A STUDY ON THE APPLICABILITY OF LANDAU CAVITY TO THE 1.2GeV BOOSTER SYNCHROTRON AT TOHOKU UNIVERSITY*

F. Hinode#, K. Akiyama, H. Hama, M. Kawai, K. Kasamsook, A. Kurihara, T. Muto, K. Nanbu, Y. Shibasaki, S. Takahashi, T. Tanaka, M. Yasuda
Laboratory of Nuclear Science, Tohoku University, Sendai 982-0826, Japan

Abstract

A 1.2 GeV Stretcher-Booster (STB) ring at Laboratory of Nuclear Science (LNS), Tohoku University, has been mainly operated for experiments of nuclear physics. One of the many issues limiting performance of the STB ring is supposed to be strong longitudinal coupled-bunch instability. In order to suppress the instability, applicability of a third-harmonic Landau cavity has been studied. The 1.5 GHz harmonic cavity was manufactured and installed in the ring. As a preliminary result of the beam test, it was turned out that the very strong signal of collective synchrotron oscillation was able to damp drastically depending on tuning angle of the harmonic cavity. Present status of the STB and the first test result of beam operation with harmonic cavity are described in the paper.

INTRODUCTION

In these years, the STB ring has been mainly operated in the booster-storage mode in which the high energy gamma-ray beam generated via bremsstrahlung from internal target wire has been utilized for experiments of nuclear physics [1]. The STB ring had been designed and constructed so as to have functions of: 1) pulse-beam stretcher [2], and 2) booster ring as an injector for a light source project [3]. The main parameters of the ring are listed in table 1. The STB is not the light source ring but also has storage ring-like function. Although the stored beam current is sufficient level (~15 mA) in the present operation for the nuclear physics user, it has still continued to increase the stored current toward the future application such as light source. The injected beam from linac is ramped up to variable top energy (1.2 GeV max.) during about 1 sec. The flat top time is also variable. The injection energy is not high enough (150 or 200 MeV), so that radiation damping time is much long (~ 1 s in the longitudinal direction). Although the injector linac provides sufficient beam current without beam stacking, circulating beam current decays rapidly due to instabilities before the beam reaches the top energy. One of the main causes of the beam current limitation might be supposed due to strong coupled-bunch instability because any care for the ring impedances had not been taken. Actually very strong synchrotron oscillation signal have been observed around 3.6 GHz. Since the main rf cavity itself does not have adequate HOM in such frequency region, any other possibility for the narrow band impedance source has been investigated. On the other hand, Landau cavity might be effective in order to suppress the instability. It is also supposed that the Landau cavity can improve the beam lifetime by increasing the bunch length. This approach is successfully employed in many light sources such as MAX-II, ALS and BESSY-II so far [4-6]. This technique is getting well established, but there may still remain difficulty and/or less knowledge in low energy ring where the radiation damping is very weak. Especially in the booster ring with large energy deviation from injection to flat top, to study the effect of the harmonic cavity seems to be interesting for longitudinal beam dynamics.

Table 1: The main parameters of STB ring

Lattice type	Chasman-Green
Superperiodicity	4
Circumference	49.7 m
Maximum energy	1.2 GeV
Injection energy	0.2 or 0.15 GeV
Betatron tune (ν_x,ν_y)	(3.22, 1.15)
Chromaticity (ξ_x,ξ_y)	(~ -5.5, ~ -4.7)
RF frequency	500.14 MHz
RF voltage	140 kV
Harmonics	83
Natural emittance	170 nmrad (@ 1.2 GeV)
Momentum compaction	0.0378

HIGHER HARMONIC CAVITY FOR STB

Among some choices we decided to test the normal-conducting passive third harmonic cavity because of that simplicity and easier understanding of beam dynamics. The tentative target was set to 100 mA for the design of higher harmonic cavity. The parameters of the cavity are listed in table 2.

