FLORIS Calibration Unit

Design Report

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Change Record

Modification	Page	Iss.	Rev.	Date
First Issue	all	1	0	30.11.2017
Second Issue		2	0	22.01.2018
Functional description section moved to EICD document as per KO action AI-5 and AI-6				
Update of geometrical constraint description	§7.1.1			
Update of figures according to modification from KO	Fig.21,30,31, 37,38,40,41,50			
Third Issue (complete revision for PDR)		3	0	31.08.2018
Update of diffuser design taking into account URR RID-010	§5.4.3.3			
Specification Tree added as per URR RID-021	§5.8			
Mass optimization performed as per URR-RID 034	§6.1			

Modification	Page	Iss.	Rev.	Date
Electrical connection scheme revised as per URR-RID 67	§4.1			
PDR-CU-AI#020: Active Baumer switches for reset position corrected in par text in "Reset position"	§4.1.1	4	0	01.02.2019
PDR-CU-AI#021: caption of Figure 42 corrected	§5.4.4.3			
Update for EQM MRR: - Mass budget - Power budget - Introduction of separated end-stop - Corrugation for stray-light reduction is removed from design - Reference to RFD list	 §6.1 §6.2 §5.4 §5.4 §6.4			

Contents

1 Introduction

1.1 Project Overview

The Earth Explorer - Fluorescence Explorer (FLEX) mission will map vegetation fluorescence to quantify photosynthetic activity.

The conversion of atmospheric carbon dioxide and sunlight into energy-rich carbohydrates through photosynthesis is one of the most fundamental processes on Earth – and one on which we all depend.

Information from FLEX will improve our understanding of the way carbon moves between plants and the atmosphere and how photosynthesis affects the carbon and water cycles.

In addition, information from FLEX will lead to better insight into plant health and stress. This is of particular relevance since the growing global population is placing increasing demands on the production of food and animal feed. At the moment, photosynthetic activity cannot be measured from space, but FLEX's novel sensor will observe this faint glow.

The FLEX satellite will orbit in tandem with one of the Copernicus Sentinel-3 satellites, taking advantage of its optical and thermal sensors to provide an integrated package of measurements.

Mission objectives can therefore summarized as follows:

- To assess the quality of fluorescence-derived photosynthesis data against classical optically-based methods (i.e. from fraction of absorbed photosynthetically active radiation times Light Use Efficiency).
- To address in more detail temporal and spatial scaling issues (from towers to satellite footprints).
- To identify and characterize the effects of different types of stress on fluorescence and photosynthesis (especially drought and freezing air temperatures).
- To indicate potential applications of the novel fluorescence observations.

Mission orbit:

- Orbit: Sun-synchronous
- Measurement altitude: 815 km

The FLEX Space Segment consists of a single satellite carrying the FLuORescence Imaging Spectrometer (FLORIS) push-broom instrument. This high-resolution imaging spectrometer will acquire data in the 500– 780 nm spectral range, with a sampling of 0.1 nm in the oxygen bands (759–769 nm and 686–697 nm) and 0.5–2.0 nm in the red edge, chlorophyll absorption and Photochemical Reflectance Index bands.

The monthly global maps will have an on-ground spatial resolution of 300 × 300 m2 with a swath width of 150 km.

1.2 Scope of the Document

The objective of the design definition file (DDF) is to establish the technical definition of a system or product that complies with its technical requirements specification (as defined in ECSS-E-ST-10-06 Annex A).

The design definition file is a basic structure referring to all information relative to the functional and physical architectures and characteristics of a system or product, necessary for its identification, manufacturing, utilization, support, configuration management and removal from service.

The DDF is a collection of all documentation that establishes the system or product characteristics such as lower level technical specifications, design and interface description, drawings, electrical schematics, specified constraints (e.g. on materials, manufacturing, processes, and logistic).

It details the as-designed configuration baseline (as defined in ECSS-M-ST-40) of the system or product and is built up and updated under the responsibility of the team in charge of system engineering. It is the technical baseline for the production, assembly, integration and test, operations and maintenance of the product.

2 Applicable and Reference Documents

2.1 Applicable Documents

Ref.	Title	Reference	Iss.
AD 105	Cover Letter	FLX-LET-FNM-INS-0003	3
AD 106	Special Condition of Tender	FLX-OF-FNM-INS-0001	4
AD 100	Contract for FLEX Unit/sub-system	Draft Contract	
AD 101	Generic Statement of Work for FLEX Unit/sub-system	FLX-SOW-FNM-INS-0001	2
AD 102	Specific Statement of Work	FLX-SOW-FNM-INS-0005	2
AD 103	Floris Calibration Unit User Requirement Specification	FLX-RS-FNM-INS-0006	5
AD 201	FLORIS Radiation Environment RS	FLX-RS-FNM-INS-0016	4
AD 202	FLEX FEMM Requirements Specification	FLX-RS-FNM-INS-0023	1
AD 203	FLEX GMM &TMM Requirements Specification	FLX-RS-FNM-INS-0024	1
AD 204	FLEX CAD Model Requirements Specification	FLX-RS-FNM-INS-0025	1
AD 205	FLEX Cleanliness Requirements for Sub-contractors	FLX-RS-FNM-INS-0028	3
AD 206	FLEX Instrument General Design Interface Requirements	FLX-RS-FNM-INS-0029	3
AD 208	FLEX PA Requirements for Subcontractors	FLX-RS-FNM-INS-0021	2
AD 209	FLEX PA SW Requirements for Subcontractors	FLX-RS-FNM-INS-0022	1
AD 210	FLEX Configuration Control and Documentation Management Plan	FLX-PL-FNM-INS-0001	3
AD 211	FLEX List of Acronyms and Abbreviations	FLX-LI-FNM-INS-0003	2

2.2 Reference Documents

Ref.	Title	Reference	Iss.	Date
[RD01]	FLORIS Calibration Unit Almatech Proposal	17-10S-225	1.0	15.06.2017
[RD02]	Leonardo Clarification Letter	FLX-LET-FNM-INS-0009	--	18.10.2017
[RD03]	Floris CU Negotiation Meeting #1 between Leonardo and Almatech	FLX-MIN-FNM-INS-0041		15.11.2017
[RD04]	Calibration Unit AIT plan	FLX-PL-ALM-CU-0006	4.0	20.11.2018
[RD05]	Calibration unit Structural Analysis Report	FLX-RP-ALM-CU-0001	3.0	06.12.2019
[RD06]	Calibration Unit Functional Analysis Report	FLX-RP-ALM-CU-0002	3.0	to be issued
[RD07]	Calibration Unit Thermal Analysis Report	FLX-RP-ALM-CU-0003	2.1	19.11.2018
[RD08]	Contamination and Control Plan	FLX-PL-ALM-CU-0005	4.0	23.01.2019
[RD09]	Flex CU EQSL	FLX-LI-ALM-CU-0005	3.0	18.07.2018
[RD10]	Flex CU MICD	FLX-ICD-ALM-CU-0001	E	12.01.2019
[RD11]	Flex CU EICD	FLX-ICD-ALM-CU-0002	4.0	01.02.2019
[RD12]	Flex CU Design, Development and verification Plan	FLX-PL-ALM-CU-0007	3.0	20.11.2019
[RD13]	NC and RFx PAD List	FLX-LI-ALM-CU-0011		Latest available

2.3 Acronyms and Abbreviations

The abbreviations and acronyms used in this document are in accordance with [AD 211].

3 Summary of the Project and Technical Requirement

The main User Requirement Specification presented [AD 103] are summarized in the following sections.

3.1 General Requirement

The calibration unit shall guarantee throughout its whole operational life (BOL and EOL) all the required performances **[FLO-CU-URD-REQ-0010]**. The optical element evolution from BOL to EOL depend primarily on cleanliness. Particular attentions and provisions are introduced in the design. First, venting paths are designed to minimize optical components contamination as per **[FLO-CU-URD-REQ-0140]**. In addition, the proposed mechanism concept presents measures for contamination control and protection from external sources (space environment) and internal sources (mechanism wear). In particular, CU design optimization lead to:

- optimal position of optical elements in the carousel,
- closure of both aperture during launch,
- design of a "protective vane"

All these measures simultaneously protect sun diffuser, black target and observation baffle from contamination generated from launch environment **[FLO-CU-URD-REQ-0045]**.

The proposed design is demonstrated to be robust against misalignment introduced during launch. Indeed, the calibration allows for precise positioning of nadir baffle, sun calibration diffuser and dark calibration target **[FLO-CU-URD-REQ-0020 to 40]** located on the CU carousel. Each of the reported position shall be detected by redundant sensors **[FLO-CU-URD-REQ-0145]** whose relative position with respect to optical elements remains unchanged w.r.t. delivery/characterization conditions.

The mechanism launch position is designed to be stable according to **[FLO-CU-URD-REQ-0100]** to maintain the unit safe and protected from contamination. In addition, each position is maintained in powered and unpowered conditions **[FLO-CU-URD-REQ-0070]**.

The use or need of a launch lock device is let to the technical judgement of the applicant under provided restriction **[FLO-CU-URD-REQ-0110/0120]**. To minimize system complexity (need of drive electronic, accommodation of LLD), mass restriction and risk mitigation, the use of LLD is not considered as a viable design baseline. For this reason, the design displays adequate margins with respect to the rotor stability during launch.

3.2 Performance Requirements

The mechanism shall provide a minimum step size and repeatability better than ±0.1° **[FLO-CU-URD-REQ-0190]** while the 3 main positions shall be reached and held with an accuracy better then ±0.2° **[FLO-CU-URD-REQ-0200]** including all source of error **[FLO-CU-URD-REQ-0210/0220]**. On the other hand, the Sun calibration position shall be known with an overall accuracy of +/-0.04° and the Observation and Darck calibration position shall be known with an overall accuracy of +/-0.1° **[FLO-CU-URD-REQ-0240]**.

The mechanism exported micro-vibrations disturbance shall be minimized **[FLO-CU-URD-REQ-0280/0300]** and its transfer function provided **[FLO-CU-URD-REQ-0260].** For this reason rotor assembly shall be equilibrated to minimize exported loads during operation **[FLO-CU-URD-REQ-0270]**.

The emergency position, coincident with the dark position, shall be reached in maximum 15 seconds **[FLO-CU-URD-REQ-0310].** This activation mode is the worst case for motorization margin calculation as the inertia loads are the highest amongst other operational modes.

The thermal flux dissipated by the CU shall be less than 5W which comprehend motor activations and sensor budgets **[FLO-CU-URD-REQ-0320]**. Considering the motor current and voltage (27.5V and 0.3A) provided in **[FLO-CU-URD-REQ-0065]**, the maximum instantaneous thermal power dissipated by the motor is 9W, however the average thermal dissipated power over an orbit is compliant to specifications. A detailed budget is referenced in Section 6.2.

The CU functional modes are reported in **[FLO-CU-URD-REQ-0400]**, and describe usual mechanism mode:

- Motor OFF sensors ON
- Motor ON sensors ON
- All systems OFF
- Observation mode: sensor ON, motor ON
- Calibration mode: sensor ON, motor ON
- SAFE mode
- END stop: Reset position

The last mode, END STOP is detected by switch activation.

3.3 Mechanical Interface Requirements

The CU shall respect the allocated volume statically and dynamically, the main axis depicted in the provided MICD as well as the provided interface **[FLO-CU-URD-REQ-0360/0370/ 0380/0385/0386]**. The compliant with the dynamical envelope is verified by analysis and by test.

The mechanical interface of the CU shall be in accordance with **[FLO-CU-URD-REQ-0385]** and it is agreed with LDO.

The total CU mass shall be smaller 7.5 kg including margin **[FLO-CU-URD-REQ-0390]**. The design maturity and mass optimization loop performed for the PDR show that the required mass can be guaranteed non considering margins. The mass budget and the discussion of this requirement is presented in Sections 6.1.

The CoG position shall be measured with an accuracy better than 1mm **[FLO-CU-URD-REQ-0410]**. However, for units weighting less than 8kg review and analysis of CAD model is sufficient **[Table 4-1 in AD 101].** Therefore no COG measurement is performed. However, the required CU CoG is reported in TBD in FLX-DW-FNM-IOMS-002C. The actual values are out of specification. In general the actual CU CoG is not aligned with the rotational axis and it is closed to the optical bench.

The CU first natural mode frequency shall be higher than 180Hz+15%=207Hz **[FLO-CU-URD-REQ-0420/0430]**. The first frequency also plays an important role in the gap definition between stator and rotor. The higher the first frequency gets, the smaller the rotor radial movement is and thus the smaller the gap between stator and rotor can be. As a smaller gap will reduce the contamination and stray-light, a first Eigenmode shall be maximized.

