ANALOG COMPUTATION OF TRANSIENTS IN THE POWER AMPLIFIER OF DTL RF SYSTEM

A.I. Kvasha
Institute for Nuclear Research RAS, 117312 Moscow, 60-th October Anniversary Prospect, 7a
E-mail: kvacha@rambler.ru

Some peculiarities of DTL pulse RF system operation are connected with its load – a high quality factor cavity. In case of coinciding of tank and feeder frequencies overvoltages may appear at the falling edge of RF pulse in the power amplifier anode-grid cavity. In the paper by means of program Micro-Cap V an influence of the RF system at an overvoltage value is investigated.

PACS: 29.17.+w

1. INTRODUCTION

RF system of the Moscow Meson Factory (MMF) DTL consists of six identical RF channels: five operating RF channels and one reserve channel [1], working at the frequency 198.2 MHz with RF pulse length 300 µs, duty factor – 0.03, RF pulse power in the tank up to 3 MW.

Every tank (excepting the fifth short one) is excited by the two moving loops through a long (20...30 m) coaxial transmission line with the mighty phase regulator (PR) in it. The right adjustment of the RF channel, loaded at a high-quality tank, has to provide:

- the given level of the accelerating field in the tank;
- the optimal operation of the PA and high efficiency of the modulator amplitude control during the beam load;
- the allowable level of overvoltages in the PA anode-grid cavity. The main cause of overvoltage appearance is the RF energy stored in the tank and released in the PA cavity after cutting off the modulator pulse.

Unfortunately, the listed above conditions frequently come in contradictions with each other. The procedure of RF channel tuning, as usual, consists of the following main steps:

1. RF amplifiers are tuned in operation of the PA at the matched RF load;
1. coupling between the tank and the CTL is adjusted with the matched RF load, connected to the loop, exiting the tank. The loops are simultaneously moved till the tank quality factor is halved.
2. The transmission line CTL is connected to the tank and the last one is tuned exactly (by changing the tank cooling water temperature) to minimize a tank reflected wave value in the CTL.

Thus, after fulfilling the above-described procedure only one degree of freedom remains i.e. the length of transmitting line between the RF power amplifier and the tank. As a rule, changing of the CTL length is the most-used method of the RF overvoltage damping in the PA anode-grid cavity. In [2] it was shown, that a magnitude of RF voltage in the PA cavity depends on the order of so-called "feeder frequencies" (or side frequencies [3]) relatively of the master-oscillator frequency. In turn, the feeder frequency (FF) values are the function of the CTL length and complex loads on both their ends, in other words, the tank and PA cavity tuning. In paper [2] the analysis of the generalized RF system, loaded at a high quality cavity (tank), is considered. But expressions, obtained in the paper for the FF values calculation, are rather complicated transcendental equations and, moreover, any changes in the RF system scheme parameters leads to the necessity of solving the new transcendental equation. This process is tough one and it takes a lot of time. That is why attempts were made to use possibilities of the well-known programs for RF circuit investigations, such as Multisim, Microwave Office, Micro Cap V. It turned out, that an analysis of RF system scheme is the most convenient to carry out by means of MC-V [4], which allows estimating not only a frequency response of the scheme but also its transients. Below the equivalent scheme of the RF system, loaded at the high quality tank, similar to that of first part of the Moscow meson factory DTL is investigated.

2. EQUIVALENT SCHEME OF THE RF SYSTEM

The simplified equivalent schematic diagram of the RF system connected to the tank is shown in Fig.1, where the RF power amplifier is represented by the independent voltage source V2 and the internal resistance R1, the value of which is estimated for the vacuum tube GI-54A,

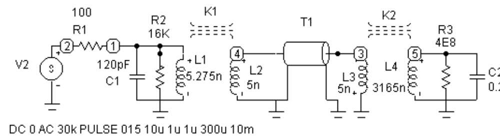

Fig.1.Equivalent scheme of the RF system

installed in the PA of the MMF RF system. The circuit, consisting of C1 (vacuum tube plate-grid capacity), L1, R2, represents the anode-grid cavity of the PA, the circuit C2, L4, R3 represents the DTL tank, the parameters of which are determined from the measured shunt impedance and the quality factor of the tank. Inductances L2 and L3 are that of the loop couplers in the PA cavity and the tank. Both circuits at the scheme are tuned at the same frequency 200.04 MHz, close to the resonance frequency of MMF DTL tanks. K1 and K2 values, as a matter of fact, reject relations between the magnetic field flow, run through the loop, and the whole magnetic field in the PA cavity and the DTL tank. K2 value is determined from the matched condition between the tank input impedance and that of a lossless transmitting line T1. Before investigation transients in the PA cavity it is necessary to determine K1 and K2 values.

