PREPARATION OF THE SPS AS LHC INJECTOR

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Abstract

A major project (SLI) for the preparation the SPS in its role as the final link in the injector chain to the LHC was launched one year ago [1,2]. The major areas of work include the upgrade of the RF and the injection systems, together with the provision of a new extraction channel to serve ring 2 of the LHC. In addition, studies have been made on the ability of the SPS to meet the stringent transverse and longitudinal beam requirements of the LHC. This has lead to several other programmes of work including upgrades to the beam instrumentation, the transverse damper and the shielding of over 800 inter-magnet pumping ports to reduce the impedance of the machine. The planning of the project is influenced by the continued operation of LEP and the proposed new long base-line neutrino facility (NGS). In addition, during the machine upgrades, the SPS must continue to deliver high quality proton beams to the fixed-target experimental community and for an extensive range of experimental detector test beams. The major areas of work to complete the upgrade will be explained, together with the present status of the project and the future planning.

1 REQUIREMENTS FOR LHC BEAMS

The LHC requires five different intensity beams to be made available from the injectors [3]; the pilot, setup, commissioning, nominal and ultimate beams. The characteristics for these are summarised in table 1.1.

Table 1.1: SPS beams required for LHC

	Protons per bunch	*Number of bunches*	*Total current (mA)*
pilot	0.05×10^{11}	1	0.02
setup	0.05×10^{11}	81	1.6
commis.	0.17×10^{11}	243	29
nominal	1.05×10^{11}	243	177
ultimate	1.70×10^{11}	243	287

Normal LHC filling will consist of 12 SPS injection supercycles per ring. Each SPS supercycle contains three batches of 81 bunches, each one provided by a single injection from the PS. In total, the three batches in the SPS will occupy 3/11th of the machine circumference.

A 1σ definition of the transverse normalised emittance is used. Thus a 5μm normalised 1σ emittance corresponds to 20π in the previous SPS 2σ notation. The transverse emittance is the same in both planes.

In the SPS, injection from the PS will take place at an energy of 26 GeV/c and extraction to the LHC will be at 450 GeV/c. Table 1.2 summarises the beam and machine parameters for the SPS for the ultimate LHC beam. For the commissioning beam the transverse emittances requires ε_t = 1μm.

Table 2.2 : SPS parameters for ultimate LHC beam [1].

		SPS	
Momentum	*GeV/c*	*26*	*450*
SPS radius	*m*	*1100*	
Min. vac. pipe radius	*mm*	*25*	
Revolution time	*μs*	*23*	
Revolution frequency	*kHz*	*43.3*	
Betatron tunes		*26.7*	
Gamma Transition	*GeV/c*	*23.23*	
Number of bunches		*243*	
Particles per bunch	*10^{11}*	*1.7*	
Total intensity	*A*	*0.29*	
Bunch spacing	*ns*	*25*	
Bunch frequency	*MHz*	*40*	
(Full) bunch length	*ns*	*4*	*1.74*
(Full) bunch length	*mm*	*1200*	*520*
Peak intensity	*A*	*10.9*	*25*
Trans. norm. emittance	*mm.mrad*	*3.0*	*3.5*
Average beam size	*mm*	*2.3*	*0.6*
Longitudinal emittance	*eVs*	*0.5 - 1*	*0.5 - 1*
(Main) RF frequency	*MHz*	*200*	

2 UPGRADES AND NEW SYSTEMS

In the following sections the various upgrades and new systems for the SPS are briefly presented.

2.1 Beam Cleaning

The LHC will be very sensitive to particles in the transverse beam halo. A succession of four fast scraper sweeps (two horizontal and two vertical) to a radius of about 4 *rms* beam sizes will cost barely 0.1% of total beam intensity.

2.2 Internal Beam Dump

The internal beam dumping system consists of a pair of kicker magnets that deflect the circulating beam onto an

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absorber built around the vacuum pipe. Two beam dumps are installed; one to dump the beam at, or near, injection while the other is used above 100 GeV/c.

