

SUPERCONDUCTING RF ACTIVITIES AT FZ-JUELICH

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Abstract

Two types of superconducting cavities are currently under investigation at the research centre FZJ in Juelich. The niobium prototype of a four-gap spoke cavity is already under fabrication at the central workshop after analysing and tests of copper models.

As a second activity, a new pulsed linac for the cooler synchrotron COSY has been designed based on superconductive half-wave resonators (HWRs). These resonators are well suitable to accelerate polarized protons and deuterons ending up to a similar energies of about 50MeV. Two prototypes of the 160MHz HWR have been ordered at different manufactures. We will present the mechanical analyses of the HWR as well as a study for an optimized high pressure cleaning system. The results of different mechanical fabrication options will be shown.

LIGHT-ION LINAC

The physics at the cooler Synchrotron COSY in FZ-Juelich is getting dominated by experiments using polarized protons and deuterons. A new linac had been designed to fill up COSY to the space charge limit with polarized protons and deuterons at a similar energy [1]. The luminosity gain of the new injector is summarized in table 1.

Table 1: polarized beam at COSY

	existing facility	Proposed facility
Ion source	10 μ A, 20ns	2mA, 500 μ s
injector	Cyclotron 500nA	Linac 2mA
COSY injection	Stripping multiturn, ~10000	Stripping multiturn, ~100
COSY, flat top	5*10 ⁹ particles	2*10 ¹¹ particles (space charge limit)
Luminosity (pol. gas target, p*D=10 ¹³ cm ⁻²)	5*10 ²⁸ cm ⁻² s ⁻¹	2*10 ³⁰ cm ⁻² s ⁻¹

The linac based on superconductive half wave resonators (HWR) together with two interchangeable RFQs will fit into the existing COSY hall (fig. 1). The superconducting (SC) part of the linac consists of 11 modules which had been minimized in length and the room temperature diagnostic and focussing section (fig. 2). The design values of the HWRs will lead to an high real-estate gradient of about 2.7 MV/m within a unit cell. If this assumptions can be reached, the injection energy into COSY will be about 52 MeV for protons and nearly 56 MeV for deuterons.

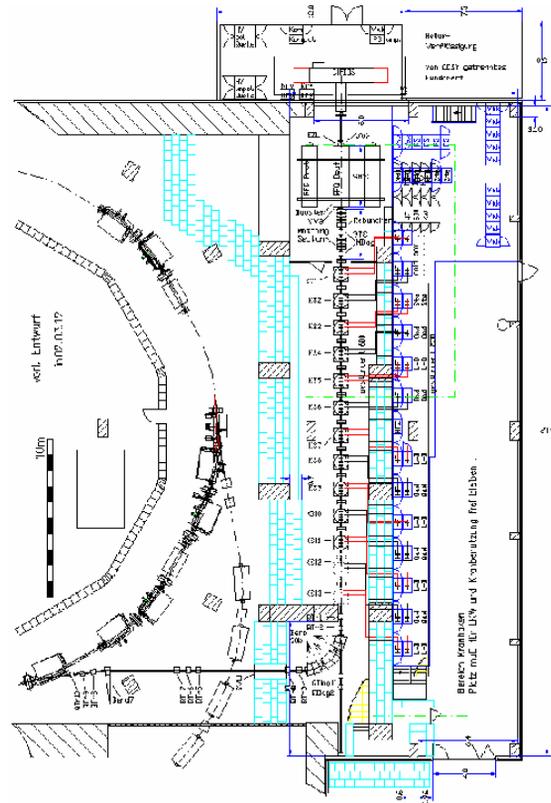


Figure 1: Layout of proposed linac.

