POSITION MEASUREMENT OF FAINT BEAM
WITH
ELECTROSTATIC MONITOR

S. Watanabe, N. Tokuda, M. Takanaka and A. Noda

Institute for Nuclear Study, University of Tokyo
Midori-cho, Tanashi, Tokyo 188, Japan

Abstract

Position measurement with electrostatic monitor has been carried out in TARN. Accuracy of position detection is achieved within +-1 mm at beam current of 0.5 eμA or higher.

Introduction

Electrostatic position monitors are used in synchrotrons and storage rings for detection of beem orbit and for correcting the frequency of acceleration field.

In all these cases, it is no problem that the beam orbit is measured with the electrostatic position monitor at the higher beam intensity (>1 emA). However, influence of the noise is to become the most delicate problem at the lower beam intensity (<1 eμA). The noise is mainly composed of the RF noise generated by the accelerating cavity and the thermal noise occured in signal amplifier[1].

Complete way to prevent an invasion of RF noise is to enclose the pick-up electrode and amplifier system with an electromagnetight chamber. One way to reduce the influence of thermal noise is to employ the low noise preamplifier and the tracking filter. In this way, an automatic tuning technic of the tracking filter is required in order to follow the beam with a variable revolution frequency. For this purpose, a dual channel tracking filter (DCTF) has been developed.

In this paper, the pick-up system with the DCTF and its performance in TARN are reported.

Configulation of electrostatic position monitor

The schematic of the monitor[2] is shown in Fig.1. The pick-up port consists of a pair of electrodes (a) and two shields (inner shield (b) and outer shield (c)).

They are assembled in a vacuum chamber with accuracy better than +-0.5mm. Ceramic spacers (d) are used in assemblage, and the electrical insulation between them is better than $1*10^{9}$ ohms. The capacitance between one of the electrodes and the inner shields is measured to 180 pF. The voltage between them induced by the beam is measured across a resister connecting them.

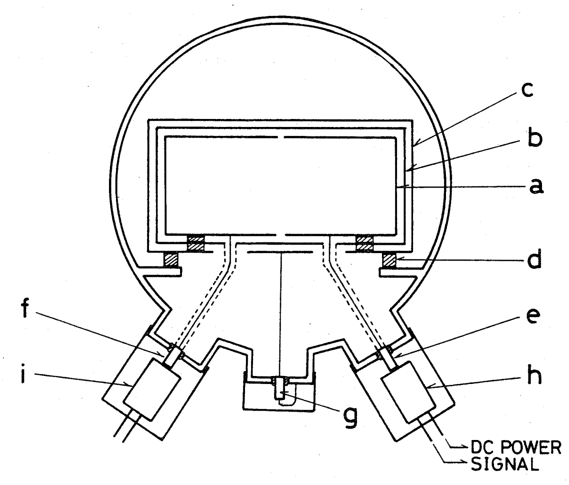

Fig.1 Schematic of Electrostatic Beam Monitor (cross section of pick-up part and feedthrough port)

There are three feedthroughs (e,f and g). They are BNC connectors of ultra-high vacuum tight and insulated from the vacuum chamber. Two feedthroughs (e,f) are provided for the pick up electrodes and the other (g) is provided for flowing the split beam current which hits the outer shield.

Two low noise preamplifiers (h,i) are attatched directry to the feedthroughs and covered with the shield case so as to prevent the invasion of RF noise.

DC power feed and signal extraction lines are well-shielded low loss coaxial cables.

AC power line for a monitor power supply is insulated from the RF system and filterd by the low pass filter.

Prior to installation, calibration is carried out with a current flowing through a wire. According to this result, picked up signal level in proportion to the transit position is observed over the useful aperture of this monitor. The coupling impedance is 1.1 ohms at the center of the electrode.

Electronics

The dual channel tracking filter (DCTF) has been developed in order that the bunched beam is selectively amplified. That is provided with a tracking range of 6 MHz to 10 MHz and a selective pass-band width of 3 kHz and 12 kHz. The block diagram of the DCTF is shown in Fig.2.

Beam signal tracking at each channel of the DCTF is carried out as follows:

The amplified beam signal is fed through the low loss cable to the DCTF in the control room.

The beam signal is mixed with the local signal by a double balanced mixer and its output is fed to the intermediate frequency amplifier (IFA). The IFA is provided with a frequency converter from input frequency 10.7 MHz to output frequency 455 kHz. The envelope of output signal is detected by a diode and a CR filter.

In order to detect the bunched beam signal the local signal frequency is composed of the sum of the 10.7 MHz inter-mediate frequency and 8 MHz bunch frequency (harmonic number is 7) . A total gain of 10^{5} is attained by the combination of low noise pre-amplifier and amplifier stage of the DCTF. And thus, an amplitude of fourier component of the bunched beam is detected.

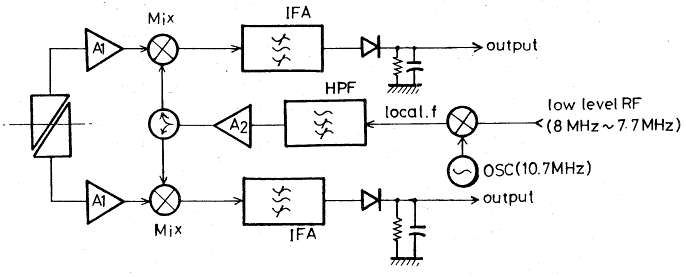

Fig.2 Block diagram of the Dual Channel Tracking Filter, which detects the bunched beam signal during injection and RF stacking process.

