

THERMODYNAMICS SIMULATION FOR THE CW RADIO-FREQUENCY QUADRUPOLE ACCELERATOR

S. M. Polozov, Y. Y. Lozeev, National Research Nuclear University “MEPhI”,
 115409, Moscow, Russia

Abstract

Design and construction of CW high intensity linacs are important issues of worldwide accelerator technology development. RFQ linacs are useful for large scale research facilities such as SNS, ADS and FRIB. RFQ are necessary to use for low-energy nuclear and radioactive ion physics (e.g., DERICA - Dubna Electron – Radioactive Ion Collider fAcility project, Dubna, Russia) [1]. Some solutions are applied for RFQ to operate in CW mode. The decrease of the accelerating field and of the RF field overvoltage is one of such solutions. The maximal field for CW RFQ traditionally limit by 1.3-1.5 of the Kilpatrick criterion value comparatively with 1.8-2.0 for the pulse mode. But the thermostabilization of the RFQ cavity is very important problem. Accelerating structure undergoes high thermal loads for operating a CW mode, therefore water cooling system is needed. In this report, a selection of an optimal resonator shape and water cooling system configuration was done and thermodynamics simulation results are also presented.

INTRODUCTION

Today CW RFQ ion linacs are used as an initial part for large scale accelerator facilities mainly in accelerator driven subcritical reactors (China Accelerator Driven Sub-critical System, [2]) or compact neutron sources (FRANZ, Frankfurt Neutron Source, [3]) or rare isotope accelerators (FRIB, [4]).

Current results of thermodynamics simulations of CW-RFQ cavity are presented in this paper. Accelerating structure is segmented-vane cavity (SV-RFQ) operating on 162 MHz. Main parameters of CW RFQ are presented in Table 1. Results of the beam dynamics study and previous design of the SV-RFQ cavity were presented in [5-8].

Table 1: Main Parameters of the CW RFQ

Parameter	Value
Ions	protons
Input energy, keV	46
Output energy, MeV	2
Frequency, MHz	162
Voltage, kV	90
Length, cm	345
Average radius, cm	0.530
Vanes half-width, cm	0.412
Modulation	1...2.25
Synchronous phase	-90°...-33°
Max. input beam current, mA	10
Max. input emittance, cm·mrad	6
Particle transmission, %	> 99

COMPARISON OF THERMODYNAMICS SIMULATION FOR TWO MODELS OF THE SV-RFQ CAVITY

CW operation mode of accelerating structures implies high thermal loads which can lead to operating mode frequency shift. As it was shown by simulations, power losses for 162 MHz CW-RFQ are about 100 kW (or ~35 kW per meter) for the maximum E-field at the electrode surface 15.8 MV/m. Such values of the dissipated power increase equilibrium cavity temperature up to 430 K, so water cooling is critical for the cavity. A number of water coolant channels usually are fabricated inside the cavity electrodes in order to provide its thermal stabilization under CW mode.

Water coolant channels can be drilled around magnetic coupled windows as the main points undergoing strong thermal loads are nearby their edges. Current distribution varies depending on the coupled window shape. Semi-elliptical and rectangular windows were chosen for comparison. Models with semi-elliptical and rectangular windows with their coolant system are presented in Fig. 1 and 2 respectively. Main parameters of coolant system are presented in Table 2.

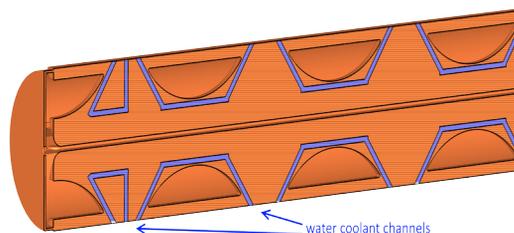


Figure 1: Water coolant system layout for model with semi-elliptical windows.

