RF System of VEPP-4M Electron-Positron Collider

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Abstract

RF system of the VEPP-4M collider consists of six 181 MHz copper cavities fed from a single RF power source. The cavity has a *Q* of 50,000 and a shunt impedance of 15 MOhm. The cavities are connected to a waveguide distributing system with the aid of coaxial lines. The distance between cavity connections is equal to one wave length. Dimensions of the rectangular waveguide are chosen in such a way that the guide wave length is equal to two free-space wave length. Power distribution along the cavity chain is proportional to the distribution of cavity shunt impedances due to a proper design of the coax-to-waveguide transitions. The two-tube tetrode amplifier presently has an output RF power of 300 kW. After upgrading of the RF system its power will increase to 1.2 MW.

INTRODUCTION

VEPP-4M electron-positron collider is the modified VEPP-4 storage ring designed for operation with two electron and two positron bunches at the energy up to 6 GeV for each bunch. The storage ring has the circumference of 366 m and the beam revolution frequency of 819 kHz.

Main RF system of the VEPP-4M consists of the control electronics, RF grid tube power amplifiers, RF power transport and distribution system and six RF accelerating cavities (presently only five RF cavities are installed into the storage ring). The frequency of the main RF system is 181 MHz that corresponds to 222nd harmonic of the beam revolution frequency. Table 1 presents some design parameters of the RF system.

Table 1: Main Parameters of RF System

Energy of particles, GeV –	5.3	6.0
Total electron and positron current, mA –	200	80
Radiation energy loss, MeV –	2.7	4.4
Accelerating voltage, MV –	5.5	8.5
Power loss in RF cavities, kW –	250	600
Power transferred to beam, kW –	550	400
Total RF power, kW –	800	1000

RF CAVITIES

The geometry of the cavity and its design are shown in Figure 1. Cavity characteristics are summarized in Table 2.

Cavity walls and other internal parts are made of copper. They are cooled by demineralized water. The cavity is placed in a stainless steel tank. A very high vacuum in the cavity (10^{-7}–10^{-8} Pa) is obtained by a sputter ion pump and a gettering pump. The stainless steel tank is evacuated separately by a sputter ion pump to about 10^{-5} Pa. The cavity can be baked out to a temperature of 300–400°C using tape heaters mounted on the cavity wall inside the vacuum tank. Thermal shields are used for reduction of the heat losses.

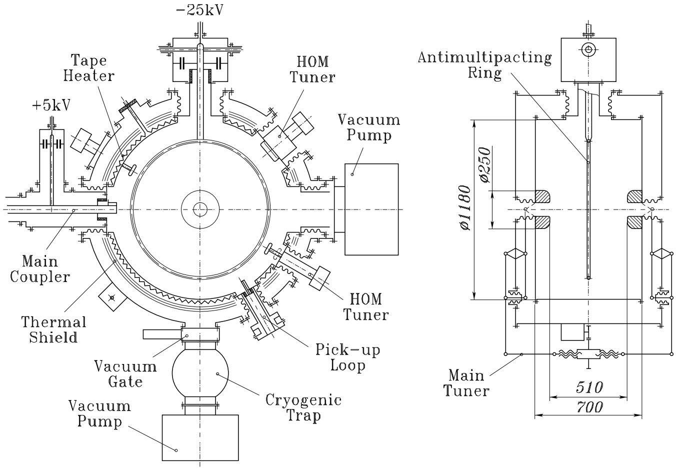

Figure 1: *Schematic view of RF cavity*

Table 2: Parameters of the cavity

Resonance frequency –	180.9	MHz
Tuning range of cavity frequency –	200	kHz
Tuning rate –	4	kHz/s
Accelerating voltage (*V*) –	0–1500	kV
Q value –	50,000	
R/Q value (*) –	292	Ohm
Shunt impedance (*) –	15	MOhm
Wall loss at $V = 1000$ kV –	150	kW
Maximal power flux at $V = 1500$ kV –	4.8	W/cm^2

(*) Shunt impedance R is defined as $R = V^2/P$,
$V^2 = (\int E_z \cos(kz)dz)^2 + (\int E_z \sin(kz)dz)^2$

The tuning of the cavity is performed by squeezing the side walls using a d.c. motor drive with a gear box and levers. There are no sliding joints at this way of cavity tuning.

Three special HOM tuners are provided for tuning the higher order modes of the cavity in order to avoid beam instabilities. This technique is described separately [1].

A ring-shape d.c. biased electrode is placed in the cavity in order to suppress multipacting. For the same purpose the main loop is isolated from the cavity and also d.c. biased.

