A quality assurance approach for the Full Remote Alignment System

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Abstract

The Full Remote Alignment System is a multi-sensor monitoring and alignment system for the position determination and adjustment of accelerator components in the High-Luminosity Large Hadron Collider. The objective of this development was the creation of an asset management for equipment of the Full Remote Alignment System that allows a simple, intuitive and time-optimised handling. Experience from previous interventions was analysed regarding the parameter definition and work steps management. Furthermore, tools available at CERN were identified and reviewed for their use in the asset management and information tracking of the sensors. This work evaluates the framework to fully provide an asset management allowing to store the obtained information during validation, calibration, deployment and maintenance processes of the equipment and provide this information to other interfaces during the lifetime of the installation. The overall concepts for asset management and group internal coordination are established. The created, structured analysis allows the implementation of a CERN tools-based asset management for mechanical components together with an infrastructure to efficiently track these assets.

CERN-BE-2023-011
31/10/2022

INTRODUCTION

The Full Remote Alignment System (FRAS) is a multi-sensor monitoring and alignment system for the position determination and remote adjustment of accelerator components in the High-Luminosity Large Hadron Collider (HL-LHC) [1, 2]. It will be installed in the Long Straight Sections (LSS) around the ATLAS and the CMS experiments from 2026 to 2028, covering the elements located closest to the experiment up to 211 m from the Interaction Point.

The nine different sensor systems, will comprise approximately 1150 sensors and have 344 actuators deployed for the remote positioning. Any information gap in the parameters of the sensors or inaccurate data of the sensors will lead to errors in the position determination and to a misalignment of the machine. Clear data structures providing the availability of measurement data, a carefully thought through data flow, data storage and data consistency mechanism necessitate a rigorous, and at the same time, simple asset management system interfacing to the relevant databases.

To prepare this infrastructure, conclusions can be drawn from the current LHC monitoring and remote alignment system installation. This return of experience provides insight in more than 14 years of operation of a similar, although much smaller, system with less sensors and sensor types. Remote sensor validation systems installed during the Long Shutdown 1 (LS1, 2013 - 2015) and consolidation work on the sensors and measurement systems with respect to the initial concept during the Long Shutdown 2 (LS2, 2019 - 2021) provide further input to define the needs of the FRAS.

The key feedback is that the current LHC system was based on theoretical assumptions of what data is needed and how it should be structured. Past experience allows a much better definition of the needs and implementations for the FRAS system. One crucial point, the online and on-site asset management, has proven difficult in the past as handheld devices for access to the asset management system on-site were not easily available. The double tracking, writing down in tunnel and then transferring the information to the digital interface in the office, was time consuming and error-prone. Nowadays, this is easy to overcome with the technical devices available and the deployment of wireless communication infrastructure in the machine tunnel that took place after the original LHC installation.

Although, an asset management concept is already in place for the LHC, the return of experience indicates that it is not used to its full potential and is obviously not adapted to cope with the needs of the FRAS configuration. The objective of the project was to create a data handling concept that is easy to use during the on-site intervention, minimising the possibility of errors or lack of data due to post-processing in the office. This approach shall guarantee a rigorous quality assurance and control for the FRAS in terms of data handling.

Before the implementation in the HL-LHC environment, two test installations will allow to qualify the processes and technical solutions: the Single Component Test and the Inner Triplet String Test Facility [3]. The automated data retrieval by the geodetic compensation software from the databases will allow the FRAS to become a semi-autonomous, operational tool for beam operation. In the long term, the traceability of the assets is also important for maintenance, sensor failure understanding and radioactive waste management.

METHODS

The methods and tools presented focus on the data handling, but do not consider any reliability or safety aspects linked to the system configuration. These studies are part of the FRAS software functional specification [4].

At the current state, the sensor configuration can still evolve and thus the developed concept shall allow for future modifications in the layout and the structure of the asset management keeping a backward compatibility to what has already been implemented [5].

Analysis of the current implementation. The return of experience on the current implementation was an important step to evaluate the needs for the future concept and identify clearly parts that have to be modified and parts that are already well developed.