The alignment angular error between the telescope nadir and CU nadir aperture as well as the nadir telescope direction and sun baffle directions shall be less the 5′ (0.083°) **[FLO-CU-URD-REQ-0460]**.

The CU mechanism shall have a reliability better than 0.999 **[FLO-CU-URD-REQ-01220]**.

3.4 Thermal Requirements

The interface thermal design is let to the customer technical judgement **[FLO-CU-URD-REQ-0500].**

The interface design is tightly connected to the one of the structure. Indeed, the thermal flux from the space environment is conveyed by the apertures through the CU toward the OBA interface.

The CU is assumed to be strongly thermally connected to the optical bench. A conductive thermal conductance of $1000W/(m^2 \times K)$ is associated to the CU interface surface area.

The thermal radiative environment is presented in **[FLO-CU-URD-REQ-0515]** the interpretation of the fluxes as function of maneuver and orbit is reported in [RD07]

The CU operating mode temperature is within +17°C and +27°C, while the non-operative temperature range is -15°C to +55°C **[FLO-CU-URD-REQ-0510]**.

The CU shall be compatible with a maximum temperature difference between CU interfaces less than 2°C **[FLO-CU-URD-REQ-0520]**.

The proposed operative and non-operative environments are judged fair and do not presents any concern for the mechanism. The detailed analysis reported in [RD07] confirms the assumption.

3.5 Optical Requirements

The nadir and sun baffle position are described respectively in **[FLO-CU-URD-REQ-0540/0550/560]** and **[FLO-CU-URD-REQ-0660/0670].** The nadir baffle vane positions are reported as TBC and are intended to be optimized during the project by the client. The proposed solution is reported in Section 5 and compliant with provided values.

The baffle mounting/repeatability tolerances are ±0.05mm (all axis) and ±3 arcmin (0.05°) (tilt) **[FLO-CU-URD-REQ-0570]**. In addition, the Rotor observation axis shall be aligned to the nadir LoS with a tolerance of 3' (0.05°) and centering better than 0.1mm **[FLO-CU-URD-REQ-0585].** A careful test plan is established to measure these tolerances (see [RD04]).

The internal reflectivity of the Nadir Baffle in the range of 300-1000nm is set to 5% **[FLO-CU-URD-REQ-0580]** whereas the one on the sun baffle is set to 9% without wavelength specification **[FLO-CU-URD-REQ-0680]** it is assumed that the same wavelength requirement as per the nadir baffle apply.

The BRDF of the black target shall be better than $9\%/\pi$ known with an accuracy of $\pm 0.5\%/\pi$ within the range of 500-780 nm **[FLO-CU-URD-REQ-0690]**. Dedicated tests are foreseen to assess this important requirement (see [RD04]).

The diffuser material is defined by the client to be space grade Spectralon **[FLO-CU-URD-REQ-0600]**, dimensions of the diffuser are given in **[FLO-CU-URD-REQ-0590]** and are optimized according the angle of view in the proposal. The nominal angle of the diffuser w.r.t. the optical axes shall be $25° \pm 0.1$ and $90° \pm 0.1$, these values are the results of the trade-off requested in **[FLO-SPE0005-SOW-REQ-0104]**. Moreover, the final position shall be known with a resolution of 0.004° which requires noncontact measurement for cleanliness reasons and a dedicated integration procedure which is presented in [RD04].

In addition, the manufacturing tolerances and flatness of the diffuser are quite large which requires a common understanding on how the reference plane of the diffuser is chosen.

Strict characterization of the Diffuser optical properties beginning of life (BoL) is required in **[FLO-CU-URD-REQ-0620/0625/0630]** and end of life (EoL) **[FLO-CU-URD-REQ-0640]**. Dedicated tests are foreseen to establish properties degradation with solar irradiation in clean and simulated contaminated conditions (see [RD04]). Particular attention during the integration is reserved to protect the diffuser (see [RD04]) during AIT activities **[FLO-CU-URD-REQ-0645]**.

Finally, the overall optical design concept shall not allow for any radiation entering the instrument telescope when the CU is in black calibration position **[FLO-CU-URD-REQ-0700]**. This requirement requires careful attention during the design phase and the demonstration by a dedicated test which are both presented in [RD04]. Furthermore for this design aspect this requirement is linked to the **[FLO-CU-URD-REQ-0045]** and **[FLO-CU-URD-REQ-0940]** because of the sizing of the rotor/stator gap.

3.6 Electrical Requirements

The electrical interface is agreed with the client as defined in **[FLO-CU-URD-REQ-0720]**. Both connector and cable connections are possible with minor modifications. Connectors and cables are standard space components. Temperature sensors are implemented in the motor and on the CU base as requested by **[FLO-CU-URD-REQ-0730]**. Grounding provision is provided by the indication of a bonding stud on the stator **[FLO-CU-URD-REQ-0860]**

3.7 CU Mechanism Lifetime

On ground total number of cycles is set to 600 **[FLO-CU-URD-REQ-0950]**. The in orbit number of cycles is subdivided per type of activation **[FLO-CU-URD-REQ-0960]**:

- Observation position to dark calibration and back: 1 movement every 100 min for 4 years
- Observation position to san calibration + dark calibration and back: 1 movement every 14 days for 4 years
- In orbit commissioning, validation, calibration period of 3 months is considered **[FLO-CU-URD-REQ-0970]**

CU life time is calculated according to ECSS margins **[FLO-CU-URD-REQ-0980].** The number of cycles is judged in the range of usual lifetime for space mechanisms (see [RD06]).

3.8 CU Cleanliness

CU cleanliness issues are addressed in the contamination and cleanliness control plan which provides also the contamination budget. The main cleanliness requirements reported in [AD103] are [FLO-CU-URD-REQ-1050] and [FLO-CU-URD-REQ-1060].

The cleanliness requirement are challenging and requires that the assembly and integration are performed in a flow bench. It also requires that all test and calibration are done in cleanroom ISO 5 condition. It must be noted, however, that the major source of potential particle contamination is the Sun Diffuser which is composed of sintered particle and is therefore prone to release them during dynamic excitation.

The bake-out required as per **[FLO-CU-URD-REQ-1071]** will be able to reset the MOC contamination but not the PAC. Therefore, a careful planning of the activities is required. Almatech proposed approach is detailed in the contamination control plan and AIV section and foresees ad hoc means like late integration of the most sensitive items and apertures covers provisions to reduce contamination as well as removable witness samples **[FLO-CU-URD-REQ-1072]**.

An important part of the thermal analysis is dedicated to the assessment of temperature difference among the elements of the assembly. In particular, the diffuser temperature shall never acts as cold trap for contaminants with margin **[FLO-CU-URD-REQ-1073/1075]** (see [RD07]).

The whole design is conceived to reduce to the minimum the contamination from the bearing. The assessment required by **[FLO-CU-URD-REQ-1077]** is thus performed since the earliest design phase (see [RD08]).

In addition, material are selected in compliance with low outgassing values (RML<1.0% and CVCM <0.1%) **[FLO-CU-URD-REQ-1240].**

3.9 Mechanical Loads

The type of required mechanical analysis is reported in **[FLO-CU-URD-REQ-1110].** All the analyses will be provided during the project. Correlation to the experiment is also proposed. Strength analysis results are provided in [RD05] in order to prove the robustness of the proposed design. In particular, quasi static, modal, random, and thermal analysis are considered as essential to the latter scope.

The launch environmental loads are: Quasi-static 40g all directions, Sine 22g out of plane direction and 16g in plane, Random 25.2grms out of plane and 22.5 in plane direction, Shock 900g all directions **[FLO-CU-URD-REQ-1290/1300/1330/1335/1340]**. The loads are severe. The verification will be performed by test and analysis.

The in orbit environment is defined by the micro-vibration requirement **[FLO-CU-URD-REQ-1360]** translational: 20mg<100Hz, 30mg up to 1000Hz and rotational: 20mrad/sec2 acceleration. The proposed verification is by analysis and test. Simulation tools are available for the prediction of the behavior of component under micro-vibration.

4 Functional Description

4.1 Functional Architecture

The functional architecture expressing connections between components and sensors is described in details in [RD11] and reported for convenience in Figure 1.

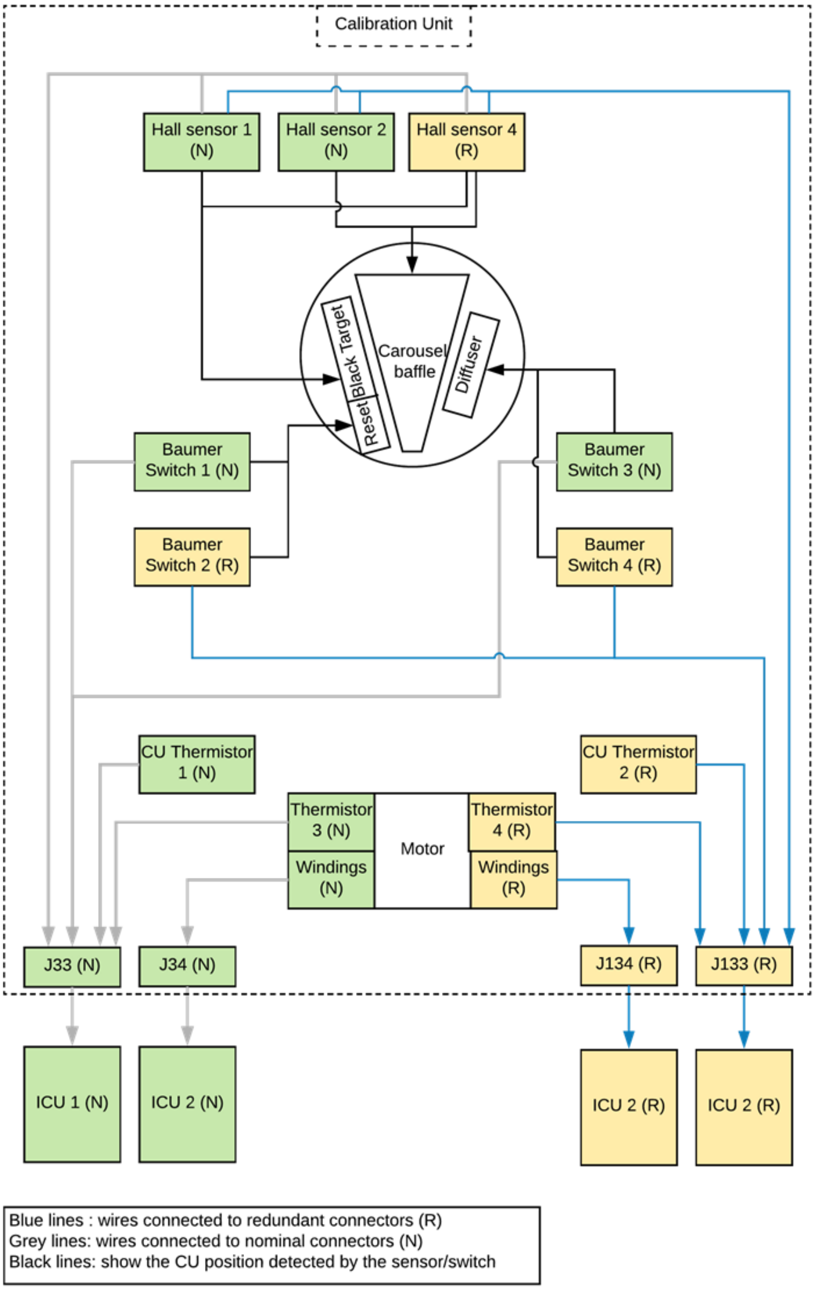


Figure 1: CU baseline Functional Architecture and Electrical Diagram

The **design baseline** w.r.t. sensor configuration and detection performances is reported in Table 1. The baseline configuration is extensively tested during early phase of the project for what concern the detection of sun calibration position with required accuracy. The back-up solution w.r.t to sun diffuser detection capability is also reported in Table 1.

The **baseline configuration** takes advantage of the design flexibility and intrinsic repeatability of the Baumer switch to perform precise detection of the sun calibration position.

Table 1: Position detection attribution for each CU sensor

	baseline configuration		
CU Position	**Sensor main**	**Sensor Redundant**	**Resolution**
Sun calibration	Baumer3	Baumer4	±0.04°
Nadir	Hall2	Hall4	±0.1°
Black calibration = launch position	Hall1	Hall4	±0.1°
Reset Position	Baumer 1	Baumer 2	0.028°

The number of sensors for the baseline configuration are reported in Table 2.

Table 2: Number and type of sensors for baseline and back-up configuration.

	baseline configuration
Hall sensor	3
Baumer switch	4

4.1.1 Sensing Configuration

The sensors position with respect to CU base plate is reported in Figure 2. Each carousel position detection logic is described hereafter.

