DEMONSTRATION OF BUNCH TRIPLE SPLITTING IN THE CERN PS

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Abstract

A technique for splitting bunches into three has recently been proposed as an alternative to debunching-rebunching in a synchrotron[1]. The preservation of longitudinal emittance and the possibility of maintaining a gap in the bunch train are key features expected from this new process. A proof of principle has been established experimentally at the CERN PS in 1999. This showed that the nominal longitudinal characteristics of the proton beam for the LHC could be achieved at the exit of the PS with the help of triple splitting. The method is described and experimental results presented. Other possible applications are sketched.

1 INTRODUCTION

In order to meet the stringent requirements of the LHC concerning transverse and longitudinal beam emittance, important modifications have been made and new rf hardware has been installed in the PSB and PS[2,3,4]. In the transverse phase planes, the specified beam characteristics have been obtained at the exit of the PS[5]. In the longitudinal phase plane, the emittance budget was known to be particularly tight because of debunching-rebunching[6] and, in practice, instabilities in the debunched beam lead to a final emittance which is 40% above the specifications[3,4,5]. Consequently, a new scheme has been proposed which avoids debunching and achieves the required bunch spacing using a series of splitting processes. One such step is a new method for triple bunch splitting.

2 PRINCIPLE

2.1 Multiple splitting scheme

The complete process is sketched in Fig. 1. Six bunches delivered in two batches by the PSB are captured on harmonic h=7 in the PS. Triple splitting is started as soon as the second batch is received, which provides 18 consecutive bunches on h=21. The beam is then accelerated on this harmonic up to the 25 GeV flat-top, where each bunch is twice split in two to give 72 consecutive bunches on h=84. Finally, these bunches are compressed by stepping up, in 25 ms, rf voltages at 40 MHz (h=84) from 100 to 300 kV and at 80 MHz (h=168) from 0 to 600 kV. This leaves a 320 ns gap in the bunch train for the rise-time of the ejection kicker.

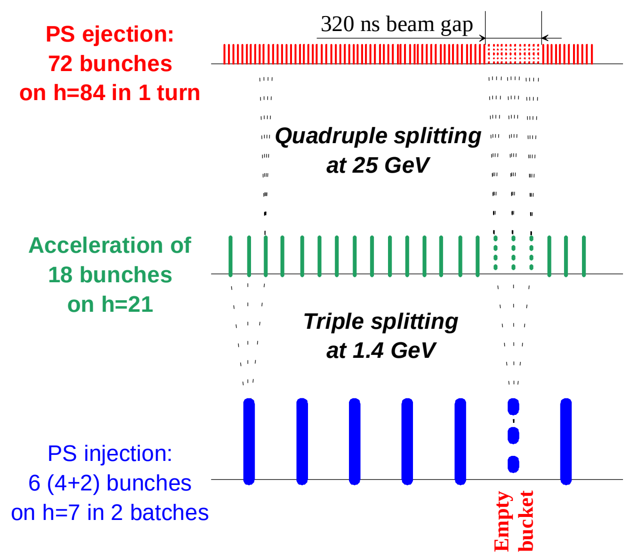

Figure 1: Multiple splitting scheme for the LHC

Simulations show that the emittance blow-up is negligible.

Uncertainty in the performance of this scheme is limited to the triple splitting, since double splitting has been amply demonstrated with excellent operational experience[3,4].

2.2 Triple bunch splitting

Triple splitting requires three simultaneous rf harmonics (h=7, 14 and 21). The voltages of these three components and the corresponding evolution of the distribution of particles in the longitudinal phase plane are represented in Fig. 2. A stable phase on h=21 and an unstable phase on h=14 coincide with the stable phase on h=7. Starting with h=7 alone, the effect of increasing the voltages on h=14 and 21 is to flatten the bunch (t=7 ms in Fig. 2). In phase space, two new stable points emerge close to the initial one, encircled by 3 buckets. If the rate of change of the voltages is sufficiently slow, the particles of the initial bunch are gradually captured in these new buckets, whose area grows as the voltage decreases on h=7 and increases on h=21 (t=14 ms in Fig. 2). Using numerically determined laws of variation, the three areas are kept equal throughout the process, so that layers of increasing emittance in the initial bunch are progressively peeled off and accumulated evenly into the three new buckets. Three equal bunches are finally obtained, each with the same distribution of particle density as the initial one (t=25 ms in Fig. 2).

