THE CERN PROTON SYNCHROTRON BOOSTER

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Summary

The main features of this 800 MeV injector are described. The design philosophy is discussed.

Introduction

The CERN Proton Synchrotron Booster (PSB), under construction since January 1968, is to provide 10^{13} protons per pulse for transfer into the CERN Proton Synchrotron (CPS). The transferred intensity should not exceed the CPS space charge limit, and beam emittance and energy spread must be suitable for high energy physics experiments with both external targets and the CERN Intersecting Storage Rings (ISR).

After studying a number of possible solutions[1] a four-ring slow-cycling 800 MeV synchrotron was finally chosen for the following reasons[2,3]:

Four rings (i) fit the numerology resulting from the CPS RF harmonic number (20) and the ISR beam stacking requirements[4], (ii) should ensure a sufficiently high phase space density[2], (iii) lead to a design intensity per ring only moderately higher than current values, and (iv) make for an acceptable hardware filling factor.

Slow-cycling, besides saving CPS cycle time, permits one to stack conveniently the PSB beam in CPS phase space in various ways, as illustrated below.

800 MeV final energy puts one sufficiently above the CPS space charge limit for most stacking cases studied[4].

Main features[2,3]

The four rings of 25 m radius are superposed vertically (Fig. 1). The beam from the existing 50 MeV linac is distributed by an electrostatic deflector[5] to the three additional levels[6] and injected into the PSB in either single-turn or multi-turn mode. The four beams are then accelerated simultaneously to 800 MeV, ejected, recombined, and transferred to the CPS.

The separate function magnet system[7] consists of 32 four-gap C-type window-frame bending magnet units (Fig. 2) and 48 quadrupoles lens units arranged in triplets. Bending magnets and lenses will be powered in series from a rectifier set[8] connected directly to the alternating current power line[9]. The single fourfold RF accelerating unit[10] consists of two ferrite-loaded air-cooled quarter-wavelength push-pull coaxial resonators per ring. Tuning is accomplished by means of two biasing loops around the ferrite rings. The four metal-seal vacuum systems are interconnected via 32 manifolds each fitted with a 500 l/s sputter ion pump[11]. A control computer will be used for data acquisition and controls. The equipment rooms and the auxiliary circular tunnel have been designed for permanent access[2].

For the standard twenty-bunch single-turn filling of the CPS the five bunches of each of the four rings are ejected sequentially by means of kicker magnets with 50 ns rise time[12], and brought to the CPS beam level by the magnet system[13,14] shown in Fig. 3. At a later stage bunches from two rings may be ejected simultaneously, combined vertically in the transfer line and injected into the CPS as shown in Fig. 4. Two-turn injection of these bunches into the ISR is expected to lead to higher interaction rates and to reduce the uncertainty of the collision energy[4].

Design philosophy

The emphasis has been on reasonable risk and high reliability bearing in mind cost efficiency and available resources.

With the sixteen focusing periods chosen there is no systematic resonance in the range Q = 4 to 5. The auxiliary quadrupole supplies provide a corresponding tuning range at injection and less at 800 MeV.

The PSB design beam emittances have been scaled from the CPS values for a tenfold increase of the 50 MeV space charge limit[2]. Some extra aperture has been added, to allow for possible transverse beam blow-up due to various space charge effects[15]. Multipole lenses are planned for Landau damping and straight section space is reserved for other damping devices.

About 20 °/o of the design RF voltage serve to offset the RF bucket reduction due to longitudinal space charge forces[16].

High voltages, current densities, as well as fabrication, stability and alignment tolerances, though occasionally demanding, have generally been kept at conservative values.

In particular, the magnet lattice chosen leads to ejection kicker voltages of 30 kV and ejection magnet deflection angles of about 50 mrad (0.25 Tm at 800 MeV), which is only 25 times the maximum beam divergence angle.

The resulting parameters are listed in the following Table.

LIST OF PSB PARAMETERS[2,3]

Main parameters		
Design kinetic energy	injection	50 MeV
	transfer	800 MeV
Total design intensity		10^{13} p.p.p.
Number of superposed rings		4
Average radius	R	25 m
Magnetic bending radius	ρ	8.3 m
Average energy gain per turn		1 keV
Design vacuum pressure		6 10^{-8} Torr
Minimum repetition time		1.2 s
Rise time		0.6 s
Orbit parameters		
Lattice: separate function, triplet focusing		F O F D D
Number of lattice cells		16
Tuning range of betatron wave numbers		4 to 5
Phase advance ($Q_H = 4.55, Q_V = 4.7$)		~ 104°
Amplitude function	$\beta_{H_{min,max}}$	3.6, 7.3 m
	$\beta_{V_{min,max}}$	3.4,17.8 m

Momentum compaction function	$R\alpha_p$	1.06, 1.46 m
Transition energy/rest energy	γ_{tr}	4.4
Beam emittance at injection	E_H	130π 10^{-6} radm
	E_V	40π 10^{-6} radm
Magnet system		
32 bending magnets of magnetic length		1.62 m
"Gap" dimensions		70 high x 182mm wide
Magnetic field		0.13 to 0.6 T
32 lenses of magnetic length		0.52 m
16 lenses of magnetic length		0.92 m
Bore radius		60 mm
Focal constant	K	0.7 to 0.8 m^{-2}
Maximum gradient		4 Tm^{-2}
Radio frequency accelerating system		
Harmonic number		5
Number of cavities per ring		1
Frequency		3 to 8 MHz
Peak voltage per turn		12 kV
Synchronous phase angle		4.8°

Status and conclusions

Most of the PSB design is frozen. A prototype bending magnet unit and a quadrupole unit are on order, a RF cavity prototype and a power amplifier are being developed, the connecting tunnels with the CPS have been constructed and the ring tunnel is being built. Commissioning is scheduled for 1972.

