RF SYSTEM OF ELECTRON INJECTOR FOR THE RACE-TRACK MICROTRON - RECUPERATOR

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Abstract

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. Maximum current of injector (45 mA) is realized at 22.5 MHz repetition rate of electron bunches. The electric charge of one bunch is 2 nC. RF System has 3 180.4 MHz cavities. One is a buncher cavity and two others are accelerating cavities. Buncher cavity operates at the accelerating voltage of 120 kV and the accelerating cavities operate at the accelerating voltage up to 850 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.

INTRODUCTION

A 60 MeV, 1 A 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 120 kV, of each of the accelerating cavities—850 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.

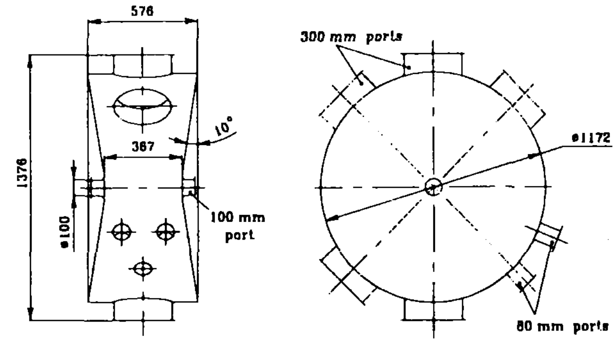

Figure 1: Geometry of RF cavity.

Table 1: Parameters of the cavity.

CW accelerating voltage (V) [1] —	0–850 kV
Q value [2] —	40,000
R/Q value [3] —	215 Ohm
Shunt impedance [2, 3] —	8.5 MOhm
Resonance frequency —	180.4 MHz
Tuning range of cavity frequency —	320 kHz
Tuning rate —	5 kHz/s
Wall loss P at V = 850 kV —	85 kW
Maximal power flux at V = 850 kV —	1.8 W/cm^2

[1] Accelerating voltage is specified for relativistic or subrelativistic particles.

[2] At the room temperature.

[3] Shunt impedance R is defined as $R = V^2/P$,

$$V^2 = (\int E_z \cos(kz)dz)^2 + (\int E_z \sin(kz)dz)^2$$

Parts are kept forced against each other due to shrinkage of stainless steel in welds. After pumping the cavity down to a vacuum its frequency at the fundamental mode decreases by about 60 kHz.

All cavity units are joined to the cavity body using TIG welding at stainless steel. There are no vacuum seals in the cavity. Good electrical connection of different parts is always ensured by copper. Units are pressed against cavity ports by external flanges.

During operation in the accelerator, many higher order modes (HOMs) may be excited in the RF cavity by the beam. At some unfavorable circumstances the

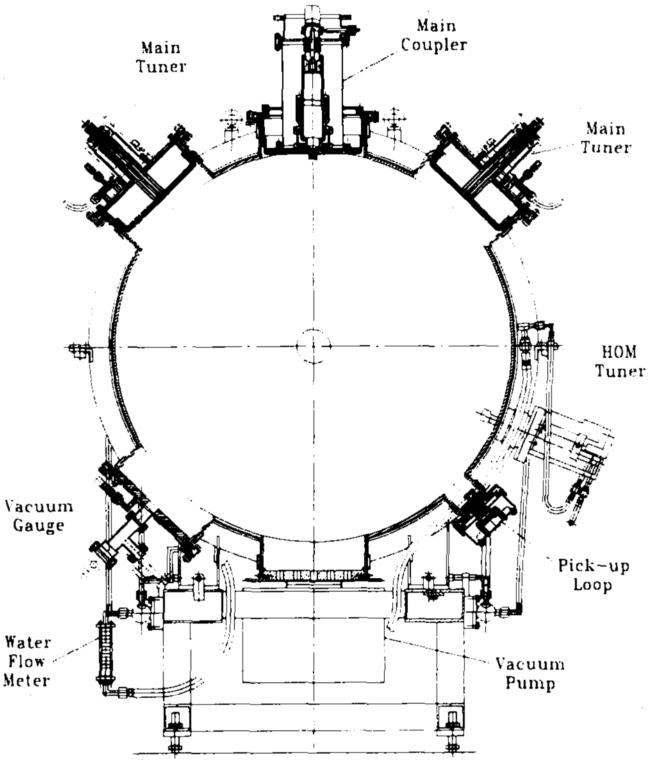

Figure 2: RF cavity with insertion units.

HOMs may cause an excessive bunch energy spread and beam instabilities. Two special HOM tuners are provided for correcting such HOMs frequencies of the cavity. These tuners have a negligible effect on the fundamental mode. The working head of an HOM tuner is a plate of an 8-like shape, the bigger axis of which is parallel to the beam axis. The design of a HOM tuner is shown in [3].