2.1. DETERMINATION OF THE K2 VALUE

Fig.2 shows the scheme for finding of the K2 value. It corresponds to the well-known procedure of the tank exciting loop positioning, when the tank is excited by means of the pickup probe from the low-power oscillator V1 and the loop is connected to the matched CTL.

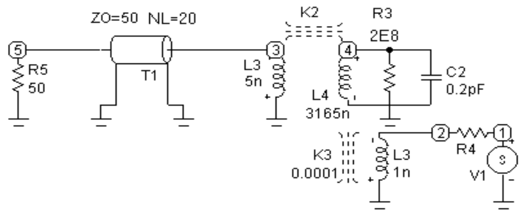

Fig.2. Equivalent circuit for finding of K2 value

By means of the program MC-V (AC analysis), the value of K2=0.0127, which corresponds to double decreasing of the tank quality factor, was found.

2.2. DETERMINATION OF THE K1 VALUE

Now when the K2 value is determined let us find the K1 value. For that it is necessary to optimize the K1 value, which corresponds to the RF amplitude maximum in the matched load, connected to the CTL instead of the tank (see fig.1). This procedure is in agreement with the preliminary that of PA tuning. As above the K1 value is changed in some limits - from 0.1 to 0.9 with the step value ΔK1=0,1. Results of AC analysis by means of MC-V for parameters of the scheme in fig.1 allow choosing the optimal value of K1=0,75, that corresponds to the best delivery of the RF power to the matched load.

3. FEEDER FREQUENCIES

As it was shown in paper [2] a value of overvoltages in PA cavity depends on the mutual position of so-called “feeder frequencies” and the tank resonance frequency (TRF). Program MC-V allows convenient and fast estimating of FF values at any RF system parameters. For illustration in fig.3 the results of AC analysis of the scheme in fig.1 (node 1) are presented, R1 value changing from 100 to 5 k. The last one corresponds to the internal resistance of GI-54A without RF exciting and plate supply, i.e. at the falling edge of RF pulse.

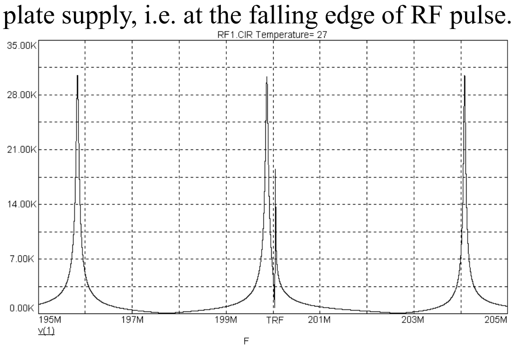

Fig.3. The nearest to TRF feeder frequencies (L_{CTL}/λ=20.2)

In fig.4 the nearest to the tank resonance frequency FF values as a function of the CTL relative length are shown.

The more is the CTL length, the closer are FF values and the less is its slope, and on the contrary. But in any case, there are always some CTL lengths at which coincidence of feeder frequency and TRF takes place. Just at these lengths the highest values of overvoltages in PA cavity are appeared. It is necessary to have in view, that variations in the K1 value and PA cavity tuning have an affect on the mutual position of the tank resonance and feeder frequencies. Really, as follows from experiments, with any CTL length it is always possible to achieve the overvoltage value maximum in the PA cavity by means of appropriate tuning of it.

