INITIAL RESULTS FROM BEAM COMMISSIONING OF THE LHC BEAM DUMP SYSTEM

B.Goddard, I.Agapov, E.Carlier, L.Ducimetière, E.Gallet, M.Gyr, L.Jensen, R.Jones, V.Kain, T.Kramer, M.Lamont, M.Meddahi, V.Mertens, T.Risselada, J.Uythoven, J.Wenninger, W.Weterings, CERN, Geneva, Switzerland

Abstract

Initial commissioning of the LHC beam dump system with beam took place in August and September 2008. The preparation, setting-up and the tests performed are described together with results of the extractions of beam into the dump lines. Analysis of the first detailed aperture measurements of the extraction channels and kicker performance derived from dilution sweep shapes are presented. The performance of the other equipment subsystems is summarised, in particular that of the dedicated dump system beam instrumentation.

INTRODUCTION

The LHC beam dump system is a critical component of the machine protection system [1], and is designed to safely extract the beam from 450 GeV to 7 TeV with beam energy up to 350 MJ. Its main components comprise (per beam) 15 MKD extraction kicker magnets, 15 MSD Lambertson septum magnets, 4 horizontal and 6 vertical MKBH/V dilution kickers and the external TDE dump block. A fixed diluter TCDS and mobile collimator TCDQ protect the MSD and LHC machine against unsynchronised dumps. Dedicated instrumentation for beam steering and diagnostics comprises (per beam) 3 BTV beam screens, 3 BPM beam position monitors, 2 BCT beam current transformers and 32 beam loss monitors BLM. The dump kickers were extensively tested without beam in the period between December 2007 and August 2008 [2].

The tests for the beam dump systems were prepared in detail as part of the LHC commissioning plan [3]. LHC optics sequences with complete aperture information were prepared for the extraction regions and dump lines. For the injection test a 10 km long “transfer line” sequence was used, comprising SPS extraction in LSS4, TT40, TI 8, LHC arcs 78 and 67, and TD62. The sequences were used in an online version of madx [4] to generate measurement bumps and knobs.

RESULTS

During the series of beam injection tests from 8th August to 9th September 2009, pilot beam of 5×10^9 p+ was repeatedly injected into parts of the LHC [5]. These tests were used primarily for the commissioning of the full TI 2 and TI 8 transfer lines and both injection systems in the LHC, but also for the first beam tests of the beam dump system for beam 2 during the third test (5 – 7th September). The dump system for beam 1 was first used with beam on September 10th, and a limited series of checks and commissioning measurements were made on both systems during the few days of LHC ring operation between 10th and 19th September, in all cases using low intensity single bunch beam of 2 – 5×10^9 p+.

Element Strengths

In the 3rd injection test beam 2 was initially extracted to the TDE without the MKD kickers, using instead the two upstream horizontal orbit correctors in the LHC to provide the required 0.35 mrad and 50 mm at the MSD septum entrance. Beam was seen on the first shot on the BTVDD screen, but the beam trajectory in TD62, Fig. 1, was significantly too high in the vertical plane, with large beam losses along the TD line. Vertical correctors were used to steer through, with an angle of over 100 μrad required to reduce the losses. The problem was quickly found to be due to a simple 200 μrad error in the requested MSD strength.

The extraction and dilution kickers were then switched on and the beam was extracted correctly, Fig. 2, with the kicker strengths observed to be in the correct range. Subsequent extractions during the ring commissioning with uncaptured beam showed that the sweep form was of the correct diameter, indicating that the dilution kicker strengths were as expected, and that the beam was reasonably well centred on the extraction block (see for example Fig. 6), indicating that the MKD, MKB and MSD strengths were correct.

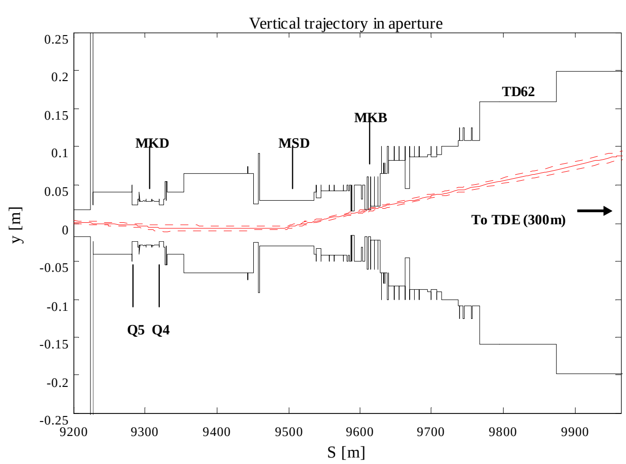

Figure 1: Vertical trajectory of first beam extracted into TD62. A ±3 sigma envelope for nominal optics and measured emittance is shown. The aperture restriction 15 m before the MKB is the differential pumping section.