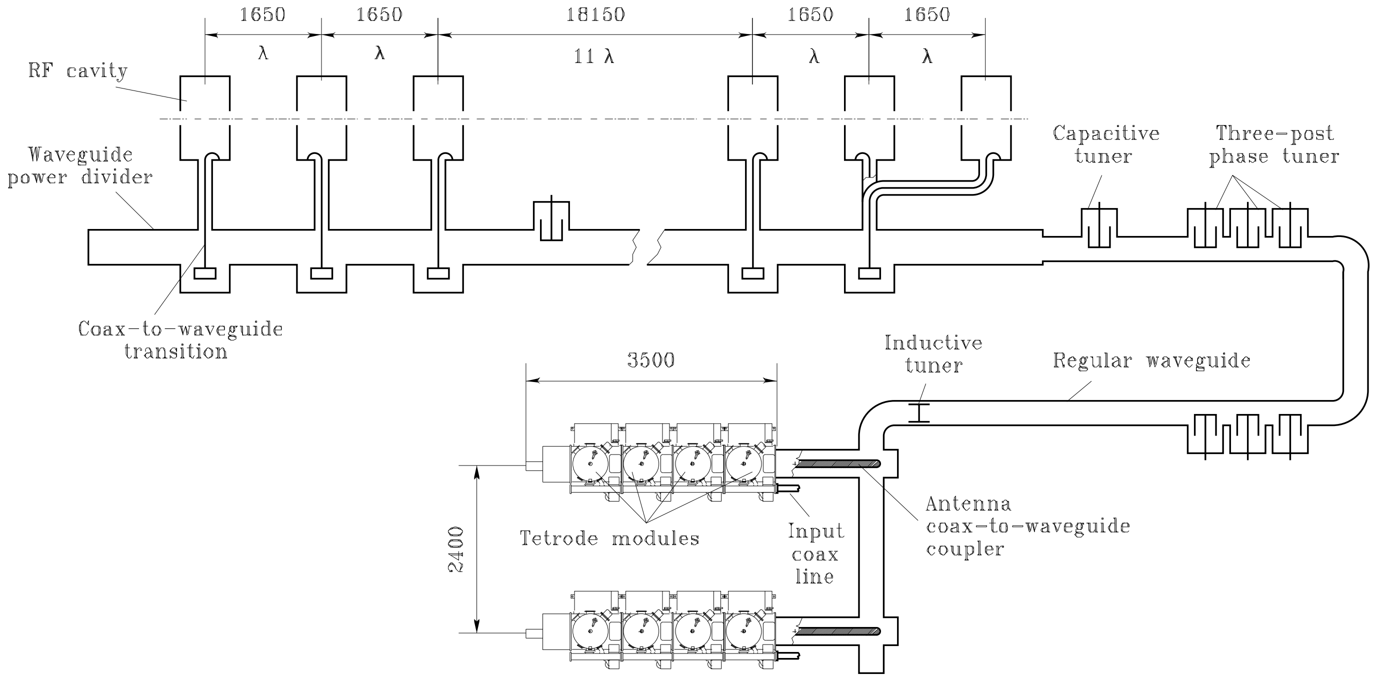

Figure 2: *Scheme of RF system*

RF POWER TRANSPORT AND DISTRIBUTION SYSTEM

The general scheme of the power part of the RF system is shown in Figure 2. As one can see, there are no magic tees or directional power dividers, no ferrite circulators in the RF system. The cavities in the storage ring are grouped by three. The distance between two cavities in a group is equal to the free-space wave length λ (165 cm). The distance between cavity groups is equal to a multiple of λ. Therefore, the fields in the cavities must be in phase. All cavities are driven by a single RF power source.

RF power is transmitted over a rectangular waveguide. The waveguide has different cross-sections in different parts: between cavities in a group (waveguide power divider), between cavity groups, and between cavities and power amplifier (regular waveguide).

Each cavity has a main coupler of a loop type. It is connected to the waveguide with a short coaxial line using a coax-to-waveguide transition which is placed near a small side wall of the waveguide. The waveguide between RF cavities has cross-section of 95.6×50 cm^2. The guide wave length Λ is equal to two free-space wave length λ. So the distance between coax-to-waveguide transitions in a group is equal to $\Lambda/2$ and the distance between cavity groups is equal to a multiple of Λ.

For obtaining the right phasing of cavity fields, the main coupling loop in the middle cavity of a group is rotated on 180^o to the loops of other cavities.

There is a special feature of connection of the cavity #1 to the waveguide divider. Due to a lack of free space the cavity is connected to the waveguide in the cross-section of the cavity #2 but near the other side wall. For the right phasing of the cavity #1, the length of coaxial line is at $3\lambda/2$ more than for the cavity #2.

