STATUS OF 174 MHz RF SYSTEM FOR BEP

Yu.A. Biryuchevsky, E.I. Gorniker, E.K. Kendjebulatov, S.A. Krutikhin, G.Ya. Kurkin, V.M. Petrov, A.M. Pilan
Budker INP, Novosibirsk, Russia
E-mail: Kendjebulatov@mail.ru

The new RF system for the BEP storage ring (which is an injector of VEPP-2000 accelerating complex) will increase the particles energy in the BEP from 0.9 to 1 GeV. RF system operates at a frequency of 174 MHz and consists of an accelerating cavity, RF power generator and control system.

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1. INTRODUCTION

Booster storage ring BEP is a part of the injector of VEPP-2000 accelerator [1]. BEP is used to store electron and positron beams and to accelerate them up to the energy of 0.9 GeV, before injection into the storage ring VEPP-2000. The BEP upgrade program requires a replacement of the existing RF system (operating at a frequency of 26.8 MHz – second harmonic of the revolution frequency) by a new one with operating frequency of 174.4 MHz (13th harmonic of the revolution frequency). The new booster RF system consists of an accelerating cavity, RF generator and control system.

A coaxial accelerating cavity with maximum voltage of 120 kV has mechanisms for tuning the fundamental and higher order modes (HOM). Maximum output CW power of RF generator is 20 kW. A GU-92A tetrode is used in its output stage. Preliminary stages of the generator are based on transistors. The control system controls the amplitude and phase of the accelerating voltage and provides synchronization for filling the ring separatrixes. Parts of the RF system are in production now.

2. ACCELERATING CAVITY

New cavity dimensions should not exceed the dimensions of the existing one, because the cavity will be installed at the same location of the storage ring. Basic requirements to the new BEP cavity are: operating frequency – 174.4 MHz, accelerating voltage – about 110 kV, maximum RF power transferred to the beam – about 14 kW.

The cavity design is shown in Fig.1.

