# RESONATOR RESEARCHES OF ACCELERATING SYSTEM OF THE APPLIED ION INSTALLATIONS

*Yu. Svistunov, A. Budtov, V. Mudrolubov, V. Petrov, S. Silaev*
*The Scientific Research Institute of Electrophysical Apparatus, Scientific Production Complex of Linear Accelerators and Cyclotrons, Saint-Petersburg, Russia;*
*npkluts@ niiefa.spb.su*

433 MHz RFQ and APF-cavity construction, manufacture and tuning are considered. These resonators are developed at the D.V. Efremov Institute for applied complexes where ion beams are used. In particular, there are considered proton and deuteron versions of the contraband detection complex with linac. Computer results of simulation of electromagnetic and thermal fields in resonators are given. Calculations of the cooling system and possible structure deformations in consequence of mechanical and thermal tensions are presented.

PACS: 29.17+w

## 1. INTRODUCTION

Scientific Production Complex of Linear Accelerators and Cyclotrons (NPK LUTS) has developed the technology of manufacturing the ion rf linacs in the frequency range 400-500 MHz. It is proposed to use RFQ as the first stage (up to 1…2 MeV) of the ion linacs with output energy 5…15 MeV and APF resonators as the second stage of linacs. In particular, in contraband detection technological complex (CDTC) which is developed in the NPK LUTS [1], one proposed to use 3.5 MeV deuteron beam or 10 MeV proton beam to produce a pulsed neutron flow. In this case the output energy of the first stage's accelerator will be 1 MeV (deuterons) or 2 MeV (protons). Accelerating of particles up to 3.5 MeV (or 10 MeV) is produced by APF cavities. Description of the NPK LUTS APF-resonator design is given in paper [2].

## 2. RFQ INVESTIGATIONS

RFQ consists of the four identical chambers (quadrants), two cells at the ends and a matching section at the input of the resonator.

Main electrodynamics RFQ parameters were calculated with ISFEL3D code [3] solving 3D-field problems by the finite elements method. On 2MeV proton RFQ modeling having length 1.525 m and small average aperture diameter 7mm a dense mesh with 2800000 elements was used. At the beginning only a quadrant of RFQ construction had been analyzed. Dipole and quadrupole mode selection had been realized by choice of suitable boundary conditions on planes of symmetry. Five-frequency modeling for a separate variant of cavity need of about 30 hours of PC P3-700/256 calculation time. At first it is supposed the resonator has infinite length without matching section and terminal cells. In this case resonator cross sizes are determined approximately and dipole modes have a frequency by 12.1 MHz lower then the quadrupole one. Resonator of symmetrical quadrants has two types of dipole modes with different distribution of an electrical field between electrodes [4]. The real construction has symmetry violation, dipole modes are mixed and their quantity is half as much as a symmetrical case. Asymmetry is simulated by the change of net steps on $10^{-4}$ in comparison with the symmetrical case. Simulation of the finite-length resonator is produced at the second stage. Terminal cells and matching section were taken into account too. Lengths of the terminal cells were chosen to minimize unevenness of the rf field distribution along resonator. Lengths of input and output terminal cells are different because of the matching section influence. Spectrum of the finite-length resonator after terminal cells optimization is given in fig.1. The distance between dipole and quadrupole mode is decreased from 12.1 to 3.5 MHz. Values of the Q-factor are given for copper. Deuteron RFQ provides particle acceleration from 0.06 up to 1 MeV under working frequency 433 MHz. Its cross-section is shown in fig.2,a. The contour of the quadrant (total number of quadrants is four) is shown in fig.2b ($\alpha$=10˚, $r_0$=3.5 mm, t=68 mm). Material of the cavity is chromium copper. All parts of the structure were manufactured with usual machinery but concluding the treatment and modulation of vanes produced by a new universal five-coordinate machine of PARPAS form HS-328. It has deflection table plane throughout all area 0.02 mm only and additional axis which allows one to change the treatments plane (from horizontal to vertical). Applying modulation is labour-consuming process including theoretical and practical parts. Real shape of vanes is modelled with the 3D field code. At the same time, we calculated analytically the data file of points describing a quasi-sinusoidal profile.

