A NEW 200 MHz POWERFUL PULSE TRIODE FOR THE OUTPUT POWER AMPLIFIER OF DTL RF SYSTEM

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Abstract

Designed about 30 years ago 200 MHz powerful pulse triode GI-54A has supplied Moscow Meson Factory DTL operation as a vacuum tube in the output power amplifier (PA). Last years in connection with the worsening of the economic situation in Russia and a complexity of the manufacture of GI-54A its production was ceased. Instead of GI-54A in CSC "SED-SPb" more simple and cheap vacuum tube was designed with output RF power up to 3 MW in pulse, anode power dissipation up to 120 kW and power gain about 10. In the paper results of the design and testing of the new generator triode in the PA of the MMF DTL RF system are described.

1 INTRODUCTION

The power pulse grid triode “Katran” is developed for use in output power amplifiers (PA) of DTL RF system of Moscow Meson Factory within its modernization [1]. The main purpose of new triode development instead of the GI-54A triode used before (the analogue of vacuum tubes ## 2054, 7835 developed by RCA, USA during the sixties) was a creation of a tube more simple in design and production process, with higher reliability and resistibility to self-excitation. It was necessary to keep the electrical parameters and dimensions of new tube maximal close to ones of GI-54A so that it could be installed in the output PA plate-grid cavity instead of GI-54A. Design of the GI-54A tube developed earlier was very complicated and labour-consuming. Its manufacturing required a number of laborious operations, unique technological and test equipment, trained personell of high qualification. In connection with decreased requirements to parameters of DTL RF system of the MMF in comparison with initial project an opportunity to use in output PA a tube of more simple design was created.

2 THE MAIN PARTICULARITIES OF THE NEW TRIODE DESIGN

The design of new triode was based on the use of experience of such power grid tube development as GI-27A, GU-88A, GU-101A, GU-104A etc. designed by CSC "SED SPb". The main features of these tubes are pile metal-ceramic base, concentric electrode system that consists of thoriated tungsten mesh cathode, grid, made of metal pins with cross winding, massive copper anode. Initially it was supposed to use a grid of pirolitic graphite as having a lot of advantages in comparison with metal grid. In particular, pirolitic graphite grid has considerably smaller thermoelectron emission and greater form stability, its mechanical strength grows at the temperature increasing [2]. This is very important because the grid receives a significant part of radiation power from the cathode and the RF losses value in the most intensive area of the grid exceeds electron bombardment power [2]. However unfortunately, it was to be refused use pirographite grid. It was connected with the unreasonably large expenses for maintenance of pirographite grids production taking into account small market for these tubes. Therefore one of the main problems was a design of the grid with permissible thermoelectron emission level. The negative consequences of the thermoelectron emission presence become strong in pulse conditions at DC anode voltage and also at grid leak presence. In these cases the system efficiency may fall considerably and operating regime of stage becomes unstable. But in MMF DTL RF system two output power amplifiers are supplied by one anode modulator and cathode self-bias is used. Thus there are no main negative factors in this system. In spite of this, it is impossible to exclude a possibility of thermoelectron emission source localization and electron beam orientation to some parts of cathode area. That may be a reason of anode overheating or even its partial smelting. Calculations which have been carried with use of Richardson-Dashman law [3] have shown that at operating temperature of about 1400K of the grid, dusted with thorium, thermoelectron emission is 60 $\mu A / cm^2$. A special technology for antiemission covering was developed. It allows to decrease the level of thermoemission approximately 10 times. It was necessary to develop a cathode with the same emission capability as that of the GI-54A tube. The GI-54A tube had cathode emitting surface 440 cm^2, emission current 1200 A, anode pulse current 600 A at the working point. For the new tube a mesh cathode have been chosen, which allows to vary operating temperature and surface in wide range by variation of its geometry dimensions. The cathode temperature was chosen so as to provide cathode operating life of about 5000 hours. Specific emission of that cathode achieve 2.5-2.7 A/cm^2 and hence cathode emission surface have to be of about 500 cm^2. The cathode cylinder diameter was chosen close to 137 mm to use unified parts and invariable anode ceramic. The cathode cylinder height is limited by allowable length of the output gap which, in turn, is limited by output cavity resonance frequency and by anode location in the cooling tank. Taking into account necessary clearances, the

