IMPROVING OF THE DTL CAVITY RF VOLTAGE STABILITY BY MEANS OF ANODE MODULATOR FEEDBACK

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Abstract

In the DTL RF systems of ion pulse accelerator, operating at frequencies up to 300 MHz, are used vacuum tubes power RF amplifiers (PA). At that, the vacuum tube discharger has to be used in anode pulse modulator regardless of the PA output RF power mode of operation: RF driving or PA vacuum tube plate supply. Just these modes allow supporting an accelerating RF voltage stability by means of amplitude control system. The efficiency of the system, in particular, depends on the modulator speed of response and time delay in the feedback. The simplest and cheapest way of modulator speed of response improving is a modulator feedback.

INTRODUCTION

The subject of this paper investigation is the amplitude control system (ACS) of an accelerating RF voltage in the DTL tanks, operating at frequencies below 300 MHz. The point is that at these frequencies RF system includes in her structure vacuum tube amplifiers with the RF output power amplifier (PA), operating in B or C mode. It means that any changes of PA vacuum tube RF driving result in changes of the dc component of the anode current. Moreover, nearly all now in use powerful triodes like RCA 7835, GI-54A, GI-71A can be controlled by means of plate voltage only. As an example in fig.1 control characteristic of the INR DTL RF power amplifier are presented for cavity voltage (U/Uo) and RF power (P/Po), dissipated inside of cavity; Uo and Po correspond nominal values of cavity voltage and RF power.

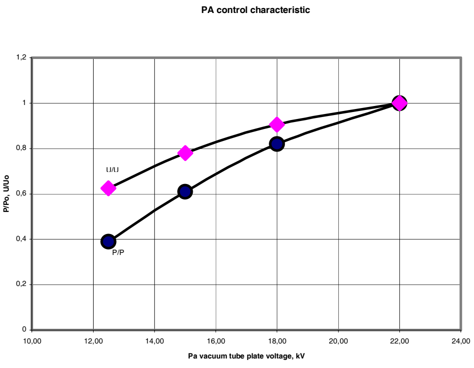

Fig.1. INR DTL power amplifier control characteristic.

That is why vacuum tube as an actuator of the DTL tank RF voltage amplitude control system is available in the PA anode pulse modulator.

At that, series connection of the modulator vacuum tube and the load (inner resistance of the PA vacuum tube over the dc component of the anode current) takes place. Obviously, in this case the modulator vacuum tube fulfills two functions: discharge of energy storage device (capacity battery or artificial forming line) at the load and control of the discharge voltage value at the load. In turn, there are two ways of the series connection of modulator vacuum tube and load:

- The load (PA) is connected to the anode of modulator vacuum tube (MVT) by means of pulse transformer
- The load is connected to the cathode of modulator vacuum tube.

The last case opens possibilities of high-speed modulator development without powerful pulse transformer. For that it is necessary to solve a problem of the control signal transmitting at the modulator vacuum tube grid. The point is that the MVT cathode is under pulse high voltage and, hence, the control signal also has to be put up at the pulse high voltage platform. Some decisions were considered in [1, 2], and they had shown their operability.

Designers of the INR DTL RF system had chosen the simplest decision: the load connected to the cathode of MVT also, but separation of control circuit from high voltage platform was realized by means of step down pulse transformer (see fig.2) with high voltage isolation between primary and secondary windings.

In that case the modulator speed of operation is, in the main, determined by the pulse transformer parameters (leakage inductance and parasitic capacitances of transformer winding) which, in turn, depend on pulse transformer overall dimensions and passing pulse power. Certainly, the pulse transformer operation at low-resistance load – MVT grid current, allows reducing the primary inductance and, hence, the leakage inductance too. However, remarkable reducing of the primary inductance results in modulator pulse tilt, which is additional inner disturbance for the amplitude control system ACS. It isn't true as the control system has been developed to cope with outside accidental disturbances, the main of which is beam loading.

ANODE MODULATOR OF THE INR DTL RF SYSTEM

In fig.2 simplified scheme of the PA anode modulator is presented. As one can see the pulse transformer is placed directly in front of MVT that simplifies the modulator structure: with the exception of the pulse transformer only two transformers – bias and filament ones are under output pulse high voltage. On the other hand a pulse power value that comes through the transformer at the MVT grid achieves tens of kW. At that level of the pulse power it is difficult to design the pulse transformer (and the modulator as a whole) with high response speed. The simplest and cheapest way of the modulator bandwidth

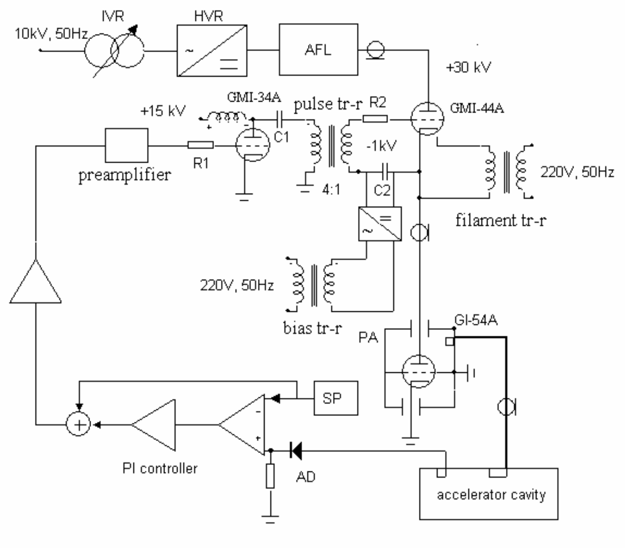

Fig.2. Anode modulator of the RF power amplifier. IVR-induction voltage regulator, HVR-high voltage rectifier, AFL - artificial forming line, SP-ACS set point.

