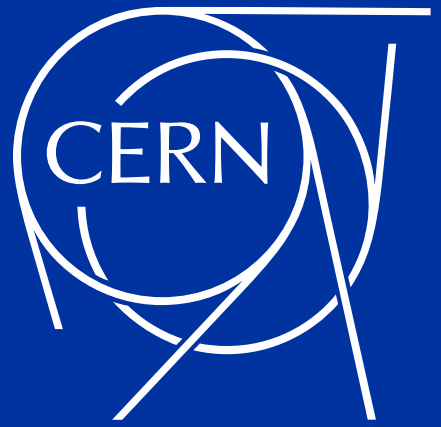


Update of machine-protection checklists for intensity ramp-up and cruise

C. Wiesner, C. Hernalsteens, J. Uythoven, D. Wollmann
Many thanks to all the system experts and rMPP members for their contribution!

March 18th, 2022, 220th Machine Protection Panel (MPP)

Outline

- **Overview of machine protection checklists**
- **Intensity checklists: contents and systems covered**
- **Intensity checklist tasks: review and update**
- **Conclusions**

Overview of machine protection checklists

- **MPP tree in OP checklist tool**
  - Used to follow the re-commissioning of the machine-protection systems (→ see presentation by C. Hernalsteens, this MPP)

- **Checklists for intensity ramp-up***
  - Intensity ramp-up based on stepwise increase of stored energy and number of injected bunches: Steps at 3/12 - 75 - 300 - 600 - 900 - 1200 - 1800 - 2400 - 2700 bunches**
  - For each intensity step: monitor behavior during at least 3 fills and 20h stable beams, and verify correct functioning of machine-protection systems via checklist
  - Checklist filled by system experts and checked by rMPP before advancing to the next intensity step
- **Checklists for scrubbing**
  - Intermediate scrubbing checklist after ~300 bunches, final checklist at the end of scrubbing
- **Checklist for intensity cruise:**
  - Issued during the Run every ~8 weeks (e.g., between TS) to check behaviour of machine-protection systems
- **Final checklists documented in EDMS in the rMPP tree**

All intensity checklists use the same template

*Intensity ramp-up discussed in the 217th MPP and 10th "Evian" workshop

**exact number of bunches depend on agreed filling schemes and beams

Intensity checklists: contents

- **The intensity checklists include:**
  - Overview of checklist period, including bunch pattern, fill number, issues encountered
  - Overview of all fills in the period, including main beam parameters, MPS dump cause and MPS expert comment
  - Statistics of dump causes
  - Check tasks for the machine-protection relevant systems

Check list period		
	Bunch pattern / intensity	25ns_109_108_0_0_32-8b4ebpi_MD3270; 25ns_1227b_1214_1054_1102_144bpi_14inj; 25ns_157b_2b_2_0_0_48bpi_MD3263_MD4; 25ns_158b_158_0_0_48bpi_MD3263_MD4_V2; 25ns_2556b_2544_2215_2332_144bpi_20injV3; 25ns_26b_26_9_12_12bpi_4inj_MD3294; 25ns_300b_288_178_190_96bpi_4inj; 25ns_37b_0_0_0_12bpi; 25ns_3b_2_0_0_BTFMD4-2018; 25ns_603b_590_524_542_48bpi_17inj; 25ns_75b_62_32_62_12bpi_9inj; MD2484_8b4e_1812b_96bpi; Single_10b_0_0_0_Instabilities; Single_12b_9_1_5_BSRT_2018_pilot; Single_14b_6_0_0_ADTPickupMD; Single_20b_0_0_0_Instabilities; Single_2b+13p_1_1_1_1bpi15inj; Single_3b_1_1_1_1nc; Single_3b_2_2_2; Single_3b_2_2_2_with_probes; Single_7b_1_1_1_5ncPilots2cNom; Multi_525ns_152_150_0_0_8bpi_19inj; Multi_525ns_152_150_0_0_8bpi_19inj_V2
	Start date	22-SEP-2018 00.02.29.692000
	End data	31-OCT-2018 06.44.42.892000
	Fill numbers	7195-7394
	Comment	73 fills including MDs at top energy
	Next intensity	Intensity ramp-up after TS3 with Ions

Example: intensity-cruise checklist TS2-TS3 2018

Intensity checklists: systems covered

System	Responsible persons
Magnet powering (MP3)	Arjan Verweij, Zinur Charifoulline
Interlocks	Ivan Romera Ramirez, Jan Uythoven
RF	Wolfgang Hofle, Andy Butterworth
Beam Instrumentation	Belen Salvachua Ferrando, Christos Zamantzas
Collimation	Stefano Redaelli, Roderik Bruce, Frederik Van Der Veken
Operation, orbit and feedbacks	Jorg Wenninger, Matteo Solfaroli Camillocci
Beam dump	Yann Dutheil, Chiara Bracco
Injection	Yann Dutheil, Chiara Bracco
Heating of Equipment	Benoit Salvant (Giovanni Iadarola)

E-group LHC-Intensity-Checklist@cern.ch has been updated accordingly.

