TEST RESULTS OF 433 MHZ DEUTRON LINAC (RFQ)

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Abstract

The results of bench tests of an RF-frequency deuteron accelerator (RFQ) with an output energy of 1 MeV and operating frequency of 433 MHz are presented. The paper describes specific features of the RFQ construction and assembly, RF power supply system and test procedures. Parameters of the facility when operating with a beam energy analyzer and Be target are given.

INTRODUCTION

Starting from 2005, JSC "NIIEFA" carried out R&D works on the creation of compact accelerating structures with RFQ and APF. These structures can be used in contraband detection systems, ADS, medical facilities for BNCT, or carbon therapy [1]-[3]. In the paper we consider an RFQ structure designed for use as a part of a small-scale facility for neutron production. The main design parameters of the structure are shown in Table 1. Specificity of operation at a frequency of 433 MHz and problems in the manufacturing of an RFQ with a precise channel for the beam acceleration are discussed in [4].

FEATURES OF DESIGN AND ASSEMBLY

Four massive parts with space-modulated vanes made of oxygen-free copper serve as a base of the RFQ construction, Fig.1. When assembling, the components are joined together in pairs like a sandwich, and adjusting copper spacers are set between the parts. The rigidity of the construction is provided by bolting the parts with numerous connecting rods placed along the vanes from the outer side. Bolting power is used for additional tuning of operating frequency. The longitudinal alignment of modulated vanes consists in a small shifting of supporting parts and control of their mutual position. In case of the vane-tip damage, a 10-20μm layer can be removed from the tip surface with a corresponding decrease in spacers height to remain unchanged the operating frequency.

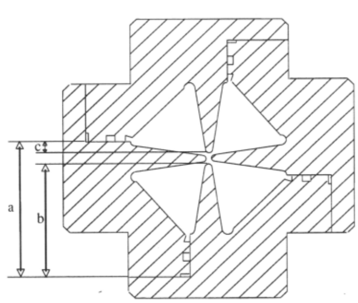

Figure 1: Structure cross-section.

Table 1: RFQ Design Parameters

Parameter	Value
Type of resonator	4-vane
Accelerated particles	$D^{\pm}$
Operating frequency, MHz	433
Beam injection energy, keV	25
Beam output energy, MeV	1
Current pulse length, μs	100
Pulse repetition rate, Hz	10
Intervane voltage, kV	50
Average channel radius, mm	1.8
Minimal channel radius, mm	1.18
Peak surface electric field, Kilpatrick	≤ 2
Input beam synchronous phase, degrees	-90
Output beam synchronous phase, degrees	-23
RFQ acceptance (norm.), π·mm · mrad	0.89
Vane length, mm	1090
RFQ resonator length, mm	1300

The modulation of each vane was checked in twenty points with a precision calibrated ruler of black granite and a linear encoder for sub-micron measurements. The results have shown that deviations in the modulation amplitude were not more than 8 μm. A difference in the distance between neighboring vanes, which disturbs the channel quadrupole symmetry, was not more than 10 μm. High quality of the RFQ manufacturing and assembly made unnecessary special tuners reserved for the equalization of the RF field along the resonator length.

ELECTRODYNAMIC CHARACTERISTICS OF RFQ RESONATOR

The measured Q-factor of the resonator was 6800. The results of measuring the magnetic field distribution along the resonator are shown in Fig.2. Fig.3 demonstrates the intervane voltage as a function of measured RF power. The RFQ intervane voltage corresponding to different levels of RF power was determined from the endpoint of the bremsstrahlung spectrum [5]. To make the spectral analysis, a measuring system [6] with a scintillation detector was used. The results of the detector calibration by reference to Am-241 are shown in Fig.4. The FWHM–to-maximum position ratio is 21keV/59.5keV, consequently, the detector energy resolution is 0.35.

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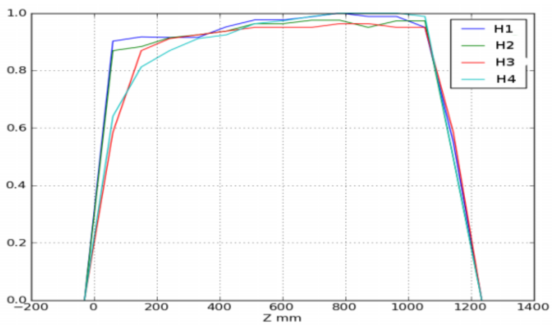

Figure 2: Distribution of a normalized magnetic field along RFQ quadrants.

