MACHINE DEVLOPMENT PRIORITIES

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Abstract

The Machine Development requirements for Run 2 are largely determined by the overall commissioning plan of the LHC in 2015 and foreseen operational challenges related to optics, beta* squeeze, instabilities and equipment performance. Electron cloud scrubbing is not part of the MDs. The requests from the different groups involved, expressed during the "MD Day" on 2 September 2014, are presented and evaluated in the context of importance for the machine performance, the constraints imposed by the available beams (from the injectors and in the LHC) and the available MD time. Organisational aspects of the MDs, like procedures, contact persons and MD notes, will also be outlined.

INTRODUCTION

Machine Development (MD) aims at improving the understanding of the LHC, its equipment and beam physics in general. This should result in the improvement of machine performance (=integrated luminosity) *on the longer term*. MDs are performed in designated periods on the LHC schedule and some days of floating MD, which are indicated as such on the MD schedule.

MDs have to be compared to 'Operational Development' and 'Commissioning' defined work, which have an *immediate* impact on the machine performance and are performed during the foreseen commissioning period, intensity ramp-up period or physics time. Electron cloud scrubbing and related beam tests are not part of the MD time either.

A correct balance between measurements to be done as MD and work done during Operational Development or Commissioning time needs to be found.

As a start-up year after the Long Shutdown 1, 2015 will be a special year with a large part of the year devoted to the re-commissioning of the machine at the new top energy of 6.5 TeV and with the new nominal bunch spacing of 25 ns. No MD periods are foreseen during this re-commissioning period [1]. Many results of what would normally be qualified as MD will be required before the first MD period. On top of this, some MD like measurements can be performed very efficiently during the initial start-up because of the different energy ramps with low beam intensities foreseen. For these reasons it is very important to determine before start-up the measurements that should be part of the re-commissioning period and the measurements that have to be performed as MD.

In this paper the measurements required for 2015, either during the commissioning period or during the MD periods, will be outlined by analysing the presentations by the different interest groups during the LHC Studies Working Group Day on 2 September 2014 [2]. Longer term MD request, going up to LS3, are presented in [3]. Finally the organisational framework for the MDs in Run 2 will be outlined, taking into account organisational and machine protection aspects.

STATISTICS OF MDS DURING RUN 1

The MD time during the LHC Run 1, attributed to the main user groups, is shown in Fig. 1. The distribution is based on a total of 657 MD hours. It clearly shows that the ABP group is the main user with optics, aperture, collimation, instabilities and beam-beam related topics. Second largest user is the RF group, followed by injection studies.

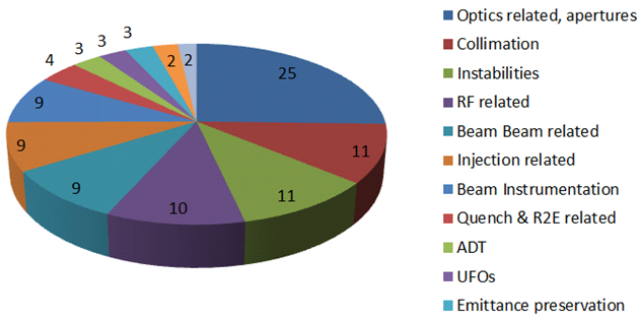

Figure 1: Main MD users in % of total MD time for the LHC run 1.

PLANNING FOR RUN 2

Presently three MD blocks of 5 days are foreseen in week 28, 37 and 45 plus an additional floating MD of 4 days, see Fig. 2. Due to the time required for re-commissioning after LS1, this is less than during a normal operational year. The first MD is foreseen late July. This means that 'urgent' MD-like measurements need to be done during the initial commissioning period. It also needs to be noted that during the first MD block no high intensity 25 ns beams will be available.

The second MD block is presently foreseen just before a change to lower beta*. Results from this MD block come too late to be included in the timely planning for the run with lower beta* and therefore the studies required to define the minimum values of the beta* in operation in the second half of the run will have to be performed well before the second MD block as part of the operational development.

As in other years it is foreseen to combine the MD blocks with dedicated runs or studies, e.g. scrubbing runs or special physics run. This will have a positive impact on

the overall physics programme (fewer interruptions) but implies a heavy load on the operational teams and experts.

Figure 2: Provisional LHC schedule [1] with foreseen MD periods.

