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LHC

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LHC-TC-EC-0014

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ENGINEERING CHANGE REQUEST

First Phase of Installation of Low Impedance Secondary Collimators (TCSPM) in IR7

BRIEF DESCRIPTION OF THE PROPOSED CHANGE(S):

The LHC impedance budget is dominated by the contribution of the LHC collimators, and in particular by the eleven secondary collimators (TCSG) per beam of the betatron insertion region, located in IR7. The baseline upgrade of the LHC collimation system foreseen by the HL-LHC project considers to replace all the IR7 TCSGs with new ones (TCSPM) to reduce impedance and ensure with sufficient margin the stability of the brighter HL-LHC beams. The installation of the new hardware will proceed in two stages, with four collimators per beam installed during the Long Shutdown 2 (LS2) and the remaining seven collimators per beam during LS3 based on the results of the measurements performed during Run 3. This ECR details the first phase of installation, taking place during LS2.

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DOCUMENT SENT FOR INFORMATION TO:

ATS groups leaders

SUMMARY OF THE ACTIONS TO BE UNDERTAKEN:

Note: When approved, an Engineering Change Request becomes an Engineering Change Order.

1. EXISTING SITUATION AND INTRODUCTION

The betatron collimation system [1] of the Large Hadron Collider (LHC) is located in the Insertion Region 7 (IR7). For each beam it is composed by:

- three primary collimators (TCPs), intercepting tail protons;
- eleven secondary collimators (TCSGs), aimed at intercepting most of the beam particles leaking out of the TCPs;
- shower absorbers (TCLAs), aimed at containing the most energetic component of the secondary particle showers started in the upstream collimator families.

Due to the relatively high number of TCSG collimators, the jaw material and gaps deployed in operation, they are the largest contributors to the machine impedance [2]. Octupoles are used in LHC operation to stabilise the beam, compensating the machine impedance with enough margins that can be used for compensating also other sources of instability.

The High Luminosity LHC (HL-LHC) project [3] foresees to collide beams brighter than those presently available in the LHC. Numerical calculations [4] show that if no action in reducing the collimator impedance is taken, then there would be not enough margin for the octupoles to stabilise the beams. Therefore, the HL-LHC project foresees to replace the present TCSG collimators with low impedance ones (TCSPMs).

It is proposed to proceed with the installation of the new collimators in IR7 in two phases. The first one will be carried out during the Long Shutdown 2 (LS2), when four TCSGs per beam will be replaced with the equivalent number of TCSPMs. During LS3, the seven remaining TCSGs per beam will be replaced based on the results of the measurements performed during Run 3. The present ECR details the LS2 installation.

2. REASON FOR THE CHANGE

While the low-impedance upgrade of the IR7 collimation system is part of the baseline upgrades foreseen by the HL-LHC project [4], it has been proposed to proceed in two installation phases. The assets of this approach are:

1. Having some low-impedance collimators already installed in LS2 already provides an important reduction of the collimator impedance for the LHC Run III, when the upgraded beam parameters from the LHC Injector Upgrade (LIU) program will progressively become available. This will provide important benefits to the LHC operation and will allow studying better the possible impedance limitations;
2. A staged deployment allows possible further iterations on the new collimator design for the second production line for LS3;
3. The staged approach also allows distributing resources that would otherwise have to be made available in LS3, when various other parallel activities for different HL-LHC upgrades will be on-going, in particular the collimation upgrade of the high-luminosity insertions IR1 and IR5.

3. DETAILED DESCRIPTION

The present TCSPM design [5] (see

Figure 1) is an evolution of the present TCSGs [1]; among the most noticeable differences, there are material and coating of the jaw, and the presence of in-jaw Beam Position Monitors (BPMs). Other features are described in [6].

The design foresees jaws made of a composite material (MoGr) obtained from Molybdenum and graphite, chosen for its similar robustness and superior impedance characteristics with respect to the jaw material of the present TCSGs, in particular since a thin, 5 μm-thick coating layer will be deployed. The collimator jaws are equipped with BPM button pick-ups, for an easy determination of the beam closed orbit at the collimator and fast and precise alignment of the jaws. A third BPM is installed on the tank, to measure the beam position on the axis orthogonal to the one of cleaning. The BPMs shall be added in the database with the same notations used for the present TCTP and TCSP collimators. Table 1 summarises the main collimator parameters of the TCSPM design, whereas Table 2 - SmarTeam codes of the assembly sub-modules. lists all the SmarTeam codes of the assembly submodules.

