CERN
Esplanade des Particules 1 P.O. Box
1211 Geneva 23 - Switzerland

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MPS COMMISSIONING PROCEDURE

MPS Commissioning Aspects of the Beam Charge Change Monitoring (BCCM) System

ABSTRACT:

This document describes commissioning procedures for the **LHC Beam Charge Change Monitoring (BCCM) system**.
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DOCUMENT PREPARED BY:	DOCUMENT TO BE CHECKED BY:	DOCUMENT TO BE APPROVED BY:
M. Gasior, SY/BI T. Levens, SY/BI	D. Alves, T. Lefevre	J. Uythoven M. Solfaroli Camillocci D. Wollmann C. Wiesner

DOCUMENT SENT FOR INFORMATION TO:

lhc-eic, lhc-machine-coordinators

HISTORY OF CHANGES

REV. NO.	DATE	PAGES	DESCRIPTIONS OF THE CHANGES
1	2021-07-20	20	First draft for discussion
2	2021-11-19	21	Version presented to the MPP - BCCM intensity tolerance properly addressed - Added one beam test for the energy above 0.5 TeV

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1. INTRODUCTION

The LHC is protected against potentially dangerous beam losses by a distributed Beam Loss Monitoring (BLM) system, based on some four thousand detectors. To provide an additional level of safety, the LHC is equipped with a Beam Charge Change Monitoring (BCCM) system, which detects fast beam charge drops and triggers beam dumps for their potentially dangerous rates. The BCCM system is redundant for either LHC beam and based on signals from four beam sensors, so it is much simpler than the large and distributed BLM system.

The challenging beam dump threshold levels defined for the BCCM system and the required operational reliability proved to be difficult to satisfy at the same time. The Run 1 and Run 2 BCCM versions based on signals from Fast Beam Current Transformers (FBCTs) did not achieve the required performance to operate as an LHC protection system [1-3]. Because of these difficulties, a completely new system version based on signals from Beam Position Monitors (BPMs) was designed, prototyped and tested with beam at the end of Run 2. This document concerns only this new BCCM system, which has the following features:

- The BPM signals are much larger than the FBCT signals, giving more options for their analog processing and the sum of BPM electrode signals is still sufficiently independent of the actual beam position and bunch length.
- The beam synchronous ADC sampling rate is 40 MHz, four times lower than the one used in the previous systems, facilitating the digital signal processing.
- Chosen signal processing algorithms do not require the ADC sampling phase to be adjusted to the beam signal, which increases the system robustness significantly.
- The system bandwidth is controlled by analog low pass filters.
- The new algorithm of evaluating turn-by-turn beam intensity (1) changes is based on a simple concept of a one-turn digital delay line: the beam signal changes are calculated for samples spaced exactly by one revolution period, allowing simple and efficient signal processing in the time domain.

2. SCOPE

This document covers the tests which will be performed to validate the correct functioning of all the components of the BCCM system in relation with the Machine Protection System (MPS) for both LHC beams. The tests cover all the components of the BCCM system and its connections to the MPS.

(1) In the document terms "beam intensity" and "beam charge" are equivalent.

3. PURPOSE

This document describes the procedures concerning the tests and their sequence, related to the participation of the BCCM system in the MPS.

Each described test is labelled with at least one of the letters listed in Table 1. The letters specify at which interval, or at which occasion the described test needs to be repeated.

Table 1: Labelling of the tests repetition

Label	Repetition
S	To be repeated after every **s**hutdown
E	To be repeated after **e**nd-of-year stops
C	To be repeated after any significant **c**hange in the system
D	To be repeated after every beam **d**ump

This document is meant to be the reference document for the checklist, which will be used during the commissioning of the MPS.

All test results are reported by logged BCCM system properties.

4. THE LAYOUT

The whole BCCM system consists of four systems, two redundant systems per each of the LHC beams, which are referred to as system B1-A and system B1-B for LHC Beam 1 and system B2-A and B2-B for LHC Beam 2. The four systems use signals from the following BPMs:

- BCCM system B1-A: BPMYA.5R4.B1
- BCCM system B2-A: BPMYB.5R4.B2
- BCCM system B1-B: BPMYA.6R4.B1
- BCCM system B2-B: BPMYB.6R4.B2

The BPMs used by the BCCM system are shared with the standard BPM system, with the passive splitting of the electrode signals on the far end of the cables coming to rack BY05 located in UA47. The rack accommodates the whole BCCM system as well as the BPM electronics of the shared BPMs. A photograph of all the BCCM electronics is shown in Fig. 1.

Four signals of four electrodes of each BPM used in the system are processed by two identical BCCM front-ends. The BPM signals of systems B1-A and B2-A are processed by BCCM front-end A while the signals of systems B1-B and B2-B are processed with BCCM front-end B. The front-ends provide low-pass filtering of the signals, their summation, amplification and an envelope detection. The resulting four signals for BCCM systems B1-A, B2-A, B1-B and B2-B are sent to two VME acquisition cards, providing their 16-bit digitalisation at a 40 MHz rate, synchronously to the circulating beam. Each of the VME cards is equipped with an FPGA processing the ADC samples and providing all safety-critical functionality of the system.

The beam signals of systems B1-A and B2-A are processed by the VME acquisition card accommodated in VME crate A and the beam signals of systems B1-B and B2-B are processed by the VME acquisition card accommodated in VME crate B. Each of the two crates has a dedicated VME rear-transition-module providing the interface to one of the two CIBU modules connected to the Beam Interlock System (BIS).

