FIELDS INDUCED BY CHOPPED BEAMS IN THE TANK CAVITY

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Abstract

In order to accelerate high-intensity beams at the 12-GeV proton synchrotron complex at KEK, the 40-MeV proton linac has been successfully operated as an injector. The 40-MeV proton linac consists of two tanks. Recently, an acceleration of chopped beams has been tried to obtain good transmission from the Booster to the 12-GeV main ring. We thus measured the fields induced by chopped beams in the second tank, where the accelerating field is stabilized by post-couplers. The effects of the induced field on the longitudinal motions have also been observed. In this report, the measured results are described.

1 INTRODUCTION

The KEK 40-MeV Proton Linac has worked very well to supply beams to the 500-MeV Booster Synchrotron since the upgrade from the accelerating energy of 20-MeV to 40-MeV. Recently, an increase in the beam intensity of the 12-GeV Proton Synchrotron is required for experiments about neutrino oscillation. It is thus very important to accelerate beams with good quality and high intensity. Therefore, at first, we arranged a beam-monitor system and then improved the control system, the RF-source for a prebuncher and the RF-source for a debuncher system [1]. The effects of the tuning procedure of the linac on the transversal motions have been studied [2]. Otherwise, a beam-chopping system [3] has been developed and the acceleration of chopped beams has been attempted in order to control the bunch shape in the Booster.

At KEK, a 200-MeV proton linac for the Japanese Hadron Facility (JHF) has been designed [4]. The main features of the linac are a high peak current, a high average current, a high duty factor and a high performance for beam-loss problems. Therefore, an RF-source with high specifications must be fabricated, where we must guarantee that the accelerating field is stabilized within about ±1% in amplitude and within about ±1° in phase. In this linac, also, the acceleration of chopped beams with a micro structure and a long-pulse high intensity is required to paint the linac beams onto the longitudinal phase space in the next accelerator.

We think that in the near future chopped beams with a high peak current can be accelerated in a proton linac. We thus measured the fields induced by chopped beams and those effects on the longitudinal motions. In this report we describe the results measured with chopped beams produced by a beam-chopping system.

2 INDUCED FIELDS

Nominal beams accelerated by the proton linac have only the frequency components of (driving frequency) × *n* and a small fraction due to the phase spread. However, chopped beams have many frequency components, like (driving frequency) × *n* ± (chopping frequency) × *m* and the fraction. Figure 1 shows the frequency components of chopped beams accelerated in the first tank at KEK.

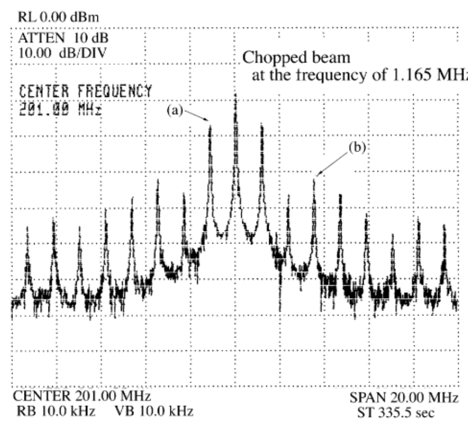

Fig. 1 Frequency components of chopped beams. Chopped beams were produced by using a beam-chopping system developed at KEK. An average beam intensity was about 8 mA. The post-1 and TM012-modes were excited by the frequency components of (a) and (b), respectively.

Furthermore, the proton linac comprises many tanks, each of which also has many resonance modes, like the TM and TE modes, and which must accelerate long-pulse high intensity beams with good quality. Therefore, when such beams pass through a tank and the beam-frequency component is near to a resonance mode in the tank, the mode would be strongly excited by the beams.

In general, such a field would be given by [5]

$$E_{bl}=\alpha_l I_l\{\exp(-j\Omega_l t)-\exp(-\omega_l t/2Q_l)\} \times \exp\{j(\omega_l t+\phi_b)\}\cos(\pi z/L). \quad (1)$$

where α_l = coefficient which is dependent upon parameters regarding to the *l*-mode,
I_l = beam-frequency component of beam bunches,
ω_l = *l*-mode frequency,
Ω_l = (TM010 mode frequency) - (*l*-mode frequency),
Q_l = total Q for the *l*-mode,
ϕ_b = accelerating phase angle,
L = tank length = 12.84 m.

