COLD TESTS OF A 160 MHZ HALF-WAVE RESONATOR

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Abstract

A new linac was projected based on superconductive half-wave resonators to fill the COoler SYnchrotron COSY Juelich up to the space charge limit.

The first prototype of a 160 MHz HWR has been built and tested. RF measurements in CW as well as in a pulsed operation will be presented. A second prototype with a slightly different way of fabrication will be completed soon.

All measurements have been performed using the 4 kW loop-coupler that was here developed especially for the HWR linac. The use of a cold window allows to change the coupling from $1*10^6$ to $1*10^{10}$ without any risk of contamination. The mechanical tuner consisting of a stepper-motor-driven coarse tuner and a fast piezo system has successfully integrated into the vertical test-cryostat. The piezos also allow to compensate for the Lorentz-force detuning.

HALF-WAVE RESONATORS

The design of the HWRs was dominated by the parameters of a linac concept to fill the synchrotron COSY at FZ-Juelich with polarized protons and deuterons up to the space charge limit [1].

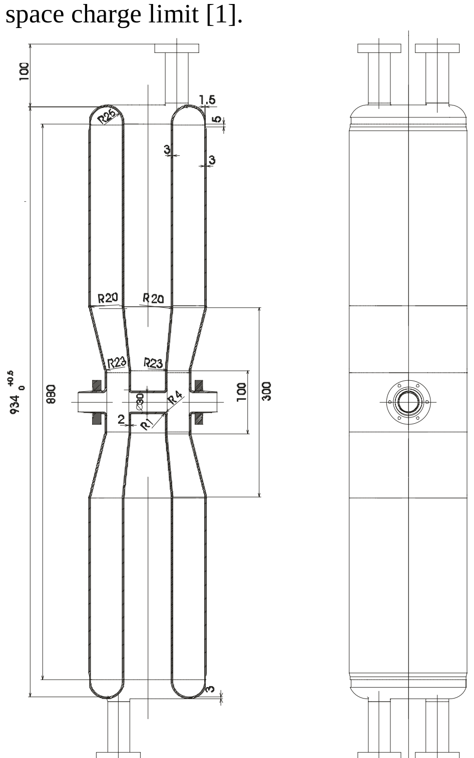

Figure 1: Layout of 160 MHz HWR.

Two prototypes had been ordered at different companies and show slight changes basically at the end-plates (fig. 2). These changes have no impact on the cavity parameters that are summarized in table 1.

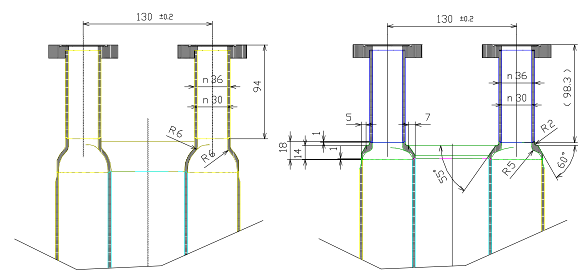

Figure 2: Different end-plate geometries of the HWRs.

Table 1: Main parameters of 160 MHz HWRs related to an accelerating length of $l = ß\lambda$

β	0.11
R/Q in Ohm	249
B_{peak}/E_{avg} in mT/MV/m	10.4
E_{peak}/E_{avg}	4.2
E_{avg} in MV/m peak	8

The first prototype of the 160 MHz HWRs was tested at room temperature prior to any chemical treatment. Figure 3 shows the good conformity of the field profiles measured and calculated by the simulation tool CST-MicroWaveStudio MWS [2].

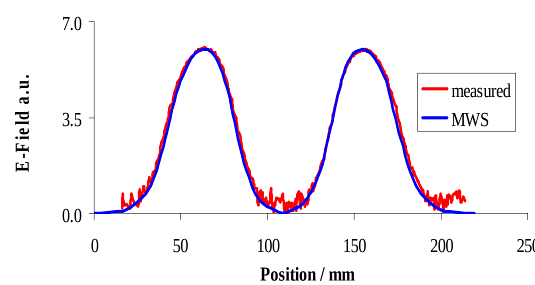

Figure 3: Field profiles, measured and calculated.

The measurements of the resonant frequency during the production process and each step towards operation (like pumping, cool-down and tuning-sensitivity) agree to the simulations [3].

