ANALYSIS OF FREQUENCY SPECTRUM OF BUNCHED BEAM RELATED TO TRANSVERSE LASER COOLING *

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Abstract

Using synchro-betatron coupling, transverse laser cooling is pursued at an ion storage/cooler ring, S-LSR, Kyoto University. Prolongation of sideband amplitudes in the right side of the revolution frequency of h=99 and in the left side of the revolution frequency of h=101 were observed adjacent to the RF frequency (h=100) in analysis of frequency spectrum of a bunched beam. We hope to utilize these kind of asymmetric phenomena to diagnose synchro-betatron couplings of a bunched beam.

INTRODUCTION

Laser cooling techniques have been available to cool down the longitudinal temperature of ion beams. The resonant coupling method, which transfer a cooling force in the longitudinal direction to the transverse direction, was proposed to achieve indirect transverse laser cooling [1]. A 40keV Mg^+ beam is introduced into Small Laser-equipped Storage Ring (S-LSR)[2], which is equipped with a frequency tuneable laser system ~280 nm for beam cooling, at ICR, Kyoto University. Horizontal(x) and longitudinal(s) directions are coupled by an RF cavity located at the position with a finite dispersion. In this two-dimensional (2-D) couplings of laser cooling, a resonant conditions has to be satisfied,

$$\nu_x - \nu_s = integer,$$

where ν_x is the horizontal betatron tune and ν_s is the synchrotron tune of the beam. In this paper, frequency spectrums in the case of synchro-betatron coupling are investigated when the resonant condition is satisfied for a possible transverse laser cooling. A symptom of horizontal laser cooling has been reported at S-LSR [3].

SPECTRUM MEASUREMENT

At S-LSR (Figure1), the cooled beam is diagnosed by a photo multiplier tube (PMT) and a CCD camera at the laser cooling section. S-LSR has 6-fold symmetry, which was designed to minimize the beam heating. Two-gap drift tube, which is RF cavity of gap interval of 113 mm, is designed to bunch the ion beam for harmonic number 100. The frequency of RF wave was 2.52MHz.. It is located at the position of a finite dispersion (D =1.1 m). Table 1 shows the main parameters of S-LSR.

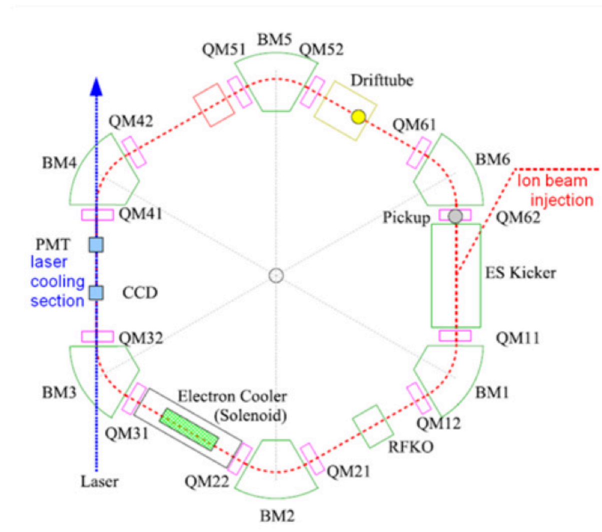

Figure 1: Layout of S-LSR.

Table 1: Main Parameter of S-LSR

Circumference	22.557 m
Average Radius	3.59 m
Length of straight section	1.86 m
Radius of curvature	1.05 m
Revolution frequency	25.192 kHz
Super periodicity	6
Ion species	$^{24}Mg^+$
Kinetic beam energy	40 keV
Transition wavelength	280 nm

Figure 2 shows the block diagram of the betatron tune measurement in the transversal phase space using beam transfer function. The beam is kicked by a pair of parallel-plate electrodes excited by a network analyzer (Agilent 4395A) and beam oscillation~~s~~ in the transverse direction is observed by a plate pickup with triangular shape, which is one of the beam positional monitors[4].

The synchrotron tune in the longitudinal phase space is measured with use of the signal indicated by green arrows in Fig.2 without RFKO excitation.

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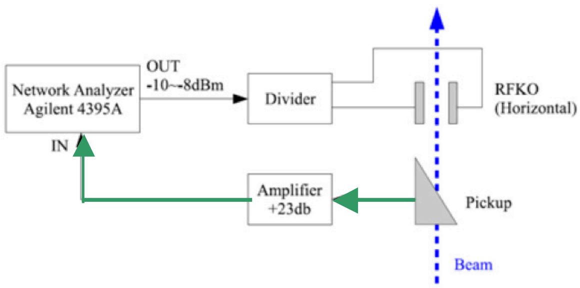

Figure 2: Conceptual diagram of Signal Measurement Pickup consists of two triangular plates.

