ENGINEERING SPECIFICATION

HL-LHC LHC CRAB CAVITIES:

SPS : DQW CRAB-CAVITIES CRYOMODULE PROTOTYPE

DESCRIPTION OF THE SURVEY MEASUREMENT

Abstract

This document presents a description of the survey measurements conducted during the assembly steps of the DQW prototype Crab-cavity in 2017-2018.

TRACEABILITY

Prepared by: V.RUDE	***Date:*** 28/01/2021
Verified by : M. Sosin	***Date:*** DD/MM/202Y
Approved by : H. Mainaud Durand	***Date:*** DD/MM/202Y
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0.1	23/06/2020	1st version
0.2	11/02/2021	Adding comments from Hélène and Mateusz
0.3		

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1 INTRODUCTION

The aim of this document is to provide a description of the survey measurements conducted during the assembly steps of the DQW prototype Crab-Cavity in 2017-2018. The experience and lessons learned gained from this measurement are transcribed on this document via the proposed procedure.

This document complements the presentation « Specific case: Crab Cavities » done during the Alignment review on the 26th August 2019:

(https://indico.cern.ch/event/831552/timetable/?view=standard_inline_minutes).

2 ASSOCIATED INFRASTRUCTURES

Two main infrastructures (for survey measurements) have been used during the assembly steps of the DQW Crab-cavity:

- A trolley for the alignment of the string line (the two cavities, the valves),
- A gantry crane for the installation of the string line in the cryomodule.

2.1 Trolley

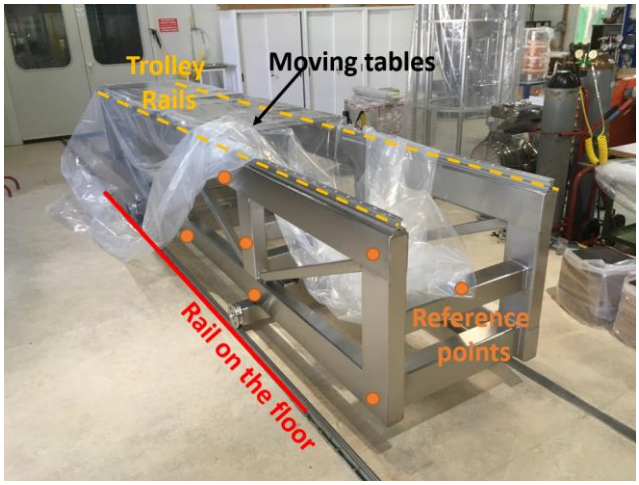


Figure 1 : Trolley for the assembly (without string line)

Figure 2 : Trolley for the assembly (with string line assembly)

2.1.1 Installation of the trolley rails

2.1.1.1 Description

The objective was to install correctly the rails of the trolley. In fact, the cavities and the valves will be installed and aligned on moving tables on the trolley rails in an ISO 5 chamber, but their connections will be done in an ISO 4 chamber, not accessible for surveyors. Longitudinal displacements will be performed along these rails up to 1 m.

Furthermore, the installation of the string line in the cryomodule will be done in a third place (below the gantry crane). These 3 places of assembly (ISO5, ISO4, below gantry crane) were linked by a linear rail with a trajectory at +/-1 mm. These different places led some constraints on the alignment on radial and vertical on the trolley path.

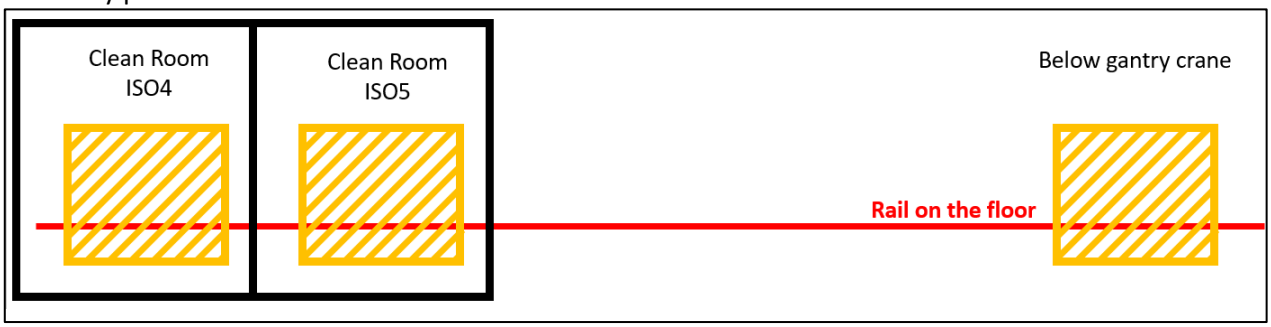


Figure 3 : The 3 places of assembly

The trajectory given by the rails of the trolley should be adjusted at +/-0.1mm with respect to a straight line (parallel to the trajectory of the rail on the floor connecting the 3 places of assembly) and the local vertical below the gantry crane (where the installation of the string line will be carried out with the cryomodule).

This measurement has been documented in EDMS report [1]

2.1.1.2 Proposed procedure

- *Install the trolley below the gantry crane, where the installation with the cryomodule will be done (at few mm on longitudinal)*
- *Mark on the floor the position of the wheels (can be useful)*
- *Measure the rail on the floor close to the wheels → definition of the trolley path: Y axis*
- *Define the vertical local (given for example by a laser tracker AT40x)*
- *Create a coordinate system:*
  - *Primary axis: axis Z: Gravity (AT401)*
  - *Secondary axis: axis Y: trolley path*
  - *Origin: on the trolley path*
- *Align the two rails of the trolley with these constraints:*
  - *Parallel to the Y axis at nominal values*
  - *In an horizontal plane (perpendicular to the vertical local)*
- *Control the trajectory of the moving plate installed on the trolley rails (+/-0.1 mm with radial and vertical)*
- *Install some reference points on the trolley and measure them with the laser tracker*
- *Install some reference points on the gantry crane (or on the floor) and measure them with the laser tracker (it will be useful for the gantry crane installation)*
- *Create a text-file with the coordinates of the reference points and the definition of the coordinate system.*
- *Create a virtual axis of the string line with an origin (has to be defined)*

