DEVELOPMENT OF SUPERCONDUCTING CH-CAVITIES FOR THE EUROTRANS INJECTOR LINAC*

F. Dziuba†, H. Podlech, M. Busch, U. Ratzinger, C. Zhang, H. Klein
Institute for Applied Physics (IAP), Goethe University Frankfurt, Germany

Abstract

The CH-structure (**C**rossbar-**H**-mode) is a superconducting multi-cell drift tube cavity for the low and medium energy range operated in the H_{21}-mode. Due to its well designed geometry and by using the special KONUS (**KO**mbinierte **NU**ll Grad **S**truktur) beam dynamics the superconducting CH-cavity is an excellent candidate for the efficient acceleration in high power proton and ion accelerators. One of many possible applications for this kind of superconducting RF cavity is the EUROTRANS project (**EURO**pean Research Programme for the **TRANS**mutation of High Level Nuclear Waste in an Accelerator Driven System, 600 MeV, 352 MHz). A prototype cavity has been developed and tested successfully with a gradient of 7 MV/m. At present a new superconducting CH-cavity with improved geometry for high power applications is under construction. The status of the cavity development related to EUROTRANS is presented.

SUPERCONDUCTING CH-CAVITIES IN HIGH POWER PROTON AND ION ACCELERATORS

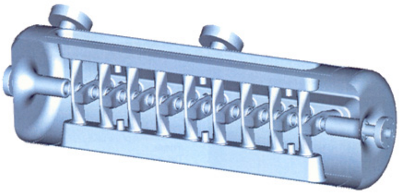

Figure 1: 360 MHz sc CH prototype cavity.

The superconducting CH-cavity has been investigated for several years at the Institute for Applied Physics (IAP) of Frankfurt University. This kind of cavity is particularly suitable for international high power applications with intense beam currents like the EUROTRANS project because its well designed geometry reduces the number of drift spaces between the cavities significantly compared to conventional low-β ion linacs [1]. Furthermore, the superconducting CH-structure delivers a better efficiency at high duty cycles in comparison with room temperature cavities. Using the special KONUS beam dynamics the transverse RF defocusing will be decreased, which provides long lens free sections inside the cavities. All these components lead to high real estate gradients with moderate peak fields [2]. Figure 1 shows the 19-cell, 360 MHz superconducting prototype CH-cavity, which has been developed and tested successfully at the IAP Frankfurt. The main prototype parameters are mentioned in Table 1.

Table 1: Parameters of the sc CH-prototype Cavity

Material	Bulk niobium
β	0.1
Frequency [MHz]	360
Total length [mm]	1048
Cavity diameter [mm]	274
Aperture diameter [mm]	25
Accelerating cells	19
RRR	250
G [Ω]	56
Q_0 (BCS)	$1.3 \cdot 10^9$
R_a/Q_0 [Ω]	3180
$R_a\,R_s$ [kΩ^2]	178
E_p/E_a (βλ-definition)	5.2
B_p/E_a [mT/(MV/m)] (βλ-definition)	5.7
E_a exp. [MV/m]	7
U_a exp. [MV]	5.6
E_p exp. [MV/m]	36
Q_0 exp.	$6.8 \cdot 10^8$

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 [3].

To initiate the transmutation protons will be accelerated up to 600 MeV with a beam current of 2.5 mA, which can

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† dziuba@iap.uni-frankfurt.de

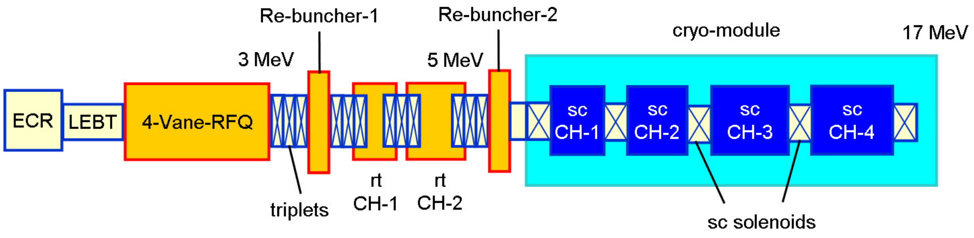

Figure 2: Layout of the 17 MeV EUROTRANS front end.

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 beam power of either 1.5 or 2.4 MW depending on the beam current. Figure 3 shows a schematic overview of the EUROTRANS proton driver linac. A linac front end proposal offered by IAP of Frankfurt University is shown in Figure 2.

