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CONSOLIDATION WORK UNIT DESCRIPTION

Consolidation of LHC Beam Wire Scanner Electro-Mechanics [ACCONS] [BE-BI]

ABSTRACT:

The eight beam wire scanners (BWS) in the LHC are essential reference instruments for beam profile measurements across the whole machine cycle.
The existing electro-mechanical instruments, dating from the LEP era, have been shown be increasingly obsolete and unreliable.
This document outlines the planned renovation of these systems for the period 2021-25

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HISTORY OF CHANGES

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0.1	2019-10-22	-	Creation of the document. [R.Veness]

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1. EQUIPMENT/SYSTEM CONCERNED AND MOTIVATION

There are eight Beam Wire Scanners (BWS) installed in the LHC. Four scanners, two in the Horizontal and two in the Vertical planes in vacuum sector E5L4.R and the same on the other beam in vacuum sector E5R4.B. This gives an operational scanner and reserve for each plane and each beam.

These are linear precision scanners which function by passing a carbon filament across the beam at ~1 ms^{-1}, producing a shower of secondary particles which are detected downstream by a scintillator. The resultant beam profile measurement data from these instruments is used primarily as a precision reference for on-line profile monitors such as the Synchrotron light monitor (BSRT). The continuing importance of these BWS instruments for Run 3 and later for HL-LHC has been re-confirmed by the findings of the recent LHC Beam Size Review [1]

The electro-mechanics of these devices were originally designed in the 1980's for use in another laboratory. The design was adopted and modified by CERN for use in the LEP collider and in the SPS. The design was modified again for the LHC, adding ferrites and other impedance-minimising features. The existing scanners were manufactured for the LHC start-up and have been in regular use since then, with some scanners operating at more than 5000 scans/year.

This system was identified as a priority for consolidation during the 'Beamline Operational Spares Strategy' (BOSS) project of 2014-15 [2]. This is a critical instrument for operations, with fast-moving parts, installed in a fully baked machine. Recent reliability issues, once with a leaking bellows and once with a blockage due to internal vacuum impact between the scanner mechanism and ferrites have caused machine stoppage during operations, presented to the LHC Machine Committee [3], [4]. Both of these failures were fixed, but revealed significant design flaws due to obsolescence and the 're-purposing' of the original design. A more recent problem which has caused measurement errors is linked to the fork design [5].

The SPS linear scanners are being replaced as operational instruments in LS2 by a new design of precision, rotary, fast scanner as part of the LIU project. An initial proposal was made to the CONS project to replace the LHC instruments at the same time, but this was delayed due to resource limitations.

2. POSSIBLE SOLUTION

There are two possible options to replace this obsolete design. A more detailed comparison of their differences and possible operating scenarios was given in the recent beam size review [6].

2.1 Option 1: Re-design a new precision linear scanner

The existing linear scanner could be replaced with a new design of an instrument fulfilling the same specification as a 1 ms^{-1} linear scanner. A preliminary concept drawing of such a device is given in figure 1.