Coupler

The coupler design differs from normally used concepts for superconducting cavities. One of the cavity access-ports, which are required for a good preparation of the cavity surface, has been chosen to hold the RF main coupler. The coupling is essentially magnetic via a current loop. It is variable and has been designed to match the beam-current as well as the unloaded cavity for an on-line

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precise measurement of the unloaded Q_0. The coupling can be changed to give an external Q_{ext} ranging from $1*10^6$ to $1*10^{10}$ at a pulsed RF-power of at least 4 kW [4].

Cold Vase Window

A cold ceramic window is used in order to preserve the cavity from entering dust during the change of the coupling strength, which could spoil the superconducting surface [5]. This window (fig. 4) – installed in the clean room - separates the cavity vacuum from the insulation vacuum of the cryostat and splits up the coupler mechanism from the prepared cavity.

Figure 4: Cold window before (right) and after Ge plating.

The ceramic surface has been coated to protect the window from static discharges and to lower the multi-pacting effects on the ceramic surface. For this coating, undoped amorphous Ge has been chosen because of its very low secondary emission coefficient, the stability, the thermal match and the moderate energy gap. The basic parameters of the Ge film are summarized in tab. 2.

Table 2: Basic parameters of the cold window

Flange material	Ti 3.7035
Cearmic material	Aluminia F99,7 (HF)
Film material	Amorphous Ge
Film thickness	80nm
DC square resist. (300K)	50 MOhm
Estimated DC sq. resist. 4.2K, 1MV/m	1E18 Ohm
4.2K, 20MV/m	1E9 Ohm
Estimated RF sq. resist. 4.2K, 160MHz	3E8 Ohm

Tuner

The layout of the mechanical tuner is shown in fig. 5. The construction with a small horizontal dislocation allows an installation into the cryostat combining two cavities [5]. No additional length in longitudinal direction is required keeping the design of the cryomodule compact. The actuating mechanics of the tuner for each HWR consists of two parts: a stepper motor driving the coarse tuner and a piezo fine tuner, both mounted outside the cryostat allowing easy access for maintenance. The possible change in length of the piezos is about +120µm. A gear of 1:7 minimizes the microphonic effects of the long tuning rods and lowers the tuning forces. The resulting strain of the cavity is sufficient to compensate for the Lorentz-force detuning during the pulsed operation.

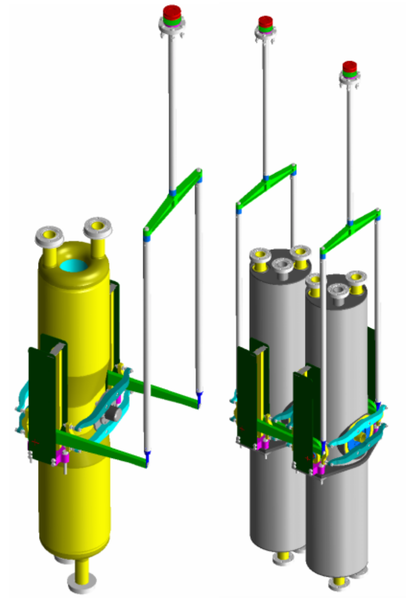

Figure 5: Tuning system and mounting position of a pair of cavities inside the cryostat.

The high sensitivity of the stepper motor system of about 1.2 Hz / step allows a frequency control based only on this stepper motor, corresponding to a frequency-change rate of 2.4 kHz / s.

The behaviour of the tuner mechanism shows a small hysteresis loop. This hysteresis does not affect the reaction of the resonant frequency control system, but can evoke a mechanical resonance when changing the direction of movement. Further investigations are undertaken to analyse this mechanical resonance in the final cryostat.

Cavity Preparation

A commercially available standard procedure has been used to get a chemical preparation of this prototype. The special high-pressure water-rinsing through the access ports at the bottom and top flanges of the HWR prototype guaranteed an optimized cleaning of the surfaces. Details of the preparation are summarized in the following list:

- 60µm BCP chemical etching in a temperature-controlled closed loop operation
- 60µm BCP after a 180° rotation of the cavity
- HPR through all of the four access-ports
- Drying by pumping
- Baking at 100° C for 4 hours
- Pumping to $1*10^{-5}$ mbar

The cavity, prepared in this manner, was cooled down to 4 K in a vertical bath cryostat without further pumping of the cavity vacuum.

