BEAM COMMISSIONING OF THE SPS LSS4 EXTRACTION AND THE TT40 TRANSFER LINE

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Abstract

The new fast extraction system in LSS4 of the SPS and the transfer line TT40 were commissioned with beam in late 2003. The layout and functionality of the main elements are briefly explained, including the various hardware subsystems and the control system. The safety procedures, test objectives and results of the system commissioning with beam are described, together with the test methodology.

LSS4 EXTRACTION CHANNEL AND TT40

The new extraction channel [1] installed in LSS4 of the SPS is a conventional fast extraction system in the horizontal plane, see Fig.1. It comprises horizontal closed orbit bumpers, extraction kickers and conventional DC magnetic septa, together with beam instrumentation, interlocks and controls.

The TT40 line is the common part of the transfer line between the SPS and the LHC TI 8 and CNGS TT41 lines. In the 2003 tests, all line elements up to the mobile beam dump element TED were commissioned, comprising some 100 m of line. The main TT40 elements are two families of horizontal dipoles, three individually powered quadrupoles, three correctors, the beam dump and various beam instrumentation, including three beam screens (BTV) and a beam current monitor (BFCT).

The beta functions are shown in Fig.2, for the SPS to TT40 junction region, up to the TED. In Fig.3 the horizontal dispersion function and extracted beam trajectory are shown.

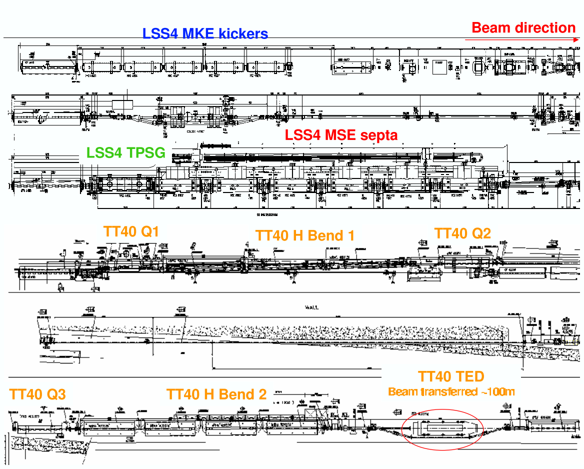

Figure 1: Layout of the LSS4 extraction channel in SPS LSS4, showing the main equipment subsystems

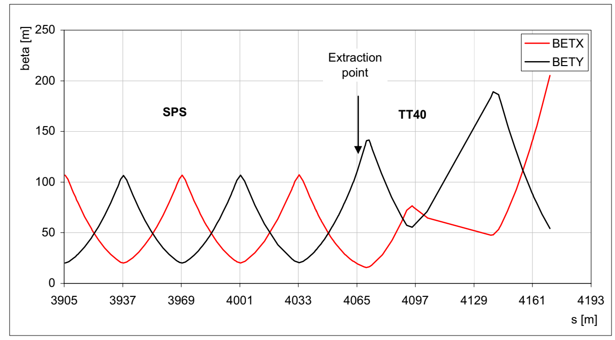

Figure 2: Beta functions at the junction between the SPS and TT40, as far as the TED beam dump

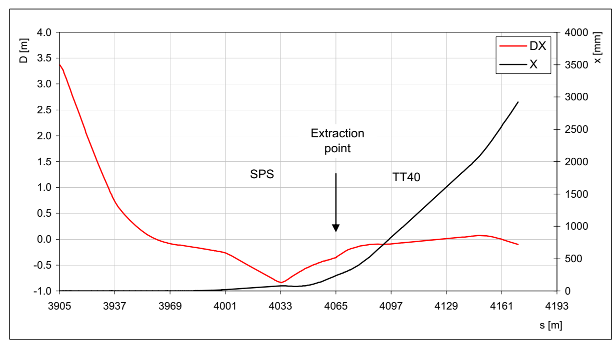

Figure 3: Horizontal dispersion function and trajectory at the junction between the SPS and TT40, as far as the TED beam dump

Equipment subsystems

Four horizontal bumper magnets and four vertical bumper magnets are used to control the circulating beam at extraction. The bumped beam is horizontally deflected across the septum by a total of 0.5 mrad using six fast pulsed kicker magnets MKE. The CNGS beam is extracted in two batches requiring a rise and fall time of the kicker pulse smaller than 1.1 μs. The kicked beam is deflected out of the SPS machine by a total of 12 mrad using six DC septum magnets MSE. A comprehensive interlock system surveys the beam positions, losses, bumper and septum currents, kicker charging voltages, etc. However, to cover other possible failure modes, a graphite and aluminium diluter TPSG is placed immediately upstream of the first septum coil, to reduce the energy deposition in the coil to a safe level.

