THE DESIGN OF THE NEW FAST EXTRACTION CHANNEL FOR LHC

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Abstract

The Large Hadron Collider (LHC) project requires the modification of the existing extraction channel in the long straight section 6 of the CERN Super Proton Synchrotron (SPS). The new extraction will be used to transfer protons at 450 GeV/c as well as ions via the 2.8 km long transfer line TI 2 to the clockwise ring of the LHC. As the resonant extraction to the present SPS West Area will be stopped after 2004, the electrostatic septa will be replaced by new fast extraction kicker magnets. The girder for the existing DC septa will be modified to accommodate a new septum protection element. Other modifications concern the replacement of a machine quadrupole, a new scheme for the extraction bumpers, new instrumentation and interlocks. The requirements and the design of the new extraction channel will be described as well as the modifications which will mainly be carried out in the long SPS shutdown 2005.

INTRODUCTION

At present the long straight section LSS6 of the Super Proton Synchrotron (SPS) at CERN, is used for the resonant extraction towards experiments in the West Area. After the closure of this area at the end of 2004, the straight section will be used to transfer protons at 450 GeV/c as well as ions via the 2.8 km long transfer line TI 2 to the clockwise ring of the LHC.

FAST EXTRACTION REQUIREMENTS

The fast extraction channel in SPS LSS6 will be used only for small emittance LHC beams. The relevant nominal beam parameters are summarised in Table 1. The value in parenthesis refers to the ultimate beam parameters.

Table 1: Main parameters of LHC beam in the SPS.

Protons per spill (10^{13})	3.2 (4.9)	
Spill length	7.8	µs
Emittance (1σ norm.)	3.5	µm
Injection energy	26	GeV/c
Extraction energy	450	GeV/c

The design has to satisfy the following conditions.

- Large enough vertical and horizontal aperture for injected, bumped circulating and extracted beams. the large emittance (14 µm emittance) CNGS beam must be accommodated at 14 GeV injection energy.
- The various field errors and supply ripples should be low enough for acceptance by the LHC [1].
- The extraction system should be adequately protected against mis-steered beams.

CONCEPT

After the run in 2004, when the shutdown starts, the electrostatic septa will be replaced by fast extraction kicker magnets. The girder for the existing DC septa will be modified to accommodate a new septum protection element called TPSG6. The extraction region is shown in Fig. 1. The magnetic lattice in LSS6 will remain unchanged with respect to the present SPS optical design. Other modifications concern the replacement of an enlarged machine quadrupole by a standard one, a new scheme for the extraction bumpers, new beam instrumentation and the necessary interlocks.

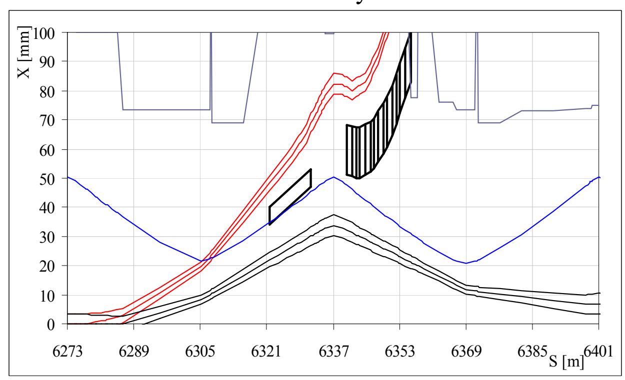

Figure 1: Extraction region in LSS6, showing injected 5σ CNGS beam envelope (blue), bumped 4σ LHC beam (black) and extracted 4σ LHC beam (red).

SYSTEMS AND PERFORMANCE

Extraction bumpers

Four horizontal bumper magnets, located at quadrupoles 414, 416, 420 and 422, allow the circulating beam to be bumped by the required 40 mm at the extraction septum next to quadrupole 418, with ample margin for additional orbit correction at 450 GeV/c.

Four vertical 'bumper' (strong corrector) magnets are located at the positions 413, 415, 421 and 423, to allow a ±10 mm vertical orbit correction at the extraction septum.

Extraction kicker system MKE

For LHC and particularly CNGS the existing MKE kickers are upgraded and/or renewed; to obtain the required deflection, four MKE magnets (two MKE-L enlarged aperture and two MKE-S small aperture) will be installed (see table 2). For extraction towards LHC there is only one extraction per SPS cycle. Since only one third of the ring is filled, there is no severe restriction on the kicker rise time (⅔ of the particle revolution time, approximately 14 µs). The flat top length must be at least 7.9 µs. Since after extraction the ring is empty, no hard limit is set on the fall time of the kicker.

Table 2: SPS LSS6 MKE kicker parameters.