The present absorber block is 4.3 m long and consists of an aluminium/copper core surrounded by a copper block. The energy deposition from the absorption of a high intensity beam causes local heating and thermal stress in the absorber block, which are already too high for the nominal LHC beam. To solve this, a core made of graphite will replace the present core.

2.3 Beam Instrumentation

Many beam instrumentation systems will be modified for the LHC beams, either for reasons of the LHC beam requirements or hardware system modifications or additions. Modifications include;

- Installation of Optical Transition Radiation (OTR) screens (0.2 mm resolution),
- upgrade processing electronics of most detectors,
- add new instrumentation for the LSS4 extraction,
- add five couplers for position measurement in TT10,
- upgrade of processing electronics for couplers,
- upgrade of the Closed Orbit (COPOS) measurement system to provide a resolution of 3 μm (in central 8 mm) and multi-turn acquisition,
- introduce a dynamic tune control system (Q-loop),
- install a new monitor using a 12 μm thin titanium OTR screen [4] to provide a measurement of the betatron mismatch to better than 1% in each plane,
- develop a quadrupolar pick-up to provide permanent monitoring between re-matching procedures,
- develop a synchrotron radiation monitor to provide continuous profile information above ~200 GeV/c,
- develop an ionisation rest gas monitor to provide continuous profile information over the whole cycle,
- extend the beam loss monitoring system.

2.4 Controls and Software

The application software used to control the SPS will be re-engineered [5] to allow more efficient operation and to cover the needs for the LHC era, in particular for variable multi cycling. The new software will be highly flexible and maintainable with standard interfaces, and will have a planned lifetime of over 10 years.

2.4 Extraction

The LHC beams will be extracted from LSS4 and LSS6 to LHC points 2 and 8 via transfer lines TI 2 and TI 8 respectively [6]. Extraction will be in fast mode, i.e. single turn. In LSS6 the existing extraction channel will be used, with the addition of an absorber or dummy septum to protect the first (electrostatic) extraction elements from accidental damage.

A new extraction channel in LSS4 will use either the existing design of DC septum (poorly adapted to exploitation with fast extraction only), or a new fast pulsed (FP) septum. This will have a 250 μs sinusoidal pulse with a superimposed 3rd harmonic for the required flat-top precision of about ±0.02 % over 25 μs, enabling extraction of a full SPS turn if required. The FP septum will use tape wound nickel-steel of 100 μm thickness as yoke material, profiting from development of tape wound steel magnets for the LHC beam dumping system. The septum proper is a passive electromagnetic eddy current screen of about 5 mm thickness, not connected to the excitation current loop. The advantages of this septum magnet are increased aperture, negligible heat generation (avoiding high pressure water cooling), very low short duration stray field, separation of the vacuum for circulating and extracted beam, and reduced complexity and cost.

Other work required for the LSS4 extraction includes;

- upgrade and installation of extraction kickers (four or five modules depending on choice of septum),
- installation of horizontal bumper system,
- installation of vertical bumper system (for closed orbit control in the extraction region),
- installation of enlarged quadrupoles with large aperture (±90 mm) and coil windows,
- development of an absorber to protect the first extraction elements from accidental damage,
- civil engineering for the SPS - TT 40 junction and to improve shielding for radio-protection purposes,
- construction and installation of the first part of TT 40 inside the SPS tunnel,
- recabling of the SPS tunnel and adjacent cavern.

2.5 Impedance Reduction

To cope with high single bunch and total intensity of the LHC beam, measures are necessary to reduce the longitudinal machine impedance. Elements with high R_{sh} and high Q (cavities) gives rise to coupled bunch instabilities, and all cavities must be sufficiently damped to reduce instability growth rates to acceptable values. Elements with high R/Q and low Q give rise to single bunch effects (e.g. microwave instability), dominated by the extraction septa and the vacuum ports. All 22 magnetic extraction septa will equipped with RF shields to reduce the R/Q. The 800 or so vacuum ports will all be shielded by introducing a screen to provide a smooth vacuum chamber transition; this very heavy task involves removing and reinstalling every second SPS main dipole. Finally, low frequency inductive impedance causes potential well distortion and can lead to the loss of Landau damping due to the coherent frequency shift, and will be reduced by about 30% with the vacuum port shielding.

