PRESENT STATUS OF THE INDUCTION SYNCHROTRON EXPERIMENT IN THE KEK PS*

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Abstract

Recent progress in the KEK induction synchrotron is presented. In the recent experiment, by using a newly developed induction acceleration system instead of radio-wave acceleration devices, a single proton bunch injected from the 500 MeV Booster ring and captured by the barrier bucket created by the induction step-voltages was accelerated to 6 GeV in the KEK proton synchrotron.

INTRODUCTION

The concept of the induction synchrotron (IS) was proposed by Takayama and Kishiro in 2000 [1] for the purpose of overcoming the shortcomings, such as a limitation of the longitudinal phase space available for the acceleration of charged particles in an rf synchrotron, which has been one of the indispensable instruments for nuclear physics and high-energy physics since its invention by McMillan and Veksler. Accelerating devices in a conventional synchrotron, such as an rf cavity, were replaced by induction devices in the IS. The acceleration and longitudinal confinement of charged particles are independently achieved with induction step-voltages in the IS, as schematically shown in Fig.1. A long step-voltage generated in the induction acceleration cells gives the acceleration energy. Pulse voltages at both edges of some time-period with the opposite sign, which are generated in other induction accelerating cells, are capable of providing longitudinal focusing forces. These pulse voltages are generated by the master trigger signal made from the bunch signal, which fires the switching power supply (SPS) to drive the induction acceleration cell. Consequently, the acceleration and confinement are synchronized with the beam revolution. The experimental demonstration was divided into three stages: (1) induction acceleration of a single bunch captured by the rf bucket, (2) trapping of an injected bunch by the barrier voltages, and (3) induction acceleration of the barrier bucket trapped bunch. Each of them will be discussed in a somewhat compact manner.

INDUCTION ACCELERATION IN THE HYBRID SCHEME

The IS has been eagerly developed at KEK since 2000. After accomplishing the key devices, such as the SPS and the induction acceleration cell, to realize induction

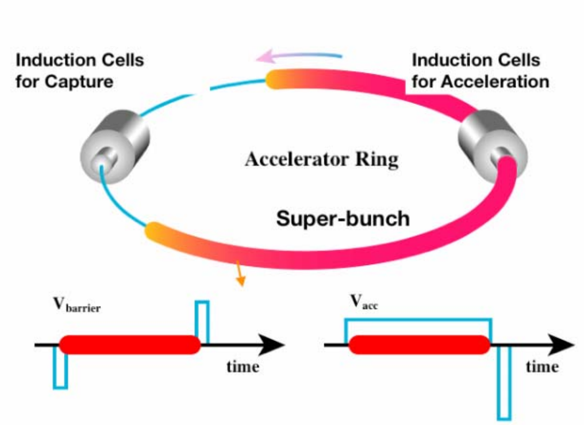

Figure 1: Schematic view of the induction synchrotron.

acceleration in a circular ring, an induction acceleration experiment was carried out step-by-step using the existing KEK 12 GeV proton synchrotron (12GeV-PS). For the first time, induction acceleration in a high-energy circular ring was demonstrated in 2004 [2], in which a single proton bunch injected from the 500 MeV Booster ring and captured in the rf bucket, was accelerated from 500 MeV to 8 GeV. This means that a hybrid synchrotron with functional separation in the longitudinal direction has been realized. Fig.2 shows its experimental result. The relative position of the bunch to the rf in phase was monitored through the entire acceleration period including the transition crossing, for three cases with induction acceleration (red), induction deceleration (blue), and without induction acceleration (green). The temporal evolution of the phase and its magnitude were in agreement with the theoretical prediction.

FORMATION OF A SUPERBUNCH IN THE BARRIER BUCKET

In a succeeding experiment [3] the proton bunch captured by the induction barrier voltages at an injection-energy of 500 MeV, and survived for more than 450 msec. The induction step-barrier voltages create a shallow notch potential, where the injected buch is trapped. The rf bunch shape injected from the 500 MeV Booster was not matched to the barrier bucket in the phase-space. After a large filamentation in the bucket, the bunch achieved its 600 nsec-long size, as seen in Fig.3.

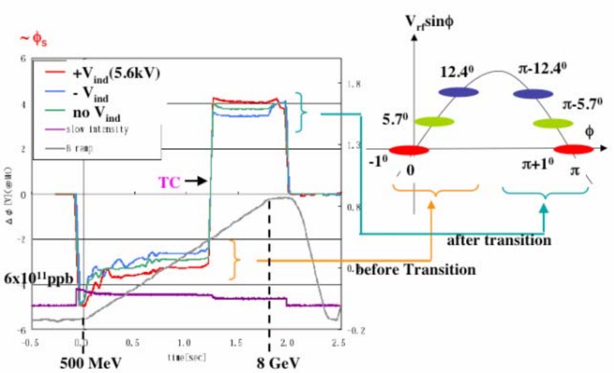

Figure 2: Proof of the induction acceleration of an rf bunch. Left, the phase monitor signals, ramping pattern, and temporal change in the beam intensity; Right, schematic views of the rf bunch and the sinusoidal rf voltage.

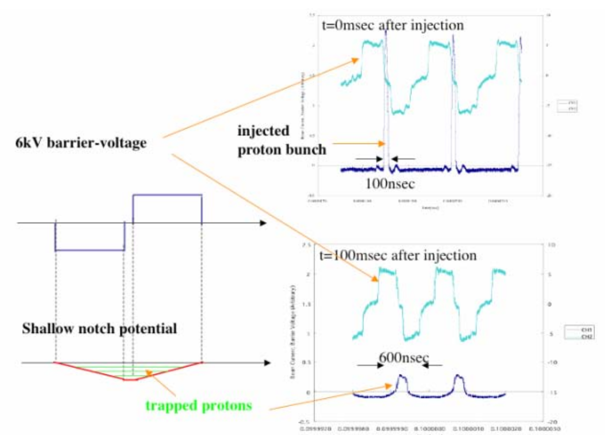

Figure 3: Left, Schematic view of the shallow notch potential; Right, the injected bunch and captured super-bunch with the barrier voltages.