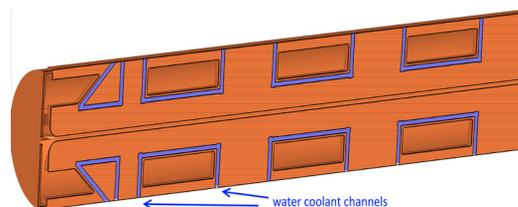


Figure 2: Water coolant system layout for model with rectangular windows.

Table 2: Comparison of results of thermodynamics simulations for models with rectangular windows and semi-elliptical windows

Parameter	Rectangle windows	Semi-elliptical windows
Number of channels	32	32
Water flux, l/min	217	217
Diameter of coolant channels, mm	12	12
Max. iris temperature, K	322.5	322.5
Max. electrodes temperature in end regions cells, K	331.1	336.2
Max. electrodes temperature in regular cells, K	311.3	313.7
Max. displacement, mm	0.187	0.20
Frequency shift, MHz	-0.68	-0.71

Thermodynamics simulations were performed for CW mode operation. Both models have 32 water coolant channels with diameter 12 mm and full water flow 217 l/min. Thermodynamics simulations shows similar results for both models. They have the same temperature distributions, close maximal temperature values, low end region cooling efficiency and different heating in regular and end regions, which leads to different frequency shift (Fig. 3 and Fig. 4).

Only one of the two models was left for further simulations. The model with rectangular windows is chosen due to easier fabrication of coolant channels.

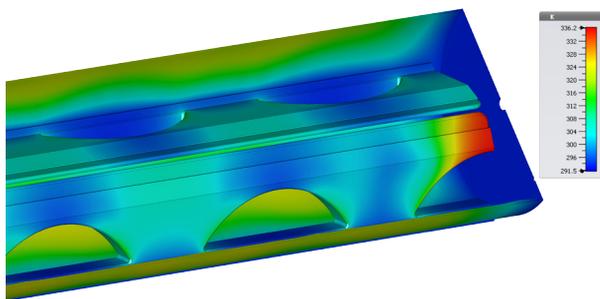


Figure 3: Temperature distribution for model with semi-elliptical windows (full water flow is 217 l/min, water temperature $T = 293$ K).

The water coolant channels form was modified in order to solve the problem of electrodes overheating in the end regions. The new coolant system layout for electrodes in the end regions is shown in Fig. 5. Results of thermodynamics simulations for different values of water flow are presented in Table 3. The most optimal regime corresponds to water flow of 108 l/min as it still has reasonable maximal electrodes temperature and smaller water consumption. Sustainable temperature distribution is shown in Fig. 6. As can be seen from Fig. 6 the

difference between maximal temperature in the end and the regular cells is relatively small and equals to 9.9 K.

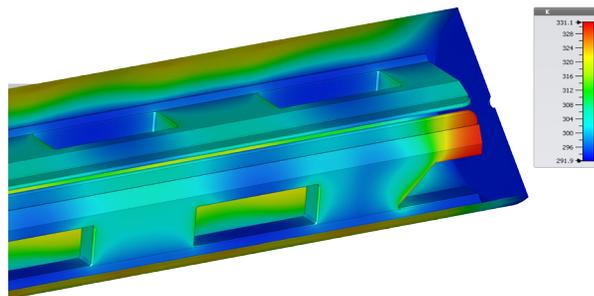


Figure 4: Temperature distribution for model with rectangular windows (full water flow is 217 l/min, water temperature $T = 293$ K).

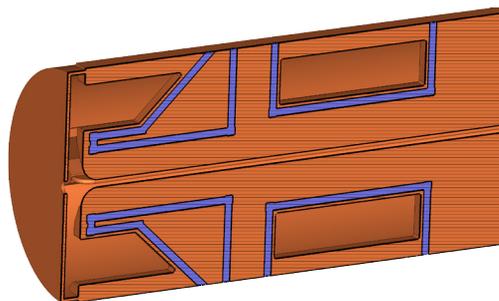


Figure 5: New water coolant layout for end regions.

