LOW BETTA SUPERCONDUCTING CAVITY FOR THE NEW INJECTOR LINAC FOR NUCLOTRON-NICA*

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Abstract
The results of the RF, mechanical and multipactor discharge simulations of the 162 MHz quarter wave resonator (QWR) for New Superconducting Injector Linac for Nuclotron-NICA are presented. Cavity design in conjunction with manufacturing features is discussed.

INTRODUCTION

The New Injector Linac for Nuclotron-Nica is the proposed replacement for LU-20 accelerator. This linac SC part general layout is showed on Fig. 1 [1-2].

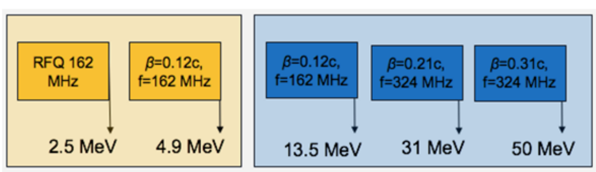

Figure 1: Proposed NICA injector layout of normal and superconducting structures.

The accelerating structures development for first SC group of linac cavities are under development by collaboration of Russian and Belorussian institutions since 2016. Cavity is planned to be produced by Physical-Technical-Institute of the National Academy of Sciences of Belarus (PTI NASB). It has a successful experience in manufacturing of single cell elliptical superconducting test resonators.

SC quarter-wave resonators (QWR) are proposed for the first group of cavities of accelerator cold part. Initial accelerating gradient requirement for this group of cavities is 7.5 MV/m [2]. Different types of cavities were considered for acceleration beamline development. Cavities should provide high gradient operation to minimize sections length. However QWRs are more difficult to fabricate comparing to single cell elliptical test cavities because they have more elements and welded assemblies. Production facilities at PTI NASB allow to manufacture these types of structures, but every additional design complication increases the production time, cost and brings new challenges for fabrication process. Estimation of possibilities and manufacturing experience together with an expert opinion show that optimal solution for successful superconducting QWR manufacturing is the choice of a cavity design as simple as possible. This is necessary for example for material behaviour estimation under forming and welding along with cavity treatment development. In this article the optimization results of simple 162 MHz 0.12c beta QWR are presented.

ELECTROMAGNETIC DESIGN

The QWR design for the first section of SC Linac Nuclotron-NICA is presented in Fig. 2.

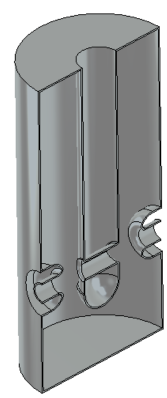

Figure 2: QWR for β=0.12.

Cavity RF simulations and optimization for peak magnetic and electric fields at the cavity surface were carried out. The results are summarized in Table 1. The cavity operation frequency is 162 MHz. The ratio of the maximum electric field Ep and the maximum magnetic field Bp at the cavity surface to the accelerating field Eacc are determined. The values of the shunt impedance Rsh, the geometric factor G and the transit time factor T are calculated.

Practical experience from several projects for similar cavities show that this QWR design could operate at 6 MV/m accelerating gradient [3]. Therefore we had to reduce our initial design requirement for E_{acc} from 7.5 to 6 MV/m [4]. It provides expectations to reduce a production presetting time, to obtain the first prototypes and gain experience in fabrication for QWR.

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Table 1: RF Parameters of QWR

Parameter	Value
f, MHz	162
β	0.12
Ep/Eacc	6.4
Bp/Eacc, mT/MV/m	11.4
r/Q_O, Ohm	488
G, Ohm	37
T	0,88

MECHANICAL DESIGN

Mechanical simulations [5-6] were carried out for different cavity wall thickness. Sensitivity for He pressure, vertical displacement of the inner conductor with temperature change and frequency shift after cool down to 4 K, first mechanical mode frequency, RF sensitivity to chemical treatment were calculated. The results are summarized in Table 2.

Production facility in PTI NASB allows to form niobium sheets up to 3.5 mm thick. But a considerations of quality and fabrication cost show that optimal thickness for test cavity is in the range of 2.5-3 mm.

Table 2: Results of Mechanical Simulations

Thickness, mm	2	2.5	3
Sensitivity to He pressure, Hz/mbar	91	35	31
Vertical displacement of the stem, mm/bar	0.6	0.3	0.2
Frequency shift after cool down to 4 K, kHz		341	
First mechanical mode frequency, Hz	254	256	257
Sensitivity to chemical treatment, kHz/mm		54	

The cavity with frequency tuner design is showed in Fig.3. Frequency is adjusted by the mechanical actuator and membrane on a cavity bottom.

Frequency tuner membrane of different designs has been considered: solid plate and one with 20 radial slots. The results are presented in Table 3.

Table 3: Results of Tuner Calculations

	solid	slots
Maximum displacement, mm	±3	
Frequency, kHz	±37	
Pressure, MPa	6.3	1.7

Radial slots considerably reduces required the tuning pressure.

