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FREQUENCY SCANNING INTERFEROMETRY AS NEW SOLUTION FOR ON-LINE MONITORING INSIDE A CRYOSTAT FOR THE HL-LHC PROJECT

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Abstract

For the HL-LHC project, the cryostats of the key components will be equipped permanently with an on-line system based on Frequency Scanning Interferometry (FSI). Such a system, based on absolute distance measurement, will determine the position of the inner triplet cold masses w.r.t. their cryostat and the position of the crab cavities also inside their cryostat, within an uncertainty of measurement of 0.1 mm, in a harsh environment: cold temperature of 2 K and high radiation level of the order of 1 MGy. The FSI system was validated first successfully on one LHC dipole cryostat and its associated cold mass to undergo qualification tests under different conditions: warm, vacuum and cold (2 K). The FSI system also equips the first crab cavities prototype cryostat. The configuration of the FSI system chosen after simulations, the conditions of tests as well as their results and analysis are presented in this paper.

INTRODUCTION

In the LHC, we continuously monitor the position of the low beta inner triplets by alignment systems: Hydrostatic Levelling Systems (HLS) and Wire Positioning Systems (WPS) [1]. Despite the micrometric uncertainty of measurement of these systems, the sensors readings do not correlate very well with the beam position [2]. The sensors are located on top of the cryostat and the stability of the position of the cold mass inside the cryostat is not known precisely enough. For the HL-LHC project [3-5], a monitoring of the position of the cold mass w.r.t. the cryostat according to 5 Degrees of Freedom (DoF) is proposed in the baseline [2]. Such an internal monitoring has been chosen as well for the crab cavities inside their cryostat. We could not apply existing methods based on Wire Position Monitors and stretched wires developed at Fermilab for the internal monitoring: the wire stretched as alignment reference inside the vacuum vessel was too invasive and such RF measurements were not possible in the crab cavities. We retained a new solution using Frequency Scanning Interferometry, providing non-contact measurements between the cryostat and the cold mass. We have undertaken additional tests on the FSI system on dedicated test setups to cross check its performance and validate the accuracy of its measurements in a harsh environment. In this paper, we present the dedicated test setups and conditions on which the FSI system was validated, results obtained and conclusions drawn.

THE FSI SYSTEM FOR INTERNAL MONITORING

FSI System

The FSI system is an interferometer to measure an absolute distance between the focal point of a collimator and a Corner Cube Reflector (CCR) within an uncertainty of measurement of 0.5 ppm, according to its manufacturer: Etalon AG [6].

For our applications, CCRs are located on the internal component, i.e. cold mass for the inner triplet, flanges of the dressed cavities for the crab cavities; optical collimators are installed on the cryostat, performing measurements via a CERN-designed feedthrough or a viewport. We need a configuration of at least six lines of sight to determine the center of the cold mass section or the center of the flanges of the dressed cavities according to six DoF. Inclined distances w.r.t. local vertical improves precision on longitudinal position.

We put in place specific procedures to determine the focus point of the collimator (“zero point of the distance”) w.r.t. external alignment targets on the collimator mount [7]. The position of these targets can be measured from a station outside the cryostat (in the tunnel or in the laboratory). The calculations consist of a succession of change of referential frames and associated measurements, to determine the position of the cold mass extremities or center of dressed cavities flanges in the referential frame of the tunnel.

FSI Configuration Chosen for Crab Cavities

In case of crab cavities, we determine the position of the center of the flanges outside each dressed cavities in the tunnel referential frame, using four absolute distances per flange, as shown in Fig. 1 [8].

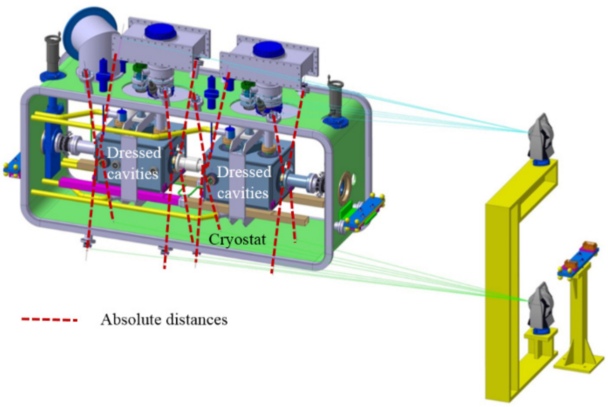

Figure 1: FSI configuration for crab cavities.

FSI Configuration Chosen for Inner Triplets

Each quadrupole vacuum vessel integrates three sections of measurements, at the level of the cold mass support feet, as shown in Fig. 2.

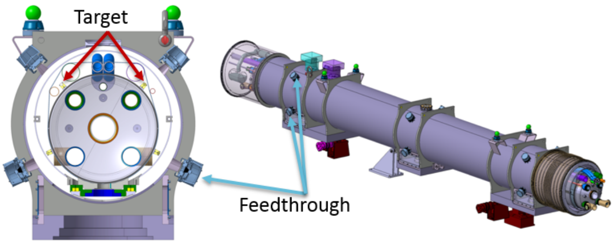

Figure 2: FSI configuration for Inner Triplet quadrupoles.

