

SUPERBUNCH ACCELERATION AND ITS APPLICATIONS

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Abstract

The principle of super-bunch formation is described in the context of the concept of Induction Synchrotron. Its proof in principle experiment being underway at KEK is introduced. Its various applications in the JHF and the MINOS experiment and Tevatron experiment at FNAL are discussed. Key aspects of super-bunch hadron colliders are mentioned.

1 INTRODUCTION

A remarkable feature of newly being developed Induction Synchrotrons [1] is super-bunch acceleration. An super-bunch in this novel synchrotrons, which is capable of holding a larger number of particles by a factor of several than in RF synchrotrons, is generated and accelerated with the same level of local density as in RF synchrotrons. An extremely long bunch of μsec order, referred to as super-bunch, is generated by a symmetric painting method or a multi-bunch stacking method employing barrier buckets created with step-voltages induced in induction gaps. It is accelerated with another step-voltage. It is shown that a high luminosity hadron collider [2] and hadron accelerators dedicated to the long base-line neutrino oscillation experiments are quite attractive as applications of super-bunch acceleration. Super-bunches in a hadron collider intersect with each other, yielding a luminosity of more than $10^{35}/\text{cm}^2/\text{sec}$. Hybrid inclined crossing with a large crossing angle is shown to be quite effective to mitigate the parasitic beam-beam effects. Important machine parameters of the super-bunch VLHC are given here. The latter application is proposed for proton machines such as the KEK 12GeV-PS, the 3GeV/50GeV Rings of the Joint Project, and the Fermilab Main Injector, which are currently operated or going to be operated for the long base-line neutrino oscillation experiments always demanding a high intensity beam current. In each case, it is estimated how much the total beam intensity can be increased beyond a magnitude obtainable in the conventional RF scheme. Beam dynamics issues, which are associated with super-bunch acceleration by the barrier bucket, such as transverse mode coupling instability (TMCI) will be addressed last.

2 PRINCIPLE OF SUPER-BUNCH FORMATION

There are two sorts of method for super-bunch formation. One is performed by a method called symmetric painting into a long barrier bucket [1], which is employed in a rapid-cycle first-stage synchrotron with a function of H⁻ stripping injection and a sufficiently large

circumference. The other is employed in slow-cycle synchrotrons downstream. Multiple RF bunches and super-bunches generated in the upstream booster ring are stacked by utilising two sets of barrier buckets. A bunch injected into the ring is captured by a matched barrier bucket. Each bunch is moved adiabatically toward the edge of the stacking bucket and then released into the stacking bucket. After this stacking process, a newly generated super-bunch is accelerated with the step voltage.

3 PROOF IN PRINCIPLE EXPERIMENT FOR SUPER-BUNCH ACCELERATION

A proof-in-principle experiment of super-bunch acceleration is planned in the KEK 12GeV-PS and will be demonstrated until 2003. It is divided into three stages, as shown in Fig.1. First three bunches trapped in the RF buckets are accelerated with induction voltage alone up to the flat-top energy. It is essential to realise the precise out-put voltage and rep-rate control synchronising with magnetic fields ramping. Then, the role of induction voltage are transferred to that of the barrier bucket and five bunches injected from the 500MeV booster are trapped in the single barrier bucket to merge into a single bunch, which can be regarded as a pseudo super-bunch. Various beam handling such as bunch lengthening/shortening is exercised by changing the pulse duration between set/reset voltage pulses. After installation of a required number of induction units, a full-spec demonstration of super-bunch acceleration with a 60% increment in beam intensity will be tried. The capture bucket can afford a dual harmonic bunch from the 500MeV Booster with a 20% increment in beam intensity and 12 bunches instead of current 9 RF bunches could be stacked by the stacking technique mentioned above. This operation is expected to dedicate to the last stage of the K2K experiment.

4 APPLICATIONS

4.1 JKF 3GeV RCS and 50GeV SCS

Application of super-bunch acceleration in the JHF rings is straightforward. The symmetric painting can be employed in the 3GeV rapid cycle synchrotron (RCS). Fig.2 shows the painting process in the longitudinal phase-space. The energy-split injection is essential to maintain the uniformity in particle distribution throughout the injection process. Computer simulations including space-charge forces indicate that a bunching factor of 0.78 is achievable at the end of injection. The number may allow us to have a 80% increment in beam

intensity. In addition, the simulations [4] have demonstrated that the uniformity can be maintained through the acceleration and the pulse length at its end is about 450nsec. Multiple super-bunches can be stacked by the technique mentioned earlier in the 50GeV ring. The 50GeV ring can afford 7 or 8 booster super-bunches instead of 4.5 RF booster batches in principle. Eventually we may expect a $1.8 \times 7 / 4.5 = 3$ times larger beam intensity than in the present conventional RF scheme.

