PERFORMANCE OF A PROTOTYPE 176 MHZ BETA=0.09 HALF-WAVE RESONATOR FOR THE SARAF LINAC

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Abstract

A prototype 176 MHz β = 0.09 half-wave resonator was designed, built and tested at 4 K in a vertical test cryostat at ACCEL. Peak electric fields of 44 MV/m corresponding to peak magnetic fields of 94 mT were achieved after some RF processing. The quality factor at the design gradient of Epeak = 25 MV/m allows operation with cryogenic losses well below 10 W. Multipacting was observed at very low field (Epeak = 0.1 MV/m) and intermediate fields (Epeak = 7-10 MV/m). Three dimensional multipacting calculations predicted these multipacting levels. Calculations show, that the low field multipacting should be strongly reduced with a new slightly changed geometry. Additional six cavities for a prototype superconducting module will be produced with this new shape.

THE SARAF LINAC AT THE SOREQ INSTITUTE IN YAVNE, ISRAEL

A superconducting linac for acceleration of protons and deuterons is currently under construction at the Soreq Institute in Yafne, Israel [1, 2]. The design parameters are listed in table 1. An proton/deuteron energy of 40 MeV with a beam current of 2 mA in cw operation shall be finally reached. The design of the linac is based on superconducting half-wave resonators operating at 176 MHz.

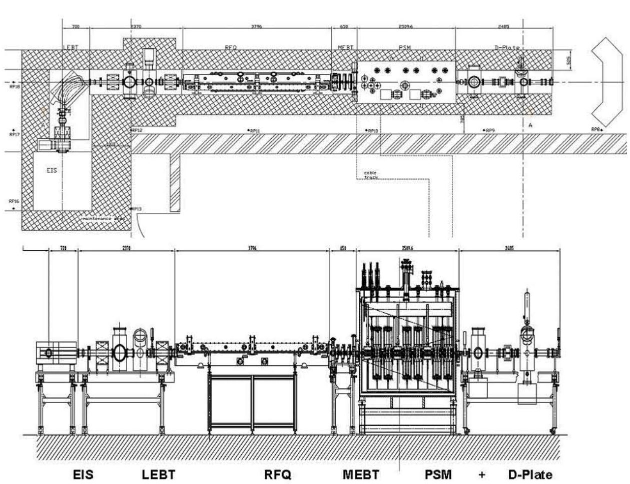

Figure 1: Schematic of the first phase of the SARAF linac. After achievement of the design specification, more superconducting modules will be installed during a second phase to reach a final energy of 40 MeV.

Two families of half-wave resonators are needed, one optimized for velocity of β=0.09 particles and the second optimized for velocity β=0.15 particles.

The project is currently devided into two phases. The first phase up to an acceleration of protons or deuterons to approximately 7 MeV is shown schematically in Figure 1. It consists out of an ECR ion source, a low energy beam transport section followed by a cw 176 MHz RFQ from which the particles are directly injected into a superconducting RF module consisting out of six superconducting half-wave β=0.09 resonators and three focussing superconducting solenoids.

The complete design and construction of the linac is done by ACCEL after the technical specification was agreed upon the parties.

Table 1: Design parameters of the SARAF linac

Ion species	Protons/deuterons
Maximum energy	40 MeV
Minimum energy	5 MeV
Energy adjustment accuracy	200 keV/step
Maximum current	2 (4) mA
Minimum current	40 μA
Current adjustment accuracy	5 μA/step
Current stability at maximum current	+/- 2.5%
Current stability at minimum current	+/- 5%
Current structure	Continuous wave (cw)
Transversal emittance (normalized, rms)	< 1 π·mm·mrad
Longitudinal emitance (rms)	< 4 π·nsec·keV/nucleon
Operation	6000 hours/year
Losses	1 nA

VERTICAL TEST FACILITY FOR HALF-WAVE REONATORS AT ACCEL

In order to test and operate half-wave resonators at ACCEL, a new test infrastructure was built at ACCEL. The vertical cryostat allows testing of naked cavities and cavities equipped with helium vessel and tuners and is shown in figure 2. The cryostat is filled up with helium out of liquid helium dewars.

Figure 2: Vertical test facility at ACCEL. The cryostat (top left) is filled with helium out of dewars (top right). The superconducting half-wave resonator is equipped with a variable input coupler for the vertical test (bottom).

