Effects of Controlling the 40-MeV Proton Linac on Transversal Motions

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Abstract

In order to accelerate high-intensity beams at the 12-GeV proton synchrotron complex, it is important to obtain detailed information about the characteristics of the beams accelerated by each accelerator. We have thus designed and installed many beam monitors around the 40-MeV proton linac. Subsequently, effects of controlling the linac have been measured in relation to transversal motions.

The effects of a prebuncher-tuning procedure and the adjustment of the phase between two tanks on the transversal motions of beams accelerated by the linac are described in this report. The field induced in the 40-MeV tank by a chopped beam is also 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, 1985. 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.

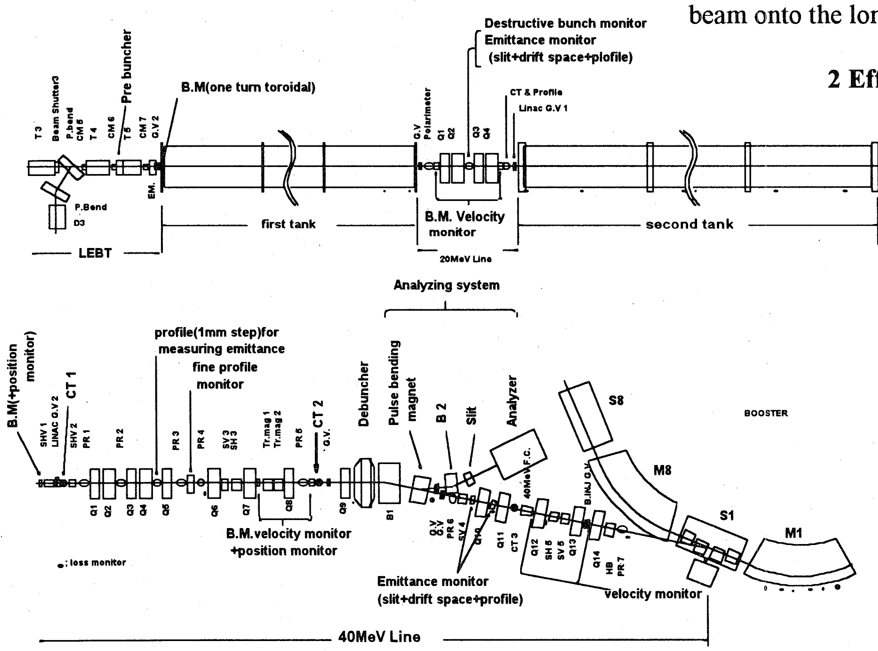

Fig. 1 Beam monitors installed around the KEK 40-MeV proton linac. The B.M. and velocity monitor are available to tune the linac.

In particular, it is very important how to inject beams ejected from the linac into the 500-MeV Booster, since the space-charge force during the injection process is so strong that the growth of emittances is generated [1], and the beam quality is almost determined by the injection procedure and by controlling the ring RF-system [2]. Therefore, we at first arranged a beam-monitor system, and then improved the control system of the 40-MeV proton linac, the RF sources for a prebuncher and a debuncher system [3]. Figure 1 shows the monitors installed around the 40-MeV proton linac.

Otherwise, at KEK, a 200-MeV proton linear accelerator [4] for the Japanese Hadron Facility (JHF) has been designed. The main features of the linac are a high-peak current, a high-average current, a high duty factor and high performance for beam-loss problems. It is thus important not only to calculate the beam-dynamics, but also to study the accelerating structures, the RF-sources, and the tuning methods. Therefore, at present, we have studied the tuning methods using the 40-MeV proton linac.

In this paper, the effects of tuning procedures of the linac are described regarding the transversal motions. In particular, the effects of prebuncher tuning and adjustments of the phase between two tanks and the field induced by the chopped beam, which would be used to paint the linac-beam onto the longitudinal phase-space, are described.

2 Effects of tuning a prebuncher

Normally, the tuning procedure of the prebuncher system has been carried out by measuring the capture efficiency of beams at the 20-MeV tank as an RF-power supplied and the phase between the prebuncher and the 20-MeV tank (prebuncher's phase) are varied, and by observing the momentum of accelerated beams. In spite of an R-dependence of the accelerating field in the cavity of the prebuncher [5], the growth of transversal emittances is not very large. We have recently measured the variations of the transversal emittances due to the RF-power supplied to the cavity of the prebuncher and the prebuncher's phase [6].

As the RF-power supplied to the prebuncher's cavity increases until about 4 kW, the horizontal emittance varies remarkably at just the entrance of the 20-MeV tank. Above

4 kW, the variations of the horizontal emittance have not been measured. The variations of the vertical one, however, have been observed little. Examples of the measured results are shown in figure 2. Thus, these variations of the horizontal and vertical emittances would be caused by the space-charge forces in the process of bunching because the horizontal β-functions (βx) are much smaller than the vertical βy in the beam line between the prebuncher and the 20-MeV tank, as can be seen in figure 3.

