THE FAST RF POWER TURN-ON IN THE MMF LINAC CAVITIES

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Abstract

At MMF Linac there are problems with frequent RF channels breakdowns and long RF power turn-on transient due to high level of the RF power dissipation in walls of the cavity [1]. To determine the condition of the fast RF power turn-on in detuned cavity after a breakdown an analysis of the turn-on transient differential equation is performed. The automatic control system with fast aperiodic RF turn-on transient is considered. It can be used in the second part of the MMF Linac, where there are 28 DAW cavities and it takes a lot of time to achieve the required RF power level in all the cavities.

1 INTRODUCTION

Linear Ion Accelerators with high average currents, such as Moscow Meson Factory (MMF) Linac, have a high level of the average RF power dissipated in cavity walls. So in the cavities (5 DT and 28 DAW) a relative resonance frequency detuning due to dissipated RF power achieves $\xi = 2 \div 3$, despite of the fact that the pulse-repetition frequency (PRF) is twice lower than the designed one.

To compensate this frequency detuning a cooling water temperature is decreased by the frequency control system (FCS) at a few degrees C. That is why we have need to use the step-by-step procedure to achieve the necessary RF field level in a cavity without breakdowns in a feeder and RF generator output stage cavity.

On the other hand, as it is shown in [1], at the MMF Linac the RF channels are frequently switched off because of a low reliability of the H/V equipment and RF generator and modulator output stages valves.

In 25÷30 s after channel being switched off the cavity is detuned entirely due to a cold cooling water and a delay time in the FCS loop, attaining 30÷40 s.

The paper consists of two parts. In the first one a method of the fast cavity tuning self-restoration after repeated channel switching on is discussed. In the second part the automatic control system of fast average RF power raising is described.

2 THE FAST CAVITY TUNING SELF-RESTORATION

As it is shown below there is a time interval (after channel switching off) during which the repeated channel switching on causes a self-restoration of cavity tuning without participation of the FCS. Let us suppose that for the entier cavity the following energy balance takes place:

$$\int_0^t P_W(t)\,dt = M_r C_m \Delta T_m(t) + C_W \int_0^t G_d(t)\left[\Delta T_m(t) - k_1 P_W(t)\right]dt, \quad (1)$$

where P_W is an average RF power, dissipated in a cavity wall, M_r is the cavity metal mass, C_m is the metal specific heat capacity coefficient, C_W is the water specific heat capacity coefficient, G_d is the cooling water mass flow rate, ΔT_m is the metal temperature change due to dissipated RF power. Appearance of the addition $k_1 P_W(t)$ in the second integral is connected with the known fact that cooling water temperature is always lower than the temperature of metal to provide a warm flow from the inner surface of the cavity to cooling water. Supposing that in the equation (1) $G_d(t) = G_d$ after differentiating it we can get the following equation:

$$k P_W(t) = A \frac{d\xi(t)}{dt} + B\xi(t), \quad (2)$$

where $A = \frac{C_m M_r}{2\pi\tau_0\alpha_t}$, $B = \frac{C_w G_d}{2\pi\tau_0\alpha_t}$,

$$k = 1 + k_1 P_w(t), \quad (3)$$

$$\xi(t) = 2\pi\tau_0\Delta f_0(t),\ \ \Delta f_0(t) = f_g - f_r(t),$$

f_g is the master oscillator frequency, f_r is the cavity resonance frequency, α_t is the temco of cavity resonance frequency changing, τ_0 is a cavity time constant which takes into account the RF generator internal resistance and circuit parameters between RF generator and the cavity [2]. If the RF pulse envelope distortions in the detuned cavity are not taken into account, the RF power $P_w(t)$ is connected with cavity detuning by the known expression:

$$P_w(t) = \frac{P_m}{1 + \left[\xi(t) - \xi_0\right]^2}, \quad (4)$$

where P_m - the RF power, dissipated in the tuned cavity, ξ_0 - steady-state cavity detuning, which compensates the RF power heating of the cavity. From equations (2) and (4) it is easy to determine the ξ_0:

$$\xi_0 = k\frac{P_m}{B} \quad (5)$$

Introducing new variable $x = \xi / \xi_0$ and using expressions (4) and (5) the differential equation (2) can be reduced to the form:

$$\frac{1}{1+\xi_0^2(x-1)^2} = T_r \frac{dx}{dt} + x, \quad (6)$$

where $T_r = C_m M_r / C_w G_d$ is the thermal time constant of the cavity. The steady-state decision of the equation (6) has one real root (x = 1) if $\xi_0 \le 2$ and three real roots if $\xi_0 > 2$:

$$x_1 = 1, \; x_{2,3} = \frac{1}{2}\left[1 \pm \sqrt{1-\frac{4}{\xi_0^2}}\right]$$