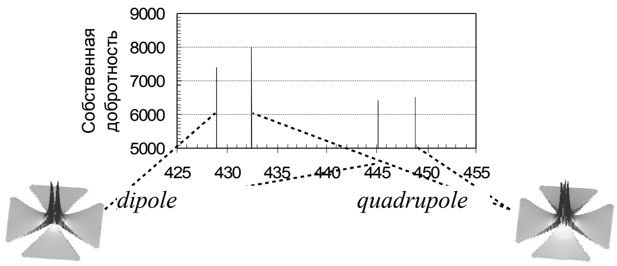


*Fig.1. Spectrum of the finite-length resonator after terminal cells optimization*

On analysis one takes into account technological restrictions. File of points is input data for technological complex of codes MasterCAM and must satisfy a required precision of modulation manufacturing. Practical part includes development of the constructional and technological documentation, preparation of making, applying modulation and preciseness control. Applying modulation on PARPAS machinery was performed for the first time and need a period for adaptation. At beginning the modulation was performed on aluminium samples and then on chromium copper vanes. Choice of an optimal cutting regime provides the accuracy of near 5 μm for 2.3 m manufacturing profile for aluminium samples. Control of sinusoidal shaped profile for chromium copper vanes was produced with a special procedure. It was shown that the accuracy of modulation manufacturing is 8 μm or better.

*a*
*b*

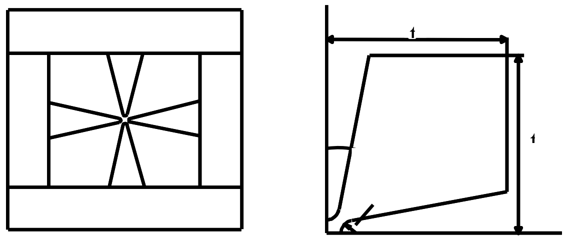

*Fig.2. Cross-section (a); contour of quadrant (b)*

Small change for the worse was determined by higher hardness of the surface of chromium copper vanes. Under treatment of 2.3 meter vane it was important to stabilize a room temperature. Temperature instability and nonuniformity lead to deformation of the cavity and may give perturbation of synchronism of accelerated particle dynamics, electromagnetic fields and consequently their energy gain is decreased. Therefore, in the construction of resonators the cooling system was provided. Its parameters were determined with the program complex ANSYS [5]. Distributions of rf loss in the metallic shell under voltage vane 98 kV, resonator length 2.3 m are calculated with the ISFEL3D code and data for ANSYS modeling were input. Distribution of rf loss in the quadrant is given in fig.3. The cooling system is built step-by-step of four Π-shaped copper tubes of small diameter. The tubes are sealed in resonator body near vanes base and metallic shell. They are jointed with each other in parallel.

