BEAM STUDY OF FFAG ACCELERATOR AT KURRI*

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Abstract

In Kyoto University Research Reactor Institute (KURRI), The FFAG accelerator complex for accelerator driven sub-critical reactor (ADSR) project has been already constructed and world first ADSR experiment has been done at March, 2009. In the main ring, proton beams of 11.5 MeV are injected and accelerated up to 100 MeV. During the acceleration, two different types of beam loss have been observed. To investigate these beam losses, betatron tune and synchrotron oscillation phase have been measured experimentally. The details of measurements will be described in this presentation.

INTRODUCTION

In Kyoto University Research Reactor Institute (KURRI), The FFAG accelerator complex for accelerator driven sub-critical reactor (ADSR) project has been already constructed and world first ADSR experiment has been done at March, 2009 [1]. In ADSR, FFAG complex is used as a neutron driver and the accelerator complex is composed of three FFAG rings; injector, booster, and main ring [2]. In the main ring, proton beams of 11.5 MeV are injected and accelerated up to 100 MeV within 20 ms. The specifications of the main ring are summarized in Table1.

Table 1: Specifications of the main ring.

Lattice	Radial, 12 cells
Acceleration	RF
Field index, k	7.5
Energy (max)	100(150) MeV
P_{ext} / P_{inj}	2.83
Average orbit radius	4.54 - 5.12 m
Repetition rate	30 Hz
Revolution frequency	1.6 - 3.9 MHz
Betatron tune (design)	Horizontal 3.71
	Vertical 1.38
Transparency	50 %
Intensity (circulating)	0.4 nA

During the acceleration, two different types of beam loss have been observed. Figure 1 shows the circulating beam picked up by an electrostatic bunch monitor from injection to extraction in the main ring.

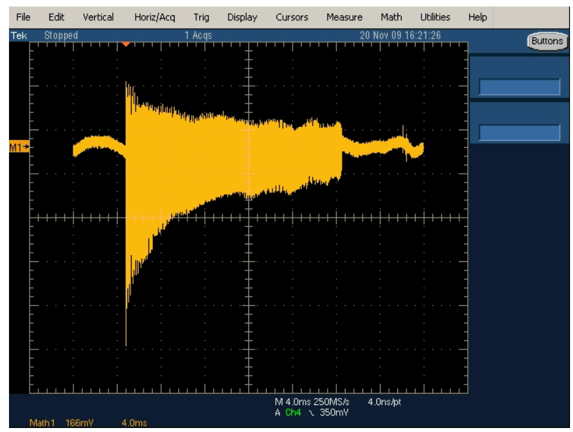

Figure 1: Output signals from bunch monitor of the main ring.

In Fig. 1, slow beam loss has been observed throughout the acceleration period. And around the 2.5 ms from the injection, rapid beam loss has been observed. To investigate these beam loss, betatron and synchrotron motion have been measured experimentally.

MEASUREMENT OF BETATRON TUNE

To investigate the beam loss due to resonance, betatron tunes have been measured experimentally. This is the first measurement of the betatron tune in the main ring. In this section, the details of the measurement are described.

Measurement setup

To excite vertical betatron oscillation, an electric field (maximum 350 V, frequency 0.4 - 2.0 MHz) has been used. Since the large aperture size of beam duct in the horizontal direction, RF cavity has been used for exciting horizontal betatron motion. Bunch signals are picked up by an electrostatic bunch monitor, which is located at the straight section in the main ring. FFT analysis of the bunch signals has been done using Spectrum analyzer (Tektronix RSA230).

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Measurement results

Using FFT analysis, decimal part of betatron tunes has been obtained as side band of revolution frequency. Figure 2 shows the measured frequency of revolution and its side band.

Figure 2: The results of FFT analysis.

Suppose revolution frequency is f_{rev} and frequency of the side band is f_{side}, decimal part of the betatron tune c is expressed by,

$$c = \frac{\left|f_{side} - mf_{rev}\right|}{mf_{rev}}, \tag{1}$$

where m is an integer.

