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BiFrost Spectrometer Vessel and Motion System for DTU Physics
Technical University of Denmark

FAT Motion Test Plan
N056.TES.020.v1

REVISION	DESCRIPTION	REVISION DATE
WRITTEN / REDACTADO:	NAME / NOMBRE: PEDRO NOGUERA	DATE / FECHA: 20/10/20
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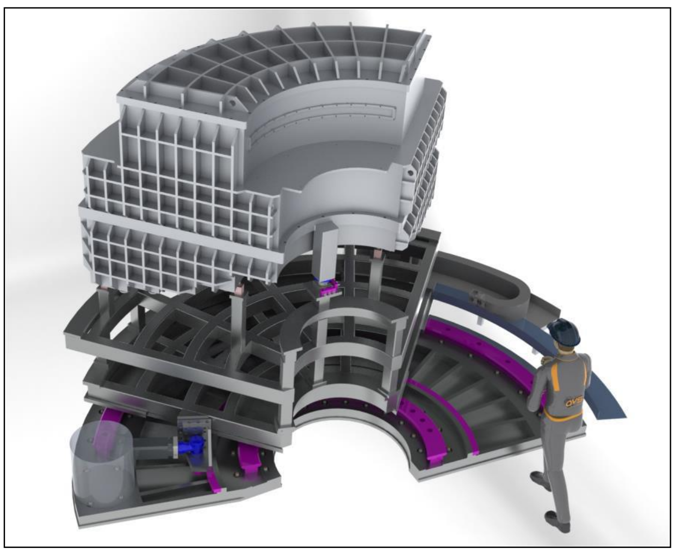
Reference documents

Code	Description	Issue date (dd/mm/yyyy)	Comments
Appendix 1 – Technical specifications.pdf	Specifications	15/06/2019	

Introduction

The BiFrost Spectrometer Vessel is a 2m x 3.5m aluminium vacuum chamber that will contain sensors for neutron spectroscopy at ESS. It will be mounted on a rail system so that it can rotate in the horizontal plane. The motion system will be tested by ADDED VALUE SOLUTIONS both at Elgoibar and once installed at the facility in Sweden.

The motion system must pass quality test during its installation at the suppliers facilities. This procedure is described below.



A general overview of the BiFrost vessel.

Testing conditions

- All tests will be conducted with the complete assembly (including vessel)

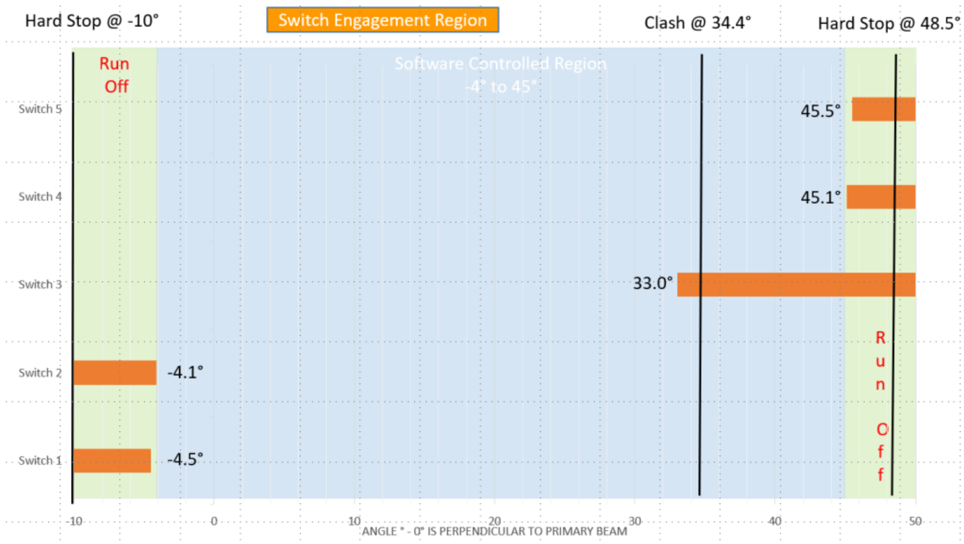
- Additional weight will be added to allow the assembly to be tested in the same conditions as when during operations. The weight to be added is 7.5 tonnes.
- All the motion tests shall be conducted using the cables and the ESS motion control test crate provided by DTU. DTU shall be responsible for the shipping and subsequent operation of the test crate during the tests
- All motion tests shall be conducted in open loop control with recording of the target position, the corresponding encoder reading and the reading of the external measuring device.
- All tests with the exception of the Torque reduced motion test shall be performed with the nominal current of the stepper motor

