12

Thermionic cathode high frequency gun and buncher cavity for SKIF synchrotron injector

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The design of the thermionic cathode grid-controlled high frequency gun and buncher cavity are presented as part of the system of the initial area of the injector (preinjector), of the fourth generation SKIF synchrotron developed in the Institute of Nuclear Physics (BINP). The technology of their manufacturing are described at the experimental production facility of the BINP. Besides, methods and results of high frequency system tests are also described. Estimated and measured characteristics of the high frequency cavities and features of their operation in the preinjector are analyzed.

Keywords: high frequency gun cavity, high frequency system manufacturing technology, electron beam welding, testing, high frequency test.

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Introduction

To generate an electron beam, most synchrotrons globally use in practie the static guns with a grid-controlled thermionic cathode. In such guns the voltage pulse with duration of 1–2 ns on the cathode unlocks the electron beam from the thermionic cathode, which, passing through the grid, accelerates in the electrostatic field of the gun. Further the obtained bunches pass through high frequency (RF) fields of buncher cavities and shorting in length to 10 ps to enable their further acceleration in a preliminary accelerator and linear accelerators based on multi-cell accelerating structures 2856 MHz, usually to energy 100–200 MeV. Most often in injectors it is necessary to obtain beam energy spread of at least 1%. The same principle is used for operation of the injector in the SKIF fourth generation synchrotron designed in the Institute of Nuclear Physics (BINP) named after G.I. Budker [1], only that instead of an electrostatic gun it uses an impulse RF gun 175.5 MHz, similar to an RF gun 90 MHz, operating in continuous mode [2].

Apart from the possibility to obtain an electronic beam with high energy, use of the RF gun is also justified by the fact that cathode ionic bombardment in it is practically absent [3], since massive ions fail to speed up in the RF field to the energies capable of damaging the cathode. As a result of this the problem of the cathode lifetime becomes irrelevant (not taking into account its ageing), and requirements to vacuum in the injector are substantially less strict. A thermionic cathode with grid control, principally the same as in ordinary static guns, is placed in the RF field in the rear wall of a special RF cavity. More detailed justification and comparison with similar systems is available in the paper by the authors [4].

This paper describes an RF gun and a buncher cavity 535.5 MHz, within the RF system of preinjector bunch grouping (fig. 1, *a, b*). A preliminary accelerator and an accelerating section based on multi-cell structures 2856 MHz widely used in the global practice [5], are also used in the SKIF injector.

1. Design of RF gun and buncher cavity

A RF gun cavity is coaxial (Fig. 1, *c, d*) with diameter of 500 mm and replaceable cathode-grid unit *6*. The cathode-grid unit is mounted into the center of the rear wall of the focusing electrode *3* so that the grid is electrically connected to this wall, and the cathode on the insulator is located at the distance of 80 μm behind the wall.

SKIF applies thermionic cathodes from spongy tungsten soaked with a mix of aluminate and coated with a layer of osmium with thickness of 20 μm. In principle, the thermionic cathode material is not critical in this case, when there is no ionic bombardment. Ordinary oxide thermionic cathodes will also do. Such cathodes (from RF triode ceramic tubes GS-34) are tested in RF guns of BINP at average current 40–100 mA [2].