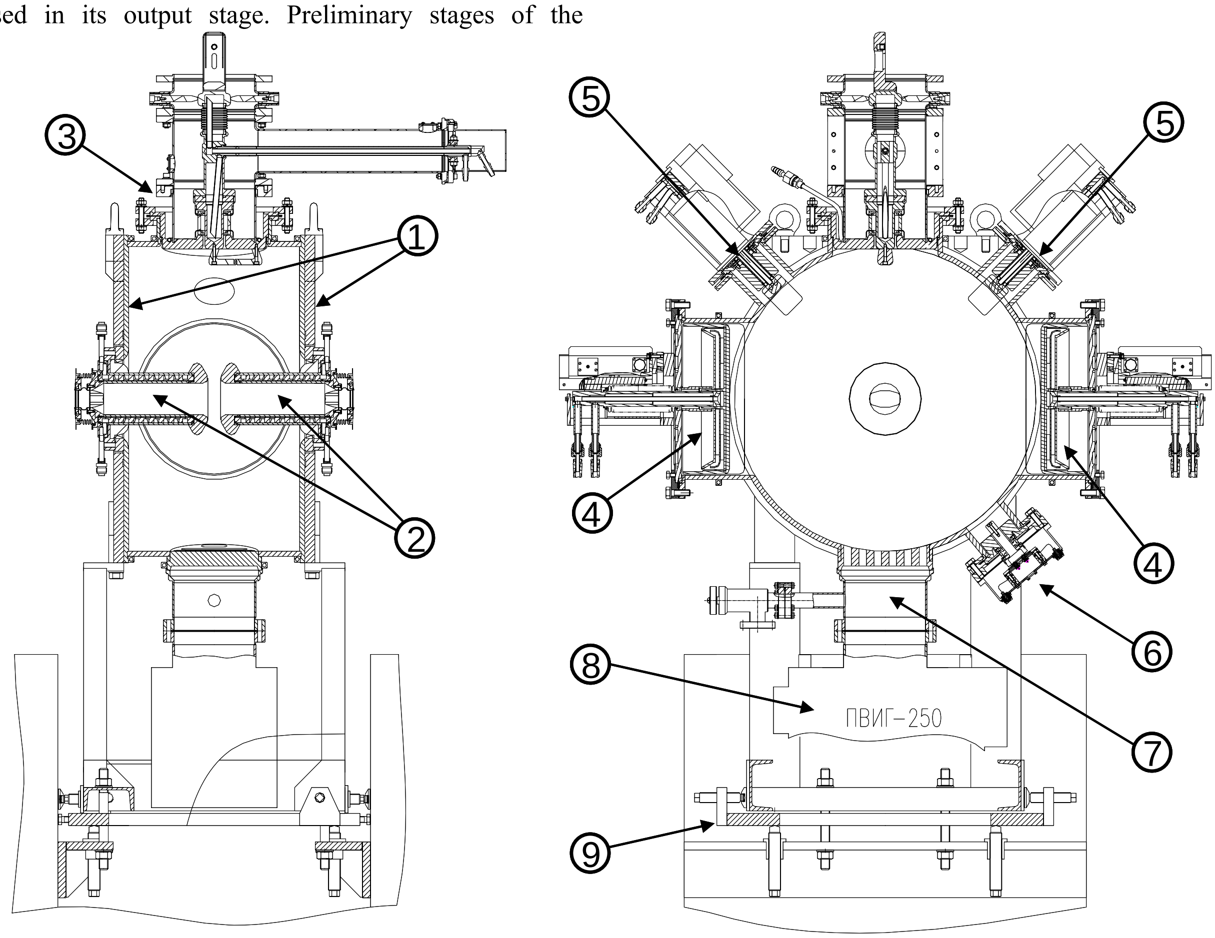

Fig.1. BEP cavity design: 1 - bimetallic walls; 2 - coaxial inserts; 3 - cavity input coupler; 4 - main cavity tuners; 5 - cavity HOM tuners; 6 - sampling loop; 7 - vacuum pumping port; 8 - vacuum pump; 9 - cavity stand

The cavity has a cylindrical body (D = 600 mm, L = 340 mm), consisting of a copper shell and bimetallic (copper/stainless steel) walls (Fig.1, pos.1). Bimetal design of the walls increases their mechanical stability and reduces the sensitivity of cavity geometry to atmospheric pressure. Coaxial inserts (pos.2) are located symmetrically at the cavity axis. This design allows to lower the frequency of the operating mode and reduces the number and influence on the beam of cavity higher order modes (HOM). Central location, symmetry and small size of the accelerating gap provide additional reduction of the HOMs influence on the beam for those HOMs with odd number of variations along the cavity axis. Vacuum cavity wall – coaxial insert conflate-joints contain additional copper rings that provide RF contact between parts. Neighboring to joints areas are rounded. As shown by power numerical simulation [2], these roundings reduce the probability of multipactor discharge in these parts.

Cavity operating frequency is tuned by two movable plungers with gear boxes. These tuners are identical to those used for the race-track microtron-recuperator cavity [3]. They are located diametrically opposite (pos.4). Maximum tuner immersion into the cavity is 20 mm. Simulations show that at such tuner stroke and cavity voltage not exceeding 120 kV, multipactor discharge at this area does not build up. Maximum possible operating frequency tuning range is 1.2 MHz. This wide range allows obtaining the desired range of operational tuning (± 130 kHz) for various combinations of the plungers positions and thus to make some preliminary detuning of HOMs.

Additional HOM detuning is produced by the cavity HOM tuners (pos.5). These elements are completely identical to those used in the race-track microtron-recuperator cavity also. Their locations provide maximum frequency shift of several first HOMs.

Cavity input coupler (pos. 3) is designed to transfer to the cavity about 20 kW of RF power. Input coupler loop sizes provide matching of fully beam loaded cavity with 75-Ohm feeding line.

Table 1

BEP cavity parameters

Harmonic number	13
RF frequency (MHz)	174.3755
RF frequency tuning (kHz)	±130
$R\tau^2_{cavity}$ (MOhm)	1.4
Total current (A)	0.2
Beam energy (MeV)	1000
Energy loss/turn (keV)	69.2
RF voltage (kV)	112
Radiation power (kW)	13.8
Cavity RF losses (kW)	4.5
Total RF power (kW)	18.3

Preliminary baking of the cavity at a temperature of 150°C, and ion-getter vacuum pump PVIG-250 (250 l/s) should provide cavity vacuum not worse than 10^{-7} Torr.

Cavity parameters are given in Table 1. At the moment cavity design is completed. Input coupler and cavity body are being produced at BINP workshop.

3. RF GENERATOR FOR BEP STORAGE RING

3.1. GENERAL PARAMETERS OF THE RF GENERATOR

The required RF power of 20 kW for driving the RF cavity in CW regime at a frequency of 174 MHz is provided by an RF generator. It consists of an output stage with vacuum tube and a solid state preamplifier. The design of the output stage with vacuum tube is based on the design that is widely used at BINP in all generators at frequencies of 180 MHz. The preamplifier can yield output power up to 2 kW. The output stage is directly connected to RF cavity through a 75 Ohm coaxial feeder. Cavity gap voltage is changed by adjusting the drive signal at preamplifier input from 0 to 5 W. The electric power for the generator is supplied from three-phase network 380 V, it doesn't exceed 50 kW.