Table 2: Parameters of the harmonic cavity (measured)

Frequency (@0mm,30˚C)	1499.1		MHz
Frequency range (tuner position)	+11.4 -1.2	(+25 mm) (-15 mm)	MHz
Pickup probe coupling	-30		dB
Loaded Q	22,270		
Shunt impedance*	3.8		MΩ

* Rsh =V^2/P : calculated value assuming R/Q by SUPERFISH

For the full energy operation, analytic modeling and simulations were first performed without consideration of HOMs in the rf cavities [7]. This allows the study of Robinson instabilities and coupled-bunch instabilities

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# hinode@lns.tohoku.ac.jp

excited by the fundamental modes of the rf cavities. The methods are described in the references [8, 9]. The modeling and simulations were then repeated with a HOM included. The results show that if three harmonic cavities are used, near-optimal bunch-lengthening may be obtained at the maximum ring current of 100 mA. The results also show that a single passive harmonic cavity will not provide sufficient voltage for optimal bunch-lengthening. For injection energy of 200 MeV, almost same analysis were performed and showed that increased energy spread from the instability or lost macro-particles occurred for nearly all currents and tuning angles. This analysis didn't include intrabeam scattering, so that they may be less accurate for low-energy operation than full-energy. Furthermore, there are a lot of impedance sources in the STB as mentioned before, thus it is difficult to estimate beam behaviour precisely.

As the first step of the study with passive higher harmonic cavity, we decided to prepare one harmonic cavity and try the beam test in the STB. The cavity was designed as a single cell pillbox type and manufactured by Toshiba Co. Ltd., which is shown in Fig. 1. Although the beam pipe diameter should be large enough so as to maintain the physical aperture, it has 40 mm in diameter to keep sufficiently high shunt impedance. To realize a tuner parking option, two tuner ports are prepared; one is used for a movable and the other for fixed one. The fixed tuner port might be used for an input port as a future option. The movable tuner can change the resonant frequency within two times of the revolution frequency. The cavity parameters in table 2 are measured ones, which are almost the same as designed values.

Figure 1: The third harmonic cavity.

BEAM TEST

Figure 2 shows observed beam spectrums for 1.2 GeV operations, which are obtained by a BPM located at dispersive section. Very strong synchrotron signal is clearly seen only at 3.6 GHz. Since there seems to be no HOM in such frequency region in the main cavity as mentioned earlier, other impedance source might cause this instability. Actually, obvious dependence on this synchrotron oscillation signal is not seen even some variations such as main cavity temperature, tuning angle and beam orbit. This instability has a threshold at 8.5 mA as shown in Fig. 3. As a possible source, it might be considered that the main cavity forms a resonator with beam ducts, which have sudden transitions of the shapes in their connections.

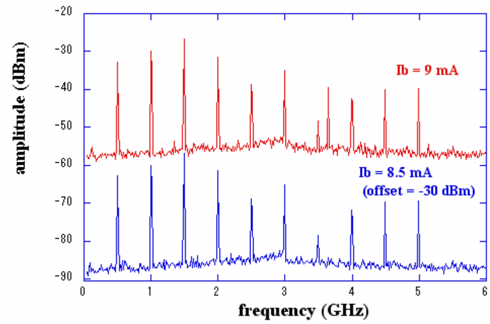

Figure 2: Observed beam spectrum by BPM located at dispersive section.

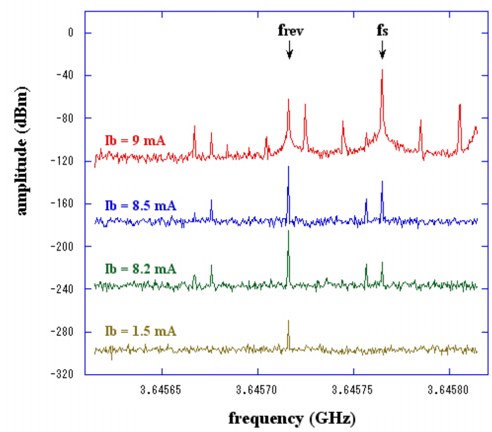

Figure 3: Observed beam spectrum (expanded around 3.6 GHz) as varying beam current. Each spectrum for lower current than 9 mA has some offset for ease to see.

In such circumstances, the harmonic cavity was installed. Figure 4 shows excited power in the cavity with respect to the tuner position. The positive implies that tuner moves toward the cavity center. The corresponding tuning angle is also shown in Fig. 4, which is defined by $\tan\psi = 2Q_L(\omega_{HC} - 3\omega_{RF})/\omega_{HC}$, where ω_{HC} and ω_{RF} are resonant frequencies of the harmonic and main cavity, respectively. Since the beam current is quite small, the excited power is also very small except for the on-resonance region.

