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CH-1211 Geneva 23
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LHC Project Document No.
LHC-xxx rev 1.0

CERN Div./Group or Supplier/Contractor Document No.
BE-ABP/OP

EDMS Document No.
xxx

Date: 2018-08-30

LHC MD3270

TELESCOPIC ROUND OPTICS WITH TRAINS

Abstract

This note summarises the key objectives of the third and last series of ATS MDs (MD 3270) which was programmed for Run II, and aims at demonstrating the operability of round telescopic optics of large telescopic indexes, with the telescopic squeeze fully embedded in the ramp. One of the main motivations is to explore possible operational scenarios for the third exploitation period of the LHC (Run III) at higher or much higher beam brightness, with, very likely intensity limitations driven by the transverse impedance of the ring. Ultimately, for this MD, the goal is to complete the validation of the ATS techniques, in the presence of several hundreds of bunches circulating in the ring, namely more than 600-700 bunches to see e-cloud for the first time in highly telescopic optics and (close to) nominal long-range beam-beam conditions. This note will fix the goal of the round ATS optics activities which are foreseen at the next block (MD3-2018), together with the detailed procedure which has been settled accordingly.

Prepared by:	***Checked by:***	***Approved by:***
X. Buffat **S. Fartoukh** **G. Iadarola** **N. Karasthatis** **A. Mereghetti** **Y. Papaphilippou** **A. Poyet** **M. Solfaroli** **G. Sterbini** **D. Valuch** **J. Wenninger**		

Distribution list :

LHC Machine coordinator, Engineers in charge, LHC operators

History of Changes

Rev. No.	***Date***	***Pages***	***Description of Changes***
0.1	30-August-2018	All	First draft
0.2	xx	All	xx

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1. INTRODUCTION & MOTIVATIONS

The Achromatic Telescopic Squeezing (ATS) scheme [1] constitutes the baseline optics scheme for the HL-LHC, and is now routinely used in operation to push beta*, but still with a quite modest telescopic index of 1.6, only reached in the end of the telescopic squeeze from beta*=40 cm down to 25 cm. This index of 1.6 can be directly compared to typical values ranging from 4 to 8 for the HL-LHC, where the telescopic index quantifies the relative increase of the peak beta in the arcs which results from the ATS squeezing techniques. Another interesting by-product of the ATS scheme lies in the fact that it boosts the efficiency of the lattice octupoles, either for increasing the level of Landau damping which is requested at higher impedance and/or higher beam intensity, or for mitigating the long-range beam-beam interactions, or for both. The gain in MO efficiency is however rather modest at low telescopic indexes (~1-1.5), but then rises quite rapidely for higher indexes (going asymptotically with the square of the telescopic index). The present MD campaign consists in commissioning a new variant for the LHC hypercycle, in particular a combined "ramp-and-double-squeeze" (CRDS) which deployes the tele-squeeze already in the ramp prior to the completion of the pre-squeeze sequence, and to study its properties from the perspective of the above-mentioned aspects. The merit of this program is therefore to converge towards a solution for the Run III optics which would be compatible with the full LIU beam intensity (as far as impedance and BBLR effects are concerned), while completing the validation of the ATS scheme for the HL-LHC (at large telescopic index). The ultimate wish is to inject, ramp and collide several hundreds of bunches in this new configuration, in order to exclude as well un-expected effects from the electron cloud, when the peak beta-functions will be as large as 500-600 m in the arcs (as reached already in the end of the new CRDS).

2. OPTICS, HYPERCYCLE AND SETTINGS (Q, MO, COLLIMATOR)

Accordingly, a new set of LHC round optics [2] has been prepared in an appropriate ordering, as described herefater.

(i) The nominal injection optics (β^*=11 m) is preserved.

(ii) The nominal pre-squeeze sequence is re-used but stopped at 2 m. It is then immediately followed by a telescopic squeeze (i.e. at constant IPQ settings in IR1/5) in order to deploy a telescopic index of 2.0/0.65~3.1, i.e. to reach a β^* of 65.0 cm, at the end of the ramp.