increasing is the modulator feedback (see fig.3). At that, it's necessary to take into consideration some peculiarities of the joint operation of the modulator and ACS feedbacks. First of all the amplitude control system becomes double-circuit and its stability depends on both modulator feedback and ACS one. In reality, the modulator feedback not only improves amplitude and phase frequency responses of the ACS, as a whole, but decreases disturbances, which appear inside of the modulator like instability high voltage supply and tilt of the modulator output pulse. Then, as can be seen from fig.2, the ACS is the automatic control system with set-point, and as DTL RF system works in pulse mode of operation the control system is subjected to 100% disturbances during every pulse due to transient in the high quality cavity. At that, the ACS feedback signal tends to achieve the set-point level as soon as possible, but due to limited possibilities of the RF system (PA with anode modulator), the ACS feedback signal puts the anode modulator in saturation until RF envelope from the tank pickup loop won't reach the set-point value SP. To achieve the maximum value of the RF pulse flat top length, the modulator feedback has to be closed too until the modulator is in saturation. Otherwise, the modulator feedback decelerates an amplitude transient in the cavity.

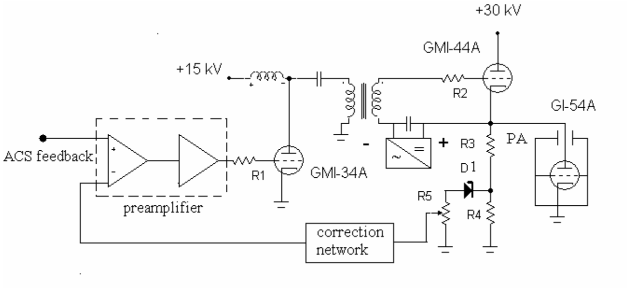

Fig.3. Anode modulator with feedback circuit.

That is achieved using the "dead zone" nonlinearity in the modulator feedback, which can be realized, in particular, by means of voltage-reference diode D1 in the modulator feedback circuit (see fig.3). Obviously, the modulator feedback will be closed if the condition $U_M \dfrac{R_4}{R_3 + R_4} - E_{st} > 0$ is fulfilled, where U_M – amplitude of the modulator output pulse voltage; E_{st}–stabilization voltage value of the voltage-reference diode. It follows to make a note, that during the transient in the cavity when the modulator is in the saturation there is not necessity to support full dynamic range in the feedback circuit operational amplifier. The dynamic range of the amplifier operation has to ensure the modulator control, in the main, during beam pulse only. At that, realization of the amplitude control system feedback circuit is simplified. So in addition to saturation in the modulator there is another nonlinearity of the saturation type – in the feedback circuit of the amplitude control system.

To optimize ACS and modulator feedback circuits, taking into account nonlinearity listed above, a model was developed in the framework of Micro Cap 8 (MC8) program. This model has some advantages before other programs like, e.g., Vissim or Matlab Simulink:

- It is relatively simple and allows using equivalent circuits of vacuum tube amplifiers and schematic circuits of modulator feedback instead of transfer functions or differential equations.
- There is the possibility to take into account nonlinearities like "saturation", which takes place in the modulator and ACS feedback circuits and "dead zone", which takes place in the modulator feedback.
- Transient process in the high quality DTL tank and PA anode-grid cavity can be presented as the process in simple RC circuits. At that, both RF channel with the tank and the feedback circuits are arranged in the same low-frequency domain.

ACS MODEL WITH MODULATOR FEEDBACK

Model of the DTL amplitude control system with modulator feedback is presented in fig.4 where the next shorthand notations are introduced:

V2, V4 – set-points of ACS and modulator feedbacks; *V2* as well is a start pulse of modulator, which is summed up with ACS and modulator feedbacks; *V4* and diode *D3* presents voltage-reference diode parameters in the modulator feedback; *X1, X4* and *X5* present transistor

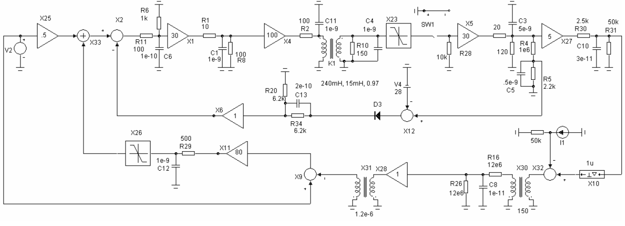

Fig.4. Model of the ACS with modulator feedback.