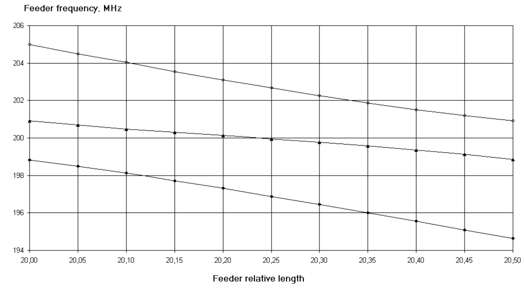

Fig.4. The nearest to TRF feeder frequencies as a function of L_{CTL}/λ

4. TRANSIENTS IN THE DTL RF SYSTEM

Within the framework of the program MC-V there is not a possibility to create a RF source at a frequency of 200 MHz. So for research of transients at the falling edge of RF pulse in the PA anode-grid cavity the circuit in fig.5 is offered. Formation of a required RF signal is carried out with the help of two switches Part.1 and Part.2. In beginning of process the switch Part.2 is closed, and the switch Part.1 is open. After the capacity C2 will be charged from a source V4, the first switch is disconnected and in some μs the second switch is closed; thus the capacity, discharging, excites attenuated RF oscillations in the tank at its resonance frequency (TRF).

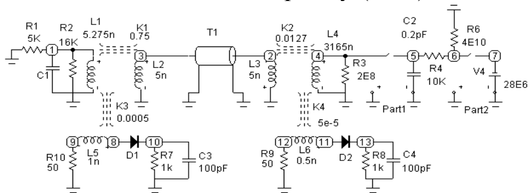

Fig.5. The circuit for research of transients

The most dangerous situation arises when the coincidence between TRF and one from FF takes place. In this case in the PA cavity the amplitude of RF voltage immediately after switching Part.1 might in a few times exceed that of the steady state RF voltage U_{ao} in exciting the tank from PA. For estimation of real amplitudes of RF voltage in the PA cavity the value of V4 in fig.5 corresponds to the steady-state RF amplitude in the tank #2 of the MMF DTL. In turn, from AC analysis it is not difficult to determine the RF voltage value U_{ao} in the PA cavity and to compare it with the value of voltage excited in the PA cavity from the tank. The situation is aggravated with, that after switching off PA (at falling edge of the RF pulse) the vacuum tube internal resistance R1 is increased almost by two orders. It is connected with employing a grounded grid GI-54A, be-cause of what the RF voltage, transmitting from the tank in the anode-grid PA cavity, does not really excite the PA cathode-grid cavity due to the low value of the PA vacuum tube capacity C_{ak} and low R_{oe} of the cathode-grid cavity. Only presence of the vacuum tube permeability maintains a small current through it. In fig.6,7 the most typical transients at the falling edge of RF pulses in the PA cavity are given.

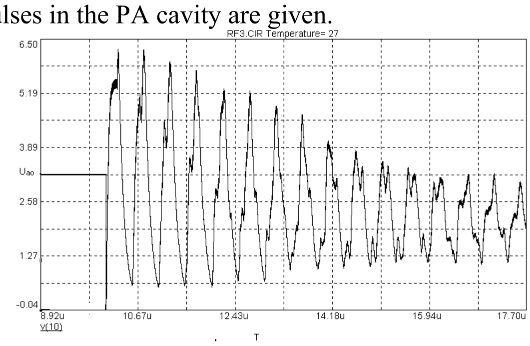

Fig.6. Envelopes of RF signal at the falling edge of RF pulse in the PA cavity ($L_{CTL}/\lambda = 20$)

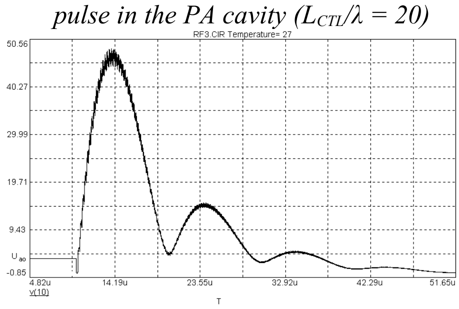

Fig.7. Envelopes of RF signal at the falling edge of RF pulse in the PA cavity ($L_{CTL}/\lambda = 20.25$)

For convenience the envelopes of the RF signals at the outputs of amplitude detectors D1 and D2 (nodes 10,13) are shown. From consideration of the transients and AC analysis it follows:

- overvoltage value might be changed almost on the order of magnitude depending on the CTL length. The highest overvoltage value in tuning the tank and the PA cavity at the same frequency takes place at $L_{CTL}/\lambda=(2n+1)\lambda/4$ and the lowest one – at $L_{CTL}/\lambda = n\lambda$;
- beating frequency value between FF and TRF is the highest at $L_{CTL}/\lambda = n\lambda$, and is the lowest at $L_{CTL}/\lambda=(2n+1)\lambda/4$;
- transient duration at the falling edge of pulses in a few times is less at $L_{CTL}/\lambda = (2n+1)\lambda/4$ than at $L_{CTL}/\lambda = n\lambda$.