As the available databases and data handling interfaces will remain the same, therefore the platforms to exchange information are well known and have to be developed accordingly. Gaps in the data handling were identified during this review process [6]:

- The defined hierarchy in the database did not reflect the physical installation hierarchy in the tunnel. Hence these relationships had to be created for some cases in a separate database table in order to allow the structured data retrieval or dedicated fields had to be created and named in a given way to allow the SQL queries.
- The initial, predefined parameters of the sensor, equipment data, had to be adapted during the initial qualification process of the sensors and during the consolidation phase in LS2. In order to minimise the impact on the existing data handling, i.e. the SQL queries to retrieve the data, and avoid a full re-qualification of the data flow, the meanings of the variables have been modified to new meanings whereas the naming remained unchanged.
- Work tasks for the initial sensor qualification had been defined in work orders. They are used to track the execution of quality assurance steps during the qualification process. Due to the mainly non-automated data flow from the work steps to the equipment data fields, these work orders were not systematically completed in the asset management system. By neglecting the use of the systems, two main issues have been created: it is difficult to track back who created the information on the sensor and due to the manual insertion of the numerical data into the equipment data fields, human errors in the copying process may lead to wrong sensor data. As an impressive example serves the calibration function of a Wire Positioning Sensor that consists of 72 parameters.
- The sensors currently used in the LHC typically consist of a set of components: the measuring part of the sensor, its associated cable and its associated electronics. Parameters such as the calibration function were stored with the sensor, whereas from a logic point of view they belong to the sensor's electronics.
- For the maintenance and error investigation, no dedicated work steps had been defined. Interventions on the sensors were therefore badly documented, updated sensor information was not automatically updated and configuration errors, e.g. after a sensor exchange, needed significant human follow up to guarantee the data consistency.
- The HL-LHC installation will only affect the monitoring systems in two out of the four interaction regions of the LHC. The other monitoring and alignment systems stay operational in their current configuration, however the consolidation project *Remote Alignment Consolidation in LS3* to harmonise the sensors and data acquisition in the two remaining points is foreseen. Thus the new data structure must be compatible with the old infrastructure and SQL query methods.

Identification and definition of FRAS needs. As a result of the analysis, it has been identified that very little has to be changed with respect to the current hierarchical structure concept of the sensors. As a minor change, the naming scheme [7] has to be rigorously applied to all new components of the FRAS.

The four major changes that were evaluated are closely linked together and concern the definition of parameters and the work steps that are linked to the definition of these parameters.

- The FRAS uses new technologies, e.g. Frequency Scanning Interferometry [8], and hence the parameters for the calibration change. At the same time, the design of the sensor changes as well and the definition of relevant reference interfaces also leads to a new definition of parameter sets.
- The calculation method in the compensation software will also evolve to a 3D network adjustment, that requires the introduction of local coordinate systems and rotation parameters to the equipment data set.
- From the technical point of view, the work steps have to be carefully defined to obtain an automated data flow for the parameters that are created during the reception, validation, calibration and installation process.
- The relationships have to be created in such a way that all hierarchical information between components can be retrieved directly from the database. Providing this information in separate tables shall be an exception.

As the FRAS is meant to reduce the exposure of personnel to radiation, standard approaches to asset management, such as regular maintenance plans, can be ignored as the FRAS specification is requiring the system to have a maintenance-free approach. On the other hand, in the case of a possible sensor failure, the error investigation work steps have to be carefully thought through to be

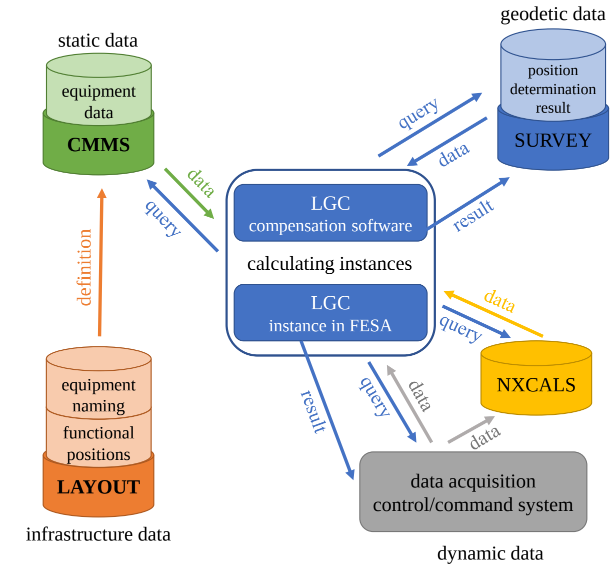

Figure 1: Relationship and exchange of equipment and measurement data between databases and geodetic compensation software.

efficient during a tunnel intervention and to limit the duration of the personnel being in proximity of radioactive equipment. In summary, the equipment data and work orders

- provide information on activities related with physical equipment, such as acceptance tests or calibrations, together with the relevant parameters,
- store technical information about equipment,
- link technical documentation and activity reports with the equipment,
- allow for stock and spare part management,
- must be accessible via queries to provide data to other interfaces,
- provide a procedure-like guidance through the work steps.

