STABILIZATION OF THE AMPLITUDE OF KLYSTRON MODULATOR OUTPUT PULSES AT 100 HZ PRR

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INTRODUCTION

The Moscow Meson Factory (MMF) linac is a pulsed machine which successfully operated during last several years at a pulse repetition rate (PRR) 50 Hz. In order to increase the average beam current in the linac it needs to raise PRR up to 100 Hz. Each accelerating cavity of the high energy part of the MMF linac is exited from one multy-beam klystron. The high-voltage pulsed modulator is used for driving the klystron. All pulsed systems of the linac use timing signals from the Master Timing System (MTS). The start of each modulator cycle occurs a fixed delay after each zero-crossing (ZX) of the 50 Hz AC line voltage. Fluctuations in the AC line frequency and phase may result in 50 Hz modulation of the pulse repetition period at 100 Hz PRR operation, and thus 50 Hz amplitude modulation of the HV modulator output pulses may occur. This may lead to considerable amplitude and phase fluctuations of the output RF signal of the klystron and consequently to variations of the accelerating field in the cavity from pulse to pulse. For getting a required stability of the accelerating field the phase and amplitude control system is used on the linac. But the integrating circuit of the «slow» system has equivalent time constant near 200-300 ms and due to this it is impossible to stabilize fluctuations with 20 ms repetition period. This is a main reason why it is necessary to estimate a probable depth of amplitude modulation in dependence on shifts between adjacent timing signals. Basing on results of this analysis and on the data of measurements of these parameters at the linac the way to stabilize the pulse repetition period and thus the amplitude of modulator output pulses is suggested.

CHARGING PROCESS IN MODULATOR

The HV klystron modulator generates pulses with the maximum amplitude 80 kV, the duration 180 μs and operates at 10, 50, 100 Hz PRR. The modulator represents a classic scheme with a pulse forming network (PFN), a charging choke, a reverse diode, thyristor keys and a pulse transformer. Every cycle a full discharge of PFN capacitors occurs. A charging process may be «resonant» or «linear». It depends on the relation between timing parameters of the charging circuit and repetition period of cycles.

A simple equivalent scheme for the description of the charging process is shown in Fig 1.

There the power supply E_o represents the stable rectifier, resistor R includes the output resistance of the power supply and ohm resistance of the charging choke L, C-capacitance of the PFN. According to [1], a steady-state charging process can be described as follows:

$$u(t)= E_o\,[1-e^{-\omega t/2Q}(\mathrm{Cos}\,\omega t-m_i\,\mathrm{Sin}\,\omega t)];$$

$$i(t)= E_o/\rho\,[e^{-\omega t/2Q}\,(\mathrm{Sin}\,\omega t+m_i\,\mathrm{Cos}\,\omega t)];$$

where $\rho=\sqrt{L/C}$ - equivalent resistance of the charging circuit, $\omega=1/\sqrt{LC}$ - own frequency of the charging circuit, $Q=\rho/R$- quality factor, m_i-coefficient which is responsible for initial conditions in the charging circuit.

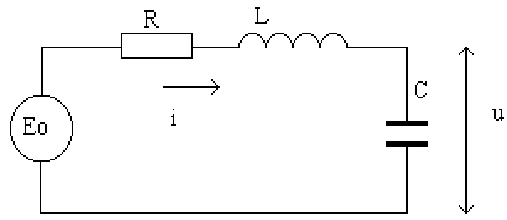

Fig.1. Equivalent scheme of the charging circuit.

Taking into account the full discharge in each cycle and using the coefficient $\chi=T_{rep}/T_{ch}$, where T_{rep} is the repetition period and $T_{ch}=2\pi/\omega$ - the period of own oscillation, it is possible to calculate the maximum PFN voltage in a steady-state regime:

$$U_{PFN}= E_o\,[1-e^{-\chi\pi/Q}\,(\mathrm{Cos}\,2\chi\pi-m_i\,\mathrm{Sin}2\chi\pi)],$$

$$\text{and } m_i= (\mathrm{Sin}\,2\chi\pi)/(e-\mathrm{Cos}2\chi\pi).$$

Using these expressions one can plot the curve of the charging voltage and current in each cycle.