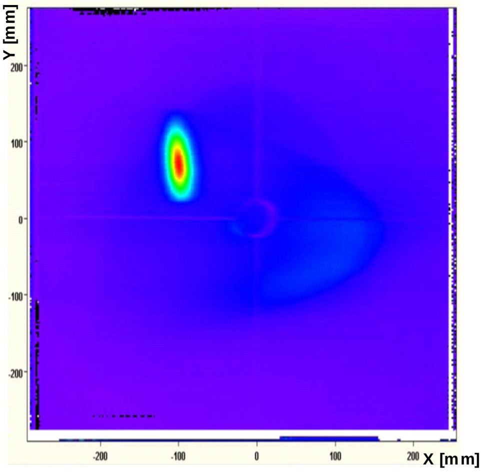

Figure 2: BTVDD image of first beam extracted to TDE 62 using extraction kickers. The visible beam spot is about 30 mm wide and 80 mm high.

Synchronisation

The locking of the redundant triggering and synchronisation (TSU) digital PLLs to the revolution frequency signal worked very well, Fig. 3, with a jitter of a few ns and locking over a wide range of RF frequency trims. The extracted beam was roughly synchronised with the MKD/MKB kickers, with the delay adjusted to bring the single bunch into the middle of the kicker gap. The "Inject and Dump" mode was rapidly commissioned, Fig. 4, which allows the beam to be dumped after completing only a partial turn, or any predetermined number of turns.

Later in the LHC commissioning, in particular during the initial RF capture studies, the bunch phase moved significantly with respect to the kicker trigger, with aborts happening throughout the kicker flat-top and indeed during the kicker rise-time.

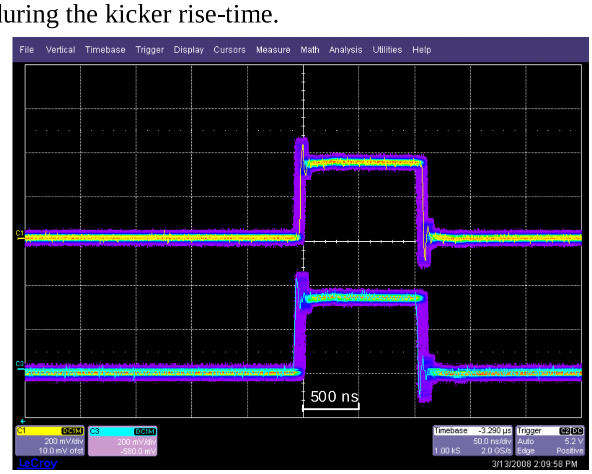

Figure 3: Locking of the two dump triggering and synchronisation unit PLLs to the RF revolution frequency.

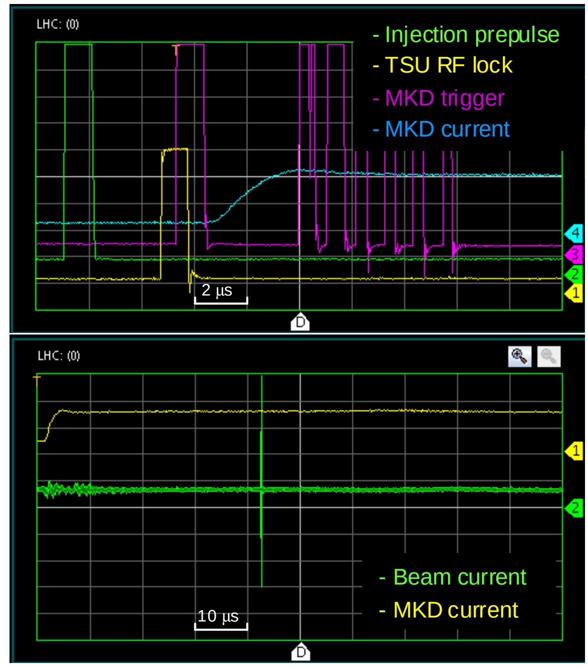

Figure 4: Synchronisation during "Inject and Dump". The injection prepulse, PLL lock and initial MKD trigger are followed by multiple re-trigger signals. The extracted bunch is in the centre of the kicker waveform.

Beam Sizes and Optics

The presence of 3 widely-spaced BTV screens in the dump lines with no intervening focussing elements should make an ideal location for emittance and optics parameter measurement. This was attempted with measured profiles fitted with 2D Gaussians, including a term for a skew component. The resulting beam sigmas did not give a sensible answer for the optical parameters at the entrance of the dump line; there is a suspicion that the scale factor for the large BTVDD screen was incorrect by 18%, which would affect the results. This is not consistent with the results from the steering analysis and must be investigated with more measurements in 2009

Aperture Measurements

A detailed series of aperture measurements was planned but unfortunately were only just begun when the LHC operation abruptly ceased. The measurements used the technique of free oscillations from two upstream correctors to adjust the measurement phase [5], and were performed with a small pilot bunch of 2×10^9 p+ with measured 1 σ RMS normalised transverse emittances of 1.0 and 0.8π µm in the H and V planes respectively. The partial results for the horizontal plane are shown in Table 2, where the edge of the beam deduced from the measurements is tabulated in nominal beam sigma. The error on this measurement is at least 1 or 2 nominal sigma. With such limited measurements and also without detailed correction of the orbit in P6 only very limited conclusions could be drawn regarding the aperture; essentially that loss-free extractions were possible, that no major problems were evident, and the measurement technique was demonstrated to work well.