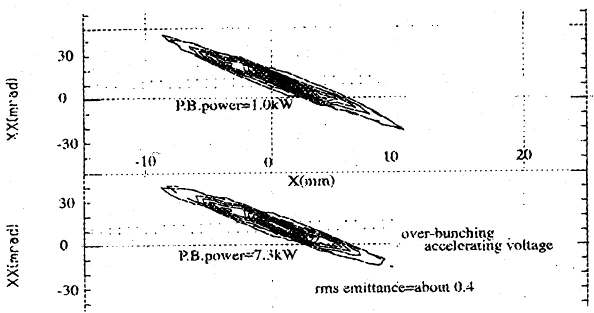

Fig. 2 Horizontal emittance at just the entrance of the 20-MeV tank. The H-emittance is strongly dependent upon the RF-power supplied until about 4 kW.

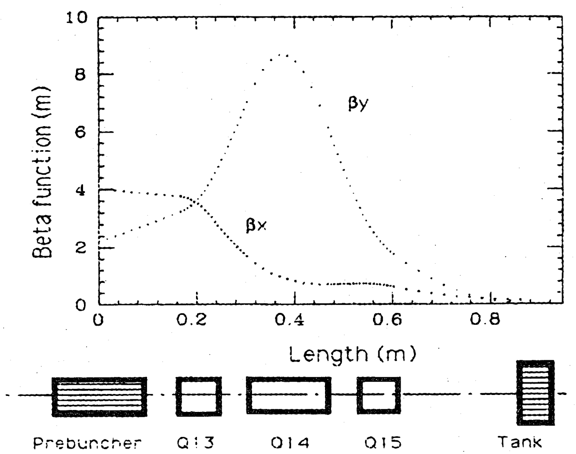

Fig. 3 β-function of the beam line.
βx is much smaller than βy between the prebuncher and the 20-MeV tank.
This figure is referred from Ref. [5]

At the exit of the 20-MeV tank, we measured the horizontal and vertical emittances while varying the accelerating voltage of the prebuncher and the prebuncher's phase. These variations of the parameters were carried out within a longitudinal acceptance of the 20-MeV tank. The particle distributions inside the vertical emittance and the skirt of the emittance were varied. However, horizontally these variations have been little measured. Figure 4 shows the variations of the vertical emittance with the prebuncher's phase. Therefore, we think that regarding the vertical motion of the beams, at just the injection stage of the 20-MeV tank, the coupling between the transversal and longitudinal motions through the space charge would cause variations of the vertical emittance.

3 Effects of the phase between two tanks

An adjustment of the phase between two tanks is a very important tuning procedure to control the central momentum and the momentum spread of beams. However, sometimes, the effect of this adjustment on the transversal motion is not considered. Thus, an optics mismatching would be generated on the transport line. At KEK, a few BPMs (like the bottom type) are installed in the 40-MeV line. We have observed the dependence of the beam position on the phase between two tanks using the BPMs installed at just the exit of the 40-MeV tank and at 470 mm downstream from the Q8-magnet. Of course, the adjustment of this phase causes variations of the accelerating energy of beams. The measured results are given in figure 5. As can be seen in Fig. 5, it is obvious that a beam ejected from the 40-MeV tank has the characteristics of dispersion. We think that the dispersion property of the beam would be produced by an injection error into six-dimensional phase space. The injection error is caused not only by a tuning error of the beam orbit , but also by an alignment error of the drift tubes, and variations of the accelerating field strength in the 20-MeV tank and the phase between two tanks.

4 Field induced by chopped beams in the cavity

The 200-MeV proton linac for the JHF would accelerate chopped beams with a micro structure and a long pulse-

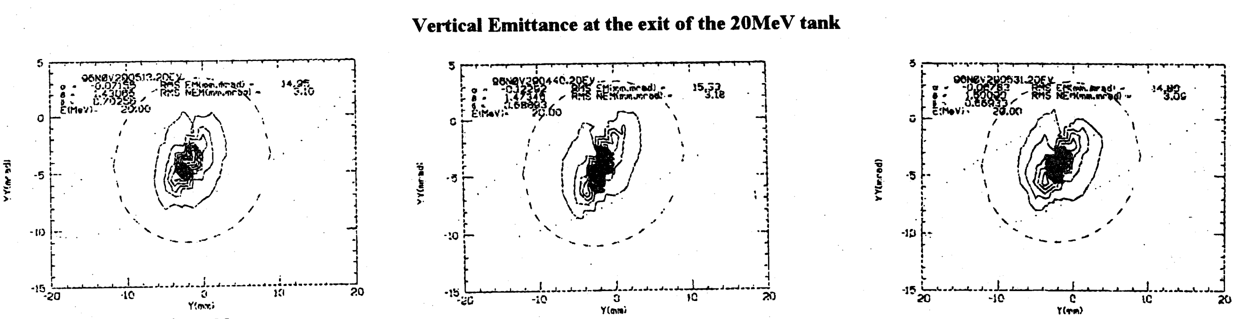

Fig. 4 Variations of the 20-MeV vertical emittances due to the phase between the prebuncher and the 20-MeV tank.

