

# QWR RESONATOR CAVITIES ELECTRODYNAMICS SIMULATIONS FOR NEW NUCLOTRON-NICA INJECTOR

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## Abstract

New linac-injector for Nuclotron-NICA is planned to consist of quarter-wave coaxial cavities (QWR) having velocities of  $\sim 0.07c$  and  $\sim 0.12c$  (beam energy from 5 to 17 MeV). These cavities are to be superconducting and operating at 162 MHz. Current results of the QWR cavities electro-dynamics simulations and geometry optimizations are presented.

## INTRODUCTION

The joint collaboration of JINR, NRNU MEPhI, INP BSU, PTI NASB, BSUIR and SPMRC NASB started a new project on superconducting cavities design, production and test technologies development and new linac-injector design in 2015. This linac intend for protons acceleration to 25 MeV (up to 50 MeV after upgrade) and light ions acceleration up to  $\sim 7.5$  MeV/u for Nuclotron-NICA injection [1-4]. The operating frequency of the linac medium energy part after RFQ is 162 MHz being further doubled to 324 MHz. Geometry choices for first group of resonators considered in this research.

The first design of the linac-injector for Nuclotron-NICA considers quarter-wave coaxial cavities (QWR) operated at 162 MHz as the best choice for velocities range of  $\sim 0.07c$  to  $\sim 0.14c$  [5-6]. QWRs are effective for frequency up to 200 MHz and velocity below  $0.2c$ . At high velocities exceeding about  $0.14c$ - $0.15c$  half-wave coaxial cavities (HWR) are preferable due to many disadvantages and limitations QWRs have.

Calculations showed that for velocity  $0.141c$  and frequency 162 MHz structure chosen as initial version, the steering effect is significant and the displacement of the beam axis is not enough to compensate it. It leads to drift tubes design modifications making cavity production more complicated.

Comparative analysis of the QWR and HWR along with beam dynamics simulation showed that there is a possibility to decrease the geometrical velocity  $\beta_G$  for the second group of resonators to  $0.12c$ . It makes the cavity cheaper because less niobium is needed and also it moves the cavity design to a lower steering effect area.

The next step was to consider 162 MHz QWR for velocities  $0.07c$  and  $0.12c$ . Choice of optimal geometry and overall dimensions, performance, operation and maintenance issues were considered.

## GEOMETRY CHOICE

Cavity basic dimensions optimization allowed us to use identical cryomodules, flanges, tuning devices etc. and minimize the number of unique parts.

Modern elliptical and conical shapes of QWR allow performance improvements, including rise in shunt impedance and decrease losses [5]. Initially simple models of cylindrical QWR based on the primary technology requirements were considered. Change of acceleration and drift sections in cavities for different  $\beta_G$  force us to optimize central conductor length for overall dimensions and frequency kept unchanged.

At the first stage accelerating gaps simulation for both constructions was done. Figure 1. presents acceleration path of two gap cavity, where  $L$  is resonator diameter.

According to ratio  $d = \beta \cdot \lambda / 2$ , optimal distance between accelerating gaps was found for  $0.07c$  and  $0.12c$  cavities. Results presented in Table 1. According to relation  $g/d = 1/3$  [6] optimal  $g$  was founded.

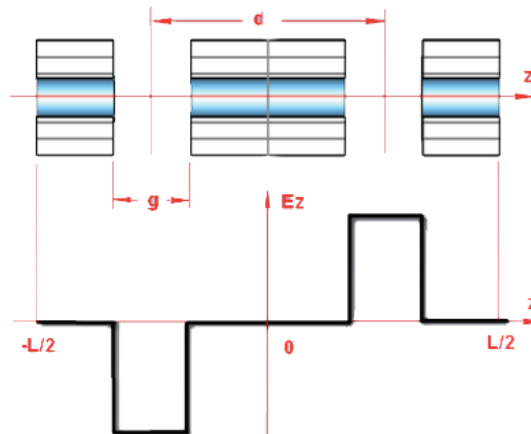


Figure 1: Acceleration path of 2-gap resonator.

Table 1: Relation velocity and dementions cavities d, g for frequency 162 MHz.

$\beta$	0.07	0.12
d, mm	63	108
g, mm	19	32

Results obtained show that minimal radius of external conductor should not exceed 90 mm keeping in mind cavities parts unification. In [6] it was shown that according to practical experience the best internal radius to external one ratio  $R_{in}/R_{out}$  should be equal to 0.3. It allows one to find an optimum between minimum magnetic field, maximum shunt impedance and geometrical factor  $G$ .

Taking into account unification requirements and sizes of internal and external conductors two different types of QWR cavities were considered: QWR with flat end of central conductor and one with donut end. Geometries presented at Figure 2.