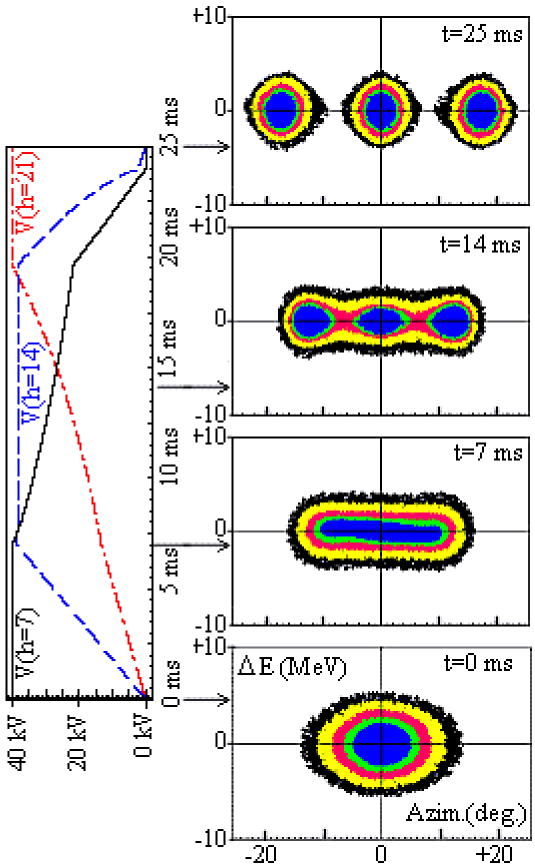

Figure 2: Simulation of triple splitting.

2.3 Benefits

The following beneficial consequences are expected:

- instabilities should be less of a problem as the beam is never debunched and its momentum spread is greater,
- performance should be very reproducible thanks to the continuous action of a beam phase loop.

3 EXPERIMENT

3.1 Implementation

The 10 ferrite-loaded cavities of the PS are split into 4 groups. During triple splitting, one group of 4 cavities is stopped and three pairs of cavities are active on h=7, 14 and 21. At the end of the process, all groups are tuned on h=21 and the full rf voltage is available for acceleration. The low-level rf is based on the infrastructure developed for the AD production beam[7]. Each cavity is driven by a dedicated Direct Digital Synthesizer (DDS) whose harmonic is computer-controlled by a function generator. All DDS are driven by a common clock on h=128 and synchronized with a common train at the revolution frequency whenever they are at an integer harmonic.

A supplementary DDS is used as a phase reference for the measurement of the beam phase. The beam phase loop controls the h=128 synthesizer. It is kept locked during all the gymnastics, switching the reference DDS from h=7 to 21 when both spectral components of the beam current are of similar amplitude (t=20 ms in Fig. 3).

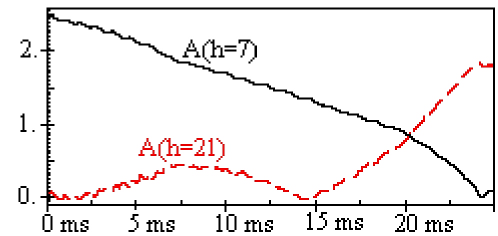

Figure 3: Beam spectral amplitudes on h=7 and 21 during triple splitting.

3.2 Results of triple splitting

The process has been adjusted at 1.4 GeV to simplify the cycle and make better use of the dynamic range of the cavity voltage servo-system. After precise adjustment of the relative phases of the different harmonics, good results were obtained (Fig. 4).

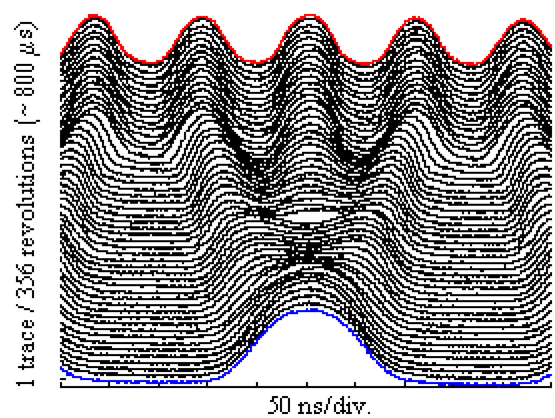

Figure 4: Triple splitting at 1.4 GeV in the PS.

Emittance is indeed preserved and performance is reproducible with up to 4 bunches from the PSB. The variation in bunch population is only +/– 10% (Fig. 5).