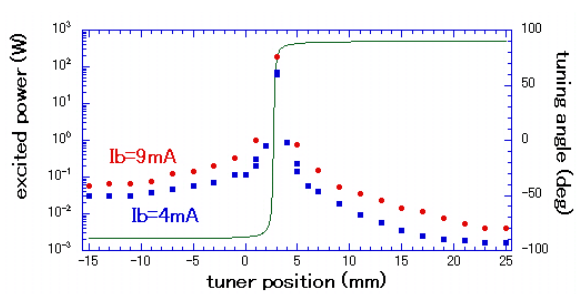

Figure 4: Excited power in the harmonic cavity for beam current of 9 and 4 mA. The tuning angle corresponding to the tuner position is also shown (solid line).

Figure 5 shows an image of the intensity of beam spectrum with respect to the tuner position. A stable region was observed around the tuner position of -10mm, where the intensity of revolution signal is not changed but synchrotron oscillation signal is drastically damped. At the 0 deg. of tuning angle (+3mm position), significant beam loss was also observed. Since the synchrotron frequency is not changed except for $\psi \sim 0$ deg., significant voltage is not induced in the harmonic cavity. It has not been well understood yet that the instability can be damped in spite of such small excited voltage. As a possible reason, HOM in the harmonic cavity might be considered. A model analysis should be done continuing the beam study whether the HOM is the cause or not.

A summary of the stable and unstable region against the coupled-bunch instability is shown in Fig. 6 for various beam currents. At the tuner position of +15mm which corresponds to $\omega_{HC} = 3\omega_{RF} + \omega_{rev}$, there is a narrow stable band, where the synchrotron amplitude is damped but beam become unstable and lost as increasing beam current.

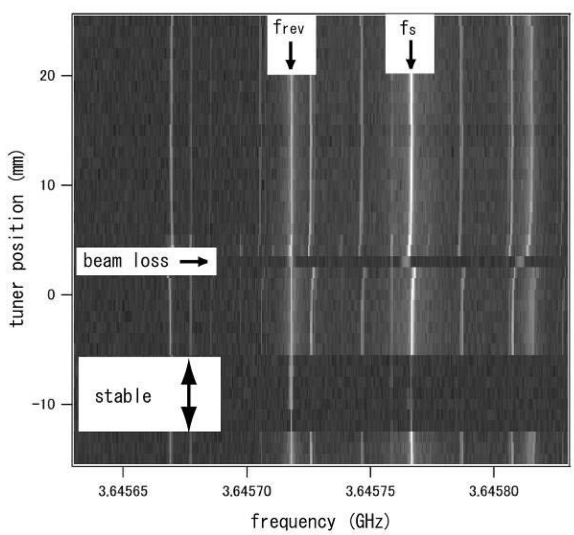

Figure 5: Image plot of intensity of beam spectrum. The image intensity increases from black to white.

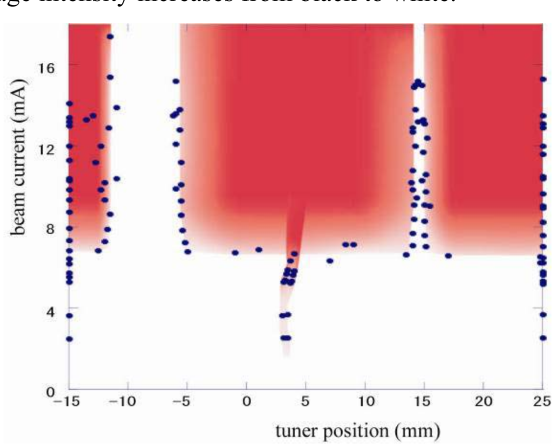

Figure 6: Stable region against coupled-bunch instability. White (Red) shows stable (unstable) region. Plots are observed points, which divide the two regions.

CONCLUSION

As the first step of the study with passive higher harmonic cavity, one harmonic cavity was manufactured and tested in the STB. The very strong synchrotron oscillation signal due to the coupled-bunch instability was drastically damped by the harmonic cavity at a specific tuning angle. However, this is not clearly understood, since any significant voltage is never excited in the harmonic cavity because of the large tuning angle. This will be made more clear using model analysis. For the lower energy operation the cavity effect might be also interesting, but any obvious improvements has not been seen yet.

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