CERN TOOLS

In this section, the available tools at CERN and their intended use for the FRAS quality assurance scheme are presented. Fig. 1 illustrates the relationships and the data types that are exchanged between the databases, the compensation software and the data acquisition or rather control/command system.

CMMS database. The computerised maintenance management system (CMMS) database is accessible via three different tools for direct data handling, e.g. during an intervention in the tunnel, allowing the online handling of work orders. This database handles only numerical data.

- The *Manufacturing Test Folder (MTF)* is the interface from the early 2000s that was created for the manufacturing and asset management of LHC components. The interface is still available, but will no longer be considered for work order and data equipment data handling.
- *EAM Light* is used today for an easy and task oriented data handling, e.g. creation of installation relationships in the tunnel and completion of work order information on site. The interface is optimised for hand held devices and has predefined categories for different types of activities (see Fig. 2). This tool will be used by the personnel performing installation tasks on site.
- *InforEAM* is the access interface for advanced users. All data handling and customised queries can be performed as well as reporting functions are available. This interface is designed for office use.

During the sensor reception and validation process, the *CERN upload utility* tool will be used for the bulk creation of the unique asset names, the uploading of calibration data and the creation of relationships between assets in a semi-autonomous way. Before the installation, the equipment will be virtually stored in the *EAM Store Kiosk* providing information about the current storage location of the equipment and the quantity of assets per type available. Finally, the *Traceability of Radioactive Equipment at CERN (TREC)* tool is available for the handling of radioactive equipment during its life cycle up to the disposal as waste.

Documents are stored in the *Engineering Data Management Service (EDMS)* that allows to manage and organise electronic documents and set them in relationship to the assets in the CMMS database via links.

NXCALS database. The *Next CERN Accelerator Logging Service (NXCALS)* provides access to current and historical device state data, i.e. sensor measurements, for different control systems at CERN. The FRAS sensors will be integrated into this concept. The typical access to this database is via Java application programming interfaces (API) queries.

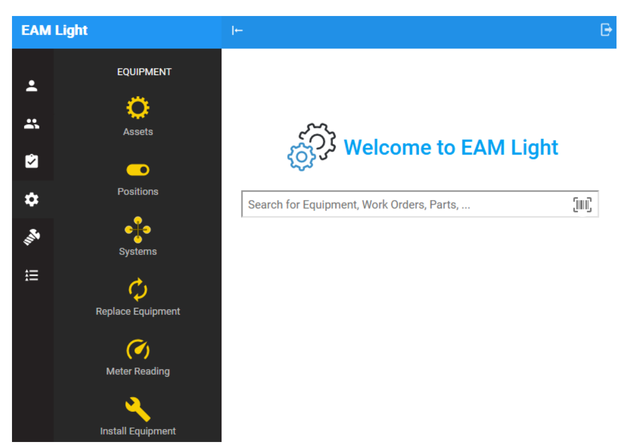

Figure 2: View of the CERN EAM Light interface.