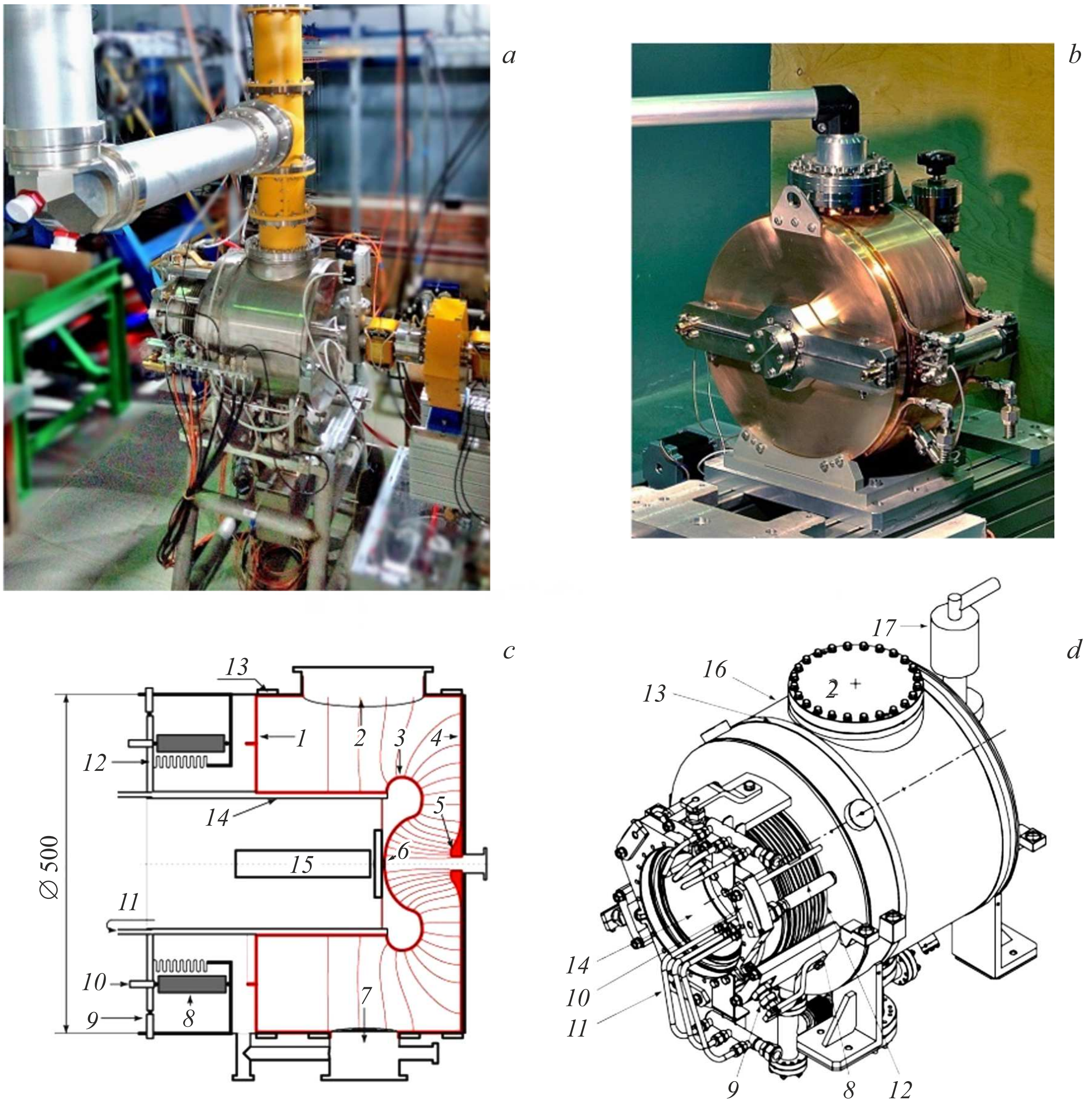

Figure 1. *a* — of RF gun; *b* — of buncher cavity; *c* — drawing of RF gun cavity with a electric RF field pattern; *d* — 3D drawing of RF gun: *1* — rear wall, *2* — port to input RF power, *3* — electrode, *4* — front (end) wall, *5* — lug boss, *6* — cathode, *7* — vacuum pumping port, *8* — piezoactuator, *9* — insert inclination adjustment screw, *10* —resonance frequency manual adjustment screw, *11* — tubes for water cooling of insert, *12* — bellows, *13* — body water cooling channels, *14* — insert, *15* — cathode-grid unit modulator, *16* — shell, *17* — vacuum gate.

The cathode-grid unit is inserted from the outer side of the cavity and is connected using a flanged vacuum seal of ConFlat type with DN 40. Supply and control of the cathode-grid unit is carried out using a block of a modulator *15*, which is inserted inside the cylindrical aperture of the insert *14* behind the cavity and is electrically connected with the help of a collect assembly. This design provides for maximum proximity of the output RF transistor of the modulator to the cathode-grid unit, generating impulses with length of up to 1 ns.

Electron bunches emitted from the cathode-grid unit pass along the axis of the cavity for the distance of 0.08 m, being accelerated in the electric RF field, and further exit the RF gun via the hole for the beam with diameter of 23 mm. The RF gun uses the electric RF focusing of bunches, which makes it unnecessary to use complex magnetic focusing. Using a focusing electrode *3* with the spherical part and the protruding lug boss *5* on the opposite wall, field power lines distribution is created with a radial component directed towards the axis (Fig. 1, *c*). Therefore, the beam is focused precisely in the estimated place, in 50 mm downstream the vacuum flange of the gun.

At the same time the necessary longitudinal distribution of electric RF field intensity is established in the cavity — with the minimum of 2 MV/m on the grid and maximum of 11 MV/m in the lug boss area. Distribution of the electric

RF field is highly heterogeneous on the surface, has two maxima 20 MV/m, one on the lug boss and on the opposite side — on the edges of the focusing electrode.

If the field intensity on the grid is 2 MV/m, it becomes possible to control the cathode-grid unit using impulses with amplitude of not more than 100 V. At the same time the level of cut off voltage, which these impulses must exceed by amplitude, is quite low to prevent emission from the cathode caused by the RF field penetrating through the grid. On the other hand, such distribution provides for high rate of acceleration to the energy of 1 MeV.

Tuning of the resonance frequency in the interval of 100 kHz is carried out by changing the width of the accelerating gap due to longitudinal movement of the insert *14* within 100 μm. Such movement practically does not influence the beam dynamics, since the time of beam appearance at the output of the gun (in units of RF phase) varies not more than by 0.02° at permissible value 1°. Movement is performed with the help of three piezoactuators *8*, located azimuthally-symmetrically relative to the axis outside the cavity. For this purpose the rear flat wall *1* of the coaxial cavity is made flexible — from copper with thickness of 8 mm, and the central electrode of the cavity *3* together with the insert *14* is mechanically isolated from the body using bellows *12*. The used piezoactuators are mechanically stable to pressure difference that causes application of force of the order of 10 kN upon them. Besides, there is manual mechanical adjustment provided within the limits of 0.5 mm using three screws *10*, mounted in series with the piezoactuators. There are also three screws *9*, directed perpendicularly to the axis of the RF gun, which change the inclination of the insert inside the cavity. These screws are designed for precise centering of the cathode in the cavity. Position of the cathode is monitored with high precision using a system of geographical indicators located on the body of the RF gun and on the insert.

Water channels are mounted on the RF gun body and inside the insert *11, 13* for thermal stabilization of the cavity at temperature $33 \pm 0.1^\circ$C. On top of the cavity on the DN200 flange there is RF power input *2*, to which a coaxial 50 Ω feeder is connected with outer diameter of 100 mm. Two sampling loops are installed on the sides of the cavity. At the bottom of the cavity *7* a magnetic-discharge pump is connected with capacity of 100 l/min via a vacuum seal DN 100. The table lists mechanical and electrical characteristics of the RF gun and the third harmonic cavity with their nominal modes of operation.

