SHORT BUNCH EXTRACTION NEAR TRANSITION ENERGY

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Abstract

For efficient production and collection of secondary beams, that is essential to some high energy physics experiments and muon collider, a short proton bunch extraction ∼1nsec is required. The extraction near transition energy is proposed to obtain such a short bunch. We have developed a multi-particle tracking code and investigated the bunch shortening near transition energy, taking the KEK-PS as a test lattice. The effects of γ_t jump were also investigated.

1 INTRODUCTION

The proton driver for the muon collider[1] and the proton source for some physics experiments are required to produce and extract a short proton bunch of ∼1nsec. To obtain such a short bunch, the extraction near transition energy is proposed where the bunch length becomes naturally very short. On the other hand, low synchrotron frequency near transition energy breaks adiabaticity. The final bunch shape will be 'leaned' in longitudinal phase space because of the fast increase of bucket height compared with synchrotron frequency. Therefore, if we make an additional synchrotron oscillation to rotate the leaned bunch, we can obtain shorter bunch length.

This paper shows the simulation results of bunch shortening near transition energy, including bunch rotation effects.

2 BUNCH SHAPE NEAR TRANSITION

The bunch shape near transition is derived in the reference[2]. With a linear approximation, hamiltonian is represented as

$$H = \frac{1}{2}\left(\delta\phi^2 + \lambda_0(\tau)\delta E^2\right), \tag{1}$$

which leads

$$\frac{1}{2S}\left\{\delta E^2 + (\frac{1}{2}\dot{S}\delta E + S\delta\phi)^2\right\} = I_0 = const., \tag{2}$$

where S satisfies

$$\frac{1}{2}S\ddot{S} - \frac{1}{4}\dot{S}^2 + \lambda_0(\tau)S^2 = 1 \tag{3}$$

and τ is

$$\tau(t) = \int_0^t \left(-\frac{eV\cos\phi_s}{T_s}\right)dt.$$

Equation (2) describe a ellipse in (δE,$\delta\phi$) space. The ellipse has the amplitude $\sqrt{2I_0 S}$ in ϕ. It can be found that the bunch length reaches the minimum near transition energy [2]. For the KEK proton synchrotron (KEK-PS), it is about 1nsec without space charge effects (Figure1).

Also, equation (2) means that the track of a particle is leaned with the angle;

$$\tan 2\theta = \frac{-S\dot{S}}{1 + \dot{S}^2/4 + S^2}.$$

If we rotate the bunch in phase space so that the ellipse becomes upright, we can obtain shorter bunch length.

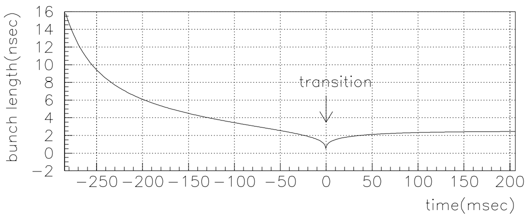

Figure 1: Analytic estimation of bunch shortening in the KEK-PS.

3 SIMULATION

3.1 qualitative analysis

In order to get a short bunch, we want to bring the particles to transition energy very closely. Needless to say, none of the particles should not cross transition energy. That is not so simple because of the finite momentum distribution in the RF bucket.

There is another trade-off in the speed approaching transition, $\dot{\eta}$. From the viewpoint of adiabaticity, we want to have very low $\dot{\eta}$. However, we do not want to spend much time around transition energy where the energetic particles go beyond transition energy and are unstable.

3.2 simulation condition

To calculate bunch shortening, we have developed a multi-particle tracking code in which γ_t is programable in time. It includes the space charge effects and second order of momentum compaction, so called α_1. We take KEK-PS as a test lattice and its parameters are tabulated in Table 1.

The KEK-PS has transition jump system as shown in Figure 2. When it is excited with reversed polarity, a sudden change of transition energy can be introduced right after a beam approaches to its nominal value. That will rotate bunch and make it upright. We include bunch rotation effects assuming the γ_t jump operation with

parameter	at injection	at transition
momentum	1.090GeV/c	6.273 GeV/c
RF frequency	6.027MHz	7.865MHz
longitudinal emittance	0.314eVs	
particle	1×10^{13} protons per ring	
harmonics	9	
RF voltage	92kV	

Table 1: The main ring parameters of the KEK-PS.

reversed polarity. We investigated three kinds of parameter dependence;

1. dependence of bunch length on the timing of γ_t jump.
2. comparision with the case of larger RF voltage.
3. comparision in the speed of approaching to transition.

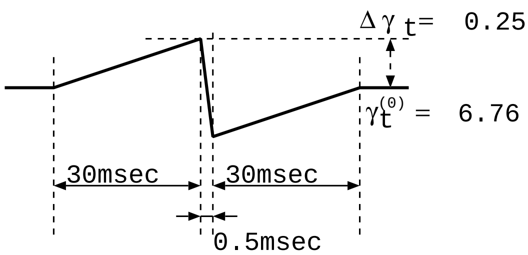

Figure 2: Operation of the KEK-PS transition jump system.

3.3 results

First, we studied the dependence of the timing of γ_t jump, comparing three operations, (a)firing γ_t jump when a beam is at the transition energy, (b)1msec earlier and (c)2msec earlier (Figure 3). Little difference was seen in the minimum bunch length between (a) and (b). The figure shows that the short bunch of 2.2nsec is obtained if we use the transition jump system when a beam is at transition. The same calculation without space charge effects gives about 1.0nsec.