Each of the four BCCM systems evaluates turn-by-turn integrals of BPM sum signals proportional to the beam current and the resulting charges are scaled so that the results match readings of the LHC FBCTs. The BCCM operates with beam charges and its beam dump thresholds are also defined in beam charges.

Fig. 1: A photograph of BCCM electronics accommodated in rack BY05 in UA47. From top to bottom: BCCM front-end A, a ventilation unit, VME crate A, BCCM front-end B, a ventilation unit, VME crate B. Two CIBU modules for systems A and B are not visible in the photograph and are located at the bottom of the rack.

The beam charge change is evaluated by subtracting beam charges from two consecutive turns. The subtraction result is every turn compared to the one-turn dump threshold, which depends also on the actual beam energy. The actual beam energy is received from the General Machine Timing (GMT) decoded by the system FPGA. The one-turn charge changes are integrated in five other time windows and compared to the corresponding dump thresholds. If any of the beam charge changes is larger than its corresponding dump threshold, then the system removes its beam permit signal, which in turn initiates a beam dump through the CIBU channel.

The lengths of the integration windows and their corresponding dump thresholds for the two beam energy ranges are summarised in Table 2 [4].

Table 2: Integration windows and their beam dump thresholds in units of 10^{11} proton charges [4].

Energy [TeV]	1 turn	4 turns	16 turns	64 turns	225 turns	1125 turns
<0.5	6	6	6	6	6	6
≥ 0.5	3	3	3	3	2	0.5

Please note that the standard charge unit in the BCCM system is 10^{11} proton charges, denoted in the document as $10^{11}\ p+$. This way the system can use fixed-point arithmetic. The system beam dump thresholds are set and logged assuming this convention.

All signal processing and dump generation is performed in the system FPGA. The system software (FESA class) provides only an interface to configure the system FPGA, monitor the system functionality and log system data and parameters.

All relevant system parameters are logged on change or once per hour if their values are constant. The most important system data is logged at 1 Hz. Appendix A contains the list of logged quantities.

5. TESTS PERFORMED DURING THE HARDWARE COMMISSIONING

Each electronic block of the BCCM system is tested for its full functionality in the laboratory prior to its installation. During hardware commissioning the system signal processing chain must be checked as much as it is possible without circulating beam, to detect potential anomalies as early as possible. The tests can only partially verify the system functionality and must be imperatively followed by beam tests described in Chapter 8.

All tests during hardware commissioning involve checking BCCM logged parameters and data. The parameters are logged "on change" or once per hour when their values are constant, to make sure that their logging is operational. BCCM data is logged once per second. If data concerns minima, maxima, or standard deviations, then their values are calculated for 1 s periods.

All BCCM parameters and data have their corresponding software (FESA) properties and in principle their values can be checked at the software level. However, checking BCCM parameters in the logging database allows also verifying the logging itself.

Parameters of the BCCM front-ends are also logged, but this data is considered as auxiliary, not critical for the system operation and meant to be used only by the system experts for checking details of the system operation.

5.1 CONDITIONS REQUIRED TO START AND PERFORM TESTS

- Both BCCM front-ends are installed and operational, their beam signal inputs are connected to the BCCM BPMs and the RF outputs of the front-ends are connected to the respective ADC inputs.
- Both VME crates are operational with all their modules:
  - front-end computer;
  - card converting GMT signal distributed over RS485 (CTDCR card);
  - card converting 400 MHz RF clocks distributed over optical fibres to electrical signals, used to clock the system ADCs (RF RX D card);
  - VME FMC Carrier module hosting the ADC FMC mezzanine and system FPGA;
  - CIBU interface rear-transition-module, interfacing the system FPGA to the current inputs of the CIBU modules.
- Distribution of the 400 MHz RF clock is operational.
- System software is operational.
- Logging is operational.

5.2 DESCRIPTION OF THE TESTS

Each test shall be done separately for each of the BCCM systems, namely B1-A, B2-A, B1-B and B2-B.

#	Rep.	Action
1	S C	Check that the logged dump thresholds correspond to the values listed in Table 2. The logged values for the beam energy range below 0.5 TeV (encoded as A) should be as follows, in the "BCCM unis" of 10^{11} *p+*: – dump_Level_W1_A = 6 (window 1 → 1 turn) – dump_Level_W2_A = 6 (window 2 → 4 turns) – dump_Level_W3_A = 6 (window 3 → 16 turns) – dump_Level_W4_A = 6 (window 4 → 64 turns) – dump_Level_W5_A = 6 (window 5 → 225 turns) – dump_Level_W6_A = 6 (window 6 → 1125 turns) The logged values for the beam energy range 0.5 TeV or above (encoded as B) should be as follows: – dump_Level_W1_B = 3 (window 1 → 1 turn) – dump_Level_W2_B = 3 (window 2 → 4 turns) – dump_Level_W3_B = 3 (window 3 → 16 turns) – dump_Level_W4_B = 3 (window 4 → 64 turns) – dump_Level_W5_B = 2 (window 5 → 225 turns) – dump_Level_W6_B = 0.5 (window 6 → 1125 turns) Please note that the above values are the maximal dump level values and they are hardcoded in the FPGA code and cannot be increased. However, for beam commissioning or other important operational reasons their values can be lowered to increase the system sensitivity at the expense of potential dumps at lower beam loss rates. During the hardware commissioning tests the beam dump threshold levels should have their default maximum values.
2	S C	Check that the presence flag for the 400 MHz RF clock is TRUE. The flag is logged as RFclkPresFlag and state TRUE is marked as 1.