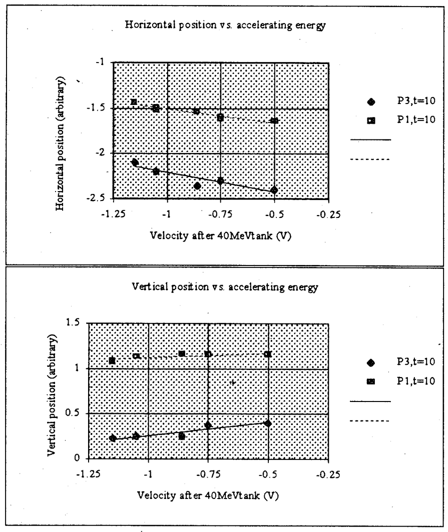

Fig. 5 Variations of the beam position by adjusting the phase between two tanks.
P1, just after the 40-MeV tank,
P3, 470mm down from Q8-mag. on the 40-MeV-line.

high intensity. Such beams have many frequency components, like (accelerating frequency)$\times n$ $\pm$ (chopping frequency)$\times m$. The beginning of each chopped beam micro-pulse is just a transient. On the other hand, the cavities used in the proton linac have many resonance modes like the TM and TE modes. Therefore, a resonance mode would be excited by chopped beams with a micro structure in a cavity if the frequency of the resonance mode and that of chopped beams overlap.

At KEK, recently, a beam-chopping system [8] has been developed and tested. We have thus measured fields induced by chopped beams in the 40-MeV tank as variations of chopping frequencies [9]. The rf-loop monitors are installed for checking the field strength of the accelerating mode. Thus, the TM01n-like mode has only been observed by using those loop monitors. The results observed are shown in figure 6. The measured resonant frequencies are 198.8MHz (post-2), 199.9MHz (post-1) and 202.6MHz (TM011) on the 40-MeV tank. On the 20-MeV tank, a frequency of 202.7MHz (TM013-mode) has been observed. The ratio of the field strength induced by chopped beams with an intensity of about 8 mA to the main field strength (201.06MHz) is about -50dB. This value is comparable to the ratio of the field induced by the unchopped beam with an intensity of about 130 mA [10]. The resonance mode has been determined by measuring the field distributions along the 40-MeV tank, as shown in figure 7.

As a result of a preliminary measurement, fields (TM01n-like modes) induced by a low-intensity chopped beam could not cause any trouble with the beam dynamics.

Next time, we will equip the other rf-field monitor in the 40-MeV tank, and will observe the effects of other resonant modes on the beam dynamics.

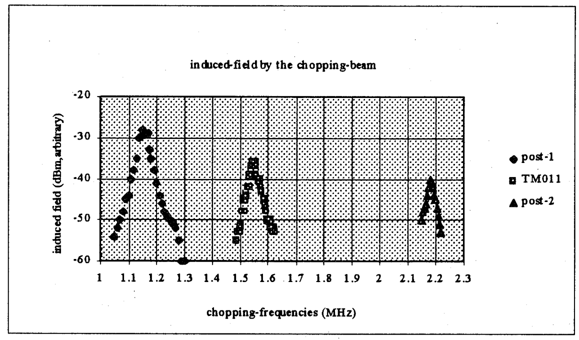

Fig. 6 Field induced by the chopped beams in the 40-MeV tank

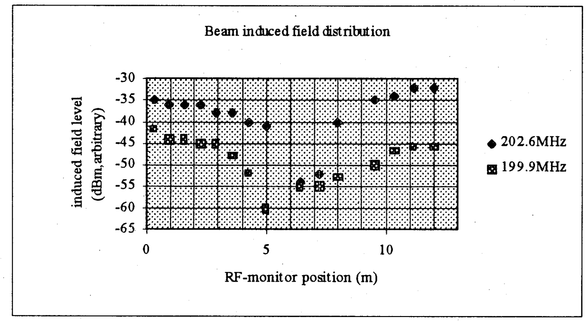

Fig. 7 Field distributions along the 40-MeV tank. By these distribution patterns, each of the resonance modes has been determined.

5 Conclusion

From these studies, it is obvious that it is very important to establish tuning methods for the stable operation of the linac, particularly, the 200-MeV proton linac for JHF.

Finally, we must emphasize that all of the measured emittances are much less than the acceptance of the 500-MeV-Booster at KEK.

References

[1] N. Kumagai et al., KEK Accelerator Department Internal Note, ASN-268, Apr. 1987.

[2] S. Ninomiya, Private communications.

[3] Z. Igarashi et al. , "Introduction of the Solid State RF Sources at KEK 40-MeV Proton Linac", in this Proceedings.

[4] T. Kato, KEK Report 96-17.

[5] T. Kato, KEK Report 91-10.

[6] E. Takasaki et al., KEK Accelerator Department Internal Memo, SR-357,374,377,382.

[7] E. Takasaki et al., KEK Accelerator Department Internal Memo, SR-388.

[8] K.Shinto et al., Rev. Sci. Instrum. 67(3), p.1048, March 1996.

[9] E. Takasaki et al., KEK Accelerator Department Internal Memo, SR-379,385,405.

[10] T. Kato and E. Takasaki : IEEE Trans. Nucl. Sci. Vol. NS-28 NO.3(1981) p.3507.