COMMISSIONING AND OPERATION OF THE MACHINE PROTECTION SYSTEM

L. Ponce, V. Chetvertkova, B. Salvachua, G. Valentino, J. Wenninger, D. Wollmann, M. Zerlauth

Abstract

The presentation is reviewing the MPS commissioning strategy we used during Run1 for the initial setup of the machine and the intensity ramp-up. Based on operational experience, new strategy for the Set-Up Beam Flag definition is proposed to cope with the new beam parameters for Run2.

MPS COMMISSIONING PROCEDURES

Before the first start-up, in order to properly commission the systems belonging to the machine protection For Run 1, series of detailed commissioning procedures defined in 2009 were used to coordinate the tests related to machine protection during the machine check-out and the beam commissioning. The EDMS reference of these procedures and the concerned systems are listed below:

LHC-OP-MPS-002	Collimation System Commissioning
LHC-OP-MPS-003	Injection Protection System Commissioning
LHC-OP-MPS-004	Beam Interlock System Commissioning
LHC-OP-MPS-005	Powering Interlock System Commissioning
LHC-OP-MPS-006	Vacuum System Commissioning
LHC-OP-MPS-007	Beam Dump System Commissioning
LHC-OP-MPS-008	FMCM System Commissioning
LHC-OP-MPS-009	BLM System Commissioning
LHC-OP-MPS-010	Warm Magnet Interlock System Commissioning
LHC-OP-MPS-014	Software Interlock System Commissioning

These procedures need to be revisited and updated as most of the system have been modified during LS1. New procedures will be added (for example for FBCCM system) and the table of contents will be modified to follow the actual intensity steps and ramp-up that will be done. The tests with beam will specify what needs to be validated at injection energy or top energy, with pilot or with bunch trains, and if tests are needed when beam parameters are changed (crossing angle, β^*,...).

A revision of the periodicity of the tests is also needed and each test will be noted in one of the following category:

MPS test follow-up

All along Run 1, the progress of the MPS commissioning was tracked by the usage of a simple SharePoint site. During the MPS review in 2013, it was proposed [[1]] to extend the AccTeststing framework used for hardware commissioning in order to replace the SharePoint site. The implementation of the new features required for the migration of the information is progressing, (barriers, dependent/composed tests) but the framework will not be fully ready for the start-up. Few type-tests are implemented, for example the source test of the BLM system or the MKD exchange.

- N: Not to be repeated (eventually only executed at beginning of run but not after Christmas stops)
- S: To be repeated only after longer shutdowns during a run (e.g. Christmas stops)
- T: To be repeated after Technical Stop (including longer shutdowns during a run)
- P: Periodical repetition required, like 1 x per month; details to be defined in th text
- O: To be repeated when LHC optics crossing scheme is changed

The SharePoint site will still be used for post-LS1 tracking of MPS tests. The site is driven by few individuals (MPP experts) in parallel of the machine coordination. The period of restart will be used to capture sequence and dependencies in view of modeling the info to be first used after Technical or Christmas stops in 2015.

SETUP FROM PILOT TO FIRST COLLISIONS

Initial set-up strategy

The Beam commissioning period starts with establishing the operational cycle with "safe" beam conditions. The main step are the 450 GeV commissioning (both beams capture, closed orbit), optics checks and aperture measurements, ramp and squeeze commissioning (both orbit establishing and optics correction) and finally collisions process.

The MPS commissioning and validation are interleaved with operation during this first phase to prepare the intensity ramp-up:

- Collimator setup and validation (so-called loss maps) at injection, flat top, end of squeeze and in collisions.
- LHC Beam Dump System (LBDS) validation (so-called asynchronous beam dump test)
- Injection protection system set-up and validation

The intensity ramp-up starts when the operational cycle is well establishing meaning the sequence of operation to be done is validated and all the MPS tests are signed by MPP for the next steps. It is also divided in 2 main steps:

first operation with nominal bunch intensity and then the bunch trains operation.

Beam Setup in 2012

Beginning of 2012, the whole process of initial beam commissioning has been done in 22 days. The details are reported in Table [1].

Date	Time	Milestone
14.03	23:30	*Beam 1 injected*
15.03	01:00	*Both Beams captured, orbit and Q adjusted*
	11:00	*Optics measured and corrected at injection*
	20:00	**Reference orbit for flat machine**
16.03	22:44	*Both beams 4 TeV*
17.03	16:30	*Beam 1 at 0.6 m β^**
18.03	11:15	*Squeeze at 0.6 m β^**
18.03	11:15	*Separation and crossing at injection*
	18:00	**Collimators set up @injection**
22.03	20:58	*Squeeze with nominal Xing and separation*
25.03	15:00	*Injection protection setup*
27.03	06:40	*Pilot through all cycle*
30.03	18:30	**Collisions, All IPs optimized**
29-30 03	15:00 22:00	**Collimators aligned @4 TeV, end of squeeze and collisions**
05.04	00:38	**First STABLE BEAMS @4 TeV**

Table 1: planning of the main milestones of the beam commissioning in 2012. The steps in italic are done with pilots intensity, the steps in bold are done with nominal bunch intensity.

