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A proposal for the time resolution of the Arc Beam Loss Monitors (BLMA)

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Summary

We determine the time resolution needed for Beam Loss Monitors in the arcs of LHC. We consider the expectable density of beam halo and the uncontrolled growth of a closed beam orbit bump together with the transient quench limits.

1 Introduction

The Beam Loss Monitoring system of LHC (below abbreviated 'BLM system') will be split into two subsystems, one with a fast time resolution located in the collimation insertions (BLMC), and another one distributed around the ring (BLMA) [1]. The aim of this note is an attempt to determine the time resolution of the BLMA sub-system which is needed to ensure a safe operation of the ring. The method proposed to determine it is described in Section 2 and the results obtained are discussed in Section 3.

2 Methodology

The uncontrolled growth of a closed beam orbit bump is considered to be the most critical incident to be handled by the BLMA system [2]. An open bump need not be considered here because it would propagate up to the collimation insertions and be safely detected by the the fast BLMC system.

In the case of a closed bump, the drift of the beam towards the vacuum will end-up with the local impact of the beam halo. With some hypotheses about the beam halo and the expected maximum drift speed of the bump, the transient growth of halo rate can be computed and compared to the time-dependent transient quench limit of the ring magnets.

Table 1: *Input parameters, see text.*

Variable	Name	Value	Unit
Injection			
CO corrector ramp	$\dot{k}_i$	2.000e-05	[rad/s]
Bump size growth	$\dot{x}_i$	4.000e-03	[m/s]
Bump size growth/turn	dx_i	3.560e-07	[m]
R.m.s betatronic size	σ_i	1.251e-03	[m]
Top Energy			
CO corrector ramp	$\dot{k}_t$	1.286e-06	[rad/s]
Bump size growth	$\dot{x}_t$	2.571e-04	[m/s]
Bump size growth/turn	dx_t	2.289e-08	[m]
R.m.s betatronic size	σ_t	3.170e-04	[m]
Both Injection and Top Energy			
Flux of Halo	ϕ	2×10^9	[protons/s]
Transverse drift speed	v_d	0.1	[σ/s]
Beam halo transverse density	ρ	2×10^10	[p/σ]

The sole free parameter of this calculation is the time resolution of the BLMA system, which can therefore be fixed by making the two rates equal.

2.1 Quench limits

The quench limits were discussed in [4] and further worked out in [**?**], in which Fig.1 is borrowed.

2.2 Beam halo

The structure of the beam halo cannot be predicted easily. It depends on magnetic defaults and time varying quantities (power supply ripples, beam-beam related variables), which up to now have never been all simultaneously introduced in long-term tracking programs. An estimate was therefore made as follows. A beam lifetime of $\tau_{beam} \sim 40$ hours is assumed, corresponding to a beam loss rate, or transverse flux $\phi = 2 \times 10^9$ protons/s. The luminosity lifetime is less than twice smaller than the beam lifetime. Whenever the time to reload the beams is taken into account, $\tau_{beam} \sim 40$ hours is not an optimum value and the beam current must be decreased for optimum integrated luminosity. This is at least implicitly the strategy adopted in the Yellow Book [3]. At the SPS collider, an effective average halo drift speed of $v_d \approx 1\sigma/s$ was measured at a distance close to the working position of the collimators [5]. Here, we use a pessimistic lower value ten times smaller, i.e. $v_d \approx 0.1\sigma/s$, see Table 1. We then compute an radial halo density $\rho = \phi/v_d = 2 \times 10^{10}$ protons/s. This value shall be

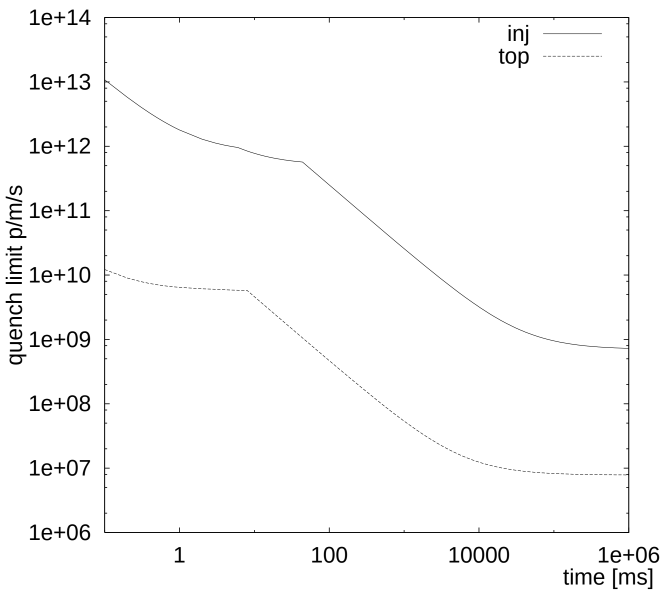

Figure 1: *Quench limits in LHC arc magnets. In abscissa, the time duration Δt of a loss process and in ordinate the corresponding allowed limit rate $\dot{q}$. The total loss rate allowed during a time Δt is $\Delta n_q = \Delta t \times \dot{q}$.*

approximately correct near the transverse amplitude which corresponds to the position of the primary collimators $n_1 = 7$. At larger amplitudes it dies out approximately linearly up to the edge of the secondary halo $n_r = 10$, but we consider a constant value up to n_r.

2.3 Closed orbit bump

We consider a closed orbit bump growing at the largest speed allowed by the ramping of the corrector dipole $\dot{k}$, given in Table 1 [6]. We use a betatron function of $\beta = 200$ m at both the dipole and maximum bump location and thus compute the speed of growth of the bump with $\dot{x} = \beta\dot{k}$, see Table 1.

