REMOTE CONTROL OF HETEROGENEOUS SENSORS FOR 3D LHC COLLIMATOR ALIGNMENT

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Abstract

Periodically the alignment of LHC collimators needs to be verified. Access for personnel is limited due to the level of radiation close to the collimators. The required measurement precision must be comparable to the other equipment in the LHC tunnel, meaning 0.15 mm in a sliding window of 200 m. Hence conventional measurements take 4 days for a team of 3 people. This presentation covers the design, development and commissioning of a remotely controlled system able to perform the same measurements in 1 h with one operator. The system integrates a variety of industrial devices ranging from sensors measuring position and inclination to video cameras, all linked with a PXI system running LabVIEW. The control of the motors is done through a PLC based system. The overall performance and user experience are reported.

INTRODUCTION

The beam cleaning [1] insertions in points 3 and 7 of the LHC [2] will become one of the most radioactive zones in the LHC. The "As Low As Reasonable Achievable" (ALARA) principle is restricting the intervention time in these areas to an absolute minimum and conventional alignment methods will clearly exceed the limits. The concerned zone is a 500m long straight section of the LHC tunnel where 37 collimators and 26 reference magnets will be measured. One of these measurements is the control of the alignment of the different components.

A remotely controlled train in the tunnel does the control of the elements' position with the operators outside of the tunnel. This train is mounted on the existing monorail in the LHC tunnel (Fig. 1).

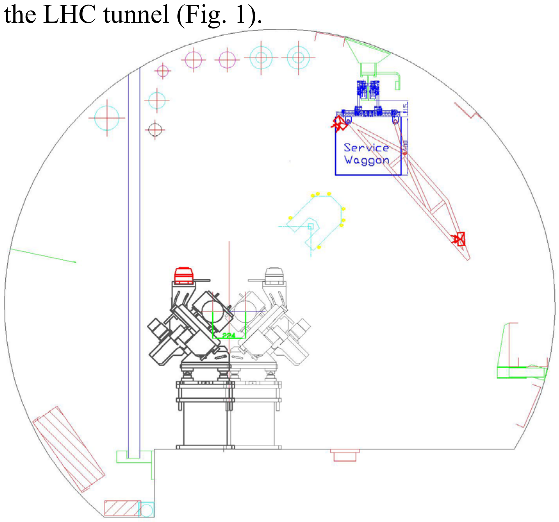

Figure 1: Drawing Model

A photogrammetric system was developed to measure the relative coordinates of the collimator elements with respect to the surrounding reference magnets. This is a fast, precise and non-tactile way to measure the sockets of the radioactive collimators. This system is limited to a relatively small volume and a considerable effort is needed to cover a 500m section of the LHC tunnel. In order to cover the whole zone, a stretched wire reference is used. More precisely, 5 overlapping and fixed wires are used to connect the different acquisition volumes of the camera system. The aim is to measure the position of the collimators with respect to the surrounding reference quadrupole magnets at the extremities of the wires (Fig. 2).

To be able to reliably handle the instruments control, the online analysis and the communication to the surface, a dedicated LabVIEW application, called Multiple Alignment Control System (MACS), has been developed using a PXI based platform.

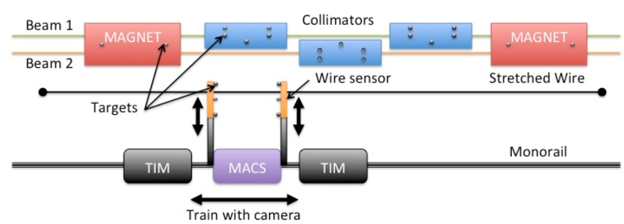

Figure 2: Collimator train concept

LAYOUT AND INSTRUMENTATION

The train itself is a modular inspection train system called Train Inspection Monorail (TIM), developed by the EN/HE Group at CERN, in order to make remotely controlled visual inspections and radiation surveys in the LHC.

General Layout

TIM is composed of 2 basic modules, a traction wagon and a battery wagon. Depending on the task, custom sensor wagons can be added. In the case of the survey train (BE/ABP-SU) 3 additional modules were added.

- A sensor wagon carrying measurement equipment.
- A control wagon carrying the sensors infrastructure.
- A camera wagon with an auxiliary camera.

TIM's network communication was in 2012 based on EDGE and will be upgraded to 3G in 2014. These communication protocols are non-deterministic and therefore it's unreliable as a device control medium. Collisions sensors are installed on each extremity of the train in order to stop the train automatically when people or obstacles are detected. These sensors, in addition to the emergency stop buttons, are part of the security chain. In case of a communication loss or breakage of the security chain, the train stops automatically. The TIM displace-

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ment as well as the safety control is achieved using a Siemens PLC.