The x_1 and x_3 roots correspond to the stable decision of the equation (6) and x_2 - to unstable one. Let us suppose that cavity cooling water temperature is kept constant after RF channel switching off, that means ξ_0 = const. In this case after the channel switching off the cavity detuning $x(t)$ is varied as

$$x(t) = \exp\left(-\frac{t}{T_r}\right) \quad (7)$$

If $\xi_0 > 2$ and $x_2 < x(t_{on}) < x_3$ to a moment $t = t_{on}$ of repeated channel switching on, then a self-restoration of cavity tuning (x = 1) takes place. In the opposite case $(x(t_{on}) < x_2)$ the value $x(t) \to x_3$ after repeated channel switching on. From equation (7) and expression for x_2 the maximum time interval between accidental channel switching off and repeated channel turn-on can be found:

$$t_m = -T_r \ln\frac{1}{2}\left[1+\sqrt{1-\frac{4}{\xi_0^2}}\right] \quad (8)$$

If $\xi_0 < 2$ then the t_{on} can be of any value, but it should be took into account that the closer the ξ_0 value to 2 the longer is the $\xi(t)$-transient.

The common solution of the differential equation (6) which determines $x(t)$ – transient after the repeated channel switching on takes the form:

$$\int\frac{dt}{T_r} + \int\frac{dx}{1-x} - \int\frac{dx}{x^2 - x + 1/\xi_0^2} = C, \quad (9)$$

where C is determined from initial conditions:

$x = x_0 = \exp\left(-\frac{t_{on}}{Tr}\right)$ when t = 0.

If $\Delta = \frac{4}{\xi_0^2} - 1 > 0$ the decision (9) takes the form:

$$\frac{t}{T_r} = \ln\frac{1-x_0}{1-x} + \frac{2}{\sqrt{\Delta}}\left[\text{arctg}\frac{2x-1}{\sqrt{\Delta}} + \text{arctg}\frac{2x_0-1}{\sqrt{\Delta}}\right] \quad (10)$$

If $\Delta < 0$ then

$$\frac{t}{T_r} = \ln\frac{1-x_0}{1-x} +$$

$$\frac{1}{\sqrt{-\Delta}}\left[\ln\frac{2x-1-\sqrt{-\Delta}}{2x-1+\sqrt{-\Delta}} - \ln\frac{2x_0-1-\sqrt{-\Delta}}{2x_0-1+\sqrt{-\Delta}}\right] \quad (11)$$

In fig. 1 $\xi(t)$ is transient in the tank #3 MMF DTL when t_{on} = 15 sec, ξ_0 = 2,5 it is shown. The curve #1 corresponds to the case ξ_0 = const during the transient, #2 - to the FCS closed loop after RF channel turn-on.

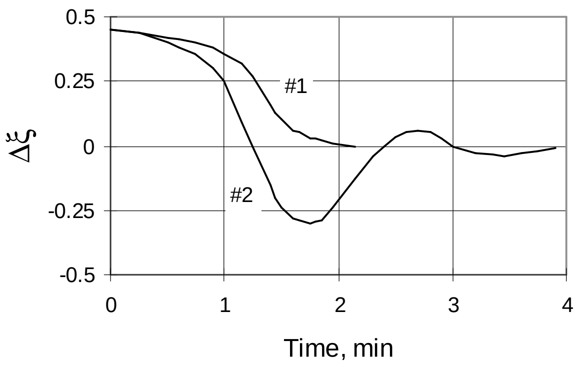

Figure 1: ξ(t)-transient in the tank #2 after repeated channel turn-on. Δξ = ξ(t) - ξ_0.

