RF System of the CW Race-Track Microtron-Recuperator for FELs

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Abstract

Geometry, engineering design and characteristics of an RF cavity and a tetrode power amplifier are described. They are parts of an RF system at the frequency of 181 MHz. The cavity has a copper clad stainless steel body and has a Q of 42,500 and a shunt impedance of 9.0 MOhm. Two cavities have been successfully tested up to an accelerating voltage of 1.2 MV what is 30% over the design value. One of them is mounted into the Duke's storage ring at Duke University. More than 20 RF cavities will be built and installed in a race track microtron-recuperator for FEL program at Novosibirsk. The RF power amplifier has a modular design. Several single tetrode modules can be easily combined in a high power unit. Two modules were used during cavity tests. A CW RF power of 300 kW was obtained from this unit. This type of tetrode modules will be used in different e^-e^+ colliders and storage rings.

INTRODUCTION

A 60 MeV, 1 A CW race-track microtron-recuperator is to be built at Novosibirsk for a free electron laser project [1]. An RF system is one of the key parts of this machine. Due to beam-cavity interaction during the acceleration cycle a part of electromagnetic energy, stored in RF cavities, is transformed to kinetic energy of the electron beam. During the recuperation cycle the kinetic beam energy is transformed to electromagnetic energy of the cavities. Therefore the average beam loading of RF cavities is small despite a high value of beam current.

The accelerator RF system will operate at 181 MHz. The main reason of this choice is the availability of RF high power tubes in Russia. More than 20 single cell RF cavities will be built and installed in the machine.

GENERAL DESCRIPTION

Fig. 1 shows a general scheme of the RF system. RF cavities of buncher, injector, and compensator are driven by separate 20 kW or 200 kW power amplifiers. All cavities of the main accelerator are divided in 4 groups, each of them is driven by a 600 kW unit.

RF cavities, fed from one RF power source, are located at a distance of one wave length from each other. Coaxial lines of equal length connect cavities to a rectangular waveguide which is used as a power distribution unit. Waveguide dimensions are chosen so that the waveguide

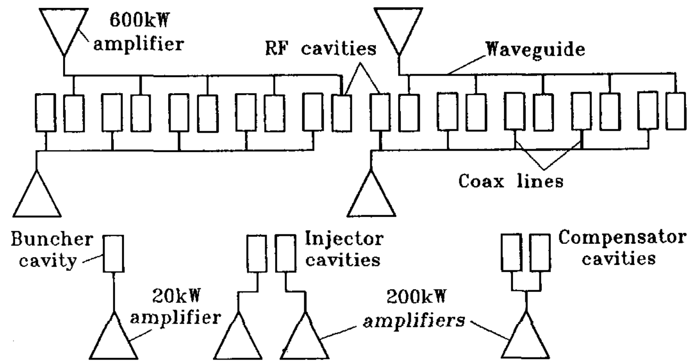

Figure 1: Scheme of RF system for microtron-recuperator.

wave length is equal to two free-space wave lengths. Therefore the coax-to-waveguide transitions are spaced by each half of the guide wave length.

A design of the coax-to-waveguide transition and a length of coaxial line to a cavity are chosen so that the matrix of transmission from the waveguide to a cavity has a form: $\begin{pmatrix} 0 & i/G \\ iG & 0 \end{pmatrix}$, where $G = I_c/V_w$ is a transconductance (I_c is a current, driving a cavity, and V_w is a waveguide voltage). Power distribution along the cavity chain is proportional to distribution of cavity shunt impedances. Right phases of cavity fields are ensured by proper rotation angles of coupling loops in the cavities. With this scheme the RF current, driving a cavity, does not depend on cavity tune. Emergency operation conditions are excluded due to this feature. Similar scheme is used in RF system of the VEPP-4 collider [2].

RF CAVITIES

Geometry of an RF cavity is shown in Fig. 2. The side walls have conical shape. It is good for mechanical rigidity and cavity electrical characteristics. The fundamental cavity mode is of E_{010}-like type. It has longitudinal electric field with angular symmetry. Cavity characteristics are summarized in Table 1.

Cavities have copper clad stainless steel walls. They have low RF losses due to low RF resistance of copper. A high thermal conductivity and a large thickness (8 mm) of copper exclude very high temperature rise at cavity surface. Stainless steel (7 mm thick) provides mechanical strength and prohibits corrosion. All cavity parts are joined to each other using TIG welding.

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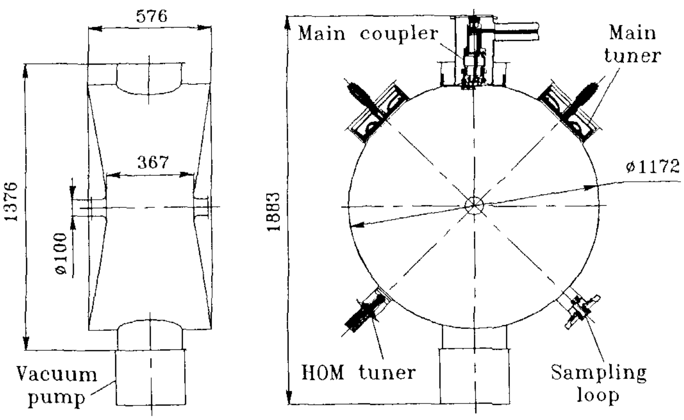

Figure 2: Sketch of the RF cavity.

