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SUMMARY OF THE WORKING GROUP ON EMITTANCE CONTROL

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The working group on emittance control judged what corrections are needed to prevent unacceptable growth of emittances in the acceleration processes for the beam to be injected into the LHC. Estimates are made of the disburbing effects. Improvements in transport devices and in feedback systems are specified.

Keywords: Collective effects; Damping; Emittance; Feedback; Filamentation; Kickers

1 INTRODUCTION

The subject of study for this group was the application of active electronic corrections to particle motions in order to reduce to a tolerable amount the emittance growth caused by (a) filamentation in phase space following a mis-steering of the beam or (b) increase of particle motions caused by spontaneous instabilities. The group limited its concerns to those operations needed for providing proton beams for the LHC; for example, the supply of lead ions was not addressed. To establish working assumptions, in those cases where it appeared that the strength of a disturbance could be reduced, the group specified that a correction be made at the source rather than attempting a large dynamic correction later.

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TABLE I Parameters of beams in the LHC

		Commission	*Nominal*
Luminosity	L [cm^{-2} s^{-1}]	10^{33}	10^{34}
Current/beam	I_{beam} [A]	0.087	0.53
Particles/bunch	n_b	0.17×10^{11}	1.05×10^{11}
Number of bunches	k_b	2835	2835
Normalized ⊥ emittance	ε_n [μradm]	1	3.75
Beam–beam parameter	ξ	0.0021	0.0034

The parameters of beams to be used in the LHC were listed by Gareyte and are given in Table I. In most of the considerations in the workshop the nominal case of Table I was the subject of study.

Clearly the less intense beam with reduced emittance will be desirable for commissioning but how to produce this beam was not much explored. A third case having 1.6×10^{11} protons/bunch was proposed as an upper goal.

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3 THE PS BOOSTER

Major changes in the operating parameters of the PSB are expected to remove the need for much of the feedback now employed in this machine. Present operation with five bunches per ring requires the dynamic suppression of $n > 0$ longitudinal coupled bunch modes. With the change to one bunch per ring with an $h = 1$ rf system, these instabilities cannot arise. Tests in 1993 with a dual ($h=1$ and $h=2$) rf system reached nominal LHC-beam intensity. High-order bunch motion (e.g. $m=3$ and 5) and beam dynamics with the dual system is now under study in a collaboration with Triumph.

At present, errors in steering the four beams leaving the PSB result in ± 2 mm motions in the PS. Improvement of the position detectors in the transfer lines can reduce this to an acceptable ± 0.5 mm (Erk).

4 THE PS

Emittance in the PS is budgeted to grow from 2.5 to 3.0 μradm. Of this 0.5 μradm growth, 0.2 μradm is allotted for injection errors. The present injection kicker should be rebuilt (Schroeder) to inject the 1.4 GeV beam with ripple and slope limited to an rms 0.5%. The total kicker deflection is equivalent to 6 mm in x at $\beta_\perp = 20$ m, making the 0.5% correspond to $\Delta x = 0.6$ mm. Combining this with the 0.5 mm Booster steering error gives an emittance increase of

$$\Delta\varepsilon_n = \beta\gamma \frac{\sum(\Delta x)^2}{\beta_\perp} = \pm 0.07\ \mu\text{radm}. \tag{1}$$

If other fluctuations can also be kept small, perhaps with the aid of automated beam steering techniques, a transverse beam damper will not be needed.

The move to 1.4 GeV at injection and longer bunches will greatly reduce space charge effects and coherent instabilities. At present, vertical motion is stable and the horizontal growth time is about 5000 turns. It is expected that with little modification the present feedback will be adequate to control bunch motions. However the added processes of debunching and rebunching call for separate consideration to see if special controls will be needed.

Kickers for PS extractions or SPS injections cannot rise or fall completely during the 25 ns interval between bunches. The affected bunches should be ejected from the PS before extraction of the desired bunches. It is suggested that a least costly method could apply to those bunches short kicks on successive turns, kicks that are synchronized with the growing betatron motion. The needed strength of these kicks is then determined by the rate of decoherence of the kicked bunches during the process.

5 THE SPS

Steering errors into the SPS are considerable; all elements in the transfer from PS to SPS contribute. For an estimate of what these errors will be, we first assume that the kickers for PS extraction and for SPS injections are to be rebuilt to have variations within $\pm 0.5\%$, including ripple. The errors in terms of σ are listed in Table II; in the SPS, the beam will have $\sigma = 2.45\,\mathrm{mm}$ at $\beta = 60\,\mathrm{m}$. In the vertical direction, Δy is assumed at $< 0.5\,\sigma$. The frequency range of these errors is estimated to be up to 5 MHz.