5.3 STATUS OF THE SYSTEM AFTER THE TESTS

After these tests, the system is as much checked as possible with the minimal set of prerequisites, namely the 400 MHz RF clock, system software and logging.

6. LINK TO OTHER EQUIPEMENT

This chapter considers only interfaces of the BCCM system related to MPS.

6.1 INTERFACES WITH THE BEAM INTERLOCK SYSTEM

The interface with the BIS is described in more detail in the corresponding test specification [5] and shall be tested within the scope of the BIS tests.

6.1.1 SIGNALS BETWEEN THE BCCM SYSTEM AND BEAM INTERLOCK SYSTEM

Each of the four BCCM systems is linked to the BIS via a CIBU channel and is connected to a maskable input. The BCCM uses Beam_Info signal from the CIBUs during the commissioning of the User_Permit connection to the CIBU module [5].

6.1.2 CONDITIONS AND SEQUENCE FOR A BEAM DUMP

The BCCM USER_PERMIT (see Fig. 2) of any of the four systems is set to FALSE if in that system:

- The detected beam intensity drop in one of the six integration windows is above the threshold limit for the actual beam energy range.
- The beam signal does not fit to the dynamic range of the system ADC.
- The 400 MHz RF clock, used to produce the 40 MHz clock for the system ADC, is missing, resulting in its presence flag to be in state FALSE.

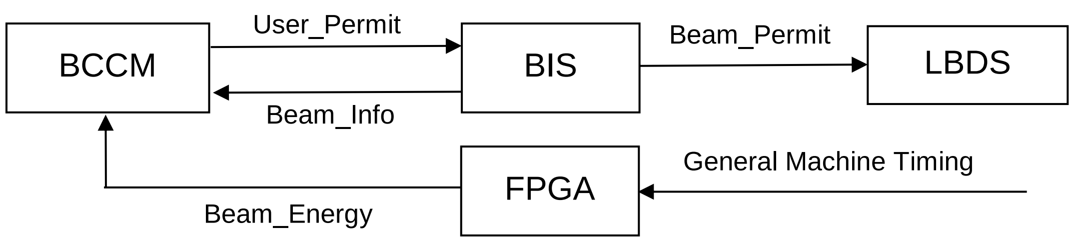

Figure 2: Schematic view of the signal flow for the Beam_Permit, Beam_Presence and Beam_Energy.

Please note that the actual beam energy distributed in the General Machine Timing (GMT) is decoded in the system FPGA and used to set the appropriate beam dump thresholds. However, this signal is not indispensable for system operation and therefore its lack does not cause a beam dump. Instead, in the absence of the beam energy information the system assumes that the beam energy is above 0.5 TeV and the lower dump threshold levels are used [4].

In order to remove dependencies which are not strictly necessary, once the beam energy becomes 0.5 TeV and the BCCM system switches the dump thresholds accordingly, the system stops checking actual beam energy [4]. The system starts checking the beam energy again after the beam has been dumped, upon execution of automatic procedures preparing the BCCM system for the next beam injection. At the same time all the system settings are initialised to their default values.

7. SYSTEM TESTS DURING THE MACHINE CHECKOUT

During this period the BCCM system will be checked as much as possible without beam in the machine. As one of the challenges of its reliable operation is potential interference originating in different LHC power systems, first checks are done on the values of the most important quantities measured by the BCCM system without beam, to confirm that they do not suffer from interferences.

7.1 CONDITIONS REQUIRED TO START AND PERFORM TESTS

- All BCCM hardware is operational.
- Distribution of the 400 MHz RF clock is operational.
- The system software is operational.
- Logging is operational.
- SMP beam energy distribution is operational.

7.2 DESCRIPTION OF THE TESTS

Each test shall be done separately for each of the BCCM systems, namely B1-A, B2-A, B1-B and B2-B.

#	Rep.	Action
1	S C	Check that the one-turn beam intensity values are published by the BCCM systems with no beam in the machine. Their 1 s logged minimum, maximum and average should be within the following ranges: – int_1T_Min $\geq -0.1 \times 10^{11}$ *p+* [(2)] – int_1T_Max $\leq 0.1 \times 10^{11}$ *p+* [(2)] – |int_1T_Avg| $\leq 0.01 \times 10^{11}$ *p+* [(2)] (|x| denotes the absolute value of x)

[(2)] Temporary value to be updated according to results of actual measurements on the installed hardware.