EXPERIMENTAL RESULTS

In Fig. 3, a relation of fractional part of tunes near a resonant point ($\nu_x = 2.10, \nu_y = 1.10, \nu_s = 0.10$) is shown when the resonant condition is satisfied. The harmonics number h satisfied h=9 where noises were minimum. Clear tune jump in synchrotron and betatron horizontal tune were observed near a fractional part of tune $\Delta\nu = 0.11$ where the exact value of resonant fractional tune was skipped. This is an evidence of Synchrotron (longitudinal) and horizontal betatron (two dimensional) coupling near the resonant point $\Delta\nu = 0.11$ [5].

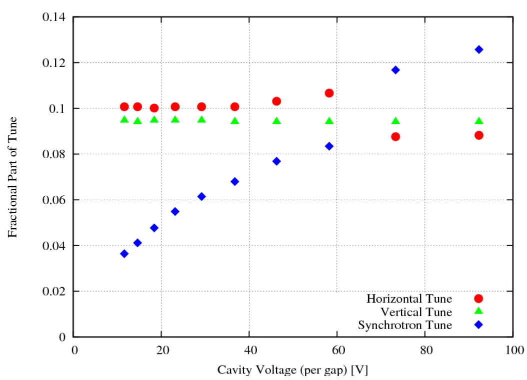

Figure 3: Synchrotron and horizontal betatron coupling near the resonant point ($\nu_x = 2.10, \nu_y = 1.10, \nu_s = 0.10$).

Sidebands of synchrotron frequencies were observed at both sides of each harmonics of the revolution frequency (25.192 kHz). In each figure of figures 4,5,6,7 and 8, five peaks are recognizable. They corresponds to frequencies of harmonic number h=98, 99, 100, 101, and 102 from the left. In h=98, 99, 101, and 102, synchrotron sidebands were accompanied in both sides. For h=100 (centre), RF wave frequency itself was dominated.

Figure 4 is the case for ν_s=0.058, Fig. 5 for ν_s=0.063, Fig. 6 for ν_s=0.066, Figure 7 for ν_s=0.072 and Fig. 8 for ν_s=0.077. In Fig. 6, the resonant condition is satisfied. Then amplitudes of the synchrotron oscillation, which is the right side of the revolution frequency h=99 as well as the left side of the revolution frequency h=101, are prolonged.

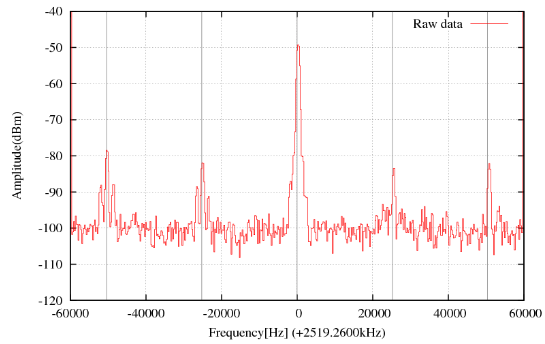

Figure 4:Sidebands for ν_s =0.058

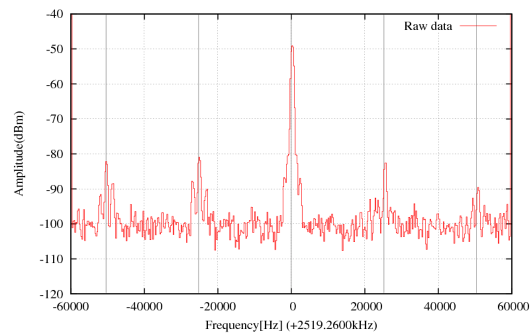

Figure 5: Sidebands for ν_s =0.063

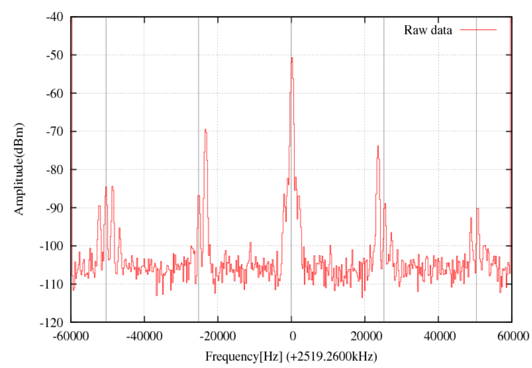

Figure 6: Sidebands for ν_s =0.066(the resonance tune).

