GAMMA TRANSITION JUMP FOR PS2

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Abstract

The PS2, which is proposed as a replacement for the existing ~50-year old PS accelerator, is presently considered to be a normal conducting synchrotron with an injection kinetic energy of 4 GeV and a maximum energy of 50 GeV. One of the possible lattices (FODO option) foresees crossing of transition energy near 10 GeV. Since the phase-slip-factor η becomes very small near transition energy, many intensity dependent effects can take place in both longitudinal and transverse planes. The aim of the present paper is on the one hand to scale the gamma transition jump, used since 1973 in the PS, to the projected PS2 and on the other hand based on these results the analysis of the implementation and feasibility of a gamma transition jump scheme in a conventional FODO lattice.

TRANSITION CROSSING REQUIREMENTS FOR THE PS2

In the non-adiabatic transition region, the dynamics of a bunch of particles, which has to go through transition, is quite intricate. Collective effects (from space charge and impedances) are discussed starting with the case of the present PS (and its most critical beam called nTOF) before drawing conclusions for the PS2. The relevant machine and beam parameters are listed in Table 1. Note that the nTOF bunch is unstable at transition in the PS if the longitudinal emittance is smaller than a threshold value (~ 2.1 eVs for 7×10^{12} p/b) [1].

Table 1: Machine and beam parameters for PS and PS2. For PS2 a 10MHz or alternatively 40 MHz rf is foreseen.

	PS	PS2						
	nTOF	nTOF 10 MHz	FT 10 MHz	LHC25 10 MHz	LHC50 20 MHz	nTOF 20 MHz	FT 40 MHz	LHC 40 MHz
R [m]	100	214.3						
ρ [m]	70	100						
Bdot [T/s]	2.2	1.5						
V_{rf} [kV]	200	500	500	500	1500	1500	1500	1500
h	8	15	45	45	90	90	180	180
α_p	0.027	0.0076						
ϵ_L [eVs]	2.3	2.5	1.5	1.5	0.7	1.5	0.4	0.6
N_b [10^{10} p/b]	800	1000	320	170	62	160	80	42
ϵ^*_T [μm]	5	6	6	2.5	2.5	6	6	2.5
$<\beta_T>$ [μm]	16[a]	15[a]						
Pipe [cm^2]	3.5×7	3.5×7						
Q_T	6.25	11.25[b]						

[a] R / Q_T.

[b] Assumption: $Q_T \sim \gamma_t = 1 / \sqrt{\alpha_p} = 11.47$.

γ_t jump in the PS

The main purpose of a γ_t jump scheme is to minimize the amount of time spent by the beam "too close" to transition. Without γ_t jump, the transition crossing speed is $d\gamma/dt = 49.9\ s^{-1}$, whereas in the presence of the γ_t jump, the effective speed becomes $d\gamma_{eff}/dt \approx 50\ d\gamma/dt$. The total height of the jump is $\Delta\gamma_{tr} = -1.24$ and the time needed to perform the jump is $\Delta t_{jump} = 500\ \mu s$ [2]. In the following section these values are scaled to the PS2.

Beam Dynamics with Collective Effects

In the presence of collective effects the required amplitude of the jump can be deducted from Fig. 1, where the evolution of the bunch length near transition for the PS nTOF bunch (2 eVs) is depicted, taking into account only the longitudinal space charge (SC). The oscillation of the bunch length after the transition crossing comes from the longitudinal mis-match at transition, which is a consequence of the fact that the longitudinal SC is defocusing below transition and focusing above transition. The idea of the γ_t jump is to rapidly switch from a certain bunch length below transition to the same bunch length above [3]. The minimum (starting at x = 0) jump required is -0.37. However, at transition the longitudinal phase space ellipse is tilted [4]. Thus, to avoid an emittance blow-up, one should start the jump at x = - 2, which in this case leads to a larger jump, i.e. -0.72. Taking into account the longitudinal and transverse impedances (leading to longitudinal and transverse microwave instabilities) [5, 6], the requirement is even more stringent and leads to a $\Delta\gamma_{tr}^{total} = -1.58$. Fig. 1 indicates why an asymmetric jump, proposed already a long time ago [3], obviates the oscillations.

