RF Power Amplifier for the First Stage of the UNK.

I.A.Kvashonkin,I.G.Umanskij, the Comintern corporation
I.I.Sulygin,IHEP
I.S.Libman,"Svetlana"corporation

Abstract

RF system for the first ring of the UNK includes 8 power amplifier channels with 850 kW CW power at 200 MHz. The output of the power amplifier consists of four powerful cascades combined with hybrids. The common grid cascades use a specially developed tetrode with the available output power of 250 kW. All rectifiers are stabilized and the tube filaments are fed with direct current. The high-voltage anode rectifier is common for all amplifier units and has a reserve one. The system is computerized. Repair and maintenance work is possible on a channel with other power amplifiers working. By now all the main parts of the RF system are manufactured. Three power amplifier units for comprehensive tests are also manufactured. The production of the complete amount of amplifier units will be over in the first half of 1993.

1 INTRODUCTION

The accelerating system of the first ring of the UNK contains 8 accelerating RF units [1]. Each unit produces an accelerating voltage of 1 MV in the fixed-target operating mode and about 2 MV in the collider one. With a high beam load and the reflection from cavities, due to the absence of detuning during the acceleration cycle, the RF power required for each acelerating unit is about 800 kW at a frequency of 200 MHz.

The required power variation during the acceleration cycle is from 10 to 100%. The UNK beam contains 12 trains of bunches each lasting about 5 μs at an interval of 0.6 μs. The maximum RF power tranferred to the beam reaches 480 kW per unit. The ± 1 MHz bandwidth at the 3 dB level of the RF power amplifier ensures the required fast response of the programmable feedback for compensation of such a beam load.

Long stacking and acceleration times, 72 s and 20 s, respectively, impose stringent requirements on the spurious modulation of the accelerating RF voltage especially at the frequencies of power line harmonics, e.g. ± 0.1% in amplitude at 200 Hz and 0.025° in phase at 100 Hz.

2 SYSTEM CONFIGURATION

Each RF channel (see fig.1) includes a 200 W transistor amplifier, a 5 kW cascade with TV tetrode GU-92B, a 80 kW driver, a hybrid power divider system, 4 parallel final cascades and a power combiner system, providing an output power of 850 kW. The driver and final cascades are identical coaxial-circuit amplifier units with a power tetrode GU-101A.

The transistor amplifier has additional low-frequency input for the signals controlling the amplitudes and phases, required for stabilization and control of the accelerating RF voltage.

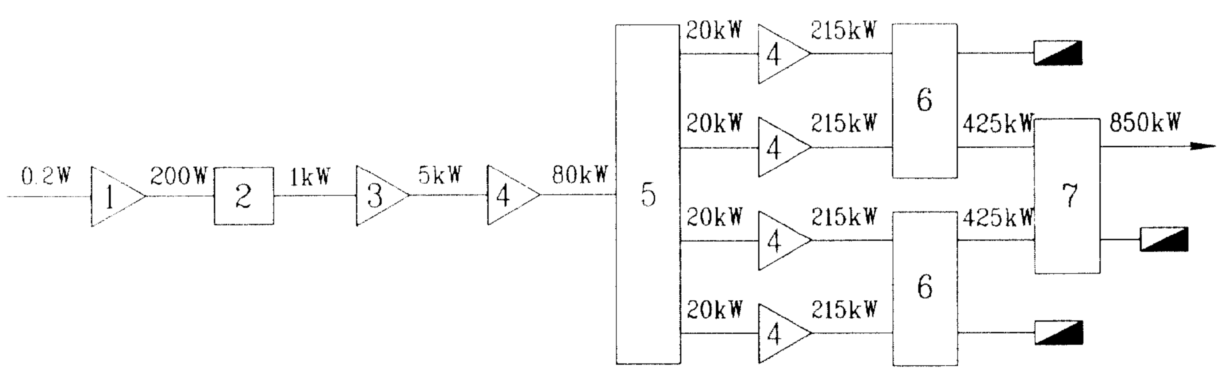

Figure 1: Configuration of the RF channel: 1 – transistor amplifier, 2 – ferrite circulator, 3 – amplifier with tetrode GU-92B, 4 – amplifier with tetrode GU-101A, 5 – hybrid divider system, 6 – coaxial hybrid combiner, 7 – waveguide hybrid combiner