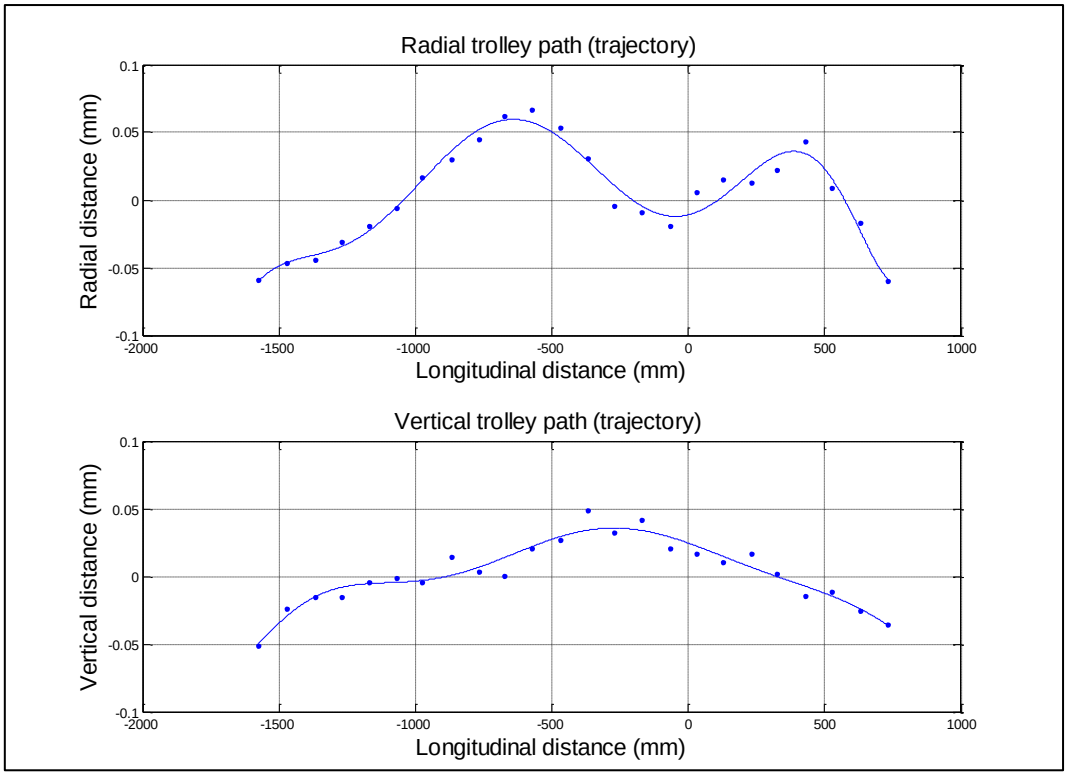


Figure 4 : radial and vertical trolley paths trajectory

2.1.2 Trolley deformation with the loads

2.1.2.1 Description

The alignment of the rails has been done without loads. It's important to validate the good performance of the trolley with a load (similar than for crab-cavities).

Figure 5 : Control of the trolley rails with loads

This measurement has been documented in EDMS report [2], [3].

2.1.2.2 Proposed procedure

- *Measure the reference points of the trolley without the loads as well as the points on the trolley rails*
- *Measure the reference points of the trolley with the loads as well as the points on the trolley rails*
- *Compare the reference points and the shape of the trolley rails*

2.1.3 Trolley deformation during the movement along the linear rail installed on the floor

2.1.3.1 Description

The trolley shall be rigid enough between the different mounting steps. The rigidity of the trolley has to be validated at different positions along the linear rail (rail on the floor or SM18 rail on the figure below).

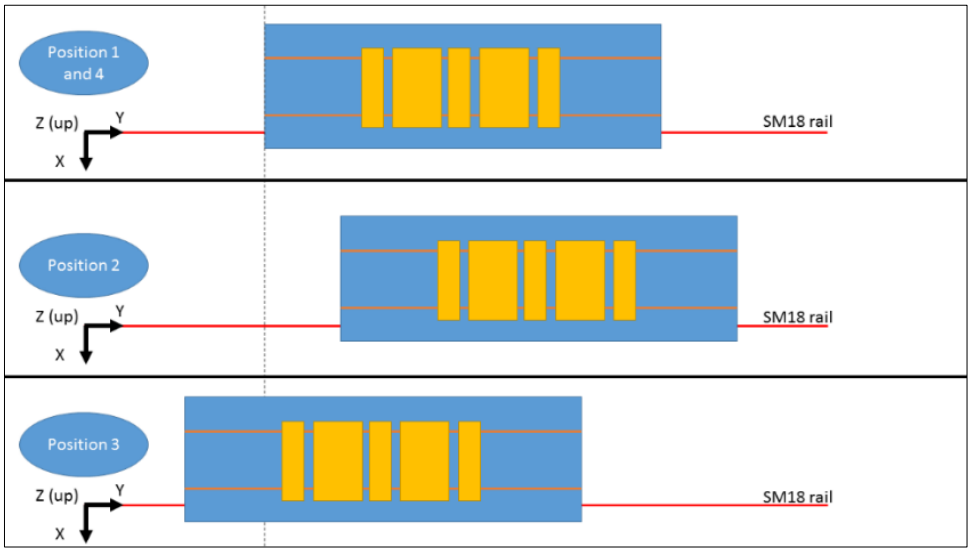


Figure 6 : Trolley positions for rigidity control

This measurement has been documented in EDMS report [4]

2.1.3.2 Proposed procedure

- *Measure the reference points of the trolley at different positions*
- *Calculate the deformation of the trolley*

2.1.4 Trolley deformation when the component on the trolley moved

2.1.4.1 Description

The trolley shall be stable when the components will be displaced on the moving plates along the trolley rails. The behaviour of the trolley has to be tested. The flexibility on the wheels can have a big impact on this test.

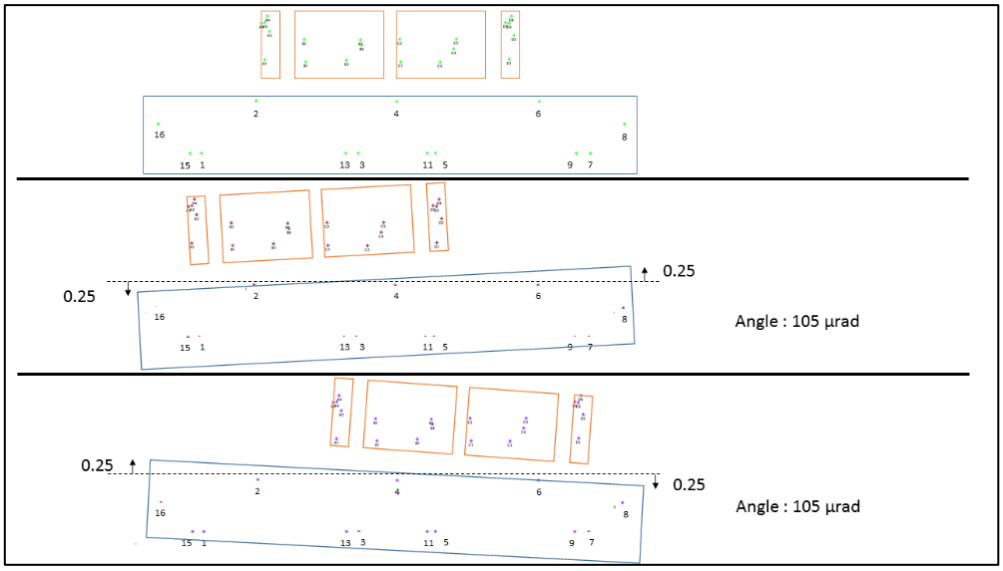


Figure 7 : Trolley deformations

This measurement has been documented in EDMS report [5]

2.1.4.2 Proposed procedure

- *Measure the reference points of the trolley at different positions of the moving table*
- *Calculate the displacement and the deformation of the trolley*

2.2 Gantry crane

2.2.1 Gantry crane installation

Different steps have been done in order to construct the gantry crane:

- Install the feet (position, rotation)
- Control of the 4 pillars (shape + rails)
- Install the pillars
- Trajectory of each pillar (vertical trajectory)

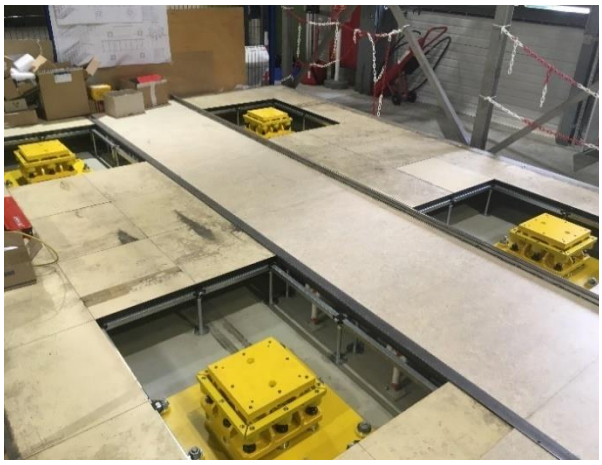


Figure 8 : gantry feet control

Figure 9 : Crane installation

2.2.2 Crane path

2.2.2.1 Description

At the end of the installation, the behaviour of the crane has to be tested. The crane path shall follow the local vertical within +/- 1 mm for 1 m of displacement. In fact, the crane will be used during the installation of the top plate as well as the installation of the string line on the cryomodule. During these two steps, the components must not collide together.
The components on the trolley will be installed in a horizontal plane. So, the crane path shall move along the gravity (perpendicular to horizontal plane).

