Beam tuning with a real-time spectrum analyzer at HIMAC synchrotron

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Abstract

With a real time spectrum analyzer, we can measure the frequency of betatron oscillation during acceleration. In this paper, the examples of beam tuning with the real-time spectrum analyzer are presented.

1 Introduction

Since the HIMAC operation was started, there was no serious break down of the machine which would cause trouble in clinical trial. Accumulated patient number is more than 600 in about 5 years. Recently, higher beam intensity is requested to make the irradiation time shorter than in the present cases. To increase the beam intensity, precise measurement of the tune is very important. The measurement is also required at the acceleration period. Until now RF-knock-out method is used to measure the tune value at the HIMAC. Though this method is easy, the measurement is limited in the flat top or bottom region. A real-time spectrum analyzer (sony tektronix 3055,3056) can be used for continuous tune measurement. By use of the analyzer, we can measure the frequency spectrum every 20 μs with a frequency span of 5MHz. This is fast enough to measure the tune during acceleration, where 500ms is required to accelerate up-to 290MeV/u. In this measurement the betatron oscillation is excited with white noise. This spectrum analyzer is also useful to measure acceleration frequency precisely for the tuning of a machine operation. In this paper, we present the examples of utilization in the machine tuning together with tune and chromaticity measurements.

2 Measurement system

A schematic diagram of the measurement system is shown in Figure 1. To measure the betatron oscillation with the real-time spectrum analyzer, the oscillation is excited with white noise. The noise signal can be mixed with revolution frequency with a double balanced mixer. In the present measurements, the white noise source (THAMWAY model T153-1316A) is directly connected to the RF amplifier via an attenuater, because the noise source has enough band width and the amplifier has enough output power. If the electric field of the RF-KO is insufficient to excite the oscillation, we can use an LPF at the white noise source. With this limitation of the frequency width of the noise, we have enough RF electric field in the frequency region of betatron oscillation. The excited betatron oscillation is measured with a COD monitor system [1]. Beam bunch signal in the form of displacement, R-L, can be used as an input to the real-time spectrum analyzer for the excited betatron oscillation amplitude. To monitor a revolution frequency, which is derived from an acceleration frequency, a monitor RF signal in the low level electronics is used directly.

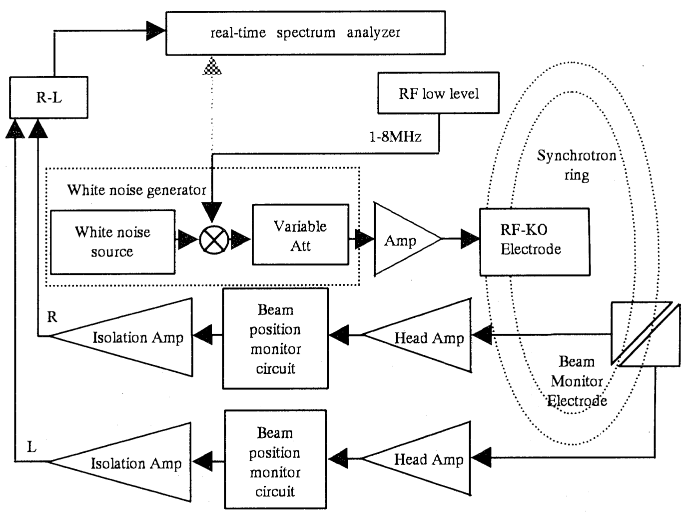

Figure 1. Schematic diagram of the measurement system of real-time spectrum analyzer. (Amp: amplifier, Att: attenuator)

3 Applications

3.1 Correction of an excitation level of dipole magnets

To obtain new beam of different energy, parameters are extrapolated from values in the tuned ones with which the beam can be accelerated well. In many cases, the beam can be accelerated well with thus calculated pattern data. However there is sometimes large beam loss at the beginning of flat top. One possible cause of this beam loss is mismatch between the field strength of the dipole magnet and the acceleration frequency at the flat top. In the adjustment we observe the frequency around transition region between the acceleration and the flat top using real-time spectrum analyzer. If there is mismatch, there is a linear ramp at the transition region as seen in figure 2. After adjustment, the measured frequency pattern is shown in figure 3. This adjustment is easy and practical in our experiences.