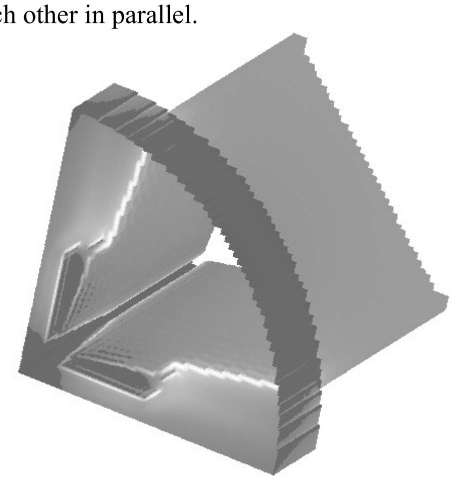

*Fig.3. Distribution rf lost in metallic shell*

Main parameter of cooling system is required cooler consumption to provide temperature difference along resonator 1˚C. Under average power lost 8 kW one need total water consumption 1.9kg/s that is a pump providing water pressure 8.9...9atm. Using compact pump of 4 atm pressure which NPK LUTS has temperature difference along resonator is increased to 1.5˚C. Thermal field's modelling was produced under assumption of thermal flow's density's invariability and it's distribution on inner surface of structure. Calculations had shown main part of power dissipated in structure is absorbed by water therefore heat exchange with air on outer boards is not considered. To determine consequences of resonator heating under temperature difference $\Delta T_{max}$=1.5˚C, modelling of tensions and thermal deformations of the structure was made. It was determined thermal deformation produce maximum change of interval gap on magnitude 1.7 mkm. Considering that aperture diameter is 7 mm frequency change in consequence of deformation is negligible. Thus one-contour cooling system with water pressure 4 atm provides normal work of the RFQ structure in nominal regime.

Structure must be fixed rigid at bottom on line which is apart from inputs structure through quarter resonator's length. On this line all shifting are forbidden. Structure's fixing on the line which is apart from resonator's output permits longitudinal shifting but transversal shiftings are forbidden. In this case the maximuml transversal deformations are not more than 106 mkm. APF deuteron structure consist of 55 drift tubes with supporting rods, beam channel of alternated diameter and two terminal cells with matching crosslike elements. Rod's sizes, distance between them and channel's diameters was chose as result modelling of particle dynamics. Outer radius and terminal cell's geometry remain undetermined. Initial meaning of the outer radius was supposed 105 mm (as proton variant of resonator). But additional electrodynamical calculations are necessity to exact this meaning. Construction of resonator is given on fig.4. To built geometrical model 1093356 finite elements were used.

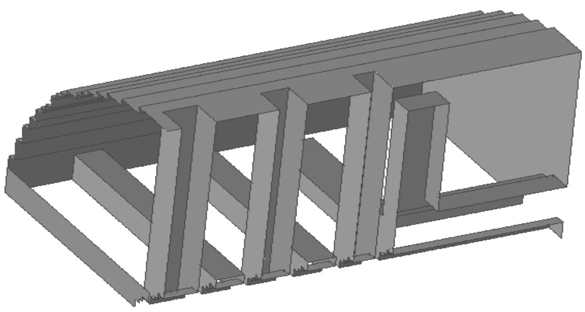

*Fig.4. Construction of resonator*

Eigenfrequencies and owned field of the five lowest modes were calculated with the PC P2-350 for 12 hours. The frequency of working mode be found equal 264.47 MHz. Decreasing of working mode frequency is determined by additional capacity between neighboring holders near beam channel where electrical field is strong. Deuteron resonator has distance between rods much less than proton resonator for the same frequency and additional capacity has big meaning. In deuteron structure working mode has lowest frequency because rods don't influence on parasite resonances in terminal cells. Results of calculation of working mode in resonator with different tube drift's number and constant radius 105 mm are given in table 1. These results display that approximate choice of outer structure radius one may analyze only initial and final parts of the structure with 15…20 drift tubes. More exact radius definition is produced by modelling of the total structure. These data of 55 cells resonator is given in table 2. Frequency's sensitivity under radius changing is equal 8.5 MHz/mm. Parasite modes connected with terminal cell frequencies near working mode are absent.

Table 1. Working mode frequency (MHz) depend on drift tube number

| Drift tubes number | Initial part of the APF cavity | Final part of the APF cavity |
|---|---|---|
| 5 | 359,66 | 385,03 |
| 15 | 264,48 | 323,69 |
| 20 | 249,38 | 299,73 |

Table 2. Working mode frequency of total structure depend on outer radius

| Frequency, MHz | Tube radius, mm |
|---|---|
| 264,47 | 105 |
| 390,26 | 75 |
| 433,49 | 70 |

Other parameters of the structure are overvoltage coefficient on the tips drift tube under rounding's radius 1mm is 2.64; accumulated energy is 0.68 J/m; quality factor is 7400.