Figure 10 : Crane installation

Figure 11 : Crane path control vs trolley

2.2.2.2 *Proposed procedure*

- *Measure the crane at different positions in order to define its trajectory*

2.2.3 *Radial and longitudinal position of the hoist (for the top plate)*

2.2.3.1 *Description*

The top plate support will be held by the hoist. The hoist was equipped with 12 holes (12 roots will be installed) in order to support the top plates. The position of the top plate shall be coherent with the string line assembly. Some reference points on the floor or on the crane have been installed during the definition of the string line on the trolley. The position of the string line can be estimated. The top plate will be fixed on the hoist by 12 roots. The position of these roots (or the holes of the roots) can be adjusted within a few tenths of millimetres.

Figure 12 : Position of the hoist for the top plate

2.2.3.2 *Proposed procedure*

- *Measure the reference point on the floor or on the crane in order to reconstruct the nominal string line position*
- *Install the hoist at the nominal height (at few mm on vertical)*
- *Adjust the holes of the top plate support at their nominal position within a few tenths of millimetres*

3 ASSEMBLY OF THE CRAB CAVITIES

3.1 Determination of the mechanical axis

The determination of the mechanical axis of the cavities came from metrology measurements performed after several installation steps. The position of the mechanical axis is determined from the average position of the two internal faces of the cavity (in black). The position of this axis is compared with the axis constructed by the 2 extremities flanges (in red).

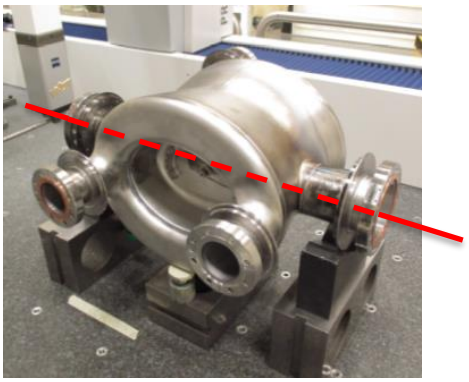


Figure 13 : Axis from extremity flanges

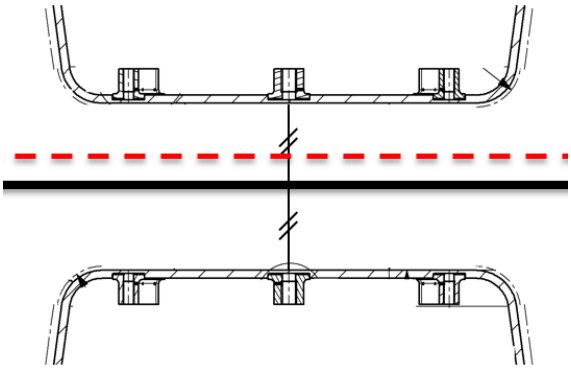


Figure 14 : Cavity reference axes

The below table details the different positions of the mechanical axis with respect to the 2 extremities flanges after several installation steps.

Tableau 1 : Mechanical axis position of the cavities

	Cavity 1	Cavity 2
Before treatment	-0.691	-0.291
After treatment	-0.673	No metrology
After tunning	-0.661	-0.165
Capacitive plate : Pins check	-0.553	No metrology
After tank welding	**-0.557**	**-0.040**

3.2 Fiducialisation of the dressed cavities

After the installation of the cavities inside their TANK, the dressed cavities have been measured by the metrology workshop. The mechanical centers of the 2 extremities flanges have been measured with respect to the FPC, Coupler, Tuner. The FSI targets used later for the internal monitoring of the dressed cavities inside the vacuum vessel have also been measured with some external targets installed on the dressed cavities in order to facilitate next measurements by a laser tracker during the assembly step.

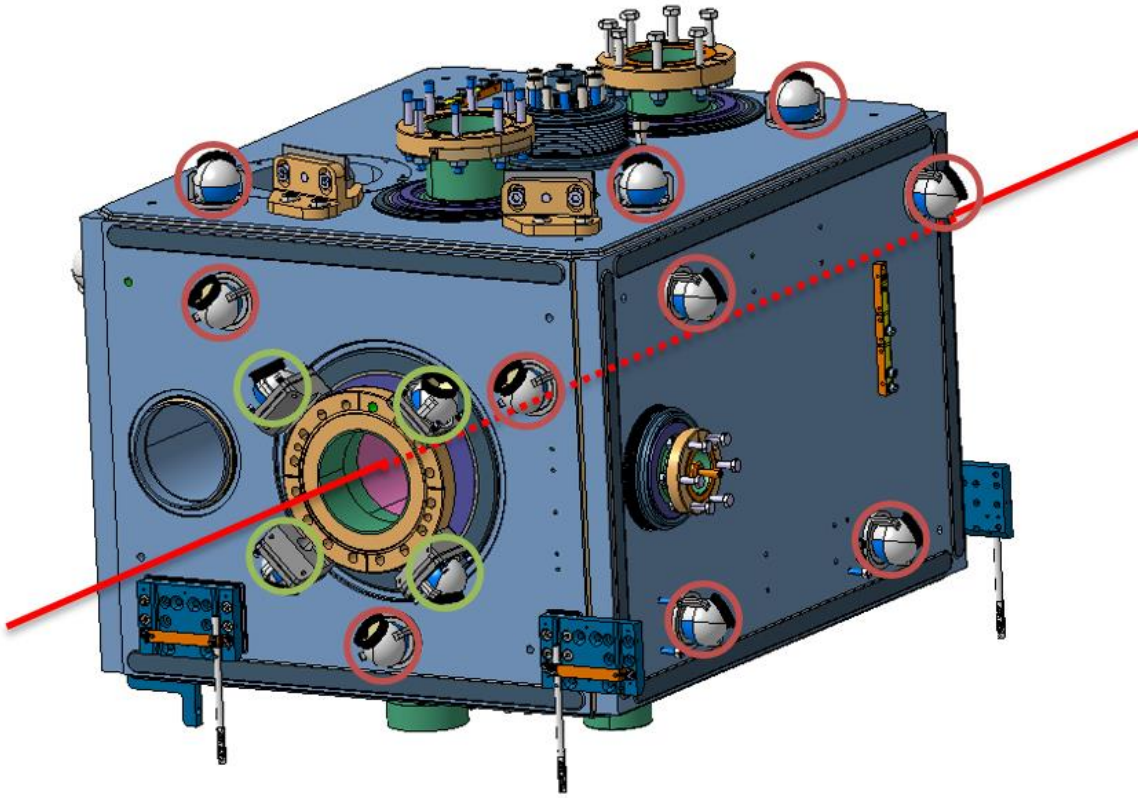


Figure 15 : Dressed cavity with external fiducials (in red) and FSI targets (in green)

This measurement has been documented in EDMS report [6] [7].