VERTICAL TEST OF A PROTOTYPE HAFWAVE RESONATOR

A prototype β=0.09 half-wave resonator was built and tested at ACCEL to demonstrate that the design field of 25 MV/m peak electric surface field can be reached safely with the present fabrication and preparation techniques available at ACCEL.

After the final welding, the resonator was prepared for vertical test at ACCEL as follows:

- Removal of 150 µm from inner surface by buffered chemical polishing (BCP 1:1:2) in the closed loop chemistry plant. During the etching process the acid temperature was controlled to stay below 15 °C in order to minimize hydrogen migration into the niobium.
- Inspection of inner surface.
- Removal of additional 30 µm from the inner surface by chemical polishing.
- High pressure water rinsing for 2 hours.
- Drying by pumping.
- Assembly, pump-down and leak check.

After this preparation the cavity was tested and showed quite poor performance (compare figure 3). A new cavity preparation was performed including additional removal of 30 µm from the inner surface and longer high pressure rinsing. At this test, the design values of cavity peak surface field and quality factor were safely achieved (compare figure 3 and table 2). We therefore conclude that the surface preparation technique is sufficient to achieve gradients and quality factors in the superconducting half-wave accelerators for a stable operation in the SARAF Linac.

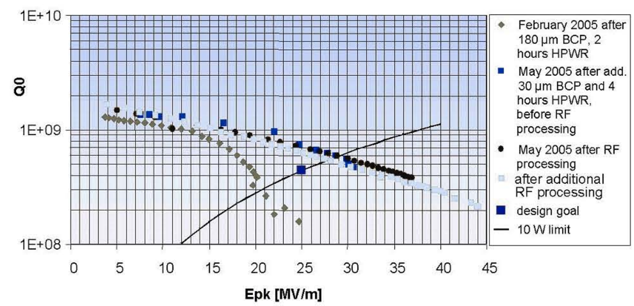

Figure 3: Vertical test result obtained on the prototype half-wave resonator for the SARAF linac. The design values for cavity field and Q were safely exceeded.

Table 2: Results of 176 MHz prototype β=0.09 half-wave resonator developed for the SARAF linac

	Design	Achieved
Maximum electric surface field [MV/m]	25	44
Maximum magnetic surface field [mT]	53	94
Dissipated power @ Epeak = 25 MV/m [W]	10	7
Q0 @ Epeak = 25 MV/m	$4.2\cdot10^8$	$7\cdot10^8$
Sensitivity for helium pressure Δf/Δp [Hz/mbar]	-16	-56
Lorentz force detuning $\Delta f/\Delta Epeak^2$ [Hz/(MV/m)^2]	-	-0.43

Multipacting

During the design of the half-wave resonator two kinds of stable trajectories for possible multipacting were detected.

Type 1: Located at the capacitive region of the resonator (see figure 4). Stable trajectories are observed only at very low field below 0.1 MV/m peak electric field.

Type 2: Located at the high magnetic field region (see figure 4). Stable trajectories are observed at peak electric field levels around 10 MV/m.

For both kind of trajectories the impact energies were calculated and are shown in figure 5. For the type 2 trajectories, the impact energies are quite low and below the threshold (100eV) where the secondary emission coefficient for niobium is above 1. Therefore they were not thought to give any trouble of multipacting during operation.

