THE SPS AS LHC INJECTOR

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Abstract

During a recent long shutdown, major modifications to the SPS have been made to prepare it for its role as LHC injector. The changes cover most of the accelerator systems including transfer and injection, RF, extraction, magnets, power converters and beam instrumentation. In addition, an ambitious programme to reduce the longitudinal impedance has been undertaken. As well as removing equipment no longer needed for operation, a total of over 1000 inter-magnet RF shields have been installed, involving the removal of over half of the main dipole magnets and most of the short straight sections in the machine. The various upgrades to the machine components will be detailed together with the studies that will be used to check the performance of the machine during operation this year. The remaining activities over the coming years, associated with the upgrade of the SPS as LHC injector, will be outlined.

1 INTRODUCTION

The SPS will be the final pre-injector for the LHC, accelerating 26 GeV protons from the PS to 450 GeV before extraction via two specially built transfer lines connecting the SPS and the LHC ring tunnels [1]. Many changes to the existing SPS machine are necessary before it can deliver the high brightness proton beams required by the LHC. To accomplish this, the main hardware modifications and additions are:

- upgrading the existing RF systems;
- construction of a new extraction channel and modification to the existing ones;
- upgrades to the beam instrumentation;
- upgrade of the transverse damper;
- upgrade of the transfer lines;
- upgrade of the injection and extraction kickers;
- development of a fast beam scraper;
- upgrade of the internal beam dump.
- Reduction of the impedance by RF shielding of all cavity-like objects.

This programme has been underway since 1997. Until the end of 2000, it had to be conducted in such a way as not to disturb the role of the SPS as the injector for LEP. Since the end of LEP operation in November 2000, the SPS has been shut down and has undergone major changes. In addition to activities associated with the work mentioned above, the civil engineering to connect the new LHC transfer tunnels has been completed and wide-ranging changes to the infrastructure and services for the machine have been made. Preparation work in several surface buildings has also been necessary to clear the space needed for the LHC transfer line equipment.

2 IMPEDANCE REDUCTION

Measurements with beam in the SPS have shown that the intensities required by the LHC are well above the threshold of the microwave instability. At the same time the transverse impedance present in the machine is of concern as the driving term for coupled bunch instabilities. Both broadband and narrow band impedance exists in the SPS; however, particular problems have been found with accidental cavities having a high R_{sh}/Q and low Q [2]. A reduction in the impedance has been attempted by following several routes:

2.1 Removal of Obsolete Equipment

A major source of impedance in the SPS was the lepton RF system. This consisted of 4x100 MHz standing wave cavities, 21x200 MHz standing wave cavities and 4x352 MHz SC cavities. All have now been removed from the machine. In addition the lepton injection and extraction equipment, including kickers and septum magnets, has all been removed.

2.2 Septum Shielding

The two presently installed extraction channels make use of a total of 16 magnetic septum magnets. All installed magnetic septa now contain shields to prevent the beam from seeing the full volume of the vacuum tank. The 10 installed electrostatic septa remain unshielded.

2.3 Kicker Tank Shielding

Due to restrictions on the aperture, the ferrite of the SPS kicker magnets is not shielded. The gaps between adjacent magnets allow the beam to see the full volume of the vacuum tank: for this shorting shields will be progressively fitted to the kicker tanks. The extraction kickers have been removed from the machine for the addition of a cooling circuit, and will have shields fitted before re-installation.

A study is also underway to investigate the possibility of installing fully shielded kickers. However, this would require the design and construction of a completely new set of kickers having a larger vertical aperture and therefore significantly longer magnetic length.

2.4 Inter-Magnet Pumping Port Shielding.

The SPS makes use of several different vacuum chamber sections, optimised to the opening of the main magnets of the machine. Between sections of chamber is a cylindrical pumping port/bellows assembly. Around 1000 of these exist in the machine and each one acts as an

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accidental cavity having a resonant frequency in the 1-1.5 GHz range. They are a major source of impedance in the machine. A programme of fitting RF shields into the pumping ports was launched in early 2000, although only a very limited number of shields could be fitted due to incompatibilities with lepton equipment.

