Specifications & requirements for a pulsed BBLR in LHC & SPS

Motivation

If the long-range beam-beam perturbations suffered by the PACMAN bunches can be compensated, the compensation of the LR beam-beam effect will gain in credibility and allow an LHC upgrade based on this principle without taking any risk.

The goal of this proposal is to establish the technical feasibility of the compensation in the LHC. The proposed SPS set-up allows testing in a beam environment a compensator and more specifically its parameters, as a beam is a very sensitive detector. It should be noted however that a single SPS device can only excite a beam and cannot by nature demonstrate compensation. However, a pulsed device in the SPS could be used to compensate the effect of an existing 'dc' wire.

Length

The space booked for each LHC compensator on either side of the high-luminosity experiments is 3 meters, including the transitions (1). This leaves about a maximum of 2 meters of active corrector length. It should be noted that it appears possible to further extend the BBLR extension, if it would be needed.

Strength (Current x Length)

The BBLR should compensate the effect of 15 long-range collisions in the LHC (occurring on one side of one IP). For nominal LHC parameters, the total strength of these 15 collisions is equivalent to an integrated BBLR strength of 82.8 Am (current x length of device). For ultimate bunch charges the equivalent BBLR strength is 120 Am. During commissioning and/or with 75-ns bunch spacing, the BBLR strength needed is about a third of the nominal or 27.6 Am. It must be possible to vary the BBLR strength to adapt to varying operating conditions and beam currents.

In the SPS, the present active length is 1.2 m with a current of 276 A corresponding to the nominal situation, i.e. 82.8 Am × 2 sides × 2 IP's = 1.2×276. To decrease the demand on a pulsed BBLR test in the SPS, the beam-wire distance could be halved, which would allow reducing the strength by a factor of 4 (scaled experiment

Excitation Pattern

LHC The BBLR pulse in the LHC has a complicated structure, which reflects the LHC filling pattern; see Fig. 1.

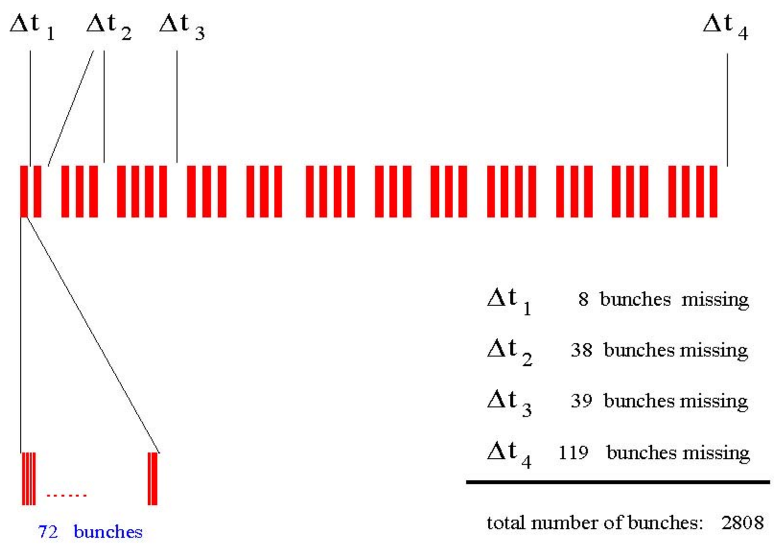

Fig. 1: Nominal bunch filling pattern in the LHC [from LHC Design Report, Vol. 1, 2004].

The filling pattern can be described symbolically as "2(72f+8e)+30e+3(3(72f+8e)+30e+ 4(72f+8e)+31e+3(72f+8e))+30e+3(72f+8e)+30e+4(72f+8e)+111e", where f and e refer to full and empty buckets spaced by about 25 ns. The number of long-range collisions on one side of the IP experienced by a bunch can be computed from the above filling pattern.