2	S C	Check that the beam intensity change values for the first one-turn integration window are published by the BCCM systems with no beam in the machine. Their 1 s logged minimum, maximum and average should be within the following ranges: – d_Int_W1_Min ≥ – 0.01 × 10^{11} *p+* (2) – d_int_W1_Max ≤ 0.01 × 10^{11} *p+* (2) – |d_int_W1_Avg| ≤ 0.01 × 10^{11} *p+* (2)
3	S C	Check that the beam intensity change values for the second four-turn integration window are published by the BCCM systems with no beam in the machine. Their 1 s logged minimum, maximum and average should be within the following ranges: – d_Int_W2_Min ≥ – 0.01 × 10^{11} *p+* (2) – d_int_W2_Max ≤ 0.01 × 10^{11} *p+* (2) – |d_int_W2_Avg| ≤ 0.01 × 10^{11} *p+* (2)
4	S C	Check that the beam intensity change values for the third 16-turn integration window are published by the BCCM systems with no beam in the machine. Their 1 s logged minimum, maximum and average should be within the following ranges: – d_Int_W3_Min ≥ – 0.01 × 10^{11} *p+* (2) – d_int_W3_Max ≤ 0.01 × 10^{11} *p+* (2) – |d_int_W3_Avg| ≤ 0.01 × 10^{11} *p+* (2)
5	S C	Check that the beam intensity change values for the fourth 64-turn integration window are published by the BCCM systems with no beam in the machine. Their 1 s logged minimum, maximum and average should be within the following ranges: – d_Int_W4_Min ≥ – 0.01 × 10^{11} *p+* (2) – d_int_W4_Max ≤ 0.01 × 10^{11} *p+* (2) – |d_int_W4_Avg| ≤ 0.01 × 10^{11} *p+* (2)
6	S C	Check that the beam intensity change values for the fifth 225-turn integration window are published by the BCCM systems with no beam in the machine. Their 1 s logged minimum, maximum and average should be within the following ranges: – d_Int_W5_Min ≥ – 0.01 × 10^{11} *p+* (2) – d_int_W5_Max ≤ 0.01 × 10^{11} *p+* (2) – |d_int_W5_Avg| ≤ 0.01 × 10^{11} *p+* (2)
7	S C	Check that the beam intensity change values for the sixth 1125-turn integration window are published by the BCCM systems with no beam in the machine. Their 1 s logged minimum, maximum and average should be within the following ranges: – d_Int_W6_Min ≥ – 0.01 × 10^{11} *p+* (2) – d_int_W6_Max ≤ 0.01 × 10^{11} *p+* (2) – |d_int_W6_Avg| ≤ 0.01 × 10^{11} *p+* (2)
9	S C	Check that the logged state of the actual beam energy read from the SMP is the range below 0.5 TeV. This is indicated by parameter beamEnergyFlag = 0.
10	S C	Manually turn off the reception of SMP energy information using the appropriate setting in the system software. The lack of this information switches the system to operate in the energy range 0.5 TeV or more. Check that this is indicated as beamEnergyFlag = 3.
5	S C	Manually turn on the reception of SMP energy information using the appropriate setting in the system software. With no beam in the machine this information switches the system to operate in the energy range below 0.5 TeV. Check that this is indicated as beamEnergyFlag = 0.

7.3 STATUS OF THE SYSTEM AFTER THE TESTS

After these tests, the system is as much checked as possible with no beam in the machine.

8. TESTS WITH BEAM

A number of tests must be performed on the BCCM system with beam to validate its protection functionality under real conditions. Before these tests, the LHC Beam Loss Monitoring system must be fully commissioned with beam and must reach its full performance.

The BCCM tests should be done with the minimal beam intensities allowing checking the tested system functionality. For some tests the beam dump thresholds need to be lowered to force the system to provoke a beam dump for beam loss rates much lower than the ones used during regular operation. This way one can avoid exposing the LHC machine for risks related to important beam losses while still performing full system testing.

Please note that changing the beam dump threshold levels does not affect the safe operation of the system, as the settings can only be lowered below the limits hardcoded in the system FPGA. In the worst case the changed settings left for regular operation will lead to a beam dump with abnormally small intensity change rates.

Beam signals from the BPMs do not change significantly with beam energy, especially for the range 0.45 – 0.5 TeV. Therefore, in order to perform almost all tests at 0.45 TeV also for the second BCCM energy range of 0.5 TeV and above, the BCCM system can be manually switched to operate in the higher energy range with the smaller dump thresholds. This is done by switching off the reception of the SMP energy information. Again, this feature does not affect the safe operation of the system, as in the worst case the system will operate with the lower beam dump thresholds, which may cause a beam dump with abnormally small beam intensity change rates.

As the BCCM operation is based on BPM signals, the BCCM beam intensity readings are not fully independent of the beam position and bunch length, which requires that the BCCM intensity readings have some tolerance with respect to the reference FBCT data. To simplify the safe implementation of the dump threshold levels summarised in Table 2 the tolerance is asymmetric: the BCCM never underestimates the beam intensity and can overestimate it by up to 20 %. The system intensity readings are checked to stay within the tolerance range of [20, 0] % during the tests with beam and at every dump during the system regular operation for the intensities of 3×10^{11} or more, relevant for the BCCM operation.

As the BCCM system can potentially overestimate the beam intensity by up to 20 %, then it is guaranteed that beam dump requests are not issued only if the actual beam intensity change rates are 20 % smaller than the dump thresholds in the system specification.

The beam intensity tolerance of the BCCM system results in ranges of the intensity change rates for which the system may or may not issue a beam dump request. The dump uncertainty intensity ranges are defined by the tolerance [20, 0] % multiplied by the dump threshold levels defined in Table 2.

Proper operation of the BCCM is monitored every beam dump regardless of its cause. If during the dump the beam intensity is above the one-turn dump threshold for the energy of the dumped beam, then the BCCM system should also issue a beam dump request. The triggering of the system will be independently checked by a post-mortem module.

8.1 CONDITIONS REQUIRED TO PERFORM TESTS

- Whole BCCM hardware is operational.
- Distribution of the 400 MHz RF clock is operational.
- The system software is operational.
- Logging is operational.
- SMP beam energy distribution is operational.
- Beam Loss Monitoring system is fully commissioned and operational.
- Beam operation has been commissioned at least to the intensity required for the performed test.

Please note that almost all tests related to the BCCM operation for energies 0.5 TeV or more are performed at the injection energy, with the system manually switched to the sensitivities required for the higher energy range. Only the last test is done for the energy above 0.5 TeV with the intensity of 3×10^{11} $p+$ and for the test the energy ramp must have been commissioned at least for this intensity.