Summary of Preliminary Tests and Results

Before CERN, FSI system applications were focused on distance measurements in a metrological environment. This is the first time such a system is planned for use in a harsh environment, e.g. 1 MGy of radiations, and cryogenic temperature (2 K) inside a technical vacuum. First tests started with an irradiation campaign of different types of targets and collimators. Ball Mounted Hollow Retroreflectors (BMRs) prisms could stand the maximum ionising dose (10 MGy) with a change of distance measurement before and after irradiation below 20 µm. No change of properties were observed on collimators [9]. Then, the repeatability of FSI measurements at 2 K was controlled at CERN Cryolab resulting in standard deviations below 20 µm [10].

To crosscheck the accuracy of FSI system, in a laboratory environment (20 °C), a specific mock-up was built, at the same scale as one dressed crab cavities (length of 50 cm). We measured the position of the centers of flanges by three different means: laser tracker AT401 [11], FSI system and Brandeis Camera Angle Monitoring (BCAM) [12]. The absolute tracker AT401 from Leica has an accuracy of ± 15 µm + 6ppm for the angle measurements and ± 10 µm for the absolute distance measurement. The BCAM system is an optical system performing radial and vertical angle measurements via CCD camera flashing on glass sphere targets, held on independent support. The precision and accuracy given by Brandeis University are respectively 5 µrad and 50 µrad. A 3D portable arm achieved the correspondence between targets measured by AT401, FSI system, and BCAM, with an uncertainty of measurement of the order of 10 µm.

Figure 3 illustrates the radial and vertical position of the cavity extremities measured by the three different system. From the measurement uncertainty point of view, AT401 is the most accurate (< 5 µm), FSI is more accurate in vertical (15 µm) than in radial (30 µm) due to the configuration of the FSI collimators, while BCAM provide the same radial and vertical accuracy (30 µm) [7]. Considering AT401 measurements as the reference, both FSI and BCAM sensors give the position of the extremities within their uncertainty of measurement.

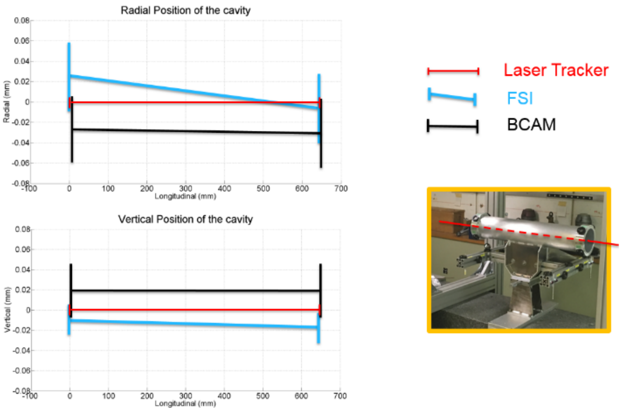

Figure 3: Cross-comparison between FSI, BCAM, laser tracker of the radial and vertical position of the flange centers.

Following these satisfactory results, we decided to install the FSI system in the crab cavities prototype.

CRAB CAVITIES TEST SETUP

Cross-Comparison at 20°C

The same cross-comparison between AT401, FSI and BCAM occurred, this time on a real component: the crab cavities prototype. Such a comparison could only take place at 20 °C, when the cryostat was open to have an access to the targets installed on the flanges. In such a configuration, as the volume of measurements had increased from 1 cavity to 2 cavities inside a cryostat, that some targets were not visible anymore and that the configuration of measurements was not the same, the uncertainties of measurements of the three measurement systems had to be slightly revised: 15 µm for AT401, 50 µm for BCAM in vertical and radial, 20 µm in vertical and 50 µm in radial for FSI. The maximum offsets observed on the flanges coordinates between the 3 means of measurements range from 25 µm to 60 µm in radial and 44 µm to 71 µm in vertical [13, 14].

Cross-Comparison at 2 K Under Vacuum

The same prototype equipped with BCAM and FSI was then closed (so no AT401 measurements were possible), vacuum pumped and cooled-down to 2K during 3 weeks (before its installation in the SPS tunnel). The maximum offsets between BCAM and FSI were obtained, ranging from 2 µm to 122 µm in radial and ranging from 1 µm to 100 µm in vertical. Such larger offsets can be explained by the fact that BCAM and FSI measure targets that are not located at the same place; in both cases, models of contraction have to be taken into account to determine these measurements at the center of the flange.

DIPOLE TEST SETUP

Test Setup

We have equipped three sections of a dipole with four distance measurements each using FSI system. Distances were measured using two configurations of targets and collimating heads: low cost aluminium reflectors with collimators installed behind ISOK DN 63 viewports or 1.5” BMR targets and collimators mounted within CERN-designed feedthroughs. The configuration of target types and collimator housing is shown in Fig. 4 below.