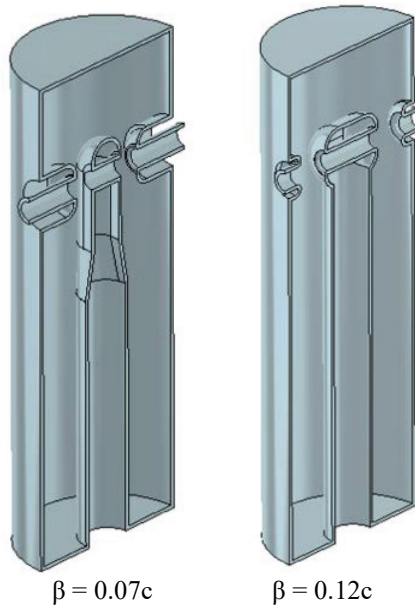


Figure 2: Designs of QWRs considered.

## ELECTROMAGNETIC DESIGN

Main requirements [5-6] for accelerating cavities are presented in Table 2.

Table 2: Main requirements for 162 MHz accelerating cavities.

$\beta$	0,07	0,12
Eacc, MV/m	3,08	7
Ep, MV/m	<40	<40
Bp/Eacc, mT/MV/m	<80	<80

The electromagnetic design and optimization mainly lies is to made peak surface fields both electric and magnetic as low as possible and to rise the ratio  $r/Q$ , (where  $r$  is shunt impedance and  $Q$  is quality factor) and geometry factor  $G = R_s Q$  (where  $R_s$  is surface resistance).

In addition we considered easy installation and tuning, reliable operation, reasonable price. Table 3 shows results for cavities presented in Figure 2.

Table 3: RF Parameters of the 162 MHz Cavity

$\beta$	0.07	0.12
Eacc max, MV/m	3,08	7
Ep/Eacc	6.6	4.96
Ep, MV/m	20	37.1
Bp/Eacc, mT/MV/m	10.5	10.7
Bp, mT	32	72.8
$r/Q_0$ , Ohm	517	432
$G$ , Ohm	30,7	33
$T_0$	0,9	0,92

$T_0$  is transit time factor. There are different versions of effective length definition for accelerating field and shunt impedance per unit length. In that article data presented with  $l_{eff} = L$ , where  $L$  is resonator diameter.

Additional optimization towards the minimal magnetic field was carried out. It needs to tune with vertical deformation of cavity butt-end. Overall dimensions after optimization are: height 510 mm, outer radius 90 mm, inner radius 30 mm.

## MECHANICAL DESIGN

Mechanical simulations were carried out for left cavity at Figure 2. cavity. Different deformation models influence to the cavity frequency were studied:

- 1) Frequency change after cool down to 4 K;
- 2) Frequency change under helium pressure;
- 3) Displacement of the central conductor under helium pressure;
- 4) Lorentz force detuning;

Three types of cavities were considered. They are presented in Figure 3: initial reference cavity design (a), cavity with rounded end faces (b) and cavity model with fixed top and bottom (c). In (a) and (b) simulation models beam axis was fixed. At c simulation model beam axis, bottom and top of resonator were fixed. Table 4 presents results of mechanical calculations.

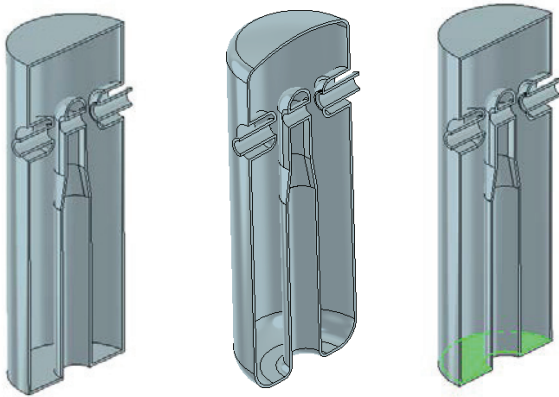


Figure 3: QWR models used for mechanical simulations: reference cavity design (a), one with rounded faces cavity (b) and cavity with fixed top and bottom(c).

Table 4: RF Parameters of the 162 MHz Cavity

Type		a	b	c
Sensitivity to external pressure, Hz/mbar	to	34	16	2
Vertical displacement of the stem, mm/bar		0.2	0.07	0.01
Frequency shift after cool down to 4 K, kHz		340	339	-
Lorentz force detuning, Hz/(MV/m) <sup>2</sup>	force	3	0.69	0.33

Simulations show that top and bottom fixing helps to reduce sensitivity to He pressure and Lorentz detuning.

### CONCLUSION

Results of SC cavities design for new JINR proton and light ion linac development for Nuclotron-NICA were discussed.

### REFERENCES

- [1] A.V. Butenko, E.E. Donets et al., Proc. of IPAC'13, 3915 (2013).
- [2] V.A. Andreev, A.I. Balabin et al., Problems of Atomic Science and Technology. Series: Nuclear Physics Investigations, 6 (88), 8-12 (2013).
- [3] M.A. Batouritski, A.V. Butenko et al., New Superconducting Linac Injector Project for Nuclotron-NICA: Current Results, Proc. of RuPAC'16, THPSC041 (2016).
- [4] G.V. Trubnikov, T.V. Kulevoy et al. Proc. of IPAC'16, 941-943 (2016).
- [5] M.Kelly, SRF 2013 Tutorial Program Sept. 19-21 Ganil, Caen
- [6] V.L. Zvyagintsev, PhD Thesis, 2013