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cathode mesh height is 150 mm. Diameter, inclination and quantity of cathode filaments were chosen to provide minimum mechanical tensions and deformations at cathode mesh heating under its own mass [4]. These values are: filament diameter - 0.35 mm, quantity of filaments - 136, angle of the filament inclination relatively to the plane normal to the cathode axis is 27 degree. Maximum thermal deformation was not more than 1.2-1.4 mm [4]. This cathode has emitting surface providing anode current 600 A in pulse and emission current 1200 A. A number of important parameters - gain factor, electron efficiency, losses on grid, - are determined to a great extent by grid structure and electron optics system. For example, in GI-54A tube the grid-cathode gap is less than 1mm. This provides transconductance of about 1000 mA/V and gain factor about 25. In the new triode, the grid-cathode gap must be not less tan 2-3 mm, as it is necessary to take into account possible deformation of cathode and grid. That is why even in spite of larger cathode surface in “Katran”, its gain factor is about 10. At plate voltage E_a = 30 kV, intensity of regime $\xi \leq 0.75$ and output power P_{out} = 3 MW the current division is $I_a/I_g = 4$, that is quite acceptable. In some conditions of GI-54A use at MMF (at unloaded of PA), self-excitation of an output amplifier took place at operating frequency. To avoid self-excitation, some samples of "Katran" have been made with lower feed-through capacity, with so-called double grid, i.e. having two grid cylinders. The second cylinder pins are positioned in shadow of the first cylinder pins. As a result the feed-through capacity has been decreased 1.5 times, down to 2 pF. Besides, this grid design allows to increase maximum grid dissipation more than 1.5 times, which helps it to use the triode in forced regimes. The main parameters of the triode are shown in a table, its anode-grid characteristics and the general view are presented in Fig.1 and Fig.2

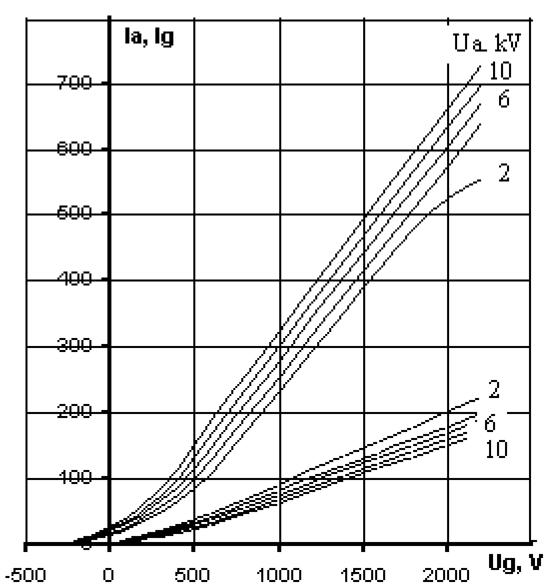
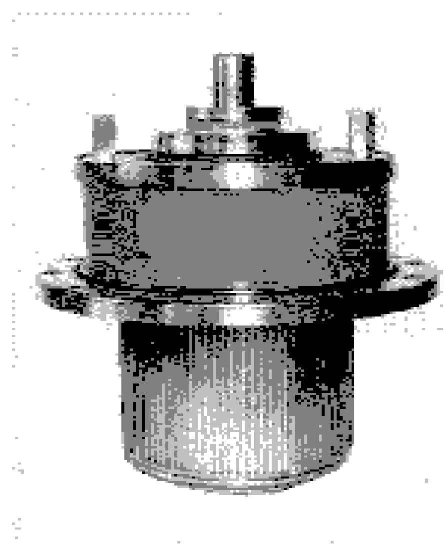


Fig.1 Anode-grid characteristics

	Parameter	Value
1	Heater supply: voltage (dc or ac), V current, A	16-16,8 850-1100
2	Negative grid-bias, V	< 1500
3	Pulse anode voltage, kV	< 35
4	Anode dissipation power, kW	< 120
5	Grid dissipation power, kW	< 2
6	Emission current (Ue=2,5kV), A	~ 800
7	Pulse duration, μs	400
8	Duty factor, %	4
9	Direct interelectrode capacitances (grounded grid), pF: Cin Cout Cpk	 250-400 70-100 1,5 – 5
10	Net weight, kg	~ 45
11	Operating position	Anode down
12	Water flow rate, l/min For anode cooling For grid cooling For cathode cooling	 60 8 10
13	Maximum Overall Dimensions: Length, mm Diameter, mm	 460 330

Table 1



In the end of this part of the paper it’s need to remind that at design of the new triode it was necessary to provide use of the exterior anode-grid cavity and tank of water cooling , used at operation GI-54A. For maintenance of overall dimensions of the anode water cooling tank the anode flange, close on a construction to a flange of a tube GI-54A, was used. For the solution of a problem of the exterior anode-grid cavity using was calculated and realized the external inductance of the anode circuit connected to the output gap of a tube “Katran” for ensuring of a resonance on frequency 200 MHz.