If undamped, the filamentation of these initial amplitudes would add unacceptable emittance growth. The growth of emittance proceeds at a rate determined by the tune spread ΔQ from nonlinearities in the betatron motion of the offset bunch. Undamped filamentation time T_F/T_{REV} in turns is on the order of $1/\Delta Q$. With damping at rate $1/\tau$, the net added rms amplitude is given (Vos) by

$$\Delta\sigma^2 = \frac{1}{2}(\Delta x)^2\left[1 + \frac{T_F}{\tau}\right]^{-2}. \tag{2}$$

The estimated strength required of dampers to limit the ε-growth from injection errors to 10% of σ^2 is given in Table III. The numbers are for deflection with electric field only. The asterisk in Table III denotes the assumption that the effective horizontal gap can be reduced by 30% from the existing kicker by modifying the plates to a channel shape. We note that because both T_F and Δx depend on injected amplitudes, the required damper strength carries a large uncertainty.

The second need for transverse feedback in the SPS is for suppressing coupled-bunch motions driven by beam impedances $Z_\perp$. The

TABLE II Errors at injection into SPS

Source	Δx [mm]	*SPS* [σ]
PS extraction (2 mrad@$\beta = 2$ m)	0.35	0.14
Transfer line ripples		0.5
SPS injection (4.5 mrad@$\beta = 60$ m)	1.35	0.55
Quadratic sum		0.8

TABLE III Injection damper strength

	ΔQ	τ/T_{REV} [turns]	Initial [μrad]	Kick [keV/c]	Kicker eff.gap [mm]	$(\Delta pc/e)$ [kVm]
Horizontal	0.02	65	1.0	26	100*	2.6*
Vertical	0.05	26	1.6	42	38	1.6

TABLE IV R-wall coupled-bunch feedback

	$Z_\perp$ [MΩ/m]	$\Delta x/\sigma$	Δpc [keV]	Vl [kVm]
Horizontal	120	0.8	72	7.2
Vertical	200	0.5	73	2.8

strongest of these is the resistive-wall at the lowest coupled-bunch frequency, 17 kHz. If we use the same kicker gap as in Table III, the R-wall feedback requirements are those in Table IV.

The similarity in requirements for error damping and for coupled-bunch control suggests that single combined systems would be sensible. For that we add the kicker voltages, provide a factor of 2 over-voltage, and arrive at 20 kVm for horizontal and 10 kVm for vertical kicks. At 5 MHz where injection errors roll off, $Z_\perp$ is reduced a factor 4 making the requirements there 9 kVm horizontal and 5 kVm vertical. Responses with reducing strength are needed to 20 MHz for full coupled-bunch control.

The specifications for such a feedback system are an extension in most parameters of the existing transverse systems. It appears that improved new systems but with not different architecture would be practical (Hoefle). The range of strong response, now rolling off at 1 MHz, must be extended to 5 MHz to cover injection errors. It may be sensible to use more total kicker length. The present source of signals in the COPOS pickup system suffers from contamination by noise and limited dynamic range. New low-level systems are indicated that are free of overload ahead of D/A conversion and have small least-count to avoid heating of the betatron motion by the feedback systems.

It was noted (Melinkov) that if the conflict between peak power needed during fast damping and the quiet, linear operation later in the cycle becomes serious, the feedback may be operated in two modes. A nonlinear (bang–bang) mode may be used during the brief damping stage, then switch to a linear, lower-peak-power mode later. Some reduction in hardware can be made in this way.

The many and diverse rf cavities in the SPS offer many impedances to drive longitudinal coupled-bunch motions. A possible bunch-by-bunch feedback against $m=1$ modes was outlined by Boussard. With three 200 MHz cavities as kickers, each powered by 150 kW, the typical 1.5 MΩ impedances could be countered. Feedback at higher frequency is being considered (Linnecar) to address modes $m=2$ and 3.

6 SUMMARY

Modifications in the injection chain for LHC beam greatly reduce the problems of suppressing emittance growth. Particularly helpful will be the change to harmonic 1 and acceleration to 1.4 GeV in the PSB.

With instability growth rate more controllable, errors introduced in the transfers between accelerators are a principal concern, as these lead to filamentation in phase space if not promptly damped. The study group recommended reductions in these steering errors throughout the chain. To ease required kicker rise and fall rates, the affected beam bunches should be kicked out of the PS.

If injection errors are reduced, instability control in the PS is not substantially increased but study of beam behavior during the change of bunch number should continue. Errors at injection into the SPS, however will call for stronger, possibly combined transverse dampers and feedbacks against resistive-wall impedance. Longitudinal feedback will be needed in the SPS where beam impedances and bunch manipulations are under study.