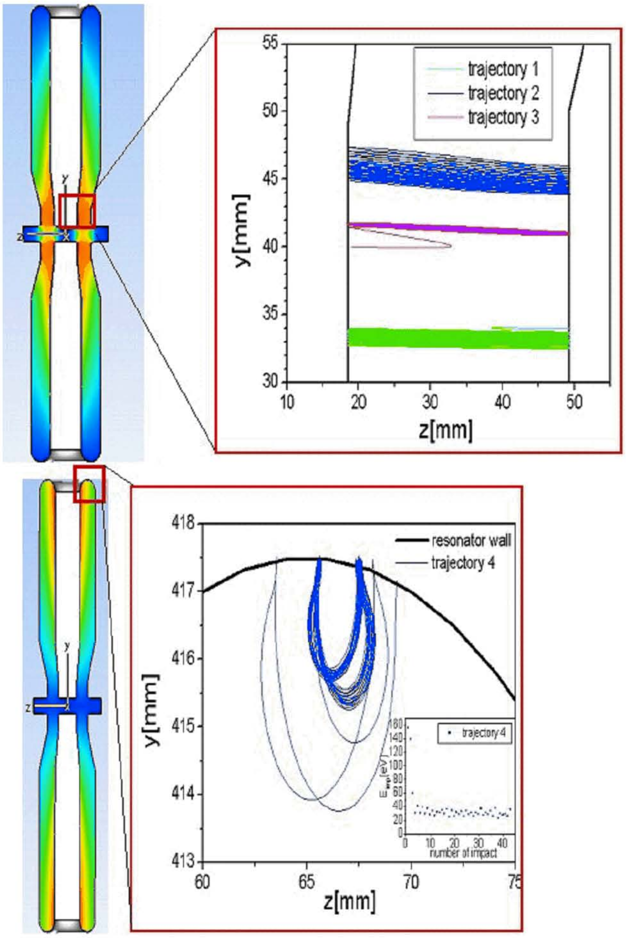

Figure 4: Two kind of stable trajectories detected inside the prototype halfwave resonator, type 1 at the high electric field region and type 2 at the high magnetic field region.

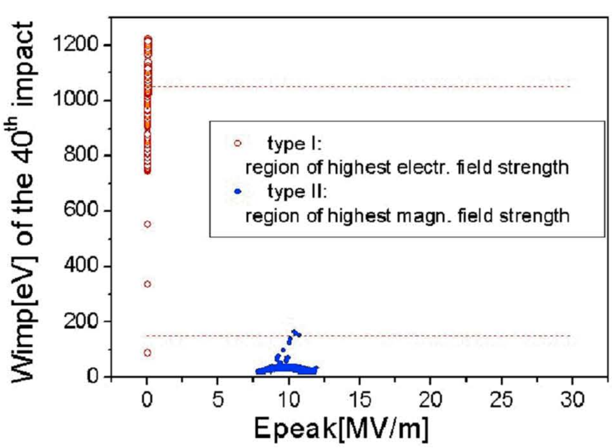

Figure 5: Calculated impact energy of the 40th electron for the two kind trajectories shown in figure 3.

The impact energies of the type 1 trajectories are in the dangerous zone between 100 eV and 1000 eV where the secondary emission coefficient is above 1 and therefore danger for multipacting was possible. But as the electric field for stable trajectories was so low, it was felt that the eventual barriers were easy to overcome and thought not to be harmful for operation.

During the vertical test of the half-wave resonators, however both predicted barriers were observed. The type 2 multipacting was easy to process and did not come back after it was processed once, but the type 1 multipacting seriously gave trouble during the test. Even after processing the barrier, it came back after operation at higher fields and it took sometimes several hours to process through the barrier again.

Therefore this barrier was believed to limit the overall performance of the linac in view of long term stable operation of the superconducting half-wave resonators and therefore the complete linac.

New calculations were performed with slightly different geometry at the high electric field region. The calculations performed with inclined inner or outer wall showed, that no stable trajectories were present in the new cavity design with even only 5° inclination of the inner wall. A new cavity is under production now with this inclined inner wall. New tests will be done with this cavity before the series production of the other cavities will be launched.

SUMMARY

A superconducting prototype cavity was developed, treated and tested at ACCEL. The cavity safely exceeded the design value of 25 MV/m peak surface electric field and showed that the infrastructure at ACCEL is well qualified to achieve the desired design fields for operation of the half-wave resonators in the SARAF linac. Multipacting was observed at the test of the prototype cavity, in good agreement with calculations performed before the test. The geometry of the cavity was slightly changed and calculations indicate, that this will lead to much reduced multipacting sensitivity. A new cavity with this geometry is currently under production.

REFERENCES

[1] D. Berkovits, et al., "Proton Beam Dynamics of the SARAF Linac, *Proceedings of the LINAC 2004 conference*, Lübeck, Germany, 2004

[2] M. Pekeler, et al., "Design of a Superconducting Half Wave Resonator Module for Proton/Deuteron Acceleration," *Proceedings of the 11th workshop on RF Superconductivity*, Lübeck/Travemünde, Germany, 2003