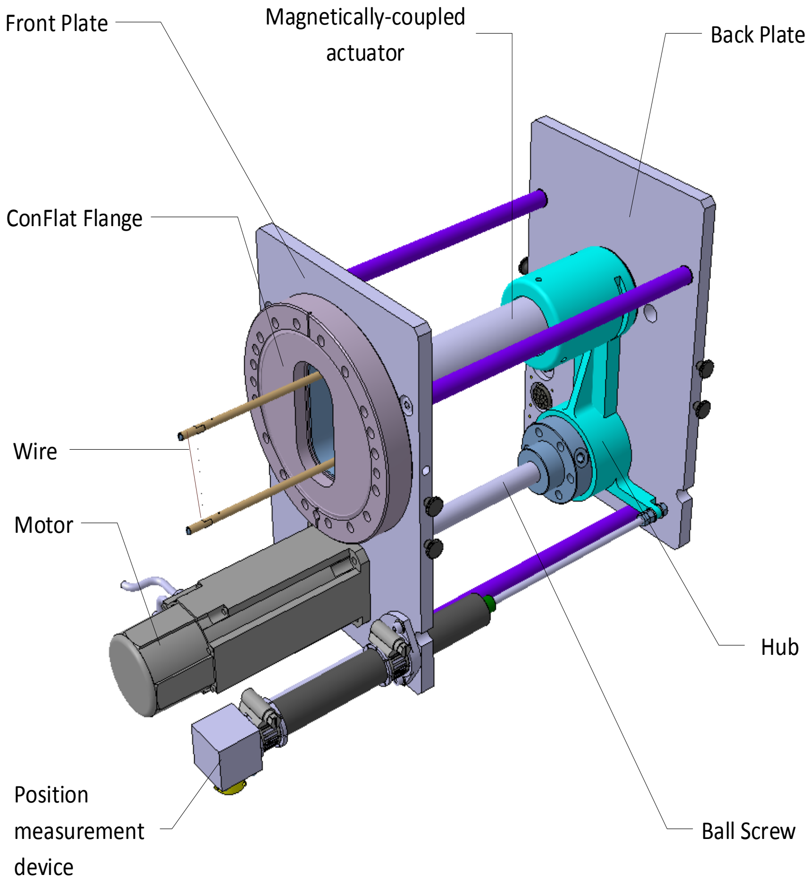

Figure 1: Conceptual design of a new linear precision scanner

This design would address the issues seen with the current design, whilst being relatively inexpensive per-unit. However, a full design would need to be made, including qualification for LHC vacuum and design for impedance and RF heating. It would also need to be qualified and proven to operate reliably in the LHC environment.

2.2 Option 2: Use the precision rotary scanner designed recently implemented for LIU

The existing scanner could be replaced with the new, fast (20 ms^{-1} scanning speed) precision scanner that has recently been tested and installed in the PSB, PS and SPS as part of the LIU project, as per figure 2.

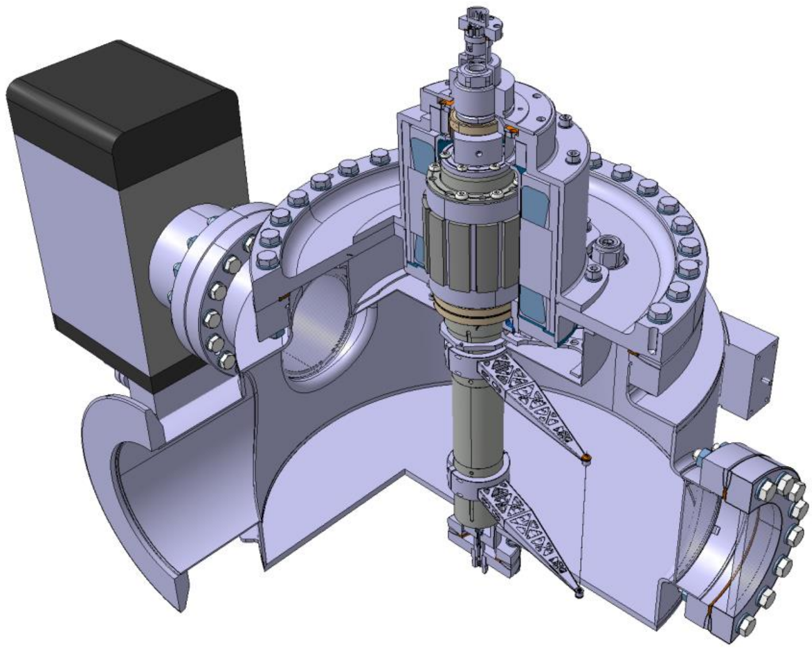

Figure 2: Part-section through LIU fast precision scanner

This is a new and recent design, fully compatible with the new electronics that are being installed in the LHC. In addition to addressing the design issues from the installed monitors it would give the option to scan at speeds up to 20 ms^{-1}, which would increase the number of bunches that could be scanned.

