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SELECTION OF THE TYPE OF ACCELERATING STRUCTURES FOR THE SECOND GROUP OF CAVITY SC LINAC NUCLOTRON-NICA

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Abstract

The paper summarises the research results aimed on the choice of superconducting accelerating cavities for the second section of the SC linac Nuclotron-NICA injector project. This choice was based on comparative analysis of accelerating structures electrodynamic characteristics taking into account technological challenges of bulk niobium cavities production.

INTRODUCTION

The collaboration of JINR, NRNU MEPhI, INP BSU, PTI NASB, BSUIR and SPMRC NASB started in 2015 the project of SC linac-injector design. The possibility of LU-20 replacement by the new superconducting (SC) linac of 30 MeV energy for protons and ≥7.5 MeV/nucleon for deuterium beam is discussed now [1-4]. The development of the SRF technologies is the key task of new Russian - Belarusian collaboration.

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 [5]. Quarter-wave resonators (QWR) will be used for the first group of the cold part of the accelerator [6].

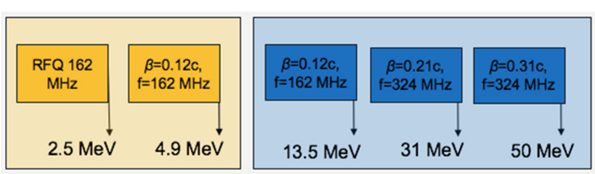

Figure 1: Proposed NICA injector layout of normal (left) and superconducting (right) structures.

According to the concept of the SC Linac Nuclotron-NICA [5] the second group of cold cavity resonators operates on 324 MHz, has phase velocity 0.21 and 7.7 MV/m accelerating gradient. Modern designs of CH, Spoke and HWR cavities allow one to reach this accelerating gradient. However, it is necessary to take into account the production possibilities and the lack of experience in superconducting accelerating resonators manufacturing. These factors are important for successful performance of the project.

At the frequency and phase velocity mentioned above CH, Spoke or Half-wave (HWR) resonators can be used. Table 1 presents the main advantages and disadvantages of these structures [7-10].

Table 1: Advantage and Disadvantage Different Types of Accelerating Structures for Medium β

cavity type, frequency and velocity range	Advantages	Disadvantages
HWR 80…500 MHz $0.1 \le \beta \le 0.5$	No dipole steering; High performance; Lower surface electric field; Wide β range	Not easy access; Difficult to tune than QWR
Spoke 325…805 MHz $0.15 \le \beta \le 0.6$	No dipole steering; High performance; Lower R_{sh} than HWRs; Wide β range	Not easy access; Difficult to tune than QWR; Larger size the HWRs; More expensive than HWRs; Quadrupole steering
CH above 170 MHz $0.07 \le \beta \le 0.45$,	Possibility of coupled structure at low β; Higher RF efficiency for $\beta \le 0.2$	Very long lens-free section for $\beta \ge 0.25$

At the stage of QWR prototypes production technological problems of manufacturing processes will be solved and the final decision on the type of accelerating structure for the second cold part cavity group will be made. Different structures of CH, Spoke and HWR type cavities were considered and simulated.

CH-TYPE CAVITY

Five-gap CH cavity is considered as one of the possible candidates. Figure 2 shows this cavity design studied. Dimensions and RF parameters of the structure are presented

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in the Table 2. The structure operates on 324 MHz and velocity 0.21. The resonator length L is 500 mm, the resonator radius $R = 204$ mm. The lowest ratio of the peak electric field on the surface of the structure E_p to the accelerating field E_a obtained was 4.75 reached by eliminating the drift tubes. The ratio of the peak magnetic field on the surface of the structure B_p to the accelerating field E_a was 8.1 mT/(MV/m).

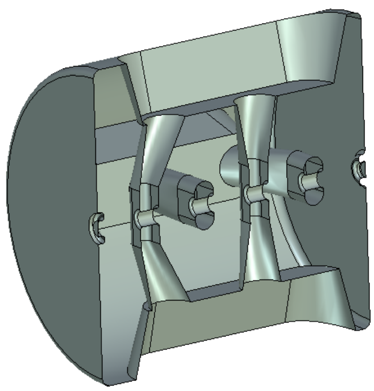

Figure 2: CH for β=0.21.

Table 2: Dimensions and RF Parameters of CH Cavity

Parameter		Value
Operating frequency	f, MHz	324
Velocity	β	0.21
Cavity radius	R, mm	204
Cavity length	L, mm	500
Ratio of the peak electric field on the cavity surface to the accelerating field	Ep/Ea	4.75
Ratio of the peak magnetic field on the cavity surface to the accelerating field	Bp/Ea, mT/(MV/m)	8.1
Geometric factor	G, Ohm	82
Ratio of shunt impedance to Q-factor	Rsh/Q0, Ohm	677

Taking into account the limitations on peak electric and magnetic fields of 35-40 MV/m and 70-80 mT [11], respectively, it is shown that the structure can be used to obtain a necessary accelerating gradient. However, the multipactor discharge simulation showed that multipactor electron trajectories could occur between the wall and pylons, so an additional optimization is required to prevent a multipactor discharge [12].

