Journal of Physics: Conference Series **2984** (2025) 012016 doi:10.1088/1742-6596/2984/1/012016

BENCH TESTS OF THE RF1 BARRIER SYSTEM OF THE NICA COLLIDER

D Morozov[1]*, V Arbuzov[2], O Brovko[1], A Grebentsov[1], A Karpuk[1], S Krutikhin[2], G Kurkin[2], A Malyshev[1], I Meshkov[1], V Morozova[1], S Motygin[2], A Murasev[2], V Osipov[2], E Rotov[2], A Shilin[1], A Sidorin[1], E Syresin[1], V Tarnetsky[2], A Tribendis[2], A Volodin[1], M Yablochkin[1], A Zhukov[2]

[1]Joint Institute for Nuclear Research

[2]Budker Institute of Nuclear Physics of Siberian Branch Russian Academy of Sciences

E-mail: morozovdm@jinr.ru

Abstract. The Joint Institute for Nuclear Research (JINR) is constructing a heavy ion collider based on the existing superconducting synchrotron, Nuclotron – NICA (Nuclotron based Ion Collider fAcility). It will be a multistage accelerator complex designed to study the interactions of ions with matter. Each ring of the collider has an RF1 station equipped with it, which is used to accumulate a significant number of particles emitted by the Nuclotron. The test results of benchmarking the stations and the inner workings of the High Frequency Barrier System RF1 - a crucial component of the collider are presented in the article.

1. INTRODUCTION

The Nuclotron based Ion Collider fAcility (NICA) [1], operating in its heavy ion collision mode is aimed at the experiments with colliding beams of $^{197}Au^{79+}$ ions at kinetic energies from 1 to 4.5 GeV/u per beam. The collider's RF system consists of three types of stations:

- Barrier RF1 (one station per ring);
- Harmonic RF2 (four station per ring);
- Harmonic RF3 (eight station per ring).

The RF1 barrier system is used to capture particles injected from the Nuclotron and to accumulate the required number of ions. Accumulation is carried out using the technique of moving barriers. In addition, if necessary, RF1 can accelerate the accumulated beam if injection occurs at an energy lower than the energy of the experiment. This is done using moving barriers technique. In addition, if necessary, RF1 can accelerate the accumulated beam.

In the system, four pulses of ±5 kV are formed at the bunch rotation frequency - two accelerating and two decelerating, these pulses invert the separatrices of injection and stack. Particles from the Nuclotron are injected into the collider, distributed and added to the stack after the barriers separating the two separatrices are switched off. In this way, the particles uniformly fill the collider rings. If necessary, the accumulated ions captured between two barrier pulses can be accelerated using a meander voltage of ±0.3 kV generated by RF1. If the bunch length exceeds the perimeter of the semiring, it is compressed by moving the barrier pulses. The ion accumulation process is accompanied by electron cooling. [2].

2. THE BARRIER STATION RF1

The high-frequency barrier station RF1 (Fig. 1) consists of an induction resonator consisting of amorphous iron rings, a control system and power supplies.

The resonator consists of twenty sections, each of which includes two shapers and a ring made of amorphous iron. 15 of these sections are used for particle accumulation and 3 sections for their acceleration. In addition, the remaining damping sections will help suppress high-frequency ringing from barriers. If there is a need to increase the barrier voltage, the accelerating sections can be used as barrier sections, but acceleration is impossible in this operating mode.

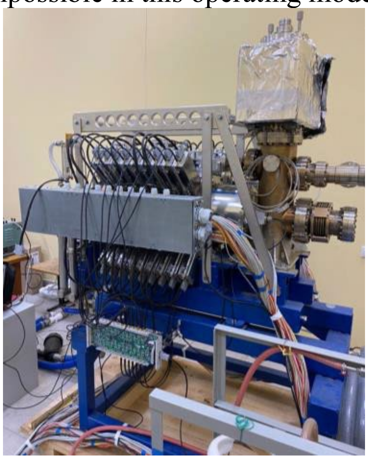

Figure 1. Resonator of the barrier station RF1

Power supplies for 360V are intended for powering the barrier section formers, for separating the dispersed particle flow into groups. If accelerating sections, which are usually powered by a 125 V source, switch to barrier formation mode, it will be necessary to switch their power supply to 360 V sources.