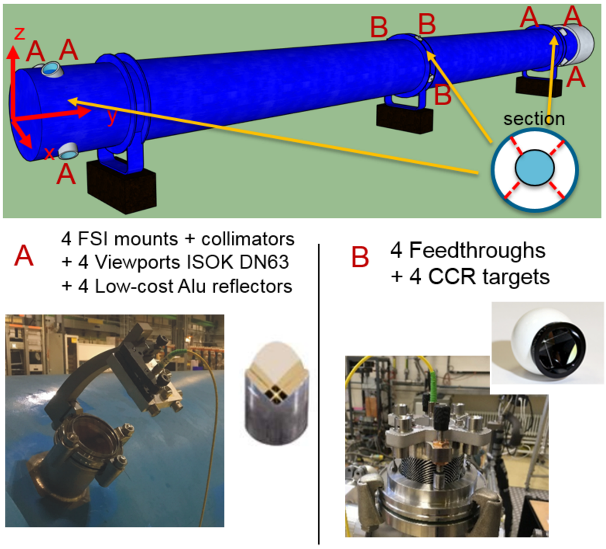

Figure 4: configuration of FSI measurements for the dipole test – vacuum vessel viewport distribution (top) viewport on the vacuum vessel (bottom left) CERN-designed feedthrough (bottom right).

First Sequences of Tests

For the first test, the cold mass and screens were cooldown simultaneously to 70 K [15]. A poor reflected signal quality of prisms located on the upper part of the cold mass was observed. After a purge of the vacuum vessel with nitrogen, we obtained a better reflection during a few days, but afterwards the return signal intensity became very low again. Pictures taken of the upper part from the viewports showed a ice-like deposition on the targets. We concluded that the FSI system is sensitive to cryo-condensation and that cryo-condensation depends on the cryostat cleanliness. As the upper thermal screen was not welded to the bottom screen, we made the hypothesis that the upper targets located on the cold mass became the coldest points locally, causing preferential spots for freezing of particles.

For the second test, the thermal screens were cooled first to 80 K to force particle condensation on the screen first and the cold mass was cooled down after. The first loss of upper prism signal occurred after 1 week of measurements at 80 K.

Proposed Solution to Solve Cryo-Condensation Issue

To solve the cryo-condensation issue, we designed a new 3D printed insulated target support (see Fig. 5) to keep a temperature of the reflector around 200 K, even if attached directly on the 2 K cold mass. The goal is to stay above the saturation temperature for all gas naturally occurring in the atmosphere at a pressure around 10^{-6} mbar [16]. The epoxy insulating support is equipped with a dedicated absorption plate with high emissivity to intercept incident thermal radiation from the vacuum vessel and heat up the reflector. A MLI collaret was added as well to limit the emission of thermal radiation to the cold mass from the interception plate and CCR.

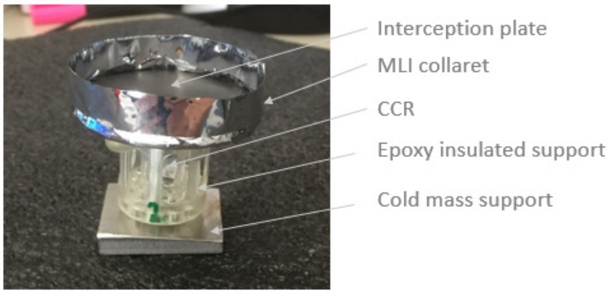

Figure 5: 3D printed insulated support for CCR.

Results and Perspectives

We replaced eight initial targets supports by insulated targets, keeping the four others as reference. The dipole was cooled down during more than 3 weeks at a temperature of 2 K. We lost the four reference targets immediately, while the insulated targets were still showing good reflection after 3 weeks of cool-down, with the same intensity signal than at the beginning.

We have found a satisfactory and efficient concept of support to solve the cryo-condensation issue. The objective is now to develop an insulated target based on a less fragile yet thermally insulating material than pure Epoxy. Commercially available *Accura blue stone* ® could be an interesting candidate and we are preparing tests to qualify the material to cold temperature.

CONCLUSION

We propose FSI as a new solution for on-line monitoring of cold objects inside a cryostat. By associating at least eight lines of sights consisting of one CCR and one FSI collimator each, we can reconstruct the position of the component to be monitored. Tests carried out confirmed that such a system can be used in a laboratory environment, and demonstrated that it can also work in a harsh environment (2K, 1 MGy), even in a “dirty” vacuum vessel. The design of a new insulated support for CCR is a real added value to solve cryo-condensation issues and decrease heat loads in the vacuum vessel.

The first tests carried out on the dipole have shown that the monitoring of the cold masses inside their cryostat from 300 K to 2 K is possible with the FSI system within an uncertainty of measurement below 0.1 mm. During this cool-down, vertical displacement of the cold mass and a thermal contraction were observed, consistent with theory.

ACKNOWLEDGMENTS

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