CONSTRACTION AND FIRST TEST RESULTS OF THE BARRIER AND HARMONIC RF SYSTEMS FOR THE NICA COLLIDER

A. Tribendis†,1, Y. Biryuchevsky, K. Chernov, A. Dranitchnikov, E. Kenzhebulatov, A Kondakov,
A. Krasnov, Y. Kruchkov, S. Krutikhin, G. Kurkin, A. Martynovsky, N. Mityanina[2], S. Motygin,
A. Murasev[2], V. Osipov, V. Petrov, E. Pyata, E. Rotov[2], V. Tarnetsky, I. Zapryagaev, A. Zhukov
Budker INP, Novosibirsk, Russia
O. Brovko , E. Syresin, A. Malyshev, I. Meshkov[3], JINR, Dubna, Russia
A. Zinkevich, Triada-TV, Novosibirsk, Russia
[1]also at Novosibirsk State Technical University, Novosibirsk, Russia
[2]also at Novosibirsk State University, Novosibirsk, Russia
[3]also at Saint-Petersburg State University, Saint-Petersburg, Russia

Abstract

This paper reports on the design features and construction progress of the three RF systems for the NICA collider being built at JINR, Dubna. Each of the two collider rings has three RF systems named RF1 to 3. RF1 is a barrier bucket system used for particles capturing and accumulation during injection, RF2 and 3 are resonant systems operating at 22nd and 66th harmonics of the revolution frequency and used for the 22 bunches formation. The RF systems are designed and produced by Budker INP. Solid state RF power amplifiers developed by the Triada-TV company, Novosibirsk, are used for driving the RF2 and 3 cavities. Two RF1 stations were already delivered to JINR, the prototypes of the RF2 and 3 stations were built and successfully tested at BINP. Series production of all eight RF2 and sixteen RF3 stations is in progress. The design modifications and test results are presented.

INTRODUCTION

The **N**uclotron based **I**on **C**ollider f**A**cility (NICA) [1] operating in its heavy ion collision mode is aimed at the experiments with colliding beams of 197 Au79+ ions at energies from 1 to 4.5 GeV/u per beam. Budker Institute of Nuclear Physics contributes to several parts of the project, including its RF systems – barrier bucket and harmonic. Barrier bucket system, RF1, is used to capture the particles injected from the Nuclotron and to accumulate the required number of ions. This is done using moving barriers technique. RF1 also can accelerate the accumulated beam if the injection energy is lower than that of the experiment. Harmonic systems, RF2 and 3, are used to form 22 bunches with required parameters [2]. Each collider ring has one RF1 station, four RF2 and eight RF3 stations.

The RF1 system generates 2 pairs of ±5 kV pulses (accelerating and decelerating in each pair) at the bunch revolution frequency thus forming the two separatrices – injection and stack. A bunch from the Nuclotron is shot into the injection separatrix, moved and added to the stack by switching off the pulses separating the two separatrices and so merging the two bunches. If the combined bunch length exceeds the half-ring perimeter it is compressed by moving the barrier pulses. Ion accumulation process is accomplished by the electron cooling. The accumulated ions trapped between the two barrier pulses may be accelerated, if needed, by ±0.3 kV meander voltage generated by the RF1 as well.

The RF2 and 3 systems operate at the 22nd and 66th harmonics of the revolution frequency respectively. They provide CW RF voltage up to 0.1 and 1 MV per ring. When the accumulation and acceleration stages are completed the RF1 system is turned off and the particles fill uniformly the entire orbit. The RF2 is turned on, its voltage is increased adiabatically and 22 bunches are formed. As soon as bunches are short enough (with help of the electron cooling) to fit into the RF3 bucket, this system is turned on and the RF3 voltage is increased slowly. Finally 66 separatrices are formed, ideally with only every 3rd separatrix populated. The RF2 voltage is kept on to enhance the bunching. Beams are ready for the experiment when the bunch length of ≤60 cm and momentum spread of $\leq 10^{-3}$ are reached.

RF1 BARRIER BUCKET SYSTEM

RF1 is an induction accelerator composed by 20 inductor sections: 15 are used to form the barriers, 3 generate accelerating meander voltage and 2 passive damping sections correct voltage shape. Each active section is driven by a pair of pulse generators. An inductor section consists of a magnetic core made from the amorphous magnetic alloy Amet 84XB-M (82% Co) and glued between the 2 water cooled copper plates (heat exchangers). The total power dissipation is ~21 kW per station (85% in the cores and 15% in the pulse generators). The assembly of 20 sections is spring loaded in longitudinal direction for thermal expansion compensation.