In the case $\chi\geq0.5$, assuming that R is small, Q is large enough to consider the expression for charging voltage like follows: $u(t)=E_o(1-\mathrm{Cos}\,\omega t)$. The PFN voltage becomes maximum 2Eo at the moment $T_o=T_{ch}/2$. In the case the diode is mounted between C and L and a leakage current is small, this level of the charging voltage remains constant to the beginning of the next cycle. The charging starts with an initial current $I_{in}=0$, and its type is «resonant». If $\chi<0.5$, the initial current $I_{in}\neq0$ and it depends on χ. The less χ, the more «linear» character has the curve of the charging voltage. As mentioned earlier the train of timing signals is formed at each ZX of the AC sine-wave voltage, and shifts between adjacent signals $\Delta T_{rep}= (T_2-T_1)$ may occur (Fig.1a). In the case of the «resonant» charging, when $\Delta T_{rep}\leq (T_{rep}-T_o)$, the PFN voltage reaches the maximum value equal U_{PFN} =2Eo and remains stable in every cycle, i.e. $\Delta U_{PFN}=0$ (Fig.2b). If $\Delta T_{rep}> (T_{rep}-T_o)$ the value U_{PFN} varies and differs from 2Eo in every second cycle (Fig.2c). The relative variation $\Delta U_{PFN}/U_{PFN}$ depends on the difference $[\Delta T_{rep}-(T_{rep}-T_o)]$ and, for example, for $\chi=0.5$, i.e. when $T_{rep}=T_o$, is expressed as follows:

$$\Delta U_{PFN}/U_{PFN}= [1-\mathrm{Cos}\,\pi\,(\Delta T_{rep}/T_{rep})].$$

If the charging is «linear», the maximum of PFN voltage is less than 2Eo (Fig.2d). It's value changes every cycle and the variation ΔU_{PFN} is more sensitive to the variation ΔT_{rep}, than in the case of «resonant», and the dependence is like this:

$$\Delta U_{PFN}/U_{PFN}= 2\Delta T_{rep}/T_{rep}.$$

Thus the 50 Hz modulation of the cycle repetition period leads to the 50 Hz modulation of the maximum PFN and modulator voltage. The type of the charging defines the depth of amplitude modulation

(One should mentioned that we consider «small» timing shifts and neglect the variation of the initial current I_{in}).

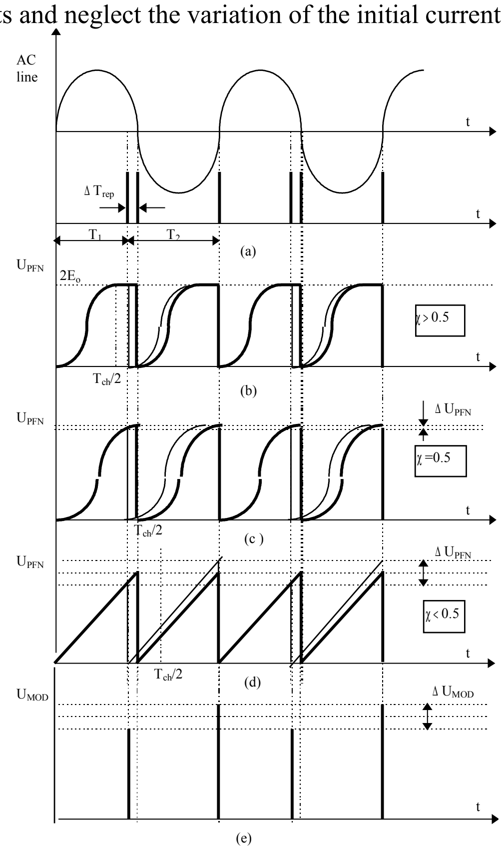

Fig.2. Charging process and modulator output pulses.

TIMING AND AMPLITUDE VARIATIONS AT THE LINAC

Recent measurements on the linac revealed that the AC line frequency slowly (during minutes and hours) changes from 50.0 Hz to 49.3 Hz. It means the repetition period at 50 Hz PRR slowly changes from 20.00ms to 20.28ms, but there are no relative shifts in the train of 50 Hz timing signals. In the case of 100Hz PRR we observed a shift of each second timing signal due to not very high accuracy of the ZX-discriminator and fluctuations in the AC line voltage. The maximum value of these shifts was ΔT_{rep}=200μs, i.e. the relative variation was $\Delta T_{rep}/T_{rep}$=2%.