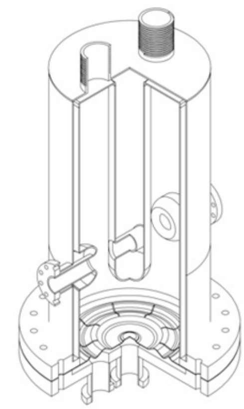

Figure 3: QWR cavity design.

MULTIPACTOR DISCHARGE

Design illustrated in Fig. 2 is simple in fabrication, but central conductor without taper can cause multipactor discharge. For this cavity geometry multipactor discharge calculations were carried out for possible accelerating field gradients E_{acc} range from 0 to 9 MV/m. Number of electrons growth for different accelerating gradient is presented in Fig. 4. The calculation was carried out using the 3D code for multipactor discharge simulation MultP-M [7].

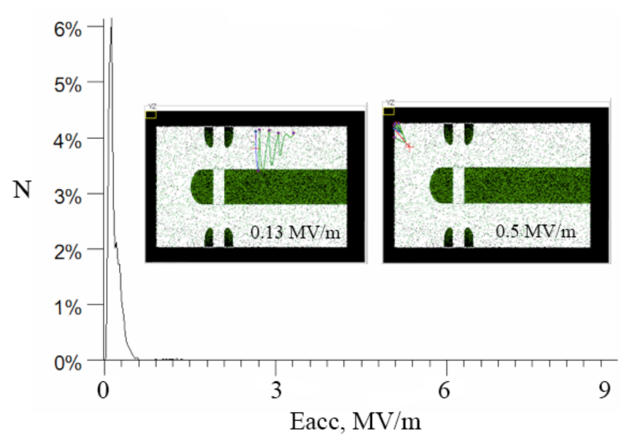

Figure 4: Number of electrons growth (N) in cavity for the different accelerating gradient.

Simulation results show that the electron number growth is significant for very low accelerating gradients. Trajectories study shows that they are decaying. It usually means that multipactor barrier may be overcome by cavity conditioning. Trajectories at low accelerating field are mainly localized at the coaxial part and at the bottom. Typical trajectories of electrons for 0.13 and 0.5 MV/m accelerating field levels are presented in Fig. 3. We can see key advantage of such a design of QWR that multipactor discharge region for E_{acc} is significantly lower than operational.

INPUT COUPLER

The development of input power coupler has been initiated. An input RF coupler design is based on a 50Ω coax-

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ial waveguide with outed diameter of 40 mm diameter with a capacitive antenna. In general, the design is illustrated in Fig. 5. Coupler allows external Q-factor tuning in 1.5–3×10^5 range by antenna to the cavity penetration variation.

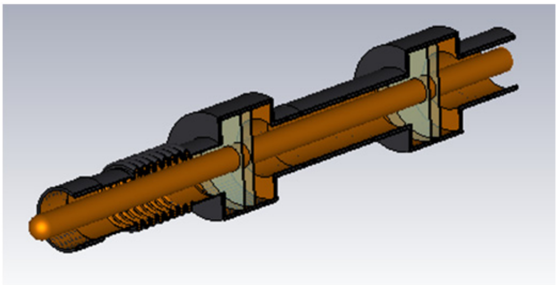

Figure 5: Model of input power coupler.

Coupler is located under 90 degrees to beam-port plane on 45 mm height from cavity bottom Fig. 6.

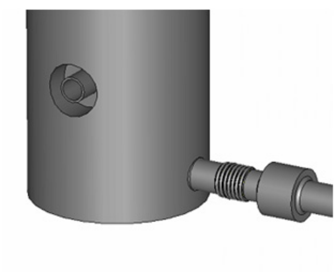

Figure 6: Coupler location.

The external Q-factor dependence on antenna penetration depth is showed in Fig. 7.

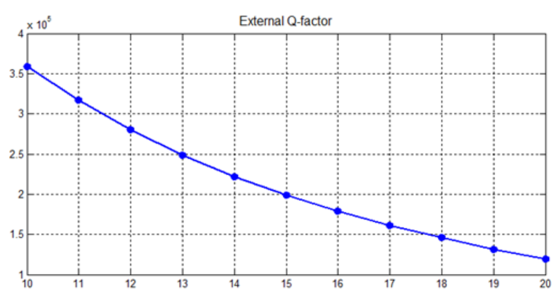

Figure 7: External Q factor dependence on antenna penetration depth.

Double flat disk ceramic windows design secures coupler operation. S11 for power coupler was calculated and after tuning of both windows the minimum value of S11=-32 dB was obtained.

CONCLUSION

The design of 162 MHz QWR (0.12 beta) prototype was developed. Based on this design the fabrication technology of QWR for the first group of SC Linac Nuclotron-NICA will be developed at Physical-Technical Institute of the National Academy of Sciences of Belarus.

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