SUMMARY PER INTEREST GROUP

Below a brief summary of the LSWG meeting [2] is given per interest group. The meeting took place over ¾ of a day with 58 people present. The presenters were asked to recall the main MD results of LHC Run 1 and give a first look at requests for LHC Run 2, differentiating between measurements as part of the commissioning period and measurements as MDs.

Linear and non-linear optics, measurements and corrections (E.H. Maclean)

During Run 1 there were 10 MDs used for Optics Measurements and Corrections, 3 for linear and 3 for non-linear optics plus 4 MDs on ATS optics, all resulting in one MD note.

For Run 2 commissioning the following measurements are required: polarity checks, chromatic coupling, coupling feedback, beam based corrections of b4 and amplitude detuning throughout the cycle.

MD requests for Run 2 concerning the linear optics consist of stability of nominal optics and modular corrections for dynamic beta* changes (e.g. for beta* levelling); study of off-momentum optics corrections especially at half integer tunes. The choice of working point at injection and throughout the cycle is also of interest. Concerning the non-linear optics possible MD topics consist of the Q' and Q'' discrepancy, natural chromaticity measurements and Q'' in the ramp, Q''' and chromatic amplitude detuning and improvement of the non-linear model of the LHC, especially at point 5.

ATS Optics (S. Fartoukh)

During Run 1 four MDs were dedicated to the ATS optics. It was demonstrated that a beta* of about 12 cm could be reached. It has been decided [4] that the ATS optics is not part of the initial commissioning in 2015 but its validation is sufficiently close and the appropriate MD time/OP time for the validation studies of ATS compatible optics should be found in the schedule to move to the ATS optics.

MDs concerning ATS optics can be dedicated to ATS flat optics, to be validated with few nominal bunches, the development and validation of special telescopic round optics for maximising the MO efficiency. Anti-ATS optics can be investigated for obtaining very large beta*.

Collimations, Crystals and Halo Control (S. Redaelli)

MDs during Run 1 were used for developing fast alignment of the collimators, quench tests, tight collimator settings and impedance measurements.

The new collimators, including those with integrated BPMs, will need to be brought into operation during commissioning. Effectiveness of the new TCLs and measurement of collimation impedance and improving the loss maps should all be part of the commissioning.

Run 2 MD request contain the following topics: collimation quench tests at 6.5 TeV; tighter collimation hierarchy, linked to impedance limits; faster collimator alignment with BLMs and integrated BPMs; passive abort gap cleaning in IR3; halo population scans at 6.5 TeV; an ambitious programme of crystal collimation experiments and finally halo control measurements.

Single and Two beam Stability (T. Pieloni)

During Run 1 MDs the growth rate of instabilities, related to octupole thresholds, chromaticity settings and damper gain were measured. Stability diagrams were obtained and coherent beam-beam and impedance measurements made (good beam 1 data are still missing).

During the commissioning period MO polarity and current, chromaticity and damper gain will need to be optimised to stabilise the beam throughout the cycle. The knowledge of machine parameters throughout the cycle remains very important and one will need to profit from set-up of pilot, single nominal bunches and trains during the commissioning period for the measurements.

For Run 2 the combination of single and two beam stability studies is possible. Topics are: remaining studies on instability growth vs. chromaticity, damper gain and octupole polarity; diffusion mechanism and impact on distribution profiles; collide and squeeze development; bunch-by-bunch and turn-by-turn measurements; beam-beam long-range studies with 25 ns, noise on colliding beams, flat beams, half-integer tune.

Impedance and Beam Induced Heating (B. Salvant)

Tune shift measurements during Run 1 gave discrepancies with the impedance model of up to a factor 2. The effect of bunch length reduction on the beam induced heating of the different devices has been measured.

During the beam commissioning in 2015 many of the beam impedance measurements can be performed parasitically. The impedance of the modified elements (TDI, TCDQ, TCTP and Roman Pots) need to be measured early in the run.

As MDs in 2015 the re-assessment of intensity limits due to impedances, compared to Run 1, is important. Other MDs consist of the localisation of impedance sources and the related heating of non-modified devices. The effect of changing bunch length and/or profile on the beam induced heating, impedance with changing gaps versus the number of bunches and the feasibility to optimise the beta function to reduce the transverse impedance are of interest.

