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BOOSTER RF SYSTEM FIRST BEAM TESTS

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Abstract

The project NICA is being constructed in JINR, to provide collisions of heavy ion beams in the energy range from 1 to 4.5 GeV/u at the luminosity level of $1 \cdot 10^{27}$ cm$^{-2}\cdot$s^{-1}.

A key element in the collider injection chain is the Booster a cycling accelerator of ions $^{197}Au^{31+}$. The injection energy of particles is 3.2 MeV/u, extraction energy is 600MeV/u.

Two Booster RF stations provide 10 kV of acceleration voltage. The frequency range from 587 kHz to 2526 kHz at the operation of the stations in the injector chain.

The RF stations were fabricated in the Budker Institute of Nuclear Physics. The main design features and parameters of the first beam tests of the Booster RF system are discussed in this paper.

RF SYSTEM

The RF System for Booster consists of two resonators, power amplification cascades, and low-voltage electronic, intellectual controller, and tester module. Main parameters of the RF cavity is presented in Table 1.

Acceleration of particles in the Booster will be made in two stages. The operational frequency range corresponds to 0.5 - 2.5 MHz.

The accelerating cavity is formed by two parts of the short-circuited coaxial lines divided by the accelerating gap (Fig. 1). A vacuum-tight ceramic insulator 6 is installed in the gap. Only the stainless-steel beam pipe and the gap ceramic are under vacuum, the remaining cavity is operated in the air [1].

Table 1: Main Parameters of the RF Cavity

Parameter	Value
Frequency range, MHz	0.5 – 5.5
Gap voltage, kV	5.0
Beam pipe diameter, mm	160
Residual gas pressure, Torr	$< 5.5 \cdot 10^{-11}$
Outside station diameter, m	1.2
Installation length, m	1.4
Real part of conductance at the cavity gap, Ohm	> 1000

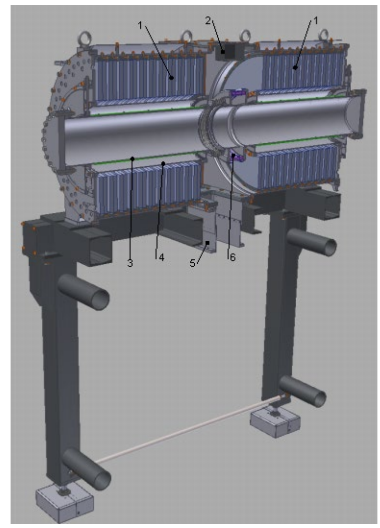

Figure 1: Accelerating cavity of RF station. 1. Amorphous alloy rings, 2. Gap voltage pickup, 3. Beam pipe, 4. Coaxial inner conductor, 5. Connecting nipple, 6. Ceramic insulator.

RF POWER AMPLIFIER

The output stage of the power amplifier employs two tetrodes GU-36B-1. The tubes are driven in the push-pull mode in the common cathodes schematic. Air-cooling of the tubes is used.

The anodes of tubes are connected directly to an accelerating gap of the cavity through the blocking capacitors C_b (Fig. 2).

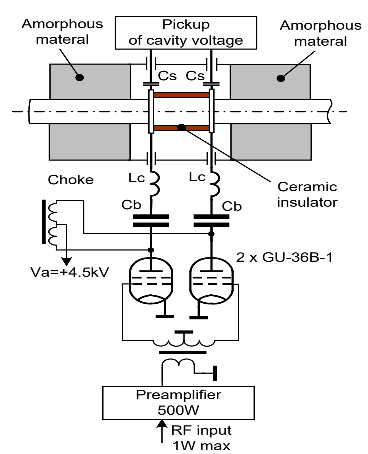

Figure 2: Block diagram of RF power amplifier.