The RF buncher cavity (Fig. 1, *b*) is made of oxygen-free copper. It consists of three parts soldered to each other — two identical end walls and shell between them (Fig. 2, *c*). In the shell there are holes to input the RF power from the top, holes for vacuum pumping at the bottom and two holes for sampling loops at the side. End walls have thickness of 5 mm so that they may be deformed in the direction along the axis without residual deformations with the help of two massive levers made in the form of a yoke. One of the walls is deformed by a lever moved by two piezoactuators by 100 μm. Piezoactuators impact the ends of the lever and are fixed at both sides of the cavity. The other wall is similarly moved by the other lever, but with the help of screws for manual adjustment. Piezoactuators in the buncher cavity tune the resonance frequency by 160 kHz.

The value of the cross section of levers and thickness of resonator walls were determined by numerical calculations in ANSYS software provided that the rigidity of levers was higher than mechanical rigidity of piezoactuators (80 N/μm), and the rigidity of the walls dependent on their thickness (5 mm), must be at the next lower order. Such conditions provide for maximum efficiency of frequency tuning without residual deformations in the cavity walls.

To maintain the stability of the cavity temperature $33 \pm 0.1^\circ$C, providing for the RF phase stability necessary for SKIF, two water tubes are soldered on the body with fittings of „Dk-Lok“ type at the ends, connected to the block of the temperature stabilization system.

2. Manufacturing of RF gun and buncher cavity

The RF gun and buncher cavity were made at the experimental production facility of BINP. The body of the RF gun cavity is bimetal, with an inner layer of oxygen-free copper with thickness of 6 mm and an outer layer of stainless steel 12X18H10T with thickness of 7 mm (no testing for residual magnetization was performed). Both layers were separately formed by cylindrical rolling from 10 mm sheets, welded by argon arc welding and precisely turned inside and outside on a turning mill. Then after silver-plating of the copper cylinder and copper-plating of the stainless steel cylinder they were inserted one into another (Fig. 2, *a*). Besides, the copper cylinder was first cooled in liquid nitrogen to make a gap between cylinders $0.5-1$ mm by temperature deviation of dimensions. After heating in a vacuum furnace, a heat conducting thermal diffusion junction was produced between the layers.

The end wall with diameter of 550 mm is also bimetal, where the copper 10 mm layer is connected to the stainless steel layer (with thickness of 30 mm) using thermal diffusion welding in the vacuum furnace. The central lug boss with diameter of 100 mm was made separately. To prevent high intensity of the RF field because of pointed defects on the lug boss surface, it was turned to the minimum possible roughness 1 μm (mirror shine) by a diamond cutter on a CNC machine providing for smooth movement of the cutter. Then it was welded by electron beam welding (EBW) to a copper layer of the end wall, previously turned on a turning mill to roughness of 2 μm. Irregularities of this weld were smoothened by an unfocused electron beam to mirror shine to prevent high RF field intensity at points, which in this area reaches 20 MV/m (Fig. 2, *b*).

The obtained cylindrical body (shell) and front end wall were welded by argon arc welding outside on stainless steel

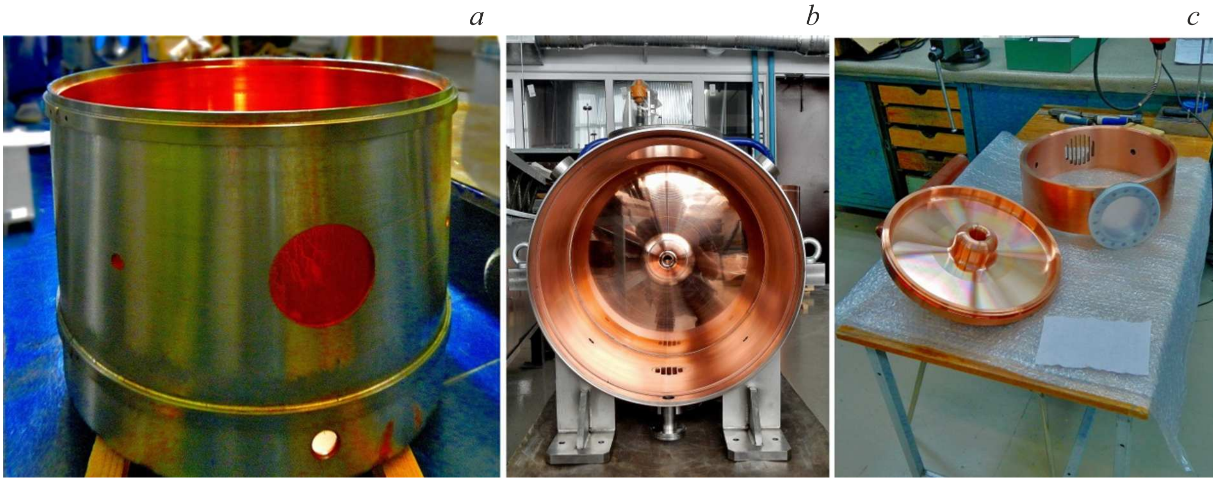

Figure 2. *a* — bimetal body of RF gun after thermal diffusion welding, *b* — view of RF cavity from inside to front wall with lug boss after EBW, *c* — one of side walls and shell of buncher cavity.