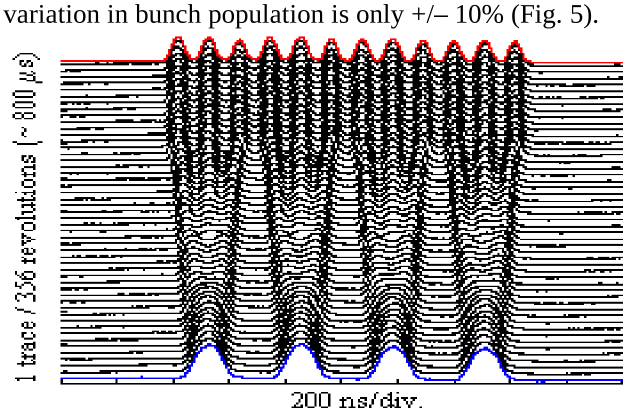

Figure 5: Splitting of 4 bunches into 12 at 1.4 GeV.

In order to stabilize the beam and minimize bunch shape oscillations upon crossing transition, some controlled blow-up is applied at the injection energy. Four bunches of nominal intensity and 0.6 eVs emittance are then accelerated to the high-energy flat-top without losses or any measurable blow-up (Fig. 6).

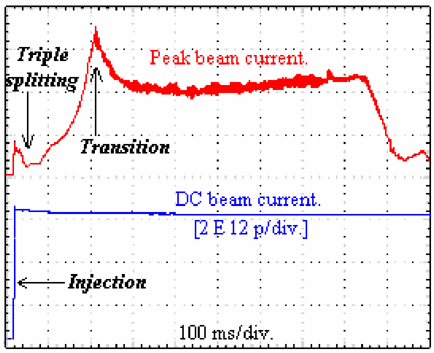

Figure 6: Capture, splitting and acceleration up to 25 GeV of 4 PSB bunches.

3.3 Status of the remaining gymnastics

The synchronization at 25 GeV, which starts at the beginning of the flat-top, is disturbed by phase shifts in the amplifier chains during the voltage reductions prior to the first double splitting from h=21 to h=42. Bunch shape oscillations are triggered which degrade the final result. Nevertheless, both splitting steps have been demonstrated and 48 distinct bunches have been obtained (Fig. 7). Improvements to the low-level hardware are being prepared.

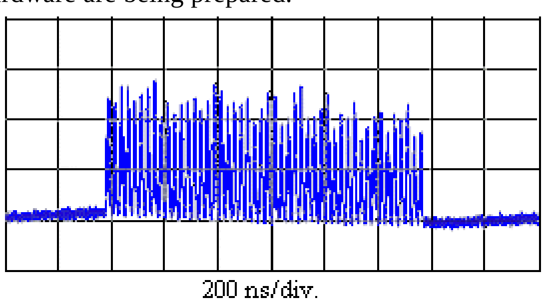

Figure 7: Bunches at the end of the 25 GeV flat-top.

4 FUTURE PLANS

The demonstration that small emittances can be maintained up to 25 GeV makes other bunch trains conceivable. For example, 120 ns gaps every 8 bunches are feasible (Fig. 8), as is 50 ns between bunches. Such possibilities are especially important to help the SPS, and possibly the LHC, study and fight against electron cloud instabilities[8], although this has to be balanced against single bunch instabilities in these machines.

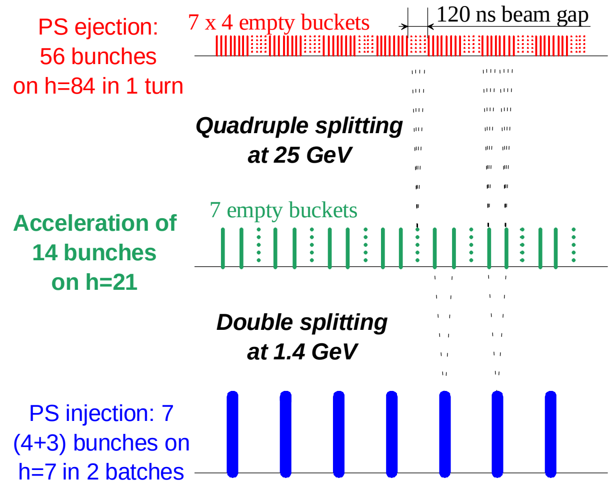

Figure 8: "Exotic" splitting giving 120 ns beam gaps

5 CONCLUSIONS

Triple splitting has been successfully demonstrated in the PS with one and four PSB bunches of the nominal intensity. The experimental results show that:

- the nominal LHC bunches can be obtained thanks to the small emittances obtained at 25 GeV,
- exotic gymnastics are also feasible which will help study and possibly fight against electron cloud effects, first in the SPS and later in the LHC.

However, hardware improvements are still needed to bring the double splittings at 25 GeV to the proper level of performance. Developments are in progress and tests with beam will resume in July 2000.

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