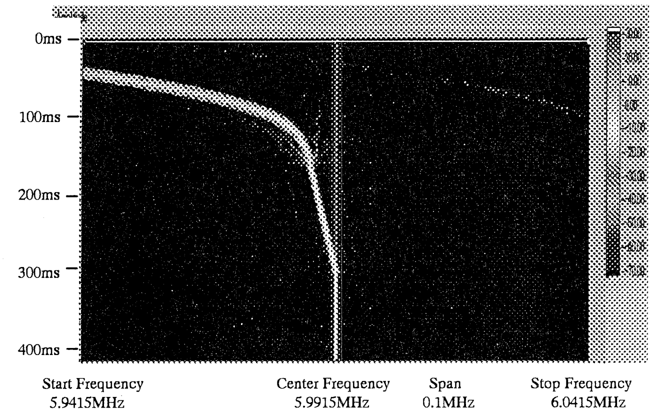

Figure 2. Revolution frequency pattern at the transition to flat top, before the adjustment. Vertical axis is time, horizontal one is frequency, and the amplitude of frequency is expressed with brightness (ranging from –10dBm to –70dBm).
(Time runs downward, and its origin is arbitrary.)

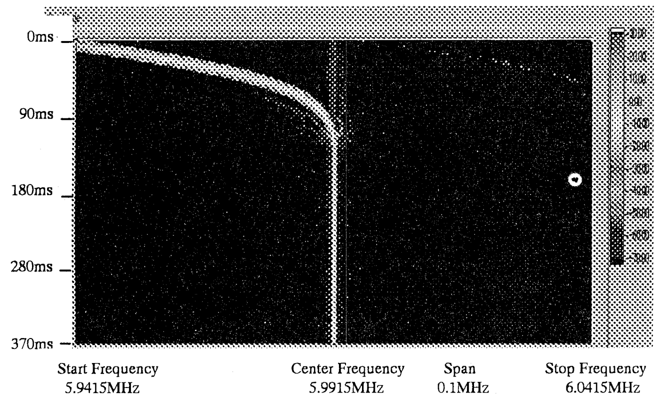

Figure 3. Revolution frequency after adjustment of dipole magnet. (290MeV/u)
(intensity range from –10dBm to –70dBm)

3.2 Tune measurement during slow beam extraction

In the operation with slow extraction, where horizontal tune shifts to the resonance condition, the tune measurement with RF-KO method is not easy at flat top. It is because the RF power is not strong enough to kick out the beam within a few msec, where the shift of tune is negligible. As mentioned in previous sections, we can observe the tune in much less than a msec span, using the real-time spectrum analyzer with white noise. In figure 4, the measured spectrum is shown, and we can see the shift of the side band frequency. The shift of horizontal tune during beam extraction is measured as shown in figure 5.

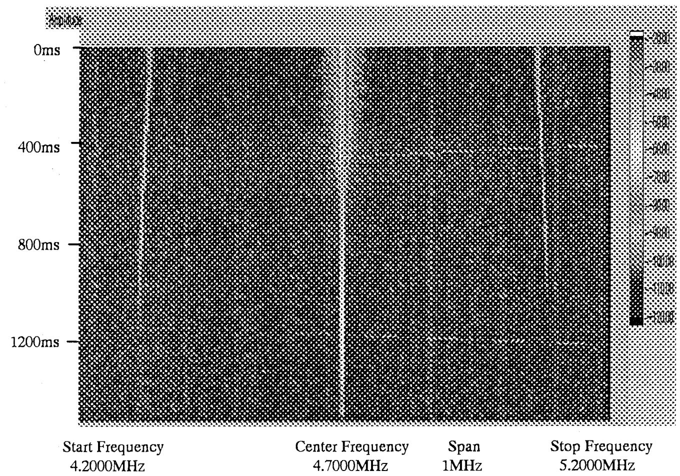

Figure 4. Revolution frequency of beam and horizontal betatron oscillation at flat top. (ordinary slow-extraction, 150Mev/u)
(intensity range from –20dBm to –100dBm)

