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OPTICS CONSIDERATIONS FOR THE PS2

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CERN, Geneva, Switzerland

Abstract

CERN envisages replacing the existing Proton Synchrotron (PS) with a larger synchrotron (PS2) capable of injecting at higher energy into the SPS. Since it should increase the performance not only of the LHC but also CNGS and other users of beams from CERN's hadron injector complex, the new accelerator must retain much of the flexibility of the present complex. A number of candidate optics, with and without transition crossing, have been evaluated systematically and compared.

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CERN envisages replacing the existing Proton Synchrotron (PS) with a larger synchrotron (PS2) capable of injecting at higher energy into the SPS. Since it should increase the performance not only of the LHC but also CNGS and other users of beams from CERN's hadron injector complex, the new accelerator must retain much of the flexibility of the present complex. A number of candidate optics, with and without transition crossing, have been evaluated systematically and compared.

INTRODUCTION

Motivation

The study group on Proton Accelerators for the Future (PAF) was set up to identify scenarios for an upgrade of the CERN accelerator complex to:

- Ensure reliable operation of the LHC including production of the ultimate LHC beam.
- Improve the complex performance in terms of beam brightness and intensity to prepare for an LHC luminosity upgrade and future physics experiments.

The PAF study group [1] proposes to replace the ageing CERN PS machine by a new accelerator (PS2) with an extraction energy (kinetic) of up to 50 GeV [2]. For the PS2 injector, two options were proposed initially: a Superconducting Proton Linac (SPL) or a combination of a linac and a rapid cycling synchrotron, both injecting at around 4 GeV [3]. The present studies concentrate on the SPL injector option, which maximises the potential for upgrades for future high power proton experiments, but may not be ideal for high performance ion beams.

Requirements

The existing PS was constructed in the 1950's and has shown some weaknesses during recent years [4]. The new PS2 must have a similar versatility to provide many different proton and ion beams for downstream accelerators or directly for experiments. Consequently, several injection and extraction systems must be implemented, including H^- charge exchange and fast ion injection, conventional fast extraction for LHC, multi-turn extraction for SPS fixed target and slow extraction for PS2 physics. The PS2 also has to be integrated into the existing complex as part of a staged upgrade scheme.

A tentative layout of the PS2, integrated into the CERN accelerator complex, is shown in Fig. 1. Several reasons led to the choice of a racetrack footprint and the layout:

- The PS2 proton injector is assumed to be the SPL, which will be the prolongation of Linac4. This latter will be constructed close to the PS complex to provide 160 MeV H^- for the PS Booster.
- The racetrack has only two long straight sections and reduces the number of dispersion suppressors. This increases the filling factor and energy reach.
- All injection and extraction systems can be installed in one long straight section [5].
- To avoid H^- beam losses due to Lorenz stripping the bending radius of the PS2 injection transfer line must be large and unnecessary bending must be avoided.
- Installation of the PS2 close to the SPS minimises the length of the high-energy transfer line.

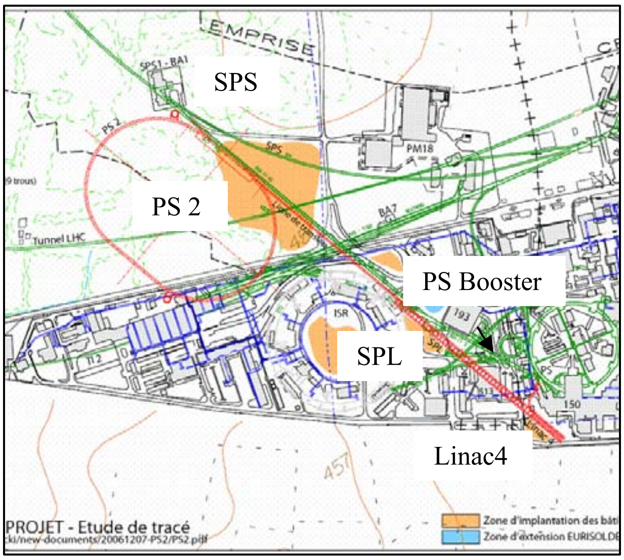

Figure 1: Proposed integration of the PS2 into the CERN accelerator complex.

DESIGN CONSIDERATIONS

To obtain an extraction energy of ~50 GeV with conventional magnets, the PS2 circumference C_{PS2} has to be at least doubled with respect to that of the PS. For optimum filling of the SPS for fixed target experiments, considering a 5-turn multi-turn extraction, C_{PS2} should be around one fifth of the one of the SPS, C_{SPS}, i.e. a bit longer than twice the one of the PS.

Following a detailed analysis of bunch patterns needed and assuming that all bunch spacings should correspond to an integer harmonic, the circumference was fixed to $C_{PS2} = (15/77)\cdot C_{SPS}$ [6].

The PS2 should provide the following beams:

- A beam for an upgraded LHC, with twice the intensity of the ultimate LHC beam, i.e. $4.0\ 10^{11}$ protons per bunch (with 20% safety factor) within transverse normalised rms emittances of 3.0 µm.
- High intensity beams for PS2 and SPS physics with intensities of up to $1.5\ 10^{14}$ protons per pulse.