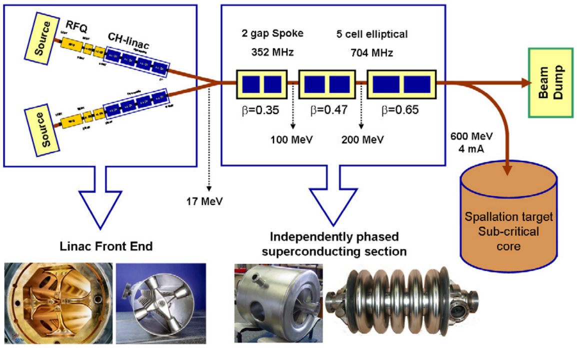

Figure 3: Schematic overview of the EUROTRANS proton driver linac.

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 redundant designed 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 (Electron Cyclotron Resonance) 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 mentioned components will be operated at 352 MHz. In addition to that, the CH-structures own a β-profile. Followed by other linear accelerating cavity types the beam energy will be increased to 600 MeV. The room temperature CH-structures are foreseen to prepare the beam for the following superconducting CH-structures. They are acting as beam loss filters and avoid a breakdown of superconductivity.

STATUS OF THE SUPERCONDUCTING CH-DEVELOPMENT FOR EUROTRANS

In context of high power applications like EUROTRANS the girder and the stem geometry of the superconducting EUROTRANS CH-cavity has been optimized in comparison with the prototype to accommodate large power couplers up to 250 kW between the stems (see Figure 4).

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 decreases the total cavity length by about 20% without changing the voltage and peak fields [4]. A high beam quality is essential to avoid beam losses and activation of accelerator components.

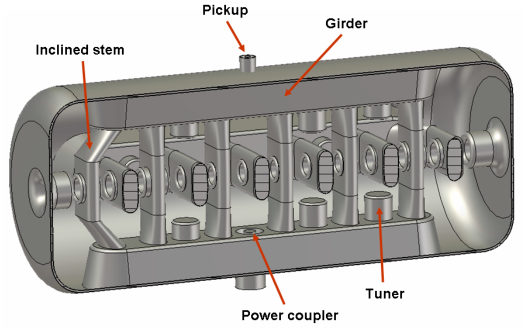

Figure 4: Side view of the first sc EUROTRANS CH-cavity (simulation with Microwave Studio [5]).

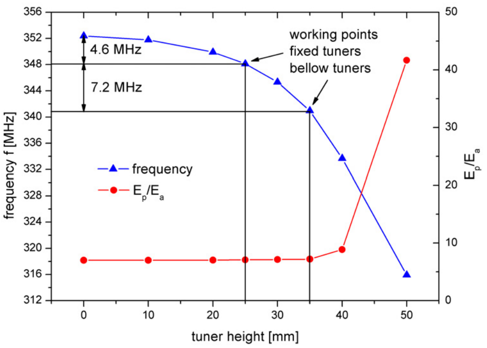

Figure 5: Simulated tuning range of ten tuners with respect to the electrical peak fields.

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, bellow tuners are provided with a tuning range of several hundred kHz. The first superconducting EUROTRANS CH-cavity includes seven fixed tuners, one fast bellow tuner against limitations like microphonics, Lorentz-force detuning etc. and two slow bellow tuners to readjust the frequency at 4.2 K [6]. By using these bellow tuners the required longitudinal space will be minimized in contrast to a tuner system pushing on the end cells. Figure 5 shows the simulated frequency depending on the tuner height using ten identical cylindrical tuners with a diameter of 40 mm for the first superconducting EUROTRANS CH-cavity.

Based on this tuning range the working points for the fixed and the bellow tuners have been chosen with the aim to maximize the frequency gain while keeping the tuner displacement and the electrical peak fields to a minimum. This tuning concept has been proven already during the fabrication of the superconducting 360 MHz prototype cavity [7].

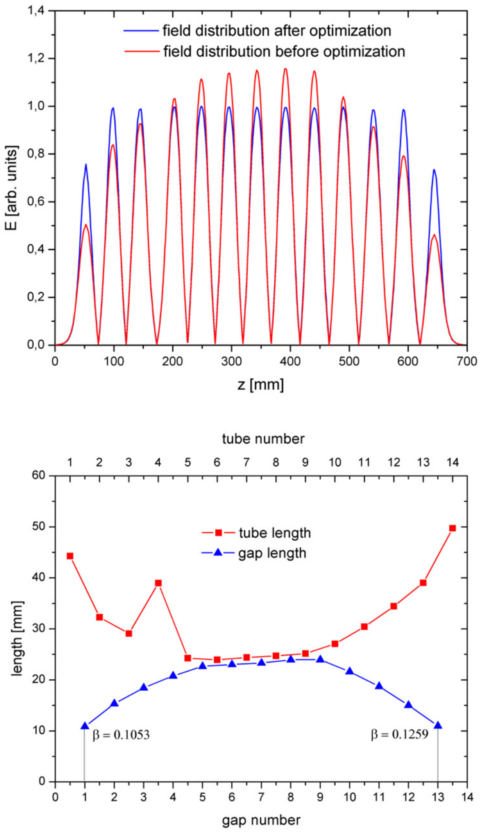

Figure 6: Simulation of the electric field distribution before and after the optimization (above), related gap and drift tube length for the flat field (bottom).