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The anode power supply voltage $V_a = +4.5$kV is applied to anodes through the inductance choke. The choke is made of two ferrite rings with dimensions of 180x110x20mm. The magnetic permeability of the rings material is 1000. The type of the used winding also allows suppressing even harmonics of the accelerating voltage at the cavity accelerating gap. A semi-conductor preamplifier with a peak output power of 500 W drives the tubes. The maximum input power of the preamplifier is 1W. During testing of the stations, the maximum output power of the preamplifier does not exceed 200 W [1].

CONTROL SYSTEM

Intellectual Controller for RF stations based on CPU module SAMA5D31-CM. The primary function of the controller is a generation of master frequency for the RF stations which deepens on the current value of the magnetic field. The frequency is generated by 2-channel DDS, each of the channels driving one station. The controller measures a magnetic field using an induction coil and provides corresponding real-time tuning of frequency according to non-linear law with a 20 µs period and better than $2 \cdot 10^{-4}$ relative accuracy.

The controller has DAC's that produce reference voltages to control the accelerating voltage and DC component of anode currents. It also employs ADC's for the measurement of the operating regimes of the stations.

The tester module is used to generate a sequence of events and signals imitating the acceleration cycle. It imitates signals from the magnetic field sensor and necessary synchronization pulses in different acceleration modes.

The tester module is intended to allow regular RF system checks. Additional software for the second Booster run was made to control the RF stations more effectively [2].

ACCEPTANCE TESTS IN DUBNA

Two Booster RF stations were delivered to Dubna in 2014 and tested at the test bench that was built for that reason (Fig. 3).

The project parameters of the RF stations such as output current from the tetrodes and output RF voltage were achieved. After that tests the Booster RF system was installed into the second straight section of the Booster ring and was tested again.

Figure 3: Booster RF station at the test bench in Dubna.

The system was tested in operating modes, the output signals from the first RF station are shown in Fig. 4.

The additional control rack was built to provide safe remote control operating.

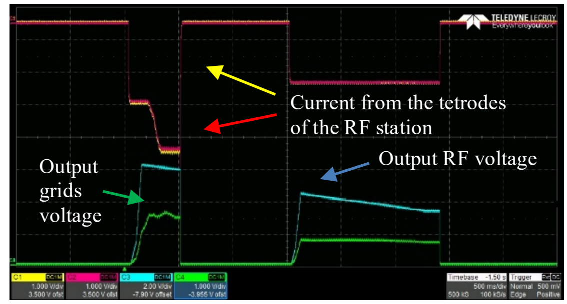

Figure 4: The main parameters of the first Booster RF station during tests.

FIRST EXPERIMENTS WITH ACCELERATING BEAMS IN BOOSTER

The installation of the Booster cryomagnetic equipment was started in September 2018. The first technical Booster run was done in November-December 2020.

At the first steps, the insulating vacuum volume and beam pipe were assembled and tested. After this, the cooling of the cryomagnetic system, commissioning of thermometry, quench protection systems, tuning of power supply, and HILAC-Booster beam transfer line systems were done.

Then the beam was injected into the Booster on the plateau of the magnetic field corresponding to the injection energy. The beam circulation was achieved without the orbit correction system. Turn-by-turn measurements were used for injection optimization. The efficiency of beam injection was achieved at the level of about 75%.

After the orbit correction and tuning of the injection system, the intensity of the circulating beam was achieved up to 7×10^{10} ions or 1.3 mA. The charge of these ions is equal to the charge of 2×10^9 Au^{31+} ions.

The He^+ ion lifetime of about 1.3 s corresponds to the average pressure in the beam pipe of about 3×10^{-10} Torr.

The beam current transformer signal at ion acceleration up the energy of 100 MeV/u is shown in Fig.5. The choice of maximal ion energy was defined by the radiation safety conditions at Booster operation without its extraction system.

The next Booster run with its extraction system and the Booster – Nuclotron transfer line was realized in September 2021 [3].

All the standard preparation and procedures of RF stations were performed.

The results of the second Booster run are given bellow. The beam current transformer signal at ion acceleration up the energy of 200 MeV/u is shown in Fig. 6.