3.3 String line assembly

3.3.1 Alignement before assembly

3.3.1.1 Description

The two dressed cavities have been installed on the trolley as well as 2 vanes. The alignment of these four components has been done in Clean Room ISO 5 with a laser tracker. Their mechanical axis should be aligned at 0.1 mm.

Figure 16 : Alignment before assembly

This measurement has been documented in EDMS report [8]

3.3.1.2 Proposed procedure

- *Measure the reference point installed on the trolley in order to reconstruct the virtual axis of the string line*
- *Measure the reference point of the dressed cavities in order to reconstruct the mechanical axis of each dressed cavity.*
- *Measure the centre of each valve*
- *Adjust the position of the dressed cavities and the valves at their nominal positions within 0.1 mm*

3.3.2 Alignment after the assembly of the string line in ISO4

3.3.2.1 Description

The dressed cavities and the valves have been connected. A control in the alignment has been done in order to see if all the components are at their theoretical position.
This measurement has been documented in EDMS report [9]

3.3.2.2 Proposed procedure

- *Measure the reference point installed on the trolley in order to reconstruct the virtual axis of the string line*
- *Measure the reference point of the dressed cavities in order to reconstruct the mechanical axis of each dressed cavity.*
- *Measure the centre of each vane*
- *Control the alignment*

3.3.3 Impact of the vacuum on the string

3.3.3.1 Description

The first vacuum test has been done in the clean room ISO 5. The displacement of the string line has been measured with a laser tracker.

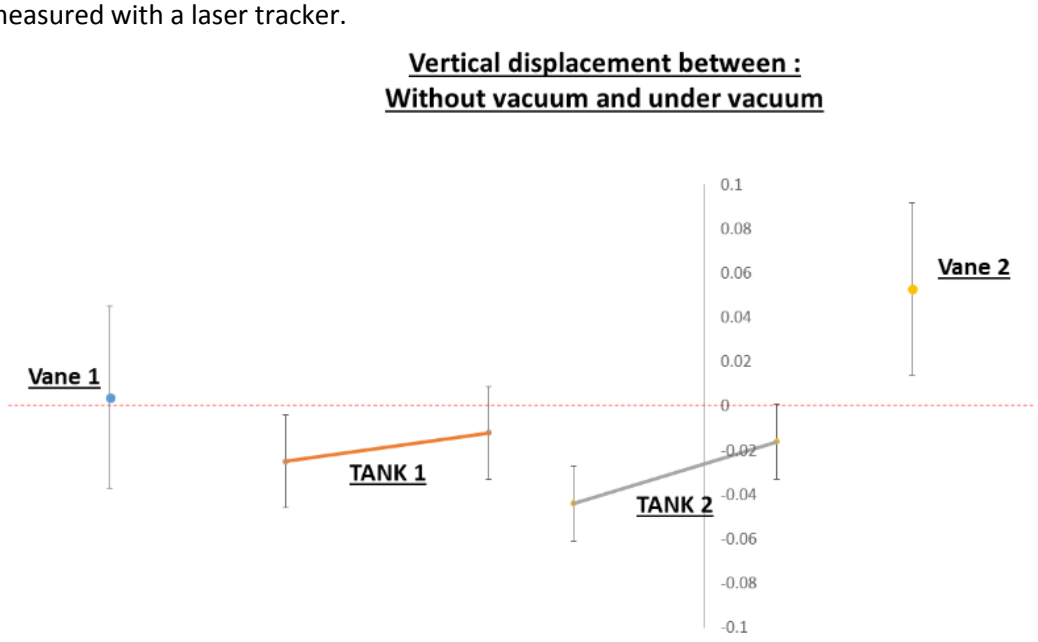


Figure 17 : Impact of vacuum on the string line

This measurement has been documented in EDMS report [10]

3.3.3.2 Proposed procedure

- *Measure the reference point installed on the trolley in order to reconstruct the virtual axis of the string line*
- *Measure the reference point of the dressed cavities in order to reconstruct the mechanical axis of each dressed cavity.*
- *Measure the centre of each vane*
- *Control the difference between ambient pressure and under vacuum*

3.4 Installation of the others components on the string line

Once the string line assembly has been carried out in a clean room, several components as cryogenic line or oblong bellows plate have been installed. Some survey measurements have been done in order to follow the proper installation of different components within a millimeter accuracy.

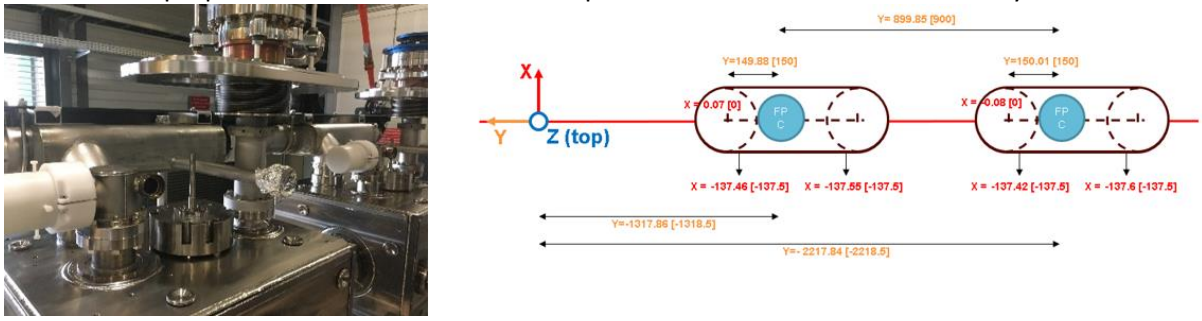


Figure 18 : Installation of others components of the string line

This measurement has been documented in EDMS report [11], [12]

3.5 Final alignment of the string line

3.5.1.1 Description

A final alignment has been done just before the installation of the top plate. The alignment should be done at 0.1 mm.

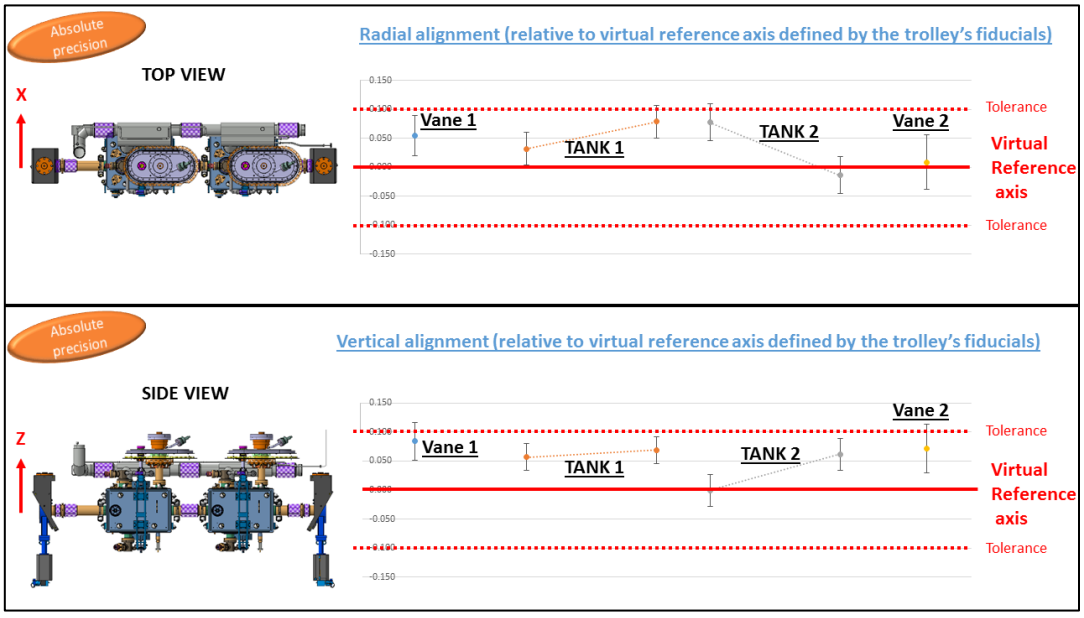


Figure 19 : Final alignment of the string line

This measurement has been documented in EDMS report [13]