Thus, the total field in the tank is given by the following superposition,

$$E = E_0 \exp(j\omega t) + \Sigma E_{bl} = E_0 \exp(j\omega t)\,\{X + jY\}. \quad (2)$$

Therefore, the phase shift relative to the driving field is Y/X and wiggles with a frequency of ω-ω_l, which would correspond to the chopping frequency. We can then estimate a phase shift of about 4°, where the ratio of the induced field to the driving field is assumed to be about -40 dB. A variation of the phase shift due to the induced field is larger than a phase stability of about ±1° required for stable operation of the JHF proton linac. At the KEK proton linac, the driving frequency is 201.07 MHz and the chopping frequency is about 2.2 MHz, which is near to a post-2 mode in the second tank.

3 MEASUREMENTS

3.1 Fields Induced by Chopped Beams at KEK

The second tank has 17 rf-loop monitors for checking the field distribution of the accelerating modes. Thus, the TM01n-like mode has only been observed by using those loop monitors. At first, we measured fields induced by chopped beams in the second tank as variations of the chopping frequencies. Figure 2 shows the relation between the chopping frequency and the induced field. The measured frequencies of all the modes are consistent with the frequencies given in Reference [6]. All of the modes were determined by measuring the field distributions along the second tank. The strength of the induced field depends upon the frequency components of the beam bunches injected to the second tank and the operational phase between the first tank and the second one. We measured the ratios between the strength of the induced field and the frequency components, as shown in Figure 3. The measured results show that the higher post-modes would be not strongly excited by the beam-frequency component.

3.2 Effects of the induced field on the longitudinal motion

Though an average intensity of the chopped beams was about 8 mA, the ratio of the field strength of the post-1 mode to the main field strength (201.07 MHz) was about -43 dB, as can be seen in Fig. 2. This ratio is comparable to the ratio of the field induced by the nominal beam with an intensity of about 130 mA [5]. We thus think that the post-1 mode excitation might affect the longitudinal motion of the beams. Therefore, we measured an acceptable phase area to the second tank at beam positions (1) and (2) and on conditions whether the mode has been excited or not, as shown in Figures 4a and b.

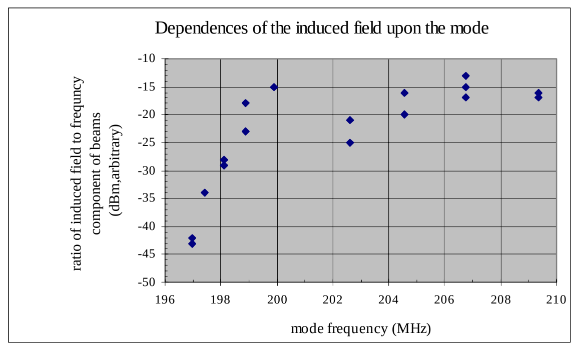

Fig. 3 Ratios of the induced field to the frequency component of bunched beams injected into the second tank. Higher modes of the post-type modes are weakly excited. However, the TM01n modes are almost equally excited.

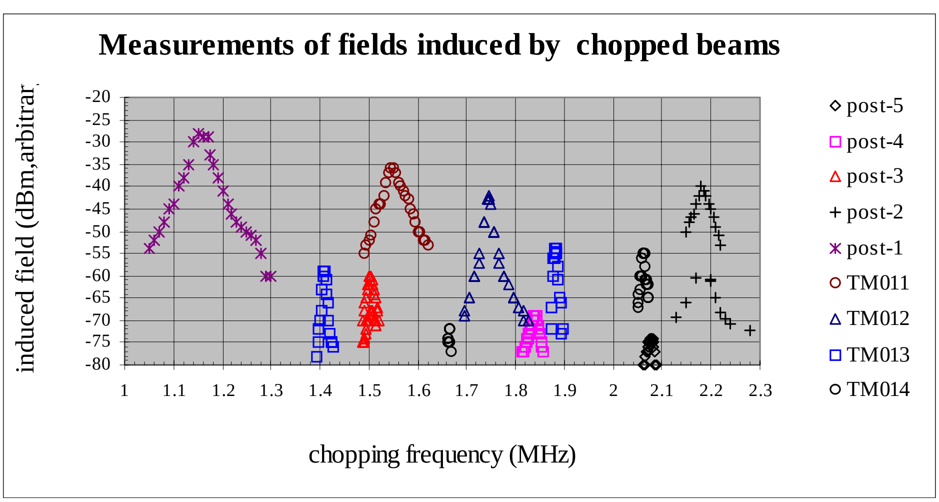

Fig. 2 Relation between the chopping frequency and the induced field. We measured the field distributions using 17 rf-monitors installed along the second tank, and then determined all modes of the measured fields. In our case, the post-2 mode is excited because the rf-frequency in Booster is about 2.2 MHz.