The desired pulse pattern for the long-range beam-beam compensator is illustrated in Fig. 2 and listed in Table 1. Details are depicted in Fig. 3. The full LHC excitation pattern is constructed by combining a number of elementary segments listed in Table 2. Note that an excitation of 0 refers to the time without opposing beam. Here, an arbitrary excitation would be possible (e.g., negative values), as long as the starting and end point are held at zero.

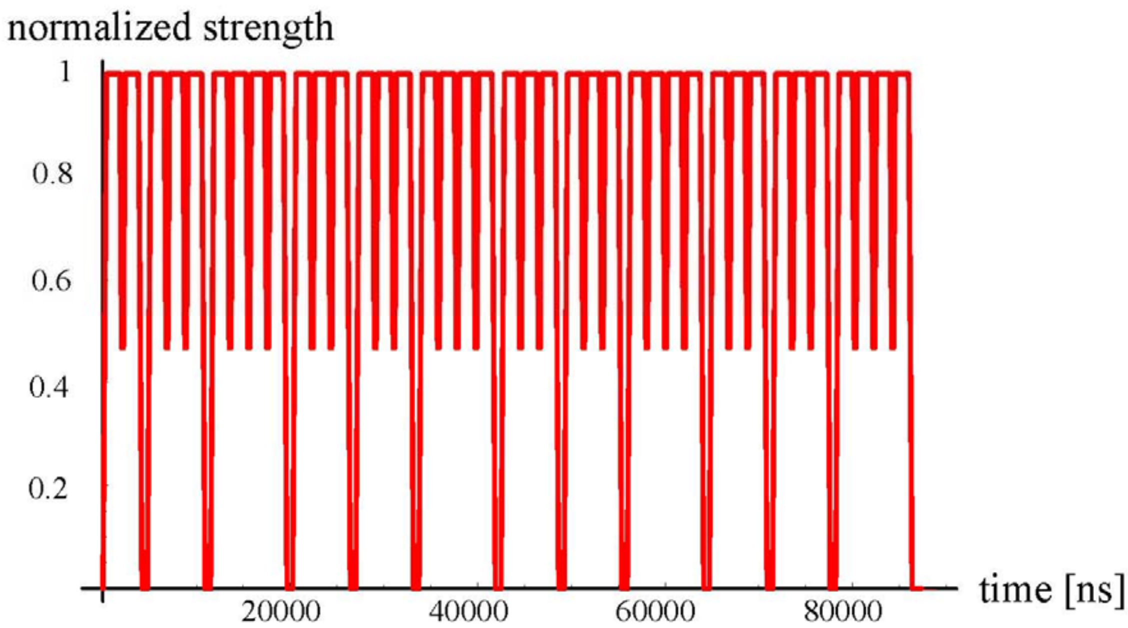

Fig. 2: Pulse pattern of a BBLR in LHC, normalized to a maximum strength of 1. One full revolution period is shown, after which the above pattern repeats.

event	amplitude (from/to)		time (from/to)	
zero (arbitrary)	0	0	0	24.95 ns
linear ramp up	0	1	24.95 ns	399.2 ns
max	1	1	399.2 ns	1821.35 ns
linear ramp down	1	0.467	1821.35 ns	2020.95 ns
min	0.467	0.467	2020.95 ns	2195.6 ns
linear ramp up	0.467	1	2195.6 ns	2395.2 ns
max	1	1	2395.2 ns	3817.35 ns
linear ramp down	1	0	3817.35 ns	4191.6 ns
zero (arbitrary)	0	0	4191.6 ns	4765.45 ns
linear ramp up	0	1	4765.45 ns	5139.7 ns
max	1	1	5139.7 ns	6561.85 ns
linear ramp down	1	0.467	6561.85 ns	6761.45 ns
min	0.467	0.467	6761.45 ns	6936.1 ns
linear ramp up	0.467	1	6936.1 ns	7135.7 ns
max	1	1	7135.7 ns	85578.85 ns
…				
max	1	1	17864.s ns	19286.4 ns
linear ramp down	1	0	19286.4 ns	19660.6 ns
min	0	0	19660.6 ns	20259.4 ns
linear ramp up	0	1	20259.4 ns	20633.6 ns
…				
linear ramp down	1	0	85977.7 ns	86352.0 ns
0	0	0	86352.0 ns	88921.8 ns (+24.95 ns)

Table 1: Pulse pattern in the LHC, highlighting the various relevant time intervals.