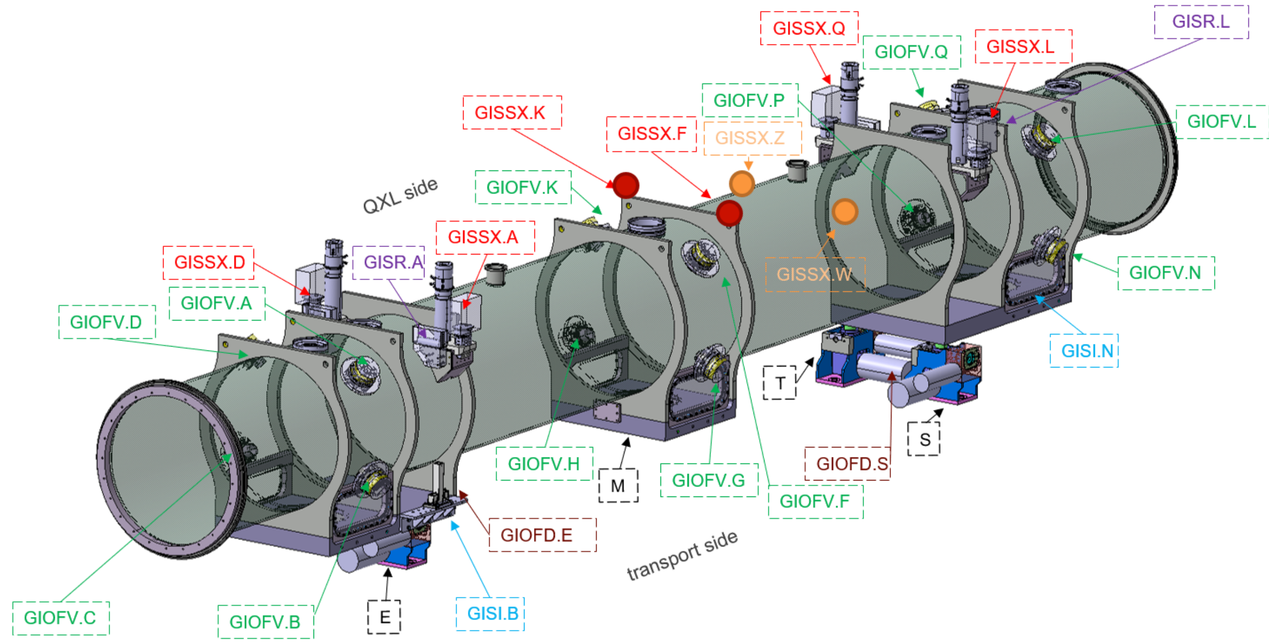

Figure 3: Point naming for FRAS components on a cryo-magnet assembly.

SURVEY database. The *SURVEY database* stores the information obtained from transfer measurements during the assembly process of the components (fiducialsation) as well as information about the nominal positions of the components. After processing the FRAS sensor data together with all other input parameters in the compensation software, the results, e.g. the current offsets to a nominal position, are stored back in the database.

Compensation software: LGC. The CERN hosted compensation software for geodetic measurements is currently available as a standalone software and not implemented as a callable dynamic link library. For FRAS, this option will be used in real-time, when measurement data will be combined from various sources of measurements. This is typically the case when a larger network is calculated to determine the overall position of the detector with respect to the acceleration, including standard measurements from the LHC tunnel, the sensor data from the FRAS and measurements from the experimental areas. For the automation of the FRAS alignment process, live position determinations in the control/command system are necessary and therefore an LGC[1] instance will be developed that can run on the Front End Software Architecture (FESA) system, real-time industrial computers.

NAMING CONCEPT

The naming concept takes care of two types of naming definitions [7]. It defines *functional positions*, i.e. the name of a location where the equipment will be installed, and the *equipment naming* that defines the equipment code to identify its type. In a second stage, this equipment code is also used to create the asset name in CMMS. Both definitions have predefined hierarchical structures such as in the case of a functional position only one asset can be attached as a child (1:1 relationship), whereas one asset can have multiple children (1:n relationship). Both definition processes run together with a careful study of the existing naming structure and the layout plans as each reference point hosting sensors will have its own functional position and each sensor, cable, electronics and sensor support being installed in the tunnel will be individually identified.

The process is has been completed for the equipment naming, approved by the HL-LHC project and implemented in the database structure. For the functional positions, a provisional definition has been made for the Single Component Test, the Inner Triplet String Test and HL-LHC.

The point identification in the SURVEY database uses a similar naming scheme as the functional positions, but has historically some differences. With the implementation of more reference points on the sensors, supports and cryo-magnet assemblies, the current concept had to be revised and enlarged to meet the requirements for FRAS. The new naming proposal, that is currently in the internal review process, is presented for the case of a cryo-magnet assembly in Fig. 3.