8.2 DESCRIPTION OF THE TESTS AT THE INJECTION ENERY

Each test shall be done separately for each of the BCCM systems, namely B1-A, B2-A, B1-B and B2-B.

8.2.1 TESTS WITH BEAM INTENSITY OF 3×10^{11}

The tests described in this section should be done with the beam intensity equal or greater than the one-turn beam dump threshold for energies 0.5 TeV or more, namely 3×10^{11} $p+$. The beam bunch configuration is not important for the test.

If the exact required beam intensity cannot be setup, then a larger value should be used. Please note that the test is done at the injection energy, however, the dump thresholds are manually switched to the energy range of 0.5 TeV or more.

#	Rep.	Action
1	SEC	Check that the beam intensity as measured by the BCCM system and reported by property int1TAvg is within the SIT of [20, 0] %.
2	SEC	Manually turn off the reception of SMP energy information using the appropriate setting in the system software. Lack of this information switches the system to operate in the energy range of 0.5 TeV or more. Check that this is indicated as beamEnergyFlag = 3.
3	SEC	Dump the beam with the operator switch. Check that the BCCM system has also issued a beam dump request for the one-turn integration window. Check that the beam dump request is also reported in the logging as dumpFlagW1 = 1.

8.2.2 TESTS WITH BEAM INTENSITY OF 2.4×10^{11}

The tests described in this section should be done with the beam intensity smaller than the one-turn beam dump threshold for energies 0.5 TeV or more, namely 3×10^{11} $p+$, minus 20 % for the potential overestimation of the beam intensity by the BCCM system with respect to the FBCTs. The beam bunch configuration is not important for the test.

If the exact required beam intensity cannot be setup, then a smaller value should be used.

Please note that the test is done at the injection energy, however, the dump thresholds are manually switched to the energy range of 0.5 TeV or more.

#	Rep.	Action
1	C	Check that the beam intensity as measured by the BCCM system and reported by property int1TAvg is within the SIT of [20, 0] %.
2	C	Manually turn off the reception of SMP energy information using the appropriate setting in the system software. Lack of this information switches the system to operate in the energy range of 0.5 TeV or more. Check that this is indicated as beamEnergyFlag = 3.
3	C	Dump the beam with the operator switch. Check that the BCCM system has not issued a beam dump request for the one-turn integration window. Check that the beam dump request is not reported in the logging, which is indicated as dumpFlagW1 = 0.

8.2.3 TESTS WITH BEAM INTENSITY OF 6×10^{11}

The tests described in this section should be done with the beam intensity above the one-turn beam dump threshold for energies below 0.5 TeV, namely 6×10^{11} $p+$. The beam bunch configuration is not important for the test.

If the exact required beam intensity cannot be setup, then a larger value should be used.

#	Rep.	Action
1	S E C	Check that the beam intensity as measured by the BCCM system and reported by property int1TAvg is within the SIT of [20, 0] %.
2	S E C	Check that the BCCM system operates in the energy range below 0.5 TeV, which is indicated as beamEnergyFlag = 0.
3	S E C	Dump the beam with the operator switch. Check that the BCCM system has also issued a beam dump request for the one-turn integration window. Check that the beam dump request is also reported in the logging as dumpFlagW1 = 1.

8.2.4 TESTS WITH BEAM INTENSITY OF 4.8×10^{11}

The tests described in this section should be done with the beam intensity smaller than the one-turn beam dump threshold for energies below 0.5 TeV, namely 6×10^{11} $p+$, minus 20 % for the potential overestimation of the beam intensity by the BCCM system with respect to the FBCTs. The beam bunch configuration is not important for the test.

If the exact required beam intensity cannot be setup, then a smaller value should be used.

#	Rep.	Action
1	C	Check that the beam intensity as measured by the BCCM system and reported by property int1TAvg is within the SIT of [20, 0] %.
2	C	Check that the BCCM system operates in the energy range below 0.5 TeV, which is indicated as beamEnergyFlag = 0.
3	C	Dump the beam with the operator switch. Check that the BCCM system has not issued a beam dump request for the one-turn integration window. Check that the beam dump request is not reported in the logging, which is indicated as dumpFlagW1 = 0.

8.2.5 TESTS WITH BEAM INTENSITY OF 300×10^{11} OR MORE

The tests described in this section aim at checking the protection action of the BCCM system for beam loss rates integrated over four to 1125 turns. Instead of generating beam loss rates as stated in Table 2, the beam thresholds will be manually lowered to provoke beam dumps upon natural beam intensity decay at the injection energy. In order to have a sufficient absolute beam loss rate, it is required to have in the machine circulating beam of the total intensity of 300×10^{11} *p+* or more.

After each test a beam dump is generated and for the next test the machine must be refilled.

#	Rep.	Action
1a	S C	Prepare circulating beam at the injection energy with the intensity of at least 300×10^{11} *p+*.
1b	S C	Check that the beam intensity as measured by the BCCM system and reported by property int1TAvg is within the SIT of [20, 0] %.
1c	S C	Manually turn off the reception of SMP energy information using the appropriate setting in the system software. Lack of this information switches the system to operate in the energy range of 0.5 TeV or more. Check that this is indicated as beamEnergyFlag = 3.
1d	S C	By changing the value of property dumpLevelW6B, keep lowering the beam dump threshold for the integration window of 1125 turns and beam energies of 0.5 TeV or more until a beam dump is triggered. The operational value of the property will be automatically reset during preparations of the BCCM system for the next beam injection.
2a	C	Prepare circulating beam at the injection energy with the intensity of at least 300×10^{11} *p+*.
2b	C	Check that the beam intensity as measured by the BCCM system and reported by property int1TAvg is within the SIT.
2c	C	Manually turn off the reception of SMP energy information using the appropriate setting in the system software. Lack of this information switches the system to operate in the energy range of 0.5 TeV or more. Check that this is indicated as beamEnergyFlag = 3.
2d	C	By changing the value of property dumpLevelW5B, keep lowering the beam dump threshold for the integration window of 225 turns and beam energies of 0.5 TeV or more until a beam dump is triggered.

