BEAM COMMISSIONING AND PERFORMANCE CHARACTERISATION OF THE LHC BEAM DUMP KICKER SYSTEMS

J. Uythoven, E. Carlier, L. Ducimetière, B. Goddard, V. Kain, N. Magnin
CERN, Geneva, Switzerland

Abstract

The LHC beam dump system was commissioned with beam in 2009. This paper describes the operational experience with the kicker systems and the tests and measurements to qualify them for operation. The kicker performance was characterized with beam by measurements of the deflection angles, using bunches extracted at different times along the kicker sweep. The kicker performance was also continuously monitored for each dump with measurement and analysis of all kick pulses, allowing diagnostic of errors and of long-term drifts. The results are described and compared to the expectations.

INTRODUCTION

The LHC [1] saw one month of beam operation at the end of 2009 (20 November to 16 December) with beam energies up to 1.2 TeV. After a short winter stop, operation started again at 27 February 2010 with beam energies up to 3.5 TeV. The beam dumping system is at the heart of the machine protection system and has to perform reliably under all circumstances. To obtain the high system reliability great care is taken during its commissioning and operation. This paper reports on the commissioning and performance of the LHC beam dumping system kickers, from the start-up in 2009 to the beginning of May 2010.

SYSTEM CHARACTERISATION

Before operation or after system interventions the 2 x 15 extraction kickers MKD and 2 x 8 dilution kicker magnets MKB of the beam dumping system are characterised by so called 'energy scans'. The results of the energy scans are used to determine the system settings and serve as references for the eXternal Operation Check (XPOC) and Internal Operational check (IPOC) [2] which analyse each beam dump action.

During an energy scan the magnets are pulsed at one minute intervals over the complete energy range at 20 predefined energies, always performing five pulses at the same energy. The measured kicker magnet current waveforms are digitised and processed off-line to determine their characteristic points, see Figs. 1 and 2, resulting in a table of calibration results per magnet, listing the average value and variance for the characteristic points at each energy. The tables for the different generators are then used to:

(1) Determine any anomalies in kicker behaviour, by checking for 'outliers' and comparison against results from previous energy scans.

(2) Determine the high voltage settings to obtain the required MKD and MKB system deflection angles by combining the results with the laboratory measurements, consisting of simultaneous current and magnetic field measurements [3].

(3) Check on synchronisation between the different MKD generators. If required, delays are adjusted by varying the trigger voltage as a function of energy or by adding delay modules in the generator.

(4) Determine references for the XPOC and IPOC checks.

(5) Obtain references for the energy tracking of the generators [4].

Any new settings or energy tracking references are uploaded to a separate data base, from which a check is made against the values loaded in the hardware, before each beam injection into the LHC.

Fig. 3 shows as example the measured extraction kicker rise time for the different MKD generators, resulting from an energy scan.

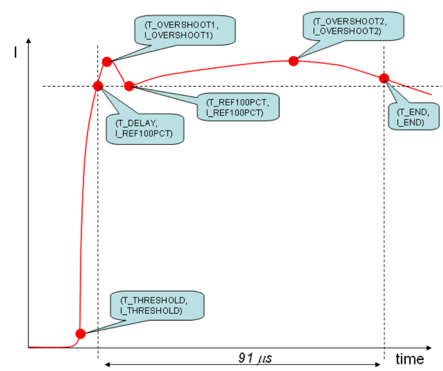

Figure 1: Description of the characteristic points of the MKD extraction kicker current waveform.

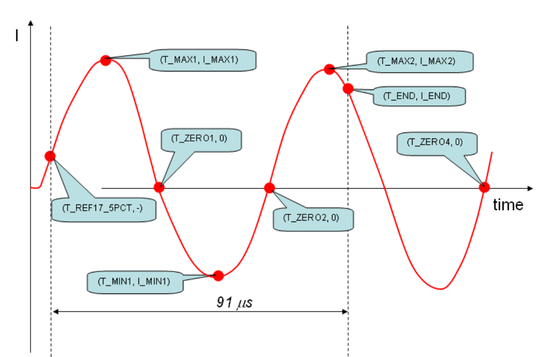

Figure 2: Description of the characteristic points of the MKB dilution kicker current waveform.

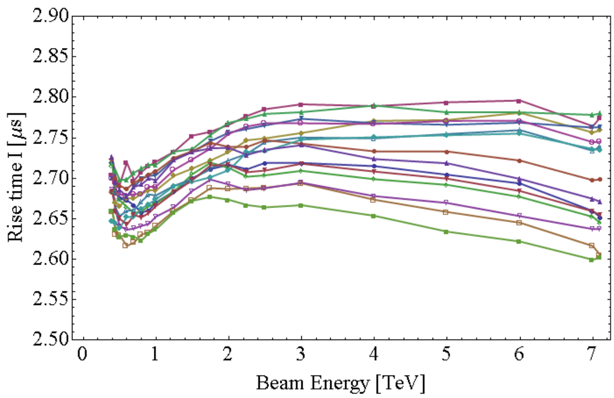

Figure 3: Measured current rise time for the 15 Beam 2 extraction kicker magnets, resulting from an energy scan.

