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MULTI-HARMONIC ACCELERATION WITH HIGH GRADIENT MA CAVITY AT HIMAC

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Abstract

A high field gradient cavity(HGC) which has been developed for high intensity proton synchrotrons is suitable to generate multi-harmonic voltage on the accelerating gap because of the broad band impedance of the cavity. In this paper, the experimental results on the dual harmonic rf, saw-tooth rf, and bunch compression by barrier bucket are described.

1 INTRODUCTION

We have developed a prototype HGC loaded with Magnetic Alloy(MA) for synchrotrons. We have succeeded to achieve the field gradient of 50 kV/m [1], because of high stability of the MA core under the large rf magnetic field.

Another advantage of the HGC is that it is a broad-band cavity. High accelerating voltage over the wide frequency range can be obtained without the tuning system. In such a wide band system, some different frequencies can be generated simultaneously on the gap. The bunch shape can be manipulated by the higher harmonics, it leads to suppressing the space charge effects. The HGC has been installed in Heavy Ion Medical Accelerator in Chiba(HIMAC) for the beam experiments.

2 EXPERIMENT

Parameters of the cavity are listed in Table 1. Using the cavity, the beam acceleration has been successfully carried out [2].

Freq. Range	1 ∼ 8 MHz
Gap Voltage	Max. 4 kV
Shunt Impedance	400 Ω @ 2 MHz
	(4 cores loaded)
Q value	0.6
Amplifier	push-pull, 60 kW,
	4CW30,000A × 2
Length	40 cm

Table 1: Parameters of the HGC installed in HIMAC.

The experiment with the higher harmonics were demonstrated on the flat base(no acceleration). The control system of the higher harmonics for the acceleration is under designing.

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Some beam parameters are shown in Table 2.

Particle	$^4He^{2+}$
Number of Particle at Injection	1.4×10^{14} ppp(Typical)
Injection Energy	6 MeV/u
Momentum Spread at Injection	±0.1 %
Revolution Frequency	261.3 kHz

Table 2: Parameters of the beam.

2.1 Dual Harmonics Mixing

The beam capture experiment by dual harmonic rf has been carried out. Usually, the experiments with dual harmonic rf need another cavity for the higher hamonics [3, 4]. In this experiment, only HGC has been used. The second higher harmonic was mixed with fundamental rf and the dual harmonic voltage on the gap was obtained. The gap voltage $V_{\rm gap}$ and the potential U are written as;

$$V_{\rm gap}(\phi) = V_1 \sin\phi + V_2 \sin 2(\phi - \phi_s) \quad (1)$$

$$\begin{aligned} U(\phi) &= \int_{\phi_s}^{\phi} (V_{\rm gap}(\phi) - V_1 \sin\phi_s) {\rm d}\phi \\ &= -V_1 \{(\cos\phi - \cos\phi_s) + (\phi - \phi_s)\sin\phi_s\} \\ &\quad + \frac{1}{2} V_2 [\cos\{2(\phi - \phi_s) - 1\}], \end{aligned} \quad (2)$$

where V_1 and V_2 are the amplitude of the voltage for the fundamental rf and the 2nd higher harmonic one, respectively and ϕ_s is a synchronous phase and $\phi_s = 0$ for the flat base. The voltage and the potential well in case of $V_1 = 1$ kV and $V_2 = 500$ V are shown in Fig. 1.

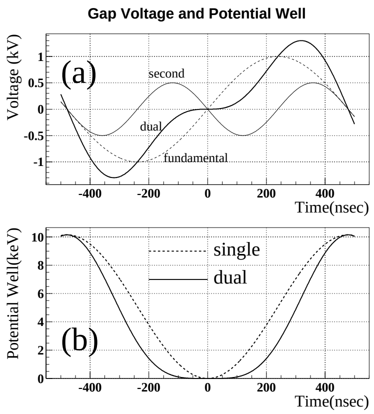

Figure 1: The gap voltage and the potential well for the dual harmonics.

The bottom of the potential well in case of the dual harmonic rf(solid line) becomes more flat than that of the single rf (dotted line) as shown in Fig. 1-(b). Since a bunch shape is related to the shape of the potential well, it is expected that the bunch is flattened and lengthened in case of the dual harmonic rf. It leads to alleviating the space charge effects.

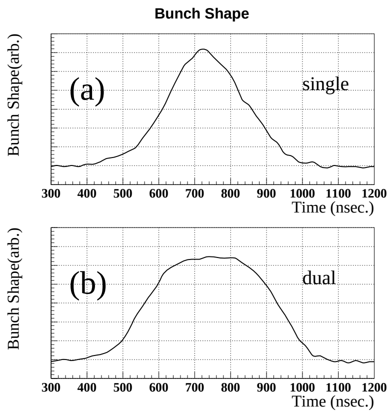

Figure 2: Experimental results of bunch lengthening by mixing the 2nd higher hamonic rf.

The bunch shape measured by an electro-static beam monitor is shown in Fig. 2. Figure 2-(a) and -(b) are the shapes for the single and dual rf, respectively. As seen clearly, the bunch shape became flat by the dual harmonic rf, then the bunching factor of 0.28 for the single rf was increased to 0.4 by the 2nd harmonic. From Eq. (2), the bunching factor for the beam with momentum spread of $\pm$0.1 % can be calculated numerically, and they are 0.27 for the single rf and 0.4 for the dual harmonic rf. It has good agreement with the experimental results.