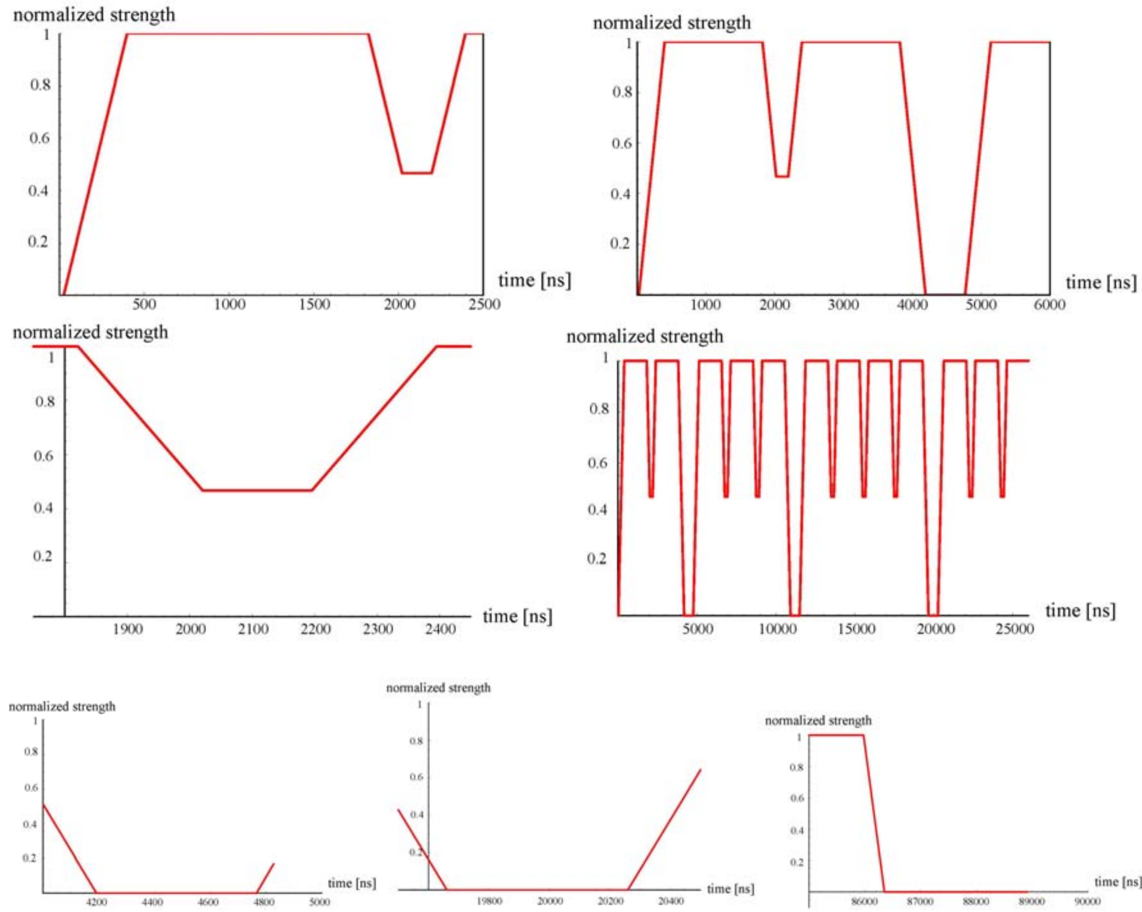

Fig. 3. Details of LHC BBLR pulse pattern, highlighting the size of various gaps.

	amplitude (from/to)		duration	comment
gap after 3 (arbitrary)	0	0	573.85 ns	after three 72-b trains
gap after 4 (arbitrary)	0	0	598.8 ns	after four 72-b trains
abort gap (arbitrary)	0	0	2594.75 ns	abort gap
max	1	1	1422.15 ns	core of bunch train
linear mini-ramp up	0.467	1	199.6 ns	end between trains
linear mini-ramp down	1	0.467	199.6 ns	start between trains
linear ramp up	0	1	374.25 ns	start of 3 or 4 trains
linear ramp down	1	0	374.25 ns	end of 3 or 4 trains

Table 2: Segments from which the full LHC BBLR excitation pattern can be constructed.