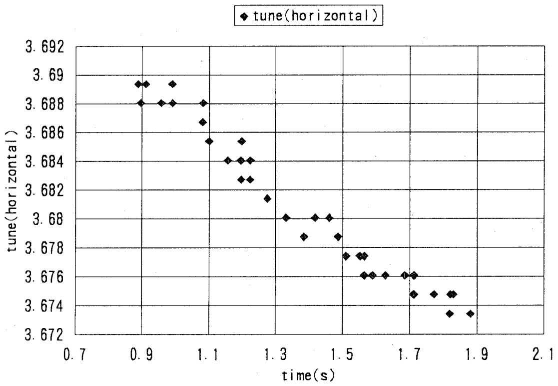

Figure 5. Horizontal tune at flat top. (ordinary slow-extraction, 150MeV/u)

3.3 Tune measurement during acceleration

In the synchrotron operation, it is important to make tracking between the dipole and quadrapole fields. If it is not obtained, the tune value will move during acceleration. This makes the beam loss, and we must minimize it to obtain the higher beam intensity. Especially at the beginning of the acceleration, there are several reasons that the tracking become inaccurate. One reason is that a ramping speed is increasing in a short time (70ms). Another one is a existence of the eddy current in a vacuum chamber, which disturbs the magnetic field. So the measurement during acceleration is important to know the resultant tune value.

With the real-time spectrum analyzer we can measure the tune during acceleration, because the frequency spectrum can be measured in a short time of 80 μ s with wide frequency range of 5MHz. In the measurement the betatron

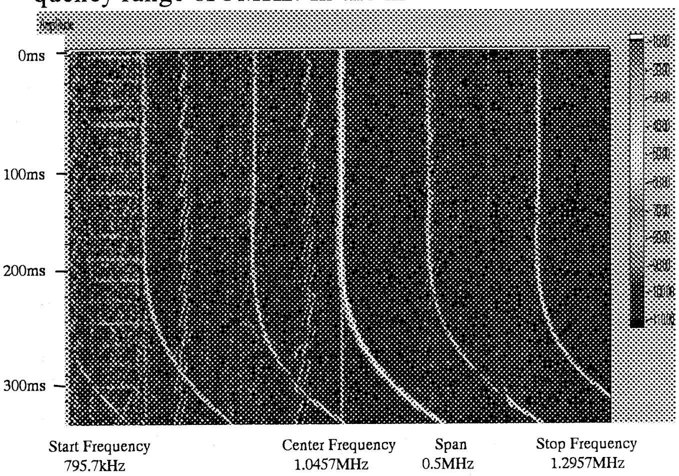

Figure 6. Acceleration frequency and betatron oscillation around flat bottom.(290MeV/u)
(intensity range from –20dBm to –100dBm)

oscillation was excited with white noise during acceleration. Figure 6 shows measured frequency spectrum, where we can see clearly the side bands of the betatron oscillation together with the acceleration frequency. Obtained horizontal tune values and the acceleration frequencies are plotted in figure 7. In this plot, we can see that the tune fluctuation is of considerable order.