3.5.1.2 Proposed procedure

- *Measure the reference point installed on the trolley in order to reconstruct the virtual axis of the string line*
- *Measure the reference point of the dressed cavities in order to reconstruct the mechanical axis of each dressed cavity.*
- *Measure the centre of each valve*
- *Adjust the position of the dressed cavities and the valves at their nominal positions at 0.1 mm*

3.6 Installation of the top plate (supporting plate of the string line)

3.6.1.1 Description

Before the installation of the top plate on the crane, a geometrical control on the plate has been done, especialy on the position of the 2 oblong holes with respect to the two extremity points

The top plate has been fixed on the hoist of the crane by the 12 roots and the trolley has been installed at its nominal position (mark on the floor during the step 2.1). A final adjustment of the top plate position has been carried out within 0.2 mm in order to fit with the position of the string line. The trajectory of the gantry crane and the postion of the oblong TANK have to be taken into account.

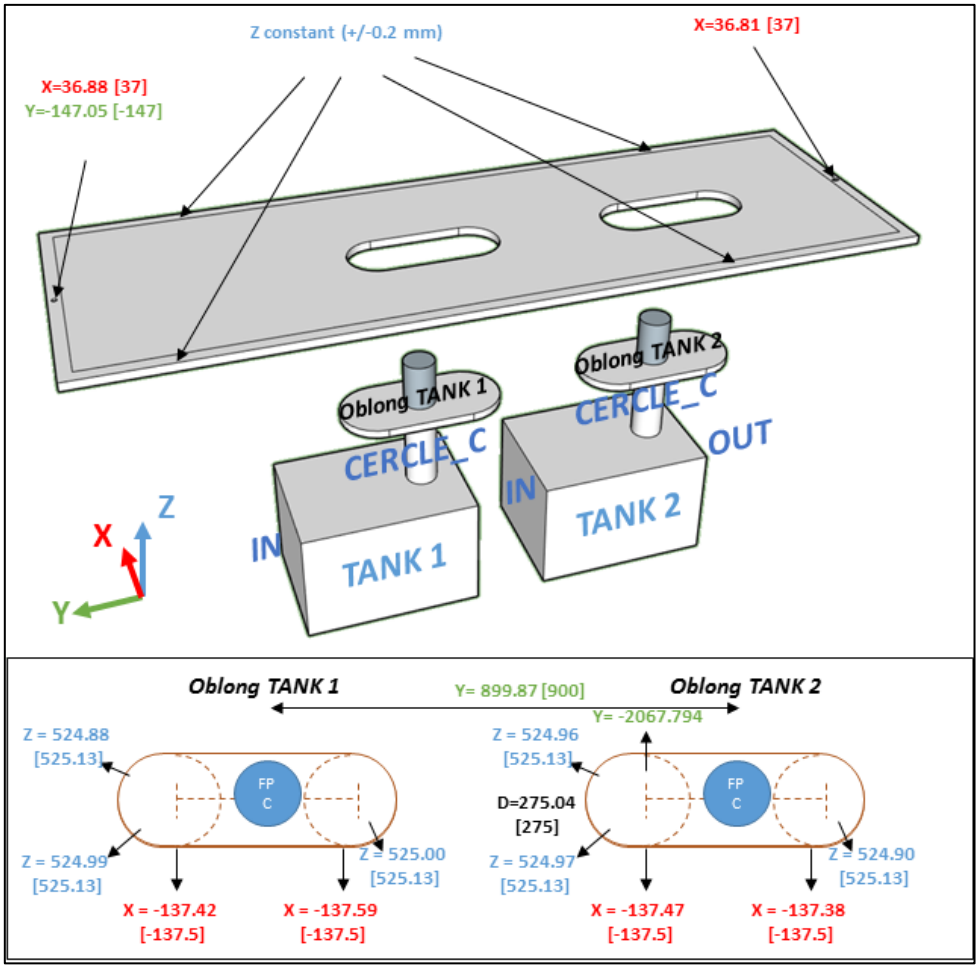


Figure 20 : Installation of the top plate

This measurement has been documented in EDMS report [14]

3.6.1.2 Proposed procedure

- *Measurement of the top plate (position of the oblong holes and the extremities points)*
- *Install the top plate on the crane*
- *Install the trolley at its nominal position (mark on the floor during the step 2.1)*
- *Adjust the top plate position in order to fit the oblong tank and the oblong hole within a few tenths of millimetre*

3.7 Insertion of string line in the cryomodule

3.7.1.1 Description

Once the string line and the top plate are connected, the installation of the string line in the cryomodule is performed. A final adjustment of the top plate position (supporting the string line) is performed within a 0.2 mm accuracy in order to fit with the position of the cryomodule.

Figure 21 : Insertion of the string line inside the cryomodule

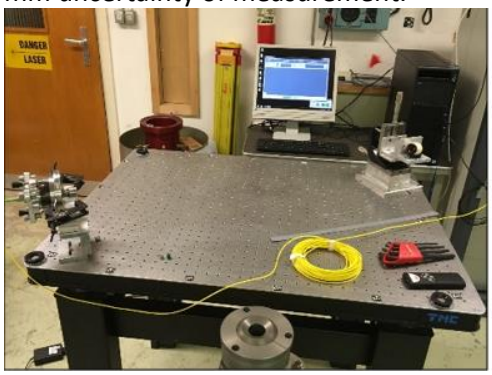
3.7.1.2 Proposed procedure

- *Measure the top plate (position of the extremities points)*
- *Install the cryomodule at its nominal position (mark on the floor during the step 2.1)*
- *Adjust the top plate position in order to fit the extremities points of the top plates and the points on the cryomodule within a few tenths of millimetre*

4 INSTALLATION OF THE MONITORING SYSTEM: FSI SYSTEM

4.1 Calibration of FSI heads

The FSI head contains the focal point of the collimator (“zero point”). The calibration consists of the determination of the focal point with respect to external references on the feedthrough within a 0.015 mm uncertainty of measurement.



