RF SYSTEM OF ELECTRON INJECTOR FOR THE RACE-TRACK MICROTRON-RECUPERATOR AND RESULTS OF ITS OPERATION WITH ELECTRON BEAM

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INTRODUCTION

The RF system is a part of the 1.6 - 2 MeV injector for the Race-Track Microtron - Recuperator (RTMR) that is under construction at BINP, Novosibirsk, for the Center of Photochemistry. RF system has three 180.4 MHz cavities. Buncher cavity operates at the accelerating voltage of 100 kV and two accelerating cavities operate at the gap voltage up to 800 kV. Cavities are driven by 3 power amplifiers. Maximum output power of amplifier which feeds the accelerating cavity is 130 kW. Low level electronics controls phase and amplitude of RF cavity gap voltages and generates signals for synchronization of the electron gun. Maximum current of injector (45 mA) is realized at 22.5 MHz repetition rate of electron bunches. The effects of beam – RF cavities interaction and the RF system operation results are presented.

A 100 MeV, 45 mA CW race-track microtron-recuperator (RTMR) is being built at Novosibirsk for a free electron laser project [1]. The whole facility includes a 1.6–2.0 MeV electron injector. It consists of a 300 keV electron gun, a buncher RF cavity and two accelerating cavities. RF system has 3 separate channels. Each of the channels includes one RF cavity, RF power generator and a set of low-level control electronics.

All cavities have the same operating frequency which is equal to the frequency of the main RF system of the RTMR (180.4 MHz). The RF voltage of the buncher cavity is 100 kV, of each of the accelerating cavities—800 kV.

A similar RF system was delivered by special order to the research center KAERI, South Korea. It was installed and tested there successfully.

CAVITY DESIGN

All cavities have a design similar to the design of the RTMR cavities [2, 3]. The geometry of a cavity is shown in Figure 1. Specifications of an accelerating cavity are shown in the Table 1.

Cavities have copper clad stainless steel walls (8 mm of copper and 7 mm of stainless steel). The cylindrical wall and the side walls of the cavity are joined to each other using TIG welding at stainless steel. Good electrical connection of the walls is ensured by copper. Parts are kept forced against each other due to shrinkage of stainless steel in welds.

The schematic drawing of RF cavity with insertion units is shown in Fig. 2. RF cavity is connected to a 75 Ohm feeder line by a coupling loop. The Al_2O_3 cylindrical ceramic window of the coupler separates vacuum volume of RF cavity from atmosphere.

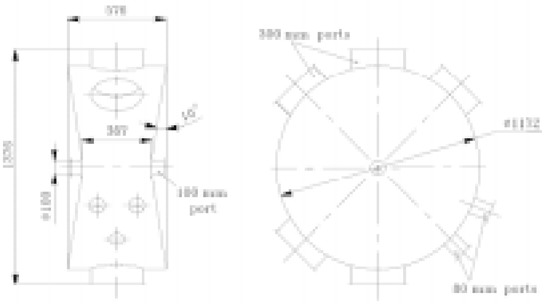

Fig. 1. Geometry of RF cavity.

Table 1. Parameters of the cavity.

/ gap voltage (*V*)	0–950	kV
⁄alue	40,000	
⁄ value [1]	133.5	Ohm
ınt impedance [1]	5.3	MOhm
sonance frequency	180.4	MHz
ning range of cavity frequency	320	kHz
ning rate	5	kHz/s
ll loss *P* at *V* = 950 kV	85	kW
ximal power flux at *V* = 950 kV	1.8	W/cm^2

[1] Shunt impedance *R* is defined as $R = V^2/2P$

There are two main tuners to control frequency of fundamental E_{010} mode. Two special HOM tuners are provided for correcting frequencies of HOMs which may be excited by electron beam. These tuners have a negligible effect on the fundamental mode. Resonance frequencies of modes versus all tuner's position are obtained from measurement of RF cavity at low power level. Water is used to cool cavity body and insertion units.

