MOSCOW MESON FACTORY DTL RF SYSTEM UPGRADE

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Abstract

The last paper, devoted to description of the first part (DTL) RF system of Moscow Meson Factory upgrade, was published in Proceedings of PAC95 Conference in Dallas [1]. Since then some new works, directed at improvement of reliability and efficiency of the RF system, were carried out. Among them there are a new powerful pulse triode "Katran" installed in the output RF power amplifiers (PA) of three channels, modifications of the anode modulator control circuit and crow-bar system, new additional RF channel for RF supply of RFQ and some alterations in placing of the anode modulator equipment, decreasing a level of interference's at crow-bar circuits. Some new, checked at MMF RF channels, ideas concerning of PA tuning are of interest for people working in this sphere of activity.

INTRODUCTION

Developed more than 30 years ago the DTL RF system equipment of the MMF (frequency 198,2 МГц, RF pulse length - 400 μs, repetition rate - 50 Гц, pulse RF power - up to 2,5 MW, amount of RF channels - 6, including RFQ), has successfully operated for 16 years. Since the last information [1] the RF system has been in operation about 18 thousand hours. During all this time the continuous work, directed at increasing of reliability and efficiency of the RF system has been fulfilled. Some results of this activity have found the reflection in papers [2,3]. Moreover, due to improvement of the water quality in the powerful vacuum tubes cooling system, realization of preventive works and more strict maintenance of the exploitation conditions it got possible to appreciably increase powerful vacuum tubes service life. So at service life of 1000 hours, guaranteed by the manufacturer of powerful modulator (GMI-44A) and RF amplifiers (GI-51A and GI-54A) vacuum tubes, it achieves now about 5000 hours for triode GI-54A, installed in the RF output power amplifier (PA), about 6000 for tetrode GI-51A, installed in the PA driver, and about 7000 for modulator tube GMI-44A. A few vacuum tubes were in operation more than 16 thousand hours. It is necessary to have in view, that these data concern to the vacuum tubes that were manufactured 20-25 years ago.

Each RF channel consists of two main parts - the four-stage RF amplifier and two pulse modulators.

PULSE MODULATORS

There are two pulse modulators in each RF channel. The first modulator provides anode supply for the first two RF amplifiers vacuum tubes; the second one provides anode supply of the last two powerful RF amplifier vacuum tubes GI-51A and GI-54A. The first modulator also serves as a driver for the more powerful second modulator. In both anode modulators were recently used a few vacuum tubes for driving and control of output pulse voltage, because stabilization of RF amplitude voltage in the DTL tank is realized by means of the modulator pulse amplitude control (see fig.1).

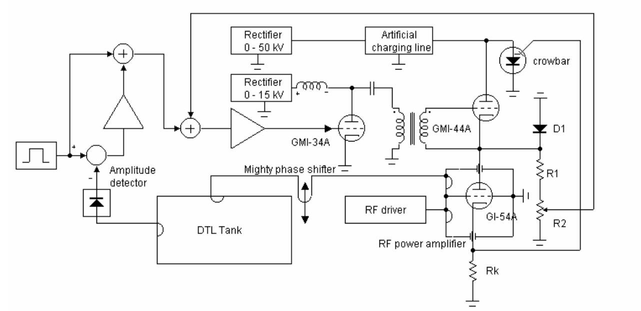

Figure 1: Common view of the DTL RF channel

During the last modernization of the pulse power supply systems were developed and established transistor pulse drivers (TPD) in all modulators. Inputting of TPD has allowed removing six vacuum tubes in each RF channel and appreciably increasing reliability of modulators operation. Besides, installation of the TPD has allowed realizing rather simply the negative feedback path around of the anode modulator (see Fig.1). The feedback increased output pulse stability and essentially improved frequency response of the modulator, which, in turn, has resulted in improvement static and dynamic characteristics of RF amplitude stabilization system in the tank. So now there are only seven vacuum tubes in every RF channel - four in RF amplifiers and three in two modulators.

