STUDY OF NORMAL CONDUCTING ACCELERATING STRUCTURES FOR MEGAWATT PROTON DRIVER LINAC

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Abstract

The preliminary design of a megawatt level proton accelerator-driver is carried out by collaboration between Russian scientific centers MEPhI, ITEP, Kurchatov Institute. This project was supported in 2013 by the Ministry of Science and Education of Russia. The linac general layout includes an RFQ section and section(s) with radiofrequency focusing. The different types of RF focusing were studied due to this project: RF crossed lenses, modified electrodes RFQ, axi-symmetrical RF focusing. All such focusing can be realized by IH-type cavities. The design of a segmented vane RFQ (SVRFQ) with coupling windows and IH- and CH-type normal conducting cavities is discussed in this report. All cavities operate at 162 MHz. The main results of the electrodynamics simulation are presented.

INTRODUCTION

The study of a high-power proton linac for 1.0 GeV was performed by a collaboration of MEPhI, ITEP and Kurchatov institute researchers in 2013. Such a linac was developed to understand the possibility of design an accelerator driven system (ADS) in Russia.

The linac will consist of an RFQ, RF focusing sections and SC modular configuration sections [1, 2]. The segmented vane RFQ (SVRFQ) with coupling windows was designed for beam bunching and low energy acceleration. Original design of elliptical coupling windows was proposed. IH- and CH- cavities were simulated and its electrodynamics characteristics were optimized.

The results of the modeling of the aforementioned structures are discussed below.

SVRFQ CAVITY

A 4-vane RFQ [3] with magnetic coupling windows is considered. The windows decrease the resonant frequency, minimize mode coupling in the RFQ and result in a smaller and more easily tuned accelerator. Specifically the following characteristics are being tuned: 1) separation of quadrupole and dipole modes' frequencies (Δf), 2) ratio of the maximal surface electric field in the resonator to the accelerating field on axis (overvoltage). The accelerating potential between the RFQ electrodes is limited by 1.2-1.5 of Kilpatrick limit units for the CW mode (~130-150 kV). The tuning is performed by variation of 1) the radius of the accelerating channel aperture (a), 2) electrode tip blend radius (VR_b) and 3) the distance between the end of a vane and the tank back wall – back end length (*BBL*). The parameters are shown in Figure 1.

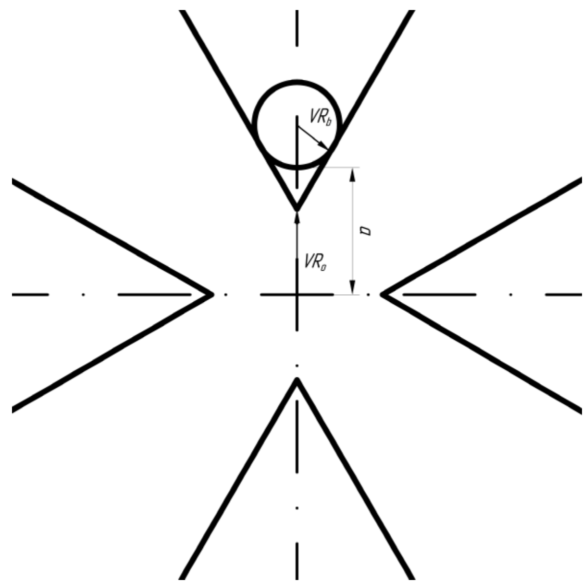

Figure 1: The SVREQ channel geometrical characteristics.

Base parameters of the optimized and tuned SVRFQ channel were discussed in [4]. Let us discuss, now, the influence of each of channel characteristics to the ratio of the surface electric field to the accelerating field and separation of the quadrupole and dipole modes' frequencies.

Aperture Radius, VR_o

The dependence of mode separation and the overvoltage (in Kilpatrick limit units, Kp [5]) against channel aperture radius variation is presented in Figures 2 and 3 respectively. These pictures show that mode separation is proportional to the overvoltage.