The unit cost of this device would be significantly higher than for option 1. However, this is a design that is complete and has been extensively validated with beam in all three injector rings, so the development costs will be significantly lower. It was designed as a bakeable instrument for the LHC, but would require some re-validation for vacuum and impedance.

3. PROPOSED SOLUTION

3.1 DESCRIPTION OF THE SOLUTION

The technical decision between options 1 and 2 has not yet been taken. There is further analysis that is required before either can be formally proposed.

However, this does not impact the schedule and is expected to have limited consequences on the budget for this CONS request. The choice between the two designs would be made before starting significant CONS-funded design work in 2021. The overall cost of the two options is the same within the current margin of error, with option 1 costing less per unit, but more for design and validation and vice-versa for option 2.

3.2 OPERATION, RELIABILITY, AVAILABILITY, MAINTAINABILITY, ENVIRONMENTAL ASPECTS

Operation aspects, Impact of delay of consolidation	The existing design limitations are already impacting on machine performance (see [5]). Some continued issues are to be expected during Run 3. Delaying beyond LS3 would likely have a noticeable impact on start-up for HL-LHC due to beam size measurement errors.
Reliability Aspects	Reliability of the existing system due to mechanical failures is currently at ~1 failure causing machine stoppage per year of operation. It would be expected that this would decrease to ~0.1 / year with a consolidated system. This does not take into account wire breakages that can have many unrelated causes.
Availability Aspects	Availability is mainly determined by wire breakages. The consolidated system would maintain the current policy of keeping a reserve instrument installed for each active scanner. Availability is therefore expected to be maintained.
Maintainability and Supportability Aspects	Existing systems use bellows with limited cycle lifetimes and obsolete drive components. Consolidated designs would be bellows-free with modern components, requiring significantly less maintenance.
Environmental Aspects	There is no measureable environmental impact that is expected from this project.

3.3 IMPACT ON OTHER ITEMS

3.3.1 IMPACT ON UTILITIES, ON SERVICES, AND ON SAFETY

Requirement	Yes	No	Comments
Cooling, Ventilation and Compressed air		X	
Cryogenics		X	
Electricity, cable pulling DEC/DIC (Demande enlèvement/installation câbles) (power, signal, optical fibres, signal, control…)	(X)	X	Cables for the new control electronics have already been installed during LS2. Depending on the results of vacuum qualification, some additional pumping may be required.
Vacuum (bake outs, sectorisation…)	X		New vacuum sectors were installed during LS2 for these systems. Design collaboration and testing from VSC will be required for either option. Some additional pumping may be required.
Special transport/ handling: (Scaffolding…)		X	Standard beamline installation tooling will be required.
Civil engineering works		X	None.
EIS-Access, EIS-Beam, EIS-Machine		X	Not EIS equipment.
Operational radiation protection (DIMR, ALARA committee…):		X	Installed in a low-radiation part of the LHC.

Radioactive waste:	X		8 obsolete instruments. ~400 kg of TFA material.

3.4 COST, SCHEDULE AND PERFORMANCE

3.4.1 BUDGET PROFILE

The consolidation headings fund materials.

Resources request	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**
Material [MCHF]			50	150	210	140	50		
FSU [FTE·Yrs]					0.5	0.5			
Fellows/students [FTE·Yrs]									

Personnel resources (earmarked and ring-fenced)

Personnel resources	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**
Needed staff		0.5	0.5	0.5	1.0	1.0	0.5		
Pledged staff		0.5	0.5	0.5	1.0	1.0	0.5		
Missing*		0	0	0	0	0	0		

*The distribution of this material budget between material, FSU and Fellows/students will depend on the technical option selected, with option 1 requiring more design office and manpower and option 2 requiring more material.