Beta Levelling and Collide and Squeeze (A. Gorzawski)*

During Run 1 there were three MDs on beta* levelling and collide and squeeze. The feasibility has been proven, see Fig. 3, with a beta* being varied from 3 m to 0.6 m and from 9 m to 3 m. During these tests the TCTs were kept at the 0.6 m settings.

During the commissioning period of Run 2 no beta* and collide and squeeze are foreseen and it remains to be determined when these options will be put in operation. MDs can be used at the end of fills, including loss maps and asynchronous dump tests. Set-up time and validation will be required before it can be used in normal operation.

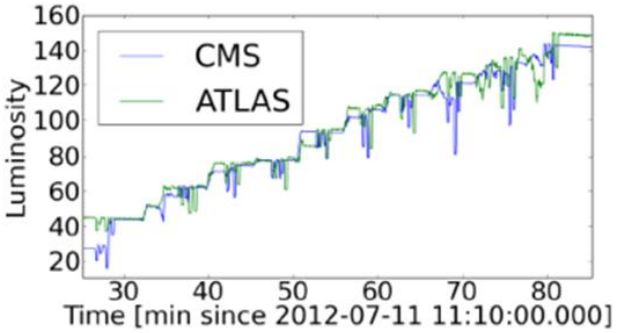

Figure 3: The measured luminosity during the variation of the beta* in collision (fill 2829).

RF studies in the LHC (E. Shaposhnikova)

Over the various RF MDs in Run 1 in total 16 MD notes have been written. During the initial commissioning in Run2 the various RF parameters will need to be optimised: main RF voltage, phase modulation, longitudinal emittance, bunch length and profile (related to beam induced heating).

Several MDs can be foreseen for Run 2: minimal RF voltage required to maintain Landau damping at 6.5 TeV; longitudinal bunch profile evolution during coast with and without collision; controlled RF phase modulation; longitudinal single and multiple bunch instabilities; emittance blow-up and shaping at 6.5 TeV in the presence of synchrotron radiation and longitudinal impedance evaluation, where there is discrepancy of a factor 2 to 3 with the model.

Transverse Damper (W. Höfle)

Run 1 has seen a combination of operational development and MDs related to the transverse damper. The transverse damper has been used in many other MDs of other groups.

During the commissioning in 2015 the new transverse damper diagnostics, including the new "Observation Box", should be brought into operation. This diagnostic tool will be vital for the understanding of potential instabilities during operation. Improvements in abort gap cleaning, using bipolar pulses, will need be brought into operation if needed. The damping will be required during the scrubbing runs and the stabilisation of the beam during 25 ns running will need to be optimised. The active excitation of the leading bunch for tune measurements can be further developed as can the measurement of the tune with the transverse damper. Loss maps with full beam by selective excitation of some bunches at the end of the fill can also be envisaged.

As part of the MDs for Run 2 a collaboration with the collimation team is foreseen to test halo cleaning with the transverse damper. Another possible MD is the benchmarking of the equations describing the transverse emittance blow-up resulting from the noise in the transverse feedback system.

Beam Instrumentation (T. Lefevre)

In Run 1 there was one MD period used for dedicated beam instrumentation measurements with 4 – 5 different activities per MD period. The aim was to measure performance limitation of the different operational devices.

All beam instrumentation will need to be commissioned during the Run 2 setting-up period, taking into account that all instrumentation has been modified in one way or another. In MDs the measurements that are not possible parasitically during normal beam operation and are not part of initial commissioning need to be made: further work on the dI/dt interlocking, directional strip-lines and the BPMs in the LSSs; bunch intensity scraping of nominal bunches and bunch length dependency of the different measurements; instability monitoring and triggering, emittance blow-up, different cross-calibrations etc.

Injection and Dump (J. Uythoven)

Injection studies during Run 1 were used for optimising the shielding in the injection regions, TDI alignment, quench margin measurements and studying the effect of

tails on injection losses. UFO studies at the MKIs and MKQs were performed. On the beam dump side the TCDQ alignment studies were performed, quench margins were determined and abort gap studies took place.

