Collimation schemes and Injection protection Devices in LHC

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Abstract

Several items related to injection, collimation and protection of the LHC rings against harmful beam losses are discussed. Some recommendations for the installation of additional devices related to these issues are proposed.

1 INTRODUCTION

Several different issues are discussed in this paper, almost all related to beam losses at injection energies. In Section 2, it is proposed to add transverse and longitudinal collimation in the transfer lines between the SPS and LHC rings. The need of a first turn stopper is discussed in Section 3. It is also proposed (Section 4) to add a few instruments in the delicate areas which are located between the injection point and the triplet of the neighbouring experiments. The efficiency of collimation at start of ramp is exposed in Section 5 and finally the need of a feedback to control the closed orbit in the collimation areas is discussed in Section 6. The reader is asked to look at the slides associated to this paper [1], where figures might help to understand better the items which are discussed in this paper.

2 DO WE NEED COLLIMATORS AT INJECTION ?

To answer this question, a few simpler ones must be answered first:

- What can happen with a mis-steered or uncontrolled beam? The average intensity of a nominal batch transferred from the SPS to LHC is $N_{\rm batch} \equiv 234$ bunches $\equiv 2.6 \times 10^{13}$ protons. A quench happens with $n_q = 10^{9-10}$ protons $\equiv 4 \times 10^{[-4,-5]}$ of a batch, lost locally. Coil damage happens with $N_{\rm damage} = 23$ bunches $\equiv 1/10$ of a batch. During one nominal year of operation ~ 5000 batches will be injected, and ~ 100.000 during the expected lifetime of LHC (~ 20 years). It seems obvious that some protections are needed.

- Can active protections do the job safely?

  By this we mean not more than one quench per year (for more than $\sim$ 5000 batch injections) and not more than one damage to the machine in its lifetime (100.000 batch injections). With a batch duration of 6 μs, it seems not doable to detect something wrong and discard the batch before it reaches the injection point in LHC. This statement, and what is said below, might be in contradiction with what was said in other sessions (see [3] and Session 8) and might require a second look.

It may be concluded that a passive protection is needed, which in addition to be inherently safe has the advantage to simplify the operation. The ring is mostly made of cold cryostats. With crowded injection areas, both closely followed by an experiment, protections, made of collimators shall be installed in the transfer lines with the additional advantage to protect the septa and the kickers. The sole protection present in the ring is the TDI absorber, which is an effective protection against a failure of the injection kickers (MKI). It catches only vertically kicked protons with the phase origin at the MKI. Therefore horizontal and vertical protections shall be foreseen. Longitudinal , or momentum , protection shall be foreseen too. A basic scheme could consist of two primary absorbers , separated by a phase advance of $\mu_{\rm x,y} = \pi/2$ in each of the transverse planes. Two secondary absorbers, one horizontal and one vertical, located at $\sim \pi/2$ from the second primary absorbers would absorb the large outscattering rate associated to grazing primary protons. A single momentum absorber shall be installed where the dispersion is large. No secondary absorber is needed for that one if it is located upstream of the transverse absorbers. A real scheme remains to be made. Considering two transfer lines, the total number of absorbers would be 14. They can be identical to the 0.5 m copper absorbers of the collimation insertion. For jaw setting purpose, and also to trigger dump action, it is advisable to install a ionisation chamber next to each absorber.

3 DO WE NEED A FIRST TURN STOPPER ?

There is no obvious and clear answer to this point. With the large intensity and energy stored in LHC, the learning process with intense batches might be difficult and cannot be made in a 'let see what happens' style. But fortunately, there is a cost-free positive reply. With single bunch operation, any collimator can do the job, while for batches, the dump can be used with a preset trigger delay relative to the time of injection. As for beam 1, injected in IP2, the way to the dump (located in IP6) is half a turn. The trigger can be preset for dump action after either $1/2\,, 3/2\,..\, n+1/2$ turns . Beam 2 is injected in point 8, with one quarter of a turn to IP6. In that case, the trigger can be preset for $1/4$ or $5/4$ .. $n+1/4$ turns or more. Using the dump has the additional advantage to avoid the deposition of radiation in the ring.