After completion of low level RF measurements the cavities were closed, pumped out and baked out to a temperature of about 300°C. A very high vacuum in the cavity 10^{-8} - 10^{-9} Torr was obtained by means of an effective pumping unit.

Before installation into an accelerator all cavities were tested at a special high power test stand. The buncher cavity was successfully tested to the accelerating voltage of 600 kV, the accelerating cavities were tested to the accelerating voltage of 1100 kV.

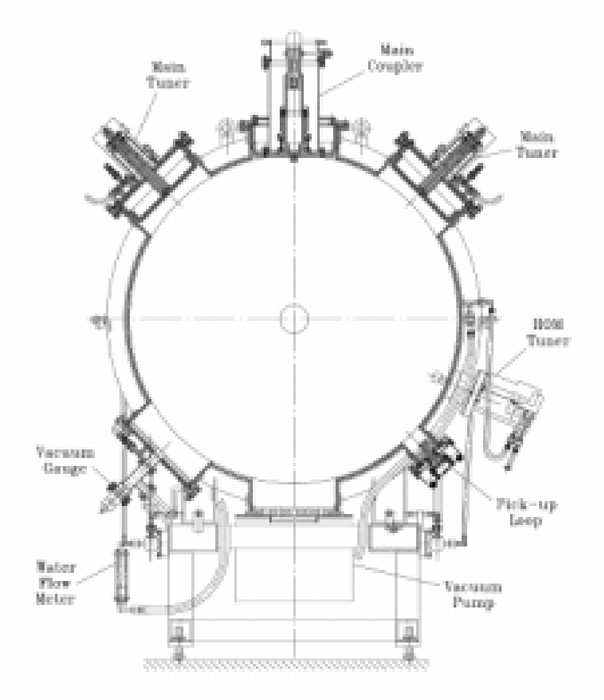

Fig. 2. RF cavity with insertion units.

RF POWER AMPLIFIERS

All RF power amplifiers were designed and produced at BINP [4]. Two high power amplifiers generate 130 kW of RF power each and drive accelerating cavities. One low power amplifier (2 kW) drives the buncher cavity. Each 130 kW amplifier has 3 stages. A modular design is used in the high power output stage (Fig.3). The main module of the stage has a tetrode tube GU-101A inside. At one side of this assembly a tuner module is mounted. At the other side of the assembly the load is connected through the coupler module. A contactless design of the frequency tuner and of the output coupler provides a high reliability and absence of parasitic modulation. The tuner is controlled remotely from control room.

RF power is transmitted from the stage output to cavities through coaxial line 160/45 mm. The coupling coefficient of the cavity coupler is adjusted so, that there is no reflected power under maximum beam load condition. VSWR in the line is less than 2.0 for lower beam load.

Two preliminary stages of the 130 kW amplifier employ tetrodes GU-92A in the grounded grid configuration. RF power at input of the first stage does not exceed 100 W and comes from a transistor amplifier. Low power 2 kW amplifier has only one GU-92A stage.

Water and air-cooling are used in power amplifying units.

Tetrodes GU-101A and GU-92A are produces by “Svetlana” firm-manufacturer in St.-Petersburg, Russia [5].

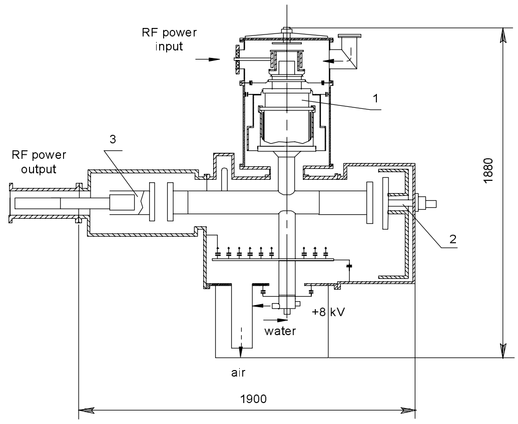

Fig. 3. Schematic drawing of power output stage.
1. Tetrode tube GU-101A. 2. Capacitance tuner.
3. Capacitance output coupler.