Survey Train Instrumentations

The two main parts are the camera and the wire detection systems.

The camera is based on the "MoveInspect" technology from AICON 3D Systems [3]. It can be considered as autonomous and ready to use with its IEEE 1394 certified interface. For each collimator, 5 targets are installed on an adapter plate mounted to a fiducial support. The photogrammetric targets are adjusted to the nominal parameters with the fiducials. MACS will trigger the camera acquisition and retrieve the data for further analysis when needed.

The wire detection system consists of two commercial optical laser micrometres, XLS35XY (XLS) from AEROEL [4], with a large measurement range of 35 mm * 35 mm, running a dedicated program according to the needs of this application. MACS retrieves the 200 points per second continuously through TCP/IP. The XLS are mounted on movable arms on the train, necessary to compensate the monorail's defects, which has been installed for transport reasons already at the times of the Large Electron-Positron (LEP) collider [5]. The rail has deviations of ± 10cm with respect to the installed wires. These movable arms are part of an active and autonomous system, which always keeps the wire at the nominal position inside the range of the wire sensors. The sensors will only be taken off to pass an obstacle.

In addition, there are two inclination sensors installed, one on each laser micrometre. The sensors are Wyler Zerotronic [6] with ±10° of range, connected via RS232.

The PXI system is connected to each device mentioned above and also communicates with the PLC for the displacement. Each device, including the PXI crate, has to be powered with 24VDC, limiting the hardware choice. All the sensors are initialized, checked and controlled by means of MACS (Fig.3).

