STATUS OF INR DTL RF SYSTEM

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Abstract

INR Linac is in regular operation since 1993. The accelerator incorporates DTL and DAW structures operating at 198.2 MHz and 991 MHz correspondingly. Initially two types of high power vacuum tubes specially designed for INR DTL (GI-54A for final amplifier and GI-51A for intermediate amplifier) were used in the RF power system. However production of these tubes has been stopped resulting in a need of DTL RF system upgrade. The main goal of the last upgrades is replacement of the old tubes by modern ones as well as development and implementation of series crowbar system. Replacement of the tubes is not an easy task, because new tubes have to be installed in the old structures. The results and the experience of INR DTL RF system upgrade are presented.

INTRODUCTION

Last time information on the status of INR DTL RF system has been presented eight years ago [1]. Since then several significant upgrades have been done in the DTL RF system including the series crowbar system implementation [2,3] and replacement of powerful grid tubes in both intermediate power amplifier (IPA) and final power amplifier (FPA). Since 1993 up to now grid tubes GI-51A and GI-54A have been in operation in IPA and FPA, correspondingly. However, at the beginning of the nineties manufacture of the above tubes at CSC "SED.-SPb" (former name – Electron Device Mfg. Corp. "Svetlana") has ceased and INR DTL RF system operation continued only due to the earlier plentiful supplies. At the same time the new grid tube GI-71A ("Katran") [4] was developed and designed in the CSC "SED-SPb" as the alternative to GI-54A. The requirement for GI-71A was to keep the dimensions and the anode-grid capacity C_{ag} about the same as for GI-54A in order to avoid essential reworking of the anode-grid cavity.

GI-71A tubes have been tested in the final power amplifiers of INR DTL RF system for ten years. Now they are installed in four of five FPA, including the most powerful amplifier for the third drift tube cavity.

Replacement of GI-51A (tetrode) by GI-57A (triode) appeared to be more complicated task and additional investigations were required.

RESULTS OF THE SERIES CROWBAR SYSTEM LONG TERM OPERATION

The series crowbar system (SCS) has been described earlier [2, 3]. At that time the system was in operation for 700 hours only. By now it is in operation for more than 5000 hours. The system cuts off anode HV pulse in case of discharges or sparking in IPA or FPA. One should note that the SCS can be realized only for vacuum tube modulators, which is the case in INR DTL RF system. Now the modulator is intended for three purposes:

1. Generation of the anode high voltage pulses for IPA and FPA tubes.
2. Control of the anode voltage with the aim of stabilization of the accelerating field amplitude.
3. Protection of IPA and FPA grid tubes in case of sparking or discharges inside of the tubes.

There are two main reasons of crowbar system activation.

The first one is due to HV breakdowns in the anode-grid cavity. Neither in IPA nor in FPA blocking capacitors are used for separation of HV and RF circuits. HV is applied to the central conductor of the coaxial cavity at the node of RF electric field. The voltage between the central conductor and the ground is a superposition of the anode pulse voltage and the cavity RF one. RF voltage is an order of magnitude higher than the anode voltage and the probability of RF breakdown is not negligible. The RF breakdown initiates HV breakdown, and, as a result, the full discharge of modulator storage device capacitors. The activated series crowbar system cuts off the modulator pulse thus preventing discharge of the capacitors and excessive local energy dissipation.

The second reason is breakdown or sparking in the grid tube directly. We have no possibility to preliminary age new tubes so there are numerous breakdowns for several days after installing new grid tubes in RF amplifiers. Earlier each sparking inside the tube resulted in interruption of accelerator operation for 10-15 minutes. New series crowbar system enables to diminish the interruptions to a few sec only. As a result we have got a possibility to age tubes during accelerator operation and have essentially decreased beam interruptions.

INTERMEDIATE POWER AMPLIFIER

Utilization of new grid tube GI-57A in IPA instead of GI-51A was not a trivial task not only due to different sizes of the tubes but also due to different modes of operation: GI-51A has operated with common cathode and GI-57A is foreseen for common grid operation.

Changing of the tube resulted in a need of additional calculation of the anode-grid cavity electrodynamics. Eigen mode frequencies as well as field distributions have been calculated and analysed. Special attention was paid to field distribution in the loop area as well as to higher modes that could be excited.

The model of the anode-grid cavity is shown in Fig.1.

ISBN 978-3-95450-125-0

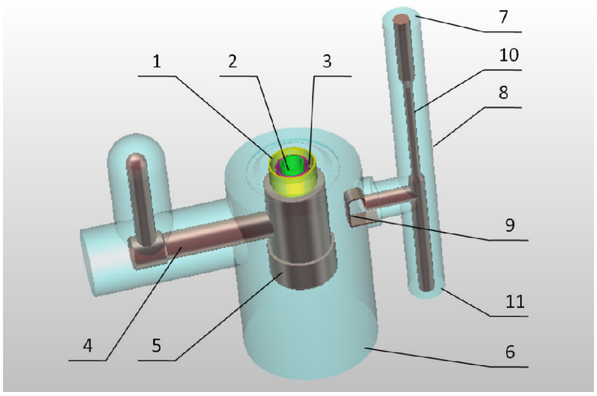

Figure 1: Model of the IPA anode-grid cavity.

