FOCUSING-FREE TRANSITION CROSSING IN THE RHIC USING INDUCTION ACCELERATION

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Abstract

A feasibility of focusing-free transition crossing (FFTC) in the RHIC is discussed. The FFTC in a hybrid system combining a rf for the confinement and an induction accelerating system for the acceleration makes the bunch length kept sufficiently enough long to suppress e-cloud production or other undesired features, through crossing the transition energy.

INTRODUCTION

Since the first proposal of an *induction synchrotron* by Takayama and Kishiro [1], an extensive R&D work on the key devices, such as an induction accelerating cell and switching power supply, has been continued at KEK. Last year, the prototype devices, which are capable of generating a 250nsec flat-top voltage of 2 kV at a repetition rate of cw 1 MHz, were assembled and installed to be combined with the existing RF accelerating system. At this stage the KEK proton synchrotron (KEK-PS) is a kind of hybrid system employing the RF for the longitudinal confinement and the induction accelerating system for the acceleration. Recently the induction acceleration of a single RF bunch was demonstrated in the KEK-PS [2], where it was accelerated from 500MeV to 8 GeV beyond the transition energy.

The concept of the *induction synchrotron* claims that a notable property of the separated-function in the longitudinal direction brings about a significant freedom of beam handling never realized in a conventional RF synchrotron, where radio-frequency waves in a resonant cavity simultaneously take both roles of acceleration and longitudinal confinement. It has been shown [1,2] that this property provides a novel transition crossing method called focusing-free transition crossing (FFTC), where a proton bunch passes through the transition energy with no longitudinal focusing forces but its acceleration is assured with flat step-voltages, which are generated with induction acceleration devices. This method is effective even in the hybrid system discussed here.

The transition energy is a singular point in the acceleration of a proton synchrotron. More or less synchrotrons crossing the transition energy on the way to their top energy suffer undesired emittance growth or beam loss. An rf bucket is remarkably deformed by an inherently non-adiabatic nature in the synchrotron oscillation. The rf bunch is shortened in the time space and stretched in the momentum space. The former leads to a growth of the line density, inducing undesired coherent instabilities, such as the microwave instability [3], as well as increasing transverse space-charge effects. The latter may restrict the momentum aperture of an accelerator ring. In addition, nonlinear kinematic effects (Johnsen effect) in the synchrotron oscillation are relatively enhanced [4]. Mismatching of the rf bunch shape to the rf bucket before and after transition crossing, which is caused by the nonlinear kinematic term and space-charge forces, is inevitable, because both effects are not time reversible. It is insisted that these awkward situations result in beam loss, which limits the operational capability of an accelerator.

Since particles consisting in the bunch see no confinement voltage for a short time period which includes both sides of the transition energy, the bunch deformation of shortening in time and stretching in momentum should disappear, because each particle simply drifts along the time axis without changing its momentum.

EXPERIMENTAL RESULTS OF THE FFTC IN THE KEK-PS

The FFTC experiment has been carried out in the present KEK-PS. In the preliminary study, the amplitude of the rf voltage was controlled by the automatic voltage controller (AVC) to obey the programmed-voltage. In order to generate the rf voltage profile desired for the FFTC, a trapezoidal pulse with a negative amplitude was superimposed on the existing programmed-voltage pattern. Consequently the RF voltage profile with a deep dip in the vicinity of the transition was obtained (see Fig.1). From some engineering concern, the rf voltage was not set to strict 0 kV but a finite magnitude, which was not sufficient to accelerate a proton bunch beyond the transition energy.

Temporal evolution of the bunch-length and beam-intensity in the vicinity of the transition energy was observed for two cases of the FFTC and the nominal TC (see Fig.2). The bunch-length and beam-intensity were measured by the fast and slow bunch monitor, respectively. Concerning the bunch length, it notes that the unexpected extension of the bunch-length even under the normal transition crossing (NTC) occurred above just the transition energy (1.25 sec after the start of the acceleration). At this moment its reason was not identified, although this suggests that any instability was induced, associated with the beam loss. Nevertheless, it is pointed out that for the FFTC the predicted stretching of the bunch length is clearly seen below the transition energy (from 1.24 sec to 1.25sec). The beam loss for the FFTC through the transition crossing was lower than that for the NTC, where all machine and beam parameters were same except the rf voltage profile.