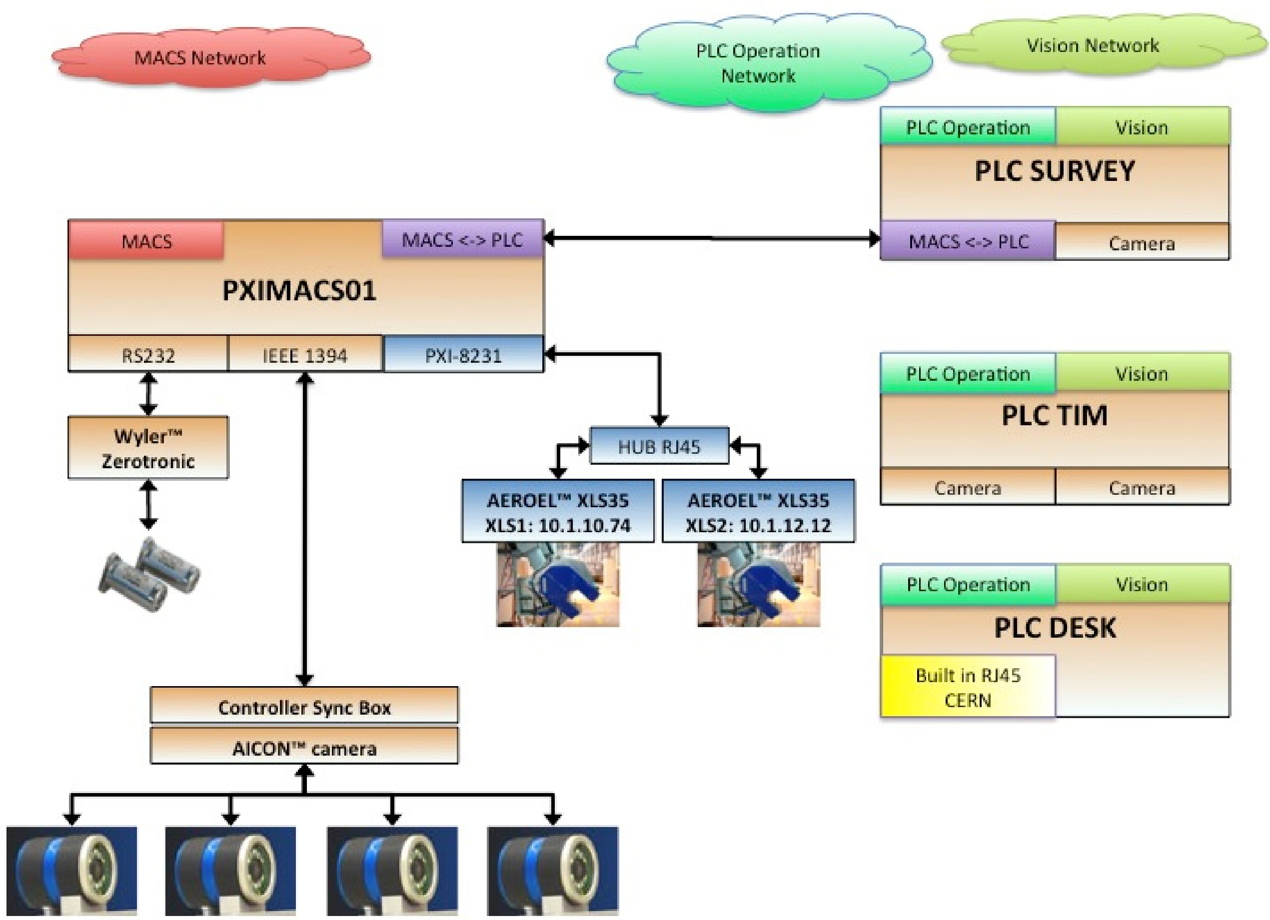

Figure 3: Instrumentation and communication layout of TIM and MACS.

Active Displacement System

TIM and MACS both need to know the position of the train in the tunnel. Its longitudinal position is measured using a rotation encoder with a resolution of 60 µm on the monorail. It has been decided that the encoder data is read by TIM and written to a PLC data block. MACS reads this information from this data block using a Fetch/Write

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communication protocol [7]. Once the system is installed the wheel offset is measured according to its position, hence the distance with respect to the other element in the tunnel is known. This distance is monitored to know the relative longitudinal displacement of the system.

MACS needs to interact with TIM to position the train in front of the element to be measured and also to control the arms holding the XLS sensors. The entire safety logic is embedded in the PLC. Nevertheless a reliable and fail-safe communication between the measurement program and TIM is needed. The communication between the PXI and the PLC is done through Ethernet, including several handshakes to make sure that both sides are alive. MACS performs its measurements by receiving and sending requests to the PLC using the Fetch/Write protocol. In both cases, Fetch and Write, LabVIEW handles the communication and the PLC stays passive. If the communication is lost, TIM is able to move by itself, withdrawing the arms and coming back to its initial position. If the communication is broken, MACS will try to re-establish the connection to the PLC and continue the measurement.

MACS runs multiple threads retrieving data at different pace for each instrument. These measurements must be processed and only the latest data is transmitted to TIM.

MEASUREMENTS AND ANALYSIS

The entire measurement and analysis sequence is done in MACS. As the train is in the LHC tunnel, where the access is limited, the application called MACS contains 2 parts both developed in LabVIEW:

- MACS-PXI: running on the PXI crate in the tunnel.
- MACS-Host: controlled from the surface by an operator.

MACS-PXI and MACS-Host communicates in real-time through the EDGE network using shared variables. For this reason, all the calculations and decision-making are done in the embedded application, MACS-PXI. The operator is informed through the MACS-Host as fast as possible. The user may be prompted for intervention if an unexpected event occurs, such as obstacle on the way.

The tight communication handshake to the PLC is done from MACS-PXI. The application MACS-Host is considered as optional during the entire design phase to ensure a high reliability of the MACS-PXI. For this reason, we describe here below the processes of MACS-PXI.

Sequence

After the start-up and calibration in situ, the operator starts the measurement sequence. The train will carry out the measurements automatically until the system demands an operator intervention.

The sequence starts with the declaration of the actual object to be measured and executes the following steps:

- Inclination sensors stability check.
- Wire sensors stability check.
- Cameras triggered and simultaneous acquisition of all other sensors.
- Wire stability repeated.
- Inclination stability repeated.
- Calculations.
- Positioning in front of next object.

Readings Corrections

The laser axes of the XLS sensors have no mechanical reference outside on the housing. As a consequence the laser axes cannot be aligned with the Z axis of the arm which is coming from the inclination sensor surface. A calibration of the angle has been carried out and showed up to 6mrad of difference in the axis directions. The XLS reading correction allows their alignment with the arm systems. Rotating the 2D XLS coordinate system into the arms coordinate system by means of 2D matrix operations does the correction.

The theoretical wire sagitta is calculated using the information of the current longitudinal position with respect to the corresponding wire extremities and the parameters of the concerned wire (see Fig. 4 and Eq.1).

