PHASE MONITOR WITH SAMPLING ELECTRONICS FOR THE RCNP RING CYCLOTRON

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Abstract

As the new phase monitor for the RCNP Ring Cyclotron, a circuit system with sampling electronics is designed and made. The RF noise suppression of the circuit system is about 45dB. It is succeeded to identify the beam waveform of the 1nA extraction beam current.

1 INTRODUCTION

To tune the accelerator, the non-intercepting type phase probes have been developed for the use as internal beam monitor at the RCNP Ring Cyclotron, which is shown in Fig.1. The beam phase at Ring Cyclotron is monitored by the circuit system with the frequency conversion method. But the information obtained using this method is in principle only the beam phase based the one of the accelerating voltage. To monitor not only the phase information but also the beam shape, the new circuit system with sampling electronics is designed and made.

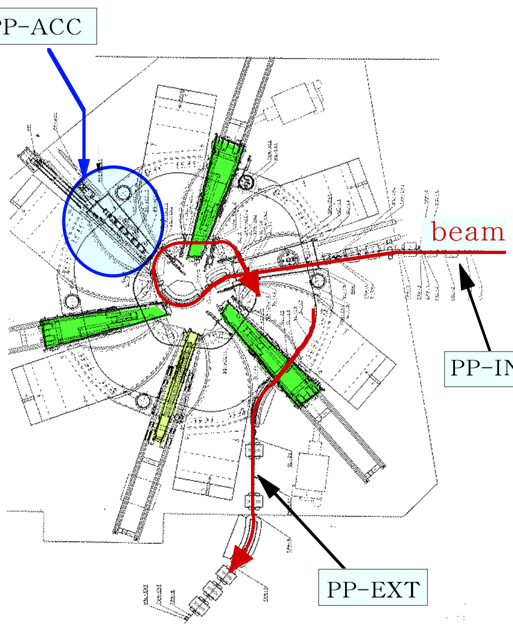

Figure 1: **Top view of the Ring Cyclotron** The 8 capacitive detectors are installed in the circled area. These detectors are named as 'Probe-Channel 1···8' from the inside of the orbital radius. These plates are 45x45mm^2 or 30x65mm^2 in size and 35mm in distance between upper and lower plates.

2 NEW CIRCUIT SYSTEM FOR THE BEAM MONITOR

2.1 *Sampling Concept*

The beam accelerated at AVF Cyclotron is injected to Ring Cyclotron every three or five RF acceleration cycles. Therefore, the output signal originated in the accelerated beam is obtained per 3 or 5 accelerating RF periods. Because of high acceleration voltage, the RF signal is much larger than the beam signal. When the beam current is several nA, a typical S/N ratio is about 1/1000. To eliminate the large RF noises from signal of phase probe, and pick out this weak signal, a signal line delayed exactly one RF period based on the other signal line is arranged, and subtract both signals.

2.2 *Sampling Electronics*

The block diagram of the sampling circuit is shown in Fig.2.

Sample and Hold circuit (Unit① in Fig.2)

The input frequency ω_d(30 - 52MHz) is converted to $\Delta\omega$(60Hz) exactly based the sampling method, and is filtered using LPF(Low Pass Filter). The characteristics of the LPF are 36dB/oct, $f_c \simeq 6.4kHz$.

Sampling Pulse generator (Unit②)

The sampling pulse generator can be operated in normal sampling mode or special sampling mode. On the normal sampling mode, the repetition (angular) frequency of the sampling pulse is set on $\frac{1}{n}\omega_s$ $(n \in N)$, and on the special sampling mode, the repetition frequency of the sampling pulse is $\frac{2}{2k-1}\omega_s$ $(k \in N)$. On the latter mode, odd harmonic components of the RF signal are rejected strongly, and only even ones are sampled [1], [2]. The sampling timing signal (ω_S) finally generates the sharp sampling pulse. The sampling pulse repetition frequency of this system are $(\frac{1}{10}, \frac{1}{30}, \frac{1}{50}, \frac{2}{21}, \frac{2}{63}, \frac{2}{105})$ x ω_S.