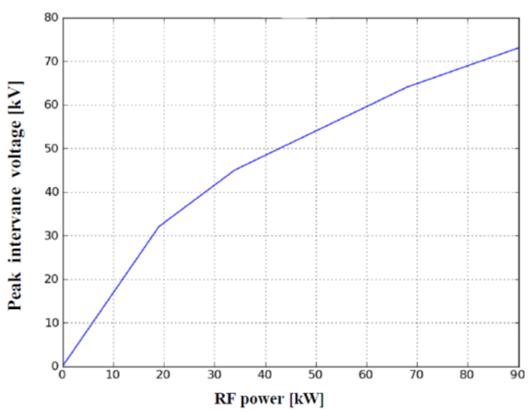

Figure 3: Peak intervane voltage versus RFQ resonator power.

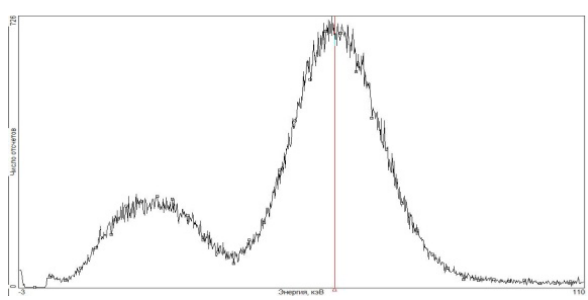

Figure 4: Energy spectrum of Am-241 at the spectrometer output.

DESCRIPTION OF THE TEST-FACILITY

The RF power was supplied to the RFQ from an amplifying system comprising a low-power master-oscillator, preamplifier with an output power of 2 kW and final amplifier with an output power of up to 450 kW per pulse. An endotron-type device, “Colesso”, was used as the final amplifier; its functional diagram is given in Fig.5. To protect amplifiers against overloads under breakdown in the RFQ cavity, a ferrite circulator was installed between the endotron and accelerating structure. Pulsed voltages of 2kV and 12 kV were fed to amplifiers from a common modulator.

Operation of the RFQ under the beam load was studied on a facility shown in Fig.7. An injector unit of the facility consists of a multi-cusp source of charged ions, two einzel (unipotential) lenses and two steering magnets. The einzel lenses were used for transport and matching the beam with the RFQ acceptance. The first step of the beam forming was done by the multi-cusp source. In the continuous mode the source can produce a weakly divergent H^- beam with a current of up to 2 mA and normalized emittance of 0.3 $\pi \cdot$ mm mrad [7]. Phase characteristics of a pulsed beam were not measured. D^- current at the output of the source vacuum chamber was measured with a movable Faraday cup. In addition, the beam intensity was controlled with two beam current transformers (BCTs) at the RFQ input and output.

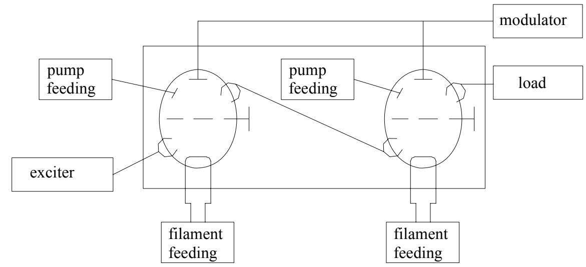

Figure 5: Functional diagram of the endotron.

MEASUREMENT OF BEAM CURRENT AND ENERGY SPECTRUM

To measure the energy spectrum and current of the accelerated particles we used either a standard magnetic analyzer with a set of lamellae or a foil analyzer (a set of Al foils of a fixed thicknesses installed in front of a beam collector). Fig.6 presents experimental data on the collector current as a function of the RFQ intervane voltage, which (in contrast to Fig.3) was found taking into account the energy resolution of the x-ray analyzer. The same figure shows the results of an end-to-end simulation of the beam dynamics under the experiment conditions. The simulation was started from the beam source with a measured beam current of 1.7мA and assumed phase distribution of particles; potentials of the 1st and 2nd einzel lenses were -16kV and -23.8kV respectively. The blue (top) curve corresponds to the calculated current of all particles at the RFQ output. The red line with crosses shows the current of particles with an energy more or equal to 1 MeV. The black line with circles describes the data obtained experimentally. The measured and calculated data are in agreement. The simulation explains the beam current losses at nominal intervane voltage by mismatch of the beam and RFQ in angle characteristics of particles. Similar conclusions were drawn in [8].