4.2 8 GeV Booster and Main Injector of FNAL

Possibilities of application for the Fermilab accelerator complex has been discussed in the seminar [4]. Super-bunch acceleration seems to be effective in order to realise a much higher bunch-intensity in the Tevatron collider mode. It may allow us to shore up the current scheme, where only 5 bunches in 84 RF bunches generated from a coasting beam are injected into the Main Ring that waits for them with $h=588$ harmonic buckets, after arriving the flat-top energy, they are rotated by 90 degrees in the $h=28$ harmonic buckets to substantially increase the peak line density, then the these short bunches are injected into the Tevatron to serve for collision. Namely, chopped beams

4.3 Super-bunch Hadron Colliders

If the heat deposited by synchrotron radiation in a hadron collider is below the limit or can be removed by any efficient engineering efforts, the last issue to prevent the collider from reaching a much higher luminosity should be a sparse bunch population that is a limit of the conventional rf synchrotron. Of course, we assume here that the particle detector does not care about the minimum bunch spacing. Use of super-bunches in the colliders has been shown to drastically increase its luminosity in the reference [2]. In order to avoid the serious parasitic beam-beam effects, the so-called hybrid inclined crossing seems to be quite useful, where a self-compensation of the space-charge effects between the horizontal and vertical directions is expected. In the reference [3,5], the super-bunch LHC and super-bunch VLHC have been discussed with possible machine parameters.

5 CONCLUSION

The ongoing plan for the proof-in-principle experiment at KEK has been described. From a physics point of view, the beam intensity and the luminosity are essential at any accelerator and collider used to search for new particles, such as Higgs and super-symmetric particles. Applications of super-bunch acceleration seem to become very attractive to such accelerators in near future, when high intensity operation will be required soon.

are injected into a sharp and relatively short barrier bucket or a dual harmonic bucket by the symmetric painting scheme to form a super-bunch (see Fig.3). Then, the super-bunch with about two times higher beam intensity than in the present RF scheme is extracted without any inherent loss, injected into a matched barrier bucket in the Main Injector, and accelerated with the induction step-voltage. The following RF manipulation is performed in the same way as in the current scheme. Eventually, proton bunches with higher intensity can dedicate to the higher Luminosity operation of the Tevatron. For the MINOS experiment, a single super-bunch is generated in the 8 GeV Booster by the method of symmetric painting, allowing 2 times higher intensity/batch than in the present 53 MHz RF scheme. Then, 12 super-bunches instead of present 6 Booster batches are stacked in the Main Injector. Two adjacent super-bunches merged into a single super-bunch by trigger manipulation of the barrier voltage as seen in Fig.4. This reduces the rep-rate of the induction devices. Eventually, a 4 times higher beam intensity could be available for the MINOS experiment.

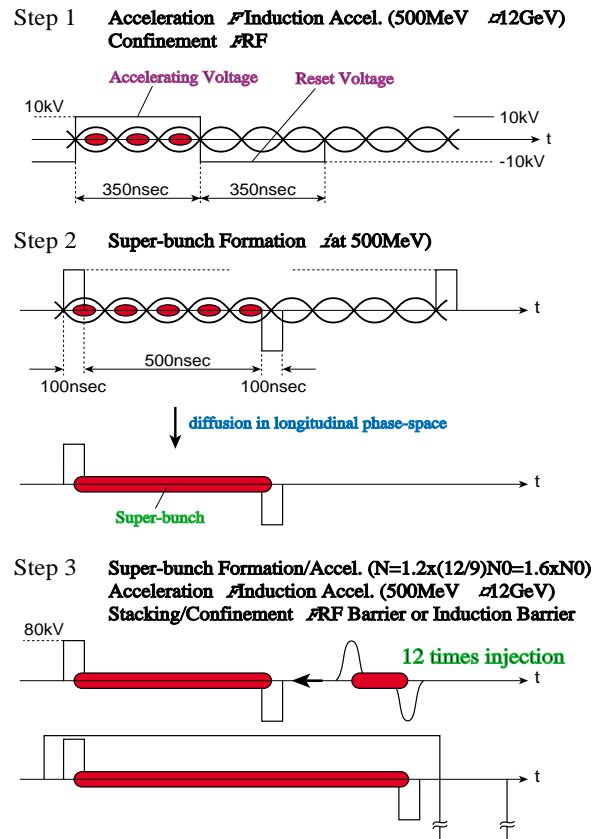


Figure 1 Scheme of the proof in principle experiment for super-bunch acceleration in the KEK 12GeV PS