2.2 Saw-tooth RF

In the case of single rf frequency, non-linearity appears for the particles which have large amplitude in the longitudinal phase space. On the other hand, if complete saw-tooth voltage like $V_{\rm gap} = \frac{V_0}{\pi}\phi\ (-\pi < \phi < \pi)$ (solid line in Fig. 3) is applied to the rf acceleration, then linear rf bucket will be obtained, and it is useful to investigate non-linear effects by comparing with the sinusoidal one.

The saw-tooth voltage is expressed as the Fourier series;

$$V_{\rm gap} = \frac{2V_0}{\pi}\sum_{n=1}^{\infty}\frac{1}{n}\sin n\phi\,, \tag{3}$$

where V_0 is the amplitude of the saw-tooth voltage. We have produced pseudo saw-tooth voltage by combining up to the 3rd higher harmonics in Eq. (3).

The measured gap voltages in case of the pseudo saw-tooth rf(bold line) and the sinusoidal rf(dotted line) are shown in Fig. 3-(a). The amplitude of the sinusoidal rf is adjusted as the gradient at $\phi = 0$ is equal to the gradient of pseudo saw-tooth one. Because the saw-tooth voltage makes a potential well to be a complete parabolic shape, the bunch shape in the the saw-tooth rf will become more parabolic than that of the sinusoidal one. Figure 3-(b) shows that the bunch shapes for the saw-tooth rf(solid line) and the sinusoidal rf(dotted line).

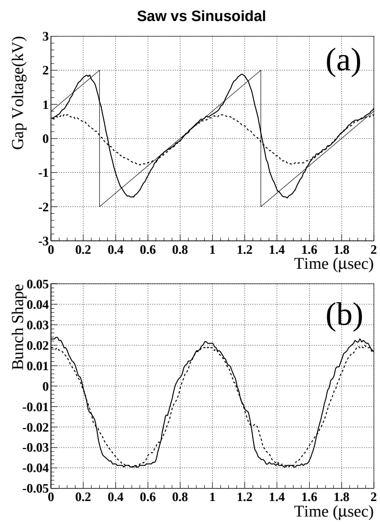

Figure 3: The measured gap voltage and the bunch shape in saw-tooth rf.

We assume the amplitude of the synchrotron motion is small to obtain the equation of the synchrotron frequency for the sinusoidal voltage;

$$\omega_s = \sqrt{\frac{heV{\omega_{\rm rev}}^2|\eta|\cos\phi_s}{2\pi\beta^2 E_0}}, \tag{4}$$

where h is harmonic number, e is unit electric charge, $\omega_{\rm rev}$ is revolution frequency, η is slippage factor, $\beta = v/c$, E_0 is total energy of the particle. However, if the beam emittance occupies the large area of the rf bucket, then the measured synchrotron frequency tends to deviate from Eq. (4) and become smaller value [5]. On the other hand, the synchrotron frequency at large amplitude of the synchrotron motion is as same that at small one for the saw-tooth rf. The measured synchrotron frequency should be consistent with Eq. (4). Actually, the measured synchrotron frequency of 1.03 kHz had good agreement with calculated one of 1.08 kHz for the saw-tooth rf, althogh the measured one was 0.75 kHz for the sinusoidal rf.

2.3 Barrier Bucket

Barrier bucket is a scheme to manipulate the bunch length by moving a single sinusoidal voltage [6]. It is mostly used to store more beam in the ring [7]. Conversely, it is possible to make coasting beam into one high density bunch by the barrier backet, then it is profitable to produce high peak current for the study of the wake field.

In this experiment, the barrier voltage was 2 kV, which corresponded to the bucket height of $\pm$0.4 % with respect to the momentum spread. The bunch of 3.8 μsec length was compressed into 1.4 μsec by the barrier bucket gymnastics spending 100 msec to conserve the longitudinal beam emittance.

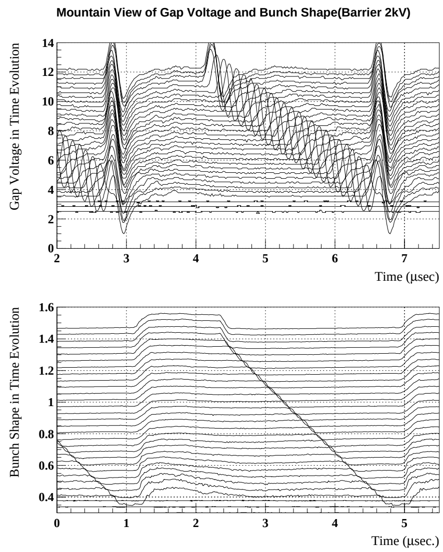

Figure 4: Bunch compression by the barrier backet operation.

Figure 4 shows the experimental result, the upper side shows the barrier voltage gymnastics and the lower side shows the bunch shape in the mountain range view. The interval of the trace is 4 ms. The compression was performed for the beam of 7×10^{10} ppp. Since a half of the beam was lost, the peak current was not so high that the beam induced voltage has not been observed.

3 SUMMARY

The experiments of the multi-harmonic rf have been succeeded by a HGC due to its broad band impedance. Although the beam was lost, the bunch shape could be manipurated.

4 ACKNOWLEDGEMENT

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