(iii) The pre-squeze sequence is restarted at flat-top energy, keeping constant the telescopic index of above (i.e. at constant IPQ settings in IR8/2/4/6), and further reducing the pre-squeezed β^* from 2.0 m down to 77.0 cm. In the end of this process, β^* takes therefore the value of 77*0.65/2.0= 25.025 cm at IP1 and IP5.

While the full sequence of above was probed with pilot beams in MD1, higher intensity tests were continued in MD2 (with setup beams), and will be continued in MD3, by colliding immediately at the end of the ramp, that is with β^* =65.0 cm at IP1 and IP5, and a half-crossing angle calibrated in the range of 100-120 μrad. As far as the long-range beam-beam interractions are concerned, note that an half-crossing angle of 110 μrad at β^* =65.0 cm gives the same normalised beam-beam separation as the one obtained with the nominal half-crossing angle of 160 μrad at β^* =30.0 cm.

The timing structure of the CRDS (**RAMP_PELP-SQUEEZE-ATS-65cm_HighTele_V1** [3]) is given in Tab. 1. It is played at constant tune .275/.295, with nominal collimator settings in IR3/6/7 but **new TCT & TCL4 functions in IR1 and IR5 and new energy/β^* interlock thresold [4]. The TCSP and TCDQ jaws of beam1 is also open by 200 μm, still within the BETS limits, towards the end of**

the ramp (linear trim starting at 825 s, i.e. at the tele-index of 1.6 of the nominal 25 cm optics). In this configuration the normalised TCDQ/TCSP settings of both beams will end up to 7.5 σ at the end of the ramp.

New **octupole ramp functions**, for either MO polarity, have also been prepared [5], much reduced with respect to the nominal settings towards the end of the ramp at high telescopic index, in order to demonstrate the full potential of the CRDS for high brightness beams in Run III and for the HL-LHC. In order to minimise the risk of instability in the physics BP, the default MO polarity is presently chosen to be positive (+200 A in ROF circuits at the end of the CRDS, corresponding to a negative value for the knob). This is however still a subject of discussion, and this choice might be reverted prior to the MD, and/or during the MD depending on the findings.

` Finally **new ADT settings (phases)** are also implemented [6] in order to cope with the new ramp timing structure, and also with the substantial optics changes in IR4 driven by the tele-squeze in the ramp itself.

At the end of the ramp, the CRDS is immediaely followed by a Q-change beam process (**QCHANGE-6.5TeV-HighTele-2018_V1** [3]) in order to reach the collision tunes of (.31/.32). Finally the two beams are put in collision using the beam process **PHYSICS-6.5TeV-HighTele-2018_V1** [3] played at constant tune (and without IP shift induced at IP2 and IP5).

Table 1: Optics, Energy and Timing structure of the combined ramp and double squeeze (CRDS) **RAMP_PELP-SQUEEZE-ATS-65cm_HighTele_V1** [3]

Matched Point	Time [s]	Parabolic Fraction	Optics name	Tele-Index	β^* [cm] at IP1 &5	Energy [GeV]
1	0	0.1	R2017a_A11mC11mA10mL10m	1.000	1100.0	450
2	15	0.05	R2017a_A11mC11mA10mL10m	1.000	1100.0	452
3	30	0.05	R2017a_A11mC11mA10mL10m	1.000	1100.0	459
4	45	0.05	R2017a_A11mC11mA10mL10m	1.000	1100.0	470
5	60	0.05	R2017a_A11mC11mA10mL10m	1.000	1100.0	485
6	90	0.05	R2017a_A11mC11mA10mL10m	1.000	1100.0	531
7	120	0.05	R2017a_A11mC11mA10mL10m	1.000	1100.0	594
8	160	0.05	R2017a_A11mC11mA10mL10m	1.000	1100.0	705
9	241	0.05	R2017a_A11mC11mA10mL10m	1.000	1100.0	1013
10	293	0.13	R2017a_A970C970A10mL970	1.000	970.0	1277
11	317	0.10	R2017a_A920C920A10mL920	1.000	920.0	1416
12	337	0.15	R2017a_A850C850A10mL850	1.000	850.0	1532
13	361	0.13	R2017a_A740C740A10mL740	1.000	740.0	1671
14	385	0.10	R2017a_A630C630A10mL630	1.000	630.0	1810
15	413	0.10	R2017a_A530C530A10mL530	1.000	530.0	1972
16	437	0.11	R2017a_A440C440A10mL440	1.000	440.0	2111
17	461	0.12	R2017a_A360C360A10mL360	1.000	360.0	2250
18	493	0.15	R2017a_A310C310A10mL300	1.000	310.0	2435
19	525	0.15	R2017a_A230C230A10mL300	1.000	230.0	2620
20	545	0.15	R2018a_A200C200A10mL300	1.000	200.0	2736
21	649	0.15	R2018aT200_A182C182A10mL300	1.096	182.5	3339
22	749	0.20	R2018aT200_A155C155A10mL300	1.290	155.0	3918
23	825	0.15	R2018aT200_A122C122A10mL300	1.633	122.5	4358