The control system is responsible for generating control pulses for high-voltage shapers, for generating a signal of readiness of the entire system, also for collecting and recording all digital and analog signals of the station.

3. BENCH TEMPERATURE TESTS OF SECTIONS

During the bench tests of the barrier sections, the analysis of the time characteristics of the barrier sections was carried out. A supply voltage of 360 V was alternately applied to the shapers. This process was organized to measure the pulse generation delay time specific to each section.
The image in Fig. 2 shows the layout and connection of the shapers, divided into damping (E), accelerating (Y) and barrier (B) sections.

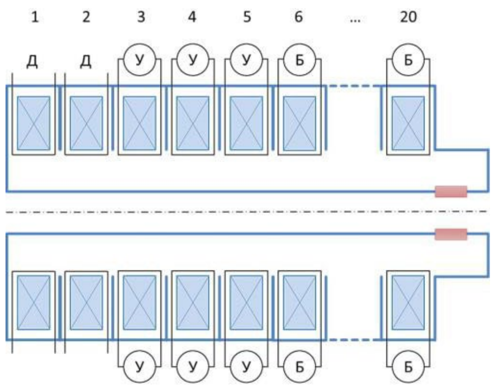

Figure 2. The layout of the barrier sections RF1.

The results of the experiment allowed us to establish that the increment of the time delay between the sections is approximately 0.25 ns..

To analyze the test results, a graph is graphically presented (Fig. 3) showing the behavior of the barrier pulse as it passes through various shapers (during the tests, the sections were assigned sequential numbers: 1,2 – damping sections, 3...5 – accelerating sections, 6...20 – barrier sections).

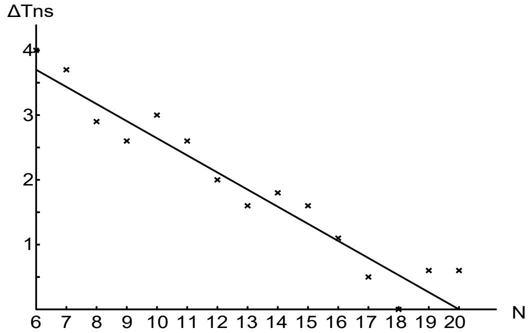

Figure 3. Change in barrier pulse propagation delay depending on the section position.

The time increments of the pulse sequence delay are acceptable for the operation of the station, however, in the future it is expected that the pulse repetition delays will be reduced. Table 1 shows some parameters of the station sections RF1.

Table 1. The main parameters of barrier pulses.

Parameter	Значение
The amplitude of the barrier voltage pulses, kV	5
The duration of the front/fall of the barrier voltage pulses, ns	10
Maximum duration of one pulse (in 4-pulse mode), ns	80
Maximum pulse duration (in two-pulse mode), ns	160
Frequency of circulation, kHz	522 - 587
Supply voltage of the barrier sections, V	360

To fully verify the station's operability, a daily test of the system was conducted in intensive operation mode. The tests were carried out when generating four equidistant pulses with a maximum frequency of 587 kHz and a duration of 72 ns. Such frequency and duration parameters were chosen to achieve the maximum current of the system, which is an important condition for the effective operation of the station. The pulses of the barrier sections were regulated by filling them in the range from 5% to 100% in increments of 5%. When 100% full, the work lasted for 7 hours. Figures 5 and 6 show data characterizing the shape of the pulse at the accelerating gap when fully filled. Figures 5 and 6 show the shape of the pulse at the accelerating gap at 100% filling.

Journal of Physics: Conference Series **2984** (2025) 012016 doi:10.1088/1742-6596/2984/1/012016

The operating mode with the maximum pulse frequency and duration allows you to simulate extreme operating conditions of the station. The test results confirmed the high reliability of the system under long-term loads.