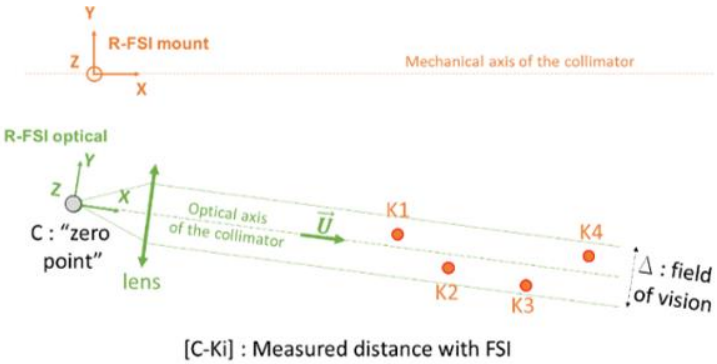


Figure 22 : Calibration of FSI heads

4.2 Installation of FSI feedthrough on the cryomodule

4.2.1.1 Description

After the installation of the feedthroughs on the cryomodule, the position of each focal point can be deduced from the position of the external references on each feedthrough within a 0.02 mm accuracy.

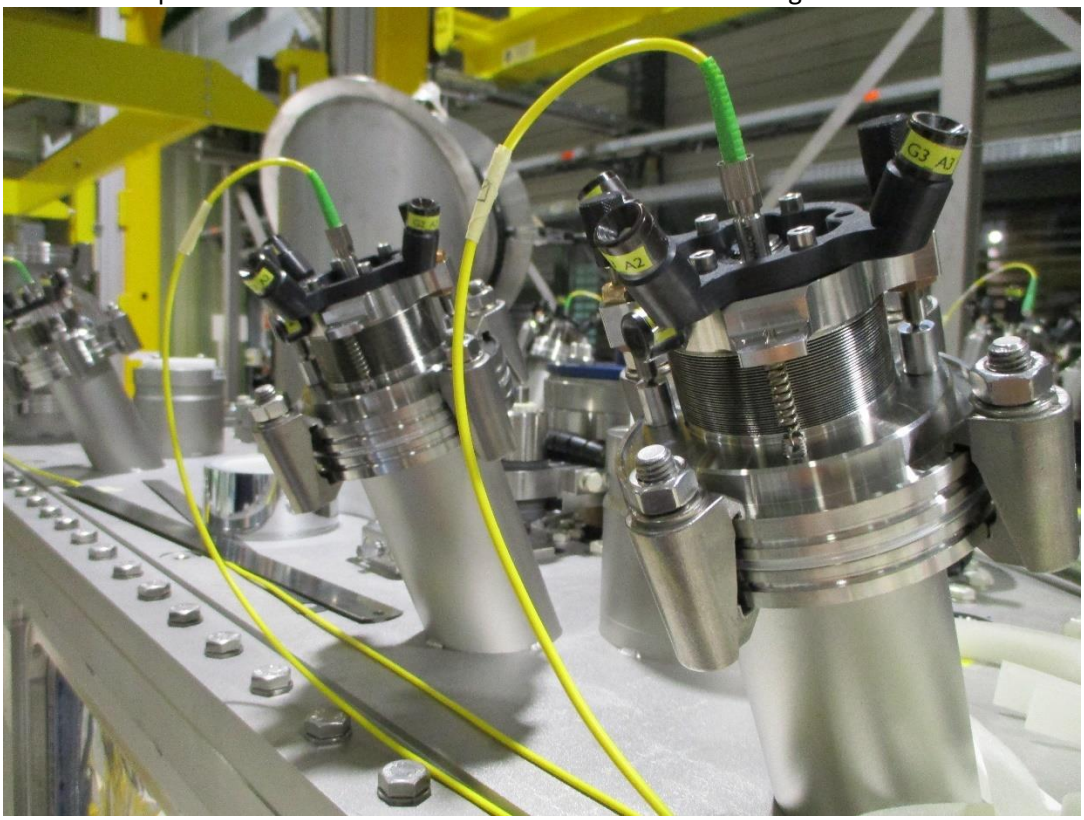


Figure 23 : FSI feedthroughs

4.2.1.2 *Proposed procedure*

- *Measure the top plate installed on the cryomodule (position of the extremities points and vertical orientation of the top plate)*
- *Construct the coordinate system of the top plate + cryomodule*
- *Measure the external references for each feedthrough*

4.3 Installation of FSI targets

4.3.1.1 *Description*

The FSI targets are fragile and shall be installed at the end of the installation. A measurement of the FSI targets and the targets installed on the dressed cavities is performed in order to control their position.

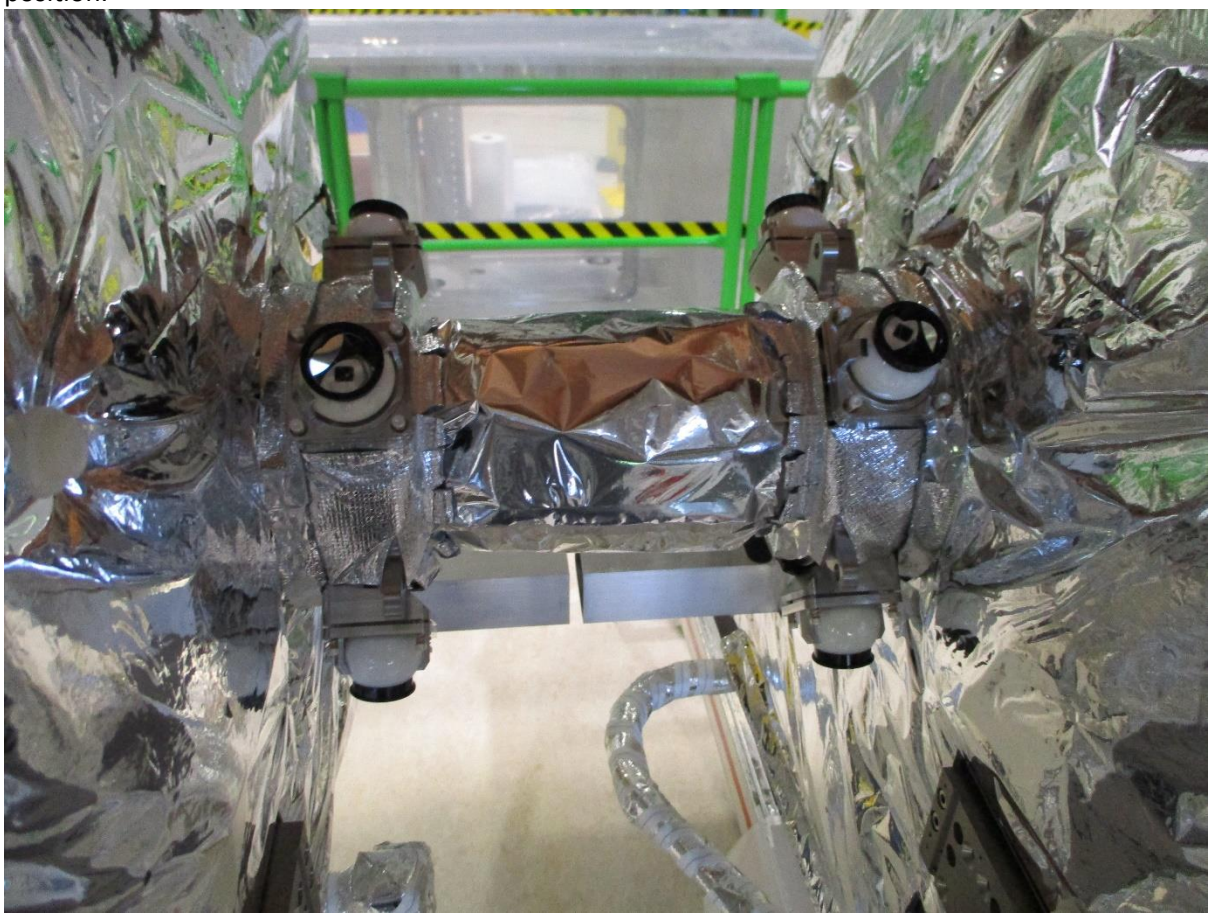


Figure 24 : FSI targets

This measurement has been documented in EDMS report [15]

4.3.1.2 *Proposed procedure*

- *Measure the external points installed on the dressed cavities for laser tracker measurement*
- *Construct the coordinate system of the dressed cavities*
- *Measure the FSI targets*

5 VALIDATION AT WARM CONDITION, UNDER VACUUM AND COLD CONDITION

5.1 Installation of an alternative monitoring system (BCAM system)

An alternative monitoring system has been installed in order to cross-check the FSI measurement.