24	925	0.16	R2018aT200_A95C95A10mL300	2.105	95.0	4937
25	1025	0.20	R2018aT200_A77C77A10mL300	2.581	77.5	5516
26	1169	0.10	R2018aT200_A65C65A10mL300	3.077	65.0	6350
27	1210	0.05	R2018aT200_A65C65A10mL300	3.077	65.0	6500

3. OBJECTIVES FOR MD3 AND OVERALL STRATEGY

3.1 OBJECTIVES & MAIN ACTIVITIES

Two shift of 3 h and 13 h (+2h for ramp down after each) are foreseen for round ATS optics activities in MD3. In the first shift, the aim is to re-validate the CRDS in terms of collimation with set-up beams. In the second shift, the aim is an intensity ramp up to ~900 b, as packed as possible (6 SPS injection of 144 b), both for BBLR studies and first e-cloud observation in highly telescopic optics, at intermediate (~150 b) and full (~900 b) intensity, respectively.

For the first shift, betatron and off-momentum loss maps will be taken in collision and end of ramp (for the betatron loss maps), followed by an asynchronous dump test (see Tab. 2 for more details).

For the second shift, the intensity ramp up to reach ~900 bunches for e-cloud observation is foreseen in 3 steps (see Tab. 3 for more details), first with ~150 bunches (1 SPS injection) for the BBLR studies, then passing by an intermediate step with 450 bunches (3 SPS injections).

3.2 BEAM & MACHINE CONDITIONS

Only set-up beams will be used for the first (validation) shift and up to 900 bunches for the second shift (see Tab. 1). The detailed filling scheme for the second shift is in preparation, where all the bunches are planned to collide at IP1 and IP5, except the first one for tune monitoring. Discussions are on-going concerning the corresponding collision schedule at IP2 and IP8.

One cycle is planned to be played for the revalidation shift, and up to 3 fills in the shift for the intensity ramp up.

Table 1: Basic beam and machine parameters during the MD

Beams required [1, 2, 1&2]	1&2
Beam energy	Injection 450 GeV, ramp & squeeze, 6.5 TeV, collision
Bunch intensity [#p, #ions]	Set up beams (<3E11) under the form of 2 colliding nominals and 8-10 pilot bunches for the first shift, and 1E14 for the second shift
Number of bunches	Up to 877 bunches (1+12+6*144) for the seoncd shift
Transv. emittance [m rad]	As small as possible
Bunch length [ns @ 4s]	Not relevant
Optics change [yes/no]	Yes (nominal injection optics but brand new ramp)
Orbit change [yes/no]	Yes (crossing angle reduction in IR1/5 in the ramp)
Interlocks [yes/no]	Yes, “relaxed” for the first shift (within the limits of setup beams)
Collimation change [yes/no]	**Yes (new TCT/TCL functions [4] and TCDQ/TCSP opening by 200 μm for Beam1 towards the end of the ramp, see Section 2)**
RF system change [yes/no]	No
Feedback changes [yes/no]	Yes (new ADT phases to cope with the new CRDS timing structure and the IR4 optics changes induced by the tele-squeeze [6])
What else will be changed	Tunes set to 0.275/.295 in the ramp (.275/.293 nominal), brand new MO ramp functions [5].

4. DETAILED STEPS TO BE TAKEN DURING THE MD

The sequence of activities for the first and second shift are detailed in Tabs. 2 and 3, respectively. There is no contingency for a second fill in the validation shift, which is a weakness in the overall MD program.

