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HL-LHC FULL REMOTE ALIGNMENT STUDY

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Abstract

This study explores the benefits of extending the monitoring and remote alignment concept, proposed in the HL-LHC baseline, to additional components of the matching sections of the HL-LHC. The objective of this study was to evaluate the benefits in terms of equipment performance and new opportunities for system simplification.

In collaboration with the HL-LHC Working Group on Alignment, critical input parameters such as ground motion, manufacturing, assembly, and alignment tolerances, have been quantified. Solutions for the selected, manually aligned components have been investigated with the particular focus on vacuum design, mechanical design and the new alignment concept compatible with reliability and maintainability requirements. In this context, collimators and masks are key elements to be included in the extended alignment system. A solution is under study to integrate their supporting systems with the concept of on-line monitoring sensors and an actuator-based, remote alignment platform.

The full remote alignment of components will have a positive impact on machine operation by reducing the need of human intervention in the tunnel and by providing enhanced flexibility to perform the required alignment adjustment as part of an operational tool for the HL-LHC.

INTRODUCTION

The High Luminosity Large Hadron Collider (HL-LHC) project aims at providing instantaneous luminosities a factor of five larger than the LHC nominal value. The main approach to achieve this goal is the replacement of 1.2 km of accelerator components in the Long Straight Sections (LSS) situated around the ATLAS and CMS interaction points (IPs) [1–4].

This goal entails also challenges for the alignment teams as all components in the LSS have to be adjusted to better than 150 µm in the transverse directions. In order to provide adequate alignment capabilities, in particular during operation, a new concept is proposed in the HL-LHC Technical Design Report [5, 6]. The alignment foresees to have permanent monitoring and remote alignment systems that will cover the main components from Q1 to Q5 in a section of approximately 210 m on each side of the IPs. The Full Remote Alignment (FRA) study was launched with the aim to investigate the possibility of extending this concept to all components of the LSS up to Q5 together with possible operational and cost-saving benefits.

FULL REMOTE ALIGNMENT STUDY

The study was promoted taking into account three motivations. Firstly, in the initial baseline, only the main components were equipped with motorised actuators and monitoring sensors as illustrated in the upper layout in Fig. 1. That implies that the alignment teams would have to spend a significant amount of time in the tunnel in order to adjust manually all intermediate components. Extending the remote alignment to intermediate components leads to the reduction in exposure of personnel to radiation by limiting the number of on-site interventions and optimising the workflow.

Secondly, the development of a six-degree-of-freedom alignment platform allows for new options to host equipment [7]. The platform adapts, after individual design for the concerned component, to various alignment scenarios: full remote with resident motors, semi-automatic with plug-in motors, or manually [8].

Finally, the previous points are evaluated for compatibility with the optimisation of the matching section (MS) where important synergies have been identified [9].

The FRA provides significant advantages for HL-LHC beam operation as it can provide mitigation measures for various issues [10]:

- Possible misalignment between the detector and the accelerator can be corrected after the completion of the detector installation;
- the yearly transverse offsets induced by ground motion can be corrected in five degrees of freedom;
- FRA provides a tool to eliminate or at least minimise the residual alignment errors using the beam as actual reference for a relative alignment (smoothing) and
- it allows to cope with unexpected sources of misalignment and thus avoiding reduction of physics time.

In addition to these technical advantages, the FRA will reduce significantly the exposure of personnel to radiation. The implementation of a FRA system will, in particular, reduce the possible downtime needed for realignment after the beam commissioning during the first year of Run 4.

ALIGNMENT SCHEME

In order to be FRA compliant, the various steps during beam commissioning and the subsequent operation have been studied based on the features of the alignment schemes.

The beam commissioning steps are based on the assumptions that no beam aperture losses appear and no large orbit corrections are needed. The time gained in the alignment process, a couple of hours compared to several weeks, results in higher integrated luminosity as a higher machine availability is possible. The FRA allows to proceed with the LSS alignment in the following way:

1. During the installation phase, the accelerator components are aligned from Q7 situated on the left

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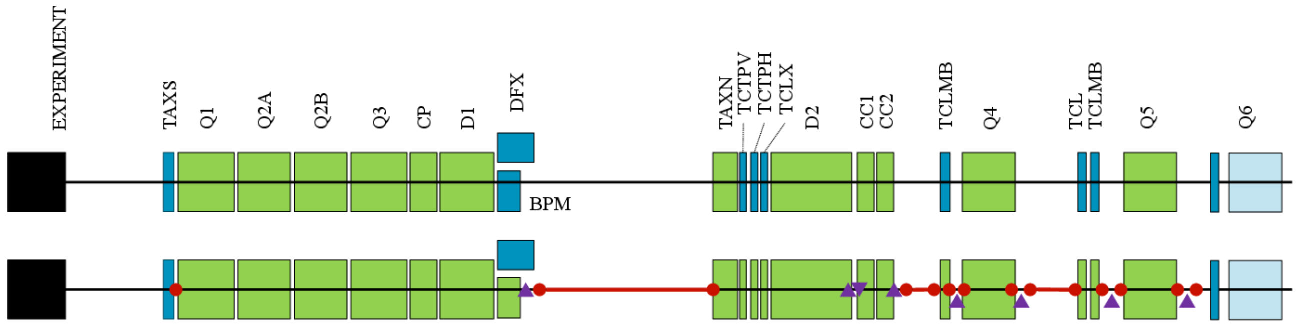

Figure 1: Side view of an HL-LHC high-luminosity IP with quadrupoles (Q), corrector package (CP), dipoles (D), collimators and masks (TC), crab cavities (CC), absorbers (TAX), deformable RF bridges (red circles), fixed beam pipe sections (red lines) and sector valves (purple triangles): HL-LHC Technical Design Report (top) and FRA Study (bottom).

side of the IP to Q7 on the right side with a line that passes through the theoretical position of the centre of the inner tracker detector.

2. During the beam commissioning phase, the best orbit to allow first collisions is established, identifying the displacement of the interaction point with respect to the centre of the inner tracker.
3. The orbit is adjusted by realigning the machine from Q1 to Q4 with the FRA system and by using the orbit correctors from Q4 to Q8 with immediate feedback of the beam. A maximum remote alignment of ±2.5 mm is permitted in the first year of operation. This value is made up of ±2.0 mm reserved for a possible rigid shift of Q1 to Q4 due to a potential inner tracker offset and the remaining ±0.5 mm for possible ground motion effects and relative movements between the components.
4. Therefore beam commissioning can continue during the first year of Run 4. In case a significant amount of the alignment range is used during the first year of operation, the full ±2.5 mm remote alignment stroke can be recuperated by adjusting the jacks back to the centre position. This optional intervention is carried out during the first Year-End-Technical-Stop as only a minor activation of the components in the LSS is expected.

This scheme is valid for the initial commissioning as well as for the future operation throughout the lifetime of HL-LHC. The FRA approach will decrease the relative movements needed between components, and thus could result in the use of standard components for vacuum and in the suppression of corrector magnets originally included in the HL-LHC baseline.

The alignment requirements for the LSS with respect to the detectors are based on a local and smooth curve of the accelerator with respect to the detector. Thus, the ranges of the jacks and platforms are defined by two criteria:

- The manual stroke of jacks and platforms must provide a range of ±10 mm for an absolute alignment in space over the HL-LHC lifetime, taking into account the accumulated ground motion of the experimental caverns and the tunnel.
- The motorised remote alignment range that will be used for relative alignment during operation or Technical Stops is ±5.0 mm, which allows to cope with the different sources of misalignment.

The compliance of the motorised alignment with machine protection requirements is mandatory. This requires to monitor the accumulated displacement in order to follow up the total movement, e.g. for bellow displacement in interconnections.

TECHNICAL PROPOSALS

Figure 1 shows the schematic layout and components that have been investigated during the FRA study. Intermediate components that have been in the scope of optimising the alignment process are collimators, protection masks for Q4 and Q5 magnets, beam position monitors (BPMs), and vacuum equipment. The study identified four possibilities for making components compliant to the FRA. Passive components, like the warm beam pipes, are designed with sufficient aperture in order to cope with ground motion effects over the HL-LHC lifetime and a possible inner tracker offset. No realignment after the initial installation is foreseen for these components.