Structure of the artificial charging line (ACL), as a storage device for the powerful anode modulator vacuum tube GMI-44A, was also changed so that during breakdowns in load of ACL, accompanied by crowbar operation, overcharge of ACL took place. In that way, fast (about 400μs) and reliable lock-out of crowbar thyristors is achieved. This is particularly important in a case of using the induction regulators, demanding of constant load for their operation, in alternating-current high voltage circuit. Obviously, the faster the thyristors are closed, the less load perturbations an induction regulator "fills" during crowbar operation. Besides, some useful rearrangements of high voltage equipment were performed. In particular, diode network D1 (see fig.1) was carried out from ACL chamber into the GMI-44A case. That resulted in the strong shortening of the HV

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cable (from 50m to 2m) and weakening of spurious coupling between the powerful RF amplifiers and crowbar circuits, arranged in ACL chamber, that, in turn, decreases the probability of false crowbar launching emergency.

RF AMPLIFIERS

The basic modernization of the DTL RF system was connected with new powerful triode "Katran" which should be installed in the channel output RF power amplifiers instead of vacuum tube GI-54A, removed from manufacture nearly ten years ago. The first mention of the vacuum tube “Katran” took place in paper [1] when the first results of the tube tests were got. The more detailed information about development, technology of manufacture and test results of vacuum tube "Katran" are presented in paper [2]. By now, vacuum tubes "Katran" are installed in three regular RF channels. One of the tubes worked for more than 9000 hours at the level of pulse RF power near 1 MW, the second tube, mounted in 2002, has up to now worked for 4500 hours at the level of pulse RF power ~1,6 MW, and the third one, installed in 2003, has worked for 1500 hours at the level of RF power ~ 1,2 MW.

This year in connection with taking off from manufacture vacuum tube (tetrode) GI-51A, which for the last 15 years was used as the driver for the output PA, tests of vacuum tube GI-57A have begun. Vacuum tube GI-57A is the triode with output pulse RF power up to 300kW. If the expected level of pulse RF power with the triode will be achieved, tandem of vacuum tubes GI-57A and "Katran" allows finishing the full modernization of the RF amplifiers in all channels of the DTL RF system.

RFQ channel

The RFQ channel that was put in operation in 1998 [3] appreciably differs from regular ones due to excitation of RFQ by means of four cables, which have to provide identical RF field in four cavities of the RFQ structure. For realization of the RFQ drive $\lambda/4$ transformer, as a RF divider, was installed into the coaxial metal feeder 300/130 mm, attached to the PA coupling loop (see Fig.2). Wave impedance of the transformer (25 Ohm) allows matching four coaxial cables, connected in parallel, with wave impedance 50 Ohm. Wave impedance and length of the transformer are more exactly determined by taking into consideration the end capacity and inductances of the four inner conductors of cables, placed inside of the divider. Lengths of the cables were preliminarily leveled during cutting, then their lengths were corrected by measuring of every cable capacity and, final correction came out from measurement of their phase length directly after their connection to the divider. After all these procedures the dispersion of cables electric lengths did not exceed units of degrees. Position of the couple loops of RFQ was chosen so that the loaded quality factor was twice lower than own one. At that in every cable nearly traveling wave was installed in a steady state. Since the RFQ was not originally foreseen