The duration of the gaps between bunch trains may be increased in LHC operation, e.g., to counteract the electron cloud or to leave more space for kickers. Therefore, the ‘min’ times (and ‘min’ values) should be held flexible, allowing for the possibility of larger ‘min’ times and lower min values (no immediate switch is necessary; a change of ‘min’ value or ‘min’ durations on the time scale of a few weeks or months would be ok).

SPS The nominal filling pattern in the SPS consists of three of four 72-bunch trains, followed by a large gap, with 24.967 ns bunch-spacing and 8 missing bunches between trains. The abort gap amounts to 692 or 612 missing bunches (17277.16 ns or 15279.8 ns). If the SPS BBLR is excited during the large gap, an overall pattern similar to that required in the LHC and with approximately the same average pulse rate can be realized. The proposed excitation pattern of the SPS BBLR is shown in Fig. 4. The different time intervals are specified in Table 3.

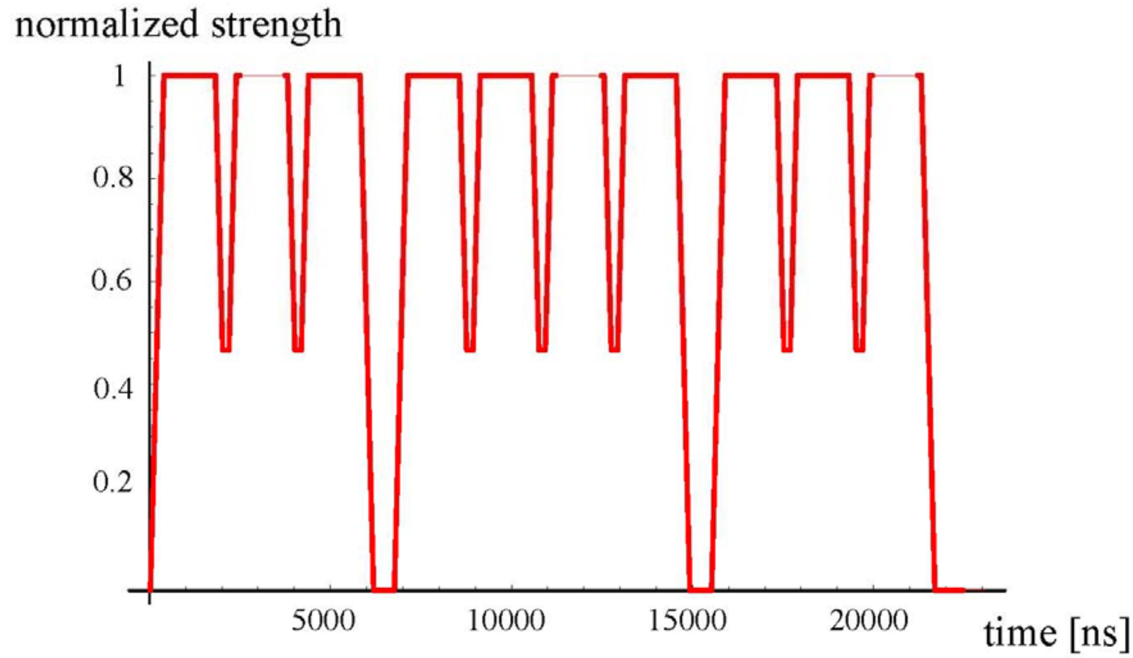

Fig. 4: Pulse pattern of a BBLR in the SPS, normalized to a maximum strength of 1. One full revolution period is shown, after which the above pattern repeats.