In Fig. 3, the measured betatron tunes as a function of acceleration time are plotted. Since the power of exciter

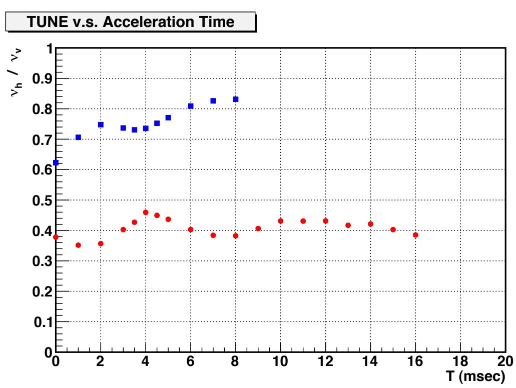

Figure 3: Measured betatron tunes as a function of acceleration time. Blue squares indicate decimal part of the horizontal betatron tune $\nu_{\rm h}$ and red circles indicate decimal part of the vertical betatron tune $\nu_{\rm v}$.

is not enough, betatron tune in horizontal direction can be measured up to 8 ms from injection. The energy of proton reaches 38 MeV at 8 ms from injection. And the strength of the side band depends on beam intensity, betatron tune in vertical direction can be measured up to 16 ms from injection. The energy of proton reaches 75 MeV at 16 ms from injection.

Using design value as an integer part of betarton tune, measured tune diagram is plotted in Fig. 4. Around 2.5 ms from injection, betatron resonance expressed by,

$$\nu_{\rm h} - 2\nu_{\rm v} = 1, \tag{2}$$

is crossed. This resonance crossing cause the rapid beam loss observed in Fig. 1.

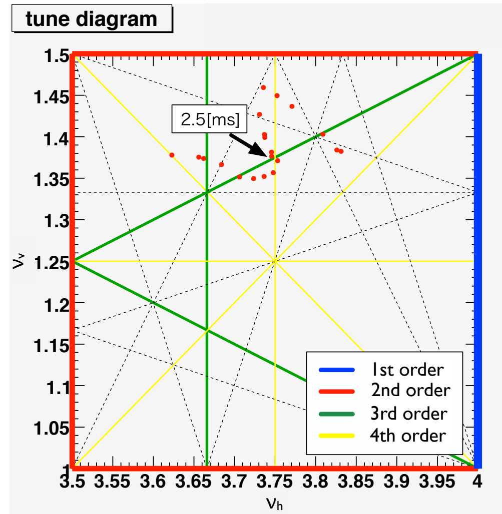

Figure 4: Measured betatron tunes diagram in the main ring.

MEASUREMENT OF SYNCHROTRON OSCILLATION PHASE

To measure synchrotron oscillation phase, a simple method has been developed. Using this method, synchrotron oscillation phase can be measured turn by turn. In this section, the details of the development and optimization of RF phase using this method is described.

Development of simple method to measure synchrotron oscillation phase

In this method, timing information of RF and bunch is used to measurement synchrotron oscillation phase. In Fig. 5, conceptual image is expressed.

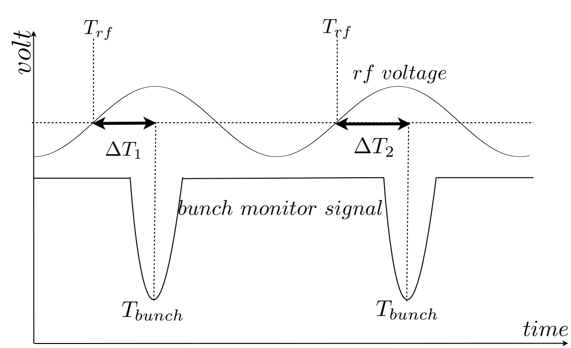

Figure 5: Concept of synchrotron oscillation phase measurement.

Suppose timing of RF is T_{rf} and timing of bunch is T_{bunch} like Fig. 5, synchrotron oscillation phase ϕ is expressed by,

$$\phi = 2\pi \frac{T_{bunch} - T_{rf}}{T_{rev}} \text{ rad}, \tag{3}$$

where T_{rev} is the revolution time.

To obtain confidence of this method, measurement of synchrotron oscillation frequency has been done and compared with the theoretical value.