The magnets in the TT40 line are conventional warm DC types. Three special C shaped dipoles MBHC are required for the first bending element; providing a total of 15 mrad deflection. The beam dump TED is capable of safely absorbing the full extracted beam energy, and comprises a graphite core surrounded by a cast iron containment structure. The TED is retracted when not required. The beam instrumentation includes beam loss monitors, beam position monitors and BTVs in the extraction channel and TT40, and a beam current transformer BFCT just in front of the TED.

Control system

The 3-tier control system used for the TT40 tests [2] was a major new development, comprising the presentation tier, the middle tier and the resource tier. The high-level control system services and applications included settings generation, trim translation, trajectory acquisition and access to configuration data. Other applications were equipment state, fixed displays for instrumentation data and steering. The middle tier services monitored the equipment and sent the data to the LHC Logging service. The general services provided were shot-by-shot logging, acquisition and display of analogue signals, and the surveillance application for the beam interlock controller.

BEAM COMMISSIONING PREPARATION

The preparation of the beam commissioning tests was made by a team comprising the system designers, equipment experts, machine operators and representatives from other areas such as safety, general services etc. The required functionality of the controls system was specified well in advance and the deployment of the software tested at an early stage, well before the final test date.

Safety issues

Access interlocks. A new access zone was defined to limit access in TI 8 and TT41 to a safe distance from the TED (based on nuclear transport calculations), and an interlock chain was installed which prevented operation of the MKE kickers, the MSE septa and the MBHC magnets, if this access zone was breached.

Beam intensity limitation. The beam intensity used in the test was limited to 2.5×10^{11} protons per extraction, in order to avoid the risk of equipment damage in the event of a mis-steered beam, and to limit the activation of components in the extraction channel and TT40 line. A dedicated software interlock was implemented which by default dumped the beam just after injection *unless* the SPS beam current was correctly measured at less than this limit.

Activation. An activation analysis predicted that the activity at the TED would be in the range $120\ \mu$ Sv/h to 3 mSv/h, 1 day after the extraction test, assuming a maximum of 2.5×10^{11} protons per extraction and a 50% test efficiency.

Safety procedures. Comprehensive safety procedures were agreed for the preparation of the test, the test period itself and the recovery period. The precautions included activation measurements before and after the tests, safety patrols before closing the access zones, tests of all new interlock chains and equipment, and logging of all extracted beam intensities.

Test objectives

The test objectives were as follows:

- to verify the correct functioning of all extraction equipment and the control system,
- to verify the correct trajectory and settings,
- to measure the acceptance of the extraction channel,
- to check the performance of the beam screens,
- to test the extraction interlock system,
- to measure the reproducibility of the trajectory,
- to perform a CNGS double batch extraction with 50 ms interval,
- to check the effect of MKE kicker ripple.

Organisation and methodology

The beam commissioning was organised around two 24 hour test periods, on the 8 September and 1 October 2003. In addition, extensive use was made of dry-runs in the months leading up to the beam commissioning. Periods of a few hours when no beam was available in the SPS were used to deploy the new control system, test the change of supercycle, power the transfer line magnets, test the equipment control, check the safety and access procedures etc. The effort invested in this proved very worth-while, in that many of the teething problems were fixed before the beam commissioning proper.

The test methodology was planned well beforehand, with a prioritised breakdown of the procedures and objectives. The commissioning was split into the following main blocks:

- Preparation of access zones, SPS machine hardware, cycles, logging and application software,
- setting-up of the beam cycle in the SPS,
- setting-up with beam on the LHC cycle, up to 450 GeV,
- setting-up of all extraction equipment and final test without beam,
- switch on and adjust extraction bump,
- extract and adjust extraction kickers and septum,
- steering and aperture checks,
- reproducibility and kicker ripple measurements,
- recovery (access zones, cycle change, data backup).