Reviewed checklist tasks (1/6)

Magnet powering (MP3)
No magnet quench after beam dump in RQ4.R/L6.
No unexplained quench or powering event in a circuit.
No problems with loss of QPS_OK for main circuits following injection process.
No unexplained firing of quench heaters.
No un-validated change to the magnet circuit protection system
No un-validated configuration change detected in the QPS configuration management system
No magnet quench due to too high BLM thresholds
In case of quench: redundancy between QPS and detection of losses (via BLMs or BCCM) due to orbit changes caused by the decay of the magnetic field, as expected.

Beam, powering interlocks and post mortem
No unexplained IPOC failure in Post Mortem for FMCM.
No unexplained IPOC failure in Post Mortem for PIC.
No unexplained IPOC failure in Post Mortem for BIC.
No unexplained IPOC failure in Post Mortem for SMP.
No unexplained CIBDS trigger.
No unexplained false beam dump from any of the Beam / Powering Interlock Systems.
No near misses from any of the Beam / Powering Interlock Systems.
No failure of BIS pre-operational check.
No failure of SMP pre-operational check.
No unexplained PM event with intensities > 8 nominal bunches
No unexplained PM event above 450 GeV.
No un-explained glitches of the Setup Beam Flag (SBF).

Tasks modified/added are shown in blue.

Reviewed checklist tasks (2/6)

Beam dump
Asynchronous dumps understood? Protection worked correctly?
Parasitic asynchronous dump data (particles in abort gap during every fill) show no loss of protection.
BPM IP6 (interlock BPM) working correctly during first beam with higher intensity and different bunch pattern.
No positioning errors on TCSP/TCDQ.
No settings or thresholds mistakes/wrong sequences/unexplained faults on TCSP/TCDQ.
Loss leakage to the critical elements downstream of the TCDQ are below predefined reference values.
No unexplained MKD, MKB kicker, TSU or BETS faults.
No potentially dangerous XPOC or IPOC failure on MKD or MKB.
No unexplained synchronization problem with TSU.
Pressure and temperature rise in TDE block within tolerances.
Requalification passed OK at 450 GeV and 6.5 TeV with pilot in case of any important component exchange.
Valid set of simulated asynchronous beam dumps (Injection, flat top, squeezed separated, colliding) performed.

Tasks modified/added are shown in blue.

Reviewed checklist tasks (3/6)

RF
Temperatures in all HOMs during all fills with the current intensity ok.
Power levels in all HOMs during all fills with the current intensity ok.

Beam Instrumentation
BLM Internal sanity checks results must be true.
Rise time (10% to 90%) of RS01 fast losses triggering a beam dump must be larger than 200 us (no unknown fast loss scenario observed)
No unexplained BLM check failures.
BLM system modification (ECRs) have to be agreed on, EDMS: notified persons signature is needed.
No non-conformities in the energy transmission to the BLM crates.
BSRA functioning and abort gap population always properly monitored
Change of BLM thresholds

BLM threshold changes in the current period:

Tasks modified/added are shown in blue.

Reviewed checklist tasks (4/6)

Collimation
Valid set of betatron loss maps (hor/ver at Inj., flat top, squeezed separated, colliding) done in last 3 months.
Valid set of off-momentum loss maps (pos./neg. at Inj., flat top, squeezed separated, colliding) done in last 3 months.
Loss maps for re-qualification after technical stop did not show unexpected losses distributions.
No observation of abnormal cleaning efficiency.
No observation of abnormal passive protection.
Collimators at agreed positions during cycle.
Correct LSA positions, thresholds, limits, warning levels.
Orbit monitoring at TCSPs and TCTPs operational, no unexplained offset changes observed.
No unexplained beam dumps due to collimators.
No beam dumps from collimator temperatures.
XRPs at agreed positions during cycle.
XRPs: Correct LSA positions, thresholds, limits, warning levels.
No unexplained beam dumps due to XRPs.
No spurious interlock by DOROS BPMs

Tasks modified/added are shown in blue.