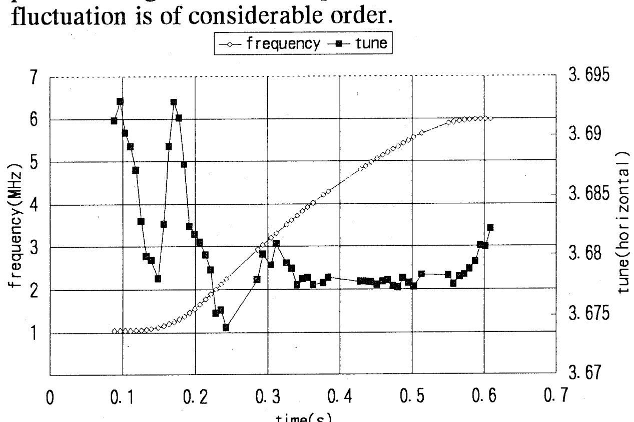

Figure 7. Horizontal tune in connection with acceleration frequency from flat bottom to flat top. (290MeV/u)

3.4 Chromaticity measurement during acceleration

Eddy current in the vacuum chamber also makes sextupole field. With this field chromaticity will be augmented, which makes beam loss at the early stage of the acceleration.

To measure the chromaticity, we can use same way as in the case of the tune, with a shift of the acceleration frequency at the flat bottom. With a corresponding magnetic field of ΔB_b that is given by frequency function, we can obtain the frequency shift (Δf) during the acceleration with the following equation.

$$\Delta f = \frac{c}{2\pi R\left\{\sqrt{1+\left(\frac{mc^2}{cq\rho B}\right)^2}\right\}^3}\left(\frac{mc^2}{cq\rho B}\right)^2\frac{1}{B}\Delta B_b \qquad (1)$$

where c is light velocity, R is average radius, m is mass of the particle, q is charge of the particle, ρ is curvature radius of dipole magnet, B is magnetic field.
With the obtained frequency shift (Δf), momentum shift is given by the following equation.

$$\frac{\Delta p}{p} = \left(\frac{1}{\gamma^2}-\frac{1}{\gamma_t^2}\right)^{-1}\cdot\frac{\Delta f}{f} \qquad (2)$$

where γ is the particle energy in units of the rest energy, γ_t is a designed transition gamma value of 3.67, p is momentum of the particle. Then the chromaticity can be obtained as follows.

$$\xi = \frac{\Delta\nu}{\frac{\Delta p}{p}} \qquad (3)$$

In figure 8, the measured chromaticities are shown, and the deviation can be seen at the early stage of acceleration. The obtained deviation may have strong effect on the beam.

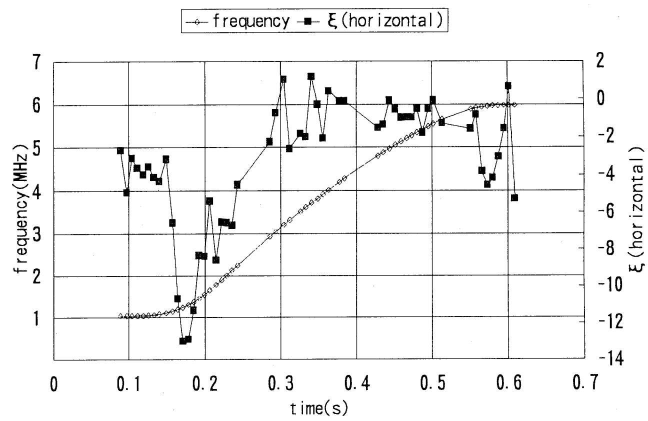

Figure 8. Measured chromaticity. (290MeV/u)

4 Summary

We have demonstrated applicability of a real-time spectrum analyzer in ion-beam acceleration tuning. Precise adjustment of magnet current was made as observing frequency around transition region with the real-time spectrum analyzer. The tune and chromaticity during acceleration were measured with white noise and the real-time spectrum analyzer. We were able to observe a large fluctuation of tune and chromaticity at the beginning of acceleration which may cause considerable beam loss. We intend to investigate tune and chromaticuty at the early stage of acceleration in more detail.

Acknowledgment

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Reference

[1] M. Kanazawa, et. Al. ,"COD MEASUREMENT AND CORRECTION SYSTEM IN HIMAC SYNCHROTRON" ,Proc. 5th EPAC, Barcelona, 1996, p. 1710-1712.