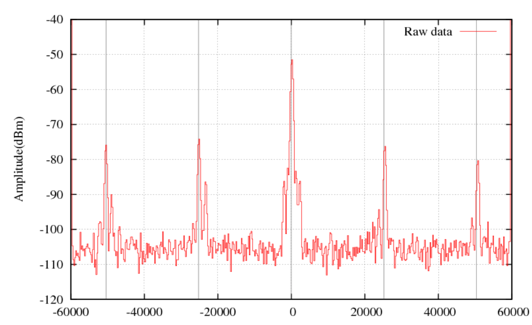

Figure 7: Sidebands for ν_s =0.072

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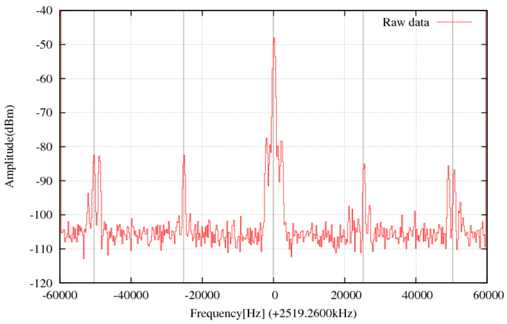

Figure8: Sidebands for ν_s =0.077

Fig. 9 shows the synchrotron oscillation amplitude in the right side of the revolution frequency h=99 is prolonged. Fig. 10 shows that the amplitude in the left side of the revolution frequency h=101 is also prolonged.

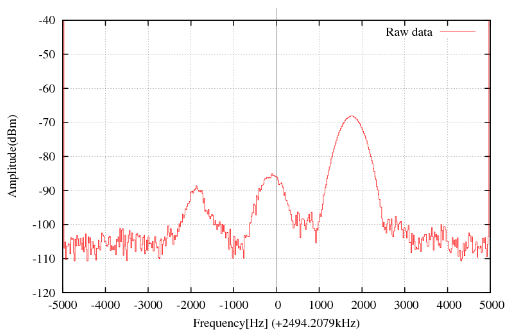

Figure 9: Enlargement of harmonic h=99 in the resonant condition ν_s=0.066. The amplitude of a synchrotron oscillation sideband in the right side of the revolution frequency h=99 (centre) is prolonged.

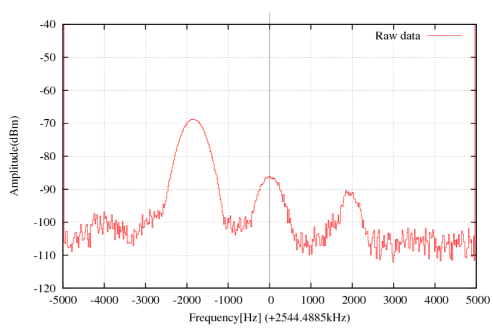

Figure 10: Enlargement of harmonic h=101 in the resonance condition ν_s =0.066. The amplitude of a synchrotron oscillation sideband in the left side of the revolution frequency h=101(center) is prolonged.

Figure 11 is the case of the resonance tune ν_s =0.066 when the ion beam was laser cooled in the longitudinal direction. It is similar to Fig.6 of no laser cooling. Generally there is no clear difference in amplitudes of synchrotron oscillation sidebands whether the ion beam was laser cooled or not.

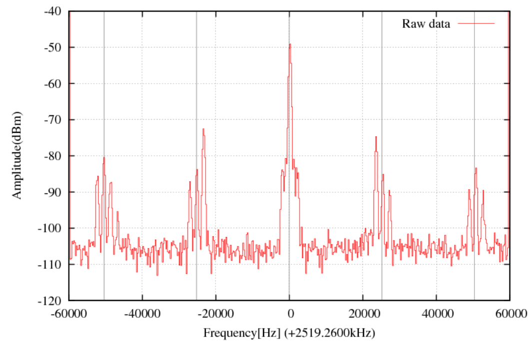

Figure 11: Laser cooled harmonics for ν_s =0.066, when the resonant condition is satisfied. Synchrotron sidebands were accompanied in both sides.

CONCLUSION

When the resonant condition is satisfied in S-LSR, prolongation of sideband amplitudes of the right side of the revolution frequency of h=99 and prolongation of sideband amplitudes of the left side of the revolution frequency of h=101 were observed: One side of two sidebands (of a particular harmonics) amplitude was prolonged. This kind of asymmetry was not observed at other harmonics numbers. On the other hand, a symmetry in the frequency spectrum occurred around the RF frequency (h=100). These phenomena happened to be observed near the RF frequency. Further investigation is necessary to find out physical mechanism of these asymmetries. We welcome any comments at the poster session.

We would like to use these symmetries to diagnose synchro-betatron couplings. An effective energy transfer between the longitudinal and the horizontal directions of an ion beam to achieve the horizontal cooling is one of our purposes.

We hope an analysis of frequency spectrum is utilized as a new diagnosis method of bunched beams.

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