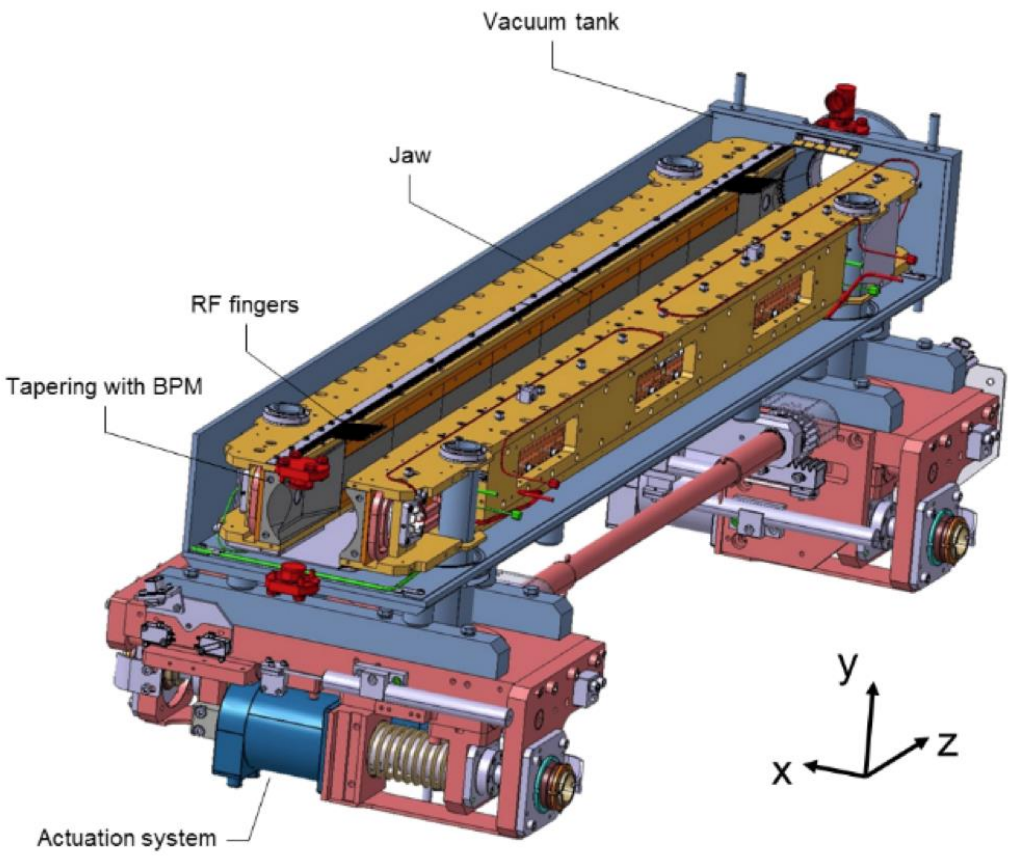

Figure 1 — 3D view [5] of the TCSPM collimator (SmarTeam code: ST0948103), showing an extremity of the jaw with the embedded BPM, the "third" BPM for orbit measurements in the plane orthogonal to the collimation plane, and the new tapered transitions made of MoGr.

Table 1 — Detailed parameters list of the TCSPM collimator design.

Characteristics	**Units**	**Value**
Jaw active length	mm	1000
Jaw absorbing material		MoGr
Flange-to-flange distance	mm	1480
Number of jaws		2
Orientation		Depending on installation slot (see Table 3)
Number of BPM buttons per jaw		2
Number of tank BPM buttons		2
RF damping		RF fingers
Cooling of the jaw		Demineralised water
Minimum gap	mm	<2
Maximum gap	mm	50
Stroke across zero	mm	5
Number of motors per jaw		2
Angular adjustments		Yes
Transverse jaw movement (fifth axis)		Yes

Table 2 - SmarTeam codes of the assembly sub-modules.