The bulk of the installation has now been made, with around 95% of the pumping ports shielded. The installation has involved the removal and re-installation of every second main dipole in the machine (some 400 magnets) and the majority of the short straight section girder assemblies. It has been one of the major undertakings during the present shutdown. As a result, the whole of the SPS has been re-aligned, both horizontally and vertically, for the first time in many years. In addition, for the first time in its 25 years of operation, the whole of the SPS has been at atmospheric pressure at the same time.

2.5 Vacuum Chamber Transitions

In the past, large diameter (159mm) vacuum chambers have been installed in all locations around the machine where no equipment is installed. In many cases this lead to significant vacuum chamber transitions and additional impedance. The large diameter chamber is preserved for the long straight sections and dispersion suppressers. In the short straight sections of the arcs, diameters adapted to the adjoining magnets have been introduced.

2.5 The Future

One of the major priorities for beam studies this year will be the re-measurement of the impedance, to confirm that the work undertaken during the present shutdown has resulted in a significant reduction. Several methods will be used and reference data exists, taken each year since the impedance reduction programme began [3]. The future of the impedance reduction programme will be determined once 2001 data is collected. A few shields remain to be fitted next year, and if necessary a campaign to attack remaining chamber transitions can be studied.

3 RADIOFREQUENCY SYSTEM

The hadron acceleration system in the SPS consists of four 200 MHz travelling wave cavities. Changes to the power and control systems around these cavities are underway. The two amplifiers per cavity are being upgraded to permit the 1MW peak power required to accelerate the LHC beam. On the cavities themselves, new couplers have been designed to cope with this increased power. The first cavity has been now been equipped with its coupler - the rest will progressively be done over the next two years. New feedback systems have also been built and installed. First tests of the feedback systems with beam last year revealed a problem with the bandwidth and linearity of the amplifiers. As a result additional equipment will be required. Circulators and pre-amplifiers will be added to the power circuits.

A 4^{th} harmonic RF system is also installed in the SPS, but has not been systematically used for normal operation. These two 800 MHz cavities have now been successfully tested for beam control, and have become the main system for stabilising the LHC beam longitudinally. As a result a significant amount of work is being undertaken in order to make the 800 MHz system fully operational. This system replaces the longitudinal feedback system originally proposed for the LHC beam.

As a result of all the changes in the RF system it was decided to completely rebuild the RF Faraday cage control room. This has been done in the 2000/2001 shutdown. All lepton RF electronics has been removed and a complete re-cabling of the control racks performed. Repairs to the structure of the Faraday cage have also been made. New electronics for RF feedback, feed-forward and synchronisation systems have been added.

4 TRANSVERSE DAMPER

The damper is the main tool to meet the very tight emittance growth budget. A major overhaul and upgrade of the transverse damper is just approaching completion. The kick strength of the system has been increased, with a new kick strength of 3.3μrad horizontally and 6.2μrad vertically. In order to improve the response of the vertical system to the situation where the tune is close to the half integer (normally the SPS runs with $q_v \sim 0.58$), one of the vertical kickers has been moved to the other side of the long straight section 2, necessitating a major modification to the infrastructure and services.

In addition to increased power, the damper bandwidth has been increased from 5 to 20 MHz to allow feedback on the 40 MHz LHC bunch structure.

5 INJECTION CHANNEL & TRANSFER LINE

The beam instrumentation in the 700m long injection line from the CERN PS to the SPS was considered inadequate to ensure good transfer of the LHC beam. Using equipment recuperated from LEP, an additional 15 beam position monitors have been installed along the line. In addition new OTR screens and a fast BCT, capable of measuring the intensity of each LHC bunch, have been installed. Next year an additional four corrector dipoles (also recuperated from LEP) will be installed to improve the trajectory correction.

The injection channel proper in the SPS has been completely re-built. The tight tolerances on the allowed kicker ripple, together with the need for a shorter rise time for ions, required modification to the kicker magnets themselves, to reduce the impedance and the addition of a fourth kicker tank. New PFNs have been constructed with distributed, rather than lumped, impedance. The complex system required for lepton injection has been completely suppressed. The opportunity has also been taken to rationalise the surface installations for the kickers. A completely new layout of equipment has been implemented in the surface building, with new power and control electronics.