		The operational value of the property will be automatically reset during preparations of the BCCM system for the next beam injection.
3a	C	Prepare circulating beam at the injection energy with the intensity of at least 300×10^{11} $p+$.
3b	C	Check that the beam intensity as measured by the BCCM system and reported by property int1TAvg is within the SIT.
3c	C	Manually turn off the reception of SMP energy information using the appropriate setting in the system software. Lack of this information switches the system to operate in the energy range of 0.5 TeV or more. Check that this is indicated as beamEnergyFlag = 3.
3d	C	By changing the value of property dumpLevelW4B, keep lowering the beam dump threshold for the integration window of 64 turns and beam energies 0.5 TeV or above until a beam dump is triggered. The operational value of the property will be automatically reset during preparations of the BCCM system for the next beam injection.
4a	C	Prepare circulating beam at the injection energy with the intensity of at least 300×10^{11} $p+$.
4b	C	Check that the beam intensity as measured by the BCCM system and reported by property int1TAvg is within the SIT.
4c	C	Manually turn off the reception of SMP energy information using the appropriate setting in the system software. Lack of this information switches the system to operate in the energy range of 0.5 TeV or more. Check that this is indicated as beamEnergyFlag = 3.
4d	C	By changing the value of property dumpLevelW3B, keep lowering the beam dump threshold for the integration window of 16 turns and beam energies of 0.5 TeV or more until a beam dump is triggered. The operational value of the property will be automatically reset during preparations of the BCCM system for the next beam injection.
5a	C	Prepare circulating beam at the injection energy with the intensity of at least 300×10^{11} $p+$.
5b	C	Check that the beam intensity as measured by the BCCM system and reported by property int1TAvg is within the SIT.
5c	C	Manually turn off the reception of SMP energy information using the appropriate setting in the system software. Lack of this information switches the system to operate in the energy range of 0.5 TeV or more. Check that this is indicated as beamEnergyFlag = 3.
5d	C	By changing the value of property dumpLevelW2B, keep lowering the beam dump threshold for the integration window of 4 turns and beam energies of 0.5 TeV or more until a beam dump is triggered. The operational value of the property will be automatically reset during preparations of the BCCM system for the next beam injection.
6a	S C	Prepare circulating beam at the injection energy with the intensity of at least 300×10^{11} $p+$.
6b	S C	Check that the beam intensity as measured by the BCCM system and reported by property int1TAvg is within the SIT.
6c	S C	Check that the BCCM system operates in the energy range below 0.5 TeV, which is indicated as beamEnergyFlag = 0.
6d	S C	By changing the value of property dumpLevelW6A, keep lowering the beam dump threshold for the integration window of 1125 turns and beam energies below 0.5 TeV until a beam dump is triggered.
7a	C	Prepare circulating beam at the injection energy with the intensity of at least 300×10^{11} $p+$.
7b	C	Check that the beam intensity as measured by the BCCM system and reported by property int1TAvg is within the SIT.

7c	C	Check that the BCCM system operates in the energy range below 0.5 TeV, which is indicated as beamEnergyFlag = 0.
7d	C	By changing the value of property dumpLevelW5A, keep lowering the beam dump threshold for the integration window of 225 turns and beam energies below 0.5 TeV until a beam dump is triggered.
8a	C	Prepare circulating beam at the injection energy with the intensity of at least 300×10^{11} $p+$.
8b	C	Check that the beam intensity as measured by the BCCM system and reported by property int1TAvg is within the SIT.
8c	C	Check that the BCCM system operates in the energy range below 0.5 TeV, which is indicated as beamEnergyFlag = 0.
8d	C	By changing the value of property dumpLevelW4A, keep lowering the beam dump threshold for the integration window of 64 turns and beam energies below 0.5 TeV until a beam dump is triggered.
9a	C	Prepare circulating beam at the injection energy with the intensity of at least 300×10^{11} $p+$.
9b	C	Check that the beam intensity as measured by the BCCM system and reported by property int1TAvg is within the SIT.
9c	C	Check that the BCCM system operates in the energy range below 0.5 TeV, which is indicated as beamEnergyFlag = 0.
9d	C	By changing the value of property dumpLevelW3A, keep lowering the beam dump threshold for the integration window of 16 turns and beam energies below 0.5 TeV until a beam dump is triggered.
10a	C	Prepare circulating beam at the injection energy with the intensity of at least 300×10^{11} $p+$.
10b	C	Check that the beam intensity as measured by the BCCM system and reported by property int1TAvg is within the SIT.
10c	C	Check that the BCCM system operates in the energy range below 0.5 TeV, which is indicated as beamEnergyFlag = 0.
10d	C	By changing the value of property dumpLevelW2A, keep lowering the beam dump threshold for the integration window of 4 turns and beam energies below 0.5 TeV until a beam dump is triggered.

