BEAM COMMISSIONING OF THE SPS LSS6 EXTRACTION AND TT60 FOR LHC

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Abstract

The new fast extraction system in LSS6 of the SPS and the first 100 m of transfer line TT60 was commissioned with low intensity beam in late 2006. The layout and functionality of the main elements are briefly explained, including the various hardware subsystems and the control system. The systems safety procedures, test objectives and measurements performed during the beam commissioning are described.

LSS6 EXTRACTION CHANNEL AND TT60

The modified extraction channel [1] installed in LSS6 of the SPS is a conventional fast extraction system in the horizontal plane, Fig.1. It comprises horizontal closed orbit bumpers, extraction kickers and two types of DC magnetic septa, together with protection devices, beam instrumentation, interlocks and controls. The TT60 line is the first part of TI 2, one of the two long transfer line between the SPS and the LHC. The extraction systems and all elements up to the beam dump (TED) were commissioned with beam in 2006, about ~100 m of line.

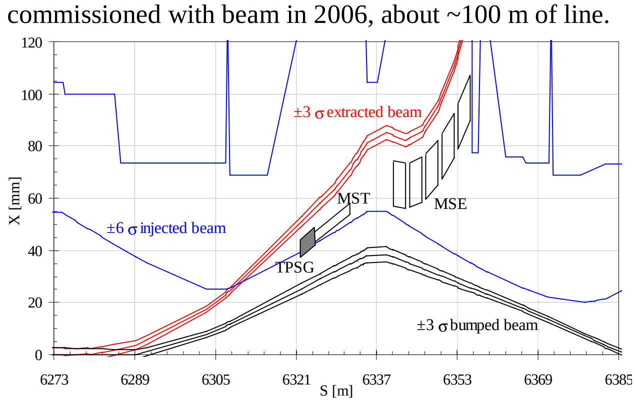

Figure 1: LSS6 extraction, showing septa and TPSG diluter, with injected, bumped and extracted beams.

Equipment Subsystems

Four horizontal 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 0.4 mrad using four pulsed kicker magnets MKE. The beam is deflected out of the SPS machine by a total of ~12 mrad using DC septum magnets, two thin (4 mm septum) units MST and five thick (16 mm) units MSE. An interlock system surveys the beam positions, losses, bumper and septum magnet currents, kicker charging voltages, etc. A composite diluter TPSG protects the first septum from kicker failures.

The magnets in the TT60 line are conventional warm DC types. The beam dump TED is capable of safely absorbing the full extracted beam, and has a graphite core surrounded by cast iron. The TED is retracted for filling the LHC. The beam instrumentation includes beam loss monitors BLMs, beam position monitors and BTVs in the extraction channel and TT60, and a beam current transformer BFCT in front of the TED. Equipment control, settings generation, trim, etc. were provided by the LHC application software, and the general control services provided shot-by-shot logging, acquisition and display of analogue signals, alarms, and other facilities.

OBJECTIVES AND PRECAUTIONS

Apart from transporting the beam to the TED, the main test objectives were to:

- verify the correct functioning of all extraction equipment and the control system;
- verify the correct trajectory and settings;
- measure the acceptance of the extraction channel;
- check the performance of the beam instrumentation;
- measure the stability of the trajectory;
- measure the MKE kicker ripple;
- check the possibility of operating with 3 MKE.

Safety and Radiation Protection

Beam intensity limitation. The beam intensity used in the test was limited to 6×10^{11} protons per extraction by an interlock which by default dumps the beam just after injection *unless* the SPS beam current was correctly measured below the limit.

Activation. An activation analysis predicted that the activity at the TED would be about 3 mSv/h immediately after the test and about 100 μSv/h after 1 day, assuming a maximum of 4×10^{13} protons extracted.

Organisation and Methodology

The 2006 beam commissioning was organised in two periods, 24 hours on the 24th August and 12 hours on 8th November (which was also used to make interleaved extractions with the SPS LSS4 LHC extraction channel). In addition, extensive use was made of "dry-runs" in the preceding months, in periods when no beam was available in the SPS, to deploy application software, test the supercycle change, power magnets, test equipment control, check safety and access procedures etc. This phase proved essential and contributed greatly to the high efficiency when commissioning with beam.