Reviewed checklist tasks (5/6)

Operation, orbit and feedbacks
OFB operational status
QFB operational status
Global orbit in tolerance at 450 GeV (< 0.2 mm rms)
Global orbit in tolerance in stable beams (< 0.2 mm rms)
Orbit IR3/IR7 collimators within ± 0.2 mm at 450 GeV
Orbit IR3/IR7 collimators within ± 0.2 mm in stable beams
Orbit at TCTs in tolerance in stable beams (≤ 1 sigma in IR1/5, ≤ 3 sigma in IR2/8)
No spurious interlock by PC interlock
Luminosity levelling

Injection
Injection protection devices at agreed positions during cycle.
Correct LSA positions, thresholds, limits, warning levels.
Injection oscillations within tolerance for all injections.
No unexplained large beam loss on TCDIs.
Expected losses for the beam to be injected at least 30 % below threshold level.
Line has been re-steered successfully if losses have been too high.
No issues in injection procedure, settings or tolerances.
Orbit in injection region in tolerance wrt reference (tolerance <0.5 mm).
Resetting of TL trajectories, TCDIs and optics done when needed.
No increased rate of MKI flashovers.
No increased rate of MKI switch erratics or missing.
No unexplained MKI vacuum or temperature activity.
No machine-protection related injection system hardware failures.

Tasks modified/added are shown in blue.

Reviewed checklist tasks (6/6)

Heating of Equipment
Heating of ATLAS-ALFA
Heating of ATLAS-AFP
Heating of BSRT and prototype BSRT tank
Heating of Collimators (TCP)
Heating of Collimators (TCS)
Heating of Collimators (TCTP)
Heating of Collimators (TCDQ)
Heating of Collimators (TCL)
Heating of Crystal Goniometers (TCPC)
Heating of BGV
Heating of MKD
Heating of MKI
Heating of TDIS
Heating of beam screen and instrumented PIMS
Heating of ALICE beam pipe
Heating of TOTEM/CT-PPS and neighbouring vacuum
Heating of LHCb VELO and SMOG2
Vacuum at LHCb VELO and SMOG2
Heating of CMS pipe
No unexplained heating of other equipment observed.
Variation of bunch length within the usual range.
Variation of beam spectrum within the usual range.
No additional non-conformities in vacuum observed (RF-fingers, etc.)

Tasks modified/added are shown in blue.

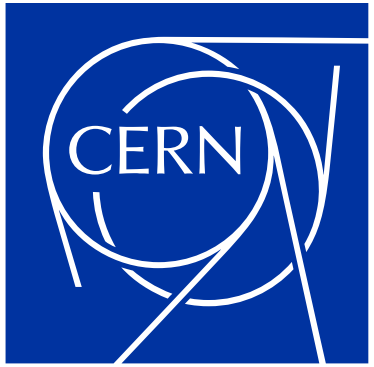
Review and update of checklist tasks: summary

- **Checklists tasks have been reviewed by system & (r)MPP experts**
  - ~85 tasks confirmed
  - ~15 tasks added or modified/clarified
- **Latest excel template can be found here**
- **Many thanks to all the people who contributed!**
- **For the checklist validation in 2022, shared excel files will be used (as in Run 2)**
  - Development of web-based tool was put on hold due to resource situation in BE-CSS

Conclusions

- Checklists used to verify correct functioning of machine-protection systems for LHC intensity ramp-up, intensity cruise and scrubbing
- Machine-protection relevant systems covered by the checklist: magnet powering, interlocks, RF, beam instrumentation, operation, orbit, feedbacks, injection, beam dumping system, heating of equipment
- Checklists tasks have been reviewed by system & (r)MPP experts: ~85 tasks confirmed, ~15 tasks added or modified, e.g.:
  - “No unexplained IPOC failure in Post Mortem for SMP”
  - “No unexplained CIBDS trigger”
  - “Luminosity Levelling”
- New checklist template ready to be used
- Many thanks to all experts for reviewing the required tasks and for performing the checks!

Thank you for your attention!