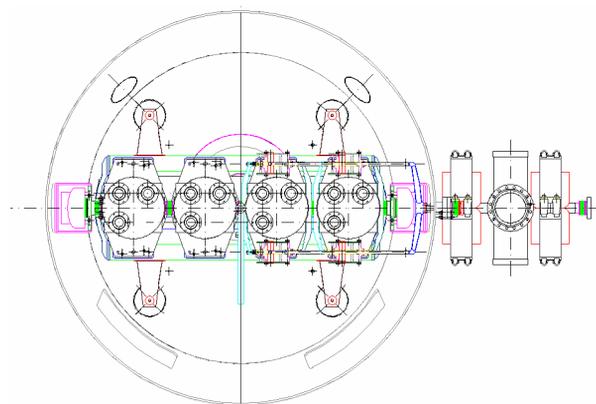


Figure 2: Top view of one unit cell (length: 1.7m).

Cryostat

The cryostat will house 4 resonators mounted on a common girder. It will operate at 4 K and requires only liquid helium, neither secondary cold gas nor liquid nitrogen is required. The cryostat will provide a separated vacuum for the beam to ensure a low dust concentration. For easy mounting, a top loading design was selected. The longitudinal space of the cryostat is restricted to 1152mm, therefore, especially the cold-warm transitions

at the beam ports must kept as short as possible. Further on, special measures were taken to achieve a good cavity alignment including an alignment port which is accessible in the cold state. More details on the cryostat can be found in [3].

HALF-WAVE RESONATORS

The main design of the sc part had been changed from quarter-wave resonators (QWRs) to half-wave resonators (HWRs) due to the intolerable emittance growth and vertical beam kick caused by the QWRs [2]. The decision to use HWRs required the development of new tuning and preparation procedures of the cavities. Besides a minimum use of niobium for cost reasons, the main optimization items were:

- minimizing $E_{\text{peak}}/E_{\text{acc}}$ and $B_{\text{peak}}/E_{\text{acc}}$
- minimizing the length in beam direction including the tuner
- high eigenfrequencies of mechanical resonances
- low Lorentz-force detuning
- low tuning forces
- good tuning sensitivity
- easy access to rinsing of all inner surfaces.

The pulsed operation of the linac requires an intensive research into the Lorentz-force detuning and transient mechanical behaviour of the cavities. The RF losses are negligible because of the low duty cycle and had not served as a design criterion. The fixed accelerating gap lengths led to tolerable transit-time factors for both types of particles (protons and deuterons) and encouraged us to use only two different families of cavities (160 and 320 MHz).

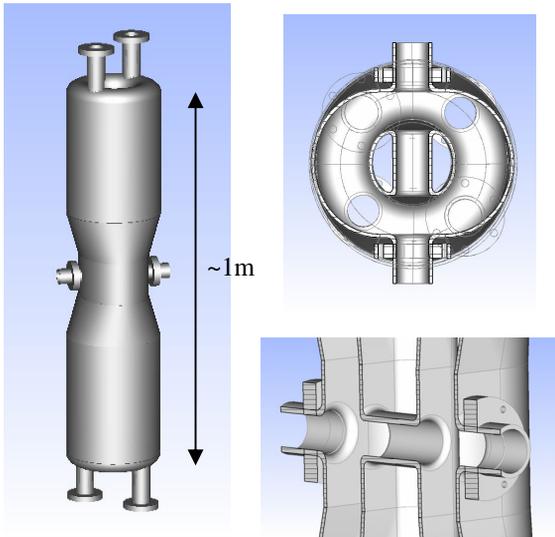


Figure 3: HWR 160MHz.

The top and bottom parts of each cavity have the same round or elliptical shapes to allow a good cleaning of the surfaces and a constant acid flow during the chemical polishing.

This is important because the linac design requires an accelerating field level of 8MV/m corresponding to a B_{peak} of about 80mT and an E_{peak} of about 35 MV/m.

Two pairs of access ports will be installed (one at the top, one at the bottom). The port axes are parallel to the cavity axis, but the symmetry planes of each port pair enclose an angle of $\pm 45^\circ$ to the beam axis. This configuration allows an optimum setup for the high pressure water rinsing. One access port at the top will be used for the main coupler [4]. The field probe will be installed at one of the bottom ports, which additionally to the second port can be used for vacuum pumping. Two prototypes of the 160MHz HWR had been ordered at different companies and are expected end of 2003. Some semimanufactured products are shown in the following pictures (ZANON).