The efficiency at adiabatic beam capture was achieved at the level of about 99%.

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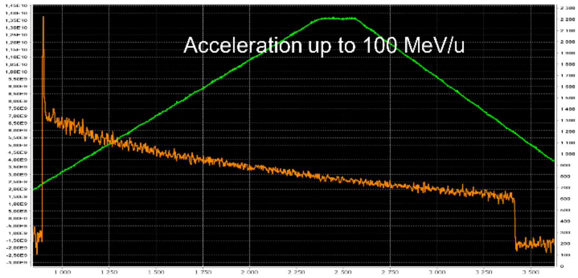

Figure 5: Beam current transformer signal at ion acceleration, first Booster run in December 2020.

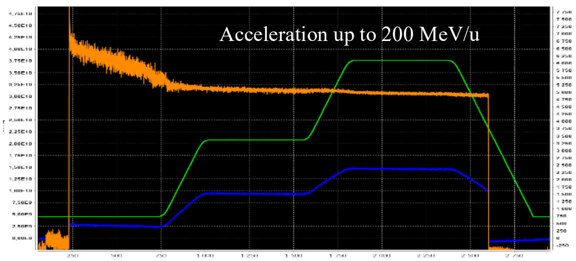

Figure 6: Beam current transformer signal at ion acceleration, second Booster run in September 2021.

The maximum energy of accelerated ions Fe^{+14} corresponds to the energy of 578 MeV/u.

The RF voltage was applied adiabatically on the table of injection magnetic field, which gives a high-quality beam capture. The beam was accelerated on the fifth RF harmonic after the first table of the magnetic field. The beam was recaptured on the first RF harmonic on the second table of the magnetic field (Fig. 7).

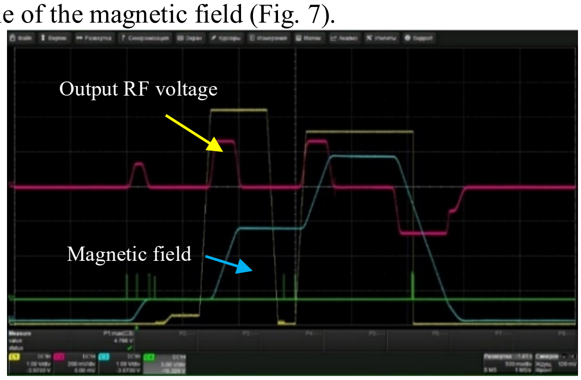

Figure 7: RF station parameters during adiabatic beam capture.

The impact of the applied adiabatic voltage on the beam is shown below (Fig.8).

One of the major goals that were reached is the possibility to use RF voltage to decelerate the Fe^{+14} particles on the falling magnetic field (Fig.9). It would improve the radiation safety conditions at Booster operation without beam extraction.

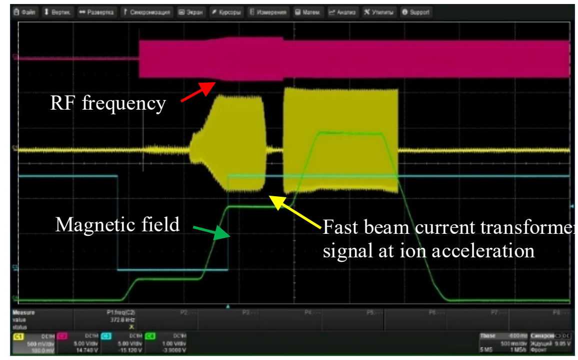

Figure 8: RF adiabatic voltage impact on the beam.

Figure 9: RF voltage applied to the falling magnetic field.

CONCLUSION

Two Booster RF accelerating stations were fabricated in Budker Institute of Nuclear Physics for Booster. The stations were tested in two Booster runs in operating mode.

The designed accelerating voltage in the frequency range of 0.5 – 2.5 MHz was obtained during the beam runs.

Due to the flexible control system, it was possible to work with adiabatic beam capture and achieve a level of efficiency of about 99%.

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