Table 2: Measured apertures (nominal sigma) in the horizontal plane for the beam 1 dump system. The measurement error is 1-2 sigma.

Meas. Phase [deg]	+ve		-ve	
	Limit	Location	Limit	Location
0	12.5	Q4	6.5	TCDS
30	13.5	Q4	6.5	TCDS
60	13.5	TCDS	n/a	n/a
90	7.5	TCDS	13.5	MSDC

Beam Dump Diagnostics

The beam dump diagnostics system is reported in detail in [6]. The automatic analysis for MKD and MKB kickers produced good results, including the finding of some disconnected trigger cables which led to a repair and an update in the procedure for maintenance. The analysis of BI systems started with beam, which was mainly the BTVDD screen. The analysis results and references agree well, for example Fig. 6 taken with uncaptured beam, which shows that the MSD, MKD and MKB strengths are all correct, with the sweep well-centred.

Figure 6: Comparison between analysed extraction sweep (red and blue) and simulated sweep (green) on BTVDD.

Beam Instrumentation

The dedicated instrumentation for the beam dump system worked extremely well, with loss monitors, BTV screens and BPMs all available immediately. All data was stored and available for analysis in the logging system. Loss monitor sensitivity was good enough to allow accurate aperture measurements, and the screen profiles proved invaluable for the initial steering of the dump lines and debugging of the strength problem with the MSD. The large BTVDD screen in particular provided a wealth of data for the post operation diagnostic checks, Fig. 7.

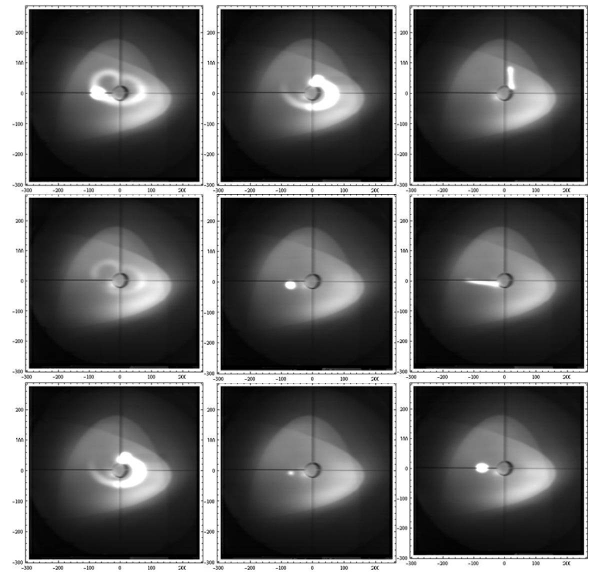

Figure 7: Various beam sweeps and sizes on the BTVDD.

CONCLUSION

The LHC beam dump system for both rings was successfully commissioned with pilot beam, during the injection tests and the short period of ring operation in 2008. The system has so far performed as expected, with the few tests performed in the limited time available. Only a small subset of the planned measurements could be carried out, enough to demonstrate the correct functioning of the main components and of the system as a whole. The main challenges for 2009-2010 will be increasing intensity and energy, abort gap cleaning and setting up of protection devices. The tools, techniques and teams deployed in 2008 performed well, and only minor improvements of diagnostic and analysis tools are needed.

ACKNOWLEDGEMENTS

The work described here is that of many people. The authors would like to acknowledge the great efforts of the CERN BT, BI, CO and OP groups, together with all the other teams involved, for the design, construction, installation and commissioning of the LHC dump system.

REFERENCES

[1] R.Schmidt et al., “Protection of the CERN Large Hadron Collider”, New J. Phys. 8 (2006) 290.
[2] J.Uythoven et al, “Results from the LHC Beam Dump Reliability Run”, Proc. EPAC’08, Genoa, 2008.
[3] http://lhccwg.web.cern.ch/lhccwg/overview_index.htm.
[4] A.Agapov, “The LHC Online Model : Design and Implementation”, CERN-AB-Note-2008-053.
[5] M.Lamont et al., “The LHC Injection Tests”, LHC-Performance-Note-001, CERN 2008.
[6] J.uythoven et al., “Experience with the LHC Beam Dump Post-Operational Checks System”, PAC ’09.