RF SYSTEM OF THE BOOSTER OF NICA FACILITY

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Abstract

The project NICA is being constructed in JINR, Dubna to provide collisions of heavy ion beams in the energy range from 1 to 4.5 GeV/u at the luminosity level of $1 \cdot 10^{27}$ $cm^{-2} \cdot s^{-1}$. One of the elements in the collider injection chain is the Booster – a cycling accelerator of ions $^{197}Au^{32+}$. The injection energy of particles is 6.2 MeV/u, extraction energy is 600MeV/u.

Two RF station are to provide 10 kV of acceleration voltage. Frequency range of operation of the stations in the injector chain is from 634 kHz to 2400 kHz [1, 2]. The provisions are made for autonomous mode of operation in the frequency range of 0.5 – 5.5 MHz at the same accelerating voltage. Amorphous metal rings produced in Russia are used in the RF cavities.

RF stations are created in the Budker Institute of Nuclear Physics, SB RAS, Novosibirsk. The stations are tested in the operative mode and have been delivered to the customer in September 2014. Main design features and parameters of RF cavity power generator and control system of the stations are described in the paper.

INTRODUCTION

Acceleration of particles in the Booster will be made in two stages.

- Adiabatic capture and acceleration at the fourth harmonic of revolution frequency up to the energy of electronic cooling of 100 MeV/U.
- Acceleration of particles at the first harmonic up to energy of 600 MeV/U.

Between the acceleration stages the electronic cooling of beam is made for a time of ~1sec with RF switched off.

During both acceleration stages the operational frequency range lays within the limits of 0.5 - 2.5 MHz.

On the customer request for autonomous operation of Booster the frequency range is extended to 0.5 - 5.5 MHz at the same gap voltage of 10 kV. The duration of the acceleration cycle in this mode is 1.5 sec, the repetition time of a cycle is 6 sec. It is supposed, that after acceleration of ions their slow extraction from Booster for physical experiments will be carried out.

THE ACCELERATING CAVITY

The accelerating cavity is formed by two pieces 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 air.

Main parameters of RF cavity are given in table 1.

Table 1: RF station main parameters

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

To increase the shunt impedance of RF cavities in the frequency range from hundreds kilohertz and in excess of ten megahertz a space between conductors of the coaxial is filled with a material with large magnetic permeability.

The choice usually is between ferrites and amorphous magnetic alloys. The last material is used in modern designs more often.

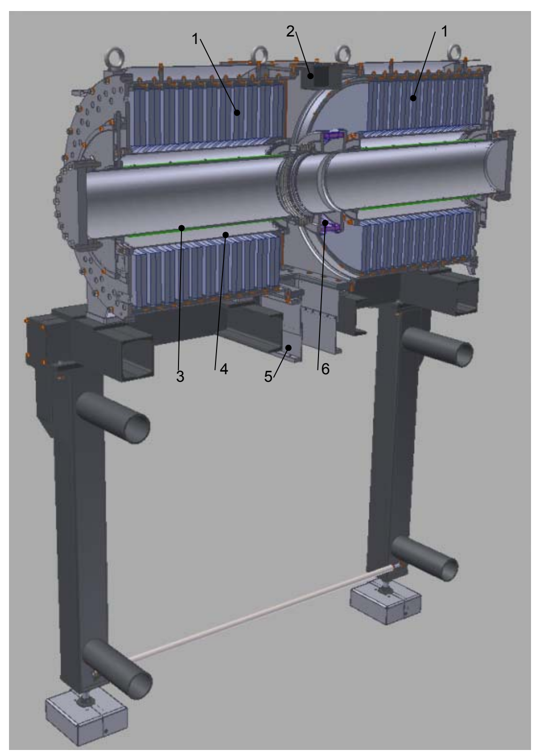

Figure 1: Accelerating cavity of RF station. 1. Amorphous alloy rings. 2. Gap voltage pickup. 3. Beam pipe. 4. Coaxial inner conductor. 5. Connecting nipple. 6. Ceramic insulator.

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In case if ferrite are used the design needs a power supply for ferrite biasing and a feedback loop to keep tuning of the cavity to resonance [3, 4]. RF cavity with amorphous material does not need these elements and flux density is much higher than that of ferrite therefore it is used in modern design more often [5,6].

In our stations the amorphous material of Russian production based on iron are used. Type of the material is 5B-M. Rings are produced by Asha Metal Works. The sizes of rings are D x d x h = 500 x 250 x 15 mm. For use in RF cavity the technology of the standard material 5B has been modified. As the reference parameter for the factory a requirement to have modulus of relative magnetic permeability (μr) above 2000 at frequency of 1 MHz had been defined. This requirement has been realized. 90 such rings were supplied to BINP by the factory.

The rings in the cavity are glued up together by pairs and fixed in the holders attached to external cylindrical wall of the cavity. There is a gap of 10 mm between neighbor pairs for cooling air. A part of airflow from the fan cooling generator tubes is used.

Air passes from RF generator compartment through the connecting nipple 5 and goes further between an internal conductor of a coaxial 4 and an internal surface of rings, being distributed between gaps.

Having passed a gap in the radial direction, air leaves the cavity through apertures in external cylindrical and face walls of the cavity.

The average power dissipation in the rings during operation in regular mode is 3 kW. Through the nipple 5 the connection is made between output stage of RF generator and RF cavity.