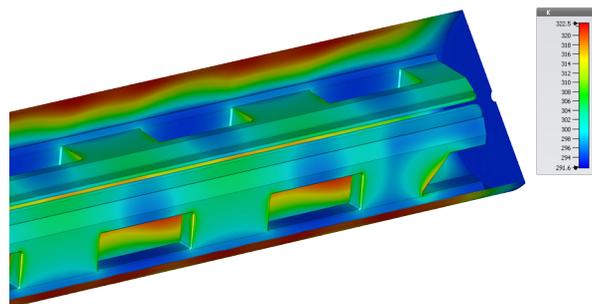


Figure 6: Temperature distribution for the model with new water coolant layout in end regions (full water flow is 217 l/min, water temperature $T = 293$ K).

Table 3: Main parameters of thermodynamics simulations for new geometry of the cooling channels for the end regions

Parameter	1	2	3
Number of channels	32	32	32
Diameter of coolant channels, mm	12	12	12
Water flux, min^{-1}	108	163	217
Max. iris temperature, K	325.5	322.6	322.5
Max. electrodes temperature in end regions cells, K	315.0	312.3	309.6
Max. electrodes temperature in regular cells, K	324.9	321.5	320.0

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Max. displacement, mm	0.164	0.152	0.144
Frequency shift, MHz	-0.62	-0.55	-0.52

RF FIELD DISTRIBUTION TUNING

Electrodynamics simulation of the cavity model was carried out to tune the uniform RF field distribution along the cavity axis. This can be obtained by means of undercutting the electrodes in the end regions. Each electrode has only one undercut from one side in this cavity model (Fig. 7). The field distribution along the cavity axis is presented in Fig. 8. Green and red curves represent the field distribution for electrodes with and without undercuts respectively. The non-uniformity of the electric field distribution is about 1.1% after tuning.

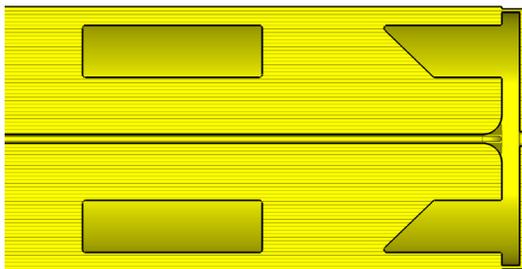


Figure 7: Longitudinal cut view of the cavity end region.

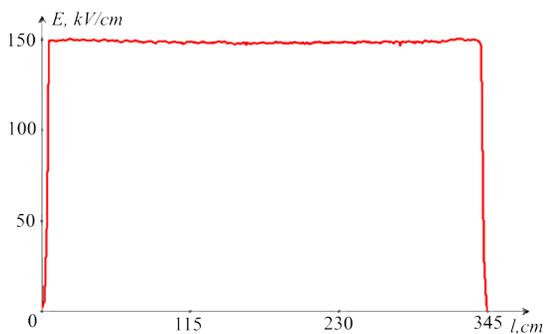


Figure 8: Electric field distribution along cavity axis with (green curve) and without (magenta curve) undercuts.

The main electrodynamic parameters of the tuned cavity were also calculated. The operating frequency decreases on 2.1 MHz after optimization of coupling windows and field distribution. The cavity radius was changed from 176.7 cm to 175.0 cm in order to compensate this frequency shift. Difference of frequencies between the operating mode (quadrupole mode) and higher modes (dipole modes) decreased from 7.1 to 5.5 MHz which is still acceptable. Main electrodynamic characteristics of the tuned SV-RFQ cavity are presented in Table 4.

Table 4: Main Electrodynamic Characteristics

Parameter	Value
Frequency, MHz	162.0
Power losses, kW	110.0
Q-factor	10350
Transverse shunt impedance, kΩ	32
RF field amplitude distribution nonlinearity, %	1.1

CONCLUSION

Thermodynamics simulation for the CW RFQ was performed. Optimal form of coupling windows and layout of water coolant channels were chosen. Values of maximal displacement and frequency shift were obtained for different water flux for the CW operation mode. It should be noted, that electric field uniformity was achieved via undercutting the electrodes in optimal model and electrodynamic parameters were also obtained.

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