BEAM COMMISSIONING RESULTS

Overall the beam commissioning tests were successful. During the first test period the extraction system and the

TT40 line were successfully commissioned using a single LHC pilot bunch, see Fig.4. The main test objectives were attained and beam extracted and transported onto the TED beam dump at the end of the line. During the second test period, the double-batch extraction required for CNGS was successfully commissioned using two single bunches, and also a 12-bunch low-intensity LHC-type beam was extracted. The intensities extracted during the second test are shown in Fig.5.

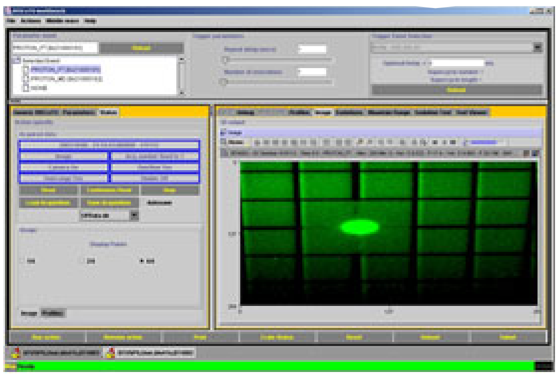

Figure 4: Beam spot on BTV screen at the TED beam dump

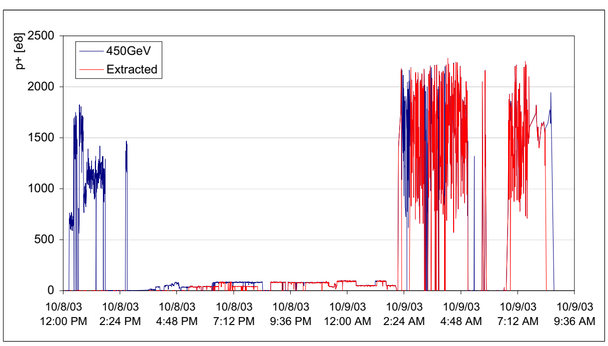

Figure 5: Extracted beam intensity per SPS cycle during the second commissioning period

System element performance

The correct functioning of the equipment, interlocks and controls was checked, and measurements were made of magnet response, instrument performance, reproducibility and aperture. An aperture problem in the SPS was found and corrected before the second beam test. Beam measurements showed that cables to two corrector magnets were inverted. The BPM response was as expected with the LHC pilot bunches, with a resolution of about ± 0.25 mm. The extraction channel aperture was measured with a beam blown up to the CNGS emittance of 14πmm.mrad, at about $7\ \sigma$ in both the horizontal and vertical planes.

During the second test the effect of the MKE kicker rise and fall times on the second CNGS batch was measured. Since the tests, the MKE system has undergone an upgrade to meet the CNGS specification for the rise time and flat-top ripple; the beam test also demonstrated that the fall time of the pulse is not fast enough and will require further study and modification to meet the specification.

Activation levels

The activation of the tunnel and the machine elements were surveyed before, during and after the tests, and the results used to confirm the calculated levels. A total of 1.2×10^{13} and 7×10^{13} protons were extracted onto the TED in the two test periods, and the resulting activation levels about 1 hour after the beam was switched off were about 0.3 and 4.1 mSv/h, in agreement with the simulations.

Test efficiency and procedures

The main test objectives were achieved within the time allocated, and no problems were encountered with safety procedures. The thorough test preparation involving detailed technical planning with the various experts meant that the tests themselves proceeded smoothly and according to the pre-defined program.

Future beam commissioning

TI 8 will be commissioned with beam in October 2004, after the completion of the line installation. As for TT40, the planning and preparation of these tests aim to be as exhaustive as possible. Interesting issues concerning operational stability, correction, aperture and matching will be investigated, which will help determine the operational procedures to be used during LHC injection.

CONCLUSIONS

During the beam commissioning tests the SPS LSS4 extraction system and the TT40 line were successfully commissioned using a single LHC pilot bunch and with multiple bunches. The main test objectives were attained and beam extracted and transported onto the TED beam dump at the end of the line. Overall the two tests with beam provided an invaluable test opportunity for many equipment subsystems.

ACKNOWLEDGEMENT

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[2] K. Sigerud, ”Controls Experience from TT40 and Prospects for the Future”, CERN, Geneva, Switzerland LHC Project Workshop - Chamonix XIII.