TEST AND CALIBRATION FACILITY FOR HLS AND WPS SENSORS

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1. ABSTRACT

The online monitoring and adjustment of the Low Beta quadrupoles surrounding each of the LHC[1] experiments is very important for the performance of the accelerator. Therefore HLS[2] and WPS[3] sensors will be used to control the position of these magnets.

Only sensors tested at reception and regularly during shutdowns of the machine can guarantee good results. Therefore a calibration facility is going to be developed at CERN to perform these tests on site.

The concept, test procedures, installation and the first results from this facility will be presented.

2. INTRODUCTION

As the LHC is an accelerator that demands very high relative alignment accuracies of ± 0.5 mm (3σ) for the low beta quadrupoles, the calibration of the sensors installed has to be verified in regular intervals. Including optical control, general function tests and finally calibration, every sensor of the LHC has to be checked. The procedure of verifying the sensor's calibration at reception needs to be done to validate the calibration values provided by the manufacturer. Recalibrations in shut down times of the machine have to be carried out as the sensors are exposed to strong magnetic fields and high radiations.

As the total number of sensors in the LHC will be 64 WPS and 100 HLS sensors, this huge amount of permanent monitoring sensors lead to the decision to install a calibration bench. On one hand it is necessary to comply with the radiation safety regulations, as the LHC is declared an INB[4] and every sensor that will be dismounted from the accelerator after first beam injection may not be shipped, no matter if irradiated or not. On the other hand, the creation of a test and calibration facility allows on site measurements and therefore it is possible to be very cost-effective in the maintenance of the sensors.

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[1] LHC Large Hadron Collider
[2] HLS Hydrostatic Leveling System
[3] WPS Wire Positioning System
[4] INB Installation Nucléaire de Base (Nuclear Base Installation)

3. OPERATIONAL AREA OF THE SENSORS

The installation of the sensors will be in the area of the main detectors of the LHC: ATLAS[5], ALICE[6], CMS[7] and LHCb[8]. The quadrupoles on both sides of each experiment are going to be linked in height by the HLS. Additionally the ATLAS and CMS caverns will be equipped with WPS sensors for a radial link between the two sides.

On the low beta magnets themselves, HLS and WPS sensors will be installed for monitoring the movements of the magnets and to determine adjustment values for the motorized jacks that are able to reposition the magnet.

Finally a hydrostatic levelling system is installed in the socket of the ATLAS experiment (bedplates) to monitor a predicted movement, when load is applied during assembly of the experiment.

4. SENSORS

The sensors used in the LHC are going to be manufactured by FOGALE Nanotech, which already provided such sensors for previous accelerators at CERN. Due to the harsh conditions during beam operation, electronic parts have to be strictly separated from the sensor and cable lengths of up to 30m arise for the transport of the primary signal.

The term *sensor* has to be regarded as the ensemble of measuring sensor surface, electronic and connecting cables.

4.1. Wire Positioning Sensors

WPS are used for measuring the displacement of the sensor with respect to a stretched wire, which serves as straightness reference. Horizontal and vertical movements can be measured with these sensors.

The capacitive sensors have a working range of 10 mm for each axis with a resolution of minor 1 µm and a repeatability of about 1 µm with integrated electronics. The data acquisition rate can be up to 10 Hz.

figure 1:WPS sensor

In addition to the sensor, the signal conditioning box and cables compose the calibrated sensor unit.

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[5] ATLAS A Toroidal LHC ApparatuS
[6] ALICE A Large Ion Collider Experiment
[7] CMS Compact Muon Solenoid
[8] LHCb Large Hadron Collider beauty experiment

4.2. Hydrostatic Levelling System Sensors

figure 2: HLS sensor

As the HLS sensor works on the same technology as the WPS, similar characteristics and working range are specified.

The electronic has up to now been integrated in the sensor shown in figure 2 to perform the signal conditioning close to the measured signal and to keep the noise of the sensor low. Strong radiation and magnetic fields force the design to be changed and have the electronic separated from the sensor itself.

Along with the leveling, temperature measurements are done to compensate influences of expansion of the vessel or dilatation of the water.

5. SENSOR TESTS

To qualify the performance of the sensors and to be able to do proper recalibrations, a variety of tests have to be performed. They can be grouped into three categories of tests:

- *generation tests:* In this case the overall performance of different sensor generations is compared to each other. Not only new developments are compared to older generations, but also new sensors and sensors already used in the LEP[9].

- *reception tests:* A general performance test including warm up, stability and the verification of the calibration polynomial is done. This is only a control of the sensor's parameters before the installation in the accelerator.