CAVITY OPERATION

A first multi-pacting (MP) level occurred at the low RF level of about 2mW and a loaded Q_L of 1E7. This MP barrier is located at the flat region near the beam ports. It needed at least about 2 weeks of different conditioning methods before the MP barrier was exceeded. Further multi-pacting has not been observed up to an accelerating gradient of more than 7 MV/m. The first measurement of the cavity performance, taken at CW operation is presented in fig. 6. The cavity quenched at 6.2 MV/m at CW operation, but reached up to 7.3 MV/m at pulsed mode.

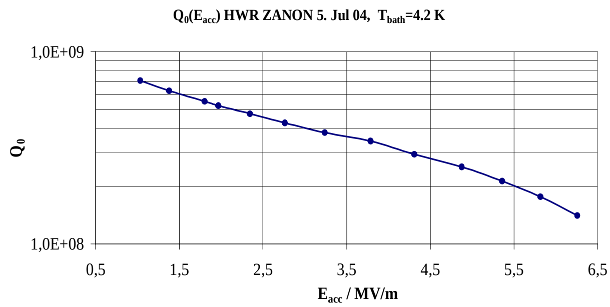

Figure 6: First Q_0- versus E_{acc} measurement.

While operating the cavity at high field, a huge dose of x-rays has been measured. The x-ray spectrum verifies the existence of high field-levels by an independent measurement. The center energy of 200 keV corresponds roughly to the accelerating fieldgradient of 6 MV/m.

Pulsed Operation

The concept of a new injector for COSY was based on a pulsed operation at a repetition rate of 2 Hz and a beam duration of 500 µs, having some impact on the cavity operation and control.

Fig. 7 shows the measurement of the Lorentz force-detuning (LFD) at a pulsed operation and the linear approximation. The resulting Lorentz-force constant of 6 Hz /(MV/m)² is about six times higher compared to the simulations [6].

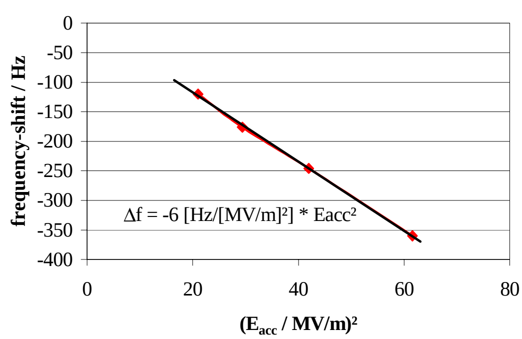

Figure 7: Measured Lorentz-force detuning.

The detuning itself stays within the operating range of the fast piezo-system, but the high rising time required for an overall compensation of the LFD limits the use of the piezos.

Mechanical resonances play an important role in the pulsed operation of a superconducting cavity, especially in the presented HWR. The most significant mechanical resonance has been found at 230 Hz (fig. 8).

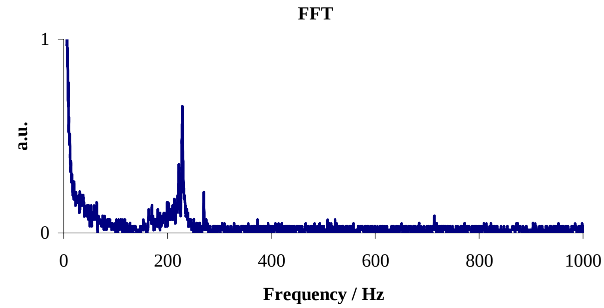

Figure 8: Fast Fourier Transformation of phase-detector signal as response to a 50V step function at the piezos.

This resonance is far away of the pulse repetition rate and 50Hz or 100Hz AC-ripple, but first measurements have shown that this resonance can easily be excited by subharmonics and fast frequency changes of the resonance-frequency control loop.

OUTLOOK

The results gained from the fist prototype cavity are very promising. The design gradient of 6 MV/m (goal 1) has been exceeded during the first test. Achieving the even more demanding goal 2 (8 MV/m in pulsed operation) seems to be within reach.

The final length of the second prototype cavity had been fixed and the last e-beam weldings have been done. The chemical preparation will start at beginning of September and testing will take place in fall. Comparable results, relating to the different behaviours of the slightly different geometries and fabrication processes will be available by the end of the year.

The first promising results of compensating the LFD by the piezo fine-tuner will be verified during the next month regarding the behaviour of the mechanical resonances in the pulsed operation foreseen for a possible new COSY-injector.

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