Acceptance criteria

- The motion system shall meet the requirements as specified in the table below. This includes but is not limited to;
  - The encoder shall provide a read-out throughout the full range of motion.
  - The accuracy and repeatability shall be tested at varying points along the full range of motion. This shall be proven by the use of surveying equipment, not just the encoder readout.
  - The speed shall be tested by translating the assembly through the entire range of motion within the time specified.
  - All limit switches shall be triggered to ensure they function and switch at the proper position.

Positional accuracy	0.1 degrees
Positional repeatability	0.05 degrees
Resolution	0.01 degrees
Motion range	Central axis to rotate from -4.5 degrees through to 45.5 degrees (0 degrees is perpendicular to the sample position)
Max speed	0.1 s^{-1}
Travel time	The assembly shall travel through the range of motion within 15 minutes
Mass of Final Assembly	Mass of tendered components + 7.5 Tonnes
Magnetic Environment	See section 3.5.3 of the Technical Specifications
General Mode of Operation	To move through the range of motion in 5 degrees segments, remaining stationary at each stop for over an hour
Switching Positions	Switches S1 to S5 according to figure below
Switching Accuracy	0.1 degrees

The following graphic shows the position of the limit switches and kill switches.



Graphic: position of the limit switches in the system

Preparatory work

1. The bench will be lying on the floor supported on the feet and anchored to the slab either as foreseen in the design or clamped with lateral holders.
2. The frame will be assembled to the bench on rails and perfectly aligned in such a way that a swift movement is guaranteed.
3. The motorization and encoder system will mechanically assembled, coupled to the chain and cabled to the control system through the energy chain. The system will be controlled and read out using ESS motion control test crate provided by DTU
4. The vessel will be supported on the kinematic mounts and adjusted in such a way that its origin defined by the machined surfaces and located at the theoretical sample position will be placed on the turning axis.

Setup

Measuring equipment

In order to measure angular position of the system, a laser tracker will be used.

Model: Leica AT403

Serial number: 394661

Calibration date: 14-08-2020

Certificate of calibration: 7020-20200814

Laser trackers are instruments that accurately measure large objects by determining the positions of optical targets held against those objects. The accuracy of laser trackers is of the order of 0.025 mm over a distance of several metres. Some examples of laser tracker applications are to align aircraft wings during assembly and to align large machine tools. To take measurements the technician first sets up a laser tracker on a tripod with an unobstructed view of the object to be measured. The technician removes a target from the base of the laser tracker and carries it to the object to be measured, moving smoothly to allow the laser tracker to follow the movement of the target. The technician places the target against the object and triggers measurements to be taken at selected points, sometimes by a remote control device. Measurements can be imported into different types of software to plot the points or to calculate deviation from the correct position