The beam for an upgraded LHC is more challenging in terms of direct space charge tune shift. Taking into account only average betatron functions, the tune shift depends on local average beam current, bunching factor and transverse emittances. An injection energy of 4 GeV is needed to limit the direct space charge tune shift to $\Delta Q_{S.C.} = 0.2$. The high intensity beam for fixed target operation fixes the required machine acceptances.

Longitudinal Aspects

The increase of both injection and ejection energies tends to slow down motion in longitudinal phase space and to increase longitudinal acceptances [7]. The implications for operation of the PS2 depend on the choice of the RF systems and two options are being discussed:

- A low-frequency RF system with a large tuning range (factor 3-4), allowing various gymnastics (double and triple splittings, batch compression, etc.) similar to those routinely performed in the PS machine.
- A 40 MHz RF system with a small tuning range (few percent) just sufficient for acceleration. In this case the bunch pattern is fixed at injection by 40 MHz chopping of the SPL beam. This option is not compatible with the present heavy ion acceleration scheme because of the limited RF tuning range.

With a 40 MHz system the RF gymnastics are limited to blow-up and bunch length adjustments and will not present any cycle time limitations. With a low-frequency large-bandwidth RF system the increase in time needed for RF gymnastics, especially at high energy, is an issue. The choice of the momentum compaction factor $1/\gamma_{tr}^2$ strongly influences the longitudinal dynamics as shown in Fig. 2. The momentum compaction factor obtained with a plain FODO lattice and the expected working point is a reasonable compromise but implies crossing transition during acceleration with all associated problems.

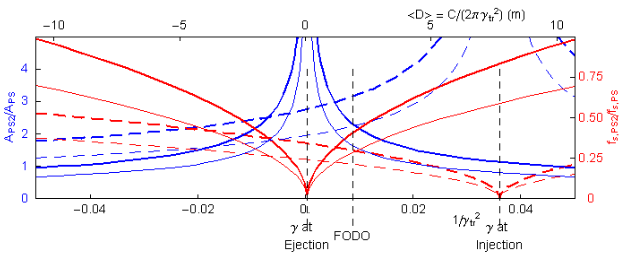

Figure 2: PS2 longitudinal dynamics extrapolated from the PS. Solid and dashed lines are for ejection and injection, respectively. Blue and red lines give the PS2 acceptances and synchrotron frequencies in terms of PS values. Thin and thick lines are for identical and twice higher RF voltages as presently available in the PS.

Lattices with small imaginary transition energy (large negative momentum compaction and thus difficult for the lattice design) would also provide a good compromise for the RF and, in addition avoid the problems of transition crossing. Large imaginary transition energies (small negative momentum compaction) are acceptable only for the 40 MHz RF system option.

LATTICE CONSIDERATIONS

Doublet and Triplet Lattices

Lattices based on focusing with doublets and triplets have been investigated, because they allow for longer drift sections without quadrupoles for insertions such as injection and extraction. The triplet offers the additional feature of significantly reduced betatron functions in the long drift, which is an advantage for dipole apertures.

For the time being, no further investigations on these lattice types are being carried out, since stronger focusing is needed due to the small distance between adjacent quadrupoles. The longer quadrupoles reduce the bending magnet filling factor and leave insufficient space for the injection and extraction systems.

Plain FODO Lattice

A plain FODO lattice with only two quadrupole families is the simplest approach. A candidate lattice is depicted in Fig. 3, based on a 90º phase advance cell to allow simple design of the transfer channels. The dispersion in the straight section is suppressed by a missing magnet scheme. The numerous transfer channels can be located within the 7 cells of one of the long section sections as indicated in Fig. 4.

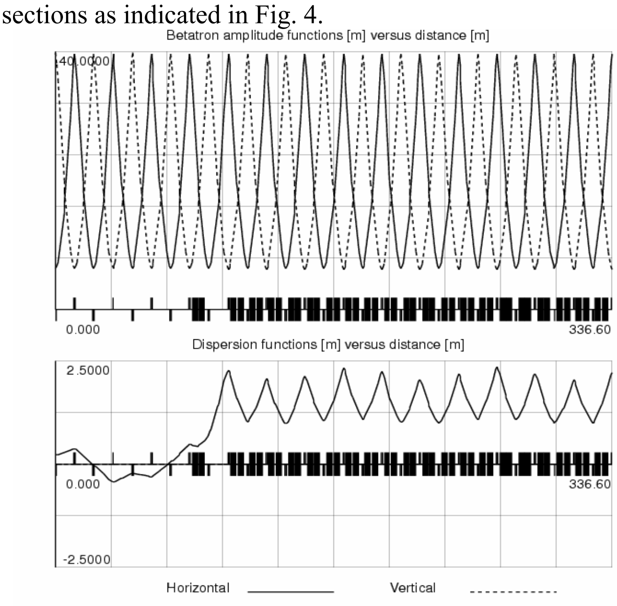

Figure 3: Lattice functions for the PS2 FODO lattice. One quarter of the machine is shown from centre arc to centre long straight section.