Dual channel system is provided for both electrodes in order to detect the beam position at a time.

In Fig.2, the source of local signal which is derived from the RF system will be able to substitute for the signal which is derived from bunched beam monitor such as the ferrite core monitor in TARN. In those case an amplitude of the signals must be held at constant level in order to ensure the generation of local signal.

The signals detected by the DCTF are applied to the signal processing system. In this system, following calculation is carried out in terms of beam position measurement:

$$R=(Va-Vb)/(Va+Vb)=cx/d \qquad (1)$$

where R; relative beam position,
Va; output voltage across the outer side electrode,
Vb; output voltage across the inner side electrode,
c; diagonal cut coefficient of the electrode,
d; mechanical center of the electrode,
x; beam position from the center.

There are two kinds of signal processing system are provided for displaying the beam orbit in TARN. The one is analog type and the other is digital type.

The analog type is composed of an operational amplifier and analog divider. The output signal is displayed on the storage oscilloscope. The digital type consists of the dual channel fast ADC with buffer memories and mini-computer (U400). The result of calculation is graphically displayed on the terminal display.

Beam Experiments

Beam position measurement has been carried out with $^{3}He^{+}$ and $^{12}C^{4+}$ beams.

In all these experiments, a beam position movement due to RF deceleration is estimated at 67.4 mm when an RF stacking frequency is sweeped from 8 MHz to 7.7 MHz. That is obtained by substituting the following parameters into the formula;

$$dx/df= \eta /Frf(1/(\gamma *\gamma)-1/(\gamma t*\gamma t)) \qquad (2)$$

where parameters are RF frequency (Frf=8MHz), dispersion function (η = 1.41 m), Lorentz factor (γ =1.00746) and transition parameter (γt= 2.23087).

The beam position movement had already checked by 7 MeV proton beam[3]. According to this result, the measured value of dx/df is 0.270 mm/kHz which is about 20 % larger than the calculated value of 0.225 mm/kHz.

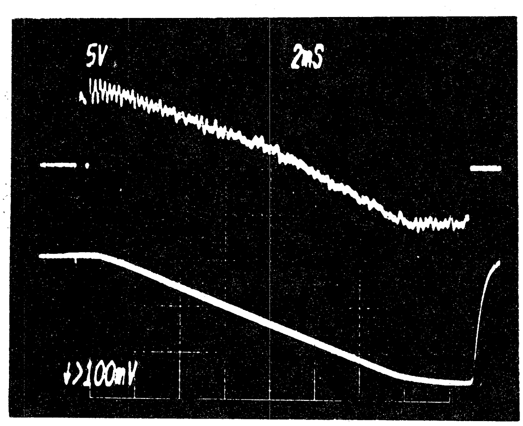

Fig.3 Decelerating frequency and beam position movement during RF stacking process. The upper shows position movement due to RF deceleration from injection to stacked orbit and the lower shows frequency change of the RF stacking system.($^{3}He^{+}$ beam ; 0.5 eμA)

The typical experimental data during RF stacking process is shown in Fig.3. This data shows the position movement from injection to stacked orbit at $^{3}He^{+}$ beam of 0.5 eμA. According to this, accuracy of the measurement is attained within +-1 mm. In a case of $^{12}C^{4+}$ beam of 0.2 eμA, accuracy is decreased within +-3 mm because the signal to noise ratio in the output signal of DCTF is decreased.

Discussion

To evaluate the signal level at the pick-up port, the following discussion is descrived.

The time structure of the bunched beam in TARN is assumed as the following equation;

$$I(t)=Io* \cos^{2} (t*\pi/\tau) \qquad (3)$$

where Io and τ are peak value of the bunched beam current and width of pulsed beam.

In order to estimate the frequency component of the bunched beam we consider the following Fourier expantion of above equation.

$$I(t)= a0+a1*\cos(2\pi t/T)+a2*\cos2(2\pi t/T)+ \text{-------}$$
$$+b1*\sin(2\pi t/T)+b2*\sin2(2\pi t/T)+ \text{------} \qquad (4)$$

The coefficient (a1) ,which comforms to the amplitude of fundamental component of the bunched beam, is expressed as

$$a1=(Io/\pi)*(\sin(\tau\pi/T)/(1-(\tau/T)**2) \qquad (5)$$

where T is interval time (periode of bunched beam).

With τ /T = 4 ns/ 120 ns ,the coefficient (a1) becomes to be 0.033Io.

Then multiplication of the coupling impedance (Zc) and the coefficient (a1) is expressed by the following equation;

$$Vo = a1*Zc = 0.033*Io*Zc \text{ (Volt)} \qquad (6)$$

When injected beam current is 1.2 eμA at 12 turns injection, the estimated injection peak current (Io) is 47.6 μA per bunch.

Therefore, the voltage (Vo) derived from above equation is calculated to be 1.67 μV. In fact, the measured value with a spectrum analyzer was 1.55 μV. This value is agree well with calculated result.

Conclusion

We have succeeded in practical position detection with electrostatic position monitor at beam intensity of 0.5 eμA ($5*10^{5}$ charges per bunch) or higher.

The subjects for the improvement hereafter are as follows;

1, Expansion of tracking range,
2, To realize the flatness of the peak level of the band-pass filter,
3, Development of the pick-up electrode of high coupling impedance.

References

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