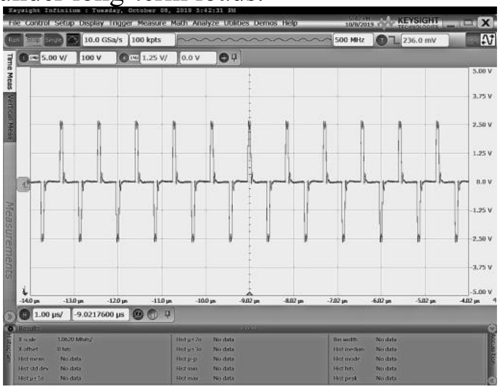

Figure 5. Form of barrier voltage across the gap (vertically, a voltage of 2.5 V corresponds to a voltage of 5 kV across the gap).

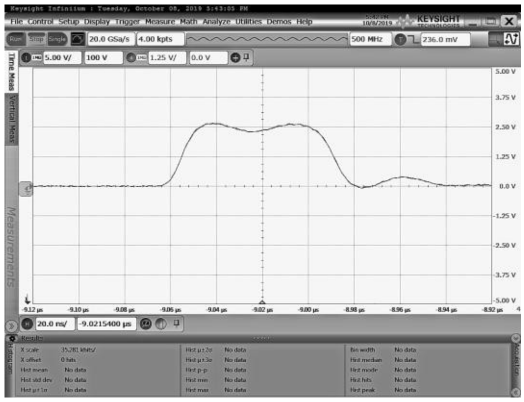

Figure 6. The shape of one pulse on an enlarged scale at the accelerating gap at 100% fill.

In addition, during operation, continuous monitoring and recording of the temperature values of the formers and the shells of the inductor rings was carried out. The maximum recorded temperature in the formers was +47 °C, the temperature of the cooling water at the inlet was +29 °C.

4. VACUUM TESTS

At the beginning, the equipment of the vacuum's stand for pumping out the RF station was installed. During the pumping process, the tightness of the vacuum connections was checked with a helium leak detector, as a result of which an acceptable leakage of <$1x10^{-10}$ mbar*l/s was obtained. Further, the stations were degassed.

Only after degassing the process of installing the heating equipment and thermal insulation necessary for heating up the RF1 was carried out. Heating up stations took place at a temperature of 300°C, because the temperatures for heating of the station's vacuum equipment were determined by the operating instructions. The rate of temperature change of the stand was 1°C/min, in addition, it was necessary to maintain it at a temperature of 300°C for at least 48 hours.

The heating equipment and thermal insulation were dismantled only after the stations had cooled down to room temperature.

5. CURRENT STATUS AND PLANS

Two RF1 barrier stations were delivered to JINR, bench tests of the RF1 barrier stations were carried out, during which the need for some modifications arose.

At the moment, the stations in Ch 1 have been installed in the collider rings. Repeated vacuum tests have been carried out and electrical tests are planned to be carried out at the end of 2024. The control racks and power supplies of the shapers were transported to the collider building. In addition, the control unit and the generator unit will be delivered and installed in the rack. Each control stand will be connected to its own resonator and to its own power sources.

6. CONCLUSION

The RF1 barrier system was delivered and assembled at the Joint Institute for Nuclear Research.during the work of the RF station of the collider, its reliability and operability in conditions close to operational ones were confirmed. Both vacuum and electrical bench tests were carried out, in which the stations operated at a given design load. The stations RF1 are installed in a ring, an electrical connection to the power supply system has been made. Repeated vacuum tests were carried out in the collider ring. The RF1 system is fully ready for electrical testing.

During the bench tests, some studies were conducted:

- Pressure measurement in the range of $1.5x10^{-9}$ – 760 Torr;
- Checking the vacuum volume for leaks;
- Residual gas spectrum analysis;
- Evacuation and pressure measurement during high-temperature degassing heating of RF1.

7. FUNDING

This work was supported by ongoing institutional funding. No additional grants to carry out or direct this particular research were obtained.

REFERENCES

[1] D. Kekelidze et al., “Three stages of the NICA accelerator complex”, Eur. Phys. J. A (2016) 52: 211. doi:10.1140/epja/i2016-16211-2
[2] A. G. Tribendis et al., “Construction and First Test Results of the Barrier and Harmonic RF Systems for the NICA Collider”, presented at the 12th Int. Particle Accelerator Conf. (IPAC'21), Campinas, Brazil, May 2021, paper MOPAB365.