ST Reference	Description
ST0948103	Model of the TCSPM collimator
ST0266511	Model of the support/pied for P7 (low)
ST0266352	Model of the lower plug-in (no BPM integrated)
ST0489484	Model of the cradle 0 degrees
ST0267922	Model of the protection 0 degrees
ST0489576	Model of the cradle 90 degrees
ST0267893	Model of the protection 90 degrees
ST0489657	Model of the cradle 135 degrees
ST0268188	Model of the protection 135 degrees

During the 2016 Extended Year End Technical Stop (EYETS 2016) a prototype of TCSPM collimator was installed on beam 2 (B2) [7]. Prototyping allowed verifying the feasibility of the new design. Moreover, the jaws of the prototype were equipped with three superficial stripes of different materials, in order to perform impedance measurements with each stripe and hence finalise the choice of coating material.

With respect to the present TCSG collimators, the jaws of the new design have improved thermo-mechanical properties and a lower impact on impedance. This is thanks to the choice of the bulk material of the jaw. The bulk material is relevant for impedance purposes since the jaw is not coated in the tapering region[1]. Moreover, it is important to have a high-conductance material under the coated layer in case of superficial scratches following accidents. Further improvements on beam impedance are provided by a metallic coating layer. At the time of writing, the baseline design considers molybdenum as coating material, even though other materials are still being explored and have not been excluded yet, e.g. copper. In case of molybdenum the minimum required thickness is 5 μm, whereas in case of copper the minimum thickness would be 3 μm.

The layout of the betatron collimation cleaning insertion was prepared for a low-impedance upgrade from the initial design phase [1]. Each IR7 TCSG has a corresponding TCSM slot, immediately downstream. These slots are all equipped with the required cabling and ancillaries (support, cooling water, beam loss monitor, etc...) for the installation of a new collimator. Cabling for the readout of the in-jaw BPMs is not part of the initial installation because the previous collimator design did not include this feature. The short, radiation-hard cables from the tunnel's cable trays to the collimator support are also not installed for every TCSM slot. The short water braided flexibles from the series water system to the collimator support are also not installed for every TCSM slot.

Therefore, where possible, the installation of the new collimators is done by using the empty slots. Such a hybrid scenario where both old and new collimators are temporarily kept operational is not favored over a long time scale because this configuration would entail the maintenance of a larger number of devices; nevertheless, this configuration is suitable for the initial commissioning of new collimators. The impact on the requirements for the collimator control units should be assessed.

At the time of writing, a complete assessment of radiation levels of the present TCSGs is not available. In case of high doses, it might be preferable or even necessary to remove the TCSG collimator in order to allow personnel to work in the areas. A detailed assessment will be carried out in 2018 depending on the progress with the luminosity performance. Presently, no show-stoppers are identified for the intervention on any TCSG slot.

Detailed numerical studies [6] allowed to spot the best set of slots for installation of the new TCSPM collimators. The optimization mainly took into account impedance reduction, energy deposition and induced thermo-mechanical stresses, and cleaning inefficiency. Table 3 lists the chosen slots for both B1 and B2 along with the DCUM ("distance cumulée"), the existing components and the name of the new ones; for ease of coordination of activities, the vacuum sector is also indicated. The TCSM slot is used whenever available, hence the new TCSPMs are added downstream of the respective TCSG. The only exception is the TCSM.D4L7.B1, where the crystal collimator is installed; hence, the TCSG.D4L7.B1 will be replaced by the new TCSPM. If tests probing the endurance of the stripes of the TCSPM.D4R7.B2 will be carried out in 2018, then this collimator will be replaced with the new TCSPM; otherwise, the TCSPM

[1] It should be noted that the angle of the tapering between the BPM buttons and the active surface of the jaw has been reduced with respect to the design of the IR6 TCSP collimators (this is the first family of secondary collimators with BPM buttons to be installed in the LHC, already in LS1). This change further improves the geometric impedance of the TCSPM.

prototype will remain in the TCSM slot, and the upstream TCSG.D4R7.B2 will be exchanged with the TCSPM. The layout names of the new collimators and the names of the embedded BPMs are listed in Table 4.