- *maintenance tests:* These tests will follow after first beam injection when the sensors can no longer leave the CERN site. Basically the reception tests are carried out with the supplement of recalibrations if necessary.

The tests presented will be the reception tests for any sensor which will be installed in the LHC.

5.1. Warm up

The warm up shows the performance when starting measurements. The term *warm up* has to be taken literally as e.g. the HLS sensor is heated to prevent from condensation.

[9] LEP Large Electron Positron Collider

Once the LHC is in operation, normally the sensors run continuously and therefore the warm up performance plays an inferior role. Nevertheless, in the unlikely event of power failure a forecast has to be given when the system is again ready for use.

Tests will reveal if a warm up time can be determined as a constant for all sensors or if this attribute is unique to every sensor.

5.2. Linearity

This test will be done for the verification of the sensor's linearity and for the determination of a polynomial curve.

During first tests with manual operation of the test device, a grid of 11 measurements will be chosen along the sensor's range of 0 V to 10 V in order to have the same amount of measurements as carried out by the manufacturer. This measurement will be sufficient for controlling the provided polynomial.

Further developments with a motorized device will open up the possibility for a set of tests including more measurements and ending up with the possibility of a calibration.

5.3. Long Term Stability

Directly following the monitoring of the sensor's warm up, a stability test will be performed. At least the 48 h performance is tracked as advised by the manufacturer, but more extensive tests will give information about the time necessary.

In fact, two tests are carried out with the long term stability test. The first test is done with the stability test vessel, shown in figure 6.a, to be sure about the measurement values of the sensor. A second test is performed in a hydrostatic network with several sensors, to see influences of evaporation of the system and if all sensors behave the same. Also water tightness can be evaluated in these conditions as the sensor's surface is exposed to a humidity of 100 percent.

5.4. Repeatability

To control the repeatability of the sensors, the sensor is mounted several times to the control bench. For the HLS this test is performed to be sure about the correct repositioning on the vessel after service inspection. For the WPS it is carried out to control the performance of the locating pins for the two parts of the sensor.

5.5. Tilt Calibration

The accuracy of the sensor installation on site is an important aspect. From this test, tilt limits have to be defined for the sensors with respect to the measured object, to gain the full potential of the sensors.

A large amount of sensors will also be installed on magnets supported by motorized jacks, the influence of the tilt has to be determined as the magnets will be inclined during operation. Weather a tilt polynomial has to be introduced into the calculations will be determined.

5.6. External Reference Calibration

The sensor has to be calibrated to external references, like e.g. the support for Taylor Hobson spheres, and therefore an offset from the sensor's main axis to the support has to be determined. This step is very important as the link between the machine components and the experiments is done from the sensor's external references.

5.7. Temperature Variation

Two tests can be performed for the temperature variation: A basic test, which shows the behaviour in an environment of 10°C to 40°C, as it is expected for the LHC accelerator, where WPS and HLS sensors will be checked.

The second test focuses on the HLS, as only this is equipped with temperature sensors and as it is directly influenced by the water dilatation and the expansion of the vessel.

5.8. Radiation Resistance

The manufacturers of external purchased equipment have to get CERN's written approval for the materials used due to radiation safety regulations. This is already an instance to avoid the used of inadequate materials.

Nevertheless all new types of permanently installed sensors used by the surveying group will be tested on the radiation predicted for their lifetime. In addition, performance tests after irradiation open up the opportunity to work with artificially aged sensors [4].

6. REALIZED CALIBRATION BENCHES

The calibration benches presented are the state-of-the-art of the development. As first prototypes for the basic tests of the calibration principles, they are manually operated and manufactured as portable devices.

6.1. Wire Positioning Sensors

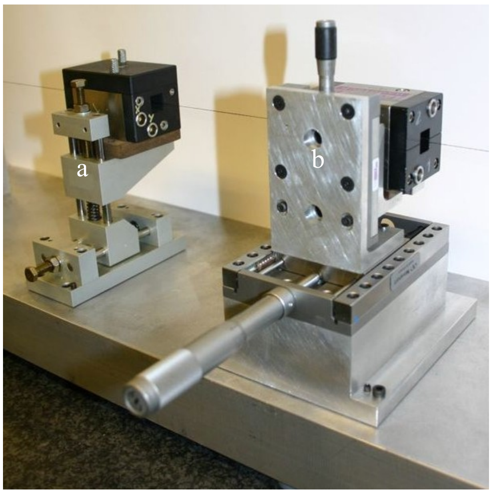

figure 3: detail of WPS test bench

WPS testing is done by installing a set of minimum three sensors on a rigid support. The sensors are mounted in a row where the inner one (figure 3.b) is effectively going to be tested, as it is mounted on two micrometric tables for the X and Y positioning. The outer sensors (figure 3.a) serve as reference and shall detect movements of the wire; nevertheless the supports have simple adjustment tools, to position them straight in the main axis of the sensor that is going to be tested.