Characteristics of RF gun and buncher cavity

Characteristic	RF gun	Buncher cavity
Resonance frequency, MHz	178.5	535.5
Impulse RF power, kW	325.2	5.3
Average RF power (repetition frequency 1 Hz), W	150	1.5
Full voltage on cavity, MV	0.74	0.151
Intrinsic Q factor	14700	20200
Effective impedance, Ω	56.6	148.2
Maximum intensity E of field on axis, MV/m	11.0	2.42
Maximum RF field on surface, MV/m	19.6	4.4
RF voltage of measuring loops, V	20	20
Coupling coefficient for input of RF power	1	1
Duration of RF impulse, μs	100	100
Frequency tuning range, μm/kHz	100/100	100/160
Manual tuning range, mm/kHz	0.5/500	0.5/800

by a vacuum-tight weld. And from inside on copper they were welded by EBW in the vacuum chamber of the EBW unit (Fig. 2, *b*), providing for the electric RF contact. For this purpose special gear was made for smooth rotation of the massive body in the vacuum chamber with constant speed without play. For this welding the special gear was also used to monitor precise aiming of the beam on the welded joint (Fig. 3, *a*).

In parallel to these works an insert was made that consisted of a two-layer copper cylindrical body with diameter of 220 mm with helical water channels inside the insert and of a focusing electrode with a hole for a vacuum seal, to which further a cathode-grid unit will have to be connected from the outside (Fig. 3, *c*). Both layers of the cylindrical body of the insert (inner and outer) were welded to each other at the ends by an electron beam (Fig. 3, *b*). The focusing electrode of the insert was turned with a diamond cutter to mirror shine with roughness 1 μm. This electrode, as well as the lug boss on the end wall of the body, for the entire time of being in the workshop, were covered with special screens protecting against dust and damage in case of random contact with surrounding objects.

Special attention was paid to precise detection of the area on this insert for its EBW to the rear copper wall of the cavity, since this determines the precision of tuning of the RF gun resonance frequency within the required limits (up to 10 kHz). For this purpose prior to the welding the preliminary assembly of the RF gun parts was carried out, and measurements of the resonance frequency were carried out depending on the insert position. Besides, the RF gun was located vertically. The insert inside the hole in the rear wall was suspended with a weight-lifting device vertically. And the wall itself on the top was pulled to the body to ensure electric contact. A regular input of RF power was connected to the body in process of measurement, which provided the necessary precision of measurements (Fig. 4, *a*). Similar measurements for the buncher cavity described further are shown in Fig. 4, *b*.

After detection of the area of insert and wall welding, EBW of this weld was performed in the EBW vacuum

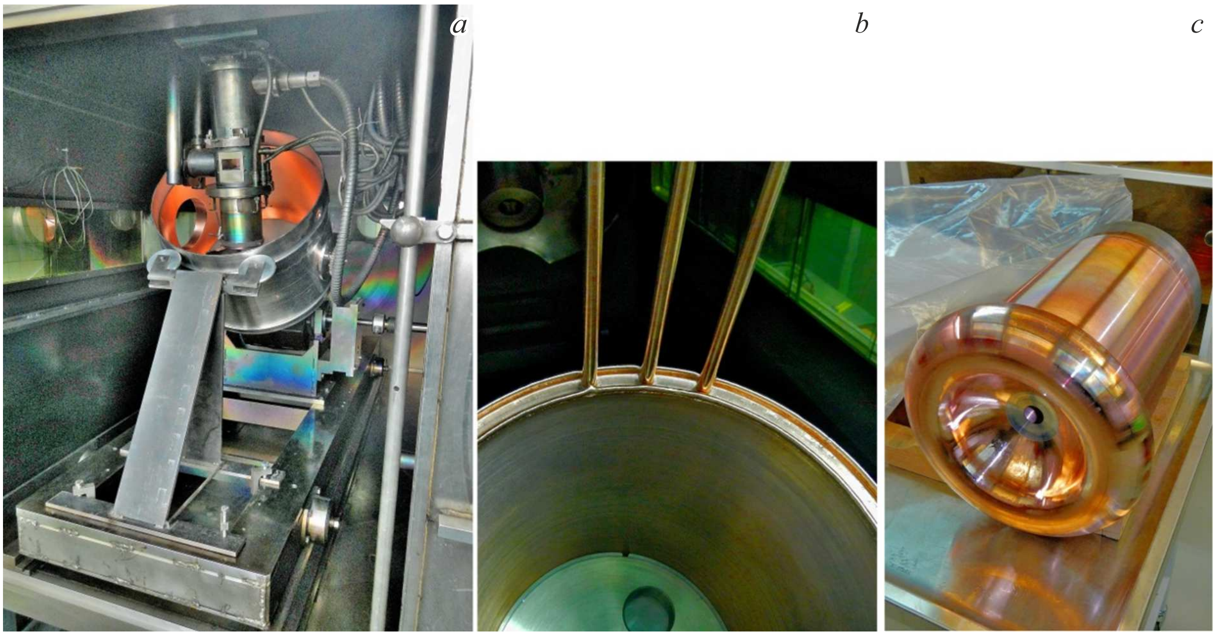

Figure 3. *a* — gear for welding of the front wall with the shell in the EBW vacuum camera and with EBW gun inside, *b* — ends of insert after EBW, *c* — insert appearance before EBW with rear wall of RF gun.