preamplifier, vacuum tube GMI-34A and GMI-44A amplifiers, correspondently; *X25* – amplifier, which gain is chosen so that to reach the modulator saturation level during amplitude transient in the tank; *K1*-pulse transformer between two vacuum tube amplifiers; *X27*, $T_{PA} = R30 * C10$ – present the gain and time constant of the loaded PA anode-grid cavity; *I1*- I source, presenting a beam current; *X30* and *X31* – step-up and step-down ideal transformers. Step-up transformer presents coupling between tank exciting loop RF voltage and RF voltage at the tank axis. Step-down transformer presents reduction factor of the pick-up loop; *X10* – time delay; *X23* and *X26* – nonlinearities of "saturation" type in vacuum tube GMI-44A amplifier and ACS feedback; *SW1*- T switch, which limits the modulator pulse length; *R16, R26, C8* determine the time constant of the tank; *X6* and *X11* present amplifiers in ACS and modulator feedbacks.

Both values of resistors and capacities in the model and pulse transformer *K1* parameters (inductances of transformer windings and leakage inductance) are result of measurement.

Parameters of the model, presented in fig.4, approximately correspond to the INR DTL tank # 5. Similar models can be developed for the every RF system of the DTL tank.

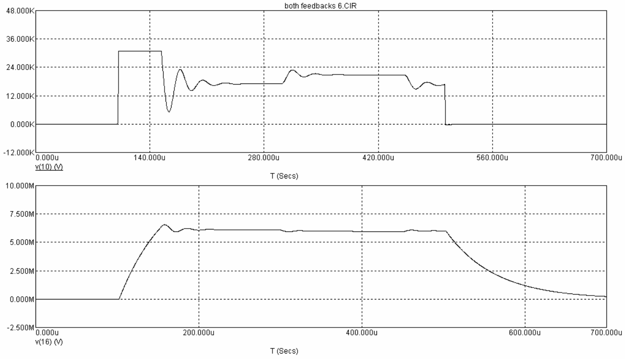

Fig.5. Transients in the ACS without modulator feedback.

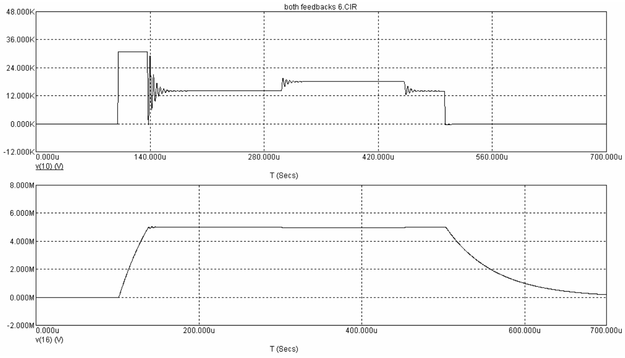

Fig.6. Transients in the ACS with modulator feedback.

In fig.5 and 6, as an example, results of the amplitude control system modeling are shown. It follows from them that the modulator feedback visibly improves a quality of the amplitude control system, in result of which the beam losses are decreased at pulse edges. As for increasing of the beam flat top stabilization factor, then it doesn't exceed 2-3 times. It follows to note that there are not so much of degrees of freedom for modulator feedback optimization in reality. The feedback amplifier *X6* and correction network, one realization of which is shown in fig.4, are among them. At that, as mentioned above, the modulator feedback shouldn't decelerate the transient in the DTL tank, i.e. during transient in the DTL tank the modulator feedback signal mustn't take out the modulator from saturation. It can be shown that in this case the next condition has to be kept: $K_{X6} = \dfrac{V_{X26}}{V_{X23} K_{X5} K_M - V4}$, where $K_M = \dfrac{R4}{R5}$, *V4*- modulator feedback set-point; V_{X26} – saturation voltage of the amplitude control system feedback circuit; V_{X23} – saturation voltage due to nonlinearity of the GMI-44A grid current; K_{X5} – gain of the GMI-44A amplifier. Fulfilling of the last condition allows keeping the maximum of the pulse flat top length and supporting desired stabilization of the RF voltage at the pulse flat top, where both (ACS and modulator) feedbacks are in operation.

As for the correction network parameters, presented in fig.4, they are, in the main, determined by the time constant *R5C5* of the divider in modulator feedback circuit. The capacity *C5* is that of coaxial cable between the divider, placed in high voltage area of the modulator, and transistor preamplifier, placed in engineering area.

CONCLUSION

Presented above model allows optimizing the anode modulator feedback taking into account some peculiarities of the amplitude control system, stabilizing RF voltage in the DTL tank. A result of modeling is in good agreement with the experimental data and allows successfully using the model for optimization of the modulator feedback. As follows from modeling modulator feedback solves two problems: improves quality of the amplitude control system and decreases an influence of modulator unstable operation - due to instability of modulator supply voltage and modulator pulse tilt, at the tank accelerating voltage. Use of the model can appreciably simplify the process of modulator and amplitude control system feedback circuits tuning.

REFERENCIES

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[2] J. Ross Faulkner "A unique high voltage factor series hard tube modulator for use in the Los Alamos meson physics facility", Proc. of the PAC1969, p.359.