POSSIBLE OBSERVATION OF TRANSVERSE LASER COOLED ULTIMATE COLD ION BEAM IN S-LSR*

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Abstract

Transverse laser cooling is pursued at an ion storage/cooler ring, S-LSR, Kyoto University. An RF bunched Mg^+ beam was cooled transversely through synchro-betatron resonance coupling by a co-propagating laser. We investigated peaks of synchrotron oscillation spectroscopically so that we can observe them stably. Oscillation signals from a parallel-plate pickup were observed by a spectrum analyzer. We also observed the coherent synchrotron modes. As the beam temperature decreases, the ion beam would be in space charge limited region. According to the computer simulation, in the case the beam turns to be space charge limited, the disappearance of peaks of synchrotron oscillation is expected. We would like to propose a capability of detecting space charge limited region by observing such a frozen synchrotron oscillation.

INTRODUCTION

In Small Laser-equipped Storage Ring (S-LSR) at ICR, Kyoto University, a frequency tuneable laser of ~280 nm is co-propagating with a 40keV Mg^+ beam, as shown in Fig.1. It was cooled in the transverse direction through resonant coupling method [1]. The Horizontal and longitudinal oscillations are coupled by an RF voltage applied at the position with a finite dispersion when a synchro-betatron resonance coupling condition (SBRC) is satisfied: a cooling force in the longitudinal direction is transferred to the transverse direction [2].

The ion beam was bunched by the RF wave of frequency 2.5192MHz. Since the revolution frequency was 25.192kHz, it corresponded to the harmonic number 100. Frequency spectra, which were obtained from preamp signals of a parallel-plate pickup in the ring, were observed by a spectrum analyzer [3]. We hope to use these frequency spectra for diagnostic purpose of ultra cold ion beams.

The RF frequency of 2.5192MHz will be printed as 2.5MHz for abbreviation, which corresponds to 0Hz in Figure 2, 3, and 5. In Figure 4, 0Hz represents 2×2.5MHz. At this stage of transverse laser cooling where the beam temperature was not yet ultra-cold to be in space charged limited region, there was no clear difference in frequency spectra whether the ion beam was laser cooled or not.

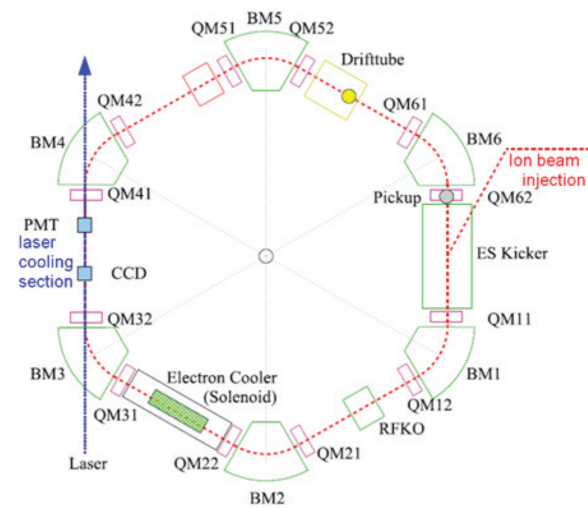

Figure 1: Layout of S-LSR.

Table 1 shows the main parameters 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

EXPERIMENTAL RESULTS

The frequency spectra of around 2.5MHz, which is located at the centre, are shown in Fig. 2. To erase sidebands (2 peaks about ±1kHz, and about±2kHz from the centre), the RF frequency was varied ∓ 0.5kHz (Fig.2-a and 2-c) when SBRC was satisfied (Resonance tune ν_s=0.066、ν_h=2.066). However, we could not erase them. They were not noises. In fact the sidebands are small enough since the ordinate is the unit of dBm.

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In Fig. 3 and 4, sidebands of synchrotron frequencies were observed at both sides of each harmonic of the revolution frequency when SBRC was satisfied. These peaks were not observed under no beam. Therefore the ion beam caused them.

In Fig. 3, five peaks are recognizable. They correspond to frequencies of harmonic number h=98, 99, 100, 101, and 102 from the left. At h=98, 99, 101, and 102, synchrotron sidebands are accompanied in both sides of each harmonic. The 1st harmonic of RF frequency 2.5MHz is observed at the centre (h=100). An enlargement of the central peak is identical to Fig. 2-b.

In Fig.4, five peaks are also recognizable. They correspond to frequencies of harmonic number h=198, 199, 200, 201, and 202 from the left. At h=198, 199, 201, and 202, synchrotron sidebands are accompanied in both sides of each harmonic. The second harmonic of RF frequency (2×2.5MHz) is observed at the centre (h=200). The peak between 199 and 200 (about −1.6kHz from the centre 200) is a <u>noise</u> since it was observed under no beam.