Figure 25 : BCAM system

5.2 Validation at warm condition

A comparison has been done at warm condition between 3 different alignment system. The position of the dressed cavities inside the cryomodule has been calculated by a laser tracker, the FSI monitoring system and the BCAM monitoring system. The difference observed were below 0.050 mm which is less than the accuracy of the determination of the position of the dressed cavities inside the cryomodule for the 3 alignment systems.

Figure 26 : Inter-comparison of the crab cavities position

This measurement has been documented in EDMS report [16]

5.3 Impact of vacuum on the string

Several measurements at ambient pressure and under vacuum have been done. The table below shows the impact of vacuum on the jumper, the cryomodule, the couplers and the dressed cavities.

This measurement has been documented in EDMS report [17], [18].

Tableau 2 : Impact of vacuum on the string

Impact of vacuum on the jumper	Up to 0.3 mm
Impact of vacuum on the cryomodule	Up to 0.7 mm
Impact of vacuum on the couplers	Up to 0.2 mm
Impact of vacuum on the dressed cavities	Up to 0.2 mm

5.4 Impact of the transport of the cryomodule on the alignment of the string line

The position of the dressed cavities inside the cryomodule is measured before and after transport. The displacements observed were below 0.050 mm.

5.5 Validation at cold condition

The position of the dressed cavities inside the cryomodule has been calculated at cold condition by the FSI monitoring system and the BCAM monitoring system. The offsets observed were below 0.050 mm which is less than the accuracy of the determination of the position of the dressed cavities inside the cryomodule for the 2 alignment systems.

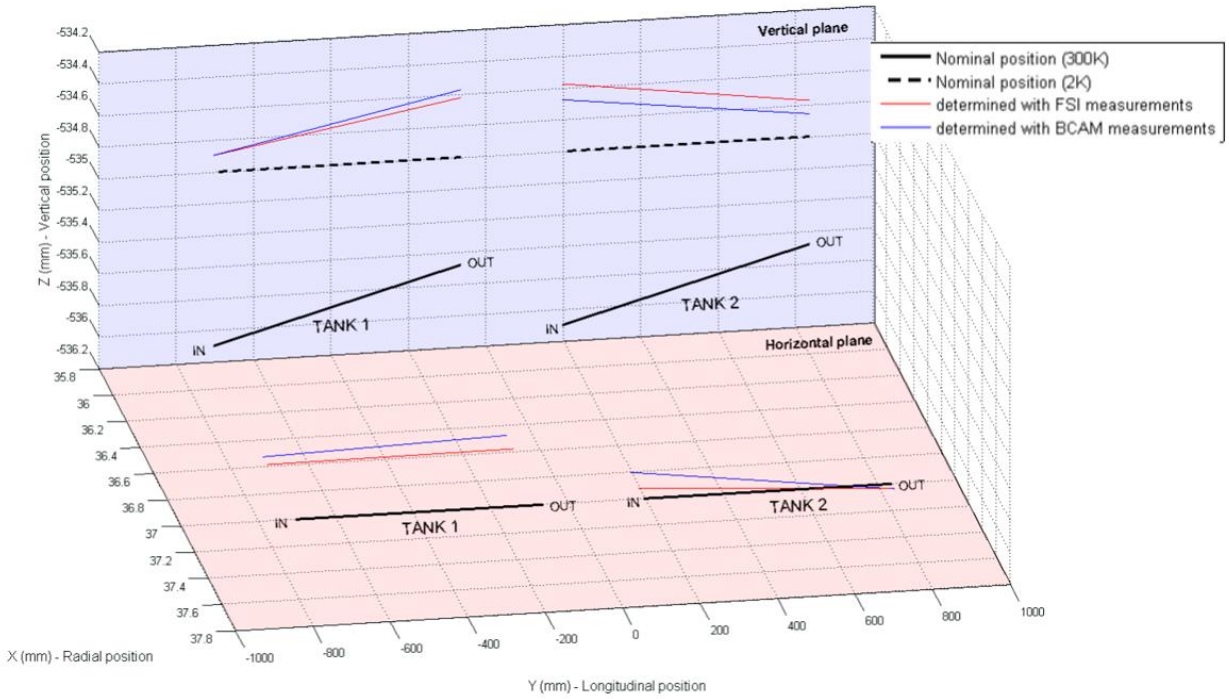


Figure 27 : Intercomparison of crab cavities position at cold condition

6 INSTALLATION OF DQW PROTOTYPE IN SPS TUNNEL

6.1 Definition and determination of a local network

A local coordinate system has been created in order to facilitate the installation of the cryomodule in the SPS tunnel. The nominal beam axis has been extrapolated from the quadrupoles QDA.61710 and QFA.61810 installed before and after the Crab-cavities area in the SPS tunnel. An uncertainty on the beam axis of the order of ±0.15 mm (1σ) has been estimated.

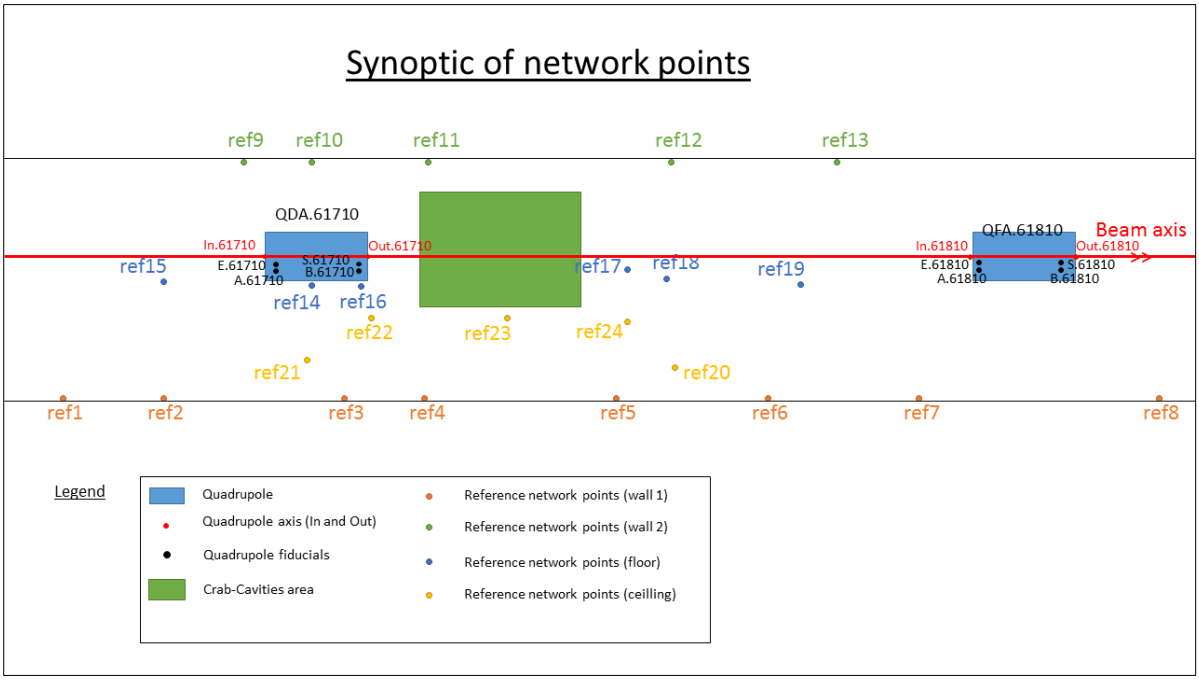


Figure 28 : Local network in SPS tunnel

This measurement has been documented in EDMS report [19]

6.2 Implantation and marking

The position of the table installed below the cryomodule and several other components is marked on the floor with a millimetric accuracy.