5. CONCLUSIONS

The limited volume of the paper does not allow presenting in the full volume all the aspects of the investigations, which have been carried out with the use of the program MC-V. Nevertheless, it is possible to suggest that the results of simulation, qualitatively, well coincide with results of experiments at the real equipment. So, at unsuccessful tuning of the PA and choice of the CTL length between the PA and the tank in the MMF DTL RF system, the overvoltages in the PA cavity are so great, that it is necessary to reduce in two - three times the PA vacuum tube plate pulse voltage to pass this point. Otherwise, overvoltages result in breakdowns in the PA cavity and switching-off of the channel by the crowbar circuit. In this case, the duration of the trailing edge of RF pulse in the tank is reduced in a few times and is accompanied by low-frequency modulation (see fig.7). What ways of overvoltages decrease might be recommended?

As it was mentioned above, the mutual position of FF and TRF strongly depends not only on the CTL length, but also on the PA cavity tuning and its coupling with CTL. Due to the sharp increasing of the PA cavity quality factor after PA vacuum tube plate pulse voltage cutting (R1 in fig.5 is increased by two orders), PA cavity detuning alongside with correct choice of the CTL length are the most effective methods of overvoltage decreasing. So, detuning of the PA cavity at 2 MHz decreases overvoltages in 2...3 times, at the same time decreasing a tank RF voltage only at 0.2...0.3%. Anyway, the control of the CTL length and PA cavity tuning, providing an arrangement of TRF symmetric concerning the nearest two feeder frequencies, guarantees the minimum values of overvoltages in the PA cavity [3].

REFERENCES

1. E.S.Esin, L.V.Kravchuk, A.I.Kvasha. Moscow Meson Factory DTL RF System Upgrade // *Proceedings of the 1995 PAC and ICHEA Conference.* 1995, Dallas, Texis, p.1175.
2. A.I.Kvasha. Investigation of Overvoltages in the Anode-Grid Cavity of the 200 MHz Pulse Power Amplifier of the MMF // *Proc. of the 2001 PAC Conference, June 18-22.* 2001, Chicago, Illinois, p.1225.
3. Reinhold Hohbach. Investigation on Stabilizing the 92 MHz, 150 kW Booster Amplifier // *TRIUMF Design Note.* TRI-DN-95-24.
4. Micro-Cap V. *Electronic Circuit Analysis Program*, Spectrum Software 1993.

АНАЛОГОВОЕ ВЫЧИСЛЕНИЕ ПЕРЕХОДНЫХ ПРОЦЕССОВ В МОЩНЫХ УСИЛИТЕЛЯХ

А.И. Кваша

Особенности работы систем импульсного ВЧ питания резонаторов с трубками дрейфа обусловлены высокой добротностью последних. В случае совпадения собственной частоты резонатора с одной из фидерных частот в анодном контуре усилителя могут возникать недопустимые перенапряжения. В работе с помощью программы Micro-Cap V исследуется влияние параметров схемы ВЧ питания на величины перенапряжений.

АНАЛОГОВЕ ОБЧИСЛЕННЯ ПЕРЕХІДНИХ ПРОЦЕСІВ У ПОТУЖНИХ ПІДСИЛЮВАЧАХ

А.І. Кваша

Особливості роботи систем імпульсного ВЧ живлення резонаторів із трубками дрейфу обумовлені високою добротністю останніх. У випадку збігу власної частоти резонатора з однієї з фідерних частот в

анодному контурі підсилювача можуть виникати неприпустимі перенапруги. У роботі за допомогою програми Micro-Cap V досліджується вплив параметрів схеми ВЧ живлення на величини перенапруг.