	amplitude (from/to)		duration	comment
gap after 3 (arbitrary)	0	0	574.24 ns	after three 72-b trains
gap after 4 (arbitrary)	0	0	599.2 ns	after four 72-b trains
abort gap (arbitrary)	0	0	1398.17 ns	abort gap
max	1	1	1423.12 ns	core of bunch train
linear mini-ramp up	0.467	1	199.74 ns	end between trains
linear mini-ramp down	1	0.467	199.74 ns	start between trains
linear ramp up	0	1	374.50 ns	start of 3 or 4 trains
linear ramp down	1	0	374.50 ns	end of 3 or 4 trains

Table 3: Segments from which the full SPS BBLR excitation pattern can be constructed.

Variation of times and revolution period

The SPS revolution frequency changes slightly with beam energy. Presently, the rf frequency varies from 200.26455 MHz at 26 GeV/c to 200.395 MHz at 450 GeV/c [T. Bohl, private communication]. The SPS harmonic number is about 4620, for a revolution

frequency of 43.3 kHz and an rf frequency slightly above 200 MHz. The revolution period changes by -15 ns from 26 GeV/c to 450 GeV/c. In addition, at a constant energy changes of the order of 50 kHz do occur, which are equivalent to a variation in revolution period by about 6 ns. Desired is a system operating for the 26 GeV central frequency. The tuning to run up to the coast energy of 450 GeV is interesting, but this could remain optional if its implementation is difficult or expensive.
The LHC rf frequency is 400.8 MHz and the corresponding harmonic number 35640. Every 10^{th} bucket is nominally filled, with a spacing of 24.95 ns. The rf frequency increases by about 1 kHz from injection to top energy, and the revolution period of 88.9 μs by about -0.22 ns.

Amplitude and Timing Jitter Tolerance

Static deviations of the excitation from the ideal curve described above may be up to 5%. However, it is crucial to limit the turn-to-turn jitter, which blows up the beam emittance. A random timing jitter from pulse is equivalent to a random amplitude jitter for the bunches sitting on the up or down ramp. The amplitude jitter tolerance is of the order of 10^{-4} [see simulations reported in LHC Project Report 502]. This translates directly into a turn-to-turn timing stability tolerance as $\Delta t \le 10^{-4} t_{\mathrm{ramp}} \approx 0.04\,\mathrm{ns}$, which corresponds to 0.05 rad / 3 degrees at 200 MHz (or 0.1 rad / 6 degrees at 400 MHz).

Summary

Table 4 summarizes the main parameters for the pulsed BBLR in the LHC and the SPS.

	LHC		SPS (26 GeV/c)	
revolution period T_{rev} (=pattern repetition frequency)	88.9 μs +/- 0.0002 μs (variation with beam energy is indicated)		23.05 μs +/-0.02 μs (variation with beam energy is indicated)	
maximum strength	120 Am		120 Am	72 Am
maximum current (smaller currents will also be needed)	120 A (1m)	60 A (2m)	100 A	60 A
0->max ramp up/down time	374.25 ns		374.50 ns	
length of max. excitation	1422.15 ns		1423.12 ns	
lengths of min. excitation (larger min. times may be needed too)	573.85 ns & 598.8 ns		574.24 ns & 599.21 ns	
length of abort gap (could vary)	2594.75 ns		1398.17 ns	
number of pulses per cycle	39		3 (4) or **10**	
average pulse rate	**439 kHz**		130 (173) or **433 kHz**	
pulse accuracy with respect to ideal	5%		5%	
turn-to-turn amplitude stability (rel.)	10^{-4}		10^{-4}	
turn-to-turn timing stability	0.04 ns		0.04 ns	

Table 4: Compilation of pulsed-BBLR parameters for the LHC and the SPS.

Note The impedance properties of the present SPS BBLR wires need to be calculated and/or measured.

References

(1) C. Fischer, LHC-BBC-EC-0001, EDMS# 503722, 27/10/2004.