The RF voltage was varied in Fig.5, which was recorded in higher resolution. Peaks indicated by blue arrows, of which synchrotron frequencies were shown, were moved among 5 peaks of +0kHz, about ±1kHz, and about±2kHz from the centre. Unexplainable low peaks were observed at ±1.7kHz in Fig5-a and ±1,5kHz in Fig5-b. They were not noises. Those low peaks were not observed under no beam.

Because of higher resolution, these peaks looks a little bit slender compared to those in Fig. 2. Synchrotron frequencies were evaluated according to the frequency formula of small amplitude synchrotron oscillation [4].

THE COHERENT SYNCHROTRON MODES

Fig. 2 manifests that sidebands are the coherent synchrotron modes (4 peaks about ±1kHz, and about± 2kHz from the centre), which occur when the RF frequency is a not exactly an integral multiple of the revolution frequency of each of circulating ions: this is the case when ions are circulating in bunches. A bunch is made of ions with different synchrotron amplitudes and phases. The coherent synchrotron modes of the bunch can be obtained by averaging synchrotron motions over the bunch distribution [5]. The coherent frequency spectra are located at harmonics of the RF frequency. Fig. 5, in which the RF voltage was varied, shows that the coherent synchrotron modes are independent of the RF voltage.

DISCUSSION

The computer simulation expects dumping of synchrotron oscillations when the ion beam is in space charge limited region [6]. When an ion beam is cooled to space charged limited region, it would be very difficult to detect it directly since the number of ions in the cold Mg^+ beam is very limited. In fact, the number of ions is estimated much less than ~10^4 [7]. A diagnostic method using scraping is already applied in a ultra-cold Mg^+

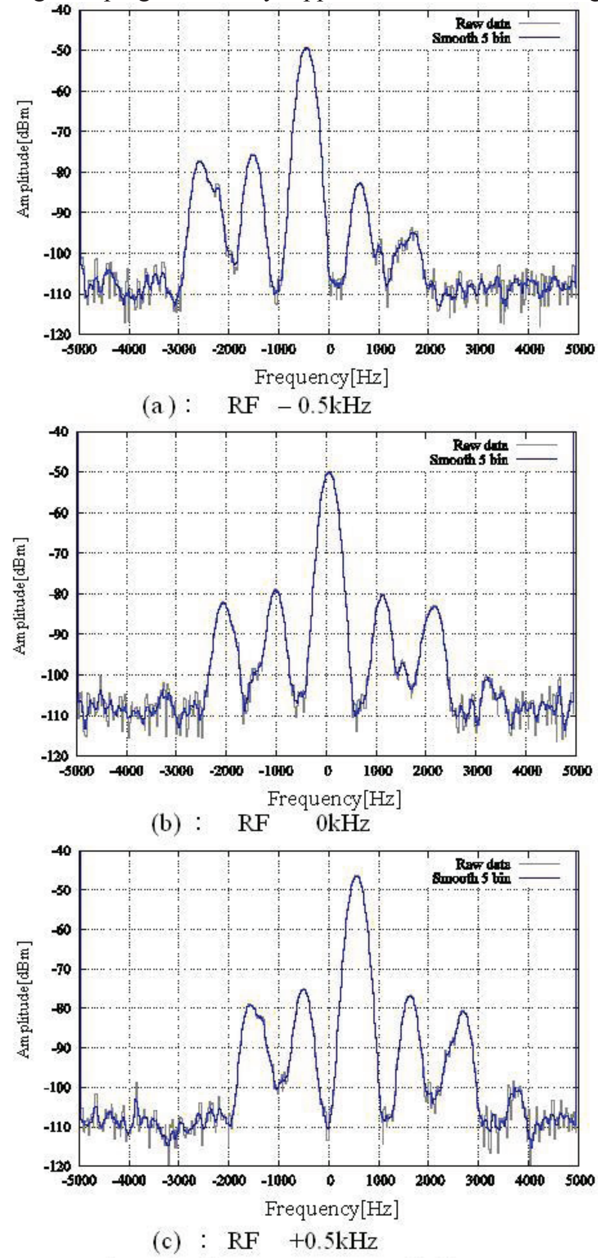

Figure 2 : Frequency spectra RF frequency was varied relative to RF frequency 2.5MHz (centre 0Hz).

beam, which, however, was not sensitive enough to be usable in space charged limited region [8].

We have observed synchrotron frequencies stably in frequency spectra. Observation of synchrotron frequencies would be helpful to confirm space charge limited ion beam since peaks of synchrotron oscillation would disappear in frequency spectra. Therefore we hope frequency spectra are usable as a diagnostic method of ultra cold ion beams.

It is also our great interest what will happen to the coherent synchrotron modes in space charged limited region, which we want to investigate with the use of the indirect transverse laser cooling when SBRC is satisfied in a near future.