The klystron HV modulator has the next parameters: full capacitance of the PFN capacitors C=96 μF, inductance L=0.85H, equivalent time constant $T_{ch} \cong$ 56ms and the time of reaching the maximum PFN voltage $T_o = T_{ch}/2 \cong$ 28ms. At 100 Hz PRR period T_{rep}=10ms, and one can conclude, that the charging process is practically «linear». In this case the relative timing shift 2% must lead to the amplitude variation of modulator pulses 4%. Measurements confirmed this fact.

There are different ways to make the depth of this 50 Hz amplitude modulation less 1%, as it is required. A new zero-crossing system with a good filtering of the AC line voltage may be developed. The accuracy of the ZX discriminator can be improved. One simple method was proposed and realized at the MMF linac.

NEW 100 HZ TIMING SYSTEM

The simplest way to stabilize the amplitude of the modulator pulses train is based on the idea to stabilize the repetition period of timing signals at 100Hz PRR. Measurements showed there is no difference between adjacent 50 Hz zero-crossing. Using 50 Hz series as a reference we have to form a new pulses train which has 10ms delay. This delay can not be fixed, because the frequency of the AC line varies, but it must be equal to a half of the period at any time moment.

A block-scheme of a new 100 Hz timing system is presented in Fig.3. Two 50 Hz trains of timing signals are forming from 100 Hz zero-crossing by dividing on 2 in the ZX-unit. An electronic Frequency-Meter measures intervals between pulses, i. e. the real repetition period. These data in a digital code are used as input to the next module, where the difference ΔT_{dif} between existing T_{rep} and ideal (T_{ideal}= 20.00 ms) intervals is calculated and halved. Then the Delay Unit, which consists of some standard modules, forms the time delay after initial ZX signals, which is exactly equal a half of the AC line period in each measurement: $\tau = (10.00+\Delta T_{dif}/2)$ms. The rate of measurements may be chosen about some seconds due to very slow variations of the AC line frequency. Thus we have two trains of 50 Hz pulses with a delay between them automatically changing. After that both series are combined to one 100 Hz train of timing signals without any shifts between adjacent pulses at any time moment.

As a result of this improvement of the timing system the PFN charging voltage remains stable and stability of the amplitude of modulator HV output pulses is less than 1%. The amplitude and phase control system of the linac provides the required accuracy of RF accelerating field in cavities.

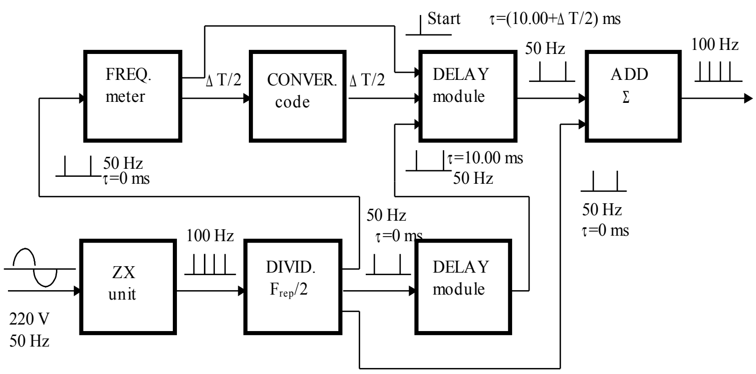

Fig.3. Block-scheme of the new 100 Hz timing system.

SUMMARY

The accelerator timing system of the MMF has been upgraded. The new circuit produces more stable reference signals for the operating of the HV pulsed klystron modulator of the high-energy part of the linac. The stability of the output voltage from pulse to pulse at 100 Hz PRR provides the required stability of the klystron output RF power and accelerating field in cavities.

REFERENCES

[1]. L.I. Yudin, «High power pulsed technics», Moscow, MEPHI, 1976, (in Russian).