IMPLEMENTATION OF CMMS STRUCTURES

In particular the creation of sequences and relationships needs careful analysis. Each work order consists of tasks that have to be completed and, as they are applicable for all

[1] Logiciel Général de Compensation (General Adjustment Software)

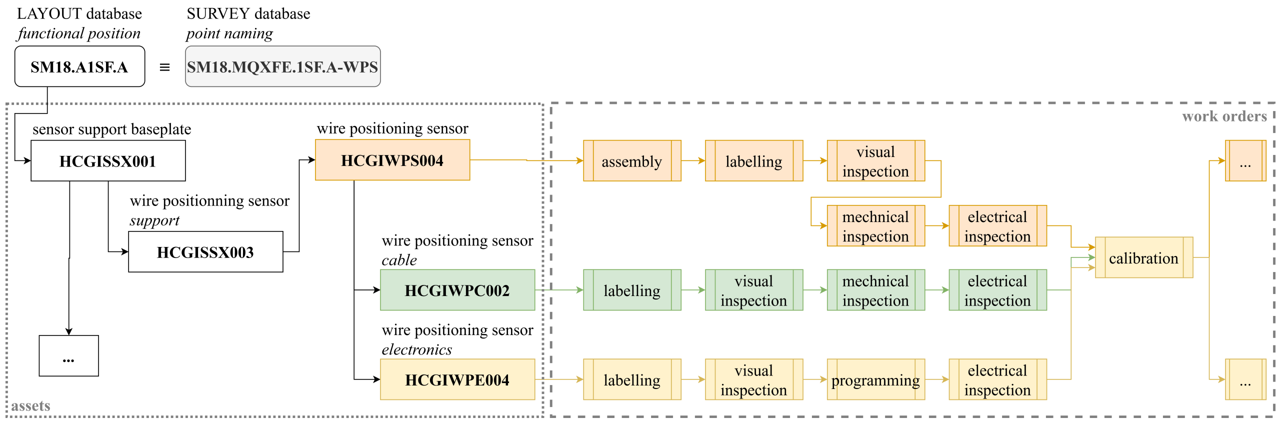

Figure 4: Combined representation of hierarchical structure, work flow and work orders at the example of a Wire Positioning Sensor. For a better readability, the individual tasks within the work order and the created parameters are not represented.

assets of the same type, they are defined as standard work orders and standard tasks. The predefined work orders, tasks and parameters are then automatically created as part of the asset during its creation in the database. This allows a consistent and efficient asset life cycle management.

In Fig. 4, the created work order sequence is shown at the example of a Wire Positioning Sensor. The illustration combines the hierarchical structure together with the work flow that is defined by the work orders. The definition of each work order contains multiple tasks that can be created as a check list, e.g. yes-no-questions or parameters that have to be entered, with the possibility to provide comments and add documents in the case of non-conformities. Parameters will be typically made available for SQL queries and will be ideally uploaded automatically to avoid errors.

RESULTS AND FUTURE DEVELOPMENTS

The quality assurance approach for the FRAS has completed the phase of defining the necessary data handling infrastructure. This step was characterised by the definition of the asset management concept, the relationships in the data storage structures and the definition of the future data flow. This included in particular the naming of assets, the functional positions and the geodetic references on the sensors, as well as defining the parameters for each sensor type. The definition of the work orders and the associated parameters, that are created with this work step, are currently being defined.

For all intermediate steps of the project, namely the Single Component Test and the Inner Triplet String Test installation, as well as for the FRAS installation in P1 and P5 of the LHC, the presented approach can be applied. Relevant specifications have been written and based on these documents the technical infrastructure is currently being created in the databases.

The timeline for this deliverable is inline with the data handling of sensors that is about to start in the process of sensor validation and calibration for the Single Component Test.

The developed part of this concept will be tested with the Single Component Test installation. During these tests, modifications in the available data, the data flow and the hierarchical representation can be identified before the generation of the production version for the Inner Triplet String Test and the HL-LHC installation. In parallel, the test installation will allow to formulate the needs for maintenance, repair, non-conformity handling and dismounting work orders.

Furthermore, the technical documentation for the Remote Alignment Consolidation in LS3 project will start in 2023, revising carefully the compatibility of the proposed structures to the existing data flow and calculation methods that shall remain unchanged as far as possible.

From a more practical point of view, the use of operational tools, such as smartphones, tables, barcode scanner will be tested on the test installation and the procedures for installation, operation and maintenance can be created an attached to the according work orders.

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