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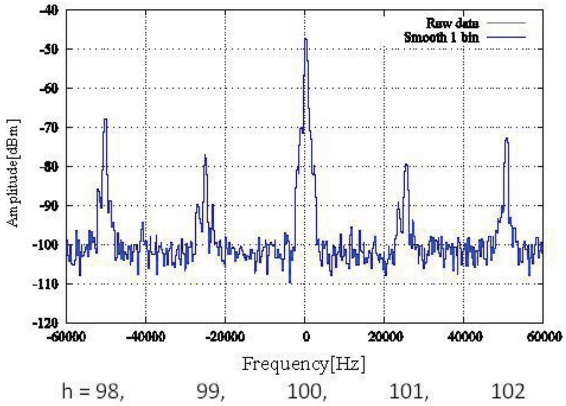

Figure 3: Frequency Spectrum from h=98 to 102. An enlargement of centre peaks (h=100) is physically the same as Figure 2-b.

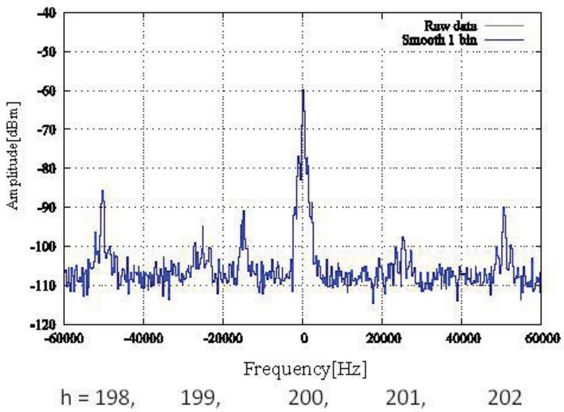

Figure 4: Frequency Spectrum from h=198 to 202. The peak between 199 and 200 is a noise since it was observed under no beam.

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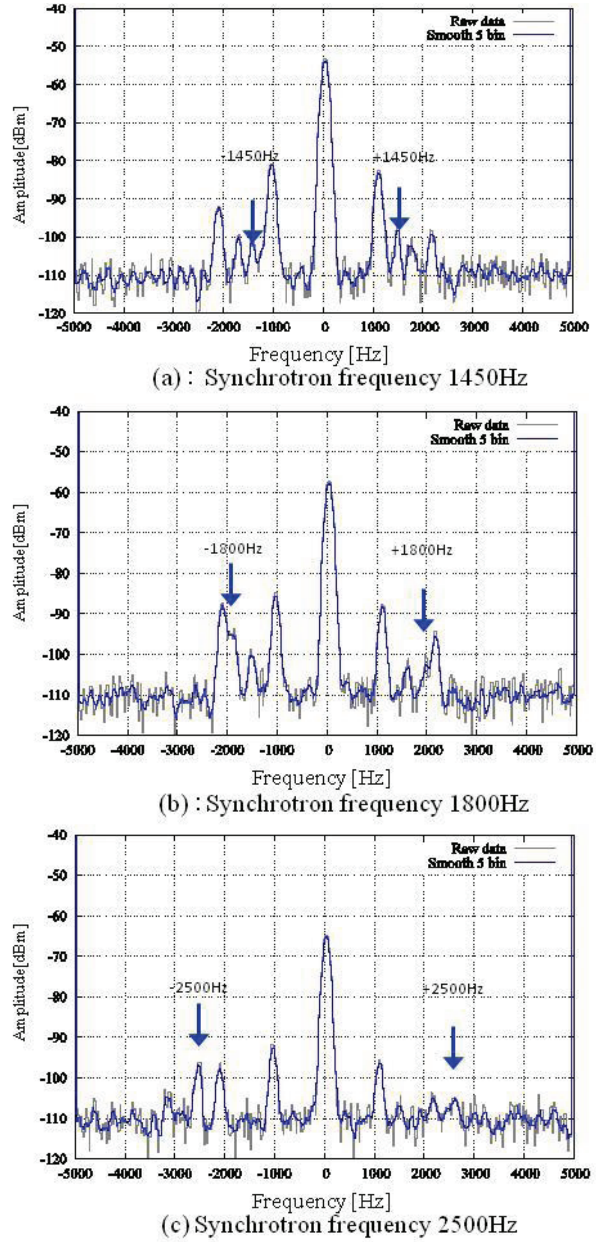

Figure 5: Frequency spectra when RF voltage was varied. RF frequency 2.5MHz is at the centre (0Hz). Synchrotron frequencies are indicated by blue arrows. Unexplainable low peaks were observed at ±1.7kHz in (a) and ±1,5kHz in (b). They were not noises. Those low peaks were not observed under no beam.