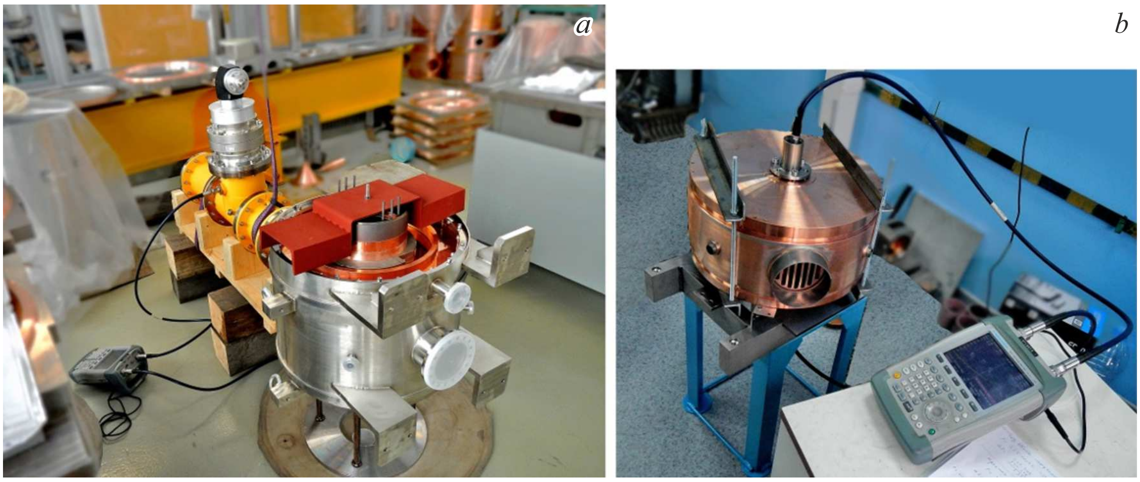

Figure 4. *a* — measurement of RF gun resonance frequency prior to EBW of insert with rear wall, *b* — measurement of resonance frequency of buncher cavity.

chamber. And already after that the final EBW of this wall (with the insert welded thereto) was performed to the copper inner layer of the RF gun body. For this welding an original gear was made with three rolls installed on the floor of the vacuum chamber (Fig. 5, *a*). The RF gun rested with the end smooth wall on these rolls and rotated around the vertical axis with a special drive using a chain connected on top with the device of vacuum input of rotation in the chamber (Fig. 5, *b*).

After manufacturing, the RF gun was heated in the vacuum furnace for degassing at temperature of 450°C for 6 h. Prior to this annealing the vacuum furnace together with the RF gun was pumped to the minimum permissible pressure value (10^{-6} Pa) for two days. The RF gun was annealed in the horizontal position with the inserted pins instead of the piezoactuators, to prevent the insert agaisnt „dipping" in process of heating. The temperature growth rate was 3° C/min. After heating the vacuum furnace with the RF gun cooled down slowly for two days to the temperature of 65°C.

The buncher cavity (Fig. 1, *b*) has the diameter 360 mm and was made on a CNC machine to obtain low roughness, by turning of solid discs from oxygen-free copper — two end walls and a shell. The inner part of the cavity end walls, especially the lug bosses in the center, were turned by a diamond cutter to mirror shine (to roughness 1 μm)

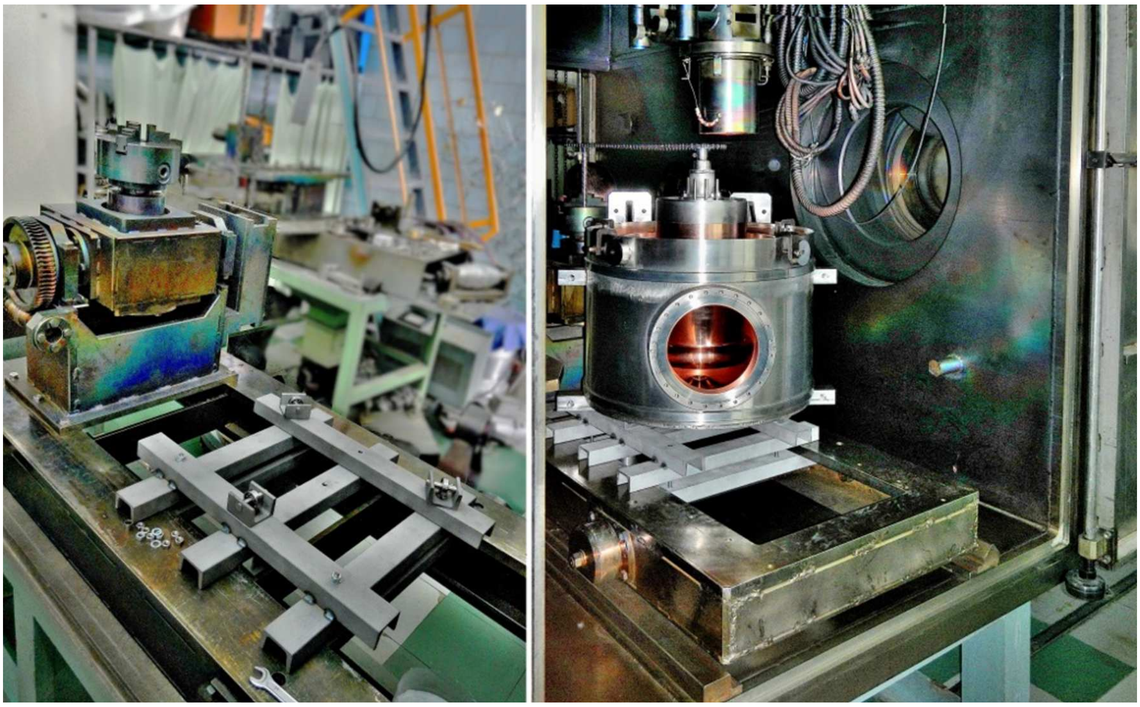

Figure 5. *a* — gear for final EBW of rear wall in cavity of RF gun with shell, *b* — RF gun in vacuum chamber of EBW with this gear and chain for rotation drive and electron gun on top.