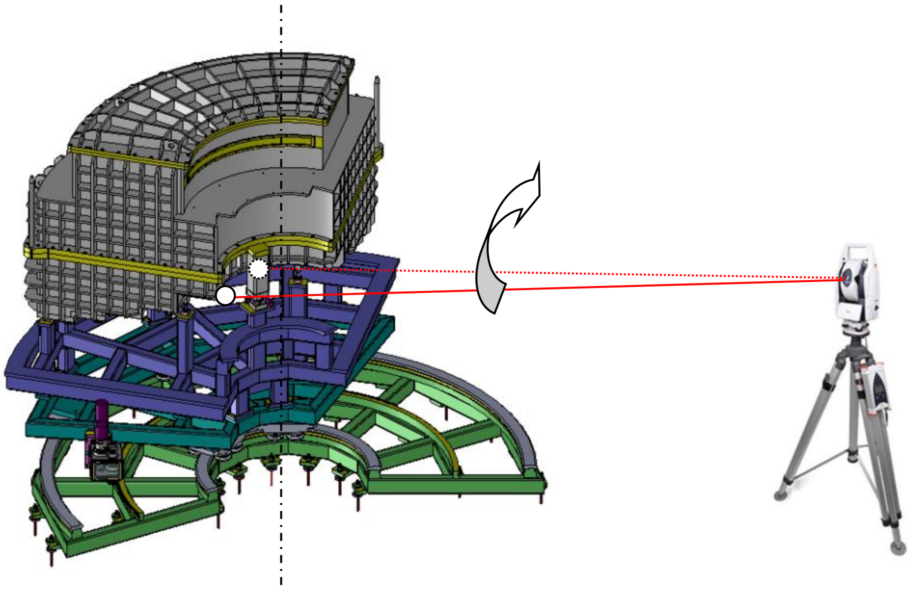
The targets are known as "retro reflective" because they reflect the laser beam back in the same direction it came from (in this case, back to the laser tracker). One type of target in common use is called a spherically mounted retroreflector (SMR), which resembles a ball bearing with mirrored surfaces cut into it.

In order to measure linear displacements, the targets are fixed to the moving part and the measuring head placed on a tripod on the ground. As this system provides the coordinates in the three axes, it is not necessary to align the hardware, but just to define a proper reference system based on the system’s motions. Both the displacements in the direction of the axis and errors in the transversal directions can be controlled as soon as the requested precision is not too high.

Measuring setup

In order to measure the angular position of the system:

1. a laser tracker marker will be fixed to the vessel at one of the fidutial points
2. by measuring several positions within the range, a vertical axis will be defined
3. the coordinate system will be moved to this vertical axis, so that the (0,0,0) will be at the position of one of the limit switches
4. any new position will be measured and the angle deduced from the Cartesian coordinates.



Motion test

Test summary

The tests will consist of:

1) Motion and travel tests
   a) Position switches activation test
   b) Motion range test
   c) Torque reduced motion test
   d) Travel with high speed (travel time test)
   e) Travel with low speed (single step)
2) Positioning error tests
   a) Unidirectional positioning test (accuracy)
   b) Bidirectional positioning test (repeatability with backlash)

1a. Limit switch activation test

The five switches are actuated manually. The proper function and wiring is either checked with the input control LED of the motion control system or with the help of a continuity tester. Actual switching positions will be checked later in the motion range test.

For the anticollision switch (S3), the continuity tester will be used.

Test conditions

Measuring device	***Not applicable***
Measurement position	***Not applicable***
Environment	***Ambient conditions***
External loads	***Manual actuation***
Control setup	***ESS motion control test crate***
Driver setup	***Not applicable***
Motor parameters	***Not applicable***

1b. Motion range test

The system is moved from one end position (hard stop) to the other and back. The position of the hard stops and the bidirectional switching positions of the switches S1 to S5 is recorded as described above (motor position, encoder position, external measurement position).

The system will reduce its speed some degrees before reaching the limit switch so that the deceleration ramp does not affect the position measurement.

The flags for the actuation switches shall be adjusted to fulfil the associated acceptance criteria above. The activation points shall be listed in a table together with the approximate location of the flag within the adjustment range (in mm).

Test conditions

Measuring device	***Laser tracker, encoder***
Measurement position	***Chamber Fidutial Point***
Environment	***Ambient conditions***
External loads	***7.500 kg load attached to the system***
Control setup	***ESS motion control test crate (open loop)***
Driver setup	***Normal step size***
Motor parameters	***Default: nominal speed.***

1c. Torque reduced motion test

The system is moved between the switches S1 and S5 with a stepper motor current reduced to 50% of the nominal current. With the reduced torque the system shall travel over the full range with any loss of steps.