Total system deflection at 450 GeV/c	0.4126	mrad
Number of MKE L magnets	2	
Number of MKE S magnets	2	
Magnetic length	1674	mm
Operating voltage of the PFN	50.2	kV
Induction field MKE-L	89	mT
Induction field MKE-S	97	mT
Flat top length duration	>7.9	µs
Flat top ripple	<1%	

System overview and general layout

The kicker system is a characteristically terminated travelling wave system, powered by a resonant charging circuit consisting of a 2 kV 50 Hz a.c. power supply that charges a capacitor bank, which feeds via a (safety) thyristor a 60 kV step-up transformer. The resonant charging circuit is connected to a Pulse Forming Network (PFN) via a capacitor, diode and resistor auxiliary circuit permitting switch-off and over-voltage limitation. Extraction is triggered by a pre-pulse to the resonant charging supply, charging the PFN to the required voltage, after which the "main" thyratron switch is triggered, discharging the PFN into the four magnets in series and into the Terminating Magnet Resistor (TMR). Fig. 2 shows schematically the MKE installation in and around LSS6.

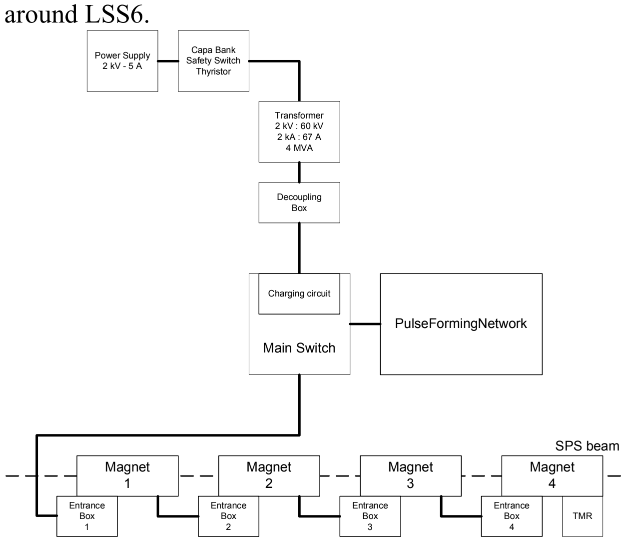

Figure 2: MKE LSS6 installation scheme.

Fig. 3 shows a cross section of an MKE extraction kicker magnet. Two capacitive pick-ups per magnet are installed enabling measurement of the magnetic field also when installed in the SPS machine [2]. These diagnostics give a detailed picture of the field rise, fall and (flat top) pulse lengths including the magnet filling time, as well as the overshoot.

The extraction kicker system will be equipped with PT100 temperature probes to provide an interlock for the loss of ferrite permeability above the Curie temperature, i.e. loss of magnetic field.

In point LSS4 of the SPS, which injects in the counter clock wise ring of the LHC, a cooling solution as already been implemented and tested on the two MKE-S and on the newly built three MKE-L magnets for the extraction kicker system, and it has been commissioned in 2003. The same cooling system is foreseen for the MKE magnets in point LSS6 of the SPS [3].

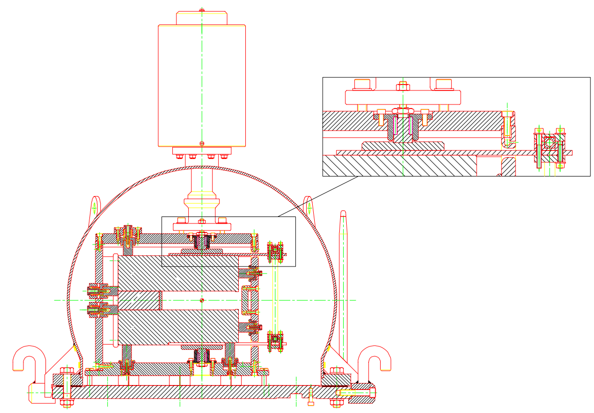

Figure 3: MKE magnet cross section, showing the C shaped ferrite core, the vacuum tank and on top the alignment device. The enlarged detail shows aluminium nitride heat transport plates.

Extraction septum magnets MST and MSE

The main parameters for the MST and MSE septa to be used are summed up in table 3 [4]. Seven septa from existing resonant extraction will be re-used, two thin MST type septa followed by 5 thick MSE type septa. These septa will provide a total deflection of 10.2 mrad. The two MST septa and the septum protection element TPSG6 will be installed together on a rigid girder which can be remotely displaced, to ease alignment of the elements. The existing MST septum girder will be modified to suit this application. A second, existing, rigid girder will carry the five MSE septa to allow their remote positioning.

Septum protection element TPSG6

Upstream of the MST septa a 'dummy' septum TPSG6 will be positioned that will, in case of a faulty extraction, protect the septa coils against beam impact. This element is made of passive absorbing materials which will easily withstand a beam sweep across this absorber and will limit the temperature rise downstream of the absorber in the copper MST coil and, more importantly, in the water (used for cooling the MST coils). Since, after construction, the hydraulic circuit of the MST coil is tested statically with 50 bars, this value is taken as the maximum allowable pressure. In case of a beam impact on the absorber, the water temperature rise in the cooling circuit of the MST septum should not exceed 8 K, as not to exceed the maximum pressure the coil can withstand.