Adjacent components are combined together on a common structure as they follow the same alignment scheme. This approach is illustrated in Fig. 2 for the collimators between TAXN and D2. The collimators, and in particular the vacuum equipment in between, were designed with the approach to be on individual plug-in supports. This concept allowed the alignment of the collimators, but kept the adjacent vacuum components rigidly attached to the tunnel floor (see Fig. 2a). In addition, the alignment has to be carried out manually in this highly-radioactive region, with estimated peak doses of 1 mSv/h for ultimate HL-LHC performance after one month of cool down time [11]. One proposal was to combine components on a common girder in order to reduce the costs for monitoring sensors and motorisation (see Fig. 2b). The aspects of precise interchangeability of these assemblies would have to be taken into account during the mechanical manufacturing. The outcome of the study is the selection of individual, heavy-

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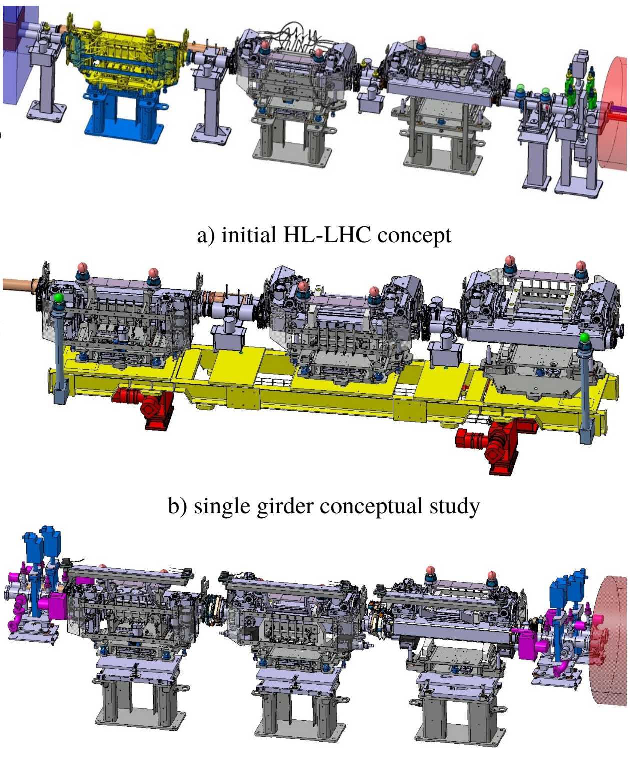

a) initial HL-LHC concept

b) single girder conceptual study

c) new HL-LHC baseline

Figure 2: HL-LHC Full Remote Alignment collimator study.

duty alignment platforms for each collimator as they allow the best possible operational and maintenance flexibility (see Fig. 2c).

Another case is illustrated for the crab cavities. As shown in Fig. 3, the two crab cavity modules are separated by only 1245 mm and have several vacuum components in between that are attached to the crab cavities. The proposed solution is to eliminate floor supports and embark the equipment directly on supports suspended from the crab cavities assembly.

In general, for the optimal functioning of the FRA, equipment positions and supporting has been optimised. For example, the warm BPM in front of D2 is changed into a cold BPM inside the D2 cryostat. Vacuum equipment can either be embarked on adjacent components, similar to the crab cavities, or will be hosted on a standardised alignment platform.

CONCLUSIONS AND OUTLOOK

All systems between Q1 and Q5 can be made FRA compliant, meaning that all remotely aligned components will be installed on motorised jacks or motorised alignment platforms with a remote alignment range of at least ±2.5 mm.

The vacuum systems are compliant with this concept as they have fixed beam pipe sections that provide sufficient aperture or use deformable radio-frequency-bridge bellows when required.

The outcome of the FRA study contributes to the optimisation of the MS, as it makes possible reusing the Q4 and Q5 cryo-magnets of the LHC. A reduction in the number of orbit corrector in Q4 from 4 to 3 and in Q5 from 3 to 1 is combined with a change in their operational temperature from 1.9 K to 4.5 K as presently in the LHC. Furthermore, the collimator design can be simplified thanks to the reduced extent of the beam-stay-clear region in this machine section.

The prospect of a machine whose misalignment error will be removed at the source will increase the expected aperture available for the beams, minimise deviations from the ideal optics models, and thus provide a more robust beam operation scheme.

Last but not least, the hardware implementation of the FRA allows for cost-saving benefit to the HL-LHC project as part of the MS optimisation.

For all these reasons, the FRA has been endorsed as the upgraded baseline for HL-LHC according to optics version 1.4 [12].

The functional specification is currently being prepared, containing relevant information about the concerned components, their alignment tolerances, design requirements, and component metrology during assembly. In parallel, the studies on the design and performance of two types of alignment platforms together with the integration of the required alignment sensors and associated actuators are pursued.