As the device is operated manually during first tests, the inner sensor is limited to one. Once the system is validated and can be automated with motors and computer control, more sensors can be tested at the same time.

The control and calibration of WPS sensors has to deal with two opposite demands: One is the temperature stabilisation during tests which normally needs a climatic chamber with a constant air flow and the other is to avoid the introduction of vibrations to the wire due to this air flow.

6.2. Hydrostatic Levelling Sensors

The HLS tests will be carried out with two devices that have been developed: One for the determination of the polynomials and the other for the long term observations.

As basic idea for both devices, the water surface has been replaced by a metal surface. This avoids the observation of waves, evaporation or tidal influences during the measurements.

6.2.1. Calibration Test Bench

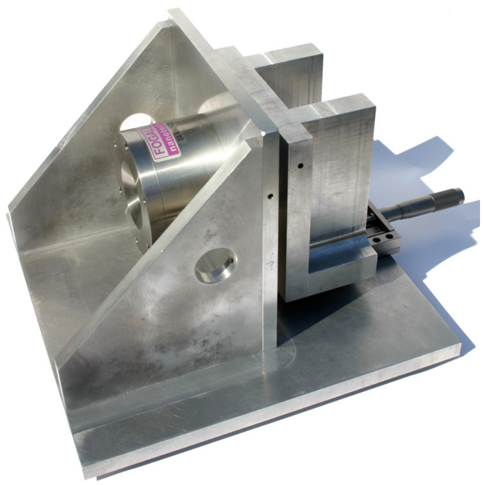

figure 4: calibration test bench

This device will be used for the verification of the sensor's linearity. The HLS sensor measures to the reference plane which is mounted on a linear unit as shown in figure 5. The surface and the plane are fixed in parallel position.

For the moment, a correlation between the measurements of the HLS sensor and the reading on the micrometer screw on the linear unit are sufficient to inspect and verify the polynomial of sensor. Once calibrations will be done with this bench, linear length gauges will be attached by keeping to the principle of Abbe.

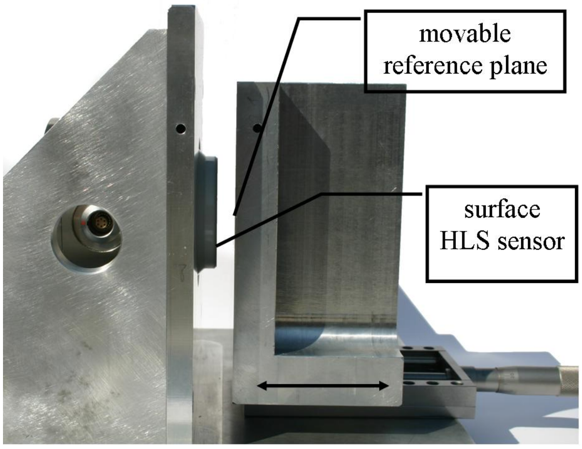

figure 5: side view of test bench

In addition, this device will be upgraded to become also the tilt calibration device (5.4). Therefore the support of the reference block has to be modified, so that defined rotations can be done either in vertical or in horizontal.

A motorization can be integrated to a later date in combination with software, to perform an automated linear calibration with an adequate sample of measurements.

The measurement period for a sensor inspection from 0 V to 10 V at intervals of 1 V takes approximately 30 minutes. During this time a constant temperature with σ = 0.3 °C can be observed. The thereof calculated 3rd degree polynomial corresponds well with the values of the manufacturer.

6.2.2. Stability test bench

For long term tests, the observation of the warm up behaviour and the noise determination of the sensor, a modified vessel will be used (figure 6.a). The shortened height allows the observation to the bottom which serves as reference.

figure 6: (a) stability test vessel, (b) HLS vessel

In an environment with constant temperature, e.g. a climatic chamber, long term observations can be done without having the perturbations mentioned above. Tests show, that this concept works well, as stable observations are achieved.

The warm up itself has to be separated in two parts: An effect that can be seen due to electronic warm up of the sensor and the second one, which is due to the warming of the sensor and the vessel which adopts the temperature.