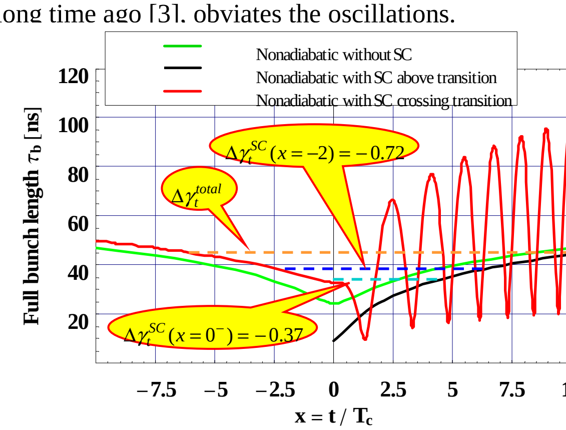

Figure 1: Evolution of the bunch length near transition for the PS nTOF bunch (2 eVs) taking into account only the longitudinal SC. T_c denotes to the nonadiabatic time (numerical values are given in Table 2).

A summary of the required $\Delta\gamma_{tr}$ jump for all the beam parameters considered is shown in Table 2, based on the assumption that the longitudinal and transverse impedances in the PS2 are identical to the ones of the PS (Z_y = 3 MΩ/m in vertical and Z_l/n = 20 Ω in longitudinal, with a resonance frequency near 1 GHz and a quality factor of 1). It can be seen that the most critical beam in the PS2 is the nTOF (10 MHz) where a transition jump of ~ -7 is required which is considered to be impossible. However, if the vertical impedance could be reduced by a factor ~ 6, the required jump is reduced to the SC limit, i.e. -1.50, which is considered to be feasible.

Table 2: Summary of the required $\Delta\gamma_{tr}$ jump for all the beam parameters considered.

	PS	PS2						
	nTOF	nTOF 10 MHz	FT 10 MHz	LHC25 10 MHz	LHC50 20 MHz	nTOF 20 MHz	FT 40 MHz	LHC 40 MHz
T_c [ms]	1.86	4.29	2.97	2.97	1.59	1.59	1.27	1.27
SC imp. [Ω]	19.9	5.36	5.36	6.62	6.62	5.36	5.36	6.62
$\Delta\gamma_t^{SC}$(x =-2)	-0.65	**-1.50**	-0.88	-0.77	-0.43	-0.39	-0.50	-0.33
$\Delta\gamma_t^{total}$	-1.35	**-6.85**	-2.91	-2.44	-1.41	-1.36	-2.68	-0.95

JUMP SCHEME REQUIREMENTS

As seen from table 2 a jump height $\Delta\gamma_{tr}$ of 1.5 within a time Δt_{tr} of 500 µs is required if the vertical impedance is reduced by a factor ~6 for the PS2. Fig. 2 shows a schematic jump:

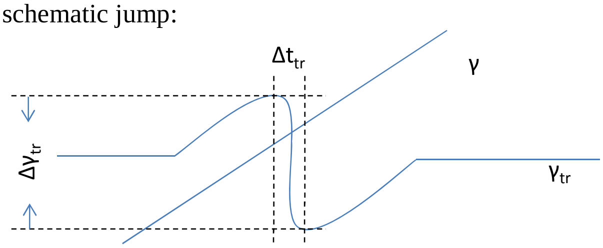

Figure 2: Transition jump schematically.

Since PS2 is foreseen for the LHC upgrade as a high intensity machine, distortion of the optics functions which leads subsequently to enlarged beam apertures has to be minimised.

FIRST ORDER JUMP SCHEME

Dispersion-free long straight sections and a horizontal phase advance of ~90˚ per cell facilitate the implementation of a first order jump scheme, i.e. the lens strength contributes linearly to the change of gamma transition. This was derived by Risselada and gives in first order [7]:

$$\Delta\gamma_{tr} = \gamma_{tr}^3/(2C)\cdot\sum_i K_i \cdot D_i^2$$

Fig. 3 shows a jump scheme with 20 lenses per arc to perform the jump and 8 lenses in the long straight section to compensate the tune shift.

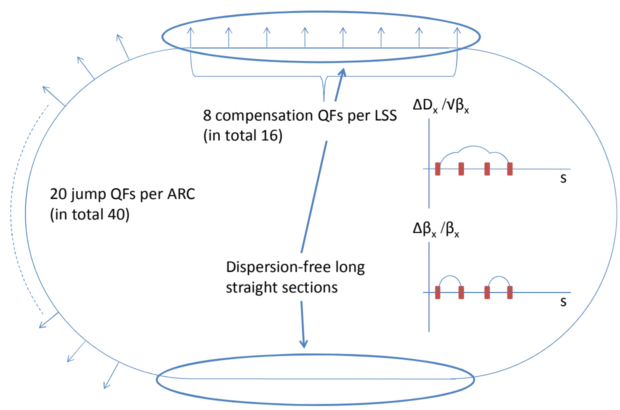

Figure 3: 1st order jump scheme.