Secondly, Figure 4 shows the bunch length when RF voltage is 207kV, which is 1.5^2 times of the nominal RF voltage. In this case, the initial bunch length becomes $\sqrt{1.5}$ times shorter and momentum spread $1/\sqrt{1.5}$ times larger. From Figure 4, it is found that the bunch length at the transition energy was reduced to 1.6nsec. However, the larger momentum spread made the partial transition crossing, and some of particles have escaped from the core as shown in Figure 5(c).

Thirdly, the dependence on $\dot{\gamma_t}$ was also studied. We compared the case $\dot{\gamma_t} = -20\text{sec}^{-1}$, 0sec^{-1} and $+10\text{sec}^{-1}$ (Figure 6). Among them, the case of flat γ_t showed the shortest bunch length, 2.4nsec, at the transition energy. For $\dot{\gamma_t} = +10\text{sec}^{-1}$, the bunch length increases quickly. It is because of the partial transition crossing (see Figure 5(d)).

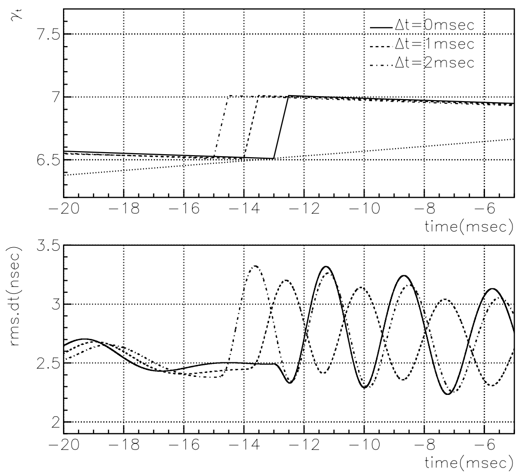

Figure 3: Difference of bunch length with respect to the timing of γ_t jump.

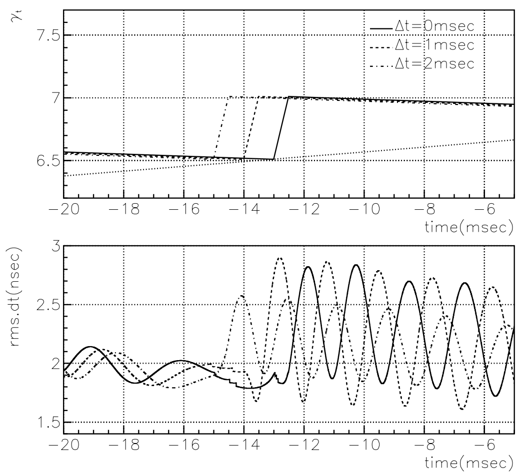

Figure 4: In the case of the RF voltage is 207kV.

4 SUMMARY

We have investigated the bunch shortening near transition to extract a very short bunch. It was found that the short bunch length of 2.2nsec is obtained if we use the transition jump system with reversed polarity and fire it when the bunch is at the transition. To obtain shorter bunch, we can make larger RF voltage, for example. If it is 207kV, we can have the bunch length of 1.6nsec.

5 REFERENCES

[1] J.Norem, The Proton Driver for the $\mu\mu$ Collider, Proc. of Part. Accel. Conf., 1997, Vancouver, B.C., Canada.

[2] K.Takayama, Phase Dynamics Near Transition Energy in the Fermilab Main Ring, Part.Accel.14, 201, 1984.

[3] J.Norem, Bunch Shortening Experiments in the Fermilab Booster and the AGS, Proc. of Part. Accel. Conf., 1997, Vancouver, B.C., Canada.

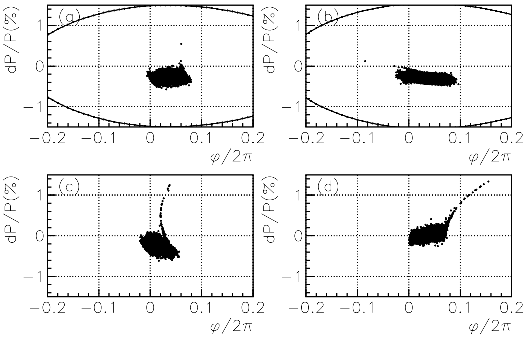

Figure 5: Distribution in phase space.(a)The shortest bunch shape (at -12.5msec) (b)The largest one (at -11.5msec). (c)The shortest bunch shape when RF voltage is 207kV. (d)The bunch shape at the transition energy in the case $\dot{\gamma}_t$ is +10sec^{-1}.

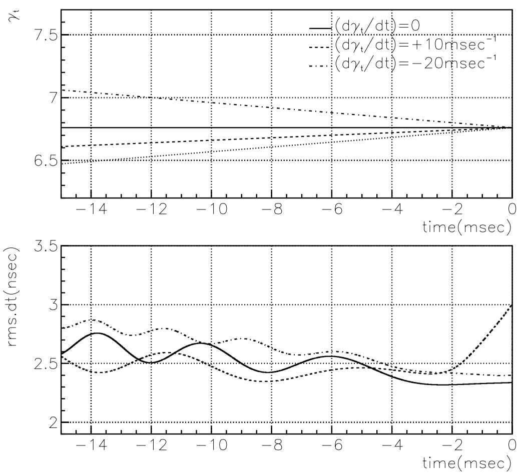

Figure 6: Difference of bunch length with respect to the speed of approaching to the transition.