THE SUPERCONDUCTING LINAC APPROACH FOR IFMIF

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Abstract

The IFMIF project requires a high current D^+-linac operated in cw. Due to the cw operation a superconducting linac using CH-structures (see fig. 1) could be an alternative solution compared with the room temperature Alvarez reference design especially with respect to avoiding thermal problems and to reducing the operational costs.

INTRODUCTION

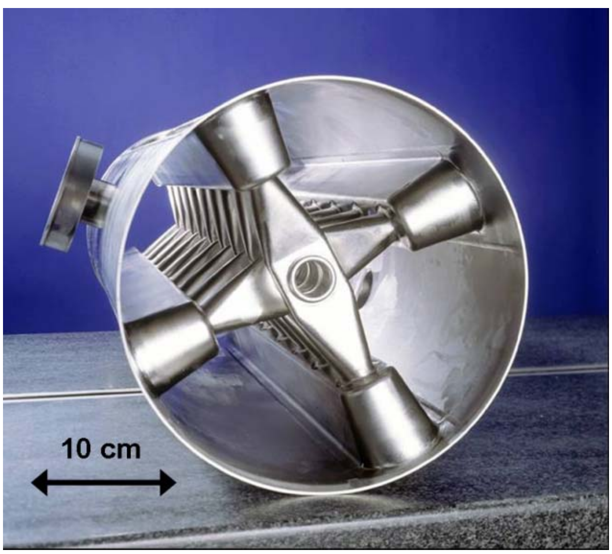

Figure 1: The superconducting CH-structure developed at IAP in Frankfurt. The prototype cavity has 19 accelerating cells, the geometrical β is 0.1. The cavity has been tested successfully at the cryogenic laboratory in Frankfurt (ACCEL GmbH).

Future fusion reactors using the D-T-reaction have to resist an extreme flux of fast 14 MeV neutrons. This is especially true for the first wall of the vacuum chamber. A certain fraction of this flux will be absorbed in the material causing displacements of lattice atoms. This will result in a fatigue of the used material. To extend the lifetime and to limit the activation of the first wall it is neccessary to find new alloys with sufficient robustness against neutron radiation. Presently no high flux source of fast neutrons exists which can imitate the conditions in future reactors.

The **I**nternational **F**usion **M**aterial **I**rradiation **F**acility (**IFMIF**) being planned will provide the neutron flux needed to develop new reactor materials [1]. The neutrons will be produced by a 40 MeV Deuteron beam hitting a liquid lithium target. The total required beam current is 250 mA with cw operation delivered by two linacs in parallel operation. The beam power is 10 MW. The loss rate along the accelerator must be very low, in the order of 1 W/m to avoid activation and to guarantee hands-on-maintenance.

The front-end of each IFMIF accelerator will consist of an ECR-source and a 175 MHz 4-vane-RFQ. Within the superconducting linac approach the beam will be accelerated after the RFQ from 2.5 AMeV to 4.5 AMeV by a 175 MHz r.t. IH- or CH-structure. One r.t. structure is advisable because a certain fraction of unaccelerated particles will exit the RFQ. In addition, the higher input energy of 4.5 AMeV has advantages in the fabrication of the superconducting CH-structures. After the r.t. cavity a chain of s.c. CH-structures accelerates the beam to the final energy of 20 AMeV. The s.c. part of the linac (see fig. 2) consists of 4 cavity doublets with a length of one KONUS period. The superconducting CH-cavity has been developed in Frankfurt and tested successfully [2, 3]. The main advantage of a superconducting solution would be the significantly lower power consumption. The two r.t. CH-cavities for both linacs need 300 kW rf power and 500 kW plug power, respectively. An estimation for the rf power in one superconducting cavity is 30 W and additionally 40 W of static losses. Both s.c. linacs require 1120 W at 4.4 K which corresponds approximately 340 kW plug power. Thus the total plug power for two CH-linacs (r.t. and s.c.) is than about 0.84 MW. The rf power of the two r.t. Alvarez-DTLs are estimated to 3.74 MW [1]. Assuming an amplifier efficieny of 60% the required plug power due to Ohmic losses in the DTL is 6.23 MW. The difference in the plug power is about 5.4 MW. Assuming 8000 hours of operation time per year a s.c. solution could save $4.3 \cdot 10^7$ kWh per year.

EVEDA PHASE

Within the EVEDA-phase (Engineering Validation and Engineering Design Activity) and the broader approach for ITER it is planned to built and to test the front end of the IFMIF accelerator with full beam current und realistic conditions. The different components will be delivered by different partners across Europe. IAP in Frankfurt has proposed to design and to built an H-type drift tube linac consisting of the r.t. IH/CH-cavity and the first s.c. CH-cavity. Within this concept the reference design (Alvarez) and the superconducting linac could be tested using the same RFQ-injector. Figure 3 gives a schematic overview the possible test setup.