Besides its direct value for the CPS users as a high-intensity high-quality proton source, the PSB shows some generally interesting features, in particular vertical stacking of rings, beam splitting and recombination, and pulsing from the electric power grid.

Acknowledgements

Initiated by P. Germain, the design study for the PSB was under the direct responsability of the MPS Division, headed by P.H. Standley. The newly created SI Division under G. Brianti is responsible for its construction. Many people in ISR, MPS and SB Divisions and in HP contributed to the design, in particular W. Hardt and H.G. Hereward.

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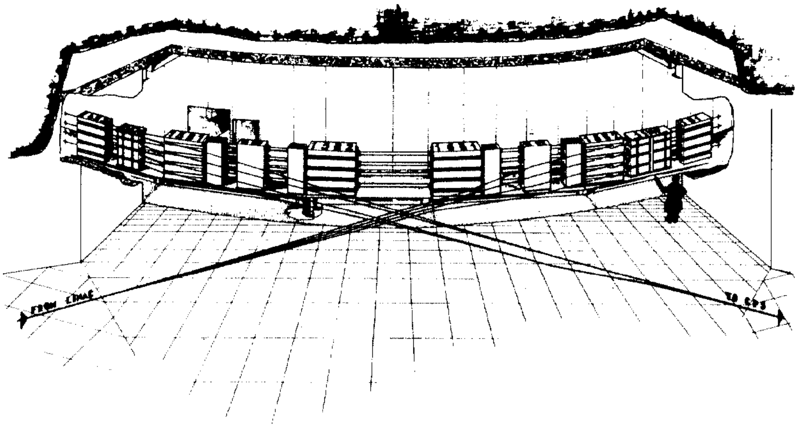

Fig. 1 : Artist's impression of the CERN Booster Synchrotron (PSB)

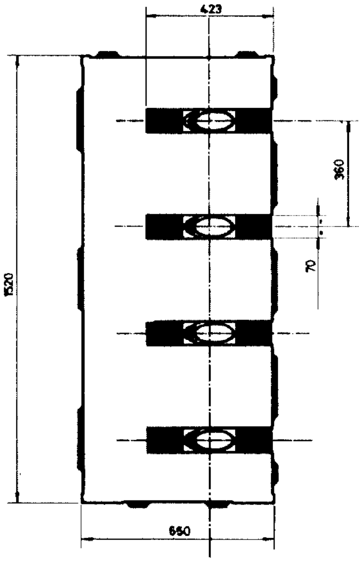

Fig. 2 : Bending magnet
(all dimensions are in mm)

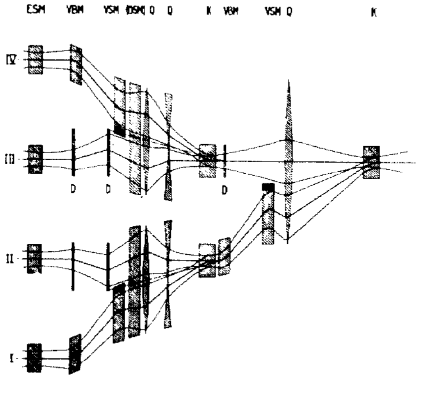

Fig. 3 :

Optics of the recombination part of the transfer line between PSB and CPS, operating in the "20 bunch" mode.

ESM : ejection septum magnets (~ 46 mrad)
VBM : vertical bending magnets (~ 80 mrad)
VSM : vertical septum magnets (~ 80 mrad)
DSM : double septum magnet (~ 5 mrad) (for vertical bunch combination)
K : kicker magnets (~ 7 mrad)
Q : quadrupoles
D : vertical dipoles (up to 6 mrad)

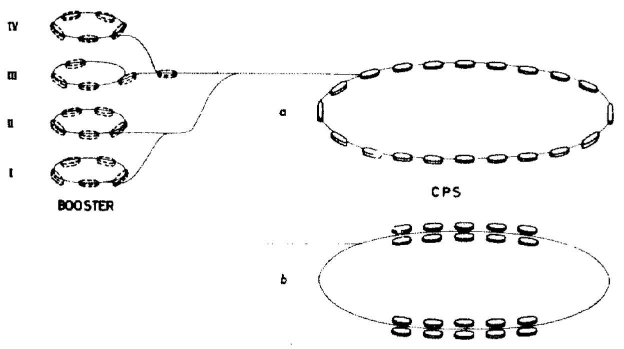

Fig. 4 :

A schematic representation of how the five bunches of protons circulating in each of the four rings (I to IV) in the Booster can be transferred to the CPS.
In the 20 bunch mode (a), they are put one after another to give the usual twenty bunches orbiting the CPS.
In (b), which is a possible future development, 2 x 5 bunches are put in opposite positions in the CPS which has particular advantages to achieve higher interaction rates when the protons are later fed into the intersecting storage rings (ISR).