TEST RESULTS WITH BERYLLIUM TARGET

In addition to the experiments described above, the accelerator was tested when operating with a Be target of 5mm thickness. The target is intended to produce

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neutrons by the $^{9}Be(d,n)^{10}B$ reaction. Cylindrical form of the target was designed for the beam power of 10 kW per pulse. The target is sited on a water-cooled 1 mm-thick copper disk.

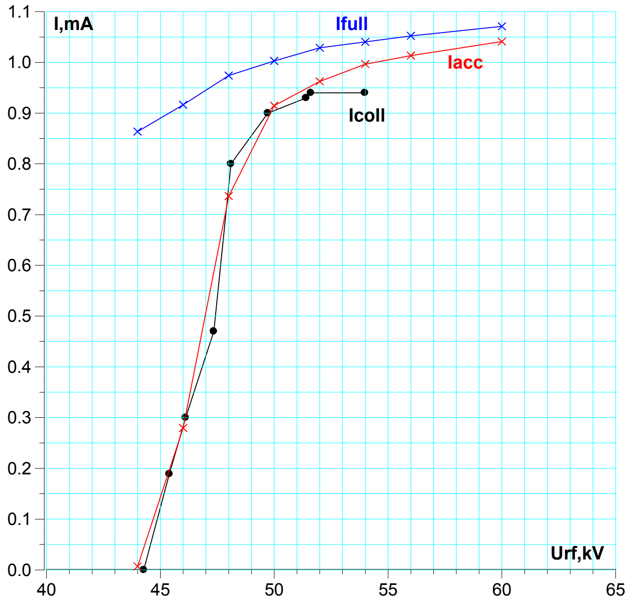

Figure 6: Beam current at the RFQ output as a function of the intervane voltage: I_{full} is the total current (calc.), I_{acc} is the current of accelerated particles (calc), I_{coll} is the current on the beam collector (measur.).

Neutron fluxes were measured in two stages by the personnel from FSUE «D.I. Mendeleyev Institute for Metrology (VNIIM)». First, direct measurements of the neutron flux at a minimum ion current of 0.033mA were done with a calibrated all-wave detector OVS-3M. Then, relative measurements were carried out with indium activation detectors at ion current values of 0.033 mA and 1.0 mA. In direct measurements, the neutron flux density was measured at angle 0° with respect to the direction of the accelerated ion beam. Contribution of the scattered radiation was estimated by the "shadow cone" method in accordance with ISO-8582. The obtained neutron flux value of 10^{8} n/s correlates well with previously published data for a beam current of 1 mA.

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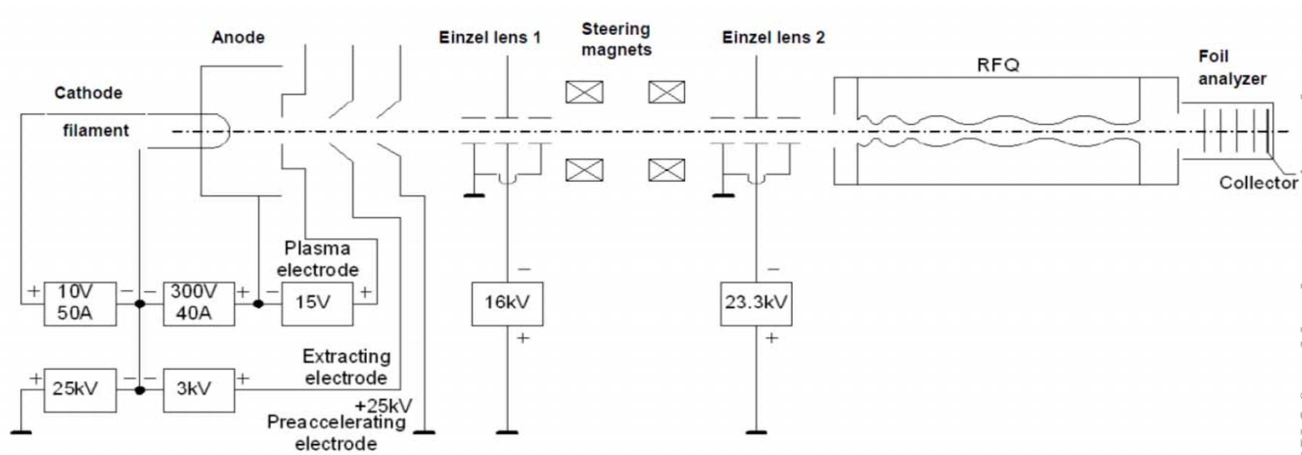

Figure 7: The test-facility schematically.

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