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Example: fill overview

Dump time	Fill #	Energy [MeV]	Intensity B1 [1e10]	Intensity B2 [1e10]	Stable Beams [hours]	Fill Luminosity [nb^-1]	MPS Dump Cause	Mps Expert Comment	Filling Scheme
31-OCT-2018 06.44.42.892000	7394	6499080	31	31	0	0	MD	MD3205 (Beam screen shielding from QH discharge investigation), quenched C28L5 at 11 kA with QPS expert tool. 3 nominal bunches per beam. Clean dump. Slightly asymmetric loss pattern in P6 (higher losses from B2). Orbit change < 100 um due to quench heater acting on the beam.	Single_3b_2_2_2
31-OCT-2018 01.36.36.402000	7393	3458280	31	31	0	0	MD	Quench triggered in MB C28L5 with QPS test mode at 5822 A (~3.4 TeV) during the ramp. 3 nominal bunches. Clean dump	Single_3b_2_2_2
31-OCT-2018 00.05.24.921923	7392	6499080	2194	2370	0	0	EOF	Programmed dump of fill with 300b after Tails-scraping MD and vacuum bump test in IR7. Clean dump.	25ns_300b_288_178_190_96bpi_4inj
30-OCT-2018 17.29.45.292000	7391	6499080	0	0	0	0	MD	Probe beam dumped by losses due to MD: Replicating HL-LHC DA. Losses in BLMQI.03R1.B1 (0.3 Gy/s). Otherwise clean dump.	Single_10b_0_0_0_Instabilities
30-OCT-2018 09.43.45.533000	7390	6499080	20	21	0	0	EOF	Programmed dump of fill with 3b for BTF MD.	25ns_3b_2_0_0_BTFMD4-2018
29-OCT-2018 15.29.05.384000	7386	6498960	1498	1487	0	0	EOF	Programmed dump of fill with 158b for LRBB-compensation MD. Clean dump.	25ns_158b_158_0_0_48bpi_MD3263_MD4_V2
29-OCT-2018 10.21.29.694000	7385	6499080	1729	18	0	0	EOF	Programmed dump of fill with 157b for LRBB-compensation MD. Clean dump.	25ns_157b_2b_2_0_0_48bpi_MD3263_MD4
28-OCT-2018 14.46.02.252000	7377	6499080	244	258	0	0	EOF	Programmed dump of fill with 14b for MD4143 (Noise studies with new ADT pickup electronics). Clean dump.	Single_14b_6_0_0_ADTPickupMD
28-OCT-2018 08.18.03.649907	7375	6499080	1	3	0	0	MD	Pilot beam dumped due to losses in MD2186 (New method to measure margins between IP6 absorbers and TCTs/triplets).	Single_3b_2_2_2_with_probes
27-OCT-2018 19.23.15.736023	7369	6499080	27	26	0	0	EOF	Programmed dump of fill with 20b for impedance MD3318, to refill for MD4505/4506. Clean dump.	Single_20b_0_0_0_Instabilities

intensity-cruise checklist TS2-TS3 2018

Example: dump causes

Dump statistics	
Dump caused by	**# of dumps**
Programmed dump (EOF)	38
Fault of BPM IR6 (BPM IR6)	
Fault of LBDS (LBDS)	
Operator fault (OP)	7
Controlles fault (CO)	
Orbit excursions (Orbit)	1
Fault of Orbit feedback (FB1)	
Fault of Tune feedback (FB2)	
Beam losses (Beam loss)	
Fault of BPM system (BPM)	
Electrical network glitch (EL Net)	
Water fault (Water)	
Fault of BLM system (BLM)	1
Fault of SIS (SIS)	
Machine Protection test (MPS test)	5
Fault of Cryogenic system (Cryogenic)	
Fault of QPS (QPS)	6
Fault of Collimation control (Coll Sys)	
Wrong collimator positions (Coll Ad)	1
Fault of BCM (BCM)	
Experiments (EXP)	2
Fault of vaccum system (VAC)	
Fault of BIS (BIC)	
Fault of PIC (PIC)	
Fault of FMCM (FMCM)	
Power converter fault (PC)	3

intensity-cruise checklist TS2-TS3 2018

MPP proposal for intensity ramp-up 2022

- Continue successful strategy applied during Run 2
- Stepwise increase of stored energy and number of injected bunches:
  Use 3/12 - 75 - 300 - 600 - 900 - 1200 - 1800 - 2400 - 2700 bunches*

Establish cycle
MP dominated
Intensity dominated

- For each intensity step: monitor behavior during at least 3 fills and 20h stable beams, and validate via checklist
- Keep bunch intensity to ~1.15×10^{11} ppb during intensity ramp-up. Then, gently increase bunch intensity (e.g., in steps of 0.05×10^{11}) up to 1.4×10^{11} ppb, depending on machine behaviour and available bunch intensity
- Use of luminosity levelling already during the intensity ramp-up
- Insertion of TOTEM/CT-PPS, AFP, ALFA roman pots to agreed settings before the first luminosity levelling step for all fills at each intensity step
- Scrubbing: Verify heating of critical elements before going to next intensity step. Intermediate scrubbing checklist after ~300 bunches (RF power, heating, …), final checklist at the end of scrubbing
- During the Run: issue Cruise Checklist every ~8 weeks (e.g., between TS) to check behaviour of MP systems

**exact number of bunches will depend on agreed filling schemes and beams*

Discussed at the 217th MPP