8.3 DESCRIPTION OF THE TEST AT THE ENERY ABOVE 0.5 TeV

To check the operation of the system for the higher energy range without manual switching the system sensitivity one test shall be performed at the energy above 0.5 TeV.

Each test shall be done separately for each of the BCCM systems, namely B1-A, B2-A, B1-B and B2-B.

The tests described in this section should be done with the beam intensity equal or greater than the one-turn beam dump threshold for energies 0.5 TeV or more, namely 3×10^{11} $p+$. The beam bunch configuration is not important for the test.

If the exact required beam intensity cannot be setup, then a larger value should be used.

#	Rep.	Action

1	S C	Check that the beam intensity as measured by the BCCM system and reported by property int1TAvg is within the SIT of [20, 0] %.
2	S C	Start the energy ramp.
3	S C	When the beam energy is at least 0.6 TeV, dump the beam with the operator switch. Check that the BCCM system has also issued a beam dump request for the one-turn integration window. Check that the beam dump request is also reported in the logging as dumpFlagW1 = 1. Check that the system switched to the high energy range when the beam energy was transiting 0.5 TeV. This is indicated in the logging by the beam energy flag beamEnergyFlag changing its state from 0 to 1.

8.4 TESTS WITH BEAM AT EVERY DUMP

Proper operation of the BCCM is monitored every beam dump regardless of its cause. If just before the dump the beam intensity is above the one-turn dump threshold, then the BCCM system should also issue a beam dump request. If just before the dump the beam intensity is below the one-turn dump threshold minus 20 % for the tolerance of the BCCM intensity measurement, then the system should not issue a beam dump request.

The beam intensity tolerance of the BCCM system unfortunately results in an intensity range for which the system may or may not issue a beam dump request. This range for the beam energy below 0.5 TeV is $[4.8, 6.0] \times 10^{11}$ $p+$ and for the energy of 0.5 TeV or more the range is $[2.4, 3.0] \times 10^{11}$ $p+$.

#	Rep.	Action
1	D	Check that the beam intensity of 3×10^{11} $p+$ or more as measured by the BCCM system and reported by property int1TAvg is: • not any smaller than the FBCT readings; • not larger than the FBCT readings by more than 20 %. BCCM intensity readings below 3×10^{11} $p+$ are not critical for the system operation and therefore are not systematically checked.
2	D	Check that the BCCM system has issued a dump request for the beam energy below 0.5 TeV if the intensity as measured by the FBCT was larger than 6×10^{11} $p+$.
3	D	Check that the BCCM system has issued a dump request for the beam energy of 0.5 TeV or more if the intensity as measured by the FBCT was larger than 3×10^{11} $p+$.
5	D	Check that the BCCM system has not issued a dump request for the beam energy below 0.5 TeV if the intensity as measured by the FBCT was smaller than 4.8×10^{11} $p+$.
6	D	Check that the BCCM system has not issued a dump request for the beam energy of 0.5 TeV or more if the intensity as measured by the FBCT was smaller than 2.4×10^{11} $p+$.

8.5 STATUS OF THE SYSTEM AFTER THE TESTS

After these tests with beam, the BCCM system can be used as an LHC machine protection system.

Please note that each beam dump is followed by automatic procedures preparing the BCCM system for the next beam injection. During the procedures all the system settings are initialised to their default values. Therefore, the system settings will automatically return to their default settings as long as the tests with beam described in this chapter are followed by a beam dump.

REFERENCES

[1] D. Belohrad et al., "The LHC Fast Beam Current Change Monitor", IBIC 2013, Oxford, UK, CERN-ACC-2013-0314.

[2] E. Bravin et al., "Beam instrumentation for machine protection", 5th Evian Workshop on LHC beam operation, Evian-les-Bains, France, 2 - 4 June 2014, pp.171-176,

[3] M. Krupa et al., "Summary of LHC MD 398: Verification of the dependence of the BCTF measurements on beam position and bunch length", CERN-ACC-Note-2015-0031.

[4] M. Gasior et al., "Inclusion of Beam Current Change Monitor as part of LHC Machine Protection Backbone", LHC-BCCM-FS-0001, EDMS 2308155.

[5] B. Todd and B. Puccio, "MPS Aspects of the Beam Interlock System Commissioning", LHC-OP-MPS-004.

APPENDIX A: LIST OF LOGGED BCCM PROPERTIES

Each of the four BCCM systems, namely B1-A, B2-A, B1-B and B2-B has its own set of logged properties. Their names are listed below.

Some comments to the logged properties:

- Unit "FS" means "Full Scale" of the ADC and that the samples are normalised so that their values are in the range from 0 to 1.
- Unit "FS*T" means "Full Scale times turn" and is used for quantities related to one-turn sums of raw ADC samples, which is the measure of the integral of the beam current, before scaling it to the FBCT reading. ADC 40 MHz sampling is synchronous to the beam, so the sum is always calculated on 3564 ADC samples.
- Logging type "OC" means "on change". Such properties are logged only when they change their values or if they do not change, once per hour, to make sure that the property is being logged.
- "1 s" logging means that the property is logged once per second.

Table 3: Names of logged BCCM properties, which are identical for all four systems. In the logging database the names are preceded by a text identifying the system, namely LHC.BCCM.B1.A, LHC.BCCM.B2.A, LHC.BCCM.B1.B and LHC.BCCM.B2.B, respectively for systems B1-A, B2-A, B1-B and B2-B.