Table 2: Breakdown of activities with time estimate for the validation shift

Activity (and comments)	Time estimate [h]
Validation fill: **Single_7b_1_1_1_5ncPilots2cNom** (2 colliding nominal + 10 non-colliding probes) **New TCT functions (centres and Nsigma) and energy/β* interlock thresolds** **All maskable interlocks (inc. collimator) masked** **New MO ramp function with positive polarity (still under discussion)**	
- Setting up at injection, and injection → 0.5 h - **Combined ramp & double squeeze** → 0.25 h - **Betatron Loss maps at flat top** (optional) → 0.25 h - Q-change immediately followed by the Physics BP, **Establish and optimize collision** → 0.5 h - **Betatron Loss maps in collision** @ 120 μrad→ 0.25 h - 120 → 90 μrad X-angle reduction and lumi optimization → 0.25 h - **Betatron Loss maps in collision** @ 90 μrad→ 0.25 h - 90 → 120 μrad X-angle increase and lumi optimization → 0.25 h - **Off-momentum Loss maps in collision** (both δp)@ 120 μrad→ 0.5 h - **Scraping (<5E10), de-bunching, asynchronous dump (TCT @ 11 σ)** → 0.5h	3.5
Total	**3.5**

Table 3: Breakdown of activities with time estimate for the intensity ramp up

Activity (and comments)	Time estimate [h]
1rst Fill: BBLR studies with trains **1 n.c. INDIV + 12 (colliding) bunches + 3 BCMS trains = 157 bunches (filling scheme in preparation)** **New TCT functions (centres and Nsigma) and energy/β* interlock thresolds** **New MO ramp function with positive polarity (still under discussion)**	
- Setting up at injection and injection → 0.75 h - **Combined ramp & double squeeze** → 0.25 h - Q-change and Setting up at flat top → 0.5h - **Collision and lumi optimisation with trains**→ 0. 5 h - **MO polarity reversal, down to -570 A & Tune scan**→ 0.5 h - **X-angle reduction down to 100-90 μrad (if life time good enough) & Tune scan** → 0.5 h - **MO scan from -570 A to +200 A (2/3 cycles in one go for each step)**→ 0.75 h - **MO @ -570 A , X-angle back to 120 μrad and lumi levelling test**→ 0. 25 h - **Offset levelling test (fast and slow Vernier scan) and beam activity observation**→ 1.0 h	5.0
Dump & Ramp down	**1.0**
2d Fill: Intensity ramp up with 450 bunches **1 n.c. INDIV + 12 (colliding) b + 3 SPS injection = 445 bunches (filling scheme in preparation)**	

New TCT functions (centres and Nsigma) and energy/β* interlock thresolds **New MO ramp function with positive polarity (still under discussion)**	
- Setting up at injection and injection → 0.75 h - **Combined ramp & double squeeze** → 0.25 h - Q-change, Setting up at flat top, and **heat-load/beam activity observation** → 0.5 h - **Collision and lumi optimisation with trains** → 0. 25 h - **MO polarity reversal down to -570 A and X-angle reduction down to 100-90 µrad (if life time good enough)** → 0. 25 h - Lumi optimisation and **heat-load/beam activity observation** → 1.0 h	3.0
Dump & Ramp down	**1.0**
3rd Fill: Intensity ramp up with 900 bunches **1 n.c. INDIV + 12 (colliding) b + 6 SPS injection = 877 bunches (filling scheme in preparation)** **New TCT functions (centres and Nsigma) and energy/β* interlock thresolds** **New MO ramp function with positive polarity (still under discussion)**	
- Setting up at injection with probes and injection → 0.75 h - **Combined ramp & double squeeze** → 0.25 h - Q-change, Setting up at flat top, and **heat-load/beam activity observation** → 0.5 h - **Collision and lumi optimisation with trains** → 0. 25 h - **MO polarity reversal down to -570 A and X-angle reduction down to 100-90 µrad (if life time good enough)** → 0. 25 h - Lumi optimisation and **heat-load/beam activity observation** (optionnal: Vernier scan towards the end) → 2.0 h - Beam dump	4.0
Total	**14.0**

5. REFERENCES & ACKNOWLEDGEMENTS FOR PREPARATION WORK

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