TEST AND MEASUREMENT RESULTS

Pilot beam was extracted to the TED on the first attempt, about 4 hours after the test period started. The equipment all worked almost perfectly, with only a few minor glitches. The controls and software all worked, without any problems, and all measurements were completed. No major issues were discovered, and the apertures, optics and settings were as expected. A short 8.4 s long LHC cycle was used in the SPS, which more than doubled the number of extractions possible and simplified data-taking. In total ~3500 extractions were made with 5×10^{9} p+ pilots, and 12 intermediate extractions with 12 bunches of 5×10^{11} p+. The switch to the 12 bunch LHC intermediate beam took ~1 hour. The total beam extracted was about 1.8×10^{13} p+, Fig. 2, almost all of which was deposited on the TED.

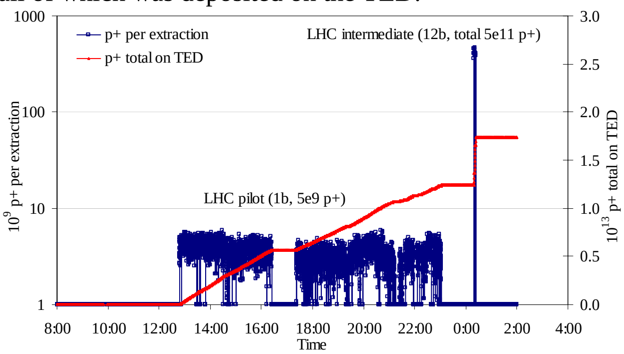

Figure 2: Intensity extracted during the test.

Activation Levels

Activation of the tunnel and the machine elements were surveyed before, during and after the tests, and the results compared to predictions. The activation around the TED, measured 1 hour after the beam was stopped, was 450 µSv/h, in agreement with expectation.

Aperture Measurements

Aperture measurements were made by varying the bump amplitude, Fig. 3, and the kick strength. The aperture for the circulating and extracted beam was as expected, ~10 σ for the extracted and ~16 σ for the circulating beam. The TT60 aperture was measured using the correctors available; no anomalies were found.

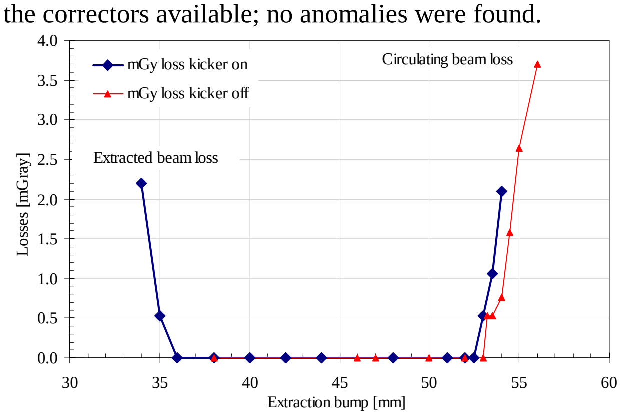

Figure 3: Variation of extraction bump and measured losses on TPSG.

Similar measurements also allowed absolute calibration of the beam loss monitor response for beam impacting the TPSG, Fig.4; factors of 1.4 and 3.7 mGy/10^{10} p+ were found for impacts on the circulating or extracted sides of the TPSG. In LSS4, measurements gave factors of 17 and 2 [2], with the difference explained by the different design of the two TSPGs in LSS4 and LSS6.