To raise the reliability of the cascade with tetrode GU-92B and of the driver with tetrode GU-101A, they give about half of the output power nominal for these tubes. The hybrid divider system contains three coaxial servo-controlled phase shifters allowing one to phase the final cascades in order to attain the maximum efficiency of the hybrid combiner system.

Each of the four final cascades at the 20 kW excitation level gives about 220 kW of the output power. The hybrid combiners of the power of two tubes are coaxial and that at the channel output is a waveguide short-slot one.

High-voltage power supplies of tetrodes GU-101A have a common anode thyristor rectifier, rated for 1000 A at 12 kV DC, and a common screen grid one rated for 1000 A at 1 kV DC. To raise the reliability of the RF system these power supplies have 100% reserve. The anodes and screen grids of tetrodes GU-101A of each of the 8 channels are fed from these rectifiers through their own LC-filters. Each channel is equipped with a thyratron crowbar to divert the energy in the event of a tube arc. Individual regulated control grid bias supplies are used for each tube.

After repair work the tubes are conditioned and blocks tested at a special conditioning stand which is a shortened RF channel having only two final cascades with their own power supplies. There is the possibility to connect them to the anode and screen grids of tetrodes GU-101A of any faulty RF channel to test and tune it after the repair work.

3 POWERFUL CASCADE

The cascade uses a water-cooled metal-ceramic tetrode GU-101A designed at the "Svetlana" Corporation (Saint Petersburg) especially for this system.

The tetrode has the foolowing parameters:

maximum output CW power at 200 MHz	250 kW
maximum operating frequency	250 MHz
gain, not less than	15
admissible anode power dissipation	250 kW
maximum diameter	270 mm
length	580 mm
weight	50 kg

The cascade is built following the scheme of common control grid and a screen grid physically grounded. The cathod input coaxial circuit has an electric length of $\lambda/4$ and the anode one has $3\lambda/4$.

The anode decoupling cylindrical mica capacitor is placed in series in the inner conductor in the current node. The coupling with the load is conductive. The anode circuit is connected with 50 Ω, 160 × 70 mm coaxial feeder through a 20 Ω, $\lambda/4$ strip line transformer. The coupling is varied by a parallel short-circuit stub, whose length is less than $\lambda/4$, connected to the output of the $\lambda/4$ transformer. The length of the screen grid - control grid circuit is much less than $\lambda/4$. The absorbing ferrites are placed into the volume of this circuit.

The cascade is placed into a 0.8 × 1.1 × 2.2 m screening cabinet. The anode is water-cooled and the flanges of the cathode and grids as well as the circuits are air-cooled.

To reduce the level of spurious amplitude and phase modulation the tetrode filament is fed with DC current. To prevent the 460 MHz intertube spurious generation, developing in the open tube and in the absence of the operating RF voltage on its control grid, the tube operates in class C.

The cascade tested at 200 MHz operated for the terminating load and also for the accelerating unit fed through a waveguide feeder about 15 m long and showed a stable operation. The parameters of the two modes of tests for the terminating load are presented below.

anode voltage	10.7 kV	12.1 kV
anode current	36 A	35.8 A
cathode current	37 A	37 A
screen grid voltage	0.87 kV	0.87 kV
control grid voltage	-310 V	-370 V
control grid current	0.7 A	0.85 A
RF output power	250 kW	250 kW
RF drive power	16.7 kW	20 kW
anode efficiency	0.6	0.54

These modes were realized for 20-s pulses and a duty factor of 50%. These modes are more stringent than those required for the operation of the cascade in the first ring of the UNK, where the required power is 220 kW with a duty factor of about 30%. In the collider mode, where continuous operation is needed, the required mean RF power does not exceed 500 kW per channel.