Clock and Trigger generator (Unit③)

The sampling timing signal(ω_s) and the RF signal(ω_d) are mixed by a DBM(Double Balanced Mixer) and generates a low frequency signal($\Delta\omega$). The signal is multiplied 256 times exactly at PLL(Phase Locked Loop) and is used as the clock for the digital elements. The frequency is 60x256 = 15.36kHz. The signal is also divided properly for a trigger pulse of an oscilloscope to observe the beam signal.

Digital Processing Unit (Unit④)

The maximum input voltage of ADC is adjusted to ±5V at OP.amp of the Sample and Hold circuit, and the output voltage of this section is ±11V. While one period of the input frequency($\Delta\omega$=60Hz), the input signal is AD-converted 256 times and the 16 bits digital data are being memorized on the 16x256 bits shift register at real time. Finally, the both (input and output of this shift register) data are subtracted and DA-converted after the bits adjustment.

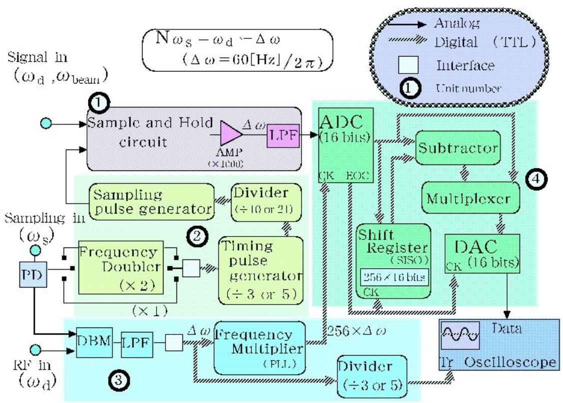

Figure 2: **SAMPLING block diagram**

3 BEAM-RESPONSE SIMULATION

The correlation between the beam and the beam-response waveform is investigated with numerical simulation. Fig.3 shows the correlation between the beam and the beam-response waveform information.

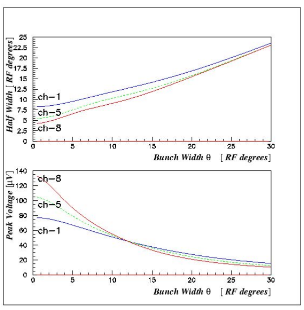

Figure 3: **Simulation result** The X-axis of both figures are the beam-bunch half width of a circulating beam. The upper figure is beam-response half width correlation, the lower figure is beam-response peak voltage one.

Index	Condition	Unit
particle	Li^{3+}	/
extraction energy	455	MeV
AVF acc. freq.	8.383392	MHz
Ring acc. freq.	41.916960	MHz

Table 1: **Experimental conditions**

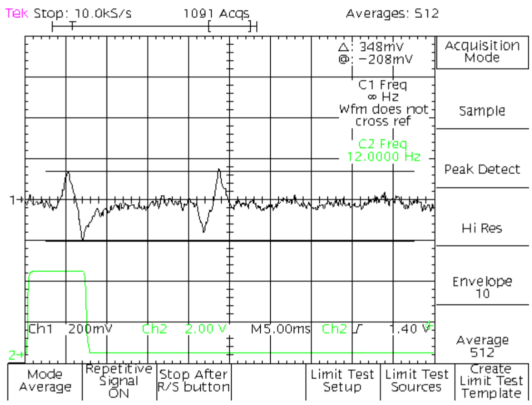

Figure 4: **Final-output** The extraction beam current is 3nA, and the averaging is 512 times. Scope: 108 RFdegrees/div, 200mV/div

4 EXPERIMENTAL STUDY

The experimental conditions of this section are indicated in table 1.

4.1 System Valuation

beam-response identification

The periodic background (main and flat-top RF etc) is excluded using the new circuit system and the non-periodic background is suppressed by averaging. Fig.4 shows the final-output from the sampling circuit. In principle, the beam-response waveform and after one RF cycle, the inverse beam-response waveform are observed. The residual noise level corresponds to beam current of about 1nA.

beam phase measurement

In Fig.5, the beam phases measured with the frequency conversion and the sampling method are shown. The beam phase is measured by the zero-crossing point in the former method and by 8th fourier component in the latter method. Phase difference between these methods is about 4 RFdegrees maximum, at present.