The following designations are used: 1,2 and 3 - cylindrical electrodes of anode, grid and ceramic seal of the tube; 4 - unit for supplying high voltage pulse and cooling water to anode; 5 - nozzle at central conductor of the coaxial cavity, which can be moved by several millimetres; 6 – outer conductor of the cavity; 7 – RF power output; 8 – short-circuited coaxial line with moving piston 11; 9 – loop; 10 – λ/4 transformer.

Unit 8 along with λ/4 transformer 10 and moving piston 11 is aimed to properly transform the 50 Ohm load impedance to the loop and to the anode-grid gap.

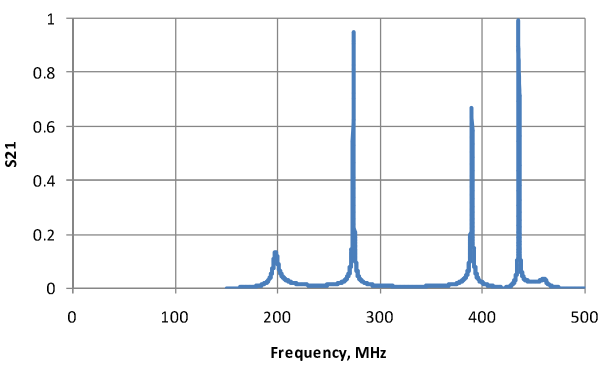

Figure 2: IPA anode-grid cavity frequency spectrum.

The geometry and the dimensions of the tube electrodes in the model do not exactly correspond to those of the real tube. The dimensions of tube electrodes were varied in the model to obtain the same operating mode frequency as in real installation. It has been verified that changing the configuration of tube electrodes with corresponding trimming of the dimensions to maintain resonant frequency does not result in observable change of RF field distributions in the main volume of the cavity except the neat tube area.

Typical IPA cavity frequency spectrum is shown in fig.2. The first f_{01} and the third f_{02} lines are of special interest. The first one is the operating frequency and the third one is very close to the second harmonic of the operating frequency. The line f_{02} can be excited by the second harmonic of the anode current.

Distributions of electric and magnetic fields at frequency f_{01} are presented in fig. 3 and 4.

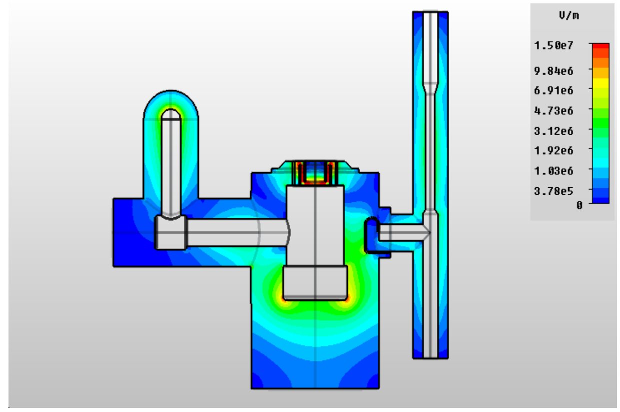

Figure 3: Distribution of electric field.

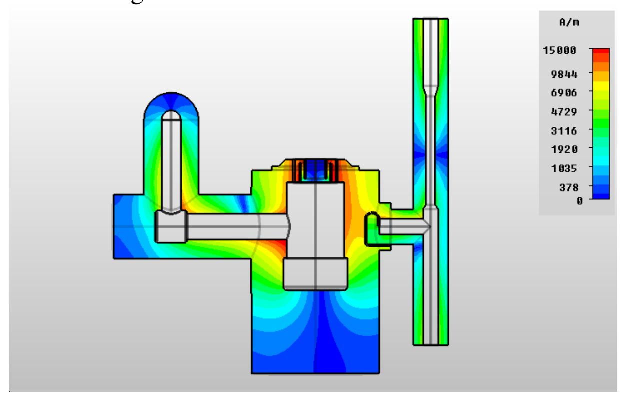

Figure 4: Distribution of magnetic field.