2.6 Kicker Magnets

The injection kicker is being upgraded in two ways, with the reduction of the ripple by a factor of two to below 0.5% for proton operation and the reduction of the rise time by 25% to 115 ns for Pb ion operation. To achieve this the impedance of the magnets will be increased from 12.5 to 16.75 Ω, and the magnet length reduced from 22 to 17 cells. This reduces the deflection strength and more modules are needed (16 instead of 12).

For the extraction kicker system a slight reduction in ripple is required, by replacing the discrete inductors in the PFN by a distributed inductance. The requirements of two-batch fast extraction for the eventual NGS project mean that the rise time must also be reduced by shortening the magnets in LSS4. This reduces the kick strength so that an extra kicker tank is needed (four or five depending on the choice of septum).

2.7 Programmable γ_t

A programmable γ_t scheme is being considered to increase the threshold of the microwave instability at injection and possibly to also help avoid the presence of 'ghost' bunches at extraction. Machine studies are presently being performed on this subject, and preliminary hardware designs are being made.

2.8 Radiofrequency

For the 200 MHz travelling wave system one cavity will be shortened to three sections, the other three having the optimum four sections, to allow complete coverage of the total cavity bandwidth by a composite RF feedback - essential for beam stability. New feedback electronics will be developed and applied to each cavity separately with a portion of the feedback signal being common to all. Feedforward electronics will also be developed. It is also necessary to redesign the couplers to cope with the increased power requirements. The amplifiers themselves must also be upgraded to permit the 1 MW peak power.

If it is shown that bunch compression at extraction is necessary, four 400 MHz superconducting cavities will have to be installed in LSS5. The power amplifiers will either be upgraded versions of the existing 352 MHz tetrode amplifiers, or new klystron amplifiers. New RF feedback and control electronics must also be developed. To prevent excessive power requirements in such a system, “fixed frequency” acceleration will be used.

The longitudinal feedback system will be installed to damp coupled bunch instabilities with typical growth times of ~10 ms, requiring peak voltages of ~110 kV for an assumed phase detection level of 50. For bunch-by bunch damping a ±20 MHz bandwidth is necessary.

2.9 Transverse Damper

The existing damper must be modified to meet the very tight transverse emittance blow up budget of 0.5 μm, 0.35 μm of which is due to dynamic effects. The maximum integrated deflection field of the deflectors will be increased to 85 kV horizontally (3.3 μrad) and 160 kV vertically (6.2 μrad).

2.10 Removal of Obsolete Equipment

Equipment that is no longer needed for the SPS operation will be removed from the machine, mainly equipment presently used for leptons, but also equipment still installed in the SPS that was used for ppbar collider operation. Included are the present 100 MHz, 200 MHz and 352 MHz lepton RF systems, the lepton kickers, the Robinson wiggler, strong insertion correctors, low-beta insertions in LSS4 and LSS5 and the harmonic correctors.

3 STATUS AND PLANNING

Most technical solutions to the problems anticipated for running the SPS as LHC injector now exist, and hardware construction has started for several systems. The bulk of the installation work must be carried out in the coming three long winter shutdowns, and in 2001 the SPS machine will be close to its final state as LHC injector. The installation program is constrained heavily by the compatibility requirements of the LEP2 project that is now in its final production years, the LHC project now in the construction phase, and the proposed NGS project to Gran Sasso (yet to be approved).

In mid 1998 the SPS will receive LHC type beam from the PS for the first time (although a single batch only rather than the full three batches). This will enable rapid progress to be made on the remaining unanswered questions, which include the aspects of the SPS to LHC transfer (in particular stability, interlocks and vetoes) and longitudinal beam instabilities.

4 CONCLUSIONS

The upgrade of the SPS as LHC injector requires major changes to almost all machine systems. These changes are now well under way, with the near-final equipment configuration expected for 2001. The SPS will then be ready to deliver beam to the LHC octant 8 for injection tests scheduled in 2003, and to provide the full spectrum of beams for the LHC commissioning in 2005.

5 AKNOWLEDGEMENTS

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