Given the limited length of 3500 mm available for the absorbing elements of the TPSG6, this limit may be hard to meet. Although the choice of absorbing materials has not been finalised at the time of writing, the present design uses graphite to dilute, followed by titanium and Inconel to absorb the energy [5]. To keep the absorber relatively easy to handle, it will be constructed as a set of 2 consecutive absorbing blades, each within its own vacuum envelope. The total longitudinal length between flanges of this assembly will be limited to 4000 mm. The absorbing elements will be edge cooled with a copper tube connected to the demineralised water circuit available on the MST girder. This cooling circuit will limit the temperature rise of the absorbing elements due to beam losses during normal operation, as well as remove the energy deposited in the absorbing elements after a beam sweep or impact.

Table 3: Individual septum magnet parameters.

	MST	MSE	
Septum thickness	4.2	17.25	mm
Gap height	20	20	mm
Maximum field	0.471	1.508	T
Magnetic length	2237	2237	mm
Deflection required	0.535	1.827	mrad
B.dl max.	1.058	3.373	T.m
Current at 450 GeV/c	5.7	19.5	kA
Magnet resistance	1.07	0.34	mΩ
Magnet inductance	13	12	μH
Minimum rise/fall time	200	200	ms
Magnet spacing (centre)	3234	3234	mm

Beam acceptance

The aperture for the injected CNGS beam is about 5 σ_x. For the bumped LHC beam at 450 GeV/c, the minimum aperture at the TPSG6 (position 6322, see Fig. 4) is 20 σ_x, and for the extracted beam the aperture is 14 σ_x . The orbit and mechanical tolerances will reduce these figures by about 4σ_x.

Effects of stray field

The stray field from the MST and MSE septum is not expected to degrade the circulating beam, since the stray field level is lower than for LSS4, where simulation showed no noticeable effect on the beam emittance [6], and extraction tests conducted in 2003 haven confirmed this.

Stability and field errors

The stability of the extraction has been treated in detail in [7]. With the specified tolerances, the random contribution (rms variation) from the SPS orbit and the LSS6 extraction system is expected to be ±0.16 σ_x and ±0.113 σ_y, with a further ±0.224 σ_x systematic variation due to the kicker waveform.

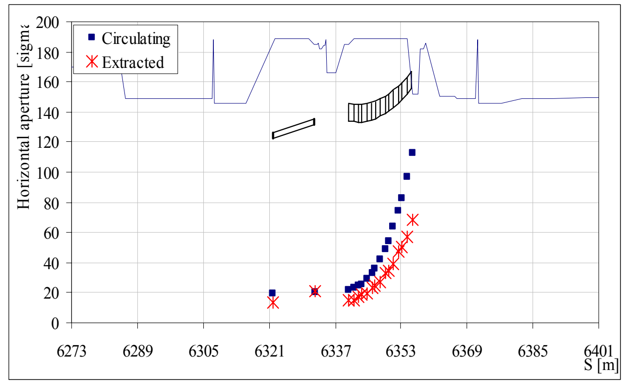

Figure 4: Horizontal apertures to septum for bumped and extracted beams.

CONSTRUCTION TIMESCALE

The modification of the extraction in SPS LSS6 should take place during the long shutdown in 2005, and will be ready to take beam in spring 2006. Early 2005, the ZS elements, and the magnetic septa will be removed, and the area will be prepared to allow the installation of the kickers. Towards the end of 2005 the MST girder will be modified, the TPSG6 will be installed on the modified girder, and the magnetic septa MST and MSE will be put back into their respective positions after the re-cabling of the equipment girders.

ACKNOWLEDGEMENTS

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REFERENCES

[1] P.Collier et al., “The SPS as Injector for LHC – Conceptual Design”, CERN SL 97-07 (DI), 1997.

[2] J.H.Dieperink, J.Uythoven, “High Precision Magnetic Field Measurements of Fast Pulsed Magnets”, 12th IMMW Proc., Grenoble, October 2001.

[3] J.Uythoven et al., “Beam Induced Heating of the SPS Fast Pulsed Magnets”, EPAC00 Lucerne, July 2004.

[4] J.Dupin, “Extraction Septum Magnets for the SPS – List of parameters”, CERN/SPS/ABT/EX/JD/ph/81-42, 1981.

[5] Y. Kadi, “Summary Notes of the 52nd Meeting of the SPS as LHC Injector Project Team, point 3”, http://sl.web.cern.ch/SL/sli/Minutes/sli_52/YKadi.pdf

[6] B.Goddard, P.Knaus, G.Schröder, W.Weterings, J. Uythoven, “The New Extraction Channel for LHC and CNGS”, EPAC00, Vienna, June 2000.

[7] B.Goddard, “Expected delivery precision of the injected LHC beam”, CERN/LHC Project note 337, February 2004.