Table 1: Parameters of the cavity

Accelerating voltage -	40-1000	kV
Q value -	42,500	
R/Q value -	212	Ohm
Shunt impedance -	9.0	MOhm
Resonance frequency -	181.3	MHz
Tuning range of cavity frequency -	360	kHz
Tuning rate -	5	kHz/s
Power loss at $V = 1000$ kV -	110	kW

Different units are assembled to cavity flanges. One of them is a main coupler. It has a coaxial design. A cylindrical ceramic RF window is incorporated in it. Coax input line has a wave impedance of 75 Ohm, the diameters of its outer and inner conductors are 160 mm and 45 mm respectively. Another unit is a sampling loop. It provides electrical signals which amplitude and phase are proportional to amplitude and phase of the cavity voltage. They are used in the RF control system.

Two main tuners are used basically for tuning the fundamental mode. Two additional HOM tuners are provided for making corrections of frequencies of higher order modes of the cavity. (At some unfavorable circumstances the higher order modes may cause beam instabilities).

A very high vacuum in the cavity ($10^{-7} - 10^{-8}$ Pa) is obtained by means of a pumping unit PVIG-630 which is a combination of a sputter ion pump and a gettering pump. But such a high vacuum can be achieved only after baking out the cavity up to a temperature of $300 - 400^{o}$C after its assembling. This is possible to do using tape heaters and thermal insulation, mounted on the outer cavity walls.

Walls of the cavity and its units are cooled by demineralized water. Special water channels are provided in SS parts of the cavity walls for this purpose. Any contact of water with copper walls is excluded. A water distribution system is mounted under the cavity, inside of its support frame.

All cavities are assembled in pairs. Each pair is mounted on a single support frame which height is adjustable. Each cavity can be aligned individually in a horizontal plane.

RF cavities produce X-rays during their operation due to field emission from the cavity surface in the areas of high electric field. The X-ray rate goes up very steeply with cavity voltage. At $V = 1000$ kV the X-ray rate at a distance of 1 m from the cavity is as high as 4-6 R/h.

Pilot RF cavities have been successfully tested up to an accelerating voltage of 1200 kV. This voltage level was achieved after many hours of RF processing to suppress multipacting. Coaxial RF windows have been tested up to an RF power level of 170 kW.

One of the cavities has been delivered to FEL Laboratory of Duke University. It has been installed into Duke's 1 GeV storage ring which will be used for FEL experiments. The geometry of this cavity was slightly modified to accommodate its frequency to the one of Duke's requirements (178.4 MHz).

RF POWER AMPLIFIERS

A modular principle of design was applied to RF power amplifiers. It gives a possibility to build power amplifiers for different applications from few standard units. A GU-101A CW tetrode [3] with the limiting value of anode dissipation of 250 kW is used in the output stage. But for better reliability the RF power, which this module can provide, does not exceed 150 kW. Several single tetrode modules can be easily combined in a higher power unit.

A 20 kW tetrode unit is used as an intermediate amplifier stage. It can be used for driving a 150 kW stage. A 150 kW module can be used for driving a multitube high power unit.

A frequency doubler is used in the pre-amplifier unit. Therefore it is driven at a frequency of 90 MHz (an input power is 5 W). This way of frequency isolation provides a better stability of the RF control system.

The output tetrode stage has an original design. It provides simplicity of combining the power of several tubes and convenience of tuning the stage.

As an example Fig. 3 shows a schematic view of a 2-tube 300 kW output stage. Tetrode assemblies are connected to a line which is a part of the anode resonator. Its size is chosen in such a way that the transfer matrix between points "a" and "b" has a form: $\begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix}$ at the operation frequency. A contactless design of the frequency tuner and the output coupler provides a high reliability and the absence of parasitic modulation. Water and air cooling is used in power amplifier units.

A coaxial line can be used for transmitting the RF power from power amplifier to RF cavities if the distance

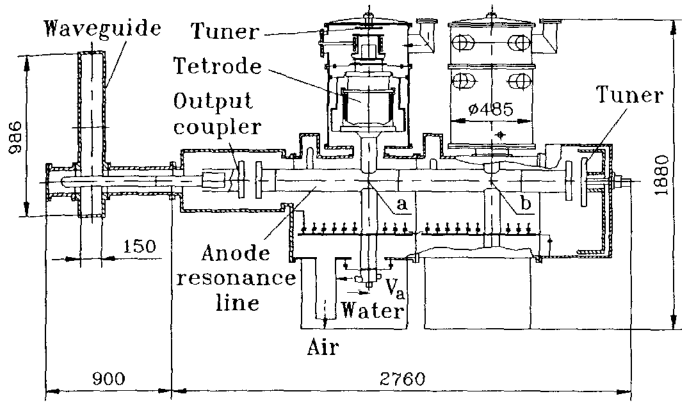

Figure 3: Design of a 2-tube RF power stage.

is not too long and the RF power is relatively low. In other cases a rectangular air-filled waveguide is used with coax-to-waveguide transitions at both ends of the waveguide.

A 8 kV dc power supply is provided for output tetrodes and a 6 kV dc power supply is provided for intermediate tetrode stages. The high voltage power supplies are equipped with fast protecting system for the protection of RF power tubes against occasional breakdowns. The time of activating this protection system does not exceed 100 μs.

This type of tetrode modules will be applied to different e^-e^+ colliders and storage rings. E. g. a 2-tube module is used in present RF system of VEPP-4 collider. Similar modules will be used in RF system of Siberia-2 storage ring. 4-tube modules are being prepared for upgraded RF system of VEPP-4.

A 2-tube unit was tested. A CW RF power of 240 kW was obtained with a water cooled resistor as a load. The load limited the power in this case. With four RF cavities as a load of power amplifier, a CW power of 300 kW was obtained.

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