PROGRESS IN 433 MHz RFQ TECHNOLOGY AT NPK LUTS NIIEFA

Yu.A. Svistunov, M.F. Vorogushin, Yu.N. Gavrish, A.A. Budtov, P.V. Bogdanov, V.A. Ershov, V.I. Grigoriev, A.K. Liverovski, V.G. Mudrolubov, V.I. Petrov, S.A. Silaev, A.P. Strokach, V.F. Tsvetkov
D.V.Efremov Sci. Res. Institute, Saint-Petersburg, 196641, Russia
V.M. Maximov
Department of Atomic Science and Technology, Moscow, 101000, Russia

The paper is a survey of progress in 433 MHz RFQ technology at Production Complex of Linacs and Cyclotrons of D.V. Efremov Institute Sci. over past three years. RFQs and APF-cavities are designed as bases for ion accelerators for different applications. The use of 433 MHz frequency determines high requirements for RFQ manufacture facilities, which are discussed herein. The test experimental results of RFQ full-scale stands and high power rf testing data under beam load of 1 MeV on a deuteron RFQ made of chromium copper are presented.

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INTRODUCTION

NPK LUTS NIIEFA plans for designing ion-linacs-based accelerating complexes for applied purposes together with first experimental results of a 433 MHz-frequency accelerating facility were presented at several international conferences (see, for example, [1] and references therein). The paper [1] is devoted to the use of accelerated protons and deuterons with an energy from 1 up to 15 MeV in medical isotope production, elemental analysis of materials and other special purposes.

It is proposed to use RFQ for deuteron and proton acceleration up to 4 MeV and H-resonators with APF for acceleration from 2 up to 15 MeV. Concurrently with accelerating system elements designing, R&D was performed into an injection system, a feed (rf) system and also into output units and information processing systems in case of a complex of explosive and fissible substances. The research is supported by Ministry of Atomic Energy of Russian Federation.

ACCELERATING STRUCTURES

As it was expected, difficulties appeared with production of accelerating structures on a chosen working frequency. Analytical estimation, numerical simulation and testing full-scale prototypes fabricated of AMG-6 and D-16 aluminium alloys showed that at a working frequency of 433 MHz manufacturing tolerances for intervane distance in the chosen construction (four-chamber RFQ) must be ±25 mkm for neighboring vanes and ±35 mkm for opposite vanes in plane of symmetry for all accelerating cells. It comes to requirements of micron tolerances for linear dimensions and construction parameters determining deviations from nominal intervane distance values. An accuracy of production of vane modulation and its positioning relative to the plane of vane beginning z = 0 must be not more than 3…4 mkm. This requirement and requirements for inner surfaces treatment not less that 10 class were not fully met while fabricating the first chromium copper resonator with RFQ for deuteron acceleration from 60 keV up to 1 MeV. As a result, after tuning, the field irregularity was rather high (±7%). Another deficiency was an imperfection of gaskets for electric contact between vanes. Therefore, the quality factor of the resonator was much lower than the estimated value. RFQ designed values and results of pilot experiment are given in the table.

RFQ designed characteristics and experiment results

Parameter	Deuterons (theory)	Protons (theory)	Protons (experiment)
Input energy, MeV	0.06	0.03	0.03
Output energy, MeV	1	0.5	0.5
Energy spectrum width, keV	±30	±30	±40
Intervane voltage, kV	98	49	49
Quality factor	8000	8000	4400
Pulse power, kW	310	77.5	215 (experiment) 146 (theory)
Input pulse current, mA	20	25	5
Output pulse current, mA	15	18	1.3
Residual gas pressure, Torr			$(7...9)\cdot10^{-7}$

Test stand of chromium copper RFQ is shown in Fig.1. The tolerance requirements were satisfied at producing the experimental structure of D-16 alloy for proton acceleration from 0.06 up to 1 MeV. General view and cross-section of this structure are depicted in Fig.2 and 3, respectively.

CUTTING TOOL CHOICE

It is necessary to provide a low value of surface roughness to except a high-frequency breakdown in paraxial area where the breakdown is most probable (not less than 10 class surface finish; Ra = 0.16 mkm); the low roughness requirements for other surfaces are coming from the necessity to provide oscillations high quality factor value probable (not less than 10 class surface finish; Ra = 0.16 mkm).