The cascade was tested also in continuous mode during some hours when the output RF power was 250 kW. However, this mode cannot be considered acceptable for this design of the amplifier. The major limiting factors are the heating of the tetrode screen grid by RF current and the insufficient cooling of the circuit system.

In addition to tetrode GU-101A with metal grids "Svetlana" corporation also developed tetrod GU-105A with pyrolitic graphite grids, having actually the same size and dimensions as the previous one. Presently two companies, "Comintern" and "Svetlana" corporations, are studying and comparing the two tetrodes with a view to finalize the type of the tetrode satisfying the UNK requirements in terms of overall technical and economic advantages.

4 CONTROL SYSTEM

The control system for the RF channel is a low-level part of the hierarcy of control system for the whole machine. The currents, voltages and RF power levels are controlled in each channel at 150 points.

The system processes and outputs the information on the mode of the channel as a whole and its single units, warns about approaching the boundaries of admissible operating modes, and diagnoses rejections.

To raise the reliability of the cascade with tetrode GU-92B and of the driver with tetrode GU-101A, they give about half of the output power nominal for these tubes. The hybrid divider system contains three coaxial servo-controlled phase shifters allowing one to phase the final cascades in order to attain the maximum efficiency of the hybrid combiner system.

Each of the four final cascades at the 20 kW excitation level gives about 220 kW of the output power. The hybrid combiners of the power of two tubes are coaxial and that at the channel output is a waveguide short-slot one.

High-voltage power supplies of tetrodes GU-101A have a common anode thyristor rectifier, rated for 1000 A at 12 kV DC, and a common screen grid one rated for 1000 A at 1 kV DC. To raise the reliability of the RF system these power supplies have 100% reserve. The anodes and screen grids of tetrodes GU-101A of each of the 8 channels are fed from these rectifiers through their own LC-filters. Each channel is equipped with a thyratron crowbar to divert the energy in the event of a tube arc. Individual regulated control grid bias supplies are used for each tube.

After repair work the tubes are conditioned and blocks tested at a special conditioning stand which is a shortened RF channel having only two final cascades with their own power supplies. There is the possibility to connect them to the anode and screen grids of tetrodes GU-101A of any faulty RF channel to test and tune it after the repair work.

3 POWERFUL CASCADE

The cascade uses a water-cooled metal-ceramic tetrode GU-101A designed at the "Svetlana" Corporation (Saint Petersburg) especially for this system.

The tetrode has the foolowing parameters:

maximum output CW power at 200 MHz	250 kW
maximum operating frequency	250 MHz
gain, not less than	15
admissible anode power dissipation	250 kW
maximum diameter	270 mm
length	580 mm
weight	50 kg

The cascade is built following the scheme of common control grid and a screen grid physically grounded. The cathod input coaxial circuit has an electric length of $\lambda/4$ and the anode one has $3\lambda/4$.

The anode decoupling cylindrical mica capacitor is placed in series in the inner conductor in the current node. The coupling with the load is conductive. The anode circuit is connected with 50 Ω, 160 × 70 mm coaxial feeder through a 20 Ω, $\lambda/4$ strip line transformer. The coupling is varied by a parallel short-circuit stub, whose length is less than $\lambda/4$, connected to the output of the $\lambda/4$ transformer. The length of the screen grid - control grid circuit is much less than $\lambda/4$. The absorbing ferrites are placed into the volume of this circuit.

The cascade is placed into a 0.8 × 1.1 × 2.2 m screening cabinet. The anode is water-cooled and the flanges of the cathode and grids as well as the circuits are air-cooled.

To reduce the level of spurious amplitude and phase modulation the tetrode filament is fed with DC current. To prevent the 460 MHz intertube spurious generation, developing in the open tube and in the absence of the operating RF voltage on its control grid, the tube operates in class C.