Pulse generator is a switching power supply based on Microsemi DRF1400 transistor unit triggered by external signals thus allowing variation of the output pulse width. The minimum gap between two adjacent positive and negative pulses is limited to 10 ns in order to ensure no through current.

While an RF system (1, 2 or 3) is off movable shorts with finger spring contacts close the accelerating gaps of the cavities. Same design of the shorts is used for all cavities:

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† A.G.Tribendis@inp.nsk.su

a tube with finger spring contacts at its ends is moved inside the beam pipe by an arm. The arm comes out of the vacuum through a bellow unit and is driven by a linear actuator located at an air side. Figure 1 shows the details of the RF1 design. Figure 2 shows the RF1 station during its assembly.

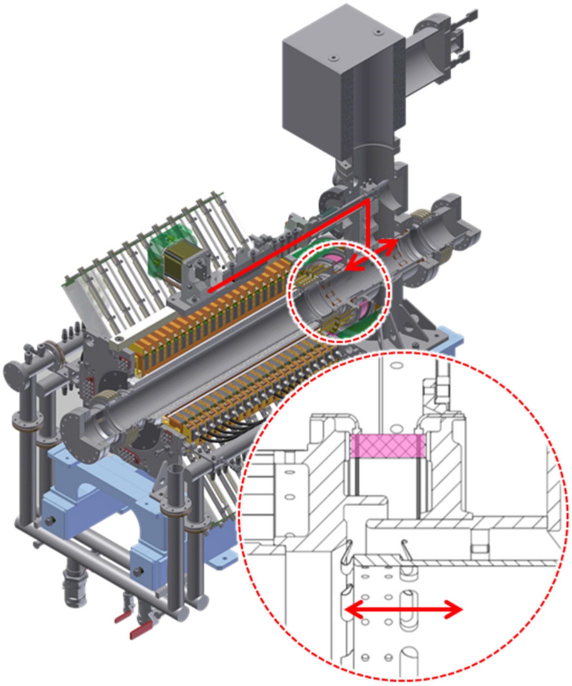

Figure 1: RF1 cavity design details.

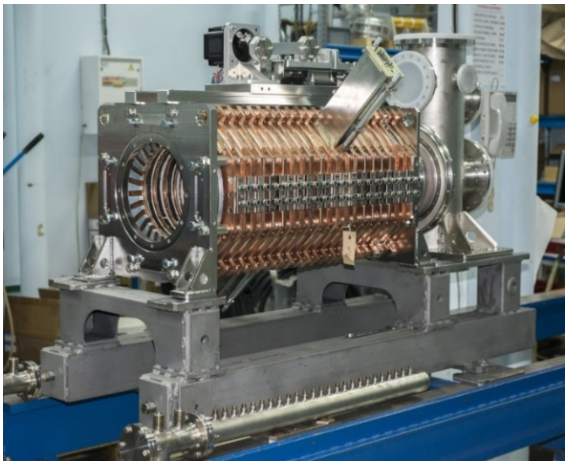

Figure 2: Photo of the RF1 cavity during its assembly.

RF2 AND 3 HARMONIC SYSTEMS

The RF2 and 3 cavities are of coaxial type which makes the cavity diameter small enough to fit in between the two collider rings separated by 320 mm only. In order to decrease the length down to an acceptable value the cavity is heavily loaded by a mushroom-like capacitor. Due to the wide operating frequency range (12%) the cavity has four capacitive tuners. Cavity concept is shown in Fig. 3. Figure 4 shows the RF2 cavity prototype. The parameters of the RF2 and 3 cavities are listed in the Table 1.

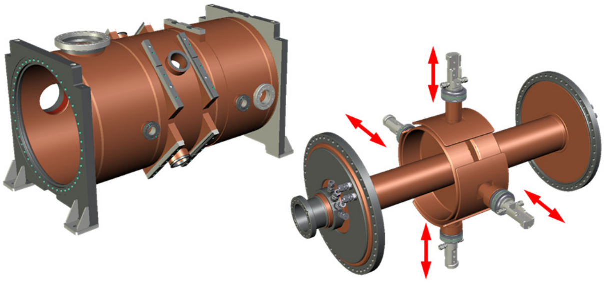

Figure 3: RF2 and 3 cavity concept.

Figure 4: RF2 cavity prototype.

The cavities are formed by a few basic units: outer shell with various flanged ports, two coaxial inserts, four segment tuners and accelerating gap short. All units are dismountable from their ports except the tuner segments which are installed into the ports from inside and TIG-welded to the flanges. Cavity parts are made either from OFE copper or stainless steel and brazed or TIG-welded together. The RF2 tuner has complicated driving system which consists of a stepping motor and piezo actuator while the RF3 tuner has only a stepping motor drive.