(Fig. 2, *c*). Attention was primarily paid to accuracy of the resonance frequency tuning. For this purpose all three parts of the cavity were assembled together before the final soldering, and using measurements of the resonance frequency, the precise width of the shell was determined, which was premanufactured with an allowance (Fig. 4, *b*). During these measurements, the regular RF power input was installed on the cavity to ensure the necessary accuracy of measurements.

3. Testing of operation of RF gun and buncher without beam

Connections of the RF gun to the generator for the first two months were carried out using a temporary circuit, without connection of the automatic system of feedback by RF level (AGC) and without phase-locked loop (PLL), and also without synchronization and thermal stabilization systems, which at that time were mounted on the bench. The resonance frequency of the RF gun varied because of unstable weather conditions of the summer and autumn period, but these changes never went beyond the range of 16 kHz. It would follow that the range of operative tuning of the RF gun resonance frequency 100 kHz suggested for design, with the help of piezoactuators, is adequate in value.

Previously, in the beginning of testing, the coupling coefficients of feeder tracts were monitored (equal to one) both with the RF gun and with the buncher cavity (when there are no stabilized RF power reflections from cavities from precise resonance tuning). The precision of setting these coefficients was monitored with the help of directional couplers by signals of incident and reflected waves shown in Fig. 6, *a*. The figure shows regular ejections of the reflected wave at the moment of arrival of the leading and trailing edges of 100-μs impulse of RF power. Subsequent attenuation after the edges occurs with the time constant of the cavities determined by their loaded Q factor. The measurements confirmed the presence of a single coupling coefficient with good precision (absence of reflected RF power prior to the impulse end).

Preliminary calibrations of voltage in the RF gun and in the buncher cavity were carried out using measured coupling coefficients of measuring loops, characteristics of RF gun cavity (Q factor, characteristic impedance) and measured incident RF power from a directional coupler in the tract from the generator.

Fig. 6, *a* also shows the change of the radiation level measured by an impulse dosimeter. Radiation occurs as in any cavity as a result of braking radiation of dark current particles emitted from the surface and accelerated under the impact of the RF field with high intensity. The level of radiation exponentially depends on the RF field level. Close to the cavity the level of accumulated radiation was 3 mSv for 2 h of operation. Fig. 6, *b* shows curves of signals at the low level of RF power, the reasons for changes in characteristics of which are described below.

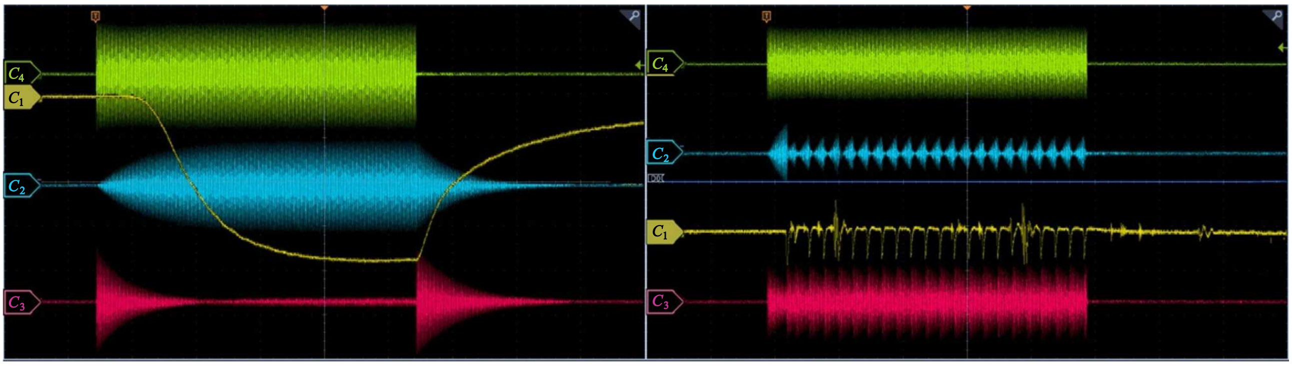

Figure 6. Signals from directional coupler and dosimeter at high level of RF power (a) and at low level (b). C_1 — signal from dosimeter, C_2 — signal of passed RF power from cavity loop, C_3 — signal of reflected RF power from directional coupler, C_4 — signal of incident RF power.

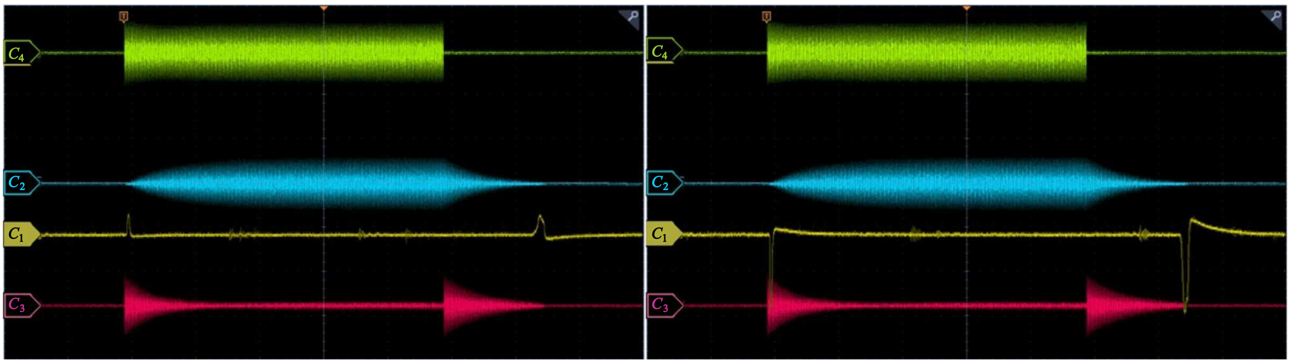

Figure 7. Signals from cathode (C_1): a — ion current, b — electron current. C_2 — passed RF power from cavity loop, C_3 — reflected RF power and C_4 — incident RF power from directional coupler.