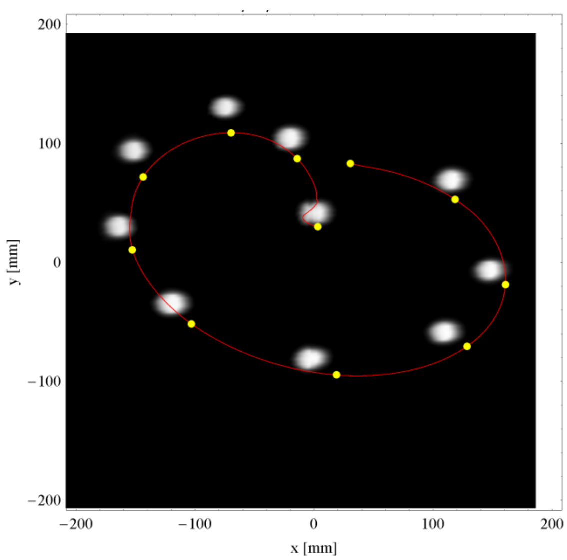

Figure 4: BTV image of a dumped 450 GeV beam with 10 bunches distributed over the ring circumference, compared with their theoretical positions.

SYSTEM PERFORMANCE

The applied high voltage settings for the extraction and dilution kicker magnets resulted in loss free extraction of the beams down the extraction line for all beam energies used so far. The image on the BTVDD screen, just in front of the beam dump block and 970 m downstream of the MKD magnets, of the beam dumped at 450 GeV (injection energy) has been compared with the expected position calculated from the measured current waveforms, see Fig. 4. Considering any variation in closed orbit at the extraction point, the agreement between measurement and expected position (yellow dots) is very good.

At higher beam energies a vertical error of the BTVDD image, increasing with energy up to almost 50 mm at 3.5 TeV beam energy, was measured. This was traced down to a calibration error of the vertically deflecting septum. Incorporating the corrected calibration curves, there is a remaining vertical error of about 15 mm at 450 GeV beam energy and almost no vertical error at 3.5 TeV. No significant dependence of the horizontal beam position on energy was measured.

For every beam dump the characteristic points on the kicker current waveform were determined by the XPOC and IPOC systems and compared with their references. Table 1 compares some applied XPOC tolerances for the different characteristic points with the difference between results from an energy scan in September 2009 and April 2010. The number of analysed dumps and false XPOC results caused by the MKD kicker waveforms are listed in Table 2. No false XPOCs of the MKB waveforms were recorded. False IPOCs only occurred in the case of failure of the IPOC ADC card.

A false XPOC result, either because of the kicker waveform analysis, but also when beam losses above threshold are registered by the beam loss monitors, stops the operation of the LHC and an acknowledgement of a beam dumping system expert is required to be able to inject any further beam into the accelerator.

Table 1: XPOC Tolerances and Stability over 7 Months

	Tolerance	**Stability**
MKD Amplitude	± 1 %	± 0.4 %
MKD Rise time	± 50 ns	± 30 ns
MKD Delay	± 50 ns	± 30 ns
MKD Overshoot1	± 0.7 %	± 0.3 %
MKD Overshoot2	± 0.5 %	± 0.2 %
MKD Pulse Length	± 0.5 %	± 0.25 %
MKB Amplitude	± 2 %	± 0.15 %
MKB End Point	± 2 %	± 0.3 %
MKB T 17.5 % Ampl.	± 500 ns	± 15 ns
MKB T Period.	± 500 ns	± 30 ns

Table 2: Operational Statistics

	Beam 1	**Beam 2**
Number of dumps 2009	1366	1175
Number of dumps 2010 (until end of April)	1689	1715
2010 XPOC failures MKD	0	3
2010 MKD System faults	5 (0.3 %)	11 (0.6 %)

The MKD overshoot 1 tolerance was increased from 0.5 % to 0.7 % as at rare occasions, but always after pulsing at 450 GeV following a 3.5 TeV pulse, the tolerance limit of 0.5 % was just reached, a phenomenon presently being investigated. The MKB tolerances have been taken larger than the MKD tolerances, as the system is far less critical: an MKD failure could possibly lead to much more damage to the LHC than a dilution failure. The aim of the tight XPOC tolerances for the MKD system is to check the system stability and to detect system failures before they become important and could lead to real performance or safety degradation.