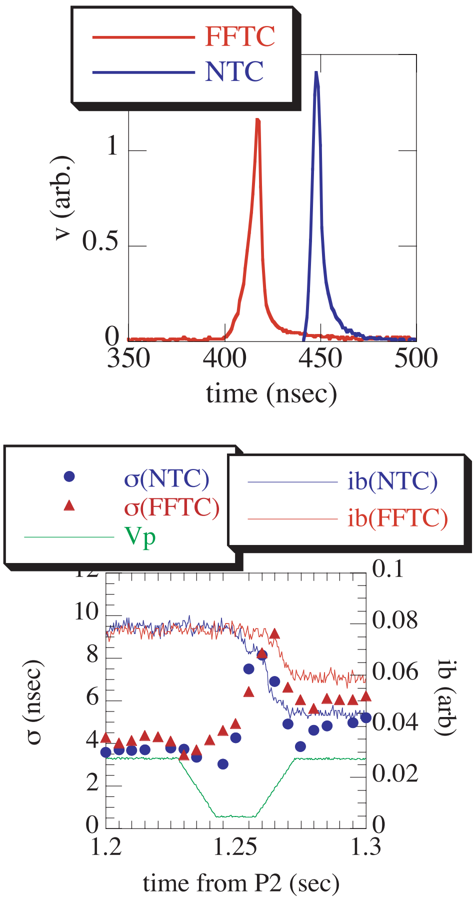

Figure 1 (a) Output of the fast bunch monitor at t=1.25 sec. (b) RMS bunch length, beam intensity and programmed-voltage around the transition energy.

SPECIFIC PROBLEMS OF TRANSITION CROSSING IN THE RHIC

RHIC is the first superconducting ring where the beam is accelerated across transition. Due to the slow ramping rate (nominal value of 48 kV per turn), the ion beams easily suffer emittance growth and beam loss upon transition crossing. Conventional beam-degrading mechanisms include the chromatic nonlinear effect, the self-field mismatch, and impedance-induced instabilities, as mentioned in Introduction. A transition jump (about one unit of gamma in 50 ms) must be used to effectively increase the crossing rate, mitigating these "conventional" undesired effects. On the other hand, the transition jump perturbs the closed orbit and the lattice optics, often causing operational complications and minor beam loss. During the year 2005, electron cloud effects at transition are found to be a serious obstacle on the RHIC upgrade path. At twice the design number of bunches (bunch spacing 108 ns), electron-ion interactions cause significant instability, emittance growth, and beam loss along with vacuum pressure rises when the beam is accelerated across transition, as seen in Figs.2 and 3. Even with the transition jump, beam loss can exceed 70% for later bunches of the bunch train. Beam loss and transverse electron-ion instabilities occur within 0.1 sec immediately after transition when the particle motion is non-adiabatic.

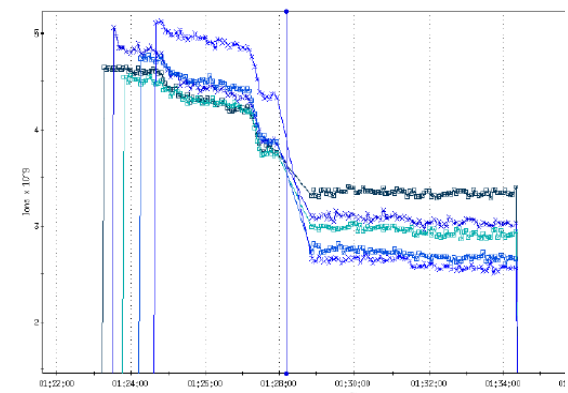

Figure 2 Electron-ion instability induced loss: the first/last bunches have loss of(13/70%).

FFTC IN THE RHIC

A hybrid scheme using the induction acceleration can effectively reduce the peak intensity and momentum spread, alleviating undesired effects at transition. Considering the effect of chromatic non-linearity alone, in the absence of the transition jump the hybrid scheme at 48 kV/turn reduces the beam loss from about 40% to 5%.