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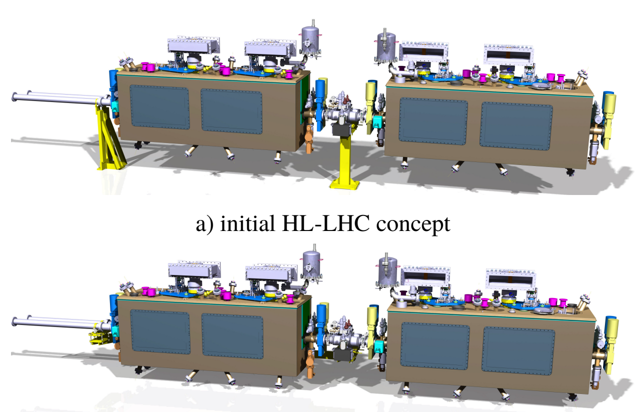

a) initial HL-LHC concept

b) new HL-LHC baseline

Figure 3: HL-LHC Full Remote Alignment crab cavity study.

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REFERENCES

[1] G. Apollinari, I. Bejar Alonso, O. Brüning, M. Lamont, and L. Rossi, "High-Luminosity Large Hadron Collider (HL-LHC). Prelimary Design Report", CERN-2015-005, CERN, Geneva, 2015. doi:10.5170/CERN-2015-005

[2] I. Bejar *et al.*, "HiLumi LHC Technical Design Report", CERN-ACC-2015-0140, CERN, Geneva, 2015. http://cds.cern.ch/search?p=CERN-ACC-2015-0140

[3] L. Rossi, "LHC Upgrade Plans: Options and Strategy", in *Proc. 2nd Int. Particle Accelerator Conf. (IPAC'11)*, San Sebastian, Spain, Sep. 2011, paper TUYA02, pp. 908–912.

[4] O. Brüning and L. Rossi, "The High Luminosity Large Hadron Collider - The New Machine for Illuminating the Mysteries of Universe", World Scientific Publishing Co. Pte. Ltd., ISSN: 1793-1339, 2015. doi:10.1142/9581

[5] G. Apollinari et al., "Alignment and internal metrology", in *High-Luminosity Large Hadron Collider (HL-LHC): Technical Design Report V. 0.1*, CERN, Geneva, 2017, pp. 365–371.

[6] H. Mainaud Durand *et al.*, "HL-LHC Alignment Requirements and Associated Solutions", in *Proc. 8th Int. Particle Accelerator Conf. (IPAC'17)*, Copenhagen, Denmark, May 2017, pp. 1893–1896. doi:10.18429/JACoW-IPAC2017-TUPIK085

[7] M. Sosin, T. Blaszczyk, A. Herty, J. Jaros, and H. Mainaud Durand, "Design and study of a 6 Degree-Of-Freedom Universal Adjustment Platform for HL-LHC Components", presented at the 10th Int. Particle Accelerator Conf. (IPAC'19), Melbourne, Australia, May 2019, paper THPGW058, this conference.

[8] A. Herty *et al.*, "Technical challenges for HL-LHC alignment and associated solutions", 15th International Workshop on Accelerator Alignment. FNAL, Batavia, IL, USA, 2018. https://indico.fnal.gov/event/16262/session/8/contribution/20/material/paper/0.pdf

[9] R. De Maria, R. Bruce, M. Giovannozzi, F. Plassard, and D. Gamba, "HL-LHC Optics and Layout V1.4", presented at the 10th Int. Particle Accelerator Conf. (IPAC'19), Melbourne, Australia, May 2019, paper MOPMP019, this conference.

[10] P. Fessia *et al.*, "Global Optimization of the Matching Section and Full Remote Alignment", CERN, Geneva, Switzerland, 8th HL-LHC Collaboration Meeting, Oct. 2018.

[11] C. Adorisio and S. Roesler, "Induced activation studies for the LHC upgrade to High Luminosity LHC", *Journal of Physics: Conference Series*, vol. 1046, pp. 012008, IOP Publishing, at 4th International Workshop on Accelerator Radiation Induced Activation, 2018. doi:10.1088/1742-6596/1046/1/012008

[12] S. Claudet and P. Fessia, "HL–LHC Engineering Change Request. Introduction of the Full Remote Alignment And New Matching Section Optimisation", unpublished. https://edms.cern.ch/document/2083813