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Modifications to the SPS LSS6 Septa for LHC and the SPS Septa Diluters

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Abstract

The Large Hadron Collider required the modification of the existing extraction channel in the long straight section (LSS) 6 of the CERN Super Proton Synchrotron (SPS), including the suppression of the electrostatic wire septa. The newly set up fast extraction will be used to transfer protons at 450 GeV/c as well as ions via the 2.9 km long transfer line TI 2 to Ring 1 of the LHC. The girder of the existing SPS DC septa was modified to accommodate a new septum protection element. Changes were also applied to the septum diluter in the fast extraction channel in LSS4, leading to the other LHC ring and the CNGS facility. The requirements and the layout of the new LSS6 extraction channel will be described including a discussion of the design and performance of the installed septum diluters.

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The Large Hadron Collider required the modification of the existing extraction channel in the long straight section (LSS) 6 of the CERN Super Proton Synchrotron (SPS), including the suppression of the electrostatic wire septa. The newly set up fast extraction will be used to transfer protons at 450 GeV/c as well as ions via the 2.9 km long transfer line TI 2 to Ring 1 of the LHC. The girder of the existing SPS DC septa was modified to accommodate a new septum protection element. Changes were also applied to the septum diluter in the fast extraction channel in LSS4, leading to the other LHC ring and the CNGS facility. The requirements and the layout of the new LSS6 extraction channel will be described including a discussion of the design and performance of the installed septum diluters.

INTRODUCTION

During the long shutdown (December 2004 – April 2006) of the Super Proton Synchrotron (SPS), the slow extraction channel in long straight section (LSS) 6 was converted into a fast extraction channel towards the clockwise ring of the LHC. Following the requirements for the LHC [1] a design was proposed [2] which uses a maximum of existing hardware to limit the cost as well as the radiation exposure to the personnel involved in the conversion.

SEPTA MODIFICATIONS

General Layout Modifications

The new fast extraction doesn't require any more the electrostatic septa (ZS). They were removed from their girder, and stored to serve at spares for the remaining SPS slow extraction in LSS2. Subsequently, the ZS girder and all auxiliary systems were removed, freeing the area for the installation of the fast extraction MKE kicker magnets [3]. To ease access and to reduce the ambient radiation levels for the personnel working in the area during the conversion, all septa magnets (MST and MSE) were 'unplugged' from the girders and temporarily stored downstream in the transfer line tunnel. The MST girder was modified by removing the segments below the first MST and the former septum protection device TPSS. This was replaced by a segment recovered from the ZS girder which now supports the newly constructed protection elements TPSG6. The removal of the TPSS and first MST imposed the shortening of the bus-bar of the MST septa. Fig. 1 shows the layout of the fast extraction channel. The MKE kickers are installed at positions 6287-6307. The TSPG6 and the 2 MST are located at positions 6323-6322 and the MSE septa at positions 6340-6356.

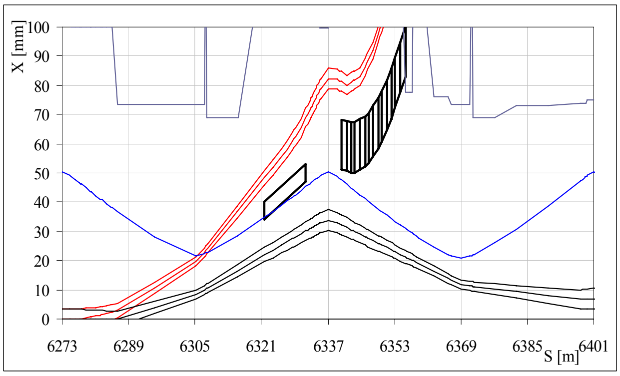

Figure 1: Extraction region in LSS6, showing the injected 5σ CNGS beam envelope (blue), the bumped 4σ LHC beam (black) and the extracted 4σ LHC beam (red).

The TPSG6/MST girder and the MSE girder were both equipped with new adjustable feet as developed and used for the extraction channel LSS4 [4], to ease the adjustment for ground movement. After the girder modifications the radial position of the elements was tuned to provide the necessary horizontal aperture.

Operating parameters

The extraction channel will be used with different current settings compared to the previous slow extraction. Because of the fast extraction the RMS current will be lower than before. The resulting reduced power dissipation allows the minimum cooling water flow settings to be lowered, and thus provides more operational margin in case cooling water channels would corrode and start to clog up. The septa magnet parameters as used for this extraction are indicated in table 1.