Analysis of the distributions as well as other results of simulations enables to formulate some conclusions and recommendations. Coupling loop is located in the region of about maximum magnetic field and there is no need to move it. Electric field between the central conductor nozzle and the bottom of the cavity is very week and, hence, frequency tuning by means of bottom displacement is ineffective. Anode-grid cavity tuning procedure includes tuning the resonant frequency as well as the equivalent resistance of anode-grid gap R_{oe} in order to maximize power transmitted to the output [5]. These adjustments are not independent and can be done with nozzle 5 and shortening piston 11. Frequency mode f_{02} has a maximum electric field in a loop-central conductor area. Adjustment of the nozzle position as well as the cavity bottom position in order to shift resonant frequency f_{01} of the operation mode simultaneously shifts the frequency f_{02}. For some positions the exact relation f_{02}.$=2 \cdot f_{01}$ is obtained thus resulting in effective excitation of f_{02} mode by the second harmonic of anode current which is dangerous from the point of view of breakdowns.

COMMON OPERATION OF IPA WITH TUBE GI-57A AND FPI WITH TUBE GI-71A

Installation of tubes GI-57A and GI-71A was done in several stages. At the first stage tubes GI-71A were only installed in FPA of the less powerful RF channels for the first and the fifth DTL cavities (nominal power 1÷1.2

MW). Long-term successful operation enabled to proceed further modernization. At the second stage tube GI-71A only was installed in RF channel for the forth DTL cavity and several problems have been revealed. To obtain the nominal power near 2 MW anode voltage had to be increased by 3÷4 kV. Local overheating of the coaxial line from IPA to FPA was also observed.

The next stage was installation of GI-57A in IPA instead of GI-51A in the forth RF channel. Though GI-57A is a triode, whereas GI-51A is a tetrode, the value of IPA output power has increased for the same input power. Nominal power at the output of FPA was obtained for smaller anode voltages and anode and grid currents of FPA thus indicating improvement of FPA efficiency. The tandem of GI-57A and GI-71A operated in the forth RF channel for 6000 hours. Though the problems of breakdowns in the coupling loop area of IPA and overheating of the coaxial line from IPA to FPA have not been overcome generally positive results of operation as well as the lack of tubes GI-54A for FPA enabled to proceed to the next stage – installation of GI-57A and GI-71A in the most powerful channel (2.5 MW) for the third DTL cavity.

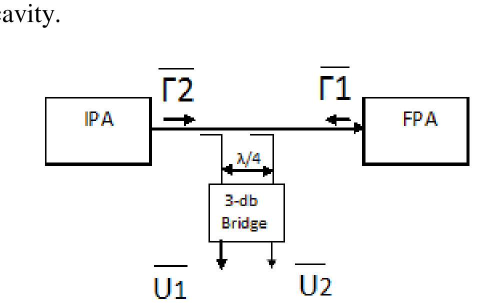

Figure 5: Directional coupler for matching measurement

In the second RF channel all the above listed problems notably increased. Due to absence of circulators between IPA and FPA breakdowns in IPA and overheating in coaxial line could be due to bad matching with FPA. To verify this version the simplest directional coupler has been installed between IPA and FPA (fig. 5). If loop sizes and lengths of cables from loops to bridge are identical, then $U_1 = kU_{inc}(1+\overline{\Gamma}_1\overline{\Gamma}_2)\overline{\Gamma}_1$ and $\overline{U}_2 = k\overline{U}_{inc}(1+\overline{\Gamma}_1\overline{\Gamma}_2)$, where U_{inc} - amplitude of the incident wave. In this case the value of reflection can be found as $\Gamma_1 = U_1/U_2$. After retuning of FPA cathode-grid cavity (by changing of short circuit coaxial cavity length) the value of the reflection coefficient Γ_1 has been decreased by a factor of 2÷3 and the situation has been noticeably improved.

Figure 6 demonstrates experimental behavior of output power (upper curve), anode current of GI-57A (middle curve) and anode current of GI-71A (lower curve) versus anode voltage, kV. The anode voltage is common for the two tubes. The FPA output was connected to powerful matched terminator.

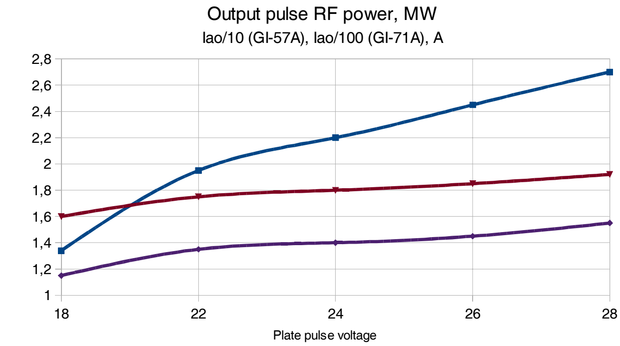

Figure 6: Experimental dependencies of FPA output power and anode currents of GI-57A and GI-71A.

CONCLUSION

The most significant INR DTL RF system upgrades for the last eight years were development and implementation of the series crowbar system as well as replacement of powerful grid tubes in the intermediate and final power amplifiers. The modernization not only decreased the problem of the tubes deficiency but also increased the efficiency of RF channels. Installation of new tubes in the next in power RF channel #2 is scheduled for the end of this year.

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ISBN 978-3-95450-125-0