Figure 7 shows the warm up effect of the electronic in the first 40 minutes after switching on the installation. The measurements shown are relative with respect to the first measurement.

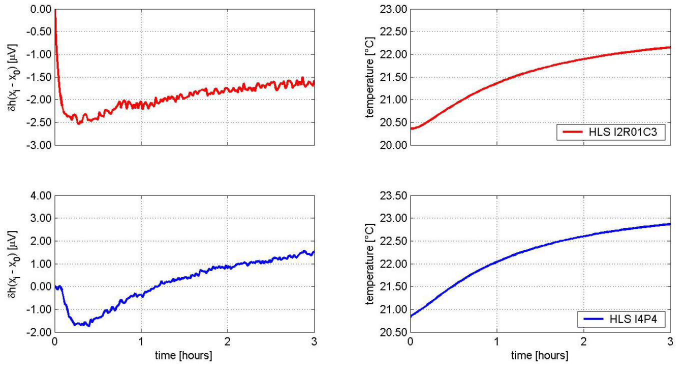

figure 7: warm up of electronic

The total warm up of sensor and vessel equals after approximately 12 hours as shown in figure 8.

In several tests, different sensor warm up curves had been observed and the absolute measured distance between sensor and reference surface has always been the same with respect to the possible repeatability of 2µV. The integrity of this test bench has therefore been proved.

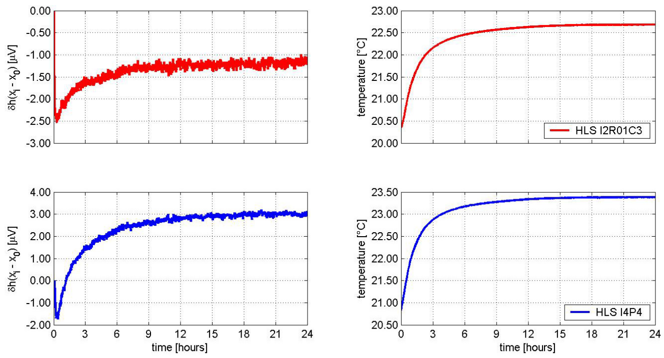

figure 8: warm up of HLS

6.3. HLS and WPS alignment bench

An alignment bench for HLS and WPS sensors [3] can be used for long term observations of the sensors in their 'natural' environment. The inspection with water and humidity for the HLS and stretched wires over a distance of 50 m for the WPS shall reveal the stability in daily use. The bench can host four sensors of each type simultaneously.

The HLS sensors are mounted on supports to the wall and form a network of 50 m in length with two sensors on each side. They are not adjustable in height, to have constant measurements. A variation in the measurements can be done by filling and purging water to the network.

figure 9: alignment bench

In contrast two of the WPS are fixed on supports to the tunnel wall and serve as reference, similar to the concept of the WPS test bench (6.1). The other sensors are installed on micrometric tables, to be moved horizontally and vertically. The whole ensemble is mounted on a carriage which can be displaced along the wire.

The supports on the wall are furthermore equipped with tilt sensors for both axes to be aware of changes during the measurements.

7. QUALITY ASSURANCE

An inspection of instruments has only significance if the test always takes place in the same way and same conditions. It seems obvious that calibration facilities are installed to guarantee always same boundary conditions, but there is also the operator who carries out the measurements involved in the procedure. He has to have a guideline to perform the tests in a repeatable and determined sequence.

The quality assurance procedure is important to document the performance of the sensors installed and to check the equipment in certain intervals. In this context it is necessary to distinguish between an *inspection* and a *calibration* [2], as different action has to be taken.

The results of inspections, calibrations and other identification attributes will be integrated into an equipment database (MTF[10]) provided by CERN's central IT service. The database is adapted to the special needs and specifications for every sensor, so that each important detail of the calibration will be available.

8. CONCLUSION

In this first period of the installation of a calibration facility at CERN, the concept of calibration will be verified by test stand prototypes which are suitable for inspections. These will serve for the reception inspections of the sensors.

A review of the test bench which takes focus on the refinement of the design and the automation of the process will succeed, when tests are completed. Therefore the results presented here should be considered as first approaches.

[10] MTF Manufacturing and Test Folder Travellers

For the moment, the autonomy from existing calibration installations like e.g. the interferometer is intended to keep those instruments available for other calibration tasks. After approving the calibration routines and software development for automatic measurements, an upgrade and integration into existing installations is planned.

Once the calibration facility is established permanently, the focus on the CERN specific type of sensors can be extended and other types of HLS and WPS systems will be integrated as ‘plug and play’ solutions.

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