HARDWARE FAILURES

All beam dumping system hardware failures were caught by the XPOC system and/or IPOC system [2]. There were no beam dumping system failures which would have caused any damage in case of higher beam intensities, assuming that all absorbers, like the TCDQ, are correctly positioned.

The most serious failure occurred several times in 2009 when the MKD and MKB kickers pulsed in phase with each other, but asynchronous with the particle free abort gap. This error was traced back to a problem within the redundancy logic of the Trigger Synchronisation Unit firmware in case of dump request during the duration of the revolution frequency pulse. The problem did not re-occur anymore after the firmware upgrade.

In the 2009 – 2010 stop one generator was inspected because the XPOC tolerance window on the pulse length (R_end) had to be increased during 2009 operation. Another generator was exchanged during the same stop because of instabilities detected. In both cases erosion of high current contacts were detected, partly due to not sufficiently tightening of the contacts. Other hardware failures caused a perfect, internally triggered beam dump, but reduced the system availability:

(1) Broken fuses on the MKB power trigger converter.
(2) Failure of underrated capacitors on power trigger units.
(3) Resistors which detect conduction of the switch not via the GTO stack were broken, leading to a loss in redundancy of switch surveillance.
(4) Breakdown of the inverters in the cooling elements of the MKD generators.
(5) IPOC digitizer cards failures (factory recall).
(6) Change of 30 kV MKD main power converter due to instabilities and change of compensation circuit power converter.
(7) Failures of 5 V power supplies.
(8) Glitches of the vacuum signal causing interlocks.
(9) One diagnostics failure falsely indicated a switch error.

The distribution of the hardware failures in 2010 is illustrated in Fig. 5. It is shown in Fig. 6 that all failures were significantly reduced in April 2010 compared to March 2010, except for the failures due to the power trigger unit, for which a replacement program is now ongoing.

Two consecutive energy ramps with beam were lost around 920 GeV because of an interlock of the beam energy tracking system [4]. The measured voltage on the MKD compensation circuit capacitors was outside the 0.5 % tracking window. This was caused by not performing an energy scan and updating the energy tracking tables after the replacement of an MKD compensation circuit power converter, about 3 months earlier.

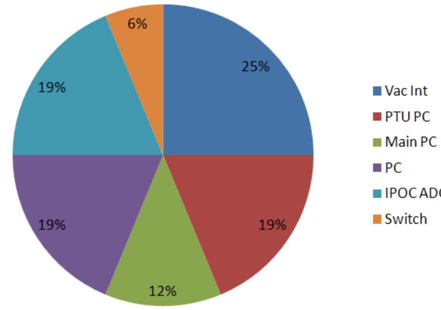

Figure 5: Distribution of the 16 hardware failures during operation in 2010 (up to end of April).

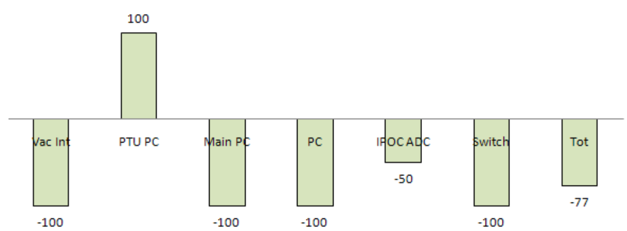

Figure 6: Relative change in system faults by April 2010 compared to March 2010.

CONCLUSIONS AND OUTLOOK

The LHC beam dump kicker systems functioned according to expectations during the 2009 and the first part of the 2010 operational period. Standard procedures for in-situ calibration, so called energy scans, are used to determine the kicker settings and provide references for automatic kicker waveform analysis after each dump. This automatic analysis with stringent limits has proven to be useful to detect upcoming kicker generator problems, like erosion of contacts due to high currents. All beam dumping system failures were caught by the automatic analysis or the interlock system. A consolidation of failing industrial components is ongoing. Failure rates continue to decrease over the operational period.

REFERENCES

[1] The LHC Design Report: "The LHC Main Ring", Vol. 1, CERN, Geneva 2004, CERN-2004-003-V-1
[2] J. Uythoven et al., "Experience with the LHC beam dump post-operational checks system", Proc. PAC09, May 4-8 2009, Vancouver, Canada.
[3] J. Uythoven et al., "Calibration Measurements of the LHC Beam Dumping System Extraction Kicker Magnets", Proc. EPAC06, June 26-30 2006, Edinburgh, UK.
[4] E. Carlier et al., "The Beam Energy Tracking System of the LHC Beam Dumping System", Proc. ICALEPCS2005, October 10-14 2005, Geneva, Switzerland.