The electric field distribution on z-axis was optimized by adjusting the gap-to-cell-length ratio. Figure 6 shows the simulated field distribution before and after the optimization (above) and the related gap respectively the drift tube length (bottom) for the first superconducting EUROTRANS CH-cavity with β-profile.

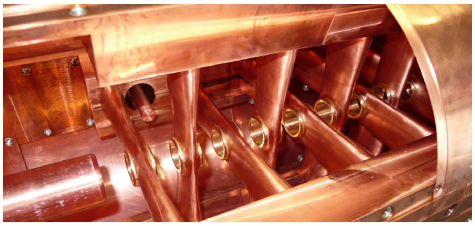

Figure 7: Picture of the rt copper model to validate electrodynamic simulations.

A room temperature CH copper model has been built to validate the mentioned electromagnetic simulations (see Figure 7). Its modular design allows measurements with different drift tube arrays. Furthermore, the total cavity length, the drift tube length and the stem positions can be changed. By setting all model variables to the EUROTRANS parameters a comparison between simulations and measurements is possible. Therefore girder extensions from massive copper bricks were built at the IAP workshop as documented in Figure 8. Figure 9 shows a technical drawing of the recent superconducting CH-cavity design.

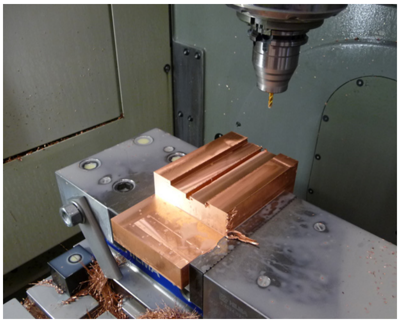

Figure 8: Manufacture of a girder extension aligned to the EUROTRANS parameters of the first sc CH-cavity.

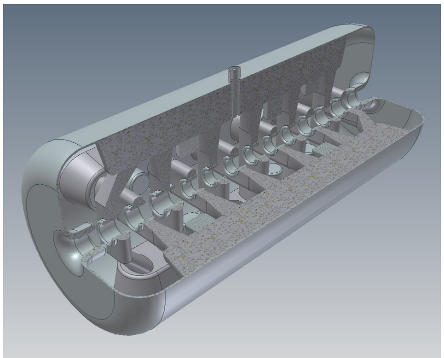

Figure 9: Recent design of the first 352 MHz superconducting EUROTRANS CH-cavity.

Table 2: Parameters of the First Two Superconducting EUROTRANS CH-cavities

	CH-1	CH-2
$\overline{\beta}$ (mean value)	0.117	0.138
Frequency [MHz]	352.1	352
Total length [mm]	696.64	862.89
Cavity diameter [mm]	286.1	300.82
Aperture diameter [mm]	25 - 30	30
Accelerating cells	13	14
Bellow tuner	3	3
Fixed tuner	7	7
Tuner height [mm]	25 - 35	25 - 35
Tuner diameter [mm]	40	40
G [Ω]	56	58
R_a/Q_0 [Ω]	1775	2143
$R_a\,R_s$ [kΩ^2]	99	124
Q_0 (BCS)	$1.4 \cdot 10^9$	$1.5 \cdot 10^9$
Q_0 (Goal)	$2 \cdot 10^8$	$2 \cdot 10^8$
E_a [MV/m] (βλ-definition)	3.9	3.9
E_p [MV/m]	26.5	28.1
E_p/E_a	6.8	7.2
B_p [mT]	39.8	35.9
B_p/E_a [mT/(MV/m)]	10.2	9.2
U_a [MV]	2.5	3.2
P_c [W] (for goal Q_0)	18	24

The current main parameters from Table 2 belong to the first two superconducting EUROTRANS CH-cavities.

SUMMARY AND OUTLOOK

The electrodynamic simulations concerning the cavity tuning and the field optimization for the first two EUROTRANS CH-structures were completed. For the third and fourth cavity the simulations are in progress. Considering the beam dynamics results the energy gain for every cavity has to be calculated and optimized in an iterative process.

To validate the electrodynamic simulations, a room temperature CH copper model was built and aligned to the first superconducting EUROTRANS cavity. Measurements of the electrical field distribution with different drift tube arrangements, of the external quality and of the tuning range, will be done in the next few weeks.

The simulations of both room temperature CH-cavities were practically completed. It is planned to build the first room temperature EUROTRANS CH-cavity and test it with full RF power in the next years.

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