The design of the coax-to-waveguide transition and the length of coaxial line to a cavity are chosen so that the matrix of transmission from the waveguide to a cavity has a form:

$$\begin{bmatrix} 0 & i/G \\ iG & 0 \end{bmatrix},$$

where $G = I_c/V_w$ is a transconductance (I_c is a current, driving a cavity, and V_w is a voltage in the middle point of the waveguide). The G value is adjusted to provide the matched conditions in the waveguide at the highest design level of RF power transferred to cavities loaded by the beam.

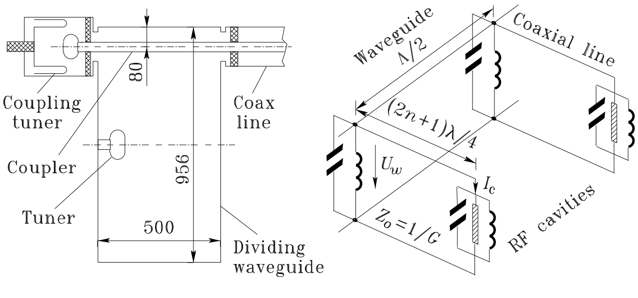

Figure 3: *Schematic view and equivalent circuit of coax-to-waveguide transition of RF power dividing system.*

The schematic view of the coax-to-waveguide transition and its equivalent circuit is shown in Figure 3. The antenna inductance is compensated by a capacitor tuner placed in the middle point of the waveguide.

With this scheme of driving RF cavities, the driving currents I_c are always equal irrespective of actual values of total cavity impedances Z_c (with due account of beam loading) and are determined only by the waveguide voltage. Therefore, power distribution along the cavity chain is proportional to the distribution of real parts of cavity impedances, $R_c = \mathfrak{R}\{Z_c\}$. If the shunt impedances and tunes of the cavities are equal, the driving powers are also equal. Emergency overload of a cavity main coupler is excluded in this scheme if the waveguide voltage does not go over the value set at the transmission of the maximal RF power. To this end the equivalent length of the transmission line between the anode of the tetrode amplifier and the reference plane of the cavities is adjusted to $(2n+1)\lambda/4$ with a three-post tuner. In this case the driving current I_c is limited by the maximum voltage in the anode resonator of the tetrode amplifier which is, in its turn, limited by the d.c. anode voltage.

Regular waveguide has cross-section of 115×37 cm^2. Matching of the dividing waveguide is performed with two stubs. One of them is a capacitive stub (a plunger), the other is an inductive stub (a rod).

RF POWER AMPLIFIER

The RF power amplifier is built from universal multipurpose units. Figure 4 presents a schematic view of a 4-tube output stage. It is similar to a 2-tube module described in [2]. GU-101A CW tetrodes [3] are used in the amplifier. Parameters of the tube are listed in Table 3, parameters of the 4-tube power stage – in Table 4.

Table 3: Limiting values of the GU-101A RF power tetrode:

D.C. anode voltage –	14	kV
Screen grid d.c. voltage –	1.2	kV
Filament voltage –	15	V
Filament current –	730	A
Anode dissipation –	250	kW
Screen grid dissipation –	3	kW
Frequency (max.) –	200	MHz
Maximum envelope temperature –	200	°C
Diameter (max.) –	295	mm
Height (max.) –	600	mm
Weight (max.) –	50	kg

Table 4: Operating conditions for a 4-tube RF power stage (grounded-grid circuit):

Frequency –	181	MHz
Output RF power –	600	kW
Input RF power –	<100	kW
D.C. anode voltage –	8	kV
Screen grid d.c. voltage –	1	kV
Filament voltage –	12.6	V
Filament current –	730	A
Anode dissipation of one tube –	100	kW
Screen grid dissipation of one tube from electron current –	1	kW
Cooling water flow –	300	l/min
Forced air flow –	20	m^3/min
Efficiency –	56	%

The power amplifier has a coaxial output. The extension of the central conductor of the coaxial line stands duty of the antenna of the coax-to-waveguide transition.

Full RF power is obtained by power combining of two 4-tube amplifiers in a waveguide combiner.

CONCLUSION

Presently the RF system of VEPP-4M collider operates at the power level of 300 kW using a 2-tube power amplifier. It affords operation of VEPP-4M up to 5 GeV. Two 4-tube amplifiers have been built and are being adjusted. Tests and commissioning of the full scale RF system will be done this year.

REFERENCES

[1] V. Veshcherevich et al., "RF Measurements and Control of Higher Order Modes in Accelerating Cavities", *This Proceedings*.

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[3] Svetlana Corp., 194156 St. Petersburg, Russia.