4. Training of RF gun and buncher cavity

A multipactor (MP) discharge usually lights up in RF cavities in areas with low intensity of electric RF field and high intensity of magnetic RF field, where low energy electrons with energies 10–1000 eV, hitting the cavity wall, kick the secondary electrons out of it. They, in their turn, being accelerated in this field, again hit the wall and kick other secondary electrons out. This process of birth of new particles develops in an avalanche like manner, i.e. has inertial nature, requiring certain time for its development [6].

The condition for occurrence of the MP discharge, apart from the presence of the coefficient of secondary emission on the surface above one, is the resonance, when the electron trajectories between hits to the surface fit in time into one or more RF periods. These conditions arise at certain levels of RF power in the cavity, called the MP discharge areas. In process of processing, due to the surface cleaning by incident electrons, the secondary emission coefficient may reduce to the level that the MP discharge will no longer be able to develop in this area. In this case it is believed that the MP discharge in this area is trained, and the processing of this area stops.

The above inertia effect in the development of the MP discharge was observed both in the RF gun cavity at the frequency of 178.5 MHz, and in the cavity of the third harmonic 535.5 MHz, operating in the impulse mode with duration of RF impulses 100 μs and repetition frequency 1–10 Hz. In the beginning of the performed tests the RF cavities were excited using a temporary circuit from separate master generators with RF impulses, having steep fronts of the order of 1–2 μs. Due to MP discharge inertia at such short fronts any of the above areas could be skipped and not trained (as the case was with the first zone in the RF gun cavity), or it was possible to start processing any of these areas in any order. Thus, the cavity 535.5 MHz was trained by this method for three days, and the RF gun — for one working day.

Despite this, the first MP area with low RF power to 1 kW remained untrained in the RF gun cavity. For this MP area, using a constant magnet, which was brought to different parts of the cavity, it was found that the MP discharge arises on the grid of the cathode-grid unit in the cavity center. For

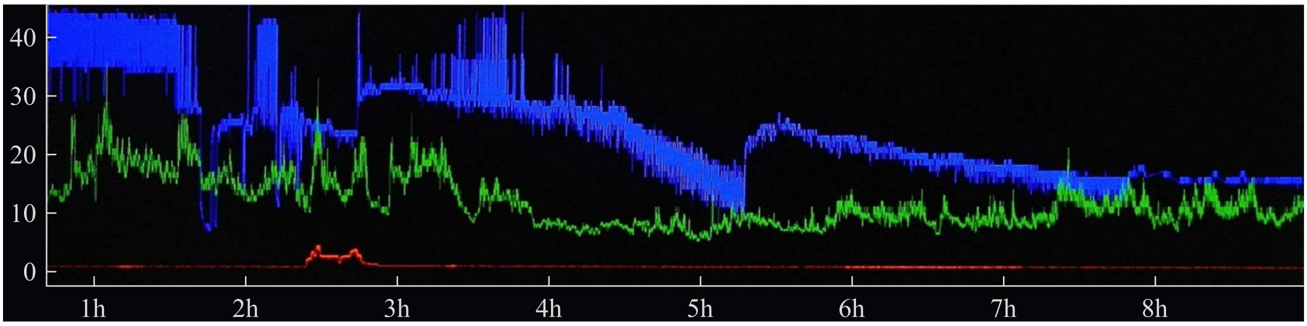

Figure 8. Change of vacuum degree when processing MP discharge in buncher cavity at low levels of RF power (blue, upper curve). Blurring of the curve means that not every RF impulse causes MP (scale in μA current of magnetic-discharge pump, $1\,\mu$A corresponds to 1.45 nPa).

the time of $100\,\mu$s RF impulse the MP discharge occurs twice — on the impulse front and on its tail. On the diagram of reflected and passed RF power the second MP discharge manifests itself by sharp break of slowly attenuating voltage at the moment when such voltage lowers to the level of MP discharge area. For impulses with the low level of power to 1 kW the MP discharge lights up and goes off periodically for the duration of the entire impulse, as shown in Fig. 6, *b*.

Another manifestation of this MP discharge, apart from vacuum deterioration, was observed by cold cathode current impulses arising on the front and tail of RF impulses. Polarity of current impulses depended on the polarity of offset voltage on the cathode, since in this case the cold cathode was either reached by electron current through the grid from the discharge area at positive offset, or by ionic one — at negative offset (Fig. 7).

It was not possible to train this MP zone on the grid, probably due to high coefficient of secondary emission from the grid, arising as a result of deposition of barium vapors on it from the cathode when it is heated. It is expected that in practice this MP discharge on the grid is not dangerous, since it is very short and, acting on the front of the input RF pulse, is skipped quickly without any development. This MP discharge does not impact the amplitude and phase stability of the RF in the cavity at the moment of bunches passing, happening much later after this MP discharge, in $90\,\mu$s, when the voltage on the cavity has already been formed without its participation.

Nevertheless, the issues with these MP discharge occurred when the cavity was connected to the standard RF complex control system. This system uses specific modulators that form $100\,\mu$s pulses and simultaneously participate in the automatic gain control (AGC) and phase-locked loop (PLL) systems. For reliable performance of the specified functions, the modulator was made on the basis of $p-i-n$-diodes, unfortunately having a side effect of pulling the front of the shaped impulses to $7-10\,\mu$s. At such fronts, as it turned out, the MP discharge on the grid manages to develop so strongly, that it becomes impossible to skip it and to obtain any considerable voltage in the cavity.