This measurement has been documented in EDMS report [20]

Figure 29 : Implantation and marking in SPS tunnel

6.3 Validation and installation of SPS tunnel table

The validation of the behaviour of the SPS tunnel table has been performed in Spain, prior to its transfer to CERN. Some additional measurements have been carried out during the installation of the table in the SPS tunnel as a final validation.

This measurement has been documented in EDMS report [21]

Figure 30 : Transfer table

6.4 Installation of cryomodule

The cryomodule has been installed at its nominal position within a 0.1 mm accuracy with respect to the SPS beam.

This measurement has been documented in EDMS report [22]

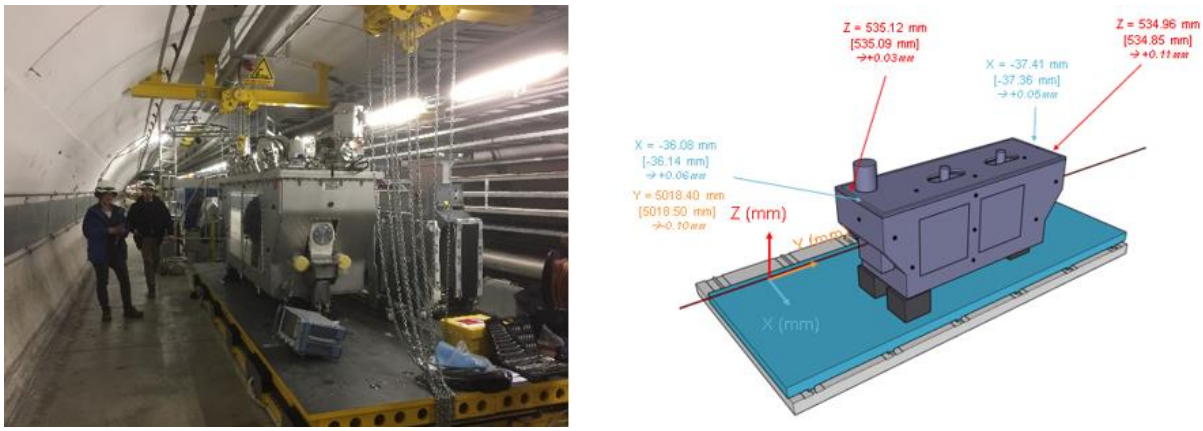


Figure 31 : Installation of the cryomodule

6.5 Alignment of the dressed cavities with respect to SPS beam

This step has not yet been performed (2020). The position of the dressed cavities inside the cryomodule was not modified since the vacuum test.

6.6 Long term follow up

During the last operation year of the crab-cavities, a follow up has been done. Several thermal cycles took place and showed a repeatability of the position of the dressed cavities inside its cryomodule within 20 µm.

This measurement has been documented in EDMS report [23]

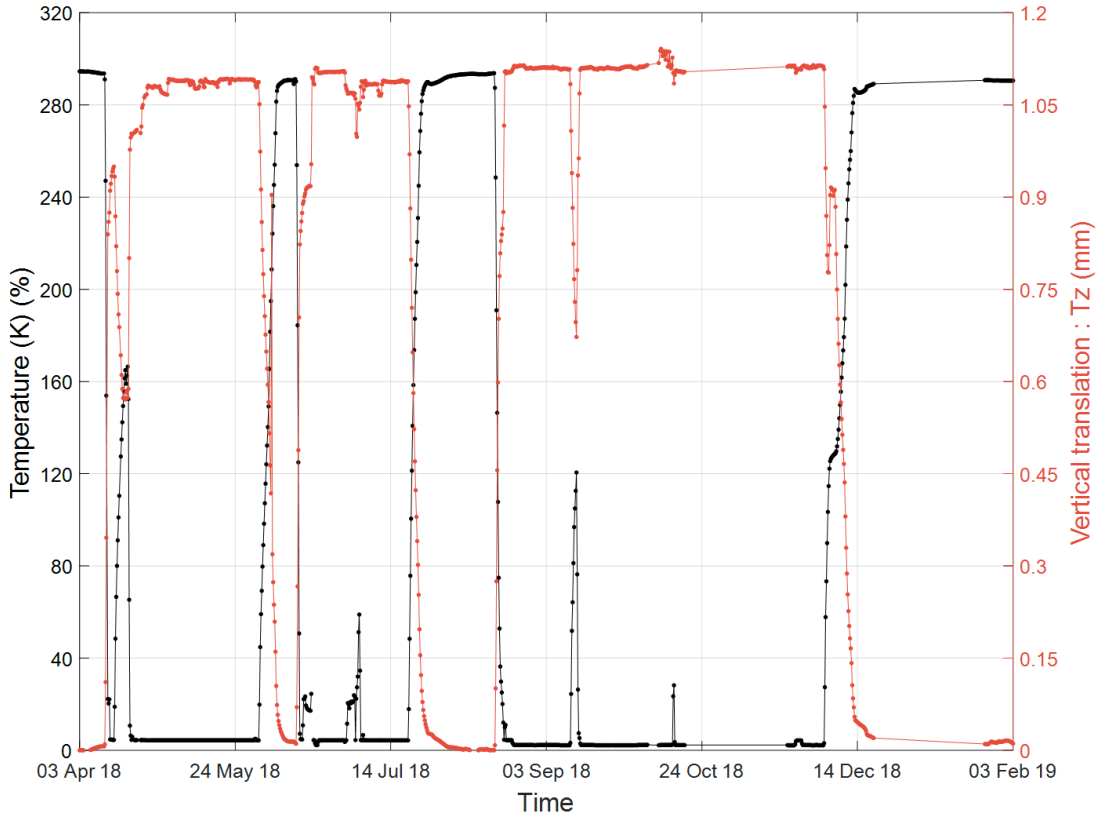


Figure 32 : Vertical translation and internal temperature between April 2018 and February 2019

7 FIGURES

8 REFERENCES

[1] R. Vivien, «Installation of the trolley rails, EDMS : 1835996,» 2017-07-05.

[2] R. Vivien, «Trolley deformation with the loads, PART 1, EDMS : 1835997,» 2017-07-20.

[3] R. Vivien, «Trolley deformation with the loads, PART 2 , EDMS : 1835998,» 2017-08-01.

[4] R. Vivien, «Trolley deformation during the movement along the linear rail installed on the floor, EDMS : 1835998,» 2017-08-02.

[5] R. Vivien, «Trolley deformation when the component on the trolley moved, EDMS : 1835998,» 2017-08-03.

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