Each jump quadrupole launches a betatron perturbation wave which is compensated by the succeeding quadrupole, separated by 90˚ in phase. Since the phase of the betatron perturbation wave propagates twice as fast as that of the dispersion, a dispersion bump is created (Fig. 3) and γ_{tr} is changed.

The maximum strength of the jump elements amounts to 0.01 m^{-2} for the normalised gradient. Assuming thin laminated magnets with a length of 25 cm, this corresponds to a pole tip field of 0.13 T. In total 56 magnets are necessary.

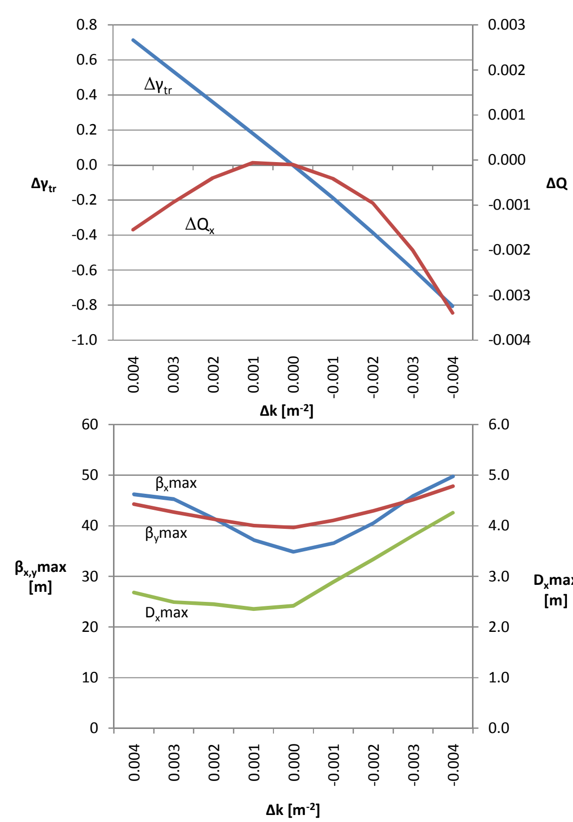

Figure 4: 1st order scheme: The upper plot shows the change in γ_{tr} and the tune shift, the lower plot the optics behaviour as a function of the lens strength.

SECOND ORDER JUMP SCHEME

A second order jump scheme on the basis of the CERN PS scheme has also been considered. In this case the lens strength k_i contributes quadratically to the change of gamma transition. Hence, two separate lens arrays are used to obtain a jump for both, positive and negative values in $\Delta\gamma_{tr}$.

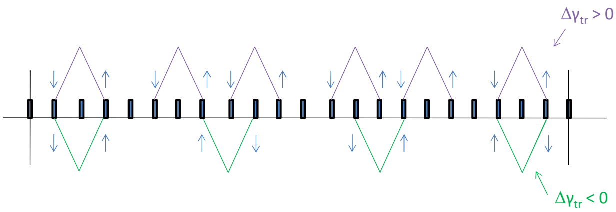

Figure 5: 2nd order jump scheme

Fig. 5 shows all the focusing quadrupoles of the arc. All doublet lenses are oppositely excited in order to fulfil the zero tune-shift condition. The doublet array indicated in purple achieves a positive $\Delta\gamma_{tr}$ whereas the green one with alternating excitation of the doublets gives a negative jump. Calculations of Schönauer [8] result in

$$\Delta\gamma_{tr} = -0.065 \cdot \psi^2 \cdot 2M \cdot \cot(\theta)$$

for the positive and in

$$\Delta\gamma_{tr} = -0.065 \cdot \psi^2 \cdot [2(M-1) \cdot \tan(\theta)]$$

for the negative jump where ψ denotes to $\beta_{0i} \cdot \int k_i dl$, M gives the number of doublet arrays and θ equals $\pi Q/M$.
Fig. 6 shows the change in gamma transition, the tune-shift and the effect on the optics for a given lens-strength.