The RF power is delivered to the cavity via coaxial inductive (loop) coupler attached to a side port.

Table 1: RF2 and 3 Cavity Parameters

Parameter	**RF2**	**RF3**
Harmonic number	22	66
f_0, MHz	11.5-13.2	34.4-38.7
Tuner stroke, mm	2.5	17
Quality factor Q_0	3400-3700	6600-7200
R/Q, Ohm	18.8-21.7	50-58
Acc. gap, mm	6	20
Max V_{gap}, kV	25	125
Max $E_S/E_{Kilpatrick}$	0.93	1.0
P_S, W/cm^2	0.6	2.8

Solid State Power Amplifiers

Each cavity is driven by a solid state power amplifier (SSPA) designed and produced by the Triada-TV company[1]. SSPAs are based on NXP Semiconductors LDMOS transistors MRFX1K80H with specified maximum power of 1800 W at V_{DS} = 60 V. For the sake of reliability the transistors in the RF2 and 3 SSPAs operate at reduced V_{DS} providing 500 and 1000 W per transistor respectively. Four transistors are combined in a single 4U 19" pallet, the pallets are gradually (2 to 1 at each step) combined using external power combiners (PC) installed at the rear part of the cabinet.

RF3 SSPA occupies two cabinets (with output PC installed on top of the cabinets W×D×H = 1150×1500×2420 mm^3) and provides up to 40 kW in the frequency range from 34 to 39 MHz (Fig. 5). Two independent RF2 SSPAs providing up to 7 kW within 11-13.5 MHz each occupy a single unit of 2 cabinets – 1 full width cabinet with amplifier pallets and 1 half-width cabinet with power supplies and control electronics (W×D×H = 1000×1200×2000 mm^3). Both SSPAs have 50 Ohms coaxial outputs – EIA 1 5/8" and 3 5/8" for RF2 and 3.

Figure 5: RF3 SSPA connected to the prototype cavity.

The transistors are soldered to water cooled heat exchangers. All connections (water, RF, DC etc.) of the pallet are of quick connect type and located at its rear panel thus allowing fast and simple pallet exchange in a plug & play manner.

VACUUM

NICA calls for high vacuum of $3{\cdot}10^{-11}$ Tor in the cavities. This requires adequate vacuum seals, careful cavity treatment and correct pumping scheme.

Two types of vacuum gaskets are used in the RF cavities: Conflat® gaskets at all connections except the RF2 and 3 joints of the coaxial inserts to the cavity shell where spring loaded HTMS® (High Tech Metal Seals) gaskets are used.

Based on the experience with the RF3 prototype cavity the following preparation steps were adopted for the series cavity production: 1) mechanical polishing of the inner copper surfaces, 2) ultrasonic cleaning (degreasing) of all cavity units, 3) baking of the units in vacuum furnaces at 450 °C (during 12 and 6 hours for copper and stainless steel parts respectively), 4) baking of a completely assembled cavity at 320 °C inside thermal insulation with heat tapes temporarily mounted on the outer surface with all heat sensitive units (short actuators, RF1 pulse generators, RF2 and 3 tuners etc.) dismounted. The RF1 inductors must not be overheated but are not removable. So the stainless steel beam pipe inside the inductors is heated up by heat tapes permanently mounted on its outer surface and wrapped in thermal insulation. A copper tube is put over the insulation and forms the inner conductor of the coaxial cavity. The tube is cooled during baking by forced air flow. The inductors are water cooled.

Each cavity has one combination (ion + sublimation) pump and (RF2 and 3) one additional TSP cartridge.

CURRENT STATUS AND PLANS

Two RF1 barrier stations were delivered to JINR, tested there and now are ready to be installed to the collider. The RF2 and 3 prototype cavities were tested above nominal voltages at 32 and 160 kV respectively, the possibility to reach the required vacuum at nominal voltage was proven. The SSPAs prototypes for the harmonic stations were successfully tested along with the prototype cavities.

Series production of the RF2 and 3 SSPAs and cavities is in progress: all eight RF2 SSPAs and cavities are planned to be completed and tested at BINP during 2021, sixteen RF3 SSPAs will be ready in 2021 as well but the cavities will be shifted to 2022 due to a time consuming cycle of each cavity preparation, processing and testing.

CONCLUSION

The three RF systems for the NICA collider were developed. Barrier system RF1 was delivered to JINR. Harmonic systems RF2 and 3 have been prototyped and are in series production.

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