In the output stage a water- and forced-air cooled tetrode GU-92A is employed. The stage is made on common-greed scheme. The tetrode works in a B class with a cutoff angle about 100º. This decreases the efficiency compared to the C class operation but improves gain linearity at low input signal power level. For effective operation of automatic gain control system it is necessary to eliminate any abrupt gain changes within full range of the input signal levels.

Preamplifier is equipped with water cooling, and is mounted inside a separate case which is fixed on a support of the output stage. DC power supplies for the output stage and preamplifier are situated in separate cabinets together with control, interlock, monitor and protection systems.

Basic requirements to DC power supplies and cooling systems are summarized in Table 2.

Table 2

Basic requirements to DC power supplies and cooling systems

Output RF power	кВт	20
Anode DC voltage	кВ	8
Anode DC current	А	5
Screen grid voltage	В	+900
Screen grid current	А	0,2
Bias voltage at 1-st grid	В	-(80…150)
1-st grid current	А	0,1
Filament voltage (decreased)	В	8,0
Filament current	А	120
Cooling water flow rate	l/min	40
Water pressure drop	Bar	2.5
Cooling air flow rate	m^3/hour	400

At present time the output stage is assembled and undergoes RF parameter measurements. Power supplies, control, interlock, monitor and protection systems are being prepared for switch on.

3.2. DESIGN OF THE OUTPUT STAGE WITH GU-92A TETRODE

The equivalent circuit of the output stage is given in Fig.2 at the left. On this scheme all locations of blocking capacitors C1-C14 are shown for reference; designations: F1, F2 – filament connections; C1, C2 – connections of the 1-st and 2-nd grids; Anode – anode output; A-RF, C-RF – sensors of RF voltages on input and output circuits; DC1 – directional coupler.

On the right part of Fig.2 there is a sketch of the output stage design.

Common grid scheme is realized by RF shortening of both grids via ceramic capacitors (5), and then by RF shortening of screen grid current to the hull via ceramic capacitors (18). Blocking ceramic capacitors (15) shorten the anode circuit RF current to the hull of the stage.

Generator tetrode GU-92A (6) with water cooling jacket (9) is designed as a quick-detachable unit. Mounting and demounting of this unit is accomplished by lever lift device (12).

The tuning of resonance frequency of anode circuit is accomplished by air capacitor (7), the movable plate of which is actuated by drive (8). Tuning range of the anode circuit is 6 MHz.

The variable air capacitor (17) changes coupling coefficient between anode circuit and output coaxial feeder going to the accelerating RF cavity. The coupling may be adjusted by changing the gap by the drive (16).

Input circuit of the stage does not need operational tuning. The required values of resonant frequency and coupling coefficient with input coaxial 50-Ohm cable. (19) are adjusted once during the first tuning by changing gaps of air capacitors – 23 and 20 correspondingly.