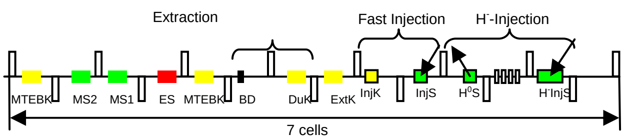

Figure 4: Layout of all injection and extraction channels in one long straight section.

NMC Modules

Negative Momentum Compaction (NMC) modules similar to existing ones (e.g J-PARC [8]) have been investigated. The first module starts from an almost regular FODO focusing structure shown in the upper image of Fig. 5, with one special cell without bends surrounded by two filled cells. The phase advance per cell is matched to the desired value (90º in the example - bringing the dispersion at the beginning and end of the module to zero). The drifts in the central cell are then reduced and the quadrupole strengths of the centre are rematched to the desired average phase advance per cell to obtain the lattice in the lower plot.

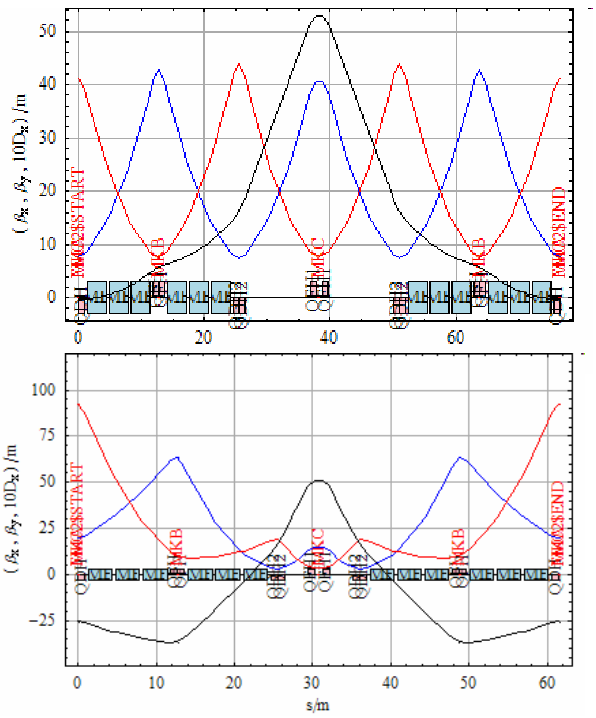

Figure 5: NMC module starting from regular FODO cells (top) and reducing central drifts.

Another NMC module is shown in Fig. 6. To improve the bending filling factor and lower the phase advance per cell, every module consists of four FODO cells and only the central shorter cell contains no bends. The functioning of the module is depicted in the upper plot showing the trace of the normalized dispersion vector during the passage of one module. The effect of the cells filled with bends is indicated by a single kick (the correct evolution of the dispersion vector is plotted as dashed line). The radius of the induced dispersion beating can be adjusted with the overall phase advance inside the module. Large radii and thus negative contributions to the momentum compaction can be obtained with a phase advance slightly smaller than 360º.

Matching sections connecting the NMC modules to straight sections with zero dispersion have not yet been designed. In order to obtain a small imaginary γ_{tr}, strong dispersion oscillations have to be provoked, which, in turn, render the design of matching modules more difficult and rule out the implementation of achromats, implying a further increase of dispersion beating.

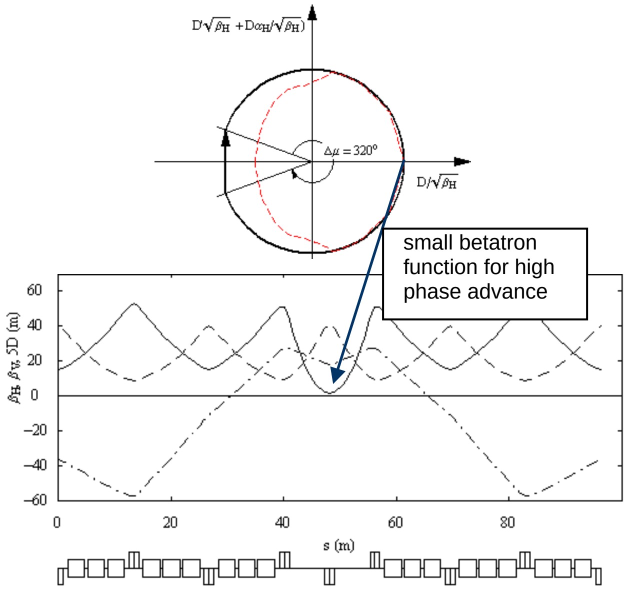

Figure 6: NMC module with increased filling factor.

SUMMARY AND CONCLUSIONS

Optics considerations to define a suitable lattice for the proposed PS2 machine are underway. The plain FODO lattice is a good candidate. Alternative negative momentum compaction lattices have been investigated. The challenges - which are yet to be solved - are to obtain a sufficiently low momentum compaction with a good bending filling factor and to match to straight sections with zero dispersion.

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