6 EXTRACTION CHANNELS

A new extraction channel is being built in LSS4 to serve both the anti-clockwise ring of the LHC (via TI 8), and the long baseline neutrino (CNGS) installation, presently under construction. The space in the machine was formally occupied by the lepton RF systems and has been completely stripped in preparation for the new installation. The major changes to the infrastructure of the tunnel and existing equipment have been performed this year and the first elements associated with the extraction system have been installed (enlarged machine quadrupoles, bumper magnets and beam instrumentation. The extraction elements themselves (kickers and magnetic septum magnets) will be progressively installed over the next two years. The original preferred choice of septum was a new design of fast-pulsed, eddy current septum magnet. Unfortunately, technical, planning and cost issues associated with this development have made the DC septum, already in use in the other SPS extraction channels, more attractive. The LSS4 extraction is now based on the use of 6 DC septa and 5 kicker magnets.

The present LSS6 extraction channel will serve the clockwise ring of the LHC. Protection of the delicate electrostatic septa (used for continuous extraction of fixed target beams) during the fast extraction will require either a mobile spoiler, or a modified extraction kicker with which can replace the electrostatic septum completely. To make the space available in the machine the electrostatic septum has now been moved downstream. (With the radioactive elements of the extraction dismounted for this work, the opportunity was taken to remove the electron injection line and the two lepton extraction lines.)

Further downstream, the future course of the LHC transfer line, TI 2, required the displacement of the west experimental area primary beam target. The work to shift the target out of the way involved constructing a new primary beam line and re-positioning 600m of secondary beam line. This work was completed at the beginning of 2000.

7 CIVIL ENGINEERING

During the long 2000/2001 shutdown, the connection of both LHC transfer tunnels to the SPS has been made. For the LSS4 extraction zone the initial part of the transfer line has been completed and handed over to CERN. This region is within the radiation limit of the SPS and cannot be accessed during machine operation. Work will start on infrastructure installation during the next shutdown. The beamline connection to the SPS machine tunnel has also been completed.

Work on excavating TI 2 has also progressed well, with the new tunnel coming right up to the SPS tunnels, and the work on lining the tunnel is well underway. The first 300m of this tunnel will now enter into the SPS exclusion zone during operation.

Civil engineering is also underway near LSS4 to construct the CNGS facility. Breakthrough into the SPS underground areas (though not within the exclusion zone) is scheduled for this summer. In addition, civil engineering for the Atlas cavern of LHC has caused big movements (8mm in both planes) of the SPS tunnel, requiring a major re-alignment of the LSS6 extraction channel. Additional movements are likely in 2001.

8 OTHER WORKS

The SPS internal beam dump was upgraded one year ago to absorb the energy deposition from the LHC beam. A new absorber block was constructed making the first use of graphite as the main absorbing element in the SPS. (This provides a good test for the LHC, where several graphite elements will be required.)

Beam instrumentation development has continued, to meet evolving LHC beam needs. Especially important are the transverse profile monitors, the mismatch monitors and the new instrumentation for the extraction channels. Several 40 MHz fast BCTs are now installed around the machine and the transfer lines.

The discovery of severe electron cloud build-up in the SPS in the presence of the LHC beam has lead to several test and measurement installations around the machine. Electron cloud studies, together with possible cures will be continued in the coming years.

On the surface, 3 SPS buildings are being prepared for new installations, to house the LHC and CNGS transfer line equipment, requiring the removal of many kilometres of old cables and installed equipment. Most of the infrastructure preparation in these buildings is complete.

9 CONCLUSIONS

The major works associated with preparing the SPS for its role as LHC injector are well underway. A large fraction of the modifications have been done during a long shutdown over last winter. An extensive series of machine studies will be undertaken during the coming run to commission the new equipment and to measure the effect of impedance reduction measures on the LHC beam stability.

Work on upgrading the SPS will continue during the next two annual shutdowns, by which time all the elements will be in place to allow commissioning of the new extraction channel in LSS4 in time for the first LHC injection tests, which are planned for 2004 via TI8. One year later, the same extraction channel will be used to send a high intensity proton beam towards a neutrino target for the CERN-Gran Sasso (CNGS) project. From 2006, the SPS will have to deliver a 450 GeV proton beam to the LHC on demand, as well as beams to CNGS and the present experimental areas.

10 REFERENCES

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