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RF System for the NICA Collider

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Abstract—The new NICA (Nuclotron-based Ion Collider fAcility) accelerator complex being built at the Joint Institute for Nuclear Research (Dubna, Russia) is intended for experiments with 197Au79+ gold nuclei at energies in the range of 1–4.5 GeV/n. The RF system of the collider should provide the capture of bunches to be injected from the nuclotron, the accumulation of the necessary number of particles, their acceleration (if necessary), and the formation of bunches. For this, in each ring of the collider, three types of accelerating stations are used: one barrier station and two harmonic stations. The barrier station accumulates the particles and can used to accelerate them up to the energy of the experiment. The harmonic RF stations operating at the 22th and 66th harmonics of the revolution frequency are used for the formation of bunches. This paper describes the operating modes of the RF system and the design features of the RF stations.

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INTRODUCTION

The NICA acceleration complex is intended for experiments with 197Au79+ gold nuclei at energies in the range of 1–1.45 GeV/n. The average design luminosity of the collider is 10^{27} cm^{-2} s^{-1}. The complex is a stage of accelerators: an injection complex, a new superconducting synchrotron (Booster), an existing superconducting synchrotron (Nuclotron), and a new collider consisting of two stacked superconducting rings [1]. The collider parameters (optional) are presented in Table 1.

The RF system of collider provides the accumulation of the particles to be injected from the nuclotron, their additional acceleration (if the injection energy is less than the energy of experiment), and the formation in each ring of 22 bunches with the given parameters. For that, three types of acceleration stations are used (see Table 2). The frequency of the stations is returned depending on the energy. The operation of stations occurs by the algorithm described below. The pressure of operating vacuum does not exceed 10^{-11} torr.

OPERATING ALGORITHM OF RF SYSTEM OF COLLIDER

The bunches of particles, which are injected from nuclotron are accumulated in the collider using the barrier stations (RF1). The accumulation is carried out by the method of barrier voltages [2]. A periodic sequence of accelerating and braking voltage pulses (barriers), the amplitude of which is 5 kV, is generated at the accelerating gap of station. The barriers set the zones of accumulation and injection. After successive injection from the nuclotron appropriately manipulating with the barriers, the new portion of the particles is added to the already accumulated particles (so-called RF stacking) and the space for the next injection is cleared. If it is necessary to additional accelerate the accumulated particles, the RF1 generates the accelerating voltage representing the meander with amplitude ±(270–330) and the barriers provide the location of the particles in the positive area. The acceleration occurs simultaneously with the rise of magnetic field. Figure 1 illustrates the operating principle of RF1.

After the accumulation of sufficient quantity of particles and their additional acceleration, the RF1 stations are switched off. The particles uniformly fill the whole ring perimeter. Then the RF2 stations, which operate at the frequency of the 22nd harmonic of revolution frequency, are switched on. The voltage at the RF2 stations increases from the initial value close to 0 up to 100 kV. Twenty-two bunches are formed. The process is accompanied by electronic or stochastic cooling. The total time of voltage rising is

Table 1. NICA collider parameters

Perimeter	503.04 m
Critical energy (γ)	7.09
Energy injection	1–4.5 GeV/u
Number of particles in one bunch to be injected	1×10^9
Length of bunch to be injected	15–120 m
Root-mean-square scattering by the impulses $\Delta p/p$ of the particles to be injected (a linear energy dependence)	$(1–3) \times 10^{-4}$
Time between two successive injections when alternate/simultaneous filling the rings	4/8 s
Energy of experiment	1–4.5 GeV/u
Root-mean-square scattering by the impulses $\Delta p/p$ of the particles under the energy of experiment 1/3/4.5 GeV/nucleon	$0.55/1.15/1.5 \times 10^{-3}$
Revolution frequency under the energy 1/3 3/4.5 GeV/nucleon	0.522/0.579/0.587 MHz
Number of bunches in each ring	22
Maximum number of particles in one bunch (in each ring) under the energy of 1/3/4.5 GeV/nucleon	$0.275/2.4/2.2 \times 10^9$
Maximum number of particles in each ring under the energy 1/3/4.5 GeV/nucleon	$0.6/5.3/4.8 \times 10^{10}$
Number of injections needed to accumulate the maximum number of particles	7–55
Accumulation time of the maximum number of particles	56–440 s
Total time of experiment cycle	5–100 min

Table 2. RF stations of collider (for one ring)

Station	Function	Voltage shape	Frequency, MHz	Σ voltage, kV
RF1	Accumulation	Mov. barriers	0.522–0.587	±5
	Additional acceleration	Meanders		±(0.27–0.33)
RF2	Bunch formation	22nd harmonic	11.484–12.914	100
RF3		66th harmonic	34.452–38.742	1000

about ~100 s until the bunch is not in the separatrix of the 66th harmonic (RF3). At this point in time, the recapture of the bunch from the RF2 into RF3 occurs (RF2 and RF3 operate simultaneously).

All stations have mechanical shorting plugs (SP) of accelerating gaps. In those time periods when, in accordance with the RF system operating algorithm, the stations are switched off, their accelerating gaps are closed (shorted) and the bunch sees the smooth chamber and not the resonant cavity.