4 ADDITIONAL INSTRUMENTATION NEAR INJECTION POINTS

The adjustment of both the injection point (MSI and MKI strength, TDI transverse position) and the orbit of the two beams in their common section (the beam-beam separation scheme needs to be stable and precise at injection too) requires a robust knowledge of the closed orbit. Presently, it is foreseen to have a BPM upstream of Q4, the next one being located between Q3 and Q2 in the triplet. This is most likely not enough to understand correctly orbit issues in this area. In particular , unkown kicks associated to alignment or tilt errors of Q4 and Q3 on the one hand and D2 and D1 stength errors on the other hand must be identified to allow straight corrections. We thus propose to install two additional warm BPM's, one next to D2 and one next to D1 (it might be good to do the same thing in the drift space D1-D2 on the other side of the insertion). The second is located in a section where the two beams are separated by 15 mm and requires a quite large aperture BPM. It is also advisable to install ionisation chambers (MSI,MKI,TDI,TCDD and next to the two collimators which supplement the TDI at Q6 beyond the crossing point). While this proposal is made in agreement with BI representatives [4], further concertation is needed.

5 EFFICIENCY OF COLLIMATION AT START OF RAMP

This item was already discussed last year [6] and is briefly summarised. Those protons which are off-bucket at the beginning of the ramp will not be accelerated. Their relative momentum offset $\delta_p = dp/p_0$ will increase in magnitude and they will eventually impact the primary momentum collimator, which is set to intercept protons of momentum deviation $\delta_{p,\mathrm{cut}} \simeq -3\times10^{-3}$, a value slightly smaller than the momentum acceptance of the ring $\delta_{p,\mathrm{ring}} \simeq 3.5\times10^{-3}$. The early part of the ramp is parabolic [7], namely

$$\delta_p(t) = \alpha t^2 = 6 \times 10^{-6}\, t^2. \quad (1)$$

With a bucket width $\delta_{p,\mathrm{b}} \simeq \times10^{-3}$ the duration of the flash of losses at the collimator is

$$\Delta t = \frac{2\,\delta_{p,\mathrm{b}}}{\sqrt{\alpha\delta_{p,\mathrm{cut}}}} \approx 10\ \mathrm{s}. \quad (2)$$

This value is two orders of magnitude larger than the time-scale $\delta t \sim 40$ ms which allows to use the reserve of helium in the superconducting coils [8]. At this time scale, the quench limit corresponds to a local loss of $n_q = 2.5 \times 10^{10}$ p/m, while the efficiency of collimation is $\eta \approx 3000$. The allowed integrated intensity of the flash is therefore of the order of

$$N = \eta \times n_q \approx 7 \times 10^{13}\ \mathrm{protons} \equiv\ \mathrm{half\ a\ coast}. \quad (3)$$

With expected off-bucket fractions at the percent levels, the margin factor is of the order of twenty, a somewhat comfortable value.

In case of a loss of control of either the RF system or some of the magnet currents, it is advisable to be able to detect the fraction of beam which goes off bucket. These protons will recess along the ring with

$$\Delta L/L \approx \alpha\delta_p = 3.5 \times 10^{-4}\,\delta_p\ . \quad (4)$$

The number of turns to recess by a full turn is therefore

$$n_{\mathrm{turns}} \approx \frac{1}{\alpha\delta_p} \approx 1.5 \times 10^6\ \mathrm{turns}\ , \quad (5)$$

with for example, $\delta_p = 2 \times 10^{-3}$. It would therefore be possible to detect these protons early enough and trigger a dump action, before they invade the dump gap in the batch structure. The development of such a detector is presently envisaged [9] and should be encouraged.

6 CLOSED ORBIT FEEDBACK IN COLLIMATION INSERTION

At 7 TeV, with the emittance $\epsilon = 5\times10^{-4}\ \mu$m and $\beta \approx 100$ m, the r.m.s beam size in the collimation insertion is $\sigma \sim (\epsilon\beta)^{1/2} = 0.22$ mm. The nominal transverse position is $n_1 = 6\,\sigma$ and $n_2 = 7\,\sigma$ for the primary and the secondary collimators respectively. The normalised size $A = 9$ of the secondary halo grows by $\Delta A \approx 0.5$ for a relative retraction error $\delta(n_2 - n_1) = 0.2$ [5]. This limit shall be respected at all times. There are therefore three kinds of consequences.