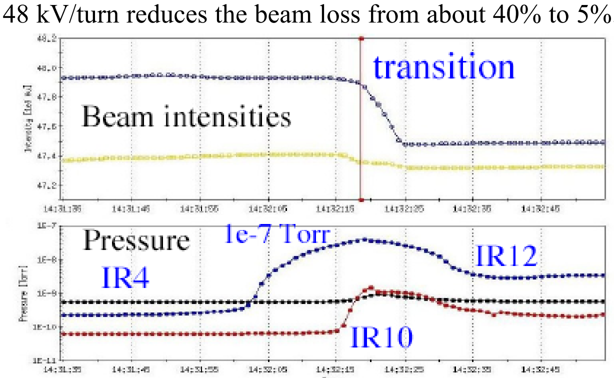

Figure 3 Beam intensity and pressure at IRs, the pressure rise occurs before the major beam loss.

At this rate of 48kV/turn, the induction acceleration can be applied for +/-125 ms around the transition. During this time period when the particle motion is non-adiabatic, the bunch length is effectively enlarged, suppressing electron-ion instability and beam loss.

Table 1

Circumference	C_0	3833 m
Transition energy	γ_t	23
Synchronous phase	ϕ_s	0.16
Acceleration RF voltage	V_{rf}	300 kV
Harmonic number	h	360

Simulation results pursuing the bunch shape are given in Figs.4,5, where the normal TC with the rf and the FFTC employing the induction acceleration.

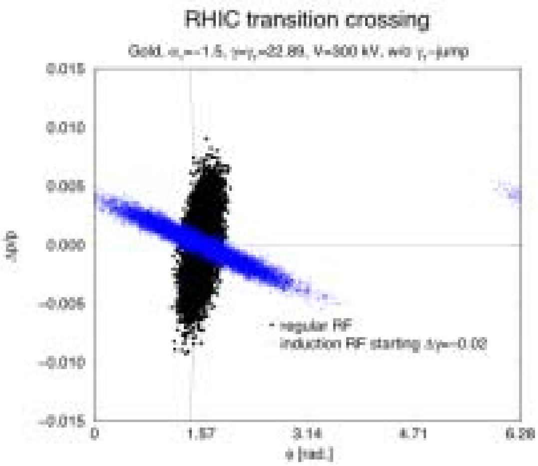

Figure 4 Bunch shapes at TC

The simulation results indicate that the stretched bunch shape at TC and a relatively smaller emittance beyond TC are realized with the FFTC.

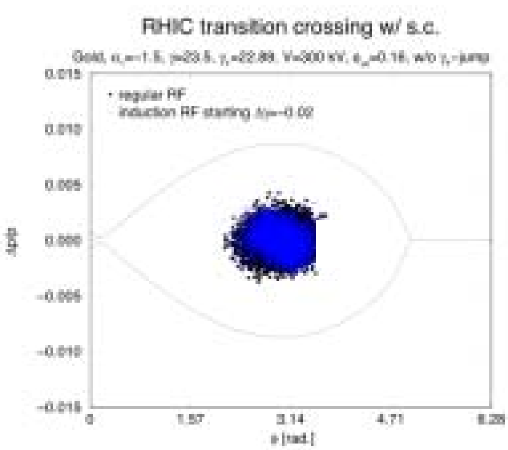

Figure 5 Phase space plots after TC

INDUCTION ACCELERATING SYSTEM FOR THE POP EXPERIMENT IN THE RHIC

The nominal operation of the RHIC requires a acceleration voltage of 48kV/turn. This number is quite big for the POP experiment. The ramping rate of the superconducting magnets will be reduced by a factor of three. The required accelerating voltage of 16kV/turn will be provided with induction accelerating systems, which are similar to the system developed at KEK. The induction accelerating device consists of 8 cells, each of which is energized by a switching power-supply and has an output voltage of 2kV. Their performance is discussed in the companion papers [2].

SUMMARY

The feasibility of the focusing-free transition crossing in the RHIC has been discussed. The simulations tell us that a root of most undesired features observed during transition crossing, bunch shortening, can be completely removed by the FFTC.

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