3.4.2 PROPOSED INSTALLATION SCHEDULE

Requirement	**LS2 2019 2020**	**2021**	**YETS 2021 2022**	**2022**	**YETS 2022 2023**	**2023**	**LS3 2024 2026**
Proposed installation schedule and duration			(A)		A		B

A: installation of a prototype during YETS 22-23 (21-22 if possible)

B: full installation of 8 instruments during LS3

3.5 IDENTIFICATION OF STAKEHOLDERS AND PROJECT SPONSORS

- BE/OP and BE/ABP are the project sponsors. This is a key instrument for operations and machine understanding and optimisation. Also for their support in selecting the appropriate option, clarifying the specification and participating in MDs for instrument validation.

- BE/ABP for support with impedance design and validation
- TE/VSC for consultation and validation of vacuum design

4. RISK ASSESSMENT

In order to compare and contrast the consolidation project requests, general information and risk assessment is to be completed. In the following tables, ***system*** refers to the existing solution, ***project*** or ***consolidated system*** refers to the solution being proposed within this consolidation request. Please complete the column(s) on the right hand-side.

Table 1 — Background Information

General Information		
Description:	***Possible Values:***	***Value:***
Number of instances of the system, or proposed composition of the project:	• Chassis • Controllers • Converters • Other (please specify)	8 mechanical units
Programs and facilities in which the system/project is or will be installed:	• LHC scientific program (Y/N) • LHC test beams (Y/N) • SPS fixed target scientific program (Y/N) • PS fixed target program (including nTOF) (Y/N) • AD scientific program (Y/N) • ISOLDE scientific program (Y/N)	LHC scientific programme
Project development and procurement strategy:	• In-house • Turn-key • Other (please specify)	In-house
When can the project be implemented?	• Any time • Technical Stop (TS) • Year-end technical Stop (YETS) • Long Shutdown (LS)	LS (YETS possible)
If the consolidation project request is not successful, what is the impact on other CERN systems/projects?	• 1 = Insignificant (no impact) • 2 = Moderate (delays to one or more) • 3 = Major (cancellation of one) • 4 = Critical (cancellation of several)	2
If the consolidation project request is successful, what is the impact on other CERN systems/projects?	• 1 = Insignificant (no impact) • 2 = Moderate (one system requires modification for compliance with consolidated system) • 3 = Major (several systems require modification for compliance with consolidated system) • 4 = Critical (complete redesign of one or more systems for compliance with consolidated system)	1

4.1 Failure Modes

For the existing system, it is important to understand the impact of failures, which have been known to occur, or which may occur.

In the table below, identify failure modes **F1** to **F4**, giving the ways in which the system has, or may, fail. Observed, should be completed with a failure mode which has occurred during the operation of the system. Potential implies a failure mode which is possible, but may not necessarily have occurred.

- For potential failures, consider the most credible case.
- Information and thresholds concerning **F4** have been elaborated in collaboration with the HSE department.

Table 2 — Main system failures

Failure modes	
Description:	***Description:***
The most frequently observed, failure mode of the system impacting on *accelerator operation* – **F1**	Observed – bellows leak from air to machine causing stoppage Observed – instrument blocked in beam causing stoppage
Worst case potential failure mode of the system impacting on *accelerator operation* – **F2**	Major vacuum leak. Major beam-loss incident (this is a beam intercepting device).
Worst case potential failure mode of the system impacting on *personnel safety* – **F3**	None
Worst case potential failure mode of the system impacting on *environment* – **F4** (please see appendix)	None

4.2 Failure Mode Occurrence / Likelihood

Historical information about the existing system **reliability** needs to be known, and compared to that which is expected to be achieved by the consolidated system. Using the failure modes which were defined in the previous table, please complete the columns on the right hand side.