- For each new coast and after the squeezing procedure to set-up low-beta conditions, the orbit must be measured and the former preset position of the collimators must be updated by the orbit difference between the present and the former coast. The orbit must be measured to an accuracy smaller than $\delta(CO) < 0.15\sigma \approx 30\,\mu$m. This accuracy can be obtained over several turns, because the jaws must be introduced slowly enough, to allow for a safe decision of beam dumping, triggered by the beam loss measurements which will be made by the local ionisation chambers, in case of unexpected behaviour of either the beam of the instrumentation (detectors or collimators). A robust measurement of the closed orbit implies the abscence of uncontrolled kicks between the BPM's and the collimators. We therefore recommend the installation of a BPM at each end of the drift spaces in which collimators are installed.
- At top energy, where the effect of persistant currents is negligeable, the main source of CO variation shall be the residual error of correction in sections of the ring where non-linear effects are large, namely near experiments where β functions are large and where the beams are offset by the beam-beam separation scheme. The amplitude of these residual errors, which shall be of the order of a fraction of σ, will propagate all around the ring. Therefore, a feed-back is needed in the collimation area to stabilise the orbit.

- No fast action on the position of the beam shall be allowed. How fast will be determined once the feedback frequency is chosen.

Considering two sources of error, namely CO measurements and feed-back error, both affecting the primary and the secondary collimators, and adding quadratically these four contributions to get $\delta x = 0.2\,\delta(n_2 - n_1)\,\sigma \approx 44\ \mu$m and supposing in addition the four contributions to be equal, each contribution must be of the order

$$\delta_i x \approx 20\ \mu\text{m}\ . \qquad (6)$$

The frequency of the feed-back can be rather low. According to H. Grote [10], the time of re-arrangment of the individual orbits by beam-beam PACMAN effects is of the order of five seconds. At HERA, the time interval between two corrections is of the order of fifteen minutes. The maximum feed-back frequency shall thus be

$$\nu_{\text{max}}^{\text{feed}-\text{back}} < 0.2\ \text{Hz}\ . \qquad (7)$$

7 SUMMARY

Several of the items discussed in this paper implied a kind of recommendation. We therefore do so, with the understanding that the recommendations spelled below shall later be endorsed or rediscussed by authorised bodies.

- Collimation at injection is needed and shall be made in the transfer line. A real case study remains to be made jointly by BT, BI and AP.

- A first turn stopper is a useful device to safely understand early and new modes of operations with substantial beam intensities. Using the dump with a preset trigger time is a cost free solution which presents the advantage to induce no radiation deposition in the ring.

- Additional orbit and beam loss instrumentation is recommended near the injection points, and more generally in the drift spaces between the D1 and D2 magnets of every experimental insertion.

- The efficiency of momemtun collimation at ramping is sufficient if the fraction of protons which are off-bucket is of the order of a few percents. A detector of off-bucket protons is advisable in case a large fraction of protons leaves the bucket accidentally, to allow for a dump action.

- A closed orbit feedback is needed locally in the collimation insertions, to ensure a beam stability of $\approx 20\ \mu\text{m}$ at top energy. The frequency of the feedback can be smaller than $\nu_{\text{max}}^{\text{feed}-\text{back}} = 0.2$ Hz. A robust measurement of the orbit in the collimation section requires the installation of a BPM at each end of the drift spaces in which collimators are installed.

8 REFERENCES

[1] http://cern.web.cern.ch/CERN/Divisions/SL/news/cham_XI/sciprog.html#s9

[2] O.S. Bruening and J.B. Jeanneret, LHC Project Note 141, May 1998.

[3] P. Collier, these Proceedings.

[4] J.P. Koutchouk, private communication, Dec. 2000.

[5] D.I. Kaltchev, M.K. Craddock, R.V. Servranck and J.B. Jeanneret, LHC Report 304, 1989.

[6] J.B. Jeanneret, Proc. Chamonix X, CERN SL 2000-007 DI, R. Le Roux et al. Eds, February 2000, p. 162.

[7] L. Bottura, P. Burla and R. Wolf, LHC Report 172, 1988.

[8] J.B. Jeanneret, D. Leroy, L. Oberli and T. Trenkler, CERN LHC Project report 44, 1996.

[9] C. Fischer, private communication, Dec. 2000.

[10] H. Grote, private communication, Jan. 2000.

[11] The Large Hadron Collider, CERN/AC/95-05(LHC),1995.