Cavity Resonant Frequency Monitor Based on a Method of Pulse Phase Modulation

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1. INTRODUCTION

Phase-type cavity resonant frequency monitor is widely used in proton linear accelerators. Operation of the phase-type monitor is based on a comparing the rf phase in the transmission line with the rf phase in the cavity. When the cavity is correctly tuned, it looks like a purely resistive load, and the cavity field is in phase with the applied voltage. Main advantages of such scheme are high accuracy and sensitivity, and simplicity of realization.

Unfortunately, there are also some disadvantages peculiar to the phase-type cavity resonant frequency monitor. First of all, it is a necessity of periodical zero calibration and unsufficient long-term stability.

During several last years a new cavity resonant frequency monitor is used in the INR proton linac. It is based on a method of pulse phase modulation (PPM). In this method the phase of a drive rf signal is modulated by a pulse of right-angle trapezoidal form, and the cavity response to this signal is analysed by means of an amplitude detector.

The PPM method can be counted as an only absolute method of cavity resonant frequency measurement, because it not needs any calibration and provides very high long-term stability.

2. PULSE PHASE MODULATION SCHEME

A simplified scheme of the PPM cavity resonant frequency monitor is shown in Fig. 1.

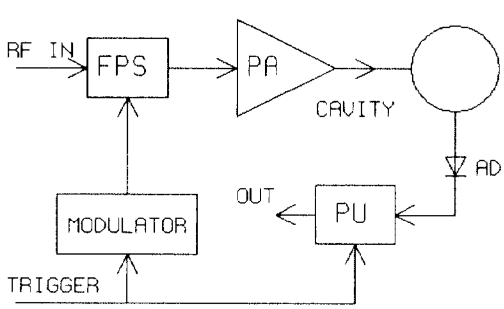

Fig. 1. Simplified scheme of the PPM cavity resonant frequency monitor.

An rf drive goes through the fast electronic phaseshifter FPS and rf power amplifier PA to the cavity. The phase of the rf drive is modulated in FPS by a pulse of right-angle trapezoidal form, taken from modulator. The cavity response to this signal is analysed by the amplitude detector AD and processing unit PU. DC voltage at the output of PU is proportional to the cavity mistuning.

3. PPM PRINCIPLE OF OPERATION

An idea of the PPM method looks as follows. Due to the phase modulation the frequency of the rf drive is shifted on a short time up and down the main one, as shown in Fig. 2.

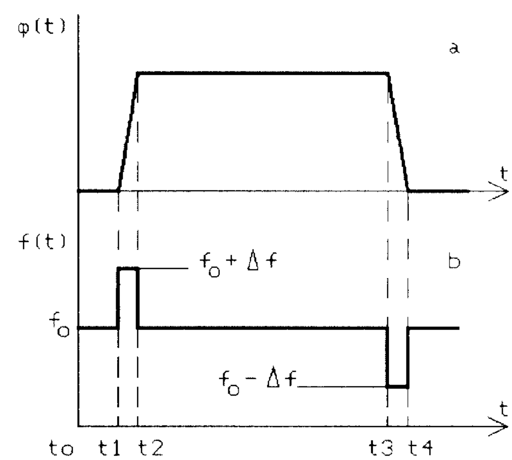

Fig. 2. Time dependence of rf drive phase (a) and frequency (b).

The value of shift Δf depends on rf phase derivative at the moment of rise and fall time of rf phase pulse (time intervals t2-t1 and t4-t3 in Fig. 2). The cavity response to this signal depends on its mistuning, i.e. the difference Δf_0 between the drive frequency f_0 and cavity resonant frequency f_r, and cavity Q-value. When correctly tuned, the cavity amplitude responses to the upper $f_0+\Delta f$ and lower $f_0-\Delta f$ side frequencies are equal. Any cavity mistuning will lead to a difference in cavity amplitude responses at upper and lower side frequencies.

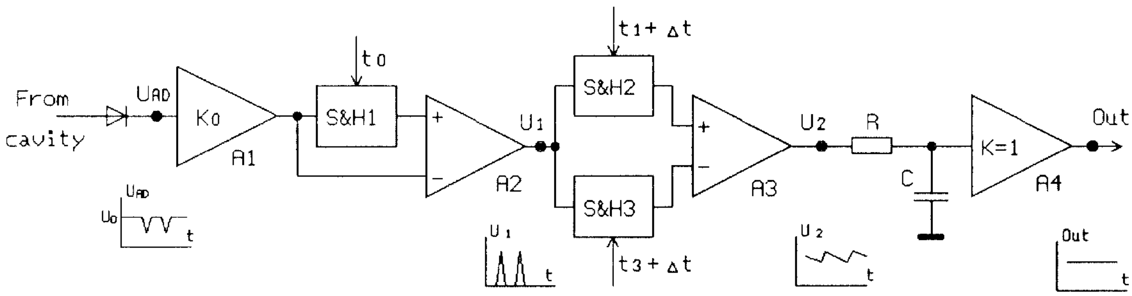

Fig. 3. Processing unit simplified schematic

The differential signal between the cavity amplitude response to the upper and lower side frequencies is an output voltage of the PPM scheme.

It can be shown that for low value of cavity mistuning the output voltage of the scheme is directly proportional to the value of mistuning:

$$U_{out} = -k\,U_0\,a_0\,, \quad \text{where} \qquad (1)$$

$a_0 = 2Q_L\,\Delta f_0/f_0$ - normalized cavity mistuning,

Uo - cavity amplitude response to the drive frequency.

Coefficient k can be expressed as follows

$$k = 2a\,/\,(1+a)^{3/2}\,, \qquad (2)$$

where $a = 2Q_L \Delta f/f_0$.

High stability of the PPM method is due to the fact that the output voltage is formed by a subtraction of two shifted on a short time signals, taken from one amplitude detector. Owing to this any changes of the rf power or amplitude detector parameters will change only a slope of PPM monitor characteristic. Its zero point which corresponds to the cavity resonant frequency, will remain stable. Besides, the PPM monitor does not need zero calibration.

4. PROCESSING UNIT

A simplified schematic of the processing unit is shown in Fig. 3. Cavity amplitude response from the amplitude detector AD goes through the amplifier A1 to the normalizing circuit, consisting of sample and hold scheme S&H1 and operational amplifier A2. The S&H1 is triggered at t=to, before the phase modulation pulse occurs. As a result, there is no dc voltage at the output of A2.

Two more sample and hold schemes S&H2 and S&H3 together with the differential amplifier A3 produce a dc voltage, proportional to the cavity mistuning. S&H2 and S&H3 are triggered at t1+Δt and t2+Δt correspondingly, where Δt is signal delay in transmission lines.

Finally, the output voltage of the PU is formed by the A4 buffer amplifier, after filtering in the RC integrated circuit.

5. CONCLUSION

The PPM cavity resonant frequency monitor can be easily build in most of the existing proton linacs, since all of them already have fast electronic phaseshifter and amplitude detector (both of them are used in a low-level rf linac subsystem).

The PPM monitor can be used in most applications where a phase-type monitor is employed. In the INR linac it is used both for zero calibration of phase-type monitors, which are in cavity temperature control systems, and in the beam phase monitor automatic frequency control loop.