The measured results are shown in Figures 5, 6 and 7. Fig. 5 shows that the field levels of the post-1 mode are dependent on the operational phase between two tanks. We could observe some differences in those dependence between the post-1, post-2 and TM-modes.

Fig. 6 shows the energies accelerated in the second tank under conditions of different excitation levels of the post-1 mode. We thus conclude that the average energy would be independent of the induced field levels.

We can see variations of the acceptable phase areas in Fig. 7, which were measured at different beam positions and under different conditions of excitation levels of the post-1 mode. We can now conclude that the field induced by chopped beams in the tank might disturb the longitudinal motion of beams, and then narrow the acceptable phase area. Hence, it would be very important to study the relations between the resonance mode of the tank cavity and the chopping frequency. Next time, we will study the induced fields, like the TE-modes and their effects.

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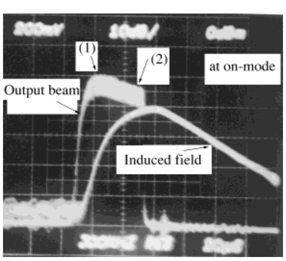

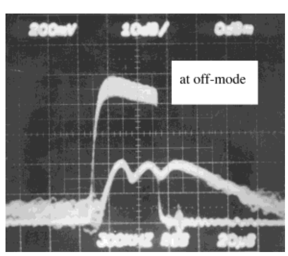

Fig. 4-a; “on-mode” Fig. 4-b; “off-mode”

In Fig. 4, the conditions are given for when we observed the effects of the induced field on the longitudinal motions. Both 91) and (2) are the beam positions measured on a long beam pulse. We selected these positions while considering that the strength of the induced field would increase exponentially.

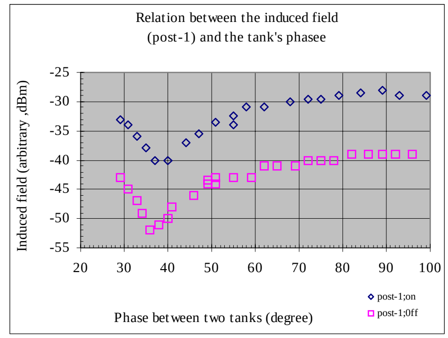

Fig. 5. Relation between the field level of the post-1 mode and the operational phase between two tanks.

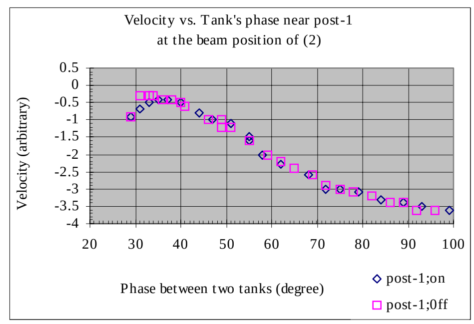

Fig. 6 Relation between the velocities and the operational phase.

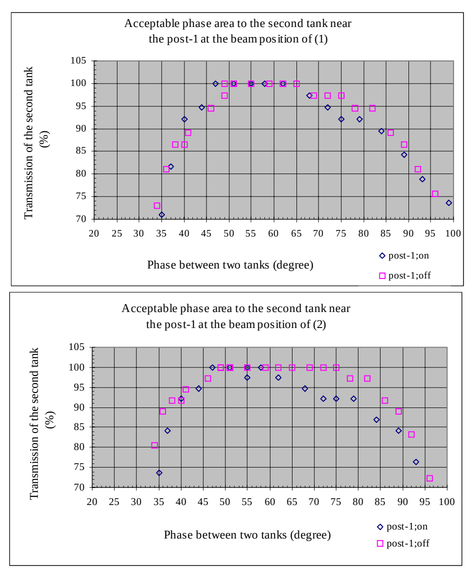

Fig. 7. Acceptable phase area on the second tank. The results measured at the beam position of (2) show that the variation in the acceptable phase area strongly depends on whether the post-1 mode is excited or not.