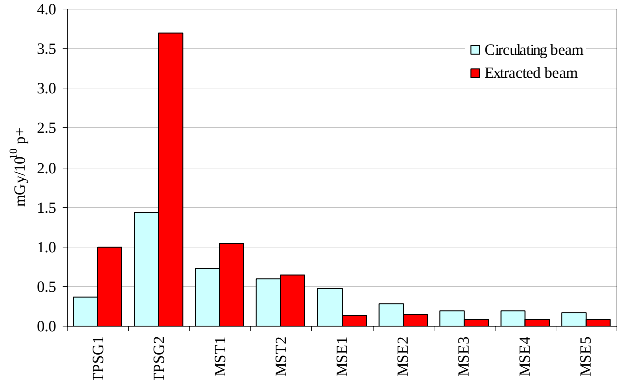

Figure 4: BLM response for losses on the TPSG.

Beam Instrumentation Performance

The large number of extractions allowed statistics to be made for the beam position monitors and screens. With these low intensity bunches it transpired that the beam screens provided a much more accurate position measurement than the BPCK couplers, Fig. 5. For the BTV the measured position was stable to an *rms* of about 30 µm, over ~400 samples, while for the same data set the BPCK coupler gave an *rms* of 300 µm. The 1.2×10^{-4} *rms* MST/E ripple is expected to produce maximum 100 µm rms offset [3], and <20 µm at these monitor locations.

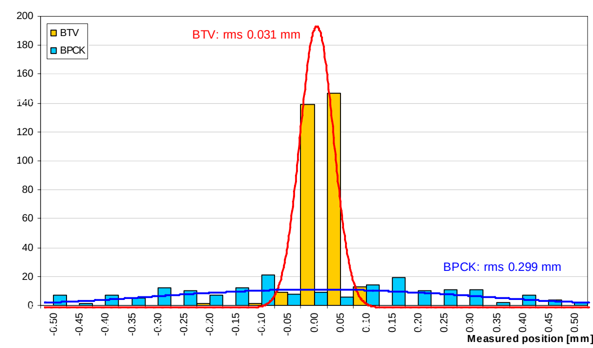

Figure 5: Beam position during stability test, as measured on BTV610252 and BPCK610211.

Response Measurements

Response measurements were made to check the accuracy of the Mad-X model and to look for major errors. The response for some key elements was analysed, including the MSE septum, Fig.6. The measured position response is in good agreement with the model. The MST septum field was also scanned to check the response and investigate the expected good field region which should extend to 89 mm of the QFA418, Fig.7; no non-linear response was measured up to the maximum trajectory of 87.7mm. The scan also showed that the MSE is correctly aligned, with the aperture as expected at low MST angles.

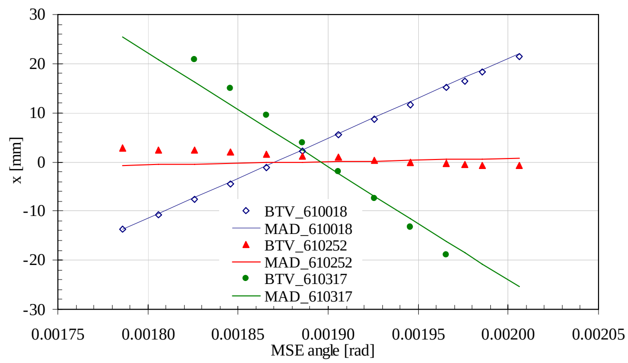

Figure 6: Measured/expected response for MSE angle.

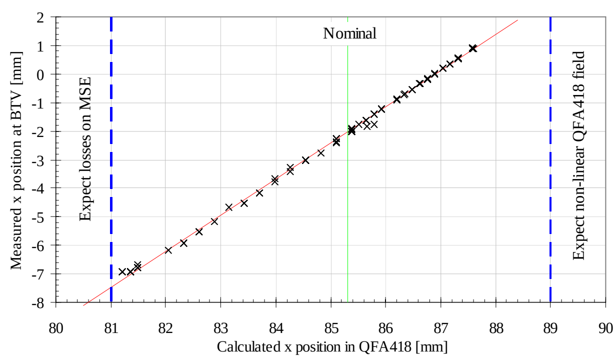

Figure 7: Scan of MST angle, showing calculated position in QFA.418 and measured offset at BTV610252.