During these 22 days, 43 MPS tests are flagged and signed in the Post Mortem database, loss maps not included.

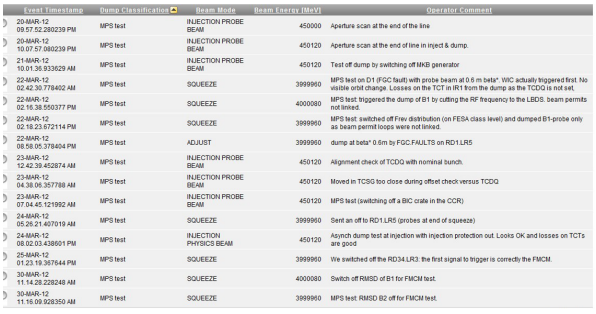

Figure 1: Examples of the MPS tests done during first phase of beam commissioning.

NEW SETUP BEAM FLAG DEFINITION

Setup Beam Flag concept

The Setup Beam Flag (SBF) is defined as the intensity limit to allow masking some pre-defined interlocks: BLM, IR6 interlocked BPM, Collimator movements, RF, AC dipole mode, PIC and Software Interlock System (SIS) Interlocks.

Based on controlled experiments with 450 GeV beam performed in 2005, beam intensity of 10^{12} protons was considered to be safe . A factor 2 was applied to this intensity value to take into account the lower emittance used during operation, so the Set-up Beam Flag was set at 5.10^{11} for 450 GeV. This limit was used to allow masking during the collimators alignment, for loss maps and asynchronous Beam Dump test, for optics and chromaticity measurement and during the ramp/squeeze process commissioning.

After experience gained during the first year of operation, in 2012, 3 different limits were used for the SBF:

- NORMAL: considered to be safe
- RELAXED: was established to allow masking with 1 nominal bunch at 4 TeV
- VERY RELAXED : was established to allow masking with 3 nominal bunches at 4 TeV

The value of the limits used during run 1 are summarized in Table [2].

	450 GeV	4 TeV
NORMAL	$5x10^{11}$	$2.4x10^{10}$
RELAXED	$5x10^{11}$	$1.2x10^{11}$
VERY RELAXED	$5x10^{11}$	$3.2x10^{11}$
IONS	$5x10^{11}$	$6.1x10^{10}$

Table 2: SBF intensities for injection and top energy energy in protons per bunch.

Inputs and limitation for the beam set-up

The different phases of the beam commissioning have been done, using the possibility to mask some interlocks, with a minimum intensity. This gives some needs for a new value of the SBF for 6.5 TeV. Minimum requirement for orbit measurements, already presented at Machine Protection Meeting [2], are the following:

- Efficient set-up of collisions in the 4 IPs :2 nominal bunches
- New sensitivity after LS1 for the IR6 BPM (interlock limit): around $2x10^{10}$ p/bunch
- BPM sensitivity for orbit measurement : $5x10^{10}$ p/bunch
- BPM sensitivity limit for collimator set-up : $5x10^{9}$ p/bunch

The strategy for the Collimators setup and validation is based on a minimum intensity per beam. The needed limits have been presented by the collimation team [3] and can be summarized as $7x10^{10}$ protons are consumed during the set-up and about $1x10^{10}$ protons are consumed per transverse loss maps with transverse damper excitation. If 1 nominal bunch could be used for alignment at flat top or after the squeeze, 2 nominal bunches are needed at injection and especially in collisions. For the validation loss maps, again in collisions, 2 nominal bunches plus 2 non-colliding probe bunches are needed. These beams intensity are above the SFB when extrapolated at 6.5 TeV.

New values proposed for SBF

In order to allow keeping the same strategy for orbit measurements and collimators setting-up, new values are proposed for the SFB for Run 2. The proposition from MPP is to keep 2 values of intensity limits for 3 bunches configuration:

- Normal SBF: $1.1x10^{10}$ for ALL users
- Relaxed SBF: $1.25x10^{11}$ x 2 bunches for Special users (for orbit and collimator set-up)
- Restricted SBF: $1.5x10^{10}$ x 16 bunches for Machine Development

The bunch configuration for the restricted and relaxed SBF will be enforce with a SIS interlock. The proposed values for SBF for the different top energies are summarized in Table [3]

	450 GeV	6.5 GeV	7 TeV
NORMAL	$5x10^{11}$	$1.1x10^{10}$	$9.4x10^{9}$
RELAXED/ RESTRICTED	$5x10^{11}$	$2.5x10^{11}$	$2.2x10^{11}$

Table 3: New proposed SBF values for injection and top energy energy in protons per bunch.