The aim is to confirm the safety margin of >1.7 in the torque calculations (requirement C4.3)

Test conditions

Measuring device	***Laser tracker, encoder***
Measurement position	***Chamber Fidutial Point***
Environment	***Ambient conditions***
External loads	***7.500 kg load attached to the system***
Control setup	***ESS motion control test crate (open loop)***
Driver setup	***Normal step size***
Motor parameters	***Default: nominal speed.***

1d. Maximum speed test (travel time test)

The system is moved from one limit switch (S1) to the other one (S5) and the traveled distance is measured. The time lapse between both positions is also controlled in order to obtain the total average speed.

Temperature is also monitored in order to avoid undesired motor overheating.

If so requested by the client, the position can be recorded periodically along the travel range in order to obtain a more precise speed curve, but this is not done by default.

Test conditions

Measuring device	***Not necessary***
Measurement position	***Not necessary***
Environment	***Ambient conditions***
External loads	***7.500 kg load attached to the system***

Control setup	***ESS motion control test crate (open loop)***
Driver setup	***Normal step size***
Motor parameters	***Default: nominal speed.***

1e. Travel with low speed (single step)

The system is moved in the middle of the travel range over a short distance in single steps with a very low speed. This is to understand the break-away behavior of the system and the possible loss of steps during the ramp up of positioning. The range shall be 200 steps with a speed of one step per 2s. For each step both, the encoder position and the position according to the external measuring device shall be recorded.

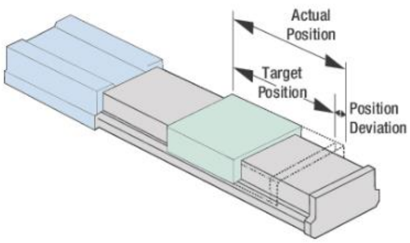
In order to synchronize the laser tracker measurements and the encoder measurements / motor signals, an absolute time scale will be used.

Test conditions

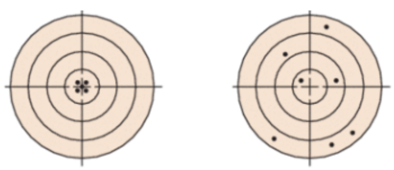
Measuring device	***Laser tracker, encoder***
Measurement position	***Chamber Fidutial Point***
Environment	***Ambient conditions***
External loads	***7.500 kg load attached to the system***
Control setup	***ESS motion control test crate (open loop)***
Driver setup	***Normal step size***
Motor parameters	***Default: nominal speed.***

2a. Positional accuracy test

The accuracy of a moving axis is defined as the closeness of agreement between a test result and the accepted reference value.



The objective of this test is to obtain an average of the measurements as close as possible to the target value, which is either defined by the measuring device.



Both measurements show a good accuracy.

Test description

The system is actuated 10 times in the same direction up to 10 selected target positions along the travel range, covering the full travel. The measuring device measurements are compared with the encoder position and the target positions.

The agreed target positions are as follows:

Position	Absolute position (laser tracker)	Target position (no. steps)	Encoder position
Start position	-5 degrees	0 steps	0,00mm
P01	0 degrees	48464 steps	189,37mm
P02	5 degrees	96929 steps	378,74mm
P03	10 degrees	145393 steps	568,10mm
P04	15 degrees	193858 steps	757,47mm
P05	20 degrees	242322 steps	946,84mm
P06	25 degrees	290787 steps	1136,21mm
P07	30 degrees	339251 steps	1325,58mm
P08	35 degrees	387716 steps	1514,95mm
P09	40 degrees	436180 steps	1704,31mm

Test conditions

Measuring device	***Laser tracker***
Measurement position	***Vessel Fidutial Point***
Environment	***Ambient conditions***
External loads	***7.500 kg load attached to the system***
Control setup	***Close loop***
Driver setup	***Normal step size***
Motor parameters	***Nominal speed***

2b. Positional repeatability test

The bidirectional repeatability is the error between a number of successive attempts to move the system to the same position but from two different directions.

The bidirectional repeatability is defined as the standard deviation of the measured values.