The cascade tested at 200 MHz operated for the terminating load and also for the accelerating unit fed through a waveguide feeder about 15 m long and showed a stable operation. The parameters of the two modes of tests for the terminating load are presented below.

anode voltage	10.7 kV	12.1 kV
anode current	36 A	35.8 A
cathode current	37 A	37 A
screen grid voltage	0.87 kV	0.87 kV
control grid voltage	-310 V	-370 V
control grid current	0.7 A	0.85 A
RF output power	250 kW	250 kW
RF drive power	16.7 kW	20 kW
anode efficiency	0.6	0.54

These modes were realized for 20-s pulses and a duty factor of 50%. These modes are more stringent than those required for the operation of the cascade in the first ring of the UNK, where the required power is 220 kW with a duty factor of about 30%. In the collider mode, where continuous operation is needed, the required mean RF power does not exceed 500 kW per channel.

The cascade was tested also in continuous mode during some hours when the output RF power was 250 kW. However, this mode cannot be considered acceptable for this design of the amplifier. The major limiting factors are the heating of the tetrode screen grid by RF current and the insufficient cooling of the circuit system.

In addition to tetrode GU-101A with metal grids "Svetlana" corporation also developed tetrod GU-105A with pyrolitic graphite grids, having actually the same size and dimensions as the previous one. Presently two companies, "Comintern" and "Svetlana" corporations, are studying and comparing the two tetrodes with a view to finalize the type of the tetrode satisfying the UNK requirements in terms of overall technical and economic advantages.

4 CONTROL SYSTEM

The control system for the RF channel is a low-level part of the hierarcy of control system for the whole machine. The currents, voltages and RF power levels are controlled in each channel at 150 points.

The system processes and outputs the information on the mode of the channel as a whole and its single units, warns about approaching the boundaries of admissible operating modes, and diagnoses rejections.

On operator's demand it releases the design data, e.g. the power of dissipation on the anode and screen grid of the tube, gain, the level of ripples, etc.

The automatic recording of the controlled signals at some points within fixed time intervals allows the operator to scan in retrospect the modes of the units of interest. The forecasting system of rejections is planned to be introduced in the future.

5 SYSTEM DESIGN AND LAYOUT

A special building for the RF powe supply system is under construction now.

The RF channel has a cabinet design which, in addition to its aesthetic function, also ensures an additional screening of the RF equipment.

The lines of the RF channels are spaced at 3 m from one another on the first floor; the length of one line is 7.4 m. Each line is connected to a 3 × 5 m box containing the mains cabinet, LC-filters, auxiliary rectifiers, control and protection units, and mechanical interlock.

In the gallery beneath the RF lines there are the hybrid RF power dividers and combiners, coaxial phase shifters, water-cooling systems and boxes of the air-cooling system.

The powerful rectifiers and their mechanical interlocks are placed on the ground floor.

6 PRODUCTION OF EQUIPMENT

Last year actually all equipment of the RF system, except for powerful cascades, was manufactured and delivered to Institute for High Energy Physics.

Since the powerful cascades are complicated and very important units in terms of the reliability of the whole RF system it was decided to manufacture first only three cascades to test them, upgrade the design and correct the technical documentation.

Now this work is over, the corrected documentation was sent to the manufacturing company. The required 45 cascades will be manufactured in the first half of 1993.

7 ACKNOWLEDGEMENTS

The authors are greatly indebted to all specialists participating in the development and tests of the RF power supply system. In particular, they are grateful to V.P. Yelin, F.Ya. Porotsky, O.V. Turchaninov, I.M. Zhukov and O.V. Stryukov for their kind assistance in testing the RF final amplyfier cascade. They are also grateful to G.G. Gurov, E.A. Petrov, and V.D. Prokofiev for fruitful discussions and helpful remarks.

8 REFERENCES

[1] Katalev V.V. et al., "The 200 MHz accelerating structure for UNK", paper presented at this Conference