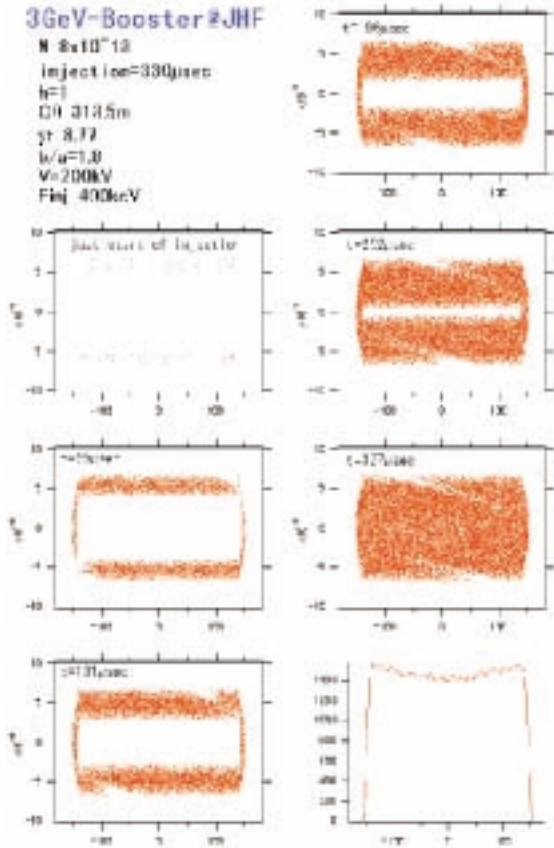
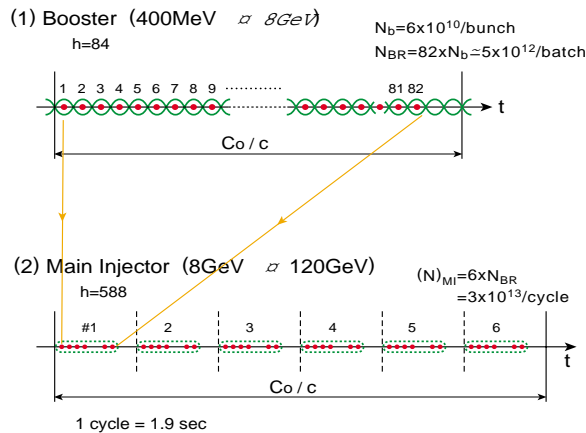


Figure 2 Symmetric painting and line density at the final stage of injection in the 3GeV RCS

RF - bunch scheme



Booster Main Injector

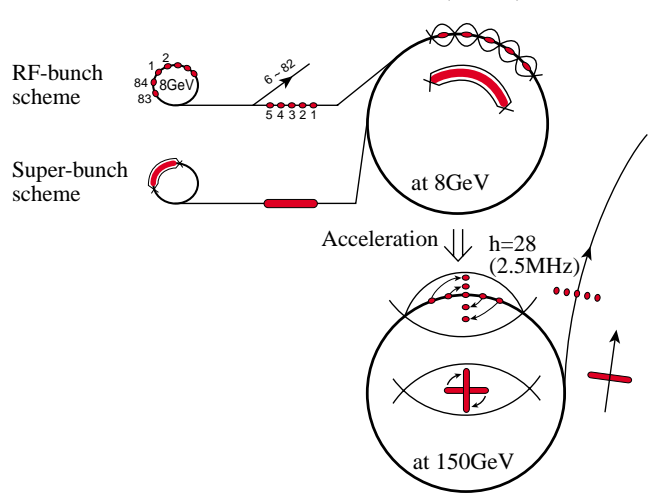


Figure 3 Proton super-bunch formation for the Tevatron

6 REFERENCES

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Superbunch scheme

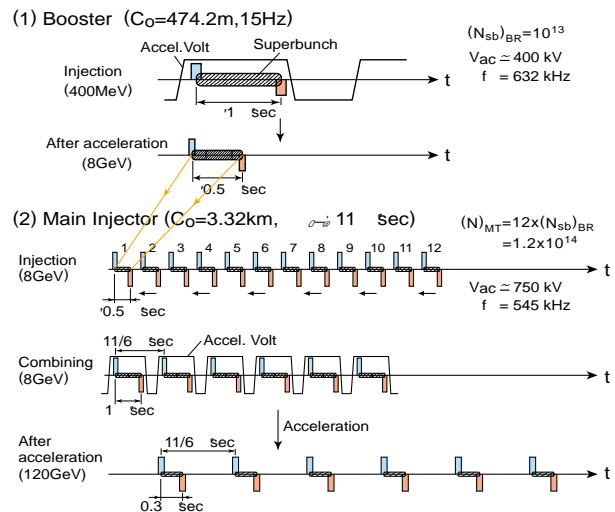


Figure 4 Super-bunch formation in the 8GeV Booster and Main Injector of FNAL for the MINOS experiment