Table 1: Main parameters of the superconducting CH-linac

cavity type	s.c. CH
No. of sc CH-cavitees	8
No. of couplers per cavity	2
Frequency (MHz)	175
Beam current	125 mA
Duty cycle	100%
Electric peak fields	< 22 MV/m
Magnetic peak fields	< 30 mT
RF losses	< 30 W
Aperture diameter	50-80 mm

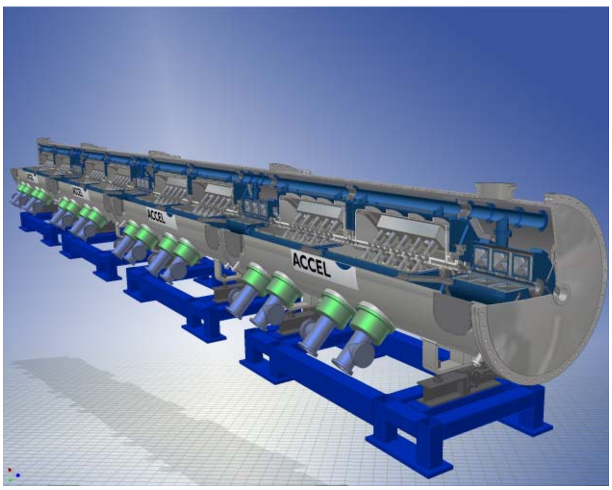

Figure 2: Study of the superconducting CH-linac for IFMIF. Eight cavities are housed in one modular cryo-module. Each cavity is fed by two 250 kW coaxial power couplers.

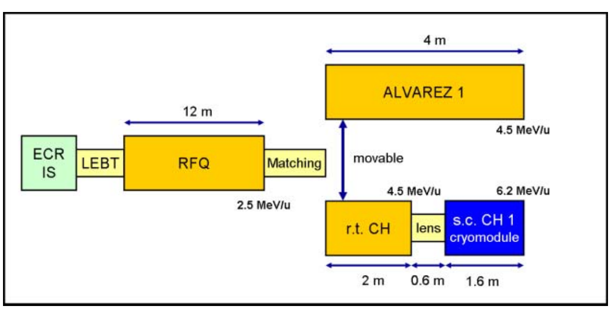

Figure 3: Possible test setup to test both the reference as well as the superconducting solution.

CAVITY OPTIMIZATION

The s.c. CH-cavities have to be optimized with respect to the various requirements of IFMIF. The emphasis of the optimization concerns the following topics:

- Minimization of peak fields
- Optimization of the field distribution
- Optimization of coupler size and location
- Minimization of drift sections
- Optimization of tuning methods

This is especially true for the power couplers. It has been decided to use two coaxial couplers per cavity. Each coupler must feed up to 250 kW cw into a cavity. Figure 4 shows the first cryo-module for the EVEDA-test with one s.c. CH-cavity equipped with two couplers. Figure 5 shows an intermediate step of the cavity optimization. Presently a model is under fabrication to study the rf properties of the first s.c. CH-cavity especially with the two-coupler operation.

One possibility to tune the frequency after fabrication which has already been proven experimentally is the use of tuning cylinders. Figure 6 shows the simulated frequency shift as function of the tuner height for different girder geometries. A girder height of 100 mm has been chosen which gives a maximum tuning range of more than 2% of the frequency. Due to the large beam current strong

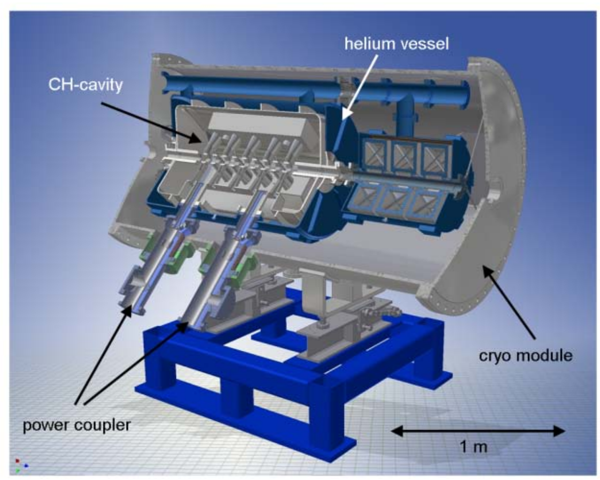

Figure 4: Cryo-module for the EVEDA-test with the first s.c. CH-cavity and two power couplers.

rf coupling is necessary to bring the power into the cavity. The required external Q-value is in the order of 10^4 for each coupler which is in the same range as r.t. cavities. The resulting broad resonance will simplify superconducting operation with respect to microphonics and pressure variations in the helium bath. Figure 7 shows a simulation of the external Q-value as function of the coupler position. This simulation showed that the required coupling can be achieved. A crucial point of the IFMIC accelerator is the beam dynamics because of the high beam current. Only very low losses are allowed to guarantee a hands-on maintenance of the accelerator. Figure 8 shows the transverse 100% envelopes along the linac without alignment errors.