FULL DEMONSTRATION OF THE INDUCTION SYNCHROTRON

In a full demonstration of the IS, the beam-orbit control was the most important issue as well as in any synchrotron. Without this function, charged particles can never be accelerated in a vacuum chamber. The so-called ΔR-feedback system is equipped to meet this requirement in a conventional rf synchrotron. A similar feedback system [4], where the gate pulse generation was determined by integrating the digital gate pulse generator for the SPS with the orbit information proportional to the momentum error, $\Delta p/p$, was introduced in the present IS. When the signal amplitude exceeds a preset threshold value, the gate trigger signal is blocked in the DSP. Accordingly, the acceleration voltage pulse is not generated at the next run and the momentum approaches the correct value, which is uniquely determined by the bending field. An outline of the gate control system is shown in Fig.4 [5].

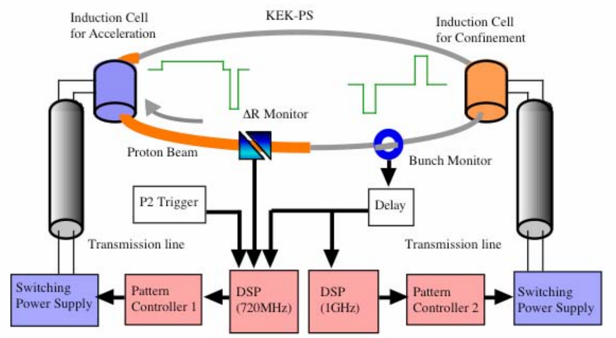

Figure 4: Schematic view of the IS with the gate control system. The induction systems for the acceleration and confinement are of the same type except, for the gate control, which can generate different voltage-patterns, as shown. P2 means the start of acceleration. The signal monitored at the bunch monitor is employed as a master gate trigger signal for the SPSs.

The experimental results were shown in Fig.5. The top line in the Fig.5 is the ΔR signal, which is kept to be 2 mm after the starting of acceleration. The beam intensity of the second line was lost in the transient region from the injection stage to the parabolic ramping region of the bending field; beyond that the intensity was held to be constant. Details of the experimental result are given elsewhere [6].

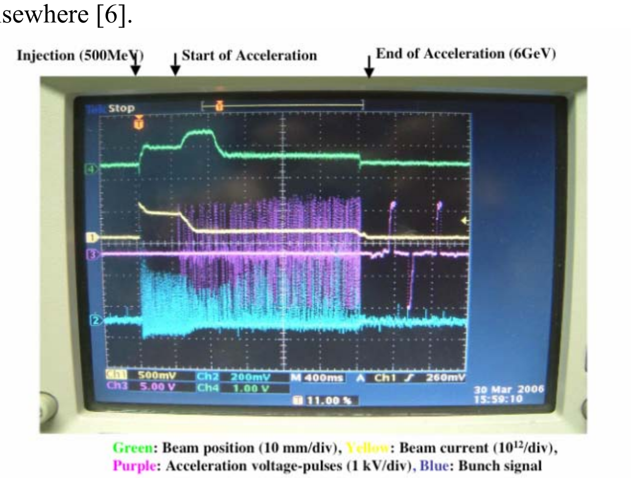

Figure 5: Typical experimental results

SUMMARY

Various applications have been considered since the first proposal of the IS. The super-bunch hadron collider [7], or a proton driver for the second generation of neutrino oscillation experiments are among them. These applications rely on the realization of a super-bunch, the line density of which is just under the space-charge limit in the transverse direction. For this purpose, a long pulse-duration between the barrier voltages and a long acceleration induction voltage is required. The induction acceleration device should be of low impedance to mitigate any serious beam-loading effects due to a large increase in the stored beam current. The SPS used to drive such a low-impedance device must be capable of carrying a larger arm current. The arm current is limited by the capability of the employed switching element. R&D work on a high-current switching supply employing newly developed solid-state switching elements, such as a mold-type SI thyristor or a SiC MOSFET, are is being conducted [8].

An all-ion accelerator [9] is under consideration as one of attractive applications of the IS. It is believed that any ion with any possible charge state including cluster ions can be accelerated from the sonic speed to high speed in a single all-ion accelerator because of a specific property that the induction acceleration devices are energized by the switching power supply synchronized with the ion-bunch circulation.

Modifying the existing rf synchrotrons to the IS is rather easy, because it is just a matter of replacing the rf devices by the induction devices. In addition, the hybrid synchrotron seems to be very attractive. As a matter of fact, a novel transition crossing method [10], which is called “quasi-adiabatic no-focusing transition crossing”, has been developed in the KEK-PS. According to this method, where the rf voltage is linearly reduced to zero at the transition energy and increased to a nominal value, the bunch size is controlled with a desired value. This allows us to avoid any serious problems, such as microwave instability, Johnsen effects, and electron cloud instability, associated with transition crossing in a conventional rf synchrotron.

The IS concept has been demonstrated in a complete form. We conclude that the principle of the induction synchrotron has been confirmed and the acceleration technology of charged particles has entered into a new era. Assuming further developments in the key devices, novel applications never realized in a conventional rf synchrotron will be expected in the near future.

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