This problem was solved with circuits, by adding an electron key with short front $1\,\mu$s at the input of the modulator, which was connected with a delay of several microseconds after modulator connection, thus providing a step with a steep front. Owing to that this MP area was then skipped favorably, and this MP discharge no longer was problematic.

Apart from MP discharge processing, the high voltage breakdowns were trained on the bench. In the cavity of the RF gun, where the intensity of E field reaches 20 MV/m at input nominal RF power of 325 kW, the electric breakdown is accompanied with severe deterioration of the vacuum degree up to actuation of the vacuum interlock. Even though operators tried to prevent a breakdown, as the processing conditions require (slow voltage rise and vacuum monitoring), breakdowns did happen sometimes in the beginning. Training of the RF gun continued for two days, and the breakdowns were trained fully with slow rise of input power to 630 kW (to cavity voltage of 1 MV).

In case of a buncher cavity, as it was mentioned already, having several MP areas, MP processing must be completed within three days. But after long downtime, when it was kept in poor vacuum caused by heating of other parts in the unit, with multiple atmosphere ingress, its repeated long-term processing was required. Unfortunately, the cavity was not equipped with a vacuum gate to isolate it from other parts of the unit, as it was arranged on the RF gun.

Repeated processing was carried out according to a different scenario, when the cavities operated in the regular RF system of the accelerating complex with long fronts of RF impulses ($7-10\,\mu$s). As it was noted before, due to such relatively long fronts it is not possible to skip the MP discharge zone. Therefore, the processing of the cavity 535.5 MHz in the entire range up to its maximum power of 12 kW must be performed starting from the first multipactor area, from 400 W. But it was decided to supply impulse RF power 7 kW right away at the first stage, gradually growing to 12 kW, even though almost all of it was reflected (the cavity received power of 400 W). Training by such (fast) method, as it turned out, does not result in stable operation, since at any random reduction of RF level to the level of lower, untrained MP area (400 W), sometimes a steady MP discharge occurs, which causes nearly complete reflection of the RF power.

The processing process is carried out using the following rules. The resonance frequency of the cavity was adjusted manually. The processing process itself was monitored by signals of incident and reflected waves from a directional coupler, and also by the level of voltage from the loop on the cavity and by readings of the vacuum meter. A connection was observed between the MP intensity and direction of the resonance frequency detuning, which means that MP lights up in the power input. In case of the RF gun, where the central rod of the power input was coated with titanium nitride, there was no MP discharge in the RF gun power input. In case of the buncher cavity such coating was not applied. Because of this the secondary emission coefficient in the power input of the buncher cavity remained high, which always caused MP in it.

Therefore, in the beginning of the processing process almost all RF power was reflected, only 400 W passed into the cavity, which had no dependence on the incident RF power, and the voltage on the buncher cavity remained the same, accordingly. Only the vacuum degree varied — the higher was the incident RF power, the worse were the vacuum level. At 7 kW vacuum meter readings first reached 10^{-7} Torr. In process of processing the RF power that passed into the cavity increased gradually, accelerating its growth to the end. As a result, after 4 h processing sessions the voltage on the cavity recovered, and reflection disappeared with substantial improvement of vacuum, and the first stage was over.

As it was noted above, this processing was not stable enough, as the lowest MP area was not fully trained. Therefore, the additional processing was required at the low level of RF power at only 400 W for the first two days, after which the vacuum degree readings improved (Fig. 8), and only then the stable operation with the beam on the unit became possible.

From these tests a conclusion was made that it was necessary to coat the inner surface of the RF power input by titanium nitride to suppress the MP discharge. Such coating, widely available in the industry for various purposes, lowers the coefficient of secondary emissions of electrons from the surface, preventing MP development.

No high voltage breakdowns were observed in cavity 535.5 MHz, which is a normal fact, since the maximum intensity of the electric RF field in it does not exceed 5 MV/m, as in standard BINP cavities with continuous mode of operation.

Conclusion

The main feature of the proposed RF gun design, the operability of which was confirmed by testing, is using special spherical geometry of the rear wall of the accelerating gap, making it possible to get high rate of acceleration at rather low intensity of RF field on the cathode and to focus the beam at the same time. The first enables control of the cathode-grid unit by impulses with amplitude of not more than 100 V, and the second one — to avoid using a system of complex magnetic focusing. Designs of the RF gun and the buncher cavity make it possible to use piezoactuators for operative detuning of the resonance frequency. Besides, mechanical regulation of the cathode position inside the RF gun is provided using the positioning and control system.

When the RF gun and gear were manufactured, the developed technology and methods of EBW demonstrated high efficiency. The obtained experience confirmed critical importance of using diamond turning to make individual parts, the need for fine tuning of resonance frequency in the cavities using electric RF measurements prior to soldering or welding, and also many more other technological methods, which are feasible to use to get high RF characteristics of cavities.

The used methods to train the accelerating system confirmed the high quality of manufacture, assembly and specifications of RF gun, and also made it possible to identify the most vulnerable characteristic of the buncher cavity — possibility of multipactor dicharge occurrence in the RF power input. Use of a coating like titanium nitride on working surfaces of the accelerating system makes it possible to effectively solve this problem, and equipment of the resonator with an individual vacuum gate preventing atmosphere ingress during repair works in the beam channel, — to considerably reduce the time for high voltage and vacuum processing of the system, to improve its reliability.

Conflict of interest

The authors declare that they have no conflict of interest.

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