Before switching on, the RF2 and RF3 stations (with the shorted gaps) are tuned to the middle between 22/23 and 66/67 harmonics of revolution frequency, respectively. The staggered resonators weakly

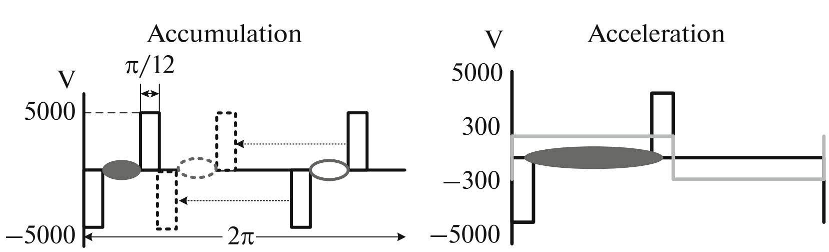

Fig. 1. Working principle of RF1: is the accumulation zone and is the injection zone.

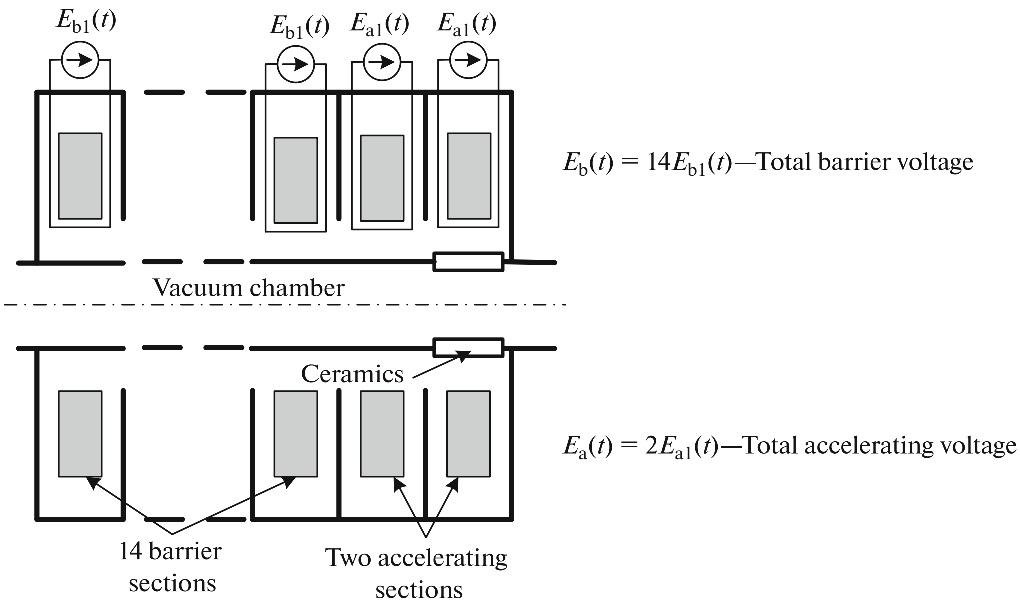

Fig. 2. Conceptual scheme of the barrier station.

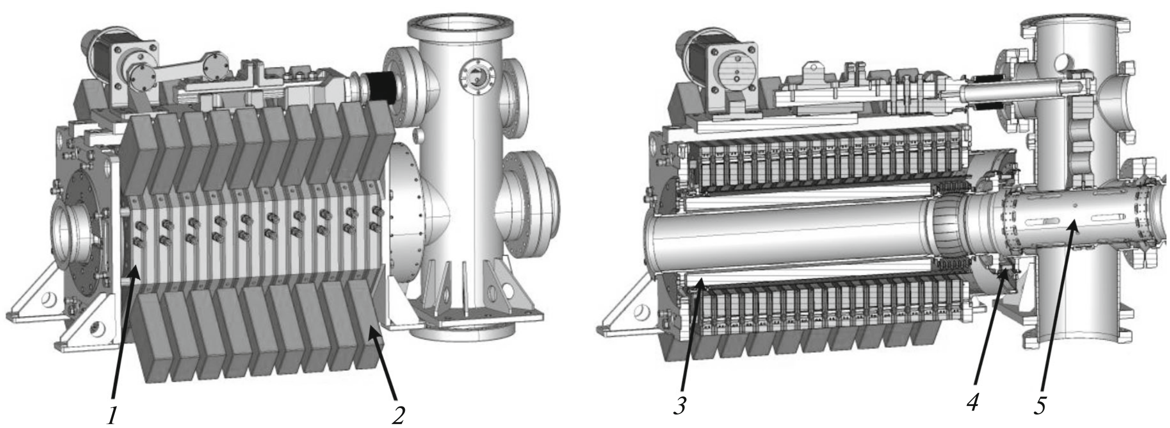

Fig. 3. RF1 station: (*1*) section with amorphous alloy ring in the water-cooled copper frame, (*2*) pulse former, (*3*) heater with thermal insulation for degassing warmup, (*4*) ceramic insulator, and (*5*) shorting plug of accelerating gap.

interact with the bunch. After breaking the gap, the adiabatic rise of voltage occurs synchronously with tuning the stations to operating frequencies.