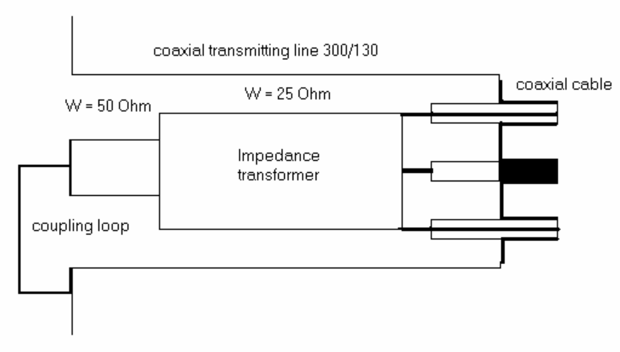

Figure 2: Construction of the RF divider

in MMF design, placement of the RF channel proved to be too far removed from the RFQ - length of cables between them achieved 24 -25 meters. At pulse RF power level in RFQ near 200 kW and specific cable attenuation value 0.05 db/m pulse RF power ~ 65 kW goes into each cable. Thus, at duty factor value 0.01 average RF power value about 300 W is dissipated in every cable. The level of RF power, dissipated inside of every cable, seems to be not so large but during a long continuous work there is an effect of accumulation of heat in them that caused the appropriate rise in temperature of cables and change of their electric lengths. It connected mainly with changing of permittivity of the coaxial cable dielectric (polyethylene) filling .As estimations show phase temperature factor of cables with entire dielectric filling is ~ 0.06deg/m*deg C at frequency 200 MHz. At long length of cables and value of warming up, which achieves 20^0C and more, a phase shift of electrical length of the cable can increase up to value of tens degrees. If synchronous changes of all four cable electrical lengths took place, RFQ accelerating field would slightly changed. However, really, at such lengths of cables it is difficult to expect absolute identity

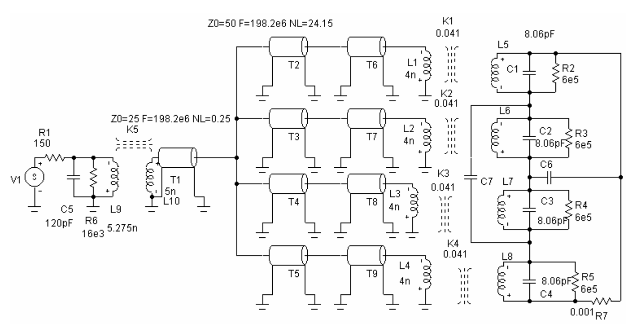

Figure 3: The RFQ RF system supply

of their behavior during heating . And indeed, during long beam sessions gradual decrease of RF amplitude in RFQ, accompanied by heating one of the cables, was observed. Attempts to restore the cavity RF amplitude resulted in further increasing of heating of the cable and breakdowns in the area of the RFQ coupling loops. For estimation of processes in cables, modeling of the RFQ

RF supply was carried out by means of program Micro Cap 7 (see fig.3). RFQ is presented as a four-vane structure, connected to the RF system by means of four ideal transmitting lines. Parameters of the cavities correspond to the real that of RFQ [3]: Q_0 = 6000, Rs = $1.5*10^5$Ohm, f_O =198.2 MHz. Coupling of transmitting lines (TL) with the cavities is determined by coefficients K1-K4, which values are defined when all loops are connected to RF matched loads and its values are changed simultaneously so that the RFQ quality factor is twice decreased. At that, in each TL at the RFQ resonance frequency traveling wave is established. Hence amplitude of RF field in the cavity does not depend on lengths of TL, if their changes are synchronous ones. K1-K4 values, as a matter of fact, determine relations between a flow of magnetic field, run through the loop, and the whole magnetic field in the RFQ cavity. Capacities $C7=C6=C_d$ determine value of dipole frequency f_d corresponding TE_{110} mode in the RFQ: $f_d = f_q(1 + C_d / C_q)^{-0.5}$, where C_q is an equivalent capacity of each of the four cavities; f_q is resonance frequency of quadrupole TE_{210} mode [4]. The external RF generator is presented as source V1 with impedance R1 and oscillatory circuit C5, L9, R6 tuned at frequency 198.2 MHz. Coupling coefficient K5 is chosen from condition of maximum RF power in the matched load. For an analysis of processes in the transmitting lines the λ/4 length line is separated in every TL. Vector values of voltage at the input $(\overline{U}_{in})$ and the output $(\overline{U}_{out})$ of the λ/4 TL allow determining the incident $(\overline{U}_{inc})$ and reflected $(\overline{U}_r)$ waves and, hence, reflection coefficient $(\overline{\Gamma})$:

$$\left|\overline{\Gamma}\right| = \frac{\left|\overline{U}_r\right|}{\left|\overline{U}_{inc}\right|} = \frac{MAG(\overline{U}_{out} + j\overline{U}_{in})}{MAG(\overline{U}_{in} + j\overline{U}_{out})} \qquad (1)$$

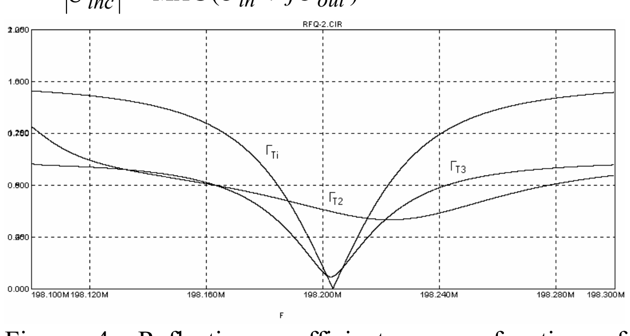

Figure 4: Reflection coefficients as a function of frequency

In figure 4 frequency responses of $\left|\overline{\Gamma}\right|$ are presented: Γ_{Ti} corresponds to a case of identical TL, equal 25λ, Γ_{T2} and Γ_{T3} - to a case when length one of TL (L_{T2}) differs from the rest of lines at small negative value (0.05λ). Fig.5 corresponds to the case when length L_{T2} differs from rest of lines at small positive value (+0.05) λ. Appearance of $\Gamma_{T2} > 1$ shows, that RF power in one cable gets off of the cavity. As follows from the dependencies, relatively small change of one of the cable length (in limits of ± 0.2% if the initial TL length is 25m) results in the strong redistribution of the RF power in the TL.

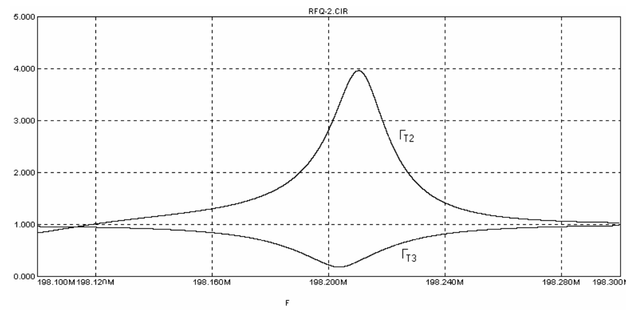

Figure 5: $L_{T2} - L_{T3}$ = +0.05λ

At that the RF losses in the transmitting lines become different ones that, in turn, increases difference between electrical lengths of the cables due to their heating. If initial length of all TL differs from nλ/2, the distribution of RF power in the TL can be quite another one. So correct choice of the initial lengths of the long cables determines the behavior of the RF system during heating cables by RF losses. For decision of the problem at the MMF, length of metal feeder 300/130 was increased as much as possible to approach the RF divider to the RFQ and decrease the length of cables. After that length of the cables was decreased from 25m to 7m and problems, connected with long cables overheating were ceased.

It is necessary to notice that above-mentioned dependencies didn't take into account the dipole mode, though it is obvious, that if the TL lengths are different ones, exciting of dipole mode always takes place. As follows from calculations if $f_q - f_d > 0.5MHz$ the dipole mode really hasn't an influence at distribution RF power between TL and also at RF amplitude in the RFQ. When the frequencies are closer than 0.5 MHz, the influence of dipole mode becomes more appreciable. It is supposed that analysis of the above mentioned RF system in detail would be carried out in separate article.

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