Name	**Description**	**Unit**	**Type**
sumRawNorm	factor normalising the BCCM intensity to the FBCTs	$10^{11}\,p+$	OC
sumRaw1TAvg	1 s average of 1-turn raw ADC sums	FS*T	1 s
sumRaw1TMax	1 s maximum of 1-turn raw ADC sums	FS*T	1 s
sumRaw1TMin	1 s minimum of 1-turn raw ADC sums	FS*T	1 s
sumRaw1TStd	1 s standard deviation of 1-turn raw ADC sums	FS*T	1 s
int1TAvg	1 s average of 1-turn intensity	$10^{11}\,p+$	1 s
int1TMax	1 s maximum of 1-turn intensity	$10^{11}\,p+$	1 s
int1TMin	1 s minimum of 1-turn intensity	$10^{11}\,p+$	1 s
int1TStd	1 s standard deviation of 1-turn intensity	$10^{11}\,p+$	1 s
rawMax	1 s maximum of raw ADC samples	FS	1 s
rawMin	1 s minimum of raw ADC samples	FS	1 s
RFclkPresFlag	presence flag for the 400 MHz RF clock	0 or 1	OC
beamEnergyFlag	0: low, 1:high, 2: high automatically, 3: high manually	0 or 1	OC
beamPresFlag	1 – beam present, 0 - no beam	0 or 1	OC
beamPresAmpl	raw ADC amplitude increase for BeamPresFlag =1	FS	OC
agRawMax	abort gap 1 s maximum of raw ADC samples	FS	1 s
agRawMin	abort gap 1 s minimum of raw ADC samples	FS	1 s
agLevel	abort gap average level of raw ADC samples	FS	1 s
agLock	ADC turn start synchronised to the abort gap	0 or 1	OC
intIIR	intensity from the system IIR filter	$10^{11}\,p+$	1 s
beamLT	beam lifetime	hour	1 s
	1-turn integration window (W1)		
dIntW1Avg	1 s average of the intensity change	$10^{11}\,p+$	1 s
dIntW1Max	1 s maximum of the intensity change	$10^{11}\,p+$	1 s
dIntW1Min	1 s minimum of intensity change	$10^{11}\,p+$	1 s

dIntW1Std	1 s standard deviation of the intensity change	10^{11} p+	1 s
dumpLevelW1A	dump threshold for the energy range below 0.5 TeV	10^{11} p+	1 s
dumpLevelW1B	dump threshold for the energy range 0.5 TeV or more	10^{11} p+	OC
dumpFlagW1	dump request flag	0 or 1	OC
	4-turn integration window (W2)		
dIntW2Avg	1 s average of the intensity change	10^{11} p+	1 s
dIntW2Max	1 s maximum of the intensity change	10^{11} p+	1 s
dIntW2Min	1 s minimum of intensity change	10^{11} p+	1 s
dIntW2Std	1 s standard deviation of the intensity change	10^{11} p+	1 s
dumpLevelW2A	dump threshold for the energy range below 0.5 TeV	10^{11} p+	1 s
dumpLevelW2B	dump threshold for the energy range 0.5 TeV or more	10^{11} p+	OC
dumpFlagW2	dump request flag	0 or 1	OC
	16-turn integration window (W3)		
dIntW3Avg	1 s average of the intensity change	10^{11} p+	1 s
dIntW3Max	1 s maximum of the intensity change	10^{11} p+	1 s
dIntW3Min	1 s minimum of intensity change	10^{11} p+	1 s
dIntW3Std	1 s standard deviation of the intensity change	10^{11} p+	1 s
dumpLevelW3A	dump threshold for the energy range below 0.5 TeV	10^{11} p+	1 s
dumpLevelW3B	dump threshold for the energy range 0.5 TeV or more	10^{11} p+	OC
dumpFlagW3	dump request flag	0 or 1	OC
	64-turn integration window (W4)		
dIntW4Avg	1 s average of the intensity change	10^{11} p+	1 s
dIntW4Max	1 s maximum of the intensity change	10^{11} p+	1 s
dIntW4Min	1 s minimum of intensity change	10^{11} p+	1 s
dIntW4Std	1 s standard deviation of the intensity change	10^{11} p+	1 s
dumpLevelW4A	dump threshold for the energy range below 0.5 TeV	10^{11} p+	1 s
dumpLevelW4B	dump threshold for the energy range 0.5 TeV or more	10^{11} p+	OC
dumpFlagW4	dump request flag	0 or 1	OC
	225-turn integration window (W5)		
dIntW5Avg	1 s average of the intensity change	10^{11} p+	1 s
dIntW5Max	1 s maximum of the intensity change	10^{11} p+	1 s
dIntW5Min	1 s minimum of intensity change	10^{11} p+	1 s
dIntW5Std	1 s standard deviation of the intensity change	10^{11} p+	1 s
dumpLevelW5A	dump threshold for the energy range below 0.5 TeV	10^{11} p+	1 s
dumpLevelW5B	dump threshold for the energy range 0.5 TeV or more	10^{11} p+	OC
dumpFlagW5	dump request flag	0 or 1	OC
	1125-turn integration window (W6)		
dIntW6Avg	1 s average of the intensity change	10^{11} p+	1 s
dIntW6Max	1 s maximum of the intensity change	10^{11} p+	1 s
dIntW6Min	1 s minimum of intensity change	10^{11} p+	1 s
dIntW6Std	1 s standard deviation of the intensity change	10^{11} p+	1 s
dumpLevelW6A	dump threshold for the energy range below 0.5 TeV	10^{11} p+	1 s
dumpLevelW6B	dump threshold for the energy range 0.5 TeV or more	10^{11} p+	OC
dumpFlagW6	dump request flag	0 or 1	OC