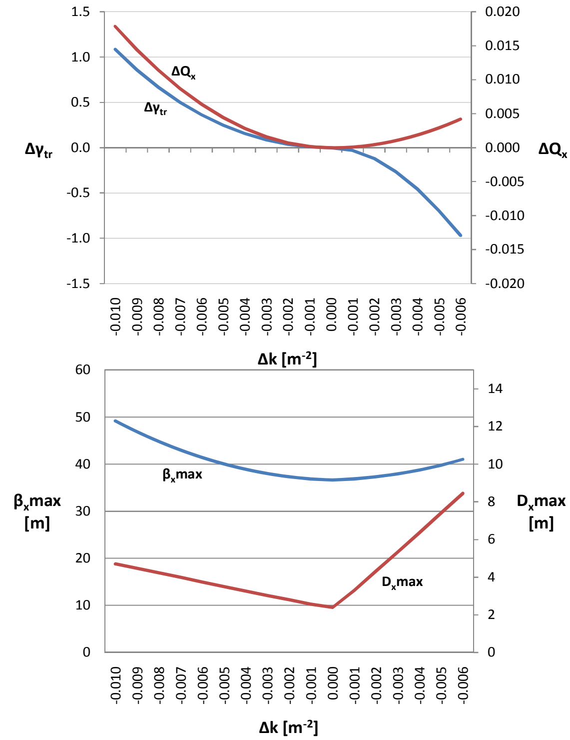

Figure 6: 2nd order jump scheme: $\Delta\gamma_{tr}$ and ΔQ in the upper plot, the optics behaviour in the lower one as a function of the lens strength.

CONCLUSION

Transition crossing with a γ_{tr} jump looks possible in the PS2 for the densities foreseen with the high-intensity fixed-target and LHC beams. It its more difficult for the present nTOF bunch (10 MHz option) where a strong reduction of the Broad-Band (BB) impedance (which might be challenging) is necessary to keep the required γ_{tr} jump below ~ -2. Further improvement of the longitudinal density beyond that of nTOF seems excluded. Concerning the time required to perform the jump in the PS2, both, the vertical microwave (BB) instability rise-times and the longitudinal negative-mass (SC) instability rise-times are larger in the PS2 compared to the present PS. This means that the time Δt_{jump} needed to perform the γ_{tr} jump of the present PS (i.e. ~ 500 μs) should be sufficient for the PS2.

Since the betatron function is only locally perturbed in the 1st order jump scheme, the effect on the betatron and dispersion functions is smaller than for the 2nd order scheme and thus the 1st order scheme is preferred. With a limit of 60 m for the betatron functions and 4 m for the dispersion function, compared to $\beta_x$max = 40 m and $D_x$max = 2.5 m for the unperturbed lattice, a γ_{tr} jump of 1.5 can be performed with a tune-shift below a few 10^{-3}. Larger jumps up to ~3 are possible with increased distortion of the optics.

REFERENCES

[1] S. Hancock and E. Métral, “Ghost Bunches and Blow-Up Losses with High-Intensity Beams”, PS/RF Note 2002-198, 2002.

[2] M.Martini, PS Report, http://ab-div.web.cern.ch/ab-div/Meetings/APC/2005/apc051208/M_Martini_slides.pdf, CERN, Geneva, Switzerland, 2005.

[3] D. Mohl, “Compensation of Space-Charge Effects at Transition by an Asymmetric Q-jump: A theoretical Study”, CERN-ISR/300/GS/69-62, 1969.

[4] K.Y. Ng, “Physics of Intensity Dependent Beam Instabilities”, World Scientific, 2006.

[5] J.L. Laclare, “Introduction to Coherent Instabilities-Coasting Beam Case”, CERN Accelerator School, Paris, CERN 85-19, p. 377, 1985.

[6] E. Metral, Overview of Single-Beam Coherent Instabilities in Circular Accelerators, 1st CARE-HHH-APD Workshop on Beam Dynamics in Future Hadron Colliders and Rapidly Cycling High-Intensity Synchrotrons, CERN, Geneva, Switzerland, 8 - 11 Nov 2004, pp.227-247.

[7] T. Risselada, “Gamma Transition Jump Schemes”, CERN PS/90-51,

[8] H. Schönauer, “Lens Configurations for the CPS to provide a large and fast γ_{tr}-Jump without Q-Change”, CERN/MPS/DL 72-7, 1972.

[9] M. Harrison, S. Peggs, T. Roser, “The RHIC Accelerator”, Annu. Rev. Nucl. Part. Sci. 2002. 52:425–69