3 AUTOMATIC CONTROL SYSTEM OF FAST AVERAGE RF POWER RAISING

Before start of a new cycle of an acceleration or after a long pause the FCS provides a coincidence of the cavity resonance and master oscillator frequencies so as to realize the first channel turn-on in the tuned cavity. As it is mentioned above, the RF power level in the cavity is raised, as a rule, gradually, waiting the end of the $\xi(t)$-transient on every step. Thus the full time of average RF power raising is determined by the FCS closed loop transient and a quantity of steps. The automatic control system with the shortest time of the RF power raising is described below. The main principle of the system is the control of cavity tuning by changing a quantity N of RF pulses in packets repeating with the frequency $F_p = F_c/n$, where F_c is a RF pulse repetition rate, n is integer. The more is n the more exactly a level of the average RF power $P_w(t) = P_m N(t) F_p / F_c$ follows cavity detuning.

The block-diagram of the system, implementing the fast average RF power raising in the DAW cavity of the MMF Linac second part is given in fig. 2.

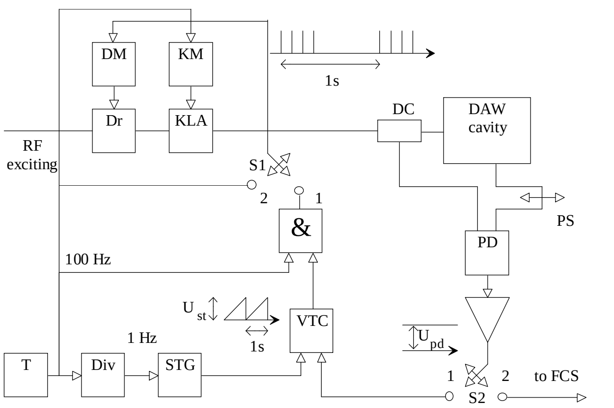

Figure 2: Block-diagram of the automatic control system for fast average RF power raising.

KLA - klystron amplifier, Dr - RF driver, KM - klystron modulator, DM - driver modulator, DC - directional coupler, PD - phase detector, PS - phase shifter, T - timer, Div - divider, STG - sawtooth generator, VTC - voltage time changer, FCS - frequency control system.

Before the beginning of the process the FCS feedback control loop is closed (switches S1 and S2 are in position 2) and the PRF is put equal to $F_p = 1$ Hz. After achievement of the required amplitude of the RF field in the cavity the loops of amplitude and phase control systems are closed and switches S1 and S2 are turned in position 1. Then cooling water temperature is gradually lowered (by switching electric heater off) up to the value which corresponds to the cavity detuning ξ_0. After a comparison of sawtooth pulses, repeating with PRF = 1 Hz, with DC voltage, proportional to cavity detuning, pulses, width of which are proportional to $\Delta f_0(t)$, are produced. The pulse width determines the RF pulses quantity N in a packet and, consequently, a value of the Pw. The process is finished when $N = F_c/F_p$ and $U_{st} = U_{pd}$. After that controlled switches S1 and S2 are returned to position 2 and the FCS feedback control loop is closed. The process in the described system is a one capacity process, and so it is possible to raise the loop gain so that the equality $U_{st} = U_{pd}$ corresponds to any permissible cavity detuning. From fig. 2 one can see that the RF pulses packet is produced by changing of the number of the RF drive pulses at the KLA input. In this case the modulator KM works in the same mode during the whole process. The full time of the aperiodic process of average RF power raising is determined only by the thermal time constants of the electric heater and cavity. So it takes about three minutes to achieve the required level of the average RF power in the MMF Linac DAW cavity.

Thus the automatic control system of the average RF power raising considered above gives the following advantages:

- during the $P_w(t)$-transient the RF channel works with closed loops of amplitude and phase control systems and the cavity tuning, supported by the system with any desired accuracy;
- a $P_w(t)$- transient is always aperiodic without overvoltages and overshooting.

4 CONCLUSION

Using of the cavity tuning self-restoration for implementation of the fast repeated turn-on of a RF channel is very effective at the DTL of the MMF Linac, where reliability of the RF channels is lower and ξ_0 value is higher than that in the DAW cavities.

The automatic control system of the average RF power raising is particularly worth using when there is a lot of cavities with a high level of average RF power dissipated in them. In this case noticeable improvement in the accelerator turn-on time can be achieved.

REFERENCES

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