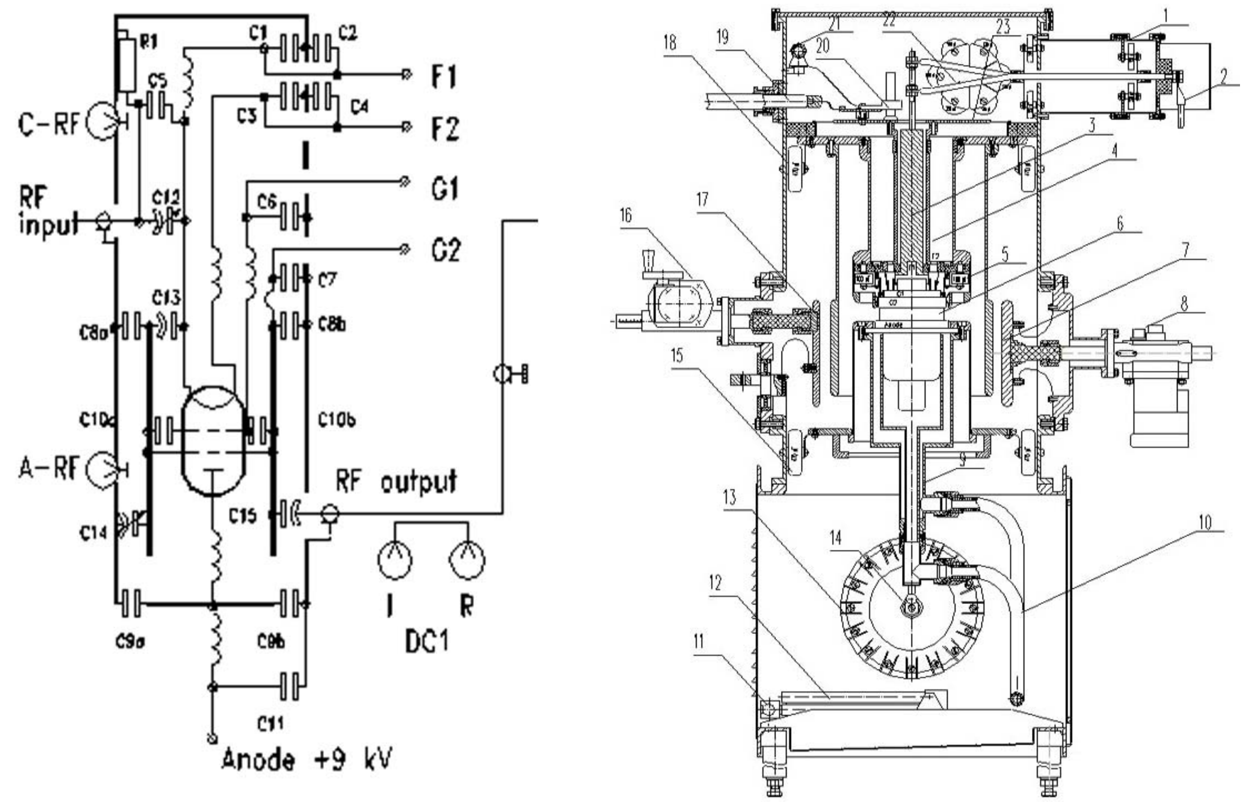

Fig.2. The equivalent circuit and design of the output stage

Resistor 200 W, 50 Ohm (21) is used for shunting numerous resonant modes of the input circuit and preamplifier in order to prevent self-excitation of the generator at frequencies much lower and much higher the operational one (the experience shows that Q-factor must be decreased to 10…100 in the frequency range of 20…1000 MHz).

Filament voltage is applied to the tube via connectors (2) and elements of the input circuit (3). Two stages of RF filters (1) weaken RF radiation from the generator to an acceptable level. DC voltage is applied to screen and control grids via RF filters (22). DC anode voltage is supplied via RF filter (13) installed inside the support of the output stage. Cooling water flows in and out through pipes (10) made of insulating material.

4. CONTROL SYSTEM

The control system controls the amplitude and phase of the 174 MHz cavity accelerating voltage. This system is similar to the one currently in operation (Fig.3). The system has three feedback loops. One of them controls the cavity gap voltage amplitude by the cavity sampling loop signal. To do this, the detected RF signal from the loop is compared to the reference constant voltage (V_{ref}) by the error amplifier (EA). EA output signal regulates the controlled amplifier (CA) transfer factor. The amplitude of the RF cavity voltage is maintained proportional to the reference voltage. Instability of the cavity RF voltage amplitude does not exceed $0.3 \cdot 10^{-3}$.

For the cavity frequency self-tuning the RF signal from the cavity sampling loop and the signal from the feeder sampling loop (which is proportional to the current of the cavity input coupler loop) are fed to Phase meter #2 (PM #2) input. The Phase meter output signal controls the servo amplifier (SA), which is connected to the cavity frequency tuning mechanism. A fixed phase shift may be set by adjusting the external reference voltage. Phase control error does not exceed 5 degrees.

The third feedback loop provides a rigid binding of the cavity RF voltage phase to the reference voltage from the master generator. The Phase meter #1 (PM #1) receives the cavity sampling loop signal and the reference RF voltage signal. The Phase meter output signal controls the electronic phase shifter PS #1. Cavity RF voltage phase instability does not exceed 0.5 deg relative to the reference RF signal. The phase shifters PS #2 and PS #3 are based on the commutated strip-lines and used for the phase meters initial setup.