System/Project Failure Mode Occurrence / Likelihood

Description:	***Possible Values:***	***Existing System Value:***	***Consolidated System Value:***
Expected system end-of-life. e.g. the dominant failures of the system are caused by ageing / cumulative effects.	• 1 = 2035 to 2040 • 2 = 2030 to 2035 • 3 = 2025 to 2030 • 4 = ≤ 2025	4	*1*
Failure frequency per year of **F1**: • For the existing system, average over the last 3 years of operation, sum for all instances. • For the proposed consolidated system, use predictions	• 1 = Low (≤1 failure / year) • 2 = Probable (≈1 failure / year) • 3 = Frequent (≈10 failures / year) • 4 = Very Frequent (> 10 failures / year)	2	*1*
Estimated frequency per year for **F2**.	• 1 = Low (1 failure / 1000 years) • 2 = Probable (1 failure / 100 years) • 3 = Frequent (1 failure / 10 years) • 4 = Very Frequent (1 failure / year)	3	*1*
Estimated frequency per year for **F3.**	• 1 = Low (1 failure / 1000 years) • 2 = Probable (1 failure / 100 years) • 3 = Frequent (1 failure / 10 years) • 4 = Very Frequent (1 failure / year)	1	*1*
Estimated frequency per year for **F4.**	• 1 = Low (once in 10 years) • 2 = Probable (once per year) • 3 = Frequent (once per month) • 4 = Very Frequent (once per week)	1	*1*

4.3 Failure Mode Impact

The impact of each failure modes is to be defined, please complete the columns on the right-hand side of the table below:

System/Project Failure Mode Impact

Description:	***Possible Values:***	***Existing System Value:***	***Consolidated System Value:***
When will components / technology of the system become unmaintainable (e.g. due to obsolescence, lack of know-how, exhaustion of spare supply, loss of backup systems)	• 1 = 2035 to 2040 • 2 = 2030 to 2035 • 3 = 2025 to 2030 • 4 = ≤ 2025	4	*1*
F1 observed downtime: • For existing system, average over the last 3 years of operation, sum for all instances. • For consolidated system, please use predictions	• 1 = < 1 hours • 2 = 1 – 12 hours • 3 = 12 – 24 hours • 4 = > 24 hours	4	*1*
F2 estimated downtime:	• 1 = < 1 week • 2 = 1 week to 1 month • 3 = 1 month to 1 year • 4 = > 1 year / beyond repair	2	*2*
F3 estimate consequence:	• 1 = Insignificant (no injury) • 2 = Moderate (injury requiring medical attention, but no loss of working days) • 3 = Major (serious injury requiring medical attention and loss of working days) • 4 = Critical (i.e. loss of life)	1	*1*
F4 estimated consequence: (please see appendix)	• 1 = minor event • 2 = moderate event • 3 = major event • 4 = critical event	1	*1*

5. REMARKS AND ADDITIONAL INFORMATION

6. REFERENCES

[1] LHC Beam Size Measurement Review Findings, October 2019. https://indico.cern.ch/event/837340/attachments/1924743/3185135/LHC_Beam_Size_Measurement_Review_-_Findings_Comments_Recommendations.pdf

[2] Beamline Operational Spares Strategy Workshop 2 minutes. July 2015. https://edms.cern.ch/document/1518782/1

[3] LHC machine committee minutes of Sept. 2012. https://espace.cern.ch/lhc-machine-committee/Minutes/1/lmc_148.pdf

[4] LHC machine committee minutes of June 2015. https://espace.cern.ch/lhc-machine-committee/Minutes/1/lmc_220.pdf

[5] LHC machine committee minutes of June 2019. https://espace.cern.ch/lhc-machine-committee/Minutes/1/lmc_380.pdf

[6] Wire scanners for the HL-LHC era, October 2019. https://indico.cern.ch/event/837340/contributions/3510895/attachments/1917381/3172062/HL-LHC-BWS-1019v2.pdf

7. APPENDIX