INTENSITY RAMP-UP

Moving towards unsafe beams

In order to operate with “unsafe” beam, the operational cycle must be well established, all the MPS tests and the global protection tests detailed in the MPS procedures should be completed and the collimators and absorbers must be in place and validated.

The ramping-up strategy proposed is the same as in 2011 and 2012. A step up of a factor 2 to 4 maximum in bunch number (factor decreasing with increasing bunch number), 3 fills making it to STABLE BEAM per step and 20 hours of STABLE BEAMS per step. For each new bunch configuration, IR6 BPM test must be repeated and MPP experts should sign off the intensity cruise checklist before each new step up.

Intensity ramp-up in 2011 and 2012

In 2011, the intensity ramp-up spread over several month, figure , driven mainly by the machine availability up to 768 bunches: MTG, Tune feedback, FGC current reading, arc detectors... But the time lost due to machine availability allowed to discover and clean-up many teething problems. The initial steps to 912 and 1092 bunches set off UFOs, vacuum activities and SEU effect. When everything goes well, with a very good machine availability, the intensity ramp up can go very fast, as in 2012 when it took only 2 weeks. The ramp-up was reduced in 6 steps:

- 3 bunches for MPS validation
- 2-3 fills and 4-6 hours of STABLE BEAMS with 264 and 624 bunches (in parallel of cycle validation)
- 3 fills and 20 hours of STABLE BEAMS with 840, 1092 and 1380 bunches.

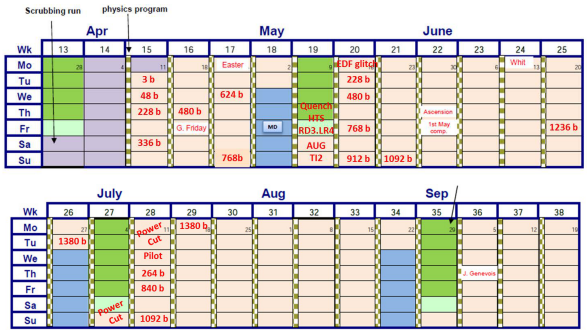

Figure 2: Intensity ramp-up in 2011.

STRATEGY FOR 25 NS BEAM

End of 2012, after the scrubbing run, the re-commissioning to move to 20 ns spacing beam was done in 10 days. The nominal cycle with a new β^* has been established with 3 nominal bunches in few days. The new tests needed were the transverse dampers set-up and the validation loss maps due to new collimators settings in collisions. The detailed planning is shown in Table 4.

SUMMARY

During Run I, we already experienced MPS commissioning for new beam parameters, we changed the energy to 4 TeV in 2012, new bunch spacing (75 ns, 50 ns and 25 ns) and we also increased the bunch number till 1380. The procedures and the reference body to follow the intensity ramp-up and the MPS commissioning are well established and will be the same for post LS1. In order to keep the same strategy, the Setup Beam Flag should be adapted to the new beam energy. The proposed values to accommodate machine safety and efficient set-up are:

Date	Time	Milestone
06.12	11:30	ADT setting
	20:00	228b injected, scrubbing
11.12	3:30	Collisions@1m with 3 nominal b
	5:00	Cycle with 3 nominal for collimators set-up
	18:00	Loss maps
12.12	16:00	TDI alignment checks
13.12	06:15	STABLE BEAMS with 72 bunches
	8:30	Loss maps at flat top
14.12	12:30	Loss maps end of squeeze and in collision
15.12	15:00	STABLE BEAMS with 12+2x48 b
	20:00	STABLE BEAMS with 12+4x48 b
16.12	09:00	STABLE BEAMS with 396 b

Table 4: Milestones of the 25 ns setup end of 2012.

Normal:	$1.1\text{x}10^{10}$p	ALL users
Relaxed:	$1.25\text{x}10^{11}$p x 2 bunches	Special users
Restricted:	$1.5\text{x}10^{10}$p x 16 bunches	MDs

Being optimistic, the intensity ramp-up will look like in 2012 but with a lot of hardware and software modifications experienced during LS1, exploring the new territory of 25 ns beam at higher top energy may recall the 2011 commissioning.

ACKNOWLEDGMENTS

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REFERENCES

[1] Software tools for MPS, K. Fuchsberger, Presentation at MPS workshop in March 2013

[2] D. Wollman, Presentation at the 23^{th} Machine Protection Meeting in 2014

[3] G. Valentino, Presentation at the Collimation Working Group 18^{th} May 2014