2.4 Loss rate

Whenever the secondary halo reaches the vacuum chamber, the loss rate integrated during a time window τ will be close to

$$\Delta n = \rho \dot{x} \tau / \sigma \ . \tag{1}$$

The value Δn is compared in Table 2 to the quench limit Δn_q for different time windows τ.

3 Results

Using the results of Table 2, obtained with the parameters and hypotheses summarised in Table 1, we can infer that

Table 2: *Loss rates and transient quench limits.*

Energy	τ [msec]	$\dot{q}$ [p/s]	Δn_q [p]	Δn [p]
Injection	10.0	7.775e+11	7.775e+09	6.397e+08
	20.0	6.425e+11	1.285e+10	1.279e+09
	30.0	5.975e+11	1.793e+10	1.919e+09
	40.0	5.750e+11	2.300e+10	2.559e+09
	50.0	5.007e+11	2.503e+10	3.199e+09
	60.0	4.174e+11	2.504e+10	3.838e+09
	70.0	3.578e+11	2.505e+10	4.478e+09
	80.0	3.132e+11	2.506e+10	5.118e+09
	90.0	2.785e+11	2.506e+10	5.758e+09
	100.0	2.507e+11	2.507e+10	6.397e+09
	110.0	2.280e+11	2.508e+10	7.037e+09
	120.0	2.090e+11	2.508e+10	7.677e+09
	130.0	1.930e+11	2.509e+10	8.317e+09
	140.0	1.793e+11	2.510e+10	8.956e+09
	150.0	1.674e+11	2.511e+10	9.596e+09
	160.0	1.570e+11	2.511e+10	1.024e+10
	170.0	1.478e+11	2.512e+10	1.088e+10
	180.0	1.396e+11	2.513e+10	1.152e+10
	190.0	1.323e+11	2.513e+10	1.215e+10
	200.0	1.257e+11	2.514e+10	1.279e+10
	300.0	8.403e+10	2.521e+10	1.919e+10
	400.0	6.320e+10	2.528e+10	2.559e+10
	500.0	5.070e+10	2.535e+10	3.199e+10
Top energy	10.0	4.608e+09	4.608e+07	1.622e+08
	20.0	2.308e+09	4.616e+07	3.244e+08
	30.0	1.541e+09	4.623e+07	4.866e+08
	40.0	1.158e+09	4.631e+07	6.488e+08
	50.0	9.278e+08	4.639e+07	8.111e+08
	60.0	7.745e+08	4.647e+07	9.733e+08
	70.0	6.649e+08	4.655e+07	1.135e+09
	80.0	5.828e+08	4.662e+07	1.298e+09
	90.0	5.189e+08	4.670e+07	1.460e+09
	100.0	4.678e+08	4.678e+07	1.622e+09
	110.0	4.260e+08	4.686e+07	1.784e+09
	120.0	3.911e+08	4.694e+07	1.947e+09
	130.0	3.616e+08	4.701e+07	2.109e+09
	140.0	3.364e+08	4.709e+07	2.271e+09
	150.0	3.145e+08	4.717e+07	2.433e+09
	160.0	2.953e+08	4.725e+07	2.595e+09
	170.0	2.784e+08	4.733e+07	2.758e+09
	180.0	2.634e+08	4.740e+07	2.920e+09
	190.0	2.499e+08	4.748e+07	3.082e+09
	200.0	2.378e+08	4.756e+07	3.244e+09
	300.0	1.611e+08	4.834e+07	4.866e+09
	400.0	1.228e+08	4.912e+07	6.488e+09
	500.0	9.980e+07	4.990e+07	8.111e+09

1. At injection, the equality $\Delta n(\tau) = \Delta n_q(\tau)$ is reached with a time resolution $\tau =$ 400 ms. A margin factor of ten would be obtained with $\tau = 35$ ms.

2. At top energy, the equality is reached with a time resolution $\tau = 2.5$ ms.

3. It must be noticed that in the arcs at top energy the beam size ($< 7\sigma_\beta \approx 2$ mm) is small, while the margin of aperture is $\Delta x \approx 10$ mm. The time needed to grow a bump to this value is $\Delta t = \Delta x/\dot{x}_t = 40$ s. This is also approximately the time elapsed between the start of the faulty action and the detection of the first substantial local beam loss increase. With a so long time at hand, it might therefore appear reasonable to secure the use of orbit corrector (i.e. software limitation of allowed bump excursions between two closed orbit acquisition ,and check, at an adequately robust level of control). In case of a rare failure of the procedure, the price to pay would be a quench. This point might be further discussed at the Machine Protection Working Group.

4. Another criterion is to avoid a destruction, which occurs at top energy with a local loss above $\Delta n_d \approx 1.6 \times 10^{10}$ protons $\equiv 0.16$ nominal bunch [7]. Looking again at Table 2, we see that with a time resolution $\tau = 400$ ms (see item 1), the loss integration at top energy would be $\Delta n = 6.5 \times 10^9$ or a factor three below the the destructive limit. A slightly lower value $\tau \approx 200$ ms (margin factor of 6) might be advisable.

4 Conclusion

With the hypotheses proposed in this note, the time resolution of the BLMA system can be chosen in the range $35 < \tau < 200$ ms, provided that a secure bump growth control is adopted at least at top energy. Otherwise a value $\tau \approx 2.5$ ms must be chosen.

References

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[2] Conclusions drawn from discussions in the Machine Protection Working Group and the Beam Instrumentation Specification Working Group, September 2001.

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[4] Quench levels and transient beam losses in LHC magnets, J.B. Jeanneret, D. Leroy, L. Oberli and T. Trenkler, LHC Project Report 44, July 1996.

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[6] J. Wenninger, Private communication, October 2001.

[7] J.B. Jeanneret, value to be confirmed more precisely.