Blend Radius, VR_b

From Figure 4 one sees that variation of blend radius VR_b affects channel aperture: increase of VR_b is equivalent to that in VR_0. Expectedly, the mode separation plots in both cases are similar; yet it is clear that direct variation of electrode offset VR_o has greater effect on mode separation.

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Back End Length, BBL

The effect of this characteristic's variation on the separation of modes is minimal, which is seen in Figure 5.

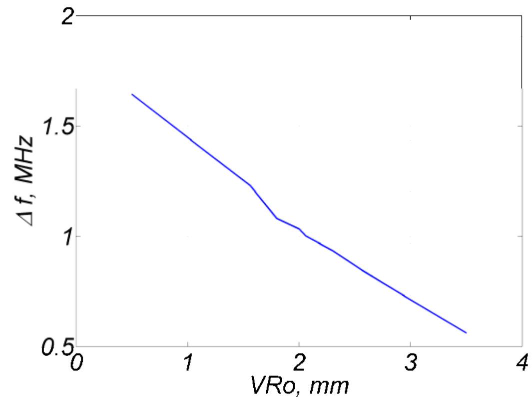

Figure 2: Mode's separation vs. aperture radius.

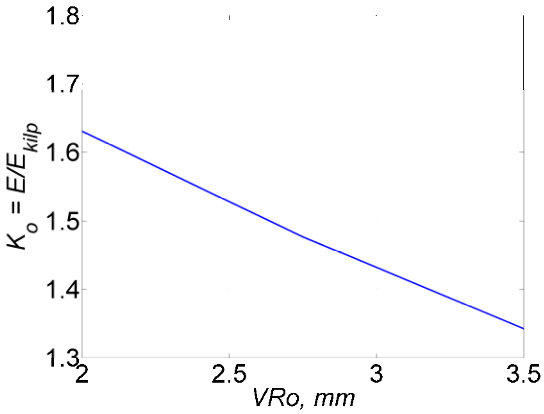

Figure 3: Overvoltage vs. aperture radius.

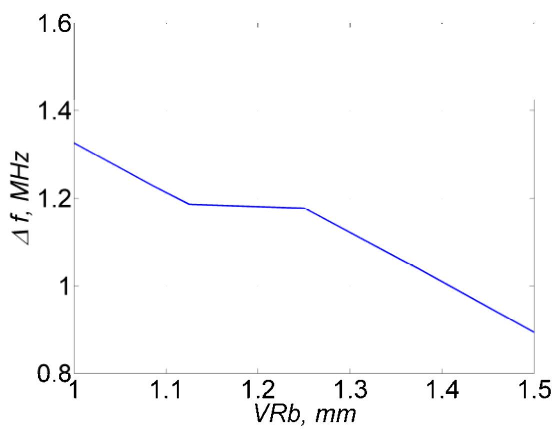

Figure 4: Mode's separation vs. blend radius.

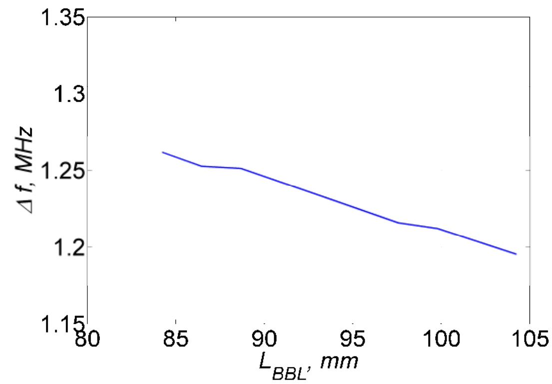

Figure 5: Mode separation vs. end region length.

Optimal Channel Geometrical Characteristics

Channel geometrical characteristics that satisfy 162 MHz resonant frequency, maximal surface electric field 1.721 Kp and mode separation 1.3 MHz are summarized in the Table 1.