Table 3 — Installation slots of the new TCSPMs in IR7.

B1 Slot	Angle [deg]	DCUM [m]	Existing components (LDB functional position)	New Components (LDB functional position)	Vacuum Sector
TCSG.D4L7.B1	90.0	19989	TCSG.D4L7.B1	TCSG.D4L7.B1	A4L7.B
TCSM.B4L7.B1	0.0	19919	VCDSS.B4L7.B	TCSPM.B4L7.B1	IP7.B
TCSM.E5R7.B1	130.5	20108	VCDSS.C5R7.B	TCSPM.E5R7.B1	A5R7.B
TCSM.6R7.B1	0.5	20143	VCDSS.6R7.B	TCSPM.6R7.B1	B5R7.B

B2 Slot	Angle [deg]	DCUM [m]	Existing components (LDB functional position)	New Components (LDB functional position)	Vacuum Sector
TCSG.D4R7.B2	90.0	20070	TCSG.D4R7.B2	TCSG.D4R7.B2	A4R7.R
TCSM.B4R7.B2	0.0	20002	VCDSS.B4R7.R	TCSPM.B4R7.B2	IP7.R
TCSM.E5L7.B2	130.5	19879	VCDSS.C5L7.R	TCSPM.E5L7.B2	A5L7.R
TCSM.6L7.B2	0.5	19844	VCDSS.6L7.R	TCSPM.6L7.B2	B5L7.R

Table 4 — 'Names' (Layout DB functional positions) of the BPMs for the new TCSPM collimators.

Name of New Collimator (LDB functional position)	Azimuthal Angle [deg]	Collimation Plane	Layout Functional Position of Upstream in-Jaw BPM	Layout Functional Position of Downstream in-Jaw BPM	Layout Functional Position of Tank BPM
TCSG.D4L7.B1	90	V	BPTUV.D4L7.B1	BPTDV.D4L7.B1	BPTUH.D4L7.B1
TCSPM.B4L7.B1	0	H	BPTUH.B4L7.B1	BPTDH.B4L7.B1	BPTUV.B4L7.B1
TCSPM.E5R7.B1	130.5	S	BPTUJ.E5R7.B1	BPTDJ.E5R7.B1	BPTUT.E5R7.B1
TCSPM.6R7.B1	0.5	H	BPTUH.6R7.B1	BPTDH.6R7.B1	BPTUV.6R7.B1
TCSG.D4R7.B2	90	V	BPTUV.D4R7.B2	BPTDV.D4R7.B2	BPTUH.D4R7.B2
TCSPM.B4R7.B2	0	H	BPTUH.B4R7.B2	BPTDH.B4R7.B2	BPTUV.B4R7.B2
TCSPM.E5L7.B2	130.5	S	BPTUJ.E5L7.B2	BPTDJ.E5L7.B2	BPTUT.E5L7.B2
TCSPM.6L7.B2	0.5	H	BPTUH.6L7.B2	BPTDH.6L7.B2	BPTUV.6L7.B2

4. IMPACT ON OTHER ITEMS

4.1 IMPACT ON ITEMS/SYSTEMS

BE/BI	BE/BI is responsible for the BPMs acquisition. Cables should be pulled for the new BPMs. Controls units DOROS should be installed for the signal processing.
BE/OP	Necessary change to the control system of the LHC must be performed to control the new collimators and read the new BPM signals.

4.2 IMPACT ON UTILITIES AND SERVICES

Raw water:	No
Demineralized water:	The circuit of cooling water of the TCSPM will have to be connected, in series to other collimators. The new collimators have the same requirements as the present ones and will not add new requirements on the cooling water flows.
Compressed air:	No
Electricity, cable pulling (power, signal, optical fibres…):	Cables have already been pulled in LS1 and need only to be connected to the new collimators; New cables needed for the BPMs.
DEC/DIC:	RQF0875886 (EN/SMM) RQF0943607 (BE/BI)
Racks (name and location):	BE/BI racks in TZ76: BY03, BY04, BY05;