Vacuum parts of the cavity – beam pipe and ceramic insulator are baked out at temperature of 300°C for reaching the designed vacuum. As a result the vacuum $3{\cdot}10^{-11}$ Torr have been obtained.

RF POWER AMPLIFIER

The output stage of the power amplifier employs two tetrodes GU-36B-1 produced by the Joint-Stock Company " S.E D.-SPb", St.-Petersburg, Russia.

The tubes are driven in push-pull mode in the common cathodes schematic. Air-cooling of the tubes is used.

Anodes of tubes are connected directly to an accelerating gap of the cavity through the blocking capacitors Cb (Fig. 2). The anode power supply voltage Va = + 4.5kV is connected to anodes through the inductance choke. The choke is made of two ferrite rings with dimensions of 180 x 110 x 20 mm. Magnetic permeability of 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 the peak output power of 500 W drives the tubes. Maximum input power of the preamplifier is 1W. During testing of the stations maximum output power of the preamplifier did not exceed 200 W.

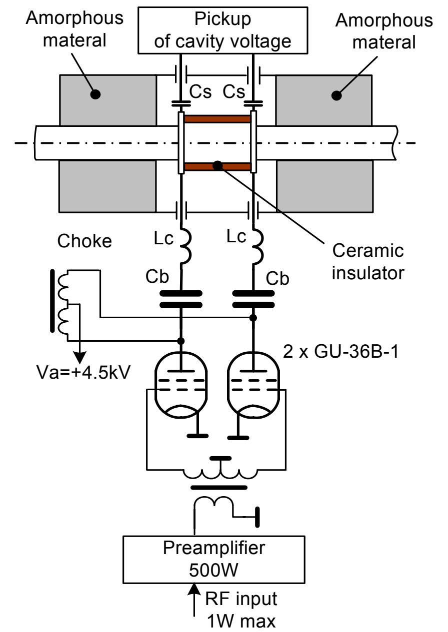

Figure 2: Block diagram of RF power amplifier.

To reduce nonlinear distortions of the accelerating voltage, tubes operate in a cycle close to class A. In a pause between cycles the tubes should be in off state for reduction of the average anode power dissipation.

The modulus of the tubes loads impedance changes in the frequency range almost twice. For reduction of average anodes power dissipation a DC component of the anode current in the acceleration cycle is controlled programmatically by a feedback. On frequencies with smaller load impedance the DC component being increased. The reference voltage for this circuit provides a DAC in the control system.

The impedance of the cavity at the accelerating gap is defined substantially by the distributed capacity of the coaxial line filled by rings and by capacity of the insulator. Therefore, on the higher side of the frequency range of 5.5 MHz this capacity shunts accelerating gap of the cavity heavily and anode current of a tube appears to be insufficient for maintenance of the necessary RF voltage.

The problem is fixed by correction of the impedance at anodes of tubes in the given frequency range. For this purpose the inductance Lc of 10 μH is inserted in series between anodes and blocking capacitances Cb (see Fig. 2). As a result, the maximum DC component of the anode current does not exceed 8A at 3.3 MHz and it is less than 5A on both sides of the frequency range. The average anodes power dissipation of the tubes is 4.9 kW for maximum rating of 15 kW.

CONTROL SYSTEM

Low level signal circuits of the control system of both stations are placed in the SCHROFF rack. The circuits

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control the amplitude of the accelerating voltage, a DC component of anode current of the tubes by means of feedback loops and protect powerful elements of stations and personnel in emergencies.

The pickup of the accelerating voltage in the cavity is a capacitive divider.

The output voltage of the pickup comes to an amplitude detector. Its output signal together with a reference voltage from a DAC comes to an error amplifier (EA). EA output controls the amplitude of RF voltage, which drives the preamplifier. A response time of this feedback loop is 150 μs.

The DC component of the anode current is measured by a probes based on the Hall sensor. Probes signals from each tube together with a reference voltage from a DAC come separately into two EA. Their outputs control biasing of the tubes control grid.

A reference voltage from DAC is common for both feedback loops, so DC anode currents of the tubes are always equal. It also prevents saturating of ferrite of the Choke. A response time of the loop is 1ms.

An intellectual controller and tester modules are installed in the same rack [7]. They are connected to Booster ring control system by Ethernet network.

The controller operates master frequency of the stations, which depends on the value of the accelerator leading magnetic field. In addition, this frequency could be corrected by signals from beam position monitors of the accelerator ring. The frequency is generated by 2-channel DDS, each of the channels driving one station. It is possible to control phase shift between output signals of the channels to provide correct phasing of accelerating voltages for any mutual position of RF stations in the ring of Booster.

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 measurement of operating regimes of the stations. Two I/O registers are provided for control and monitoring of operating modes of stations.

Tester module allows to disconnect RF stations controller from Booster signals (magnetic field sensor and synchronization pulses) and provide corresponding imitation or to through-pass these signals. This functionality is intended to provide for on-site RF Stations testing.

DESIGN OF THE STATION

The cavity rests upon 4 supports (See Fig.3). A generator box is placed under the cavity with all its power supplies and control units. A SCHROFF rack contains the low level control electronics and computer control.

CONCLUSION

Two RF accelerating stations are created in Novosibirsk Institute of Nuclear Physics for Booster, NICA project, JINR in Dubna. The stations are tested in operating modes. The designed accelerating voltage in the frequency range of 0.5 – 5.5 MHz is obtained. In the end of September, 2014 the stations have been sent to the customer. Test of stations at the customer's site is planned in November.

Figure 3: RF station on the test bench.

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