RF1 STATIONS

The RF1 station is an induction accelerator, which consists of the set of sections. The sections are put on outside the vacuum chamber (a round pipe with internal diameter of 100 mm), in the break of which a cylindrical ceramic insulator is soldered in. The break of the vacuum chamber forms the accelerating gap. A conceptual scheme of the barrier station is shown in Fig. 2.

The section is made based on the ring of amorphous cobalt alloy of the AMET-84KKhSR grade produced by PAO Ashinsk Metallurgical Works [3]. This alloy is characterized by high relative magnetic permeability (tens of thousands at low frequencies and ~600 at 10 MHz). Two pulse formers based on the switch transistor assembly of the Microsemi DRF1400 model, which generate the pulse sequences E1 and E2, are installed in each section. The duration of barrier pulses is within 20–80 ns. The pulse rise time is ≤10 ns. In the process of operation, up to 1.2 kW of thermal power is released in the ring. Therefore, the rings are placed into the copper water-cooled frame. The appearance of the barrier station and its section are shown in Fig. 3.

RF2 STATIONS

The RF2 station is a vacuum coaxial resonator shortened with a capacitance. The resonator frequency is retuned (depending on the energy of experi-

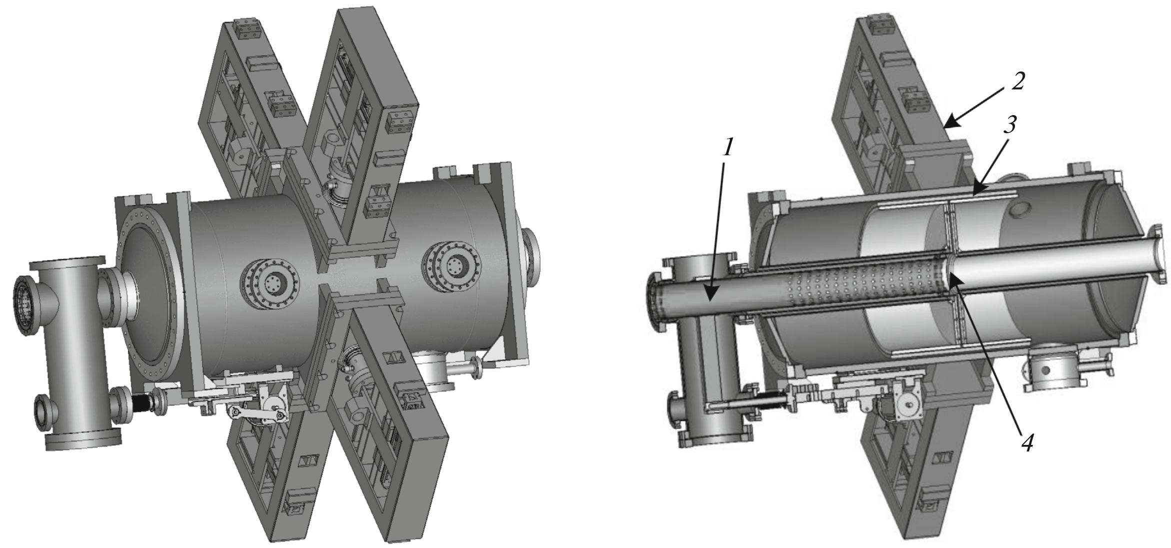

Fig. 4. Structure of RF2 and RF3 harmonic stations: (*1*) shorting plug of accelerating gap, (*2*) mechanism of tuner displacement, (*3*) tuner, and (*4*) accelerating gap.

ment) within 11.484–12.914 MHz. The operating frequency is retuned with four capacitive tuners. The tuning resolution should be ~200 Hz. This corresponds to the displacement of capacitive tuners by 1.1 mm with a positioning accuracy of 0.13 μm. To ensure such displacements, a combination drive, which sums the rough displacement carried out with a step motor and precision displacement with piezoelectric actuator, is used. The total voltage of RF2 stations is 100 kV. Four stations will be installed in each ring. Semiconductor amplifiers will be used for the power supply of the stations.

RF3 STATIONS

The RF3 station is a vacuum coaxial resonator shortened with a capacitance (similarly to RF2). The resonator frequency is retuned (depending on the energy of the experiment) within 34.452–38.742 MHz. The total voltage of RF3 stations reaches 1000 kV. Common design and engineering solutions are used for RF2 and RF3 stations. Figure 4 shows the structure of stations.

CONCLUSIONS

The prototypes of individual units (RF1 section, shorting plug, and tuner) were produced and successfully tested. Two RF1 stations were transferred to the production of the Joint Institute of Nuclear Physics. Tests of RF1 stations are planned at the Joint Institute for Nuclear Research in December 2018. The contract for the production of the full-scale prototype of the RF2 station in the Joint Institute of Nuclear Physics has been prepared. The parameters of the RF3 system are continuing optimization.

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