SPOKE-TYPE CAVITY

The possibility of using the two-gap spoke cavity was also considered. Figure 3 shows two-gap spoke cavity design. Dimensions and RF parameters of the structure are presented in Table 3. The structure operation frequency is 324 MHz and velocity β =0.21. The resonator length L was 250 mm, the resonator radius R was 215 mm. The ratios of the peak electric E_p and magnetic B_p fields on the surface to the accelerating field E_a were 4.5 and 6.3 mT/(MV/m). These values are lower than ones for CH cavity.

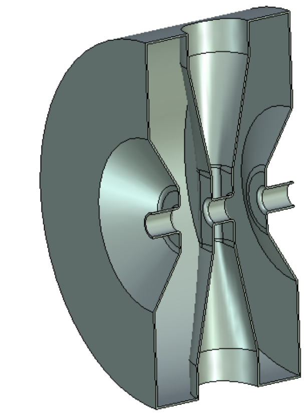

Figure 3: Spoke cavity for β=0.21.

Table 3: Dimensions and RF Parameters of Spoke Cavity

Parameter		Value
Operating frequency	f, MHz	324
Velocity	β	0.21
Cavity radius	R, mm	215
Cavity length	L, mm	250
Ratio of the peak electric field on the cavity surface to the accelerating field	Ep/Ea	4.5
Ratio of the peak magnetic field on the cavity surface to the accelerating field	Bp/Ea, mT/(MV/m)	6.3
Geometric factor	G, Ohm	79
Ratio of shunt resistance to Q-factor	Rsh/Q0, Ohm	253

It is known that in case of magnetic field on the cavity surface exceeding 50 mT, the medium field Q_0 slope (MFQS) phenomenon occurs [13]. Thus, in spite of the fact that the total length of the CH cavity will be less than CH, the latter is more tolerable to MFQS. It should also be noted that according to the simulation results multipactor trajectories in spoke cavity on operation power level were not found [12].

HWR

Two-gap HWR cavities were studied. Three design types were considered: the first one having cylindrical central conductor (Fig.4a), second – a conical central conductor (Fig.4b), and third – a conical with a transition to a flat conductor (Fig.4c). Dimensions and RF parameters for three type of the HWRs are presented in the Table 4. In either case the cavity operates on the same frequency and β as CH and spoke.

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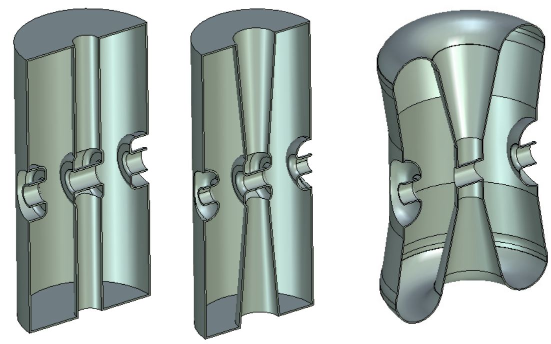


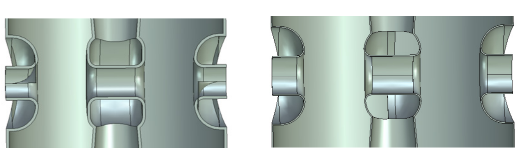
(a) (b) (c)
Figure 4: Three type of the HWR for β=0.21.

Table 4: Dimensions and RF Parameters of Three Type of the HWR

		(a)	(b)	(c)
Operating frequency	f, MHz	324	324	324
Velocity	β	0.21	0.21	0.21
Cavity height	H, mm	413	474	524
Cavity radius	r, mm	97	97	180
Ratio of the peak electric surface field to the accelerating field	Ep/Ea	6.64	5.5	4.16
Ratio of the peak surface magnetic field to the accelerating field	Bp/Ea, mT/(MV/m)	12.4	8.4	6.48
Geometric factor	G, Ohm	22	24	58
Ratio of shunt impedance to Q-factor	Rsh/Q0, Ohm	309	298	158

It can be seen that the simplest cavity design having a cylindrical conductor breaks the surface field limitation. For accelerating field of 7.7 MV/m the magnetic field on the surface exceeds 50 mT mentioned above as MFQS origin and reaches 80 mT.

For a conical central conductor design (Fig.4b), due to drift tube rounding (Fig. 5) and increasing the radii of the central conductor in the bottom region, it was possible to lower the peak electric field to $E_p/E_a = 5.5$. Peak magnetic field to accelerating gradient ratio B_p/E_a in this case was 8.4 mT/(MV/m). This value is still higher than one for the CH and Spoke, but layes below the acceptable maximum.



(a) (b)

Figure 5: Rounding in the drift tube 5 mm (a), 20 mm (b).

For HWR design having conical central conductor with transition to a flat area (Fig. 4c) the minimum values of peak electric and magnetic fields are E_p/E_a = 4.16 and B_p/E_a=6.48 mT/(MV/m). The characteristics of this design are close to the one of Spoke cavity, but this structure is inherently more complicated in comparison with designs with a conical central conductor and hardly will be chosen.

CONCLUSION

The overall dimensions and electrodynamic characteristics of CH, Spoke and three types of HWR cavities are found. The final decision on the cavity type for the second group of the SC cavities for Nuclotron-NICA injector project will be made also according to the experience gained during the first test prototypes of QWR manufacturing.

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