Vacuum Tunnel activities:	For each collimator the entire vacuum sector must be vented, the bakeout installed and finally NEG activation for a total of about 3.5 weeks of work per vacuum sector.
	In addition to tunnel activities:
	1. Vacuum acceptance test of all collimator sub-assemblies: Pickup button, PU flanges and BPM cables, motor bellows, MoGr blocks and complete jaw.
	2. Contractor vacuum test:
	  1. -Test bench procurement, and in situ installation with commissioning,
	  2. -Test follow up and validation before any shipping to CERN.
	3. Bake out procurement and equipment of each collimator at CERN

Special transport/ handling:	Shielded trolley for IR7 and palfinger.
Temporary storage of conventional/radioactive components:	No
Alignment and positioning:	The components must be updated in the CERN layout Database before Survey activities in the LHC tunnel. Survey needs to know the positions of both targets by doing a "fiducialisation" with a laser tracker few days before the transportation of the component into the LHC. Standard alignment procedures apply – at installation, the collimator position should be adjusted by the survey team.
Scaffolding:	No

Controls:	The LHC control system must be updated to include the new collimator.
GSM/WIFI networks:	No
Cryogenics:	No
Contractor(s):	No
Surface building(s):	No
Layout DB:	The layout database should be updated with new slot/functional position names.

5. IMPACT ON COST, SCHEDULE AND PERFORMANCE

5.1 IMPACT ON COST

Detailed breakdown of the change cost:	Paid by HL-LHC WP5 halo cleaning
Budget code:	HL-LHC WP05-Halo Cleaning-EN/STI : 53702 HL-LHC WP05-Halo Cleaning-EN/SMM - electronics: 53719 HL-LHC WP05 Collimator Vacuum: 99150 HL Consolidation : 53706 (for spares)

5.2 IMPACT ON SCHEDULE

Proposed installation schedule:	Installation readiness (see Table 4 for Layout Names): • TCSPM.B4R7.B2 and TCSG.D4R7.B2: 28th Feb 2020; • TCSPM.E5R7.B1 and TCSPM.6R7.B1: 4th May 2020; • TCSG.D4L7.B1 and TCSPM.B4L7.B1: 2nd June 2020; • TCSPM.6L7.B2 and TCSPM.E5L7.B2: 1st July 2020;
Proposed test schedule (if applicable):	Prior to installation: controls tests (EN/STI) and vacuum validation (TE/VSC). Impact on the EN/EL team to be evaluated.
Estimated duration:	1-2 weeks: 2 days of mechanical intervention (minimum) ; 3-4 days of BI equipment; 5 days of NEG activation; 2 days for dismantling (MECA+BI).
Urgency:	No
Flexibility of scheduling:	Limited.

5.3 IMPACT ON PERFORMANCE

Mechanical aperture:	As for all other collimators, the TCSPM has movable jaws in the collimation plane (horizontal, vertical and skew) and no deterioration is expected. Thus, this installation has no impact on the available aperture.
Impedance:	Improved compared to the present system. The impedance team requires an impedance measurement with the stretched wire technique for all produced collimators (in addition to the validation of the design that was performed through measurements on prototypes) to detect potential impedance non-conformities before installation. The EN/STI team

	assessed that this activity is compatible with the present planning. Implications on the budgets are estimated to less than 2 kCHF per collimator that can be absorbed by the general WP5 budget (BC 61071). A risk assessment is beam organised to identify other potential implications, in particular on the vacuum conformity of the collimators, before taking a final decision on the feasibility and strategy of these measurements.
Optics/MADX	Changes in the Layout DB should be transferred to the generated MAD-X LHC sequence, in order to have the new collimators and BPMs available in the sequence.
Electron cloud (NEG coating, solenoid…)	The SEY of the Mo-coated MoGr (jaw) and MoGr (tapering) has been measured and found to be close to the one of CFC in the TCSG collimators to be removed.
Insulation (enamelled flange, grounding…)	No change
Vacuum performance:	TE-VSC will perform vacuum acceptance tests on each component to assess vacuum compatibility within LHC vacuum environment based on EDMS 1752123. In case of not conformity the collimators could be rejected and not being installed.
Others:	

6. IMPACT ON OPERATIONAL SAFETY

6.1 ÉLÉMENT(S) IMPORTANT(S) DE SECURITÉ

No Impact on EISs.