It is supposed to use both HOM tuners and main tuners for correction of the resonance frequencies of HOMs due to asymmetrical influence of the main tuners on many of higher order modes.

After completion of low level RF measurements the cavities were closed, baked out to a temperature of about 300°C and installed in a test stand for high power tests.

The buncher cavity was successfully tested to the accelerating voltage of 750 kV, which is much higher than the specified operating voltage. The limitation was due to cavity cooling. The accelerating cavities were tested to the accelerating voltage of 1100 kV.

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. The main module of the stage has a tetrode tube GU-101A inside. The limiting value of anode power dissipation of this tetrode is 250 kW. But for a better reliability, the RF power, which can be provided by this module, does not exceed 150 kW. It is possible to combine 1, 2, 3 or maximum 4 of these modules assembled together. 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. The output stage of the channel employs only one tetrode module (Fig. 3) and is capable to generate up to 150 kW of output power.

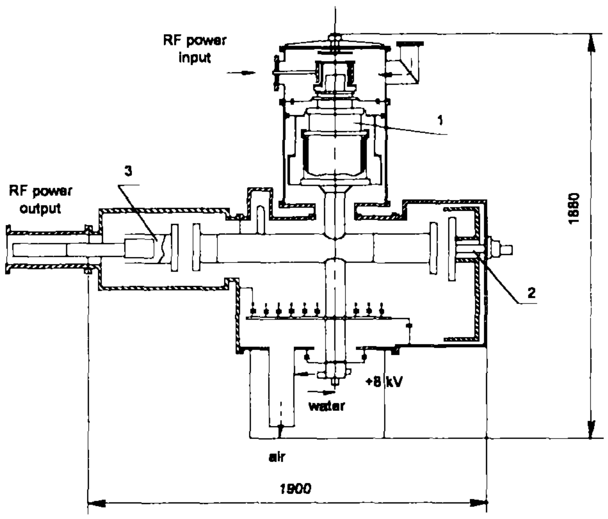

Figure 3: Schematic drawing of power output stage.
1. Tetrode tube GU-101A. 2. Capacitance tuner.
3. Capacitance output coupler.

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 is used in power amplifying units.

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

RF SYSTEM CONTROL

Basic functions of RF system control electronics are:

1. Amplitude and phase control of the cavities gap voltage.
2. Control of fundamental mode tuners (main tuners) and HOM tuners of the cavities.
3. Generation of reference signals for synchronization of the electron gun.
4. Interlock system for protection of personnel, RF power amplifier and cavities in emergency situation.

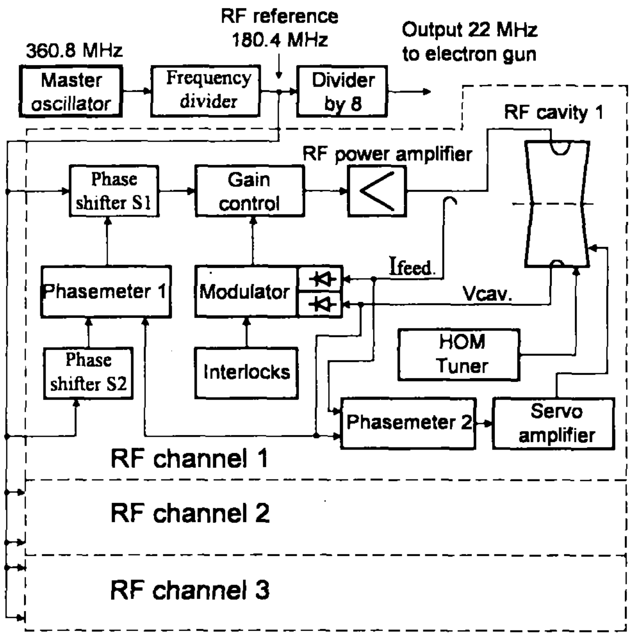

Figure 4: Block-diagram of RF system control for injector of microtron-recuperator.

The simplified block-diagramm 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.

There is a feed back loop to control amplitude of cavity gap voltage. RF signal Vcav. 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. The open loop gain is large enough, so the phase of the cavity gap voltage in relation to the RF reference is kept constant. 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 Vcav. from cavity sampling loop and signal Ifeed. from a 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 phase meter controls cavity main tuner through the servo amplifier. Reaction time of the servo loop is ~100 msec, the accuracy is ~ 5 degr.

Presently the RF System is mounted at BINP, tested successfully at nominal parameters and operates with electron beam.

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