4.2 Fourier Analysis

The beam-response waveform (included the systematic noise) obtained from the sampling circuit is analyzed by FFT-analysis. The beam-response waveform(final-output)

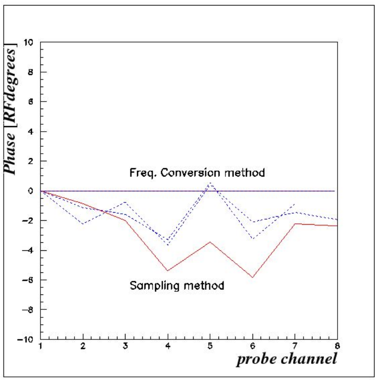

Figure 5: **Phase difference between the frequency conversion and the sampling method**

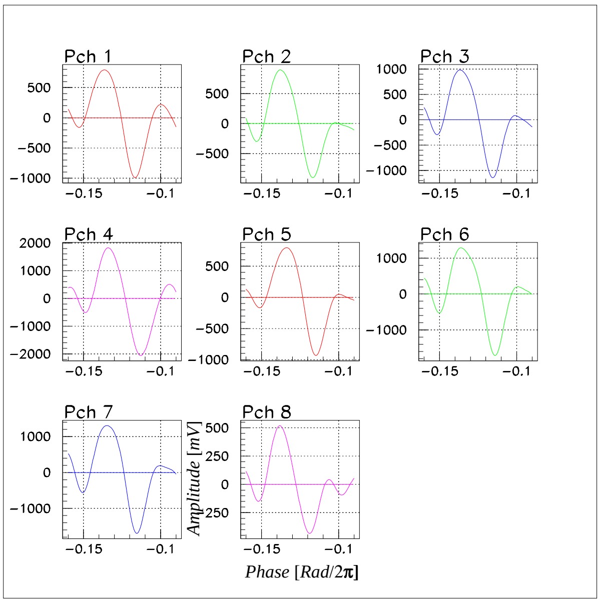

Figure 6: **Beam-response input waveform to the sampling circuit** It is reconstructed by the fourier information until the 60th harmonic components. The probe-channel is indicated by 'Pch'.

from the sampling circuit is reconstructed using the fourier information until the 60th harmonic components, corresponding to the frequency band width of the pre-Amp of the circuit system. As shown in Fig.6, the beam-response waveform at input of the sampling circuit is reconstructed using the power spectrum correction value between the input and output at the sampling circuit. Finally, by the correlation between the beam and the beam-response waveform information at section.3 the half width of the beam-bunch can be estimated. The data desired at this experiment are Fig.7 which shows the transition of the beam-bunch half width.

5 DISCUSSION AND CONCLUSION

The periodic background is excluded using the new circuit system and the non-periodic one is suppressed by averaging, consequently, it is succeeded to identify the beam waveform of the 1nA extraction beam current. As for beam phase measurement, the qualitative agreement is confirmed between both methods. At this experiment, according to Fig.7, the half width of the extraction beam-bunch is estimated about 30 RFdegrees. Hereafter the accuracy of measurement is examined. However, it is established the method to know the beam waveform from the beam-response waveform. Presently, the resolution of this system is being improved.

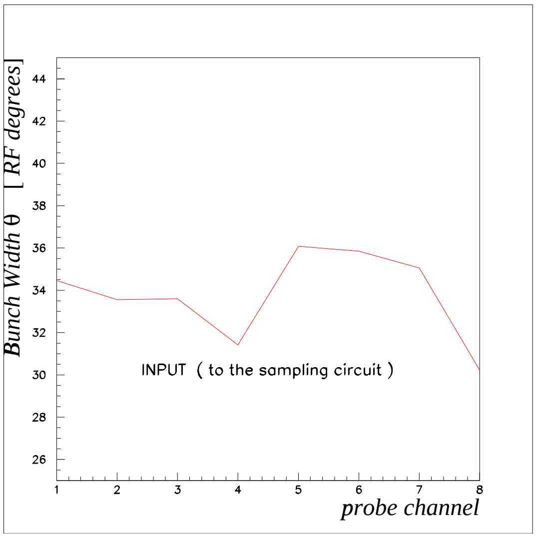

Figure 7: **Transition of the circulating beam-bunch half width**

6 REFERENCES

[1] J.F.P. Marchand, F. Shutte and H.L. Hagedoorn, Rev. Sci. Instrum., Vol.45, (1974) 361.

[2] T.Saito, H.Tamura, RCNP Annual Report (1980) 172.