Part of the normal commissioning will be the set-up of injection of 50 ns and 25 ns beams and the beam dump system together with injection gap and abort gap cleaning. The different injection and beam dump movable absorbers will need to be set up with beam. The new BETS systems on the TDI, MSI and TCDQ will need to be commissioned. Beam induced heating of the modified TDI will need to be verified. On the beam dumping system the effective rise time of the MKD system will need be determined with beam during the set-up of the Abort Gap Keeper.

MDs during Run 2 will concern injection stability, steering and injection losses, setting-up of the blindable BLMs, matching monitors and special set-up of the TCDIs and TDIs if required. Simulation of MKI failure losses and measurements, abort gap cleaning algorithms, tests of the new BSRA hardware and software, studies of the interlocked BPMs, relative TCDQ / TCT retraction and losses and Q4 quench levels in Point 6 belong to possible topics of study.

Quench Tests (B. Auchmann)

During Run 1 eight different quench tests were performed, including end-of-run tests. Tests took place for three different loss time scales: single turn, UFO time scale and steady-state losses.

No dedicated measurements are foreseen during the Run 2 commissioning period. However, a lot of data might come for free, especially UFO related. BLM thresholds need to be set accordingly.

MDs during Run 2 will again concentrate on quench tests for the three different time scales mentioned above. Improved diagnostics with LICs will be available for the Q4s in Point 6. ADT quench tests can be repeated for UFO time scale losses and steady-state losses, with improvements concerning the experimental set-up and the underlying model.

PROCEDURES

To improve the efficiency certain MD ‘rules’ will be tightened for Run 2. A written procedure will be required for *each* MD, to be submitted at least two weeks before the start of the MD period. In the past this was only required for the approval from the restricted Machine Protection Panel (rMPP), but it was noted that good procedures significantly improved the efficiency during the MD. Approval of the MD topics is to take place prior to the MD period by the LMC (at least one week). The approval by rMPP for those MDs that are considered as potentially dangerous for the machine will remain and should also be part of the approval by the LMC

The plan is to have each MD linked to a contact person within the OP group, either EIC or operator, who should help to prepare the MD and the procedures, taking into account the available beams and set-up time required in the LHC and injectors. For practical reasons, it will be difficult to always have this same person on shift for the MD, although this is preferable.

Each MD should be written up in an MD note, to be published in the four weeks following the MD. This does not have to be a full analysis of the measurements, but should at least refer to all the measurements made. This will help in the planning of any future MDs on similar topics and will be obligatory before any future MDs on the same topic are scheduled.

CONCLUSIONS

The list of possible MD topics is at least as long as for Run 1 and the limited MD time will need to be distributed carefully. Formal, written requests will be collected in early 2015. Priorities will be decided when the requests have been received. A Web page is under preparation for an efficient MD request management.

Anything which is vital for machine operation will be part of the initial Run 2 commissioning and not the MDs. The MD programme will also be affected by issues encountered during the commissioning. High priority measurements during the commissioning period are: aperture measurements; measurement of impedance of modified elements close to the beam, especially collimators; stability of the beam with octupoles, chromaticity and transverse damper; tune measurements with the transverse damper and the initial tests with the Observation Box of the transverse damper and parasitic UFO quench tests.

High priority early MDs are: change of intensity limits compared to Run 1, related to modified impedance; more beam stability studies; long range beam-beam effects with 25 ns bunch spacing and variation of the crossing angle; collimation hierarchy and tight collimation settings related to the impedance of the collimators; additional measurements with the BPMs integrated in the collimators; beta* levelling and collide & squeeze tests. Other important MDs concern the ATS optics, including the simulation of asynchronous dump losses for this optics with the less favourable phase advances.

If it is decided to apply beta* levelling during normal operation many measurements (like orbit stability and optics) should already have been done during normal operation. Required information from MD results consists of: collimator hierarchy linked to collimator impedance, beam stability limits and instability growth rates and long range beam-beam effects. During the commissioning of the low beta* optics the collimation set-up should be performed.

Finally it is to be noted that strict procedures before, during and after the MDs will be applied to optimise the efficiency.

REFERENCES

[1] J.Wenninger, “Strategy for Run 2”, these proceedings.

[2] http://indico.cern.ch/event/331020/

[3] G.Arduini, “Down selection criteria and MDs prior to LS3”, these proceedings.

[4] Minutes of the 188th LMC meeting 03/09/2014, https://espace.cern.ch/lhc-machine-committee/Minutes/1/lmc_188.pdf