Fig. 4: Nb parts of a HWR, courtesy of ZANON S.P.A.

Mechanical Analyses

The first design based on 2mm niobium sheets gave a Lorentz-force detuning constant of about 2.2 Hz/MV/m [5]. This value will be even larger taking into account that the thickness also will be reduced by deep drawing and chemical polishing. Therefore the thickness had been enlarged to 3mm. The corresponding tuning forces are unfortunately three times higher. The stresses in the niobium at 4K will be tolerable. But warming up the cavity with an unfavourable tuning setting can lead to a permanent deformation.

HWR: Manufacturing

Different forming techniques were analysed to find an optimum manufacturing of the HWRs with respect to the high gradients. Especially forming the inner and outer conductor by high pressure hydroforming of tubes can be a great challenge. The top and bottom cover can be manufactured by spinning. The change of the material thickness is negligible. Another interesting manufacturing technique for this workpiece will be again the high-pressure hydroforming. In contrast to the spinning technique the manufacturing could be realized in one step.



Figure 5: High pressure hydroforming of 230x160x2mm³ niobium sheet, depth: 30mm, 10mm bending radius.

An example of niobium hydroforming tests is given in fig. 5. Details of the calculations are given in [5].

RF Main Coupler

Several different coupling and mounting positions had been analysed taking into consideration the possibility of an adjustable coupling. An inductive coupling had been chosen using one of the upper access ports of the cavity. The first prototype of the RF main coupler is ready for installation (fig. 6). Two RF windows will be used, a warm coaxial window to separate the cryostat vacuum from the air and a vase-type cold window to separate the cavity vacuum from the cryostat vacuum. This cold window allows a coupler installation from the top flange of the cryostat and gives the possibility to adjust the coupling to a loaded Q from $Q_l=10^6$ up to 10^9 . A detail view of the coaxial window part and the coupling loop is given in Fig.6. Both ceramic windows were manufactured of high-purity alumina by FRIATEC AG, Mannheim. Due to the low duty cycle, the design was not dominated by the RF losses rather than the heat transmitted to 4K.



Figure 6: RF main coupler.

In addition, the coupler had been projected to deliver 4kW RF power under fully mismatched condition during the filling time of the cavity.

Tuning System

The mechanical tuner of each HWR consists of two parts: a stepper motor driving the coarse tuner and a piezo fine tuner mounted outside of the cryostat. The possible change in length of the piezos is about +100 μ m. A gear of 1:6 minimizes the microphonic effects of the long tuning rods and lowers the tuning forces. Nevertheless the frequency change of the piezos is sufficient to compensate for the Lorentz-force detuning.

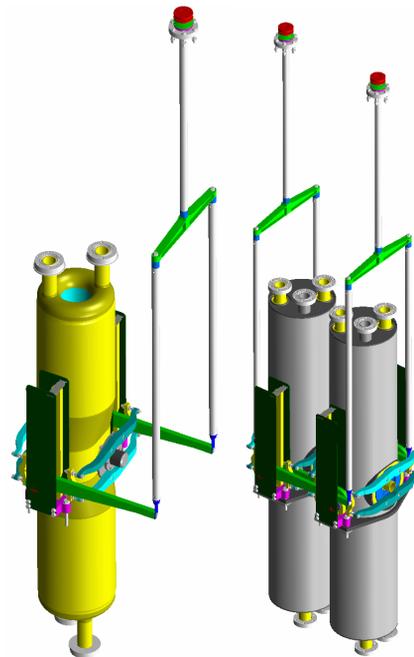


Figure 7: Tuning System and mounting position of a pair of cavities in the cryostat.