Kicker Studies

Several tests were made with the MKE kickers [4]: the first was to check if operation extracting with increased voltage at 34.6kV would be feasible, i.e. 4/3 of the 26kV nominal voltage, enabling to use 3 instead of 4 kicker magnets to have an additional operational spare and also reduce the overall SPS impedance as well as rise time. No ferrite saturation was expected up to 35kV, this was tested experimentally; no non-linearity was found up to 34.6kV, Fig. 8. The system had previously been conditioned up to 40kV without beam. During the tests one breakdown occurred at 34.5kV; more conditioning is required.

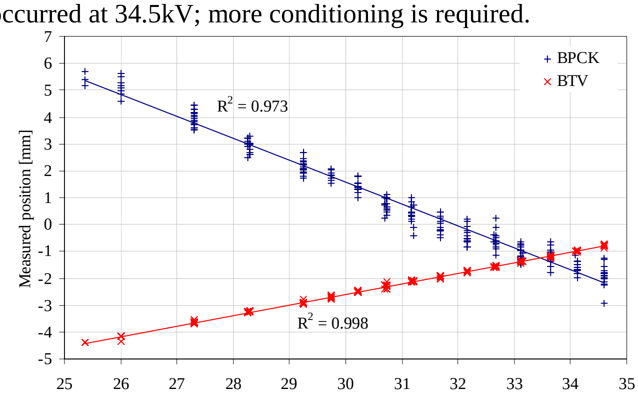

Figure 8: beam position as a function of MKE voltage. No saturation effect is visible.

The kicker waveform was measured by varying the kick timing in 2 µs steps, Fig. 9. The waveform showed a longer flat-top than the required 8 µs. The kick rise-time was ~8 µs as expected; however, the flat-top ripple was ±1%, Fig. 10, a factor of 2 above specification.

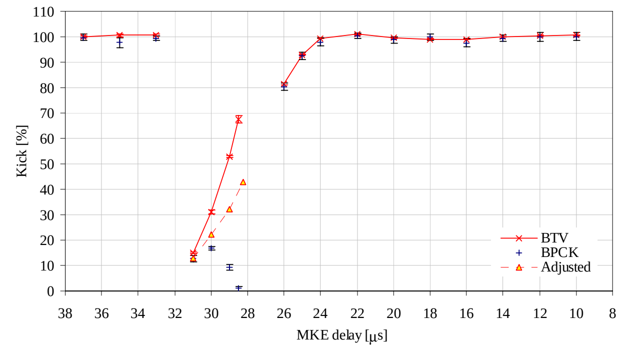

Figure 9: MKE kicker waveform measured by varying kicker timing. The "Adjusted" curve corrects for bunches kicked twice and extracted on the second turn.

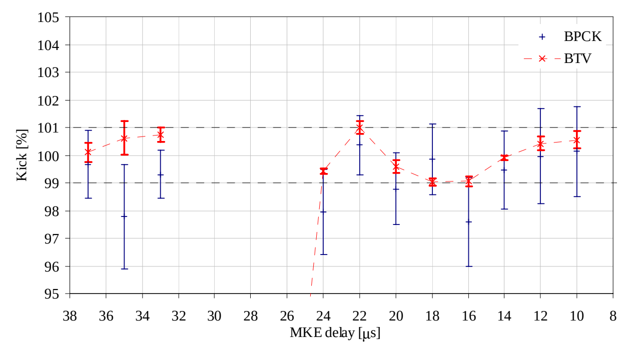

Figure 10: Kicker flat-top, showing ±1% ripple.

CONCLUSION

The SPS LSS6 extraction and TT60 line were commissioned using a single LHC pilot and multiple bunches. All of the test and measurement objectives were attained and beam extracted and transported onto the TED beam dump at the end of the line. Equipment and instrumentation performance was quantified and found to be as expected, with the exception of the extraction kicker flat-top ripple which was out of tolerance, requiring further fine-tuning of the PFN. The PFN kick pulse length could also be further reduced. The feasibility of operating with only 3 extraction kickers was demonstrated. The BTV screens were found to provide a more accurate position measurement than the couplers for the low intensities used.

REFERENCES

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