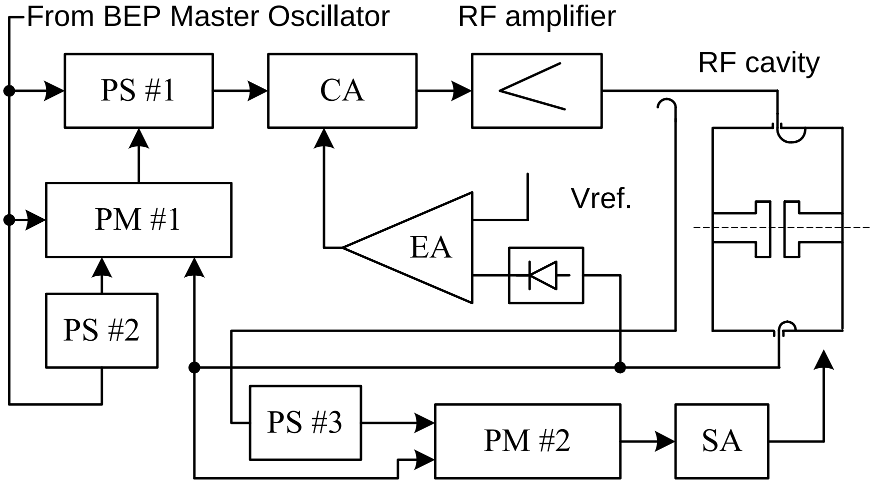

Fig.3. Simplified block-diagram of RF system BEP

It is assumed in the new RF system, that the particles will be injected into BEP from the cooling storage-ring (CSR). This ring is a part of the injection complex VEPP-5 [4], currently being commissioned. The CSR ring revolution frequency is equal to 10.94 MHz. Before the injection, BEP revolution frequency will be tuned by the phase-locked loop circuit (PLL) so that accelerators revolution frequencies ratio is equal to F_{BEP} / F_{CSR} = 352/287. Under this condition the bunch positions in both storage rings are repeated with the frequency of greatest common divisor of their revolution frequencies – 38.1 kHz. CSR deflector kickers and BEP inflector start from one of the pulses that follow with this frequency. By adjusting the delay of the BEP revolution frequency signal at the PLL input, one can choose the number of the BEP separatrix filled.

After filling of the BEP separatrix its revolution frequency is controlled independently by a computer. Further rise of the BEP particles energy follows. Before injection of the particles into VEPP-2000, the revolution frequencies of the rings are synchronizated by the scheme which is similar to the one described above. BEP revolution frequency is tuned again. The revolution frequencies ratio is $F_{BEP}/F_{VEPP\text{-}2000}$ = 299/274. In order to not excite the electron bunch phase oscillations in the BEP, a provision has been made for correction of the transient processes in the PLL circuit. In both cases, after PLL circuits is switched on, BEP particles orbit deviation from the optimal one is less than a few tenths of a millimeter, which is quite acceptable.

Resolution and accuracy of injection into BEP and VEPP-2000 is not worse than 50 ps. The control system will partly use the old electronics. New modules are being manufactured and tuned.

REFERENCES

1. Yu.M. Shatunov, et al. Project of a new electron-positron collider VEPP-2000 // *Proc. of EPAC 2000*, Vienna, Austria, 2000.
2. A.V. Grudiev, et al. Simulation of Multipacting in RF Cavities and Periodical Structures // *Proc. of PAC 97*, Vancouver, B.C., Canada, 1997.
3. N. Gavrilov, et al. *RF Cavity for the Novosibirsk Race-Track Microtron-Recuperator*: Preprint BudkerINP 94-92, Novosibirsk, 1994.
4. M.S. Avilov, et al. Status of VEPP-5 injection complex // *Proceedings of RuPAC XIX*, Dubna, 2004.

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ВЧ-СИСТЕМА 174 МГц НАКОПИТЕЛЯ БЭП

Ю.А. Бирючевский, Э.И. Горникер, Е.К. Кенжебулатов, С.А. Крутихин, Г.Я. Куркин, В.М. Петров, А.М. Пилан

Новая ВЧ-система накопителя БЭП (являющегося инжектором комплекса ВЭПП-2000) позволит увеличить энергию частиц в БЭП от 0,9 до 1 ГэВ. ВЧ-система работает на частоте 174 МГц и состоит из ускоряющего резонатора, ВЧ-генератора мощности и системы управления.

ВЧ-СИСТЕМА 174 МГц НАКОПИЧУВАЧА БЕП

Ю.А. Бірючевський, Є.І. Горнікєр, Є.К. Кєнжебулатов, С.А. Крутіхін, Г.Я. Куркін, В.М. Петров, А.М. Пілан

Нова ВЧ-система накопичувача БЕП (що є інжектором комплексу ВЕПП-2000) дозволить збільшити енергію частинок БЕП від 0,9 до 1 ГеВ. ВЧ-система працює на частоті 174 МГц і складається з прискорюючого резонатора, ВЧ-генератора потужності і системи управління.