6.2 OTHER OPERATIONAL SAFETY ASPECTS

Have new hazards been created or changed?	No
Could the change affect existing risk control measures?	No
What risk controls have to be put in place?	-
Safety documentation to update after the modification	The TCSPM safety assessment is available at [8]
Define the need for training or information after the change	-

7. WORKSITE SAFETY

7.1 ORGANISATION

Requirement	Yes	No	Comments
IMPACT – VIC:	X		
Operational radiation protection	X		RP survey needed TE-VSC: Dedicated WDP should be prepared and validated by

Requirement	Yes	No	Comments
(surveys, DIMR…):			RP for each step of the installation: mechanical, bake-out and NEG activation.
Radioactive storage of material:	X		Dummy beam pipes to be removed, TCSG.D4L7.B1, and TCSG.D4R7.B2 / TCSPM.D4R7.B2 (prototype). TCSG.D4L7.B1 and TCSG.D4R7.B2 / TCSPM.D4R7.B2 will be kept as radioactive spares.
Radioactive waste:		X	
Non-radioactive waste:	X		
Fire risk/permit (IS41) (welding, grinding…):		X	
Alarms deactivation/activation (IS37):		X	
Others:		X	

7.2 REGULATORY TESTS

Requirement	Yes	No	Responsible Group	Comments
Pressure/leak tests:	X		EN-STI TE-VSC	Water pressure test of cooling pipes must be done, as specified, before vacuum acceptance test. All cooling pipes must be emptied for the vacuum test. Any water leakage during the bake out could induce short circuits and permanent damage of the bake out system with consequently exposure to higher dose for its replacements. Helium leak test of the complete collimator before and after bake out cycle is performed.
Electrical tests:		X		
Others:	X			The impedance should be measured and validated - see section 5.3.

7.3 PARTICULAR RISKS

Requirement	Yes	No	Comments
Hazardous substances (chemicals, gas, asbestos…):		X	
Work at height:		X	
Confined space working:		X	
Noise:		X	

Cryogenic risks:		X	
Industrial X-ray (*tirs radio*):		X	
Ionizing radiation risks (radioactive components):	X		The collimators are installed in slots presently occupied by a replacement chamber or another collimators. The elements to be removed will be radioactive.
Others:			

8. FOLLOW-UP OF ACTIONS

BY THE TECHNICAL COORDINATION

Action	Done	Date	Comments
Carry out site activities:			
Carry out tests:			
Update layout drawings:			
Update equipment drawings:			
Update layout database:			
Update naming database:			
Update optics (MADX)			
Update procedures for maintenance and operations			
Update Safety File according to EDMS document 1177755:			
Others:			

9. REFERENCES

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[2] N. Mounet, "Trensverse impedance in the HL-LHC era", presentation at the 3rd HL-LHC Annual Collaboration meeting, Daresbury, UK (2013), https://indico.cern.ch/event/257368/

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[4] S. Antipov *et al.*, "Machine Impedance and HOM Power Update", presentation at the 7th HL-LHC Annual Collaboration Meeting, Madrid, Spain (2017), https://indico.cern.ch/event/647714/

[5] F. Carra, "Status of TCSPM Prototype Production", presentation at the 80th Collimation Upgrade Specification Meeting (ColUSM), Dec. 9th 2016, https://indico.cern.ch/event/591788

[6] S. Antipov *et al.*, "Staged implementation of low-impedance collimation in IR7: plans for LS2", to be published (2018).

[7] R. Bruce and S. Redaelli, "Installation of a low-impedance secondary collimator (TCSPM) in IR7", LHC-TC-EC-0006, EDMS doc. 1705738, CERN, Geneva, Switzerland (2016).

[8] C. Gaignant, "TCSPM, TCTPM and TCPPM (WP5) Safety Assessment Form", EDMS doc. 1871440, CERN, Geneva, Switzerland (2018), https://edms.cern.ch/document/1871440