Table 1: Optimal Channel Geometrical Characteristics of CVRFQ Channel

Parameter	Value, mm
Blend radius, VR_b	1.085
Aperture radius, a	5.3
End length, *BBL*	94

IH- AND CH- CAVITIES

The IH- and CH- resonators were designed for beam acceleration from 2.28 MeV to 4.73 MeV energy range. As mentioned earlier, the operating frequency of the inter-digital structure is equal to 162 MHz but for CH cavity it was changed to 324 MHz band (2-nd harmonics) since it operates at higher operating mode H_{210}. Each type of cavity works in the π-mode regime, has constant period D along the axis and acceleration gap between drift tubes $t=D/2$.

During investigation there were two main goals: 1) to optimize main electrodynamic characteristics (especially effective shunt impedance); 2) to reach uniform accelerating field distribution on the cavity axis (field flatness better than 95%). To reach these goals, design of both cavity types (CH- and IH-) consists of vanes (or pylons, see Fig. 6). It should be mentioned that the end wall of each pylon has an electrical contact with the tank sidewall. Therefore 4 magnetic fluxes around the vanes are combined in one common flux. This technique allows us to reach the uniform field distribution without critical drop of the Q-factor and shunt impedance.

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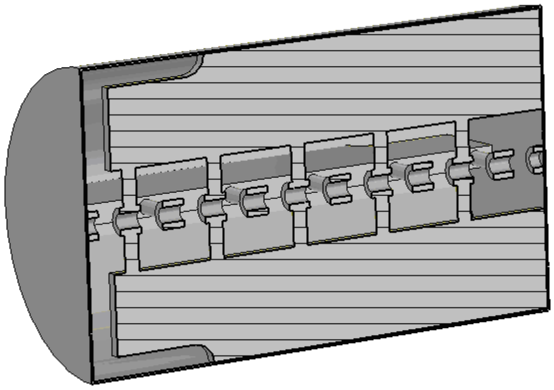

Figure 6: CH - tank layout.

During optimization, different CH- and IH- resonator models were considered. Main variable parameters are presented in Table 2.

Almost all models were optimized to the uniform field distribution (some extra cases with 13 gaps, big aperture and period length have field regularity equal to 92-93%). Some of results are summarized in Table 3 and the example of the optimized field distribution is presented in Figure 7.

Table 2: CH- and IH- resonator models design parameters.

Parameter	Value
Number of periods	7; 9; 11; 13
Aperture diameter, mm	15; 20; 30
Beam velocity, β=*v*/c	0.07; 0.08; 0.09; 0.10

Table 3: The results of CH- and IH- resonator's optimization.

Cavity type	CH	CH	IH	IH
β	0.10	0.09	0.08	0.08
Number of periods	9	7	13	11
Aperture diameter, mm	15	20	20	15
f, MHz	324	324	162	162
Effective shunt impedance, MOhm/m	83	67	145	154
Transit time factor	0.835	0.811	0.841	0.854
Q-factor	14000	11800	15500	15600
Field flatness, %	95	96	95	95

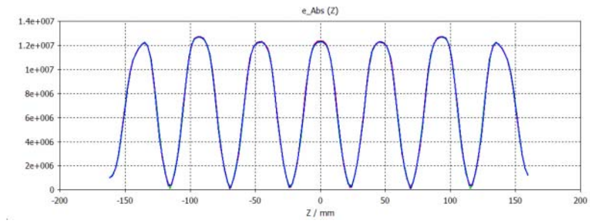

Figure 7. Typical field distribution for 7 gaps model.

CONCLUSION

Results of the electrodynamics models' development and study, and cavity designs for the normal conducting part of a 1 GeV linac were discussed. The initial section design based on a segmented vane RFQ (SVRFQ) with coupling windows was proposed. The problems of quadrupole and dipole modes' separation and electric field overvoltage were studied and discussed. The IH- and CH- resonators were designed for beam acceleration at medium energies. Both resonator types were optimized to enlarge the effective shunt impedance and Q-factor.

ACKNOWLEDGMENT

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