Table 1: Individual septum magnet parameters for LSS6.

	MST	MSE	
Number of magnets	2	5	
Septum thickness	4.2	17.25	mm
Gap height	20	20	mm
Magnetic length	2247	2237	mm
Deflection required	0.532	1.892	mrad
∫B.dl	0.798	2.838	T.m
Current at 450 GeV/c	5654	20183	A
Magnet resistance	1.07	0.34	mΩ
Magnet inductance	13	12	µH
Rise/fall time	~200	~200	ms
Flat top length	~300	~300	ms

SEPTUM DILUTER TPSG6

A new protection device called TPSG6 has been installed upstream of the MST septa to protect against mis-steered beams. In case of full impact it will dilute the beam such that the energy deposition and the subsequent temperature rise in the downstream MST septa conductors will stay at tolerable levels. In particular, the energy deposition in the cooling water of the septum conductor is critical, as it provokes a pressure wave in the cooling water circuit. The temperature rise limits were defined as less than 80 K for the copper conductor and 8 K for the cooling water. The parameters of the LHC beam in the SPS are shown in table 2.

Table 2: Main parameters of LHC beam in the SPS.

Protons per spill (ultimate)	3.2 (4.9)	10^{13}
Extraction energy	450	GeV/c
Repetition rate (nominal beam)	18	s

Diluter Layout and Performance

The extraction layout provided 4 meters between flanges for the TPSG6 with an effective length of 3500 mm for the diluting materials. The diluter width is 6 mm, to properly protect the 4.2 mm wide downstream MST coils. The choice of absorber materials was based on materials which were, at the time of the design, available in sufficient quantities on the market and of which the characteristics were known. A sequence of 2600 mm of graphite (CZ5), 300 mm of Titanium alloy (TA6V) and 600 mm of Inconel (718) was chosen. The energy deposition in the diluter and the MST were calculated, and subsequently the temperature rise of the copper conductor [5] and the water temperature and pressure rise in the MST cooling channels [6]. A temperature rise of 8 K was predicted for the ultimate LHC beam, resulting in a 25 bars pressure rise, which corresponded to the defined limits. The temperature rise in the conductor was far below the limits and therefore not calculated in detail.

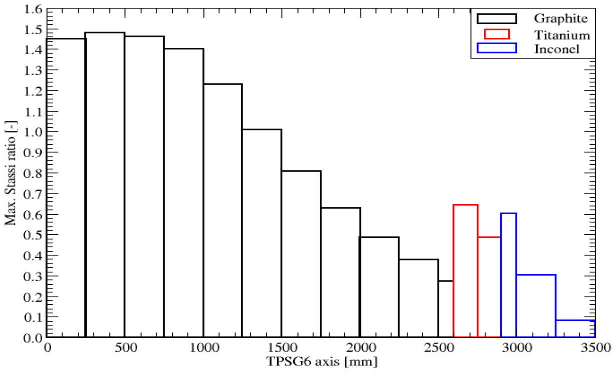

Figure 2: Stassi ratio of the TPSG6 diluter elements in case of full impact of the LHC ultimate beam.

The temperature and mechanical stress levels were calculated for the diluting materials (Fig. 2). The first 6 graphite diluter elements have a Stassi ratio higher than 1 and will break in case an ultimate LHC beam hits the TPSG6 diluter. By scaling the results the present limit for the intensity at which the TPSG6 would remain intact is estimated at about 1.9×10^{13} protons.

Diluter Cooling

In case of impact of the beam on the diluter, the temperature rise and the subsequent vacuum rise are instantaneous. Since an impact of a major part of the beam should only occur accidentally, there is no need to extract the heat thus generated as fast as possible. However during normal operation there is a permanent heat load of the TPSG6 from the beam image current and a small beam loss at extraction. Extrapolating from the calculations made for the LHC collimators [7] the heat load from the image current is predicted to be less than 77 W. Operational beam loss is more difficult to forecast; a 1 ‰ loss is assumed as worst case (upper limit set by radiation protection considerations), yielding 177 W. Hence the maximum heat load from normal operation should be less than 254 W. To avoid an unnecessarily high operating temperature of the diluter, a cooling circuit was added at the base of the diluter elements (edge cooling). The foreseen water flow of 2×6 l/min will limit the temperature rise during operation to less than 2.1 K.