RF SYSTEM CONTROL

The simplified block-diagram of RF system control is shown in Fig. 4. Master oscillator and frequency divider generate reference and driving signals for operation of 3 RF channels. All 3 channels are made and work in a similar way.

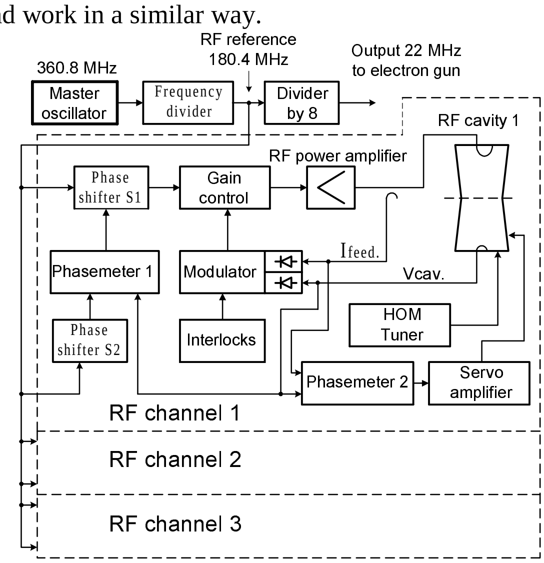

Fig. 4. Block-diagram of RF system control for injector of microtron-recuperator.

There is a feed back loop to control amplitude of cavity gap voltage. RF signal V_{cav} from the cavity sampling loop comes into linear amplitude detector input of the Modulator. Output of the amplitude detector is connected to one of a differential amplifier inputs. The reference DC voltage comes to another input of the differential amplifier from computer controlled DAC. Output of the differential amplifier controls gain of RF amplifier. A gain of the differential amplifier is large enough, so the cavity gap voltage is kept proportional to the reference DC voltage.

The other feedback loop controls a phase of cavity voltage. Phasemeter 1 measures phase difference between the signal from cavity sampling loop and the RF reference signal. Output of the phasemeter controls the Phase shifter S1. It is possible to adjust the cavity phase for normal acceleration of beam using Phase shifter S2.

The reaction time of both feedback loops is ~300 μsec. Index of parasitic phase and amplitude modulation is lower, than $2 \cdot 10^{-3}$.

The resonance frequency of cavity should be tuned continuously to compensate mostly for variation of the cooling water temperature. The Phasemeter 2 measures the phase difference between RF voltage $V_{cav.}$ from cavity sampling loop and signal I_{feed} from the sampling loop in the feeder line. Signal from the latter loop is proportional to the RF current of the cavity coupling loop. Output of the Phasemeter 2 controls cavity main tuner through the Servo amplifier. Reaction time of the servo loop is ~100 msec, the accuracy is ~ 5 degr.

PRESENT STATUS OF RF SYSTEM

Presently adjustment of the Injector is going on. Maximum beam current of 20 mA had been achieved at electron energy of 1.5 MeV. The accelerating cavities were operated at 700 kV of RF gap voltage. The total RF power of 59 kW was consumed by one cavity. 12.5 kW of this amount was being transferred to the beam.

It is required that electrons should pass the buncher cavity at the braking phase of RF voltage. For beam current of 23 mA the energy transferred to the cavity electromagnetic field from the beam is equal to the cavity wall losses, so the energy consumed from RF generator is zero.

In order to provide stable operation of RF system at the total beam current range, the equivalent feeder length between planes of equivalent representation of the cavity and the anode of RF generator tube is equal to odd number of a quarter wavelength. In that case the anode current has a small variation in the total beam current range for a given cavity voltage. The anode RF voltage phase is reversed by 180° from initial position for a beam current higher then 23 mA, so the excess of energy from cavity is dissipated at anode of RF generator tube.

For stable operation of the tuner servoloop, the Phasemeter 2 (Fig. 4) is converted into the synchronous detector.

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