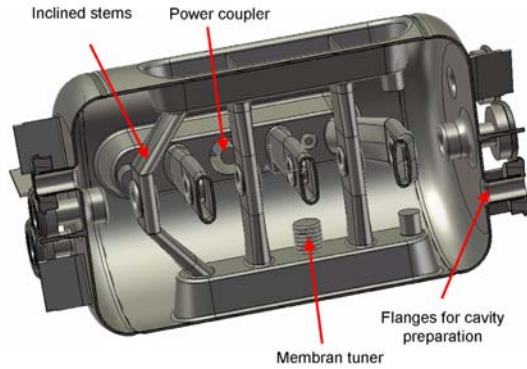


FIG. 5. Layout of the new 325 MHz superconducting CH-cavity, optimized for high power applications, which will be tested with beam at the GSI UNILAC.

TABLE I: Parameters of the 325 MHz sc CH-cavity.

f [MHz]	325.224
β	0.1585
Total length [mm]	550
Aperture diameter [mm]	30
Accelerating cells	7
Tuner height [mm]	0-60
Tuner diameter [mm]	50

The cavity tuning will be done by capacitive tuners through the girders. Currently two different types of tuner are foreseen. For coarse voltage and frequency adjustment during fabrication cylindrical fixed tuners will be used. Additionally, membrane tuners are foreseen with a tuning range of several hundred kHz. The first superconducting EUROTRANS CH-cavity (see fig. 7 and 8) includes seven fixed cylindrical tuners, one fast membrane tuner against limitations like microphonics, Lorentz force detuning etc. and two slow membrane tuners to readjust the frequency at 4.2 K. The advantage of these membrane tuners is the minimization of the required longitudinal space which would be essential by using a tuner system pushing on the end cells. Figure 6 shows the simulated frequency depending on the tuner height for the first superconducting EUROTRANS CH-cavity by using ten identical cylindrical tuners with a diameter of 40 mm.

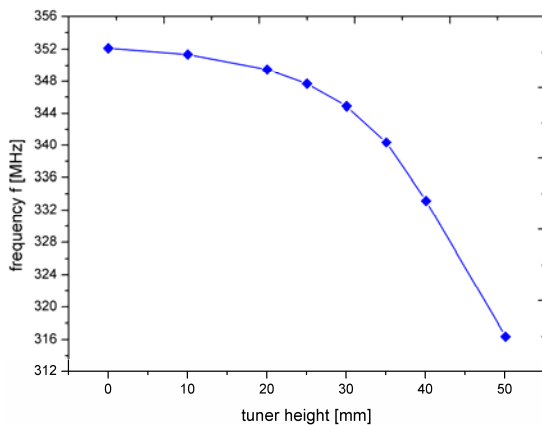


FIG. 6. Simulated tuning range of ten tuners with a diameter of 40 mm.

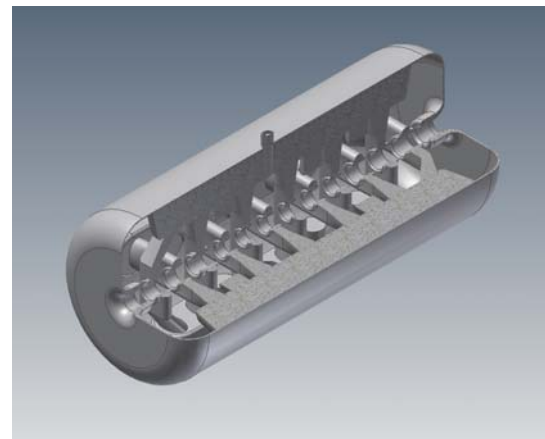


FIG. 7. Recent design of the first 352 MHz superconducting EUROTRANS CH-cavity.

Based on this tuning range the working points for the fixed and the membrane tuners have to be chosen with the aim to maximize the frequency gain while keeping the tuner displacement to a minimum. This tuning concept has been proven already during the fabrication of the superconducting 360 MHz prototype cavity [5]. The electric field distribution on z-axis has been optimized by adjusting the ratio between the gap- and the cell length. Figure 8 shows the field distribution before and after the optimization for the first 352 MHz superconducting EUROTRANS CH-cavity with an impressed β -profile.

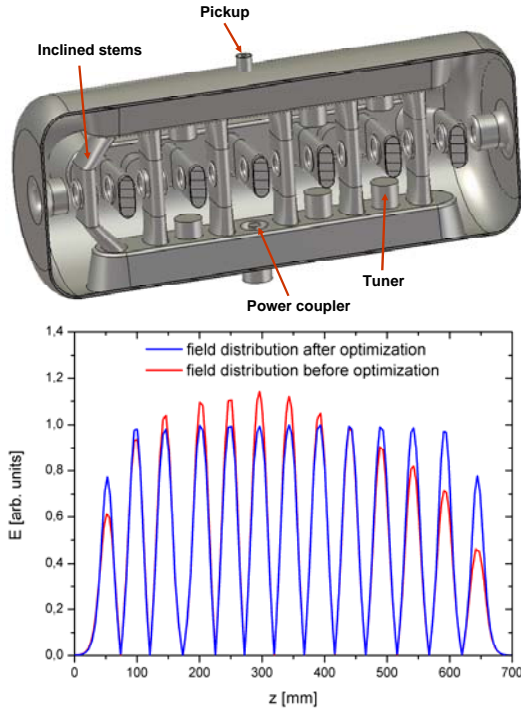


FIG. 8. Side view of the first superconducting EUROTRANS CH-cavity (above), related simulation of the electric field distribution before and after the optimization (below).

TABLE II: Parameter of the first sc EUROTRANS CH-cavity.

f [MHz]	352.2
Total length [mm]	702.64
Cavity diameter [mm]	291.6
Aperture diameter [mm]	25 - 30
Accelerating cells	13
Membrane tuner	3
Fixed tuner	7
Tuner height [mm]	25 - 35
Tuner diameter [mm]	40
G [Ω]	54
R_a / Q_0 [Ω]	1760
$R_a R_s$ [$k\Omega^2$]	95
Q_0 (BCS)	$1.4 \cdot 10^9$
Q_0 (Goal)	$2 \cdot 10^8$
E_p / E_a	7.1
B_p / E_a [mT / (MV / m)]	9.8
E_p [MV / m]	21.8
B_p [mT]	29.7
E_a ($\beta\lambda$ -definition) [MV/m]	3.9
U_a [MV]	2.5
P_c (@ $Q_0 = 2 \cdot 10^8$) [W]	25

A room temperature copper model has been built to validate the electromagnetic simulations (see fig. 9). With its modular design it is possible to use it for different drift tube arrays. By changing the cavity length, the drift tube length and the stem positions to the EUROTRANS parameters a comparison between simulations and measurements will be enabled. Also the tuner positions, their size and shape can be changed. For a measurement of the external quality different coupler arrays and sizes can be used.



FIG. 9. Photograph of the rt copper model to validate electrodynamic simulations (left), manufacture of a girder extension aligned to the length of the first EUROTRANS CH-cavity (right).

3. Acknowledgements

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4. References

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