UPGRADE OF TEST FACILITY

As the in house testing of sc niobium cavities at cold temperature will become an important activity within the next year the set-up of a cryogenic test surrounding was envisaged. A new vertical bath cryostat (Fig. 8) has been installed into the radiation-shielded area. This cryostat has an inner aperture of 700mm and will be used for testing the HWR prototypes as well as the 4-gap spoke cavities. Currently, the magnetic shielding and the diagnostic equipment are being mounted, the first cool-down is expected to take place in October.

The delivery of the first HWR resonator is expected to be in December. A 500W broadband amplifier and a 4kW pulsed amplifier at 160MHz are ready to be used for testing and conditioning of different accelerating structures.



Figure 8: Vertical bathcryostat.

The HWR will be equipped with the prototypes of the RF main coupler and the fast tuner. This will allow testing the HWRs at high field levels as foreseen for the COSY SC linac but without beam. The I/Q based control system and the fast compensation of the Lorentz-force detuning will be checked and optimised. The excellent temperature behaviour of the precise I/Q modulators, developed for us by Rhode&Schwarz GmbH Cologne, encouraged us to use them not only as modulators but also as phaseshifters.

TRIPLE-SPOKE CAVITY

Design and Construction

Since 1998 the developments of low/medium beta SC structures within the frames of the ESS project [6] has been initiated in FZJ. The very first choice was a spoke cavity [7] and its extension to a multi-gap structure. The theoretical investigations show many advantages of this type of cavities and the possibility to effectively use them in the range of $\beta=0.2-0.5$ where well developed elliptic cavities loose their rigidity. At the moment, these cavities considered as the main option for accelerating structures especially for high intensity proton linear accelerators and extensive developments are carried out in several labs in the world [8].

The realization of the first niobium super-conducting four-gap spoke cavity is at the stage of its fabrication and two identical cavities should be ready by the end of 2003. The prospect of the cavity and its main parameters are

shown on fig. 9 and summarized in table 2. The RF design is well understood and has been published elsewhere [9].



Figure 9: FZJ Triple-Spoke Cavity.

Table 2: FZJ triple-spoke cavity parameters

Frequency	MHz	784
$\beta=v/c$		0.2
Aperture rad.	mm	12
$\beta\lambda/2$	mm	42.83
Cavity cross-section	mmxmm	71.5x71.5
E_{pk}/E_{acc}		4.65
B_{pk}/E_{acc}	mT/MV/m	9.19
B_{pk}/E_{pk}	mT/MV/m	1.98

The Central Department of Technology (ZAT) of Forschungszentrum Jülich is essentially involved in design and construction of the prototype structures. The detailed mechanical design of the cavities was dominated by the intention to simplify e-beam welding as far as possible. Significant efforts were made to minimize the welding seams and to keep them completely two-dimensional. The niobium walls are formed of 2 mm thick Nb sheets, spokes and end cups of 1.5 mm. The novelty of SC RF technology for ZAT together with the complexity of the mechanical construction and the electron-beam welding joints, suggested to devote a substantial effort in building a full scale model from oxygen free copper first. This allowed testing a number of technological issues before proceeding on the Nb version.

Production of Prototypes

All pre-fabricated parts have to be precisely machined before final assembly. As the realization of SC accelerating structures is a first time task for ZAT some extra efforts were made to develop know-how and to establish adequate production procedures. For example milling is used to achieve the final shape of the end caps and to prepare all seams for welding. So this process was carefully optimized with respect to tooling, cooling fluids, machining speed and other parameters.



Figure 10: FZJ triple-spoke cavity copper model.

Further high-quality e-beam welding requires preparation by etching. A number of samples with original and machined surfaces were exposed to the acids for different times to study the removal of material and to optimize the etching process. Finally, the quality of e-beam welding is considered to be the key issue for SC cavity with high accelerating gradients. Further time will be necessary to study only the most important parameters of welding. It is well known that high quality e-beam welding of Cu is significantly more difficult than of Nb. Nevertheless, a first Cu prototype is completed and ready for testing. Components of this cavity before final assembly are shown in Fig. 10.

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