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TELESCOPIC ROUND OPTICS WITH 3E11

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, and the octupoles set to negative polarity over the full cycle. 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 intensity (with very likely limitations from transverse impedance), and, ultimately, to complete the validation of the ATS techniques for the HL-LHC in the presence of several hundreds of bunches circulating in the ring. This note will fix the goal of the round ATS optics activities which are foreseen at the next block (MD2-2018), together with the detailed procedure which has been settled accordingly.

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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 with a combined "ramp-and-double-squeeze" (CRDS) deploying 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 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, high intensity tests will continue in MD2, and later on, but colliding immediately at the end of the ramp, that is with β^* =65.0 cm in IR1 and IR5 (and a half-crossing angle calibrated to 120 μrad).

The timing structure of the CRDS (**RAMP_PELP-SQUEEZE-ATS-65cm_HighTele_V1** [3]) is given in Tab. 1. It will be played at constant tune .275/.295, with nominal collimator settings in IR3/6/7 but **new TCT functions in IR1 and IR5 [4]**. The option to **open the TCSP and TCDQ jaws of beam1 by 200 μm 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) is under discussion. In this configuration the TCDQ/TCSP settings of both beams will end up to 7.5 σ at the end of the ramp. New octupole ramp functions are also in preparation [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. Finally new ADT settings (phases) will also be implemented [6] in order to cope with the new ramp timing structure, and also the substantial optics changes in IR4 driven by the tele-squeze in the ramp itself.

At the end of the ramp, the CRDS will be 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 will be 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 MD2 AND OVERALL STRATEGY

3.1 OBJECTIVES & MAIN ACTIVITIES

A shift of 9 h (+2h for ramp down) is foreseen for round ATS optics activities in MD2. The aim is to validate the CRDS in terms of collimation and octupoles for an intensity ramp up with many trains as of MD3. In particular, loss maps will be taken on the fly in the different ramps which will be played (see Tab. 2 for more details), using new TCT functions [4] loaded in the cycle and pre-set from MADX and MD1. Dedicated beam-based TCT alignments will also take place at the end of the first ramp, and after having established and optimised the collisions at the 4 IP's, in order to fine-tune the TCT centers for the sub-sequent ramps. At a β^* of 65 cm with an half-crossing angle of 120 μrad, dedicated triplet aperture measurements are not deemed to be necessary (14.5 σ expected from MADX). The tunes and coupling will also be feedforwarded from ramp to ramp in order to clean the cycle as much as possible.

3.2 BEAM & MACHINE CONDITIONS

Only set-up beams will be used (see Tab. 1). Two cycles (at least) are planned to be played, the first one using positive octupole polarity all along and the second with negative polarity (just changing the sign of the MO knob values). If time permits, a third ramp will also be played, still with negative MO polarity, but increased current in order to anticipate the intensity ramp up with trains in MD3, where the long-range beam-beam interactions, by far non-negligible in the end of the ramp (β^* = 65 cm @ 120 μrad), will fight against the MO-induced tune spread in this configuration (with LOF<0).

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, squeeze
Bunch intensity [#p, #ions]	Set up beams (<3E11) under the form of 2 colliding nominals and 8-10 pilot bunches
Number of bunches	Up to 12 (2 nominal bunches max)
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 (within the limits of setup beams)
Collimation change [yes/no]	**Yes (new TCT 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 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 is detailed in Tab. 2.

Table 2: Breakdown of activities with time estimate

Activity (and comments)	Time

	estimate [h]
First fill: **Single_7b_1_1_1_5ncPilots2cNom** (2 colliding nominal + 8-10 non-colliding probes) **New TCT functions (centres and Nsigma) preset from MADX and MD1** **New MO ramp function with positive polarity.**	
- Setting up at injection, and injection → 0.25 h - **Combined ramp & double squeeze with 2 sets of LM's on the fly** (2.7 TeV, 4.9 TeV) → 0.25 h - Setting up at flat top → 0.25 h - **TCT alignment at flat top** → 0.25 h - **Loss maps at flat top** → 0.25 h - Q-change beam process - Life time/MO scan (+200 A → +570 A) → 0.25 h - **Establish and optimize collision** → 0.5 h - **TCT alignment in collision** → 0.25 h - **Loss maps in collision** → 0.25 h - **Scraping (<5E10), de-bunching, asynchronous dump (TCT @ 11 σ)** → 0.5h	3.0
Ramp down	1.0
Second fill: **Single_7b_1_1_1_5ncPilots2cNom** (2 colliding nominal + 8-10 non-colliding probes) **Final TCT functions (only centres). New MO ramp function with negative polarity.**	
- Setting up at injection and injection → 0.25 h - **Combined ramp & double squeeze with 2 sets LM's on the fly** (2.7 TeV & 4.9 TeV) → 0.25 h - **Loss maps at flat top** → 0.25 h - Q-change beam process - Life time/MO scan (-200 A → -570 A) → 0.25 h - **Establish and optimized collision** → 0.25 h - **Loss maps in collision** → 0.25 h - **Scraping (<5E10), de-bunching, asynchronous dump (TCT @ 11 σ)** → 0.5h	2.0
Ramp down	1.0
Third fill: **Single_7b_1_1_1_5ncPilots2cNom** (2 colliding nominal + 8-10 non-colliding probes) **Final TCT functions. New MO ramp function with negative polarity, including a margin for BBLR**	
- Setting up at injection and injection → 0.25 h - **Combined ramp & double squeeze** → 0.25 h - Q-change beam process - **MO threshold with negative polarity** → 0.75 h - If still some beams, **MO threshold with positive polarity** → 0.5 h - If still some beams, **off-momentum loss maps** → 0.25 h	2.0
Total	**9.0**

5. REFERENCES & ACKNOWLEDGEMENTS FOR PREPARATION WORK

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[3] M. Solfaroli, Combined ramp and double squeeze, and pre-squeeze continuation beam processes for the 2018 round ATS optics MD, 2018.
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[6] D. Valuch, ADT functions for the combined ramp and double squeeze, 2018.