3 TEST RESULTS OF "KATRAN"

The first reference to new triode "Katran" was made in report at conference PAC-95 (Dallas, USA) [5]. During the next five years four samples of new tube were tested in RF output amplifier of reserve chanell of MMF DTL RF system. The reserve chanell might be connected with help of power coaxial switchers, installed in CTL between output amplifiers and tanks, to matched load or to any of five DTL tanks with different levels of RF losses in walls – from 0.9 MW in the 5-th tank to 2 MW in the 2-nd one. The RF driver of "Katran" was the same as for the GI-54A tube that has double power gain. That is why due to insufficient level of RF drive it was impossible to optimize the operation mode and efficiency of "Katran".The long-term tests were made in conditions of interrupted twenty-four-hour operation during beam runs. The tests have shown that in spite of insufficient level of RF power drive some tube samples were able to supply a tank with RF pulse power up to value of 2-2,2 MW (average RF power was 60-70 kW) at Ea=30-32 kV and efficiency of 35-40%. Life time of four tested tubes was no more than 1500 hours. For all this three of four tubes failed because of emission loss. All failured tubes were sent to "SED SPb", where they were opened , causes of failures were analyzed, and necessary modifications were made. Test results of restored tubes showed that tubes' parameters were improved considerably. It gave a possibility to start new tube operation in the regular RF channal of the RF system. The first of the tubes was installed in the PA of the fifth tank RF channel. The tube has been working in this channel for more than two years up today with output RF power about 1 MW, anode voltage Ea=19 kV, anode current Ia=110 A. The total operating time of this tube is at present about 5000 hours without perceptible impairment of parameters. In addition

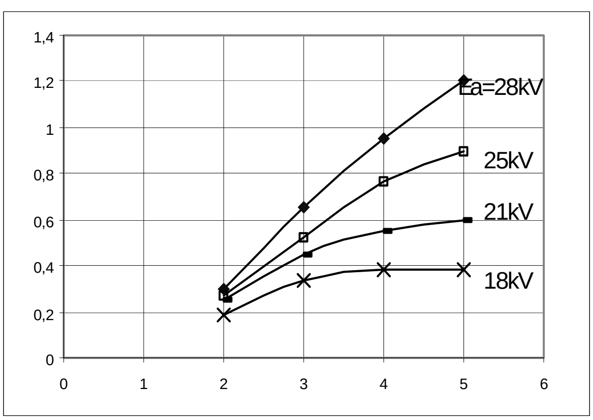


Fig.3 Experimental dependencies of the RF channel output pulse power (in MW) from a driver RF power

two sets of assambles to change over PA from GI-54 to "Katran" tube are prepared. It will give a possibility to change over two new tubes in the next RF channels. Control characteristics of amplifier channel with "Katran" are shown in Fig.3. They present dependence of RF output pulse power versus anode voltage and RF drive level that changed by adjusting of anode voltage value of two-stage RF amplifier tubes at the input of channel. As follows from characteristics above in contradiction to the GI-54A tube new triod gives a possibility to make output power regulation not only by means of plate voltage but by means of RF drive value. It clears the way to create more effective up-to-date system of accelerating field stabilization in Cartesian (I/Q) coordinates. Besides, as follows from these characteristics, with increasing plate voltage an available level of RF drive power becomes insufficient and it is required to increase plate voltage for achieving a desired level of RF power. At RF output power in pulse about 2 MW plate voltage of a tube "Katran" is 10-12 kV higher then that of a tube GI-54A .

4.CONCLUSION

- Tests of new power triode "Katran" during a few years have shown that in spite of hard economic situation at "SED SPb" it has become possible to develop new power transmitting triode with output parameters that ensure required operation mode of DTL RF systems of MMF in full that has been stated last years and is characterized by pulse beam current 10-15 mA and average current up to 100 μA.
- For more effective performance of the tube "Katran" it is necessary to undertake measures to increase RF drive level of RF output amplifier half as much, i.e. from 200 kW to 300 kW.
- The new power triode allows to realize RF power control by means of not only plate voltage, as it takes place for GI-54A, but by means of RF drive value also. It opens possibilities for creation of new control systems, stabilizing RF field in DTL tanks, on the basis of up-to-date standard integrated circuits.

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