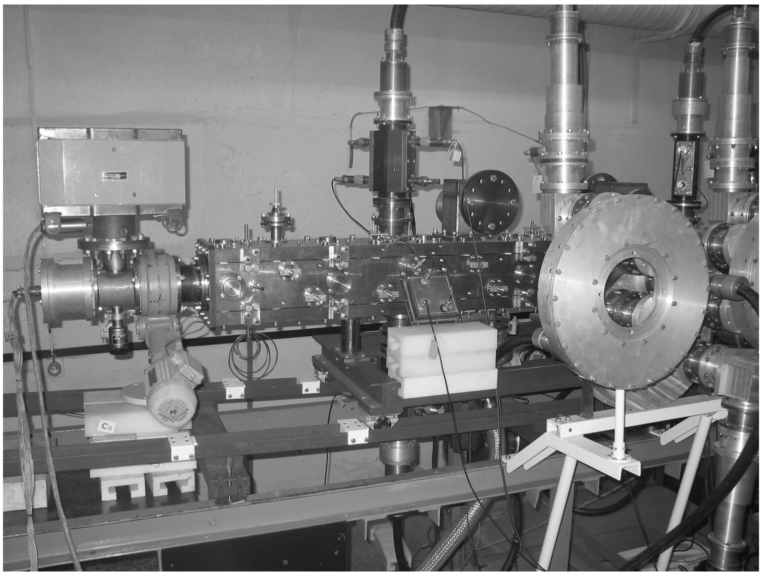

Fig.1

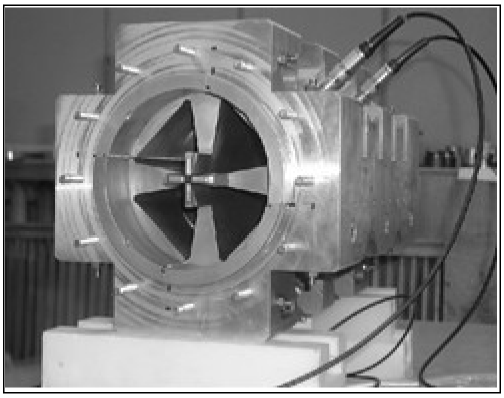

Fig.2

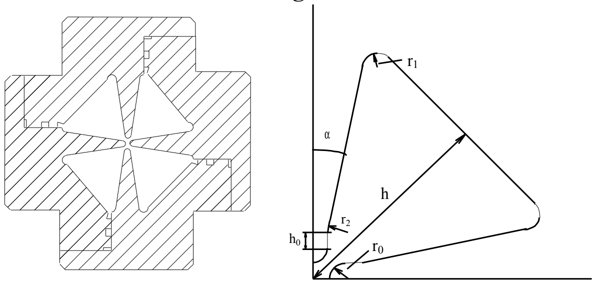

Fig.3
Fig.. 3

Material processing with the use of a diamond cutting tool gives an opportunity to solve two main problems: a) to provide low-level surface roughness (12 class or Ra = 0.04 mkm) and, as a result, to obtain cavity geometry with the required precision, b) the realization of the long-life tool and material processing without tool deterioration provide the accuracy of manufacturing at micron and submicron levels.

Solving of these two problems allows fabricating the vane docking interfaces with required accuracy.

Materials being processed by such diamond tools were tested to meet RFQ production requirements. At present, the selected materials are aluminium alloy D-16 and chromium copper one.

Examination of Talyrond trace made on a profilometer showed a diamond miller having vertical oscillations with an amplitude about 10 micron. Long surfaces processing ~1500 mm also showed slow drift in vertical direction.

Because a geometrical analysis of dimensional sequences had shown the necessity for a further design of vane docking interfaces with nonflatness not worse than 2.5 micron at a length of 1500 mm and the accuracy of size realization, forming dimensional sequences, being not worse than 5 micron, an incompatibility of these requirements with the existing range of oscillations of the cutting tool was established. To eliminate this incompatibility it was necessary to reduce the miller oscillation range from 10 micron down to 1 micron.

CUTTING MODIFICATION AND CLIMATE CONTROL FORMING

A graphical analysis of vertical oscillation (along Z axis) measurements at Z coordinate being fixed with the help of a standard machine metering system for a period of time about 10 minutes (a cycle of 80 measurements) showed the presence of a superposition of measuring value deviations of three types: a jumping deviation, a wavelike deviation and a slow drift of a value measured.

Based on these results and on measurement results obtained from standard temperature sensors of some machine modules, a strategy to find dominant sources of deviation was formed.

Investigations showed that:

- The jumping error is formed by an automatic correction of thermal deformations at the transversal axis Z and Y and is regulated in a PLC controller with a time of correction up to 5 seconds;
- The wavelike error is formed by temperature deformations in machine modules due to oil thermal fluctuations in machine hydrosystem in a cooling unit under the PLC controller operating (oil temperature full changing period is up to 5 minutes);
- The drift error is conditioned by machine modules' thermal deformation caused by a temperature change at the machine location (the temperature change period makes more than 10 minutes).

The jumping error was eliminated by matching appropriate parameters of the PLC controller.