Spare diluter construction

The TPSG6 as presently built (Fig. 3) properly protects the downstream septa in case of a full impact of even the ultimate LHC beam. However, the diluter would be irreversibly damaged in this case. During 2006 an upgraded spare diluter will be built, using stronger materials such as C-C and gamma met which are now becoming available in sufficient quantities and for which the material characteristics are now better known. This should result in a diluter that will sustain at least the LHC nominal beam (while still properly protecting the downstream septa).

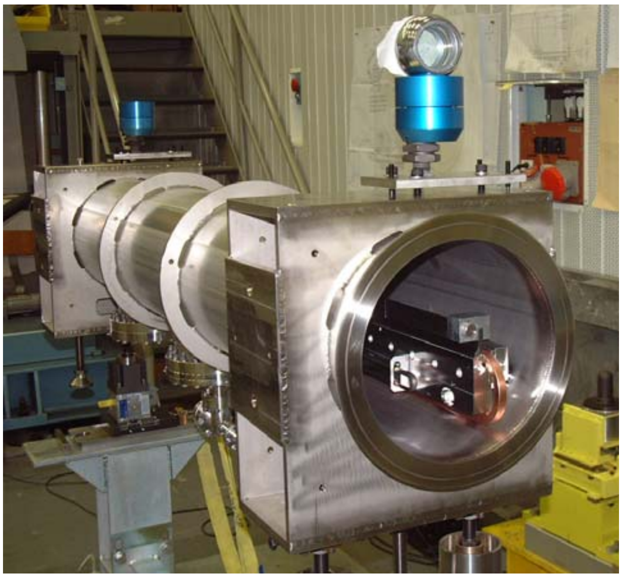

Figure 3: The TPSG6 diluter in its vacuum vessel.

SEPTUM DILUTER TPSG4

To profit from the recent development for the TPSG6 diluter, it was decided to review also the design of the diluter installed in the LSS4 extraction since 2003. This extraction channel also handles the CNGS beam (table 3), and uses only MSE type septa. Therefore the diluter must be 19.25 mm wide.

Table 3: Main parameters of CNGS beam in the SPS.

Protons per spill (ultimate)	2.4 (3.5)	1013
Extraction energy	400	GeV/c
Repetition rate	6	s

In the new design 3000 mm are available for the diluting materials, 100 mm more than in the previous one, by having the active materials extend 50 mm on each side of its shielding block (yoke, Fig. 4). A sequence of 2400 mm of graphite (CZ5), 300 mm of Titanium alloy (TA6V) and 300 mm of Inconel (718) was chosen. Calculations have shown that the TPSG4 device properly protects the downstream MSE septa in all cases. The stress levels of every block are shown in Fig. 5. The diluter itself sustains full impact of the CNGS beam, but is likely to be damaged for LHC beam intensities above 2.2 x 10^{13} protons.

Figure 4: The new TPSG4 diluter in its yoke, before installation in the vacuum vessel.

The new design now also incorporates a cooling circuit, to cope with the operational heat load. The total heat load expected due to image currents and beam losses is calculated to be less than 66 W and 373 W, respectively. The TPSG4 uses one cooling circuit, over both the top and bottom side of the active elements. With a flow of 6 l/min the operational temperature increase should be less than 9 K.

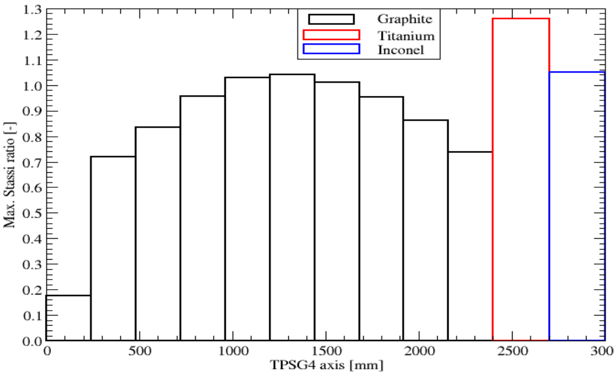

Figure 5: Stassi ratio of the TPSG4 diluter elements in case of full impact of the LHC ultimate beam.

CONCLUSION

In former slow extraction in LSS6 was converted into a fast extraction for the LHC. A new septum protection device called TPSG6 was built, which can properly protect the downstream septa up to full impact of the ultimate LHC beam. The diluter itself can sustain a full impact of 60 % of the nominal LHC beam intensity. This year an upgraded spare will be constructed which will sustain at least the nominal LHC beam. Similar results were obtained for the upgraded diluter in LSS4 where the same strategy for spare construction will be adopted.

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