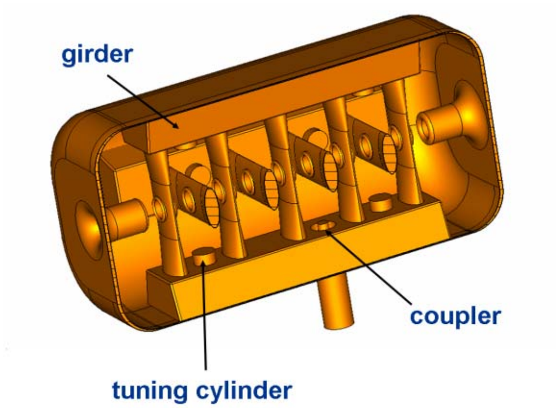

Figure 5: Model of the first s.c. CH-cavity.

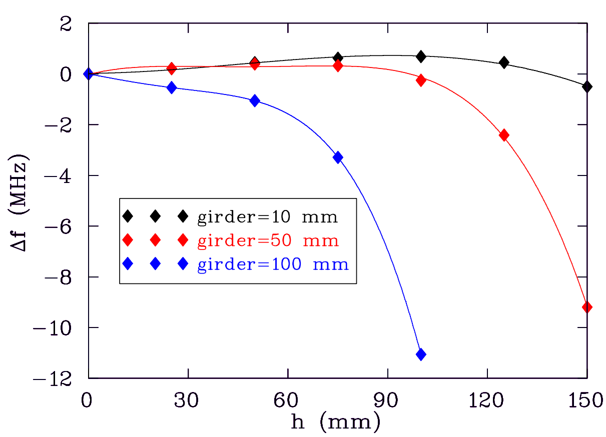

Figure 6: Frequency shift as function of the height of the foreseen tuning cylinders.

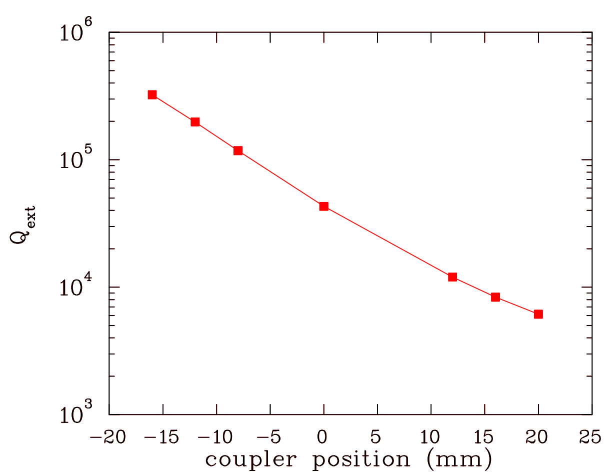

Figure 7: Simulated external Q-value as function of the coupler position. Due to the high beam current an external Q-value of 10^4 is required for each coupler.

SUMMARY AND OUTLOOK

A superconducting CH-linac is a promising alternative for IFMIF. In order to test the feasibility of such a linac it is planned to built and to test the front end with full beam current. The cavity optimization has started to meet the specifications. The fabrication of a warm model has started to test the rf properties. Beam dynamics simulation are continuing to minimize losses and emittance growth. This will include a detailed errors analysis. Additionally solenoid focusing will be investigated as a possible focusing scheme.

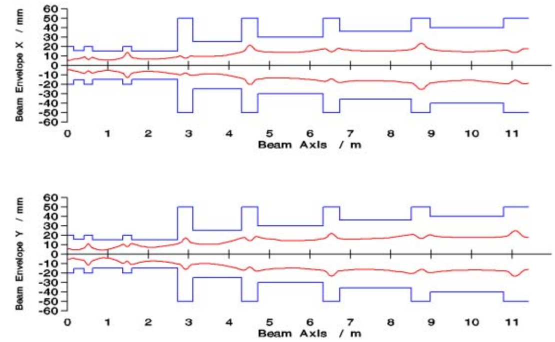

Figure 8: Plot of the transverse 100% envelopes along the proposed IFMIF-linac (without errors).

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