The necessity to eliminate the wavelike error demanded a detail analysis of some machine modules and systems that allowed bringing out operational schemes for these modules and systems at hardware and software level. The analysis of temperature diagrams for different machine modules allowed making particular suggestions about machine modules temperature stabilization. The use of additional equipment permitted to optimize the working timing cycle. Specifically, an external control operating scheme for compressor was suggested. That allowed decreasing the coolant temperature range fluctuation in the system from 5.3 C to 1.2 C and hence lowering the wavelike error component from 2 mkm down to 0.4 mkm along Z coordinate and from 2.8 mkm down to 0.8 mkm along Y one.

In order to decrease a slow component of the error in a form of a slope caused by temperature fluctuation and consequent thermal machine deformations, two air conditioners were placed on the right and left sides of the machine. Different operation modes were tested. Based on these tests, an attempt to find an optimal operation mode was made. Basing on conditioners' manual control experience it was made a decision to put an automatic control system. That allowed stabilization of air temperature within 0.25°C range in the vane seat place. Also the stand site thermal insulation was improved. Essential improvement in temperature stabilization near the vane location was obtained by a shutter installation around the carrying spindle column. Installation of the liquid (spirituous) feeding system to the cutting area allowed treatment purity and precision improvement.

These procedures permit measurements to be done with accuracy 1.5 mkm within 10 minutes. At present, the docking interfaces treatment precision at the length 1500 mm is 2.5 mkm along Z and Y coordinates (Ra = 0.04 mkm or 12 class). Maximal difficulties with experimental proton resonator of aluminium alloy arise with the last processing of the inclined surfaces (10° and 45°). Processing result for the best vane has an error of 20 mkm (Ra = 0.15 mkm or 10 class). In future it is supposed to develop and create a special equipment that will realize a pneumatic pressing of a vane in manufacturing process.

CONCLUSION

Now, the measurement accuracy on the HS-328 machine can achieve 1 mkm. Nonflatness of vane docking interface is decreased down to 2.5 mkm along Z and Y coordinates instead of 10 mkm at the beginning.

After tuning and testing the experimental RFQ of aluminium alloy, it is supposed to fabricate another proton RFQ of chromium copper. This RFQ is supposed to accelerate particles from 0.06 to 2 MeV.

REFERENCES

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ПРОГРЕСС В СОЗДАНИИ УСКОРЯЮЩИХ СТРУКТУР С ПОКФ НА ЧАСТОТЕ 433 МГц В НПК ЛУЦ НИИЭФА

Ю.А. Свистунов, М.Ф. Ворогушин, Ю.Н. Гавриш, А.А. Будтов, П.В. Богданов, В.А. Ершов, В.И. Григорьев, А.К. Ливеровский, В.Г. Мудролюбов, В.И. Петров, С.А. Силаев, А.П. Строкач, В.Ф. Цветков, В.М. Максимов

Приведен обзор работ по созданию ПОКФ на 433 МГц в НПК ЛУЦ НИИЭФА им. Д.В. Ефремова за последние три года. ПОКФ и ПФФ-резонаторы планируется использовать в качестве основных резонаторов ускорителей ионов для различных применений. Использование частоты 433 МГц определяет высокие требования для изготовления ПОКФ, которые обсуждены в статье. Представлены экспериментальные результаты тестирования полномасштабных стендов ПОКФ и данные испытаний резонатора из хромистой меди для ускорения дейтронов до энергии 1 МэВ при высоком уровне ВЧ-мощности и нагрузке пучком.

ПРОГРЕС У СТВОРЕННІ ПРИСКОРЮВАЛЬНИХ СТРУКТУР З ПОКФ НА ЧАСТОТІ 433 МГц У НПК ЛУЦ НІІЕФА

Ю.А. Свістунов, М.Ф. Ворогушин, Ю.Н. Гавриш, А.А. Будтов, П.В. Богданов, В.А. Єршов, В.І. Григорьєв, А.К. Ліверовський, В.Г. Мудролюбов, В.І. Петров, С.А. Сілаєв, А.П. Строкач, В.Ф. Цветков, В.М. Максімов

Наведено огляд робіт зі створення ПОКФ на 433 МГц у НПК ЛУЦ НІІЕФА ім. Д.В. Єфремова за останні три роки. ПОКФ і ЗФФ-резонатори планується використати як основні резонатори прискорювачів іонів для різних застосувань. Використання частоти 433 МГц визначає високі вимоги для виготовлення ПОКФ, які обговорені в статті. Представлено експериментальні результати тестування повномасштабних стендів ПОКФ і дані випробувань резонатора із хромистої міді для прискорення дейтронів до енергії 1 МеВ при високому рівні ВЧ-потужності і навантаженню пучком.