## 3. CONCLUSION

At present deuteron chromium copper RFQ had been tested (one means adjustment, tuning and vacuum evaporation). Beam test is planned on december 2003. Simultaneously RFQ manufacturing technology for frequency's range 400…450 MHz is worked out. As final result tolerances of cavity's sizes must be not worse than 10mkm and surface roughness not worse than 0.1mkm. Proton APF resonator from OFE-OK$^{TM}$ accelerating particles from 2 up to 5 MeV will be manufactured in 2003. Assembling and physical test of deuteron 3.5 MeV accelerator it is supposed to produce in the end of 2004.

## REFERENCES


1. Yu.A. Svistunov, M.F. Vorogushin, Yu.N. Gavrish, et al. NPK LUTS Project of contraband detection system // *Proc. Linac 2000 Conf., Monterey, August 21-25, 2000,* v.1, p.639.
2. S.A. Minaev, Yu.A. Svistunov, S.A. Silaev. Modeling and testing of APF-cavity rf-field *// Proc. of the 2nd Int. Workshop BDO-95, St.Petersburg, Russia, July 4-8, 1995,* p.130-137.
3. S.A. Silaev. Application of the code ISFEL3D for three-dimensional rf structure calculations // *Proc. Int. Univ. Conf. "Electronics and Radiophysics of Ultra-High Frequencies", St.Petersburg, May 24-28, 1999.*
4. S.A. Silaev, Yu.A. Svistunov, V.N. Tanchuk "Mathematical modeling of rf and thermal fields in RFQ" // *Proceedings of 10 Workshop on Accelerator's application in industry and medicine. Saint-Petersburg, October 2001*, p.328-331 (in Russian)
5. ANSYS Heat Transfer User Guide, Swanson Analysis Systems, Inc., Updl DN-R221: 50-1, June 1993.


## ИССЛЕДОВАНИЕ РЕЗОНАТОРОВ УСКОРЯЮЩЕГО ТРАКТА ИОННЫХ КОМПЛЕКСОВ ПРИКЛАДНОГО НАЗНАЧЕНИЯ


***Ю.А. Свистунов, А.А. Будтов, В.Г. Мудролюбов, В.И. Петров, С.А. Силаев***



Рассматриваются вопросы конструирования, изготовления и настройки резонаторов с пространственно-однородной квадрупольной фокусировкой (ПОКФ) и переменно-фазовой фокусировкой (ПФФ) с рабочей частотой 433 МГц, разрабатываемых в НПК ЛУЦ НИИЭФА им. Д.В. Ефремова для комплексов прикладного назначения, использующих ионные пучки. В частности, рассматриваются протонный и дейтронный варианты комплексов с линейным ускорителем для обнаружения контрабанды. Описываются результаты компьютерного моделирования электромагнитных и тепловых полей в резонаторах. Представлены результаты расчетов параметров системы водяного охлаждения и напряженно-деформированного состояния ускоряющих структур, вызванного тепловыми и механическими нагрузками.


## ДОСЛІДЖЕННЯ РЕЗОНАТОРІВ ПРИСКОРЮЮЧОГО ТРАКТУ ІОННИХ КОМПЛЕКСІВ ПРИКЛАДНОГО ПРИЗНАЧЕННЯ


***Ю.А. Свістунов, А.А. Будтов, В.Г. Мудролюбов, В.І. Петров, С.А. Сілаєв***



Розглядаються питання конструювання, виготовлення і настроювання резонаторів з просторово-однорідним квадрупольним фокусуванням і змінно-фазовим фокусуванням з робочою частотою 433 МГц, розроблювальних у НПК ЛПЦ НДІЕФА ім. Д.В. Єфремова для комплексів прикладного призначення, що використовують іонні пучки. Зокрема, розглядаються протонний і дейтронний варіанти комплексів з лінійним прискорювачем для виявлення контрабанди. Описуються результати комп'ютерного моделювання електромагнітних і теплових полів у резонаторах. Представлено результати розрахунків параметрів системи водяного охолодження і напруженно-деформованного стану структур, що прискорюють, викликаними тепловими і механічними навантаженнями.