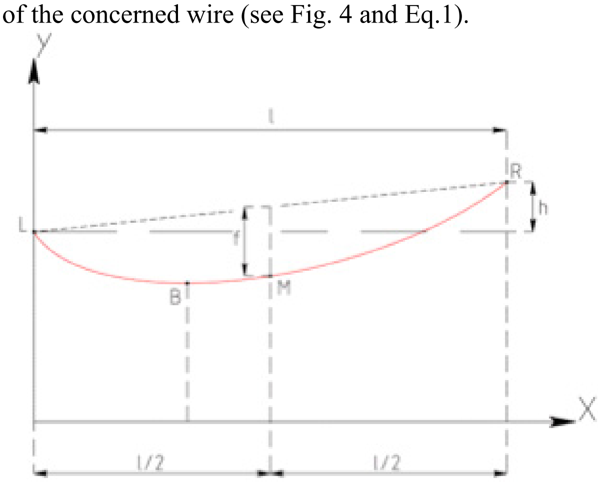

Figure 4: Wire sagittal modelisation.

- H: applied wire tension
- h: height difference between the wire fixations
- q: wire linear mass
- l: wire length

$$y(x) = \frac{qx^2}{2H} + \frac{hx}{l} + \frac{qlx}{2H} \quad (1)$$

The correction is applied directly to the two XLS measurements. All corrected points are then measured with respect to a horizontal reference line with the origin in the upstream wire extremity.

Calculations

After the acquisition, the CERN SU software for transformations called Chaba is used in order to transform the arm systems of both sensors into the photogrammetric system. Due to the complex code, the program is used as an external executable that is called. The sagitta and slope of the wire are corrected and we obtain all points in a coordinate system properly aligned with the wire and the local vertical. These coordinates are then transformed into horizontal wire offsets and height differences, which can

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be treated in the standard way using the "CERN least squares compensation program" (LGC++) [8].

RESULTS

In January 2012, a measurement campaign has been done in situ on the LHC collimators at point 7 (Fig. 5) to validate the entire system and check the results. 26 reference magnets and 35 collimators have been measured over 500m. A couple of collimators could not be measured due to communication problems. The collimators are measured within one day spending a couple of hours for the installation in the tunnel and the rest of the time at the surface. Classical methods, such as direct levelling and stretch wire, takes 4 days for 3 people being all the time in the tunnel.

Figure 5: Measurement at LHC point7.

The repeatability of the measurement is less than 60 µm in altimetry and planimetry. Compared with classical measurements, the train measurements are within 0.22mm RMS. One has to be aware that the accuracy of the classical measurements is already in this range, so the comparison is within the measurement noise. In altimetry, the earth curvature had to be taken into account to modify the train measurements to make them comparable with classical methods.

In addition to these good results, there is still room for improvement. The automatic measurement slowed down when the camera wrongly detected targets when measuring some collimators. Several shiny cables were considered as targets at several positions causing MACS to believe that the positioning was wrong. In such a situation, MACS requests a 10 cm movement to TIM, takes a set of new picture and analyse the results. It can be tricky to get the correct angle to avoid the light reflections. Passing an obstacle is also a time consuming task, as the user has to withdraw the arms so that the train can move forward. Then the arms have to be moved back around the wire, using 2 camera. This last step needs a lot of experience as no 3D vision is available to the user. We are trying to work out an algorithm to put the arms back around the stretched wire without a human intervention. This manipulation is extremely risky as one may cut the wire. This would trigger a human intervention in the tunnel to re-install the wire and repeat the entire measurement.

CONCLUSIONS

The entire system has proven to be working fine saving time and giving excellent results. Each sensor worked fine and with the expected accuracy range. The PXI crate met all the requirements for the power consumption as well as CPU availability. Choosing LabVIEW made it easy to develop specific drivers for each instrument and gather all the information in a manageable format. The PXI is now running Windows for compatibility reason with the camera software as well as the specialised application from survey team. In the future, the PXI crate will run hypervisor with Windows on 2 cores and PharLap on 2 other cores. This modification will provide an even higher reliability of the entire system.

REFERENCES

[1] R. Assmann et al., "Requirements for LHC Collimation System", EPAC'02, Paris, June 2002.
[2] The LHC Design Report, http://ab-div.web.cern.ch/ab-div/Publications/LHC-DesignReport.html, July 2004.
[3] Technical Specifications, "AICON 3D Systems Webpage", http://www.aicon3d.com/produkte/moveinspect-technology.html
[4] Technical Specifications "AEROEL Webpage", http://www.aeroel.it/en/prodotti/xls.htm
[5] S. Myers, The LEP collider, http://sl-div.web.cern.ch/sl-div/history/lep_doc.html, CERN November 1990.
[6] Technical Specifications "Wyler Webpage", http://www.wylerag.com/pages_eng/e4_421.html
[7] Siemens white paper v1.0, IPv6 in automation technology http://www.siemens.com/press/pool/de/materials/industry/iia/whitepapers/whitepaper-ipv6-e.pdf
[8] M. Jones, "An object oriented approach to processing accelerator alignment measurements", IWAA2010, Hamburg, Germany.

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