Signals from RF driver (Tektronix AWG430) have been used as timing information of RF and signals from the electrostatic bunch monitor have been used as timing information of bunch. In Fig. 6, measurement result is plotted as a function of acceleration time. To obtain synchrotron oscillation frequency, fitting analysis has been done. Fitting equation is expressed by,

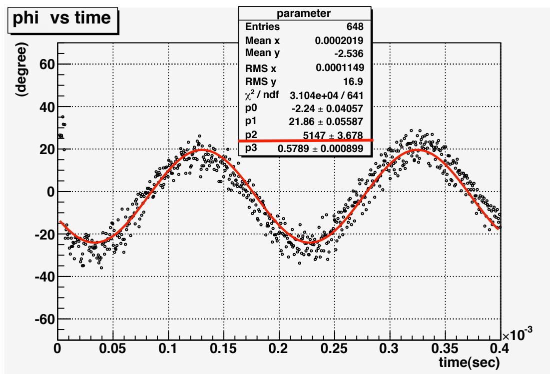

Figure 6: Measured synchrotron oscillation phase.

$$\phi = p_0 + p_1 sin2\pi(p_2 t + p_3), \tag{4}$$

where p_1 indicates the synchrotron oscillation amplitude and p_2 indicates its frequency. The measured synchrotron oscillation frequency f_s^{meas} is,

$$f_s^{meas} = 5.147 \pm 0.004 \,\text{MHz}. \tag{5}$$

Theoretical synchrotron oscillation frequency f_s^{theo} has been calculated using longitudinal parameters summarized in Table 2. The theoretical synchrotron oscillation frequency f_s^{theo} is,

$$f_s^{theo} = 5.1 \,\text{MHz}. \tag{6}$$

The both results are in good agreement.

Table 2: Parameters of longitudinal motion

RF Voltage	2.7kV
Revolution frequency	1.591 MHz
Slippage factor	0.85807
Synchro phase	50 deg
Kinetic Energy	11.6 MeV
Proton mass	938.27 MeV

Optimization of RF phase timing

Using this method, optimization of RF phase timing has been done. Figure 7 shows the measurement result of synchrotron oscillation phase using usual RF pattern. The amplitude of synchrotron oscillation is 25.4 degrees. After optimization, the amplitude becomes 8.5 degrees. It is shown in Fig. 8.

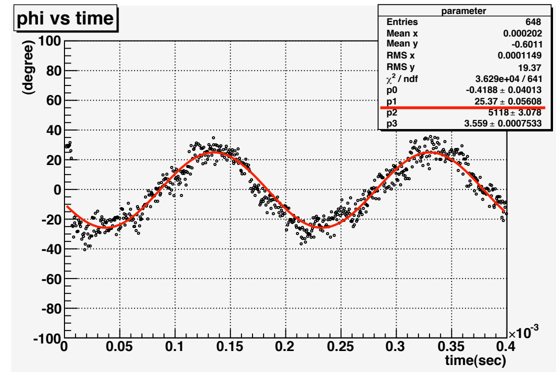

Figure 7: Measured synchrotron oscillation phase before optimization.

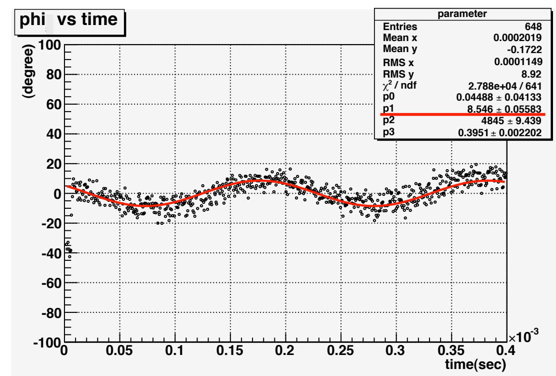

Figure 8: Measured synchrotron oscillation phase after optimization.

SUMMARY

To investigate beam loss during acceleration in the main ring, the measurement of betatron tune and development of simple method to measure synchrotron oscillation phase have been done.

Using developed simple method, amplitude of synchrotron oscillation becomes three times smaller. Through the measurement of the betatron tune, it is shown that resonance crossing causes beam loss.

To avoid this beam loss, correction of magnetic field is needed. And more precise investigation of longitudinal motion using developed method is also necessary.

REFERENCES

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[2] T. Uesugi et al., “FFAGS FOR THE ERIT AND ADS PROJECTS AT KURRI”, Proc. of EPAC08, Genova, 2008.