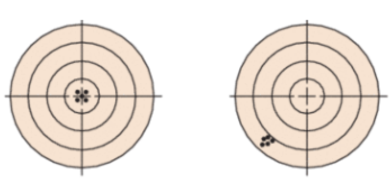
$$R_i = \max.\left[2s_i \uparrow + 2s_i \downarrow + |B_i|; R_i \uparrow; R_i \downarrow\right]$$

Being B_i the backlash,

$$B_i = \bar{x}_i \uparrow - \bar{x}_i \downarrow$$

Where $s_i\uparrow$ and $s_i\downarrow$ are the estimators unidirectional repeatability of the system at a position i from each direction, $R_i\uparrow$ and $R_i\downarrow$ are the unidirectional repeatability at this position from each direction and $\bar{x}_i \uparrow$ and $\bar{x}_i \downarrow$ are the average positions from each directin.

As for the unidirectional repeatability, the objective of this test is to obtain the smallest dispersion of measurements without taking into account how close this is to the target value. However, it takes into account the reversal error and in particular the backlash of the system.



Both measurements show a good repeatability.

Test description

The system is actuated 10 times up to one selected position and back. The position will be defined by a number of steps (open loop) or by the encoder (close loop).

After this, the is actuated 10 times up to the same position but coming from the other direction and then back.

The bidirectional repeatability is determined from the values obtained as explained in the previous section.

This test will be repeated several times at different positions defined by the client.

The agreed target positions are as follows:

Position	Absolute position (laser tracker)	Target position (no. steps)	Encoder position
Start position	-5 degrees	0 steps	0,00mm
P01	0 degrees	48464 steps	189,37mm
P02	10 degrees	145393 steps	568,10mm
P03	20 degrees	242322 steps	946,84mm
P04	30 degrees	339251 steps	1325,58mm
P05	40 degrees	436180 steps	1704,31mm

Test conditions

Measuring device	***Laser tracker, encoder***
Measurement position	***Vessel Fidutial Point***
Environment	***Ambient conditions***
External loads	***7.500 kg load attached to the system***
Control setup	***Open or close loop***
Driver setup	***Normal step size***
Motor parameters	***Nominal speed***

ANNEX 1 – CALIBRATION SHEET

Laser tracker:

- when it has to be **right** Leica Geosystems

Leica Geosystems
Calibration Certificate Metrology Gold

Calibration Certificate Metrology Gold with measurement values issued by Accredited Calibration Laboratory SCS 0079

Product	AT403	AT Controller 400 Rev. 3.0		**Certificate No.**	7020-20200814
Article No.	576361	576360		**Inspection Date**	August 14, 2020
Serial No.	394661	394661		**Order No.**	3190900
Equipment No.				**PO No.**	
Issued by	Accredited Calibration Lab. SCS 0079 Leica Geosystems AG CH-9435 Heerbrugg Switzerland		**Ordered by**	Hexagon Pol gono Industral de Jündiz C/Paduelta 23 01015 VITORIA-GASTEIZ (ALAVA) SPAIN	
Status	After Inspection		**Customer**		

Compliance
The Calibration Certificate Gold with measurement values is issued by the Accredited Calibration Laboratory SCS 0079. The accreditation (SCS 0079) is in accordance with the standard ISO/IEC 17025 and is granted by the Swiss Accreditation Service (SAS). The Swiss Accreditation Service is a member of the International Laboratory Accreditation Cooperation (ILAC) and signatory of the Mutual Recognition Agreement (MRA) which assures international acceptance of the calibration certificates.

The test equipment used is traceable to national standards or to recognized procedures.
This is established by our Quality Management System, audited by SAS (Swiss Accreditation Authority) to ISO/IEC 17025.

Certificate
We hereby certify that the product described has been tested with the following result:

- ☒ **Compliance** — The test results are within the specification of the product.
- ☐ Non-Compliance — The test results are not within the specification of the product.

Note: The statement of compliance has been taken without consideration of the measurement uncertainty ("shared risk").

Leica Geosystems AG

October 6, 2020

Jennifer Akbulut
Calibration Laboratories Laser Tracker

Holger Strack
Quality Management

Certificate No. 7020-20200814
Art. No. 866061
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