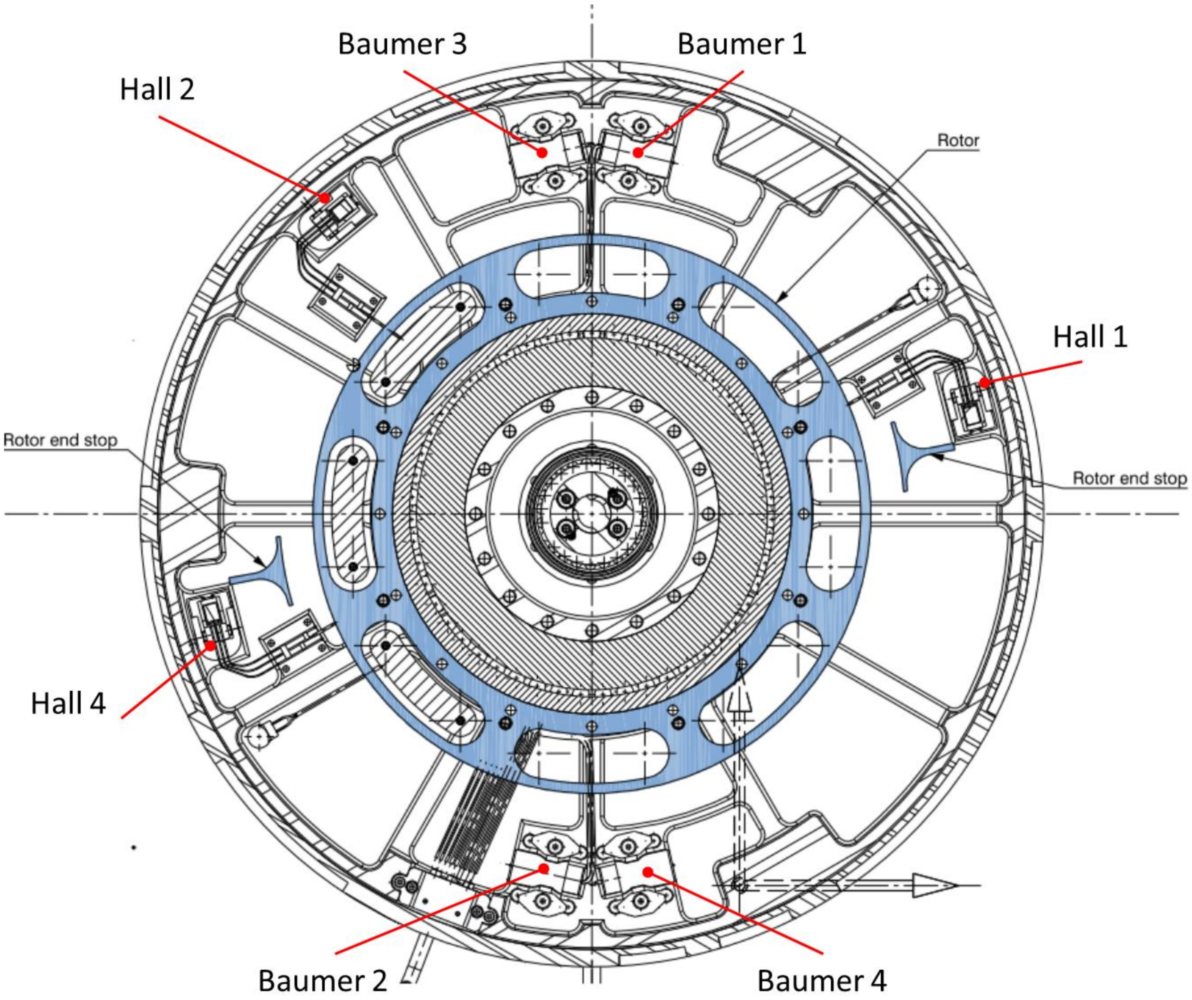


Figure 2: Carousel detection position back-up: sensor location.

Sun calibration position detection

The position is detected by the sensors Baumer 3 and Baumer 4 (main and redundant respectively). The angular resolution required for such position is ±0.04° which is ensured by the 1 micron reputability of Baumer switches and control of the switch overrun stroke.

Nadir position detection

The nadir position is detected by the sensors Hall2 and Hall4 (main and Redundant respectively). The configuration foresees the use of mu material shield. The angular resolution required for such position is ±0.1° which corresponds to a circumferential range of ±0.1mm at the hall sensors position.

Black calibration position detection and Launch position

The black calibration position is detected by the sensors Hall1 and Hall4 (main and Redundant respectively). The configuration foresees the use of mu material shield. The angular resolution required for such position is ±0.1° which corresponds to a circumferential range of ±0.1mm at the hall sensors position.

The relatively large activation range ±0.1mm guaranties that, in the improbable case of rotor oscillation during launch, the hall sensor will remain triggered.

Reset position

The reset function is ensured by Baumer1 and Baumer2 switch (main and redundant). Their resolution guarantees detection of carousel angular position within ±0.028°.

4.2 Description of Functional Chains

The main relationships between the CU and ICU for the different functional modes, TeleControl and Telemetry signals are reported at high level in [RD11]

In [RD11], the event handling and function control of the CU are also reported and detailed.

4.3 Functional Tree

The Calibration Unit provides means to perform the following list of functions:

- Carousel Current Position Identification
- Go to Black Calibration Position
- Go to Sun Calibration Position
- Go to Nadir position
- Go to Reset position
- Go to SAFE mode
- Fine position adjustment

Each of the above functions are detailed in [RD11].

5 Physical Description

5.1 Physical Architecture

This sections presents the unit design in terms of components, internal organization, and high level features. Multiple views of the CU are presented in Figure 3 to Figure 6.

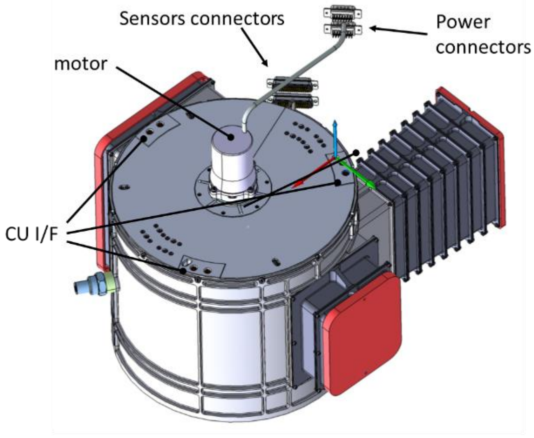


Figure 3: Calibration Unit assembly, 3D view.

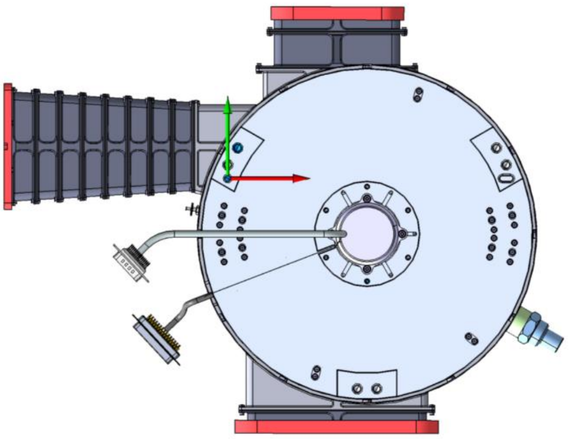


Figure 4: Calibration Unit assembly, I/F view.

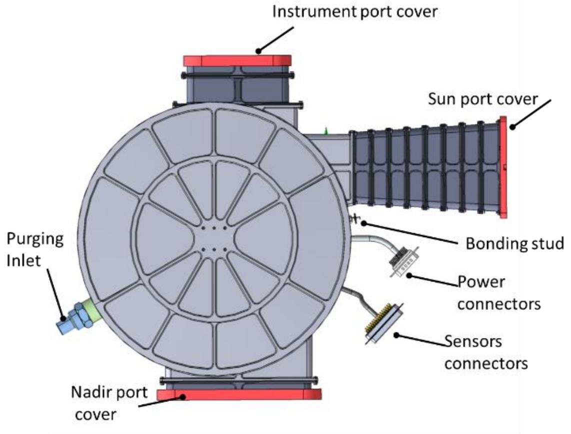


Figure 5: Calibration Unit assembly, top view.

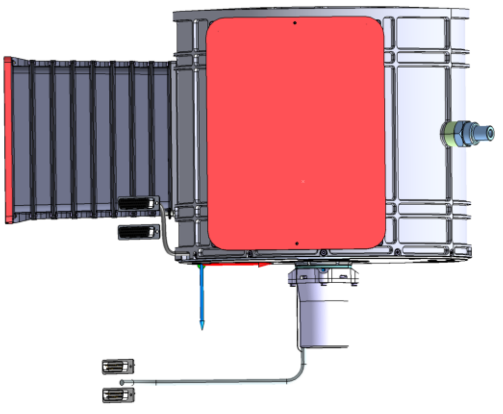


Figure 6: Calibration Unit assembly, Side view.

From a high level perspective, the following items are displayed:

- **Motor**

  Stepper motor driving the CU rotor, cold redundant windings.

- **Purging inlet**

  As required by [FLO-CU-URD-REQ-0142], the size, type of connector shall be agreed. The position of the inlet is selected to be in front of the sun diffuser.

  It is highlighted here that, considering the high cleanliness level of the sun diffuser, Nitrogen purging shall be conducted with high cleanliness class nitrogen and that carbon filters shall be foreseen in order to avoid hydrocarbon contamination of the diffuser.

- **Bonding stud**

  Grounding provision is ensured by the bonding stud according to [FLO-CU-URD-REQ-0860]

- **Nadir port cover, Sun port cover, Instrument cover**

  The CU will be delivered with ports covers in order to ensure the cleanliness of the unit as required by [FLO-CU-URD-REQ-0941]

5.2 Product Tree

The product tree of the CU is reported in Figure 7. In addition, Figure 7 shows the CU Element Breakdown and acronyms definitions.

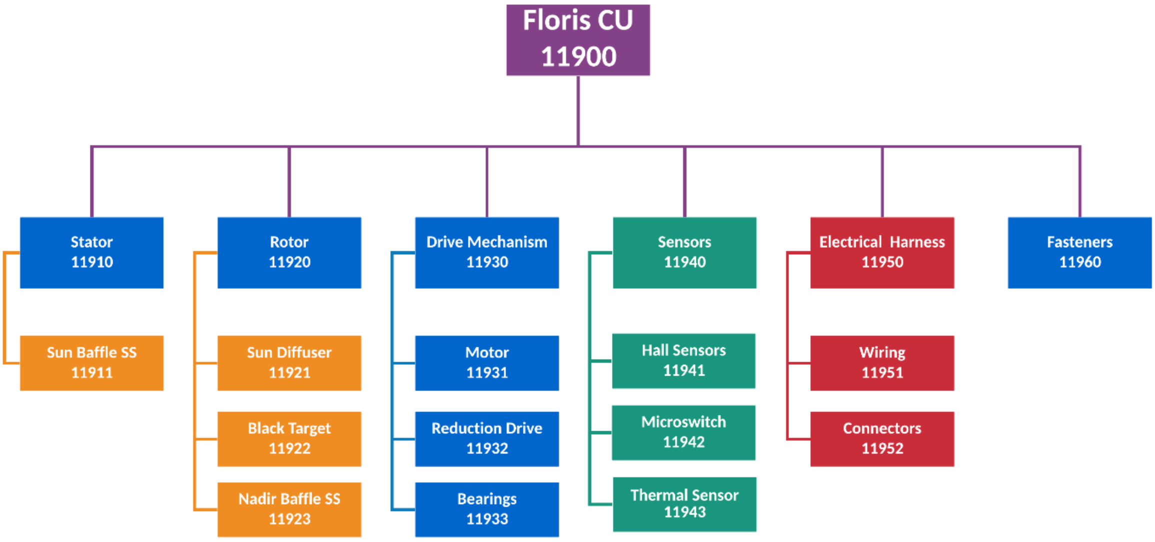


Figure 7: CU product tree

An exploded view of the CU can be found in the following Figure 8.

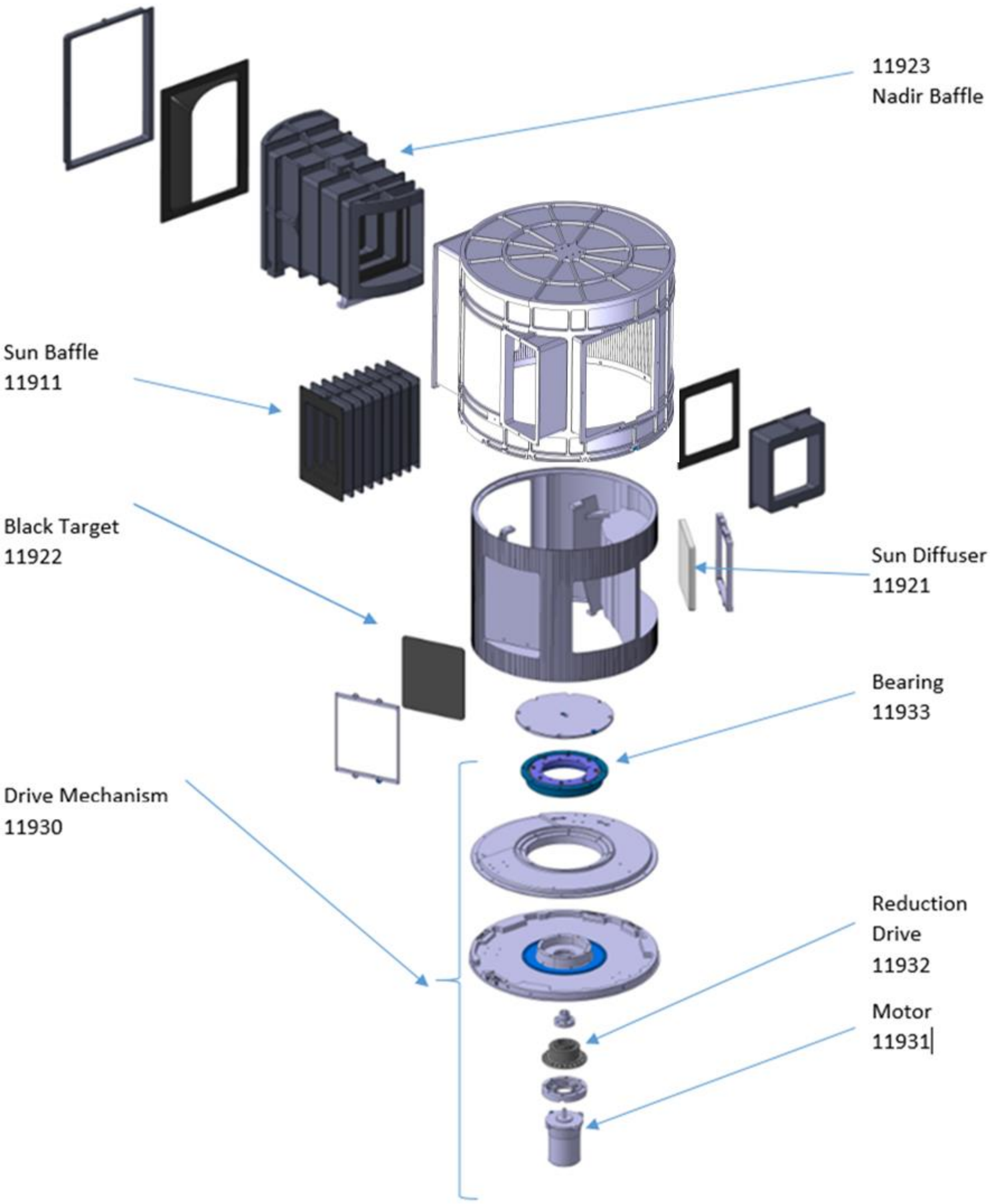


Figure 8: Exploded view CU

Table 3: CU Element Break Down

CI					Item Description	Acronym	Remarks
1	**1**	**9**	**0**	**0**	Calibration Unit	CU	Top Assembly containing mechanism and optical elements
1	**1**	**9**	**1**	**0**	Stator	ST	Aluminium Structure acting as CU Cover and Sun Baffle support
1	**1**	**9**	**1**	**1**	Sun Baffle Sub-System	SB	Sun observation Baffle
1	**1**	**9**	**2**	**0**	Rotor	RT	Aluminium Structure supporting all optical elements
1	**1**	**9**	**2**	**1**	Sun Diffuser	SD	Spectralon Material Sun Diffuser, including its clamping frame and protective Cover
1	**1**	**9**	**2**	**2**	Black Target	BT	Black coated aluminium including protective Cover
1	**1**	**9**	**2**	**3**	Nadir Baffle Sub-System	NB	Black coated aluminium Nadir Telescope Baffel Sub-System
1	**1**	**9**	**3**	**0**	Drive Mechanism	DM	Sub-Assembly containing Stepper Motor, Reduction Drive and RT bearing
1	**1**	**9**	**3**	**1**	Motor	MT	Stepper Motor for driving the RT
1	**1**	**9**	**3**	**2**	Reduction Drive	RD	Harmonic Drive Reduction Gear for increasing stepping resolution and holding torque and low Backlash
1	**1**	**9**	**3**	**3**	Bearings	BB	Superduplex Angular Contact Ball Bearing
1	**1**	**9**	**4**	**0**	Sensors	SEN	Contains all Sensors
1	**1**	**9**	**4**	**1**	Hall Sensor	HS	Hall Effect Sensor for accurate knowledge of defined Rotor positions
1	**1**	**9**	**4**	**2**	Micro Switch	MS	End Stop Switch for resetting position knowledge and mechanical end stop of Rotor.
1	**1**	**9**	**4**	**3**	Thermal Sensor	TS	Thermal Sensors used to record internal interface temperature of the CU
1	**1**	**9**	**5**	**0**	Electrical Harness	EH	Contains all harnessing elements
1	**1**	**9**	**5**	**1**	Wiring	WI	Contains all wires necessary for driving power and signals
1	**1**	**9**	**5**	**2**	Connectors	CO	Contains all necessary connectors for interfacing with the ICU
1	**1**	**9**	**6**	**0**	Fasteners	FST	Contains all fasteners such as screws, nuts, washers, etc…

5.4 Description of Elements of the Physical Architecture

5.4.1 Equipment Characteristics and Technology Readiness Level (TRL)

The following items are assembled into the CU to guarantee the demanded functions.

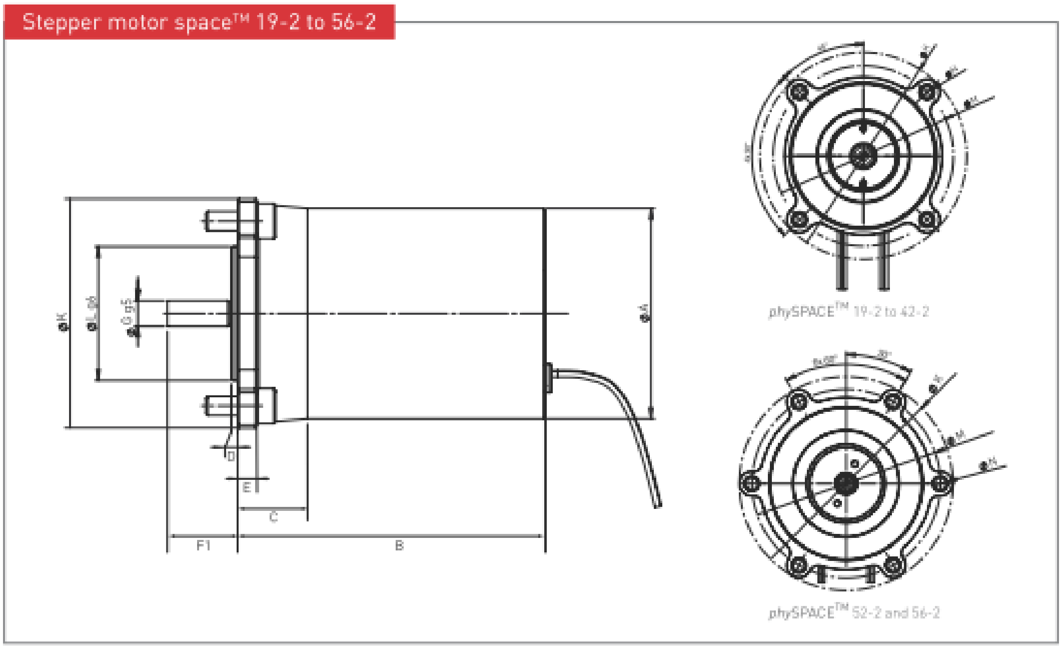
Table 4: Equipment List, TRL and Heritage

Equipment	TRL	Heritage
Motor: Phytron phySPACE 42-2-200-0,3-CR-Ti	9	Maven, BepiColombo MERTIS, Mars Rover Curosity, Juno, MIRIS, EnMAP, SOLACES, Rosetta Cosima, STEREO, XMM, Cassini-Huygens, MOS-IRS-P2
Ball bearing: ADR #WKSP 20018 TA4 DOK 6819	9	SMART-1 EPMEC, MEDET, X38, SPOT HRG MCV, Sentinel-2 CSM
Hall effect sensors: Optek OMH 090S	9	ISS, Cassini, EMTGO, Meti, Colisto, Delta IV
Switch: RUAG space grade of Baumer switch	8	Solar Orbiter SPICE, MTG CCM
Gear: Harmonic drive CPL-14-100-2A	9	GAIA, deployable sunshield, SENTINEL-2, Multi-Spectral Instrument Calibration and Shutter Mechanism, BepiColombo, Electric Propulsion Pointing Mechanism
Sun diffuser: Spectralon from lab sphere	9	Standard material

All this elements are shortly presented and described in the following paragraphs. Note that an Equipment Qualification Status List (EQSL) is presented in [RD09]. Note also that specific engineering data used for analysis are provided in [RD06]

5.4.1.1.1 Motor

The chosen motor is the Phytron PhySpace 42-2 whose informative technical data are reported in Figure 9. In [RD06] performance curves are reported and analysed.



Dimensions / Electrical and Mechanical Charcteristics

phySPACE™ Standard 200-step 4 lead parallel bipolar	Electrical Characteristics				Mechanical Charcteristics						Dimensions in mm										
	Current/Phase I_N	Resistance/Phase[4]	Max. operating voltage[5]	AWG	Holding torque[1]	Power-OFF torque	Rotor inertia	Loads[2] axial	Loads[2] radial	Mass[3]											
	A	Ω	V_{DC}		mNm	mNm	kg cm^2	N	N	g	A	B	C	D	E	F1	G[g5]	K	L[g6]	M	N
19-2	0.6 1.2	2.1 0.63		28	3.8	0.9	0.0009	10	15	70	20	34	10.5	1.5	2	7.5	2.5	32	10	27	2.2
25-2	0.6 1.2	3.25 0.95		28 26	13	2	0.0025	15	25	100	26	36	10.5	2.5	2.5	9.5	3	38	14	33	2.7
32-2	0.6 1.2	4.6 1.25	48	26	50	3	0.01	30	45	211	33	48	11	2.5	3	11	4	47	18	42	3.2
42-2	1.2 2.5	1.7 0.34		24 22	140	5	0.045	30	50	425	43	60	16	2.5	3.5	16	5	62	22	54	4.2
52-2	1.2 2.5	2.6 0.6		24 22	450	12	0.15	65	100	900	53	75.5	17	1	5	21	6	75	38	66	5.2
56-2	1.2 2.5	3.9 0.8		24 22	500	50	0.24	50	80	970	57	70	16.5	2.5	4.5	22	6	77	38	68	5.2

[1] Holding torque in bipolar mode with parallel windings. Two phases on at rated current
[2] Axial radial loads are for mounting purposes only. A flexible coupling must be used in operation.
[3] The use of titanium parts reduces the overall weight by 20 %.
[4] differently with redundant winding
[5] max. operating voltage of the power stage (intermediate circuit voltage)
All values given above refer to room temperature and atmospheric pressure. Other sizes available upon request

Figure 9: Phytron PhySpace 42-2 as per datasheet reported in [RD06].

5.4.1.1.2 Ball Bearing: ADR W K SP20664 T4 DO K7216

Super duplex ball bearing, 2 races of 54 balls, with integrated preloading system. Sizing report is attached to [RD06].

Chapter	Codification	Correspondence
1	W	Material
2	K	External conception
3	SP20664	Basic designation
4	T4	Tolerance class
5	DO	Duplex configuration
6	K7216	Specification

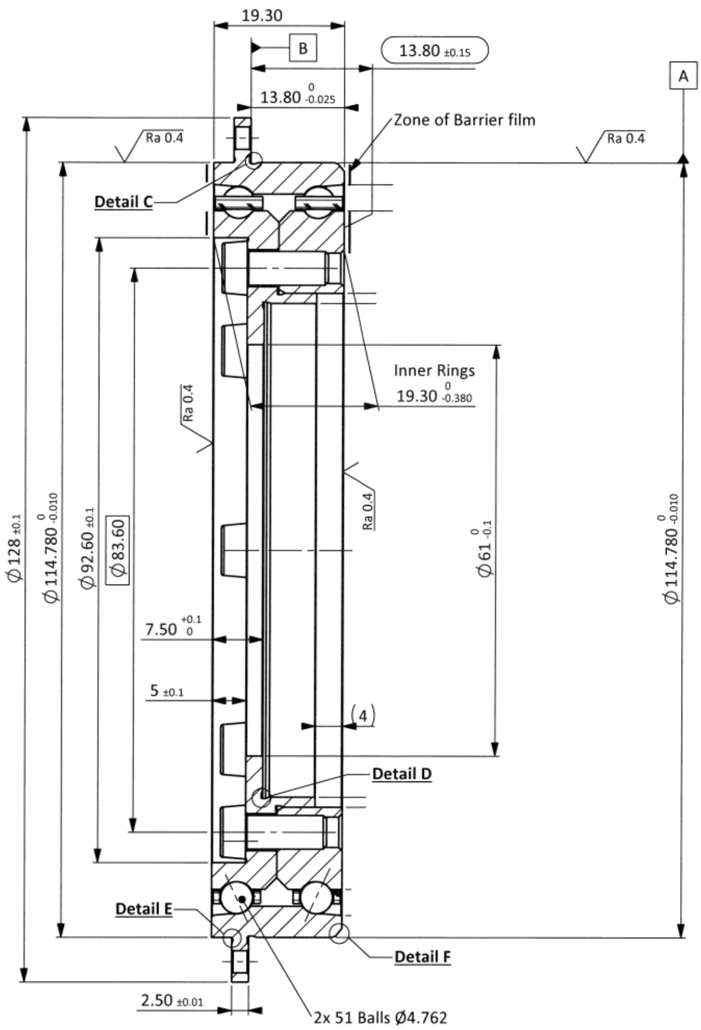
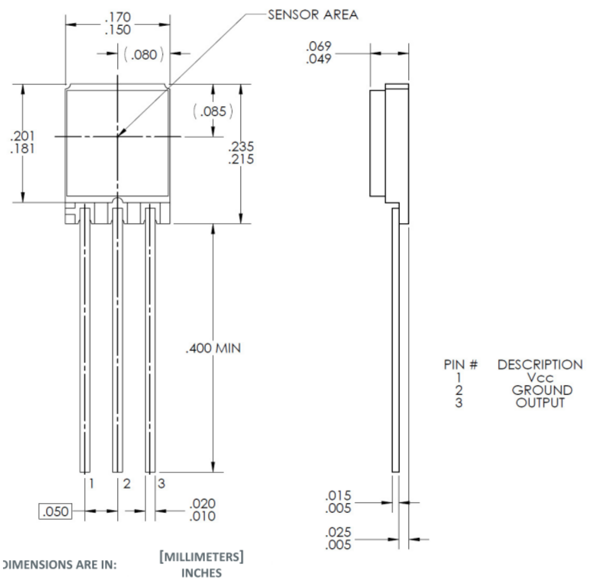


Figure 10: ADR W K SP20664 T4 DO K7216 ball bearing.

5.4.1.1.3 Hall Effect Sensor

The selected Hall sensors are the Optek OMH 3131S whose main characteristics are reported in Figure 11 (extract from datasheet reported in [RD10]).



Part Number	Hi-Reliability Hallogic® Sensor	Operate Point Gauss Min / Typ / Max	Release Point Gauss Min / Typ / Max	Hysteresis Gauss Min / Typ / Max	V_{CC} (Volts) Min / Max	Package
OMH090B		50/90/180	30 / 65 / 160	10 / 30 / 60		
OMH090S						
OMH3019B	Uni-Polar Non-Latching	175 / 300 / 500	125 / 235 / 420	30 / 100 / 155	4.5 / 24.0	Through Hole
OMH3019S						
OMH3020B		70 / 220 / 350	50 / 180 / 330	15 / 55 / 200		
OMH3020S						
OMH3040B		70 / 150 / 200	50 / 115 / 180	10 / 35 / 60		
OMH3040S						

Figure 11: Optek OMH3131S main characteristics.

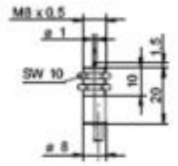
5.4.1.1.4 Switch

The switch used are the space grade version performed by Ruag of the Baumer switch MY-COM B75/80 whose technical properties are reported in Figure 12.

Baumer | My-Com precision switches

My-Com precision switches — MY-COM B75/80

dimension drawing



general data	
repeat accuracy	< 0,001 mm
activating force	75 cN
mech. pre-run / overrun	- / 1,5 mm approx.
measurement type	contact with medium
direction of approach	frontal

electrical data	
DC voltage max.	15 VDC
switch. current DC max.	2 mA
AC voltage max.	24 VAC
switch. current AC max.	50 mA
output circuit	break function (NC) mechanical

mechanical data	
activating pin	zirconium oxide ZrO2
housing material	brass nickel plated
dimension	8 mm
type	cylindrical threaded
housing length	20 mm
connection types	cable, 90 cm

ambient conditions	
operating temperature	-20 ... +75 °C
protection class	IP 50

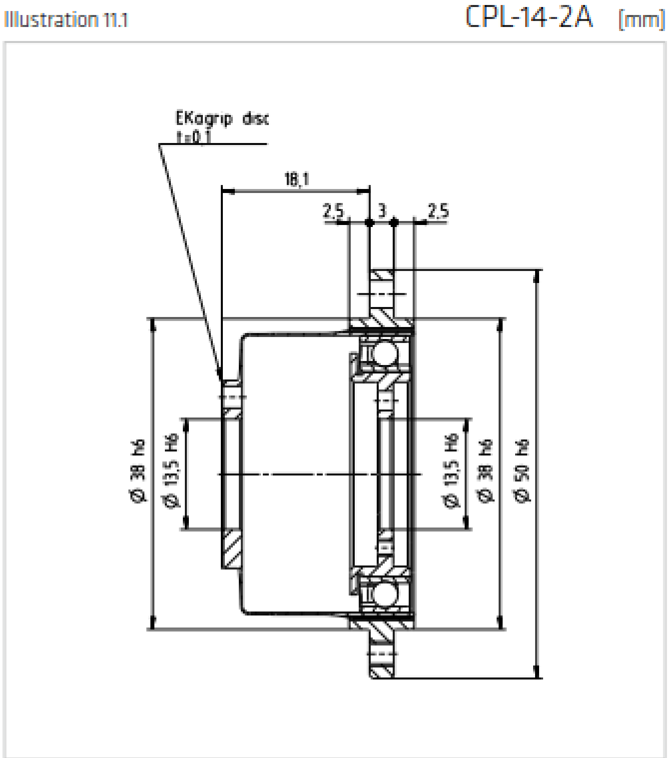
photo

connection diagram

Figure 12: Space grade version of the Baumer switch B7/80

5.4.1.1.5 Gear

The selected gear is the Harmonic drive CPL-14-2A with reduction ration of 1:100 whose characteristics are reported in Figure 13 (Extract from datasheet reported in [RD06]).

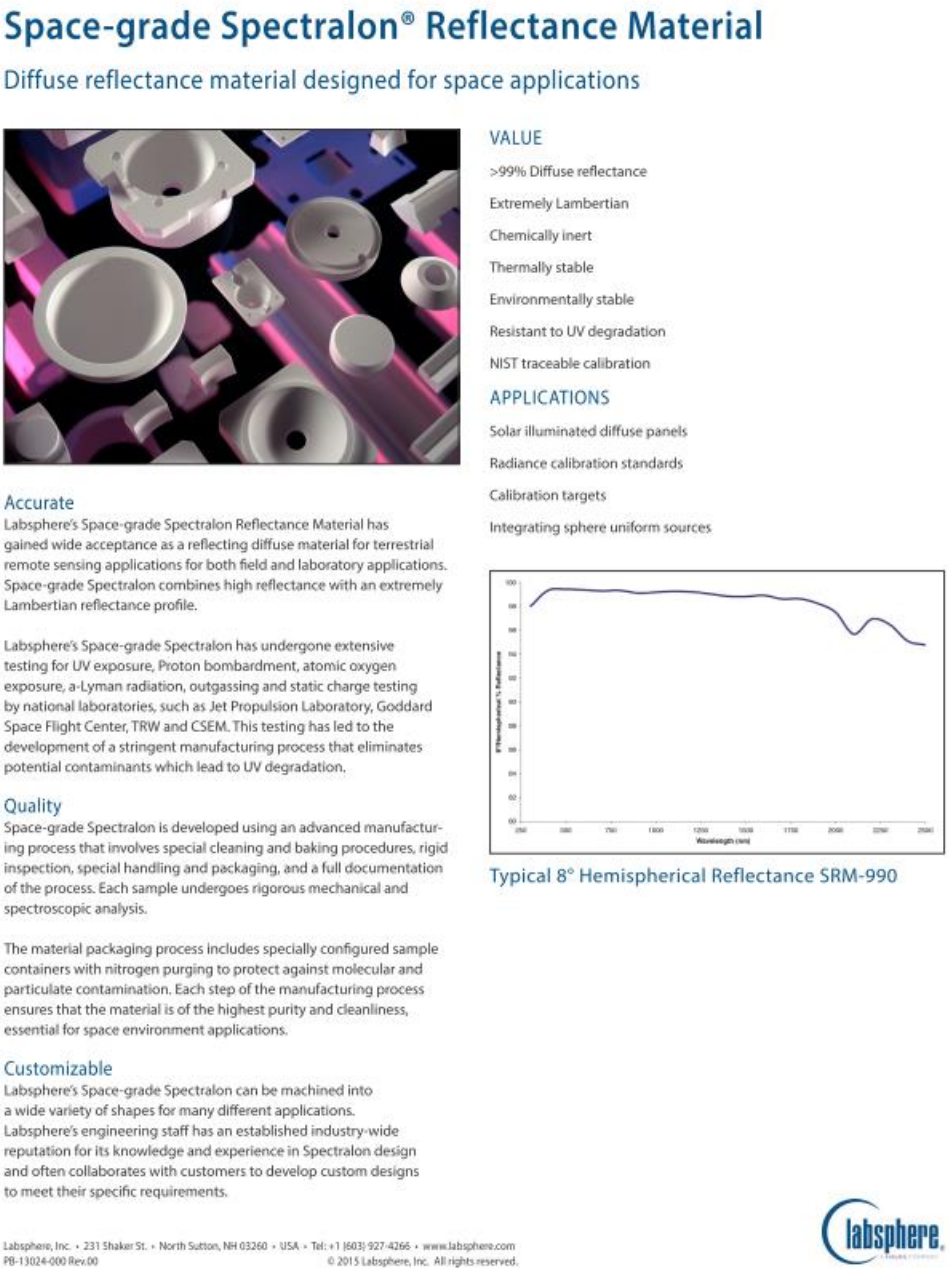


	Unit	CPL-14-2A			
Ratio	i [ ]	30	50	80	100
Repeatable peak torque	T_R [Nm]	9	18	23	28
Average torque	T_A [Nm]	6.8	6.9	11	11
Rated torque	T_N [Nm]	4.0	5.4	7.8	7.8
Momentary peak torque	T_M [Nm]	17	35	47	54
Maximum input speed (oil lubrication)	$n_{in\,(max)}$ [rpm]	14000			
Maximum input speed (grease lubrication)	$n_{in\,(max)}$ [rpm]	8500			
Average input speed (oil lubrication)	$n_{av\,(max)}$ [rpm]	6500			
Average input speed (grease lubrication)	$n_{av\,(max)}$ [rpm]	3500			
Moment of inertia	J_{in} [$x10^{-4}$ kgm^2]	0.020			
Weight	m [kg]	0.055			

Figure 13: Harmonic drive CPL-14-2A-100.

5.4.1.1.6 Sun Diffuser

The sun diffuser is made out of space grade Spectralon material from labsphere (see Figure 14).



Space-grade Spectralon® Reflectance Material

Diffuse reflectance material designed for space applications

Accurate

Labsphere's Space-grade Spectralon Reflectance Material has gained wide acceptance as a reflecting diffuse material for terrestrial remote sensing applications for both field and laboratory applications. Space-grade Spectralon combines high reflectance with an extremely Lambertian reflectance profile.

Labsphere's Space-grade Spectralon has undergone extensive testing for UV exposure, Proton bombardment, atomic oxygen exposure, a-Lyman radiation, outgassing and static charge testing by national laboratories, such as Jet Propulsion Laboratory, Goddard Space Flight Center, TRW and CSEM. This testing has led to the development of a stringent manufacturing process that eliminates potential contaminants which lead to UV degradation.

Quality

Space-grade Spectralon is developed using an advanced manufacturing process that involves special cleaning and baking procedures, rigid inspection, special handling and packaging, and a full documentation of the process. Each sample undergoes rigorous mechanical and spectroscopic analysis.

The material packaging process includes specially configured sample containers with nitrogen purging to protect against molecular and particulate contamination. Each step of the manufacturing process ensures that the material is of the highest purity and cleanliness, essential for space environment applications.

Customizable

Labsphere's Space-grade Spectralon can be machined into a wide variety of shapes for many different applications. Labsphere's engineering staff has an established industry-wide reputation for its knowledge and experience in Spectralon design and often collaborates with customers to develop custom designs to meet their specific requirements.

VALUE

>99% Diffuse reflectance
Extremely Lambertian
Chemically inert
Thermally stable
Environmentally stable
Resistant to UV degradation
NIST traceable calibration

APPLICATIONS

Solar illuminated diffuse panels
Radiance calibration standards
Calibration targets
Integrating sphere uniform sources

Typical 8° Hemispherical Reflectance SRM-990

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labsphere

Figure 14: Spectralon datasheet

5.4.2 Stator Assembly

The stator is shown in Figure 15 and it is composed by the main parts:

- CU Housing
- CU base
- Sun baffle
- Instrument side baffle
- Drive mechanism (motor, harmonic drive, internal rail of ball bearing)
- Sensors (Baumer switch and their housing, hall sensors and their PCB and positioning devices)

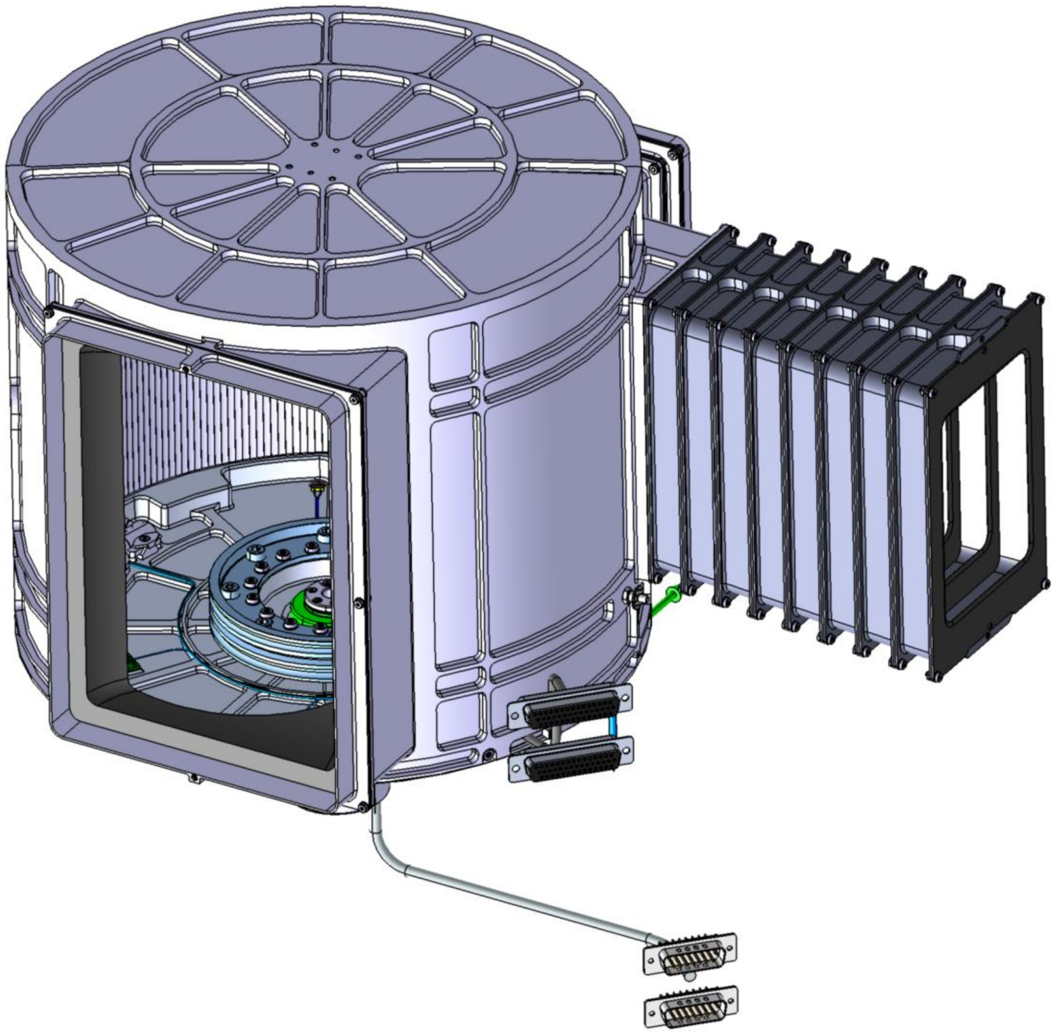

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Figure 15: parts composing the CU stator.

5.4.2.1 CU Housing

The CU Housing is machined out of a single piece of 6061 T651 material. Its shape is reported in Figure 16 and Figure 17. This design choice presents the following advantages:

- Ease of assembly
- Carousel and optical element on the rotor easily accessible by housing removal
- Rotor access once housing is removed is 360°
- The housing do not generate contamination since no bearing are installed on it
- One single part provide excellent stiffness/weight ratio and therefore high first eigen-frequency
- Ease of ports alignment with respect to optical elements on the rotor

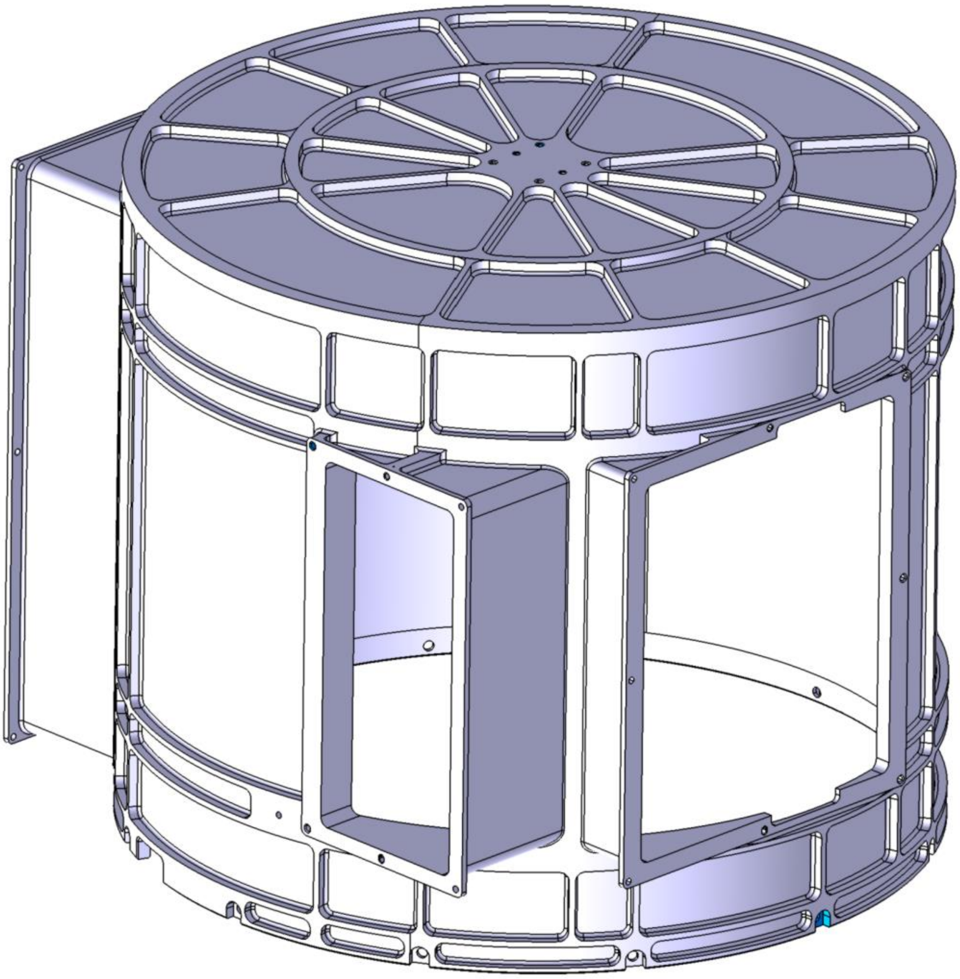

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Figure 16: CU Housing.

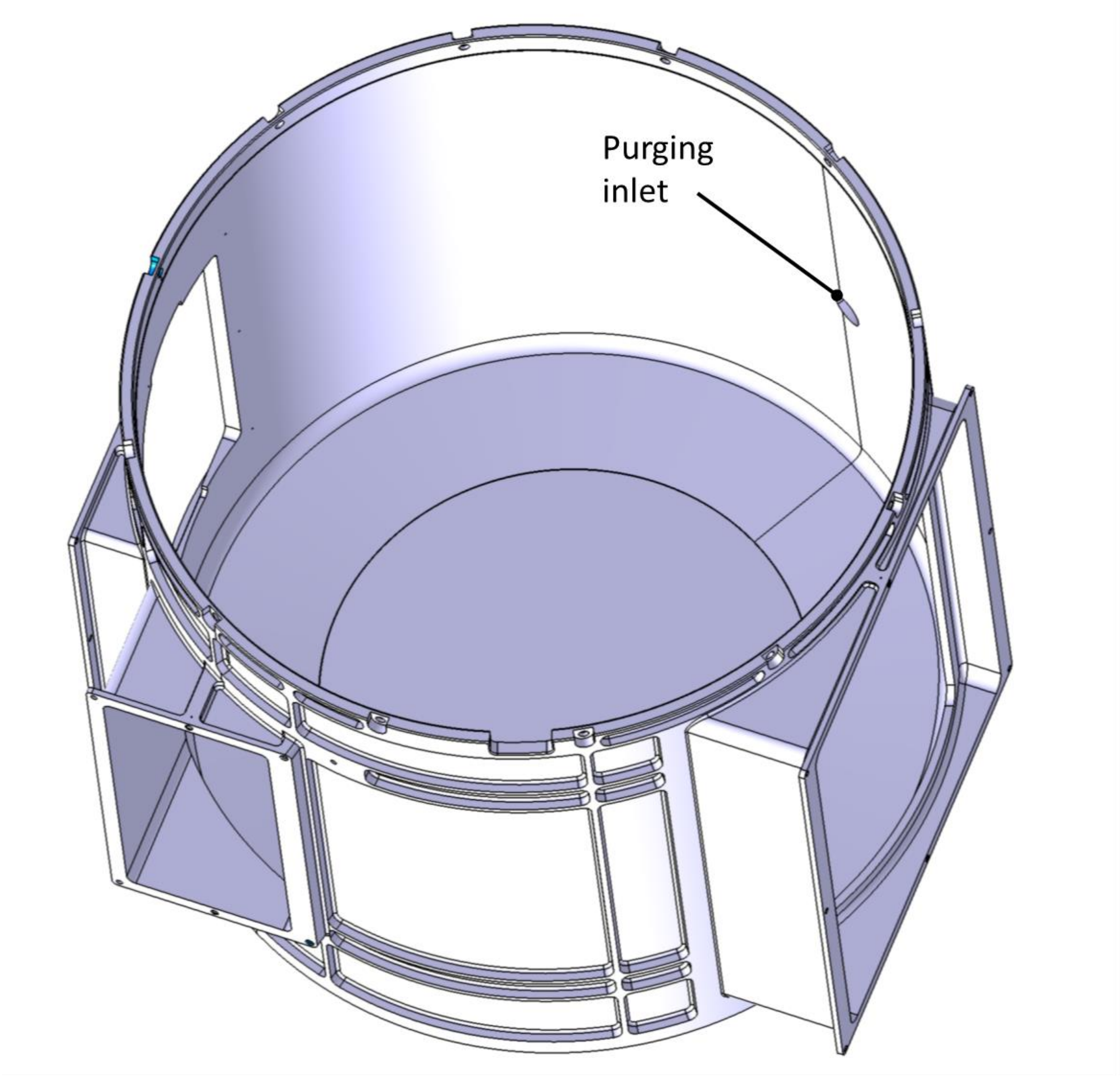

Figure 17: CU housing inside surface view.

The internal surface of the housing is smooth without corrugation being the latter not anymore needed as demonstrated by stray-light analysis performed at ESA. The nitrogen inlet is also visible in Figure 17.

5.4.2.2 CU Base

The CU base is shown in a top view in Figure 18 allowing to identify all internal elements.

The CU base allows for the mounting of the housing which is assembled on the CU base by means of diametrically oriented screws.

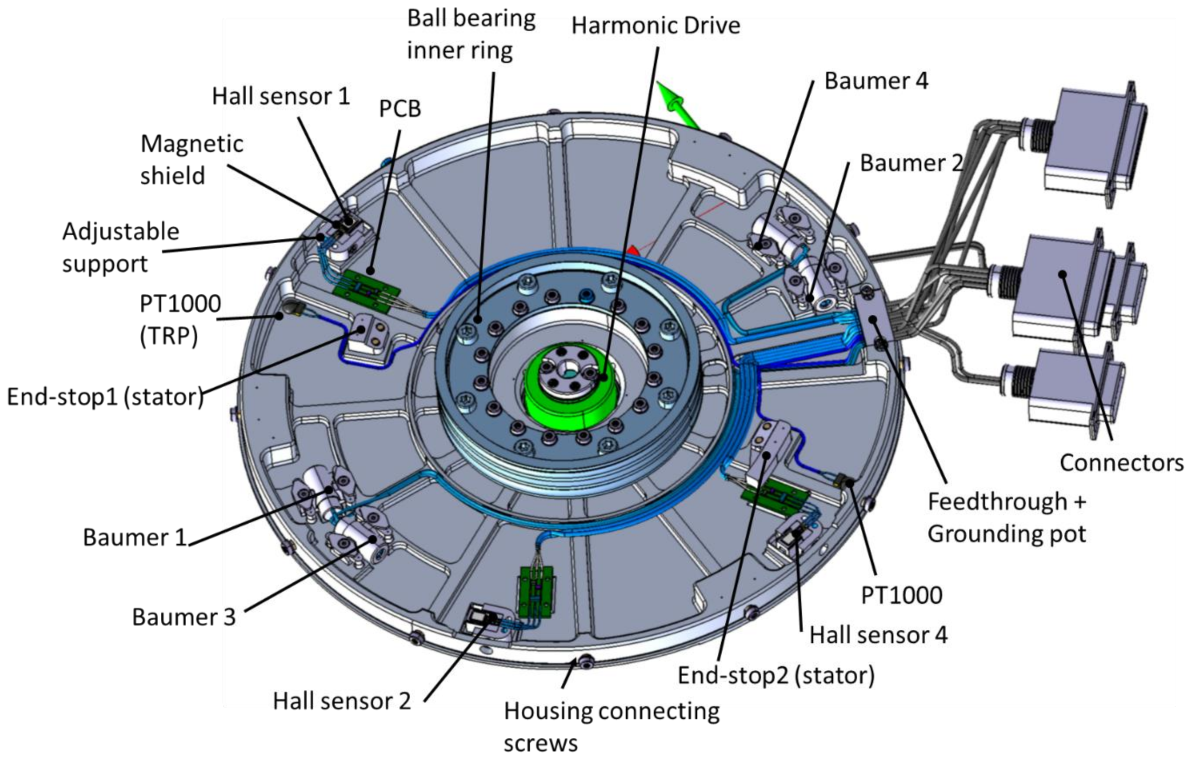

Figure 18: CU base top view.

The components located on the CU base are:

- 3x Hall sensors
  This sensors are deputed to identify the observation position and dark calibration position.

- 2 x switch pairs
  First pair (detection of the sun calibration position)

  Second pair is deputed to reset function (possibility to recalibrate the rotor position during flight).

  Each switch is mounted on a support adjustable from the bottom of the unit

- 2 x Stator end stops in 1.4543 H1000 which limit the rotation of the rotor ant the two extremities: (sun calibration and reset position)

- Ball bearing
  Inner ring displayed (balls and outer ring belong to the rotor assembly).

- 2x PT1000 (one of which is the thermal reference point (TRP)).
- The contamination control labyrinth and anti-creep barrier
  Both functionalized surfaces are the key of the particle and molecular contamination control generated by the ball bearing and harmonic drive.
- 6x Venting holes
  They are located within the bearing contamination containing zone diameter and evacuate the air trapped below the carousel through the optical bench (no contamination can pass at the CU/OBA interface) towards the instrument exterior (see Figure 19).

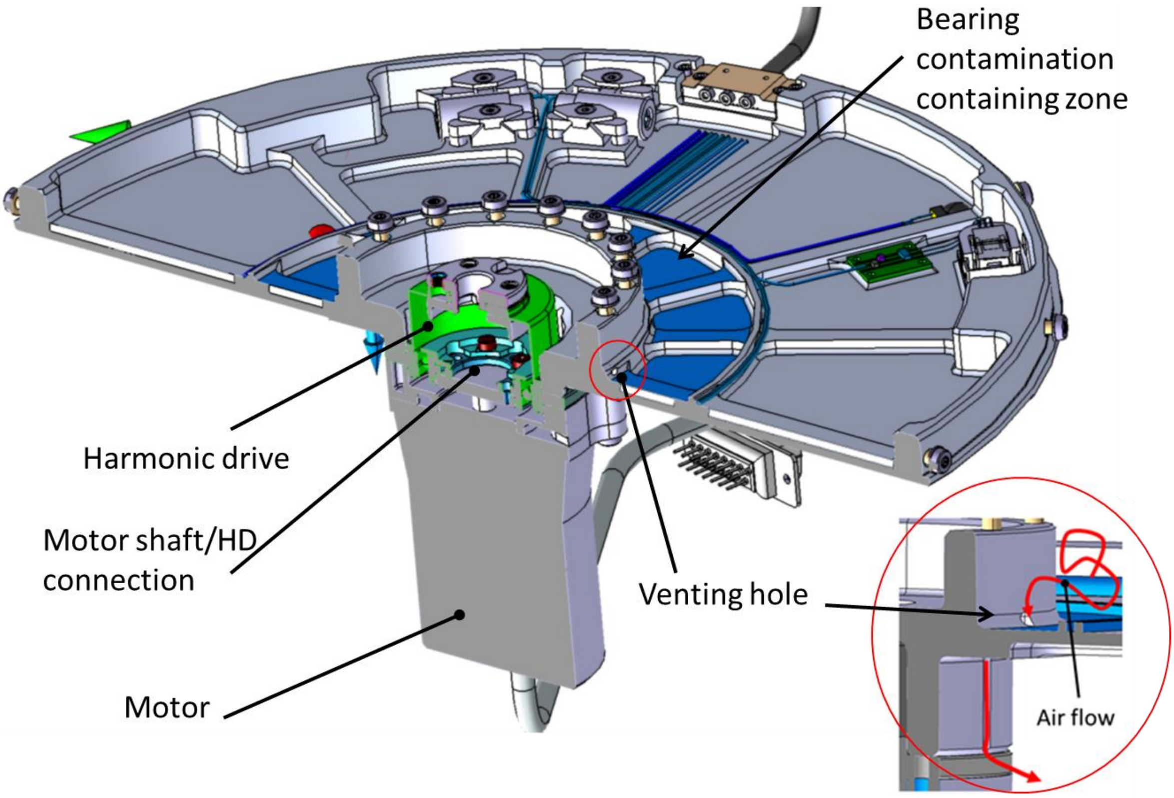

Figure 19: Cut view of the CU base with the motor already mounted.

5.4.2.2.1 Hall sensors mounting

The hall sensors are mounted on adjustable supports shown in Figure 20. The sensor is positioned in the support and carefully bonded on its edges as well as the connecting pins at their weldment with the cables. During CU base assembly, the sensor supports are temporarily positioned in their seat without further adjustment. Once the rotor is mounted and optical elements in place their final position is finely tuned in order to detect the magnetic field generated by the corresponding magnet assembly with the required accuracy. The sensor support is translated along the directions reported in Figure 20 by screwing or unscrewing the adjusting screw. The screw generates a translation of the wedge elements which generates a translation of the hall sensor along the circumferential direction. The wires soldered on the hall sensor pins are attached in such a way to allow for the displacement of the sensor.

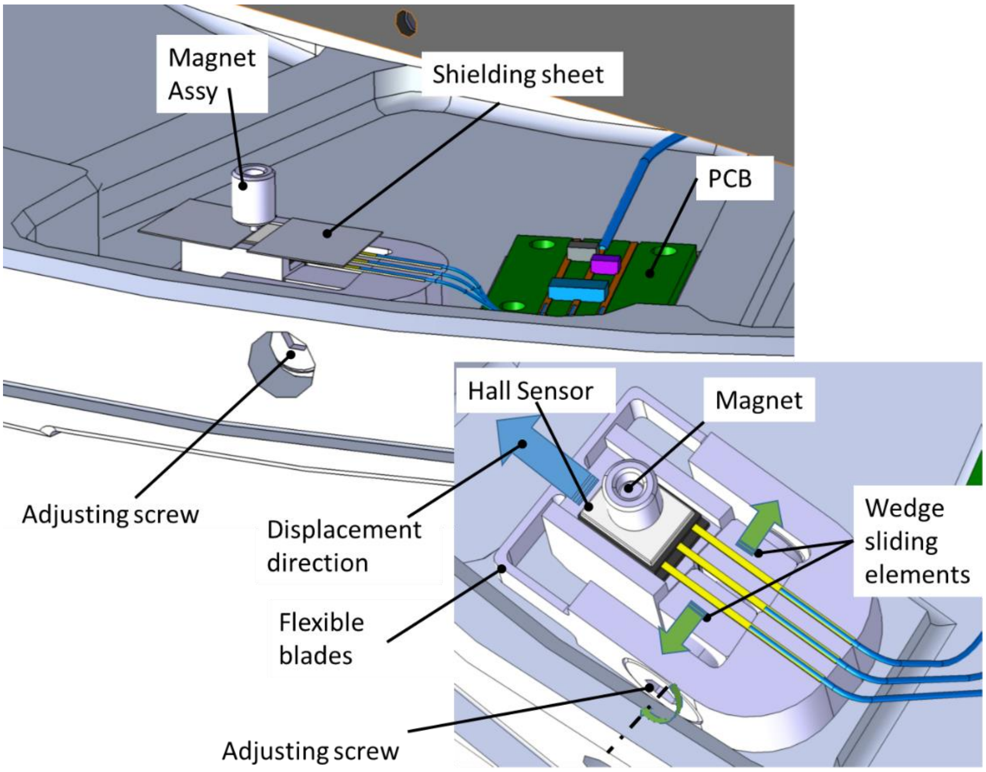

Figure 20: Hall sensors adjustable support. (Magnet Assembly is located on the rotor)

5.4.2.2.2 Baumer switch mounting

The Baumer switches are mounted on a sliding support to facilitate the correct positioning during CU carousel alignment. The configuration is reported in Figure 21. During the carousel alignment phase the rotor is put in place with the desired accuracy the motor is power off and the position in controlled again. At this point the switch assembly is put in contact with the rotor end stop and the position is locked by means of wedges which are screwed from the bottom side of the CU base.

The locking system shall be capable of sustain impact with the rotor end-stop without losing the accuracy of the position detection. The position knowledge requirement is ensured by previous calibration of the switch support wall which controls the sensor over-travel. The possibility of losing one fixation bolt is controlled by wedge detachment protection which ensure that in case of on screw fails the corresponding wedge will not float into the mechanism cavity avoiding possible mechanism jams.

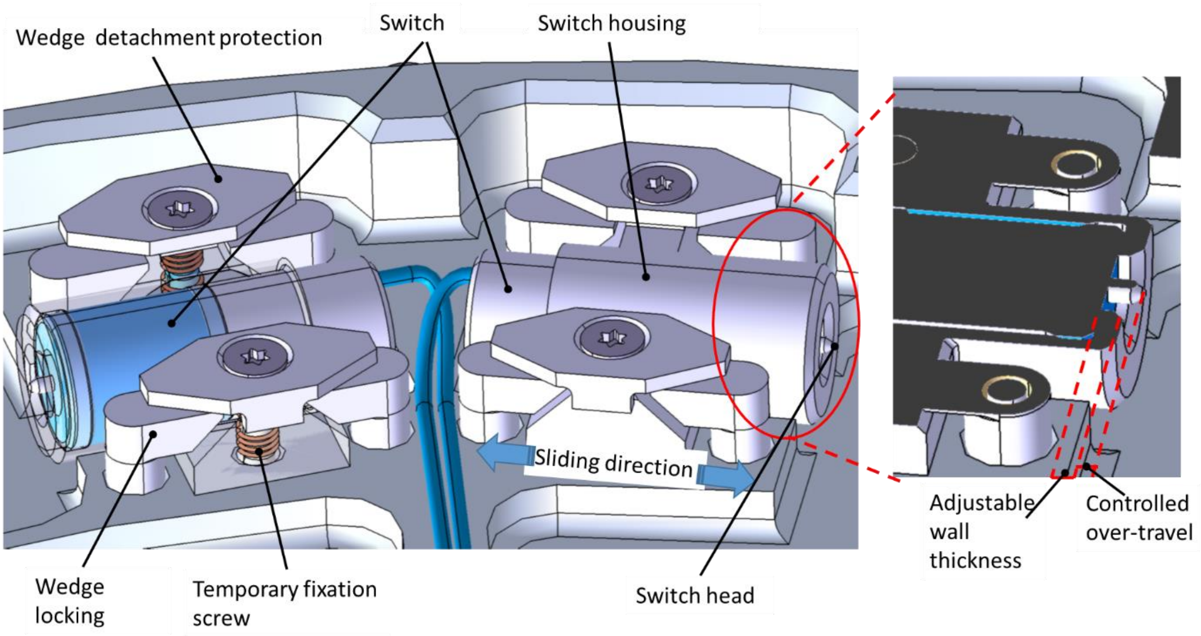

Figure 21: Baumer switch support for alignment and locking.

5.4.2.2.3 Wires grounding

The wires entering the CU base are shielded and, according to signal grouped, twisted paired. They will be clamped into a dedicated part screwed into the side wall of the CU base as reported in Figure 22. The wires shield will be electrically connected to the base.

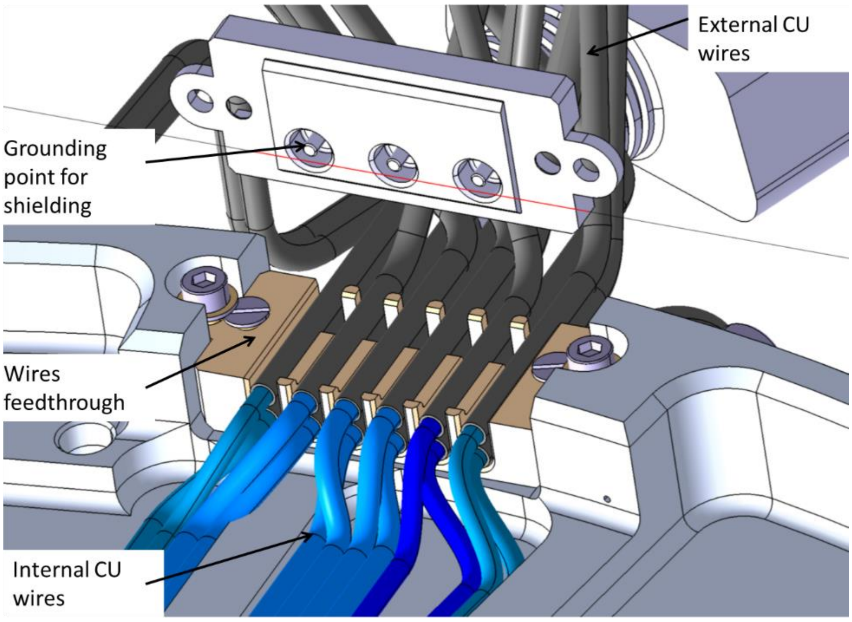

Figure 22: sensor wires exit point. Internal wires not shielded potted and clamped. External wires become shielded at the clamping point. Wires shields are grounded to the structure.

5.4.2.2.4 Sun Baffle

The sun baffle design is presented in Figure 23.

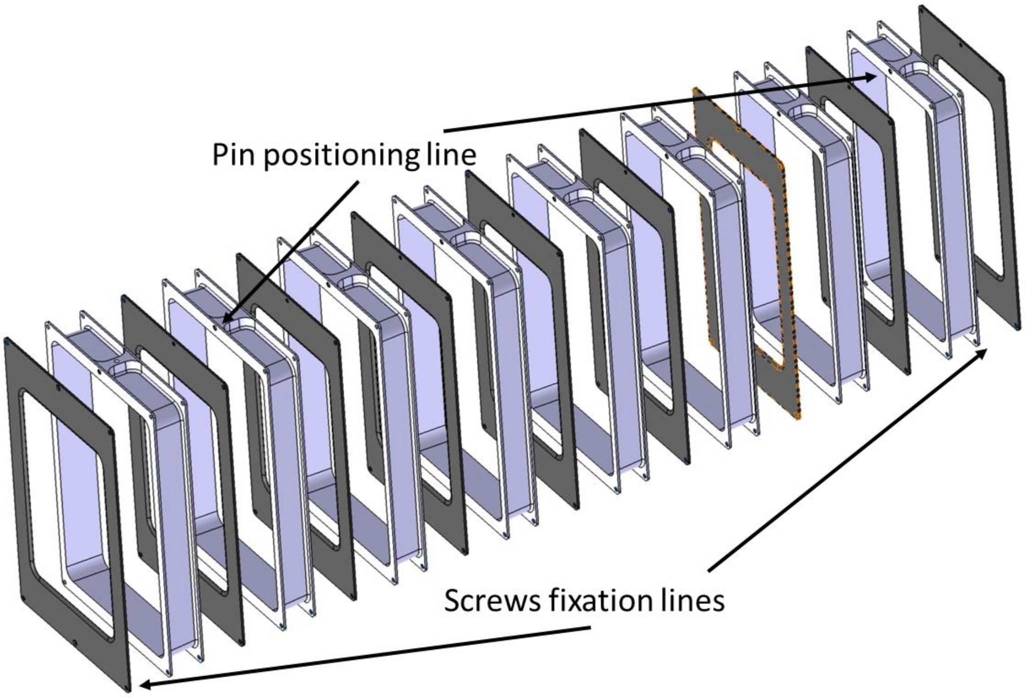

Figure 23: Sun baffle design

The design has been conceived in multiple parts in order to reduce the risk associated to a mono-block part. The axial position of the vanes, with respect to their nominal position, is adjusted during manufacturing by progressive part assemblies verifications.

The in plane vane position is guaranteed by two symmetrical lines of pins which are taken in sandwich among the parts.

5.4.2.2.5 Motor Pt1000 pass-through

The motor pt1000 wires are AWG28 twisted shielded. A small open channel will be machined on the central CU I/F zone in order to allow for the wires to be passed inside the envelope and between the CU I/F and the instrument optical bench. The wires will be kept in place by Kapton tape on the motor external surfaces and on the CU base external surface in order to avoid accidental wire damages during unit assembly. Finally the Pt1000 wires will join the sensors lines bundles before reaching the sensors connectors.

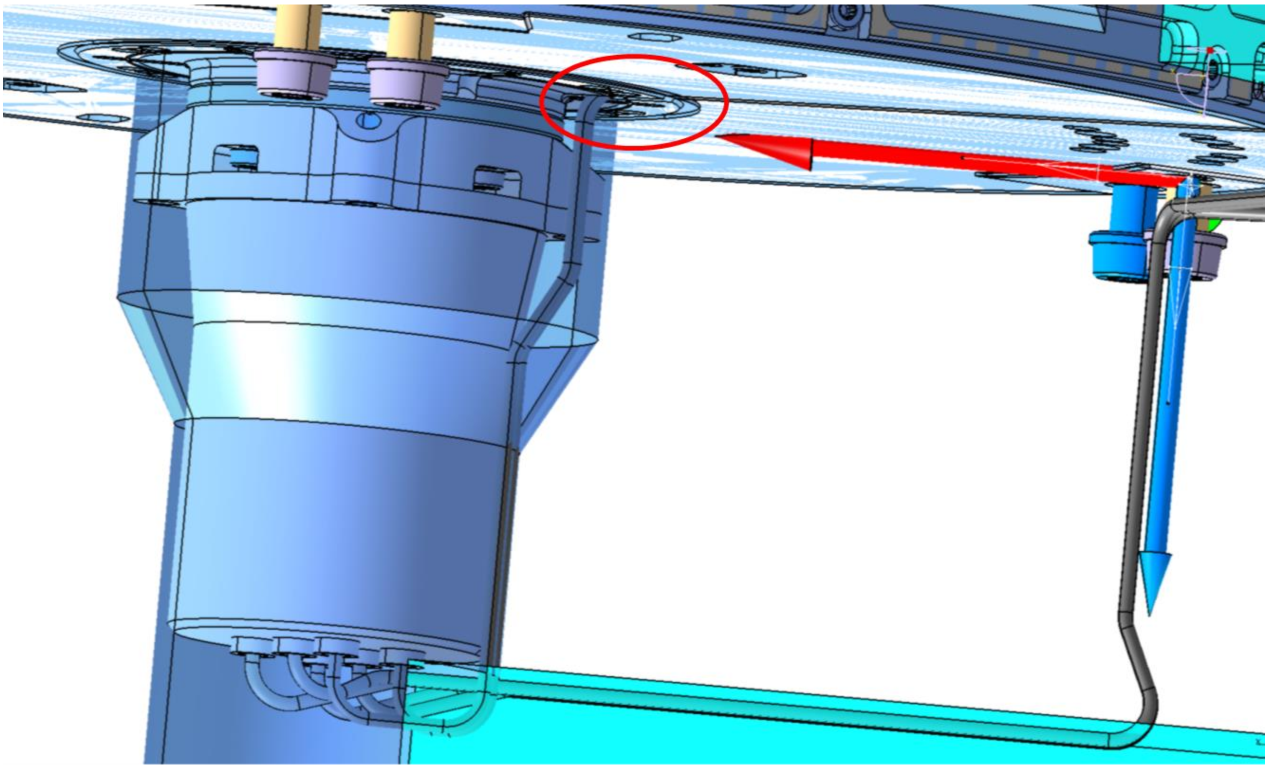

Figure 24: Motor Pt1000 wires pass-through.

5.4.2.2.6 Diffuser accessibility

The diffuser accessibility is important for the flight diffuser replacement before delivery. For this reason two cut-out are foreseen on the housing opening (see Figure 26) in order to allow the diffuser to slide through the opening during mounting and dismounting. For this operation the first 2 vanes shall be dismounted.

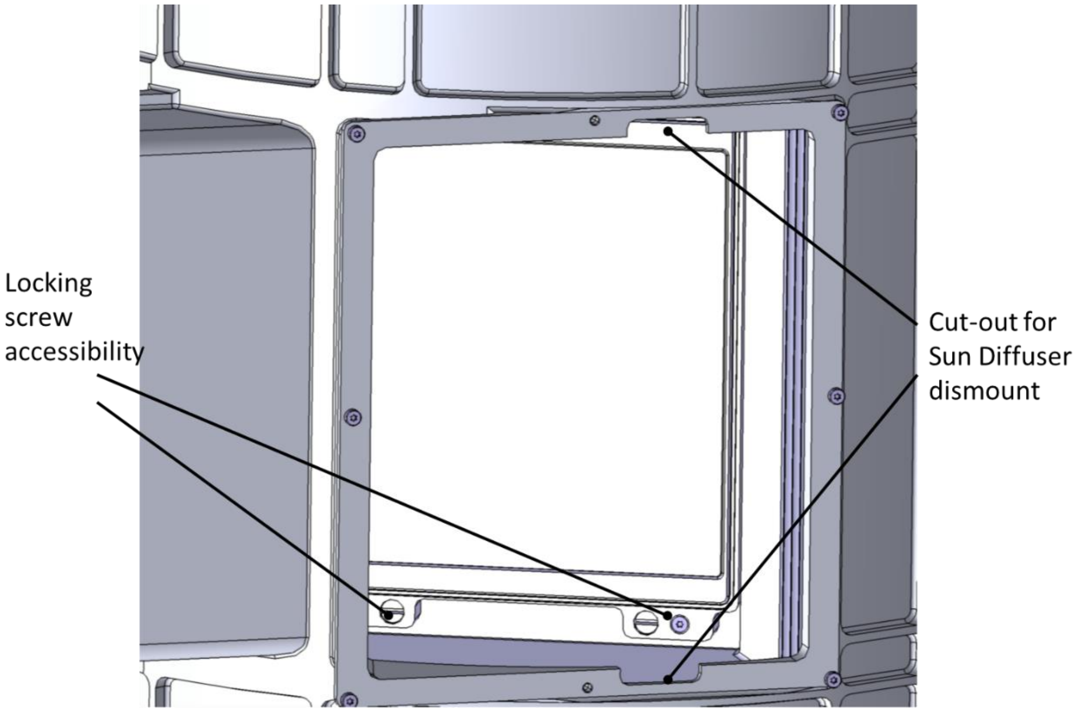

Figure 25: Sun diffuser accessibility for mounting/dismounting activities.

5.4.3 Rotor assembly

The rotor assembly is shown in Figure 26 and Figure 27. It is composed of the following main parts:

- Nadir baffle (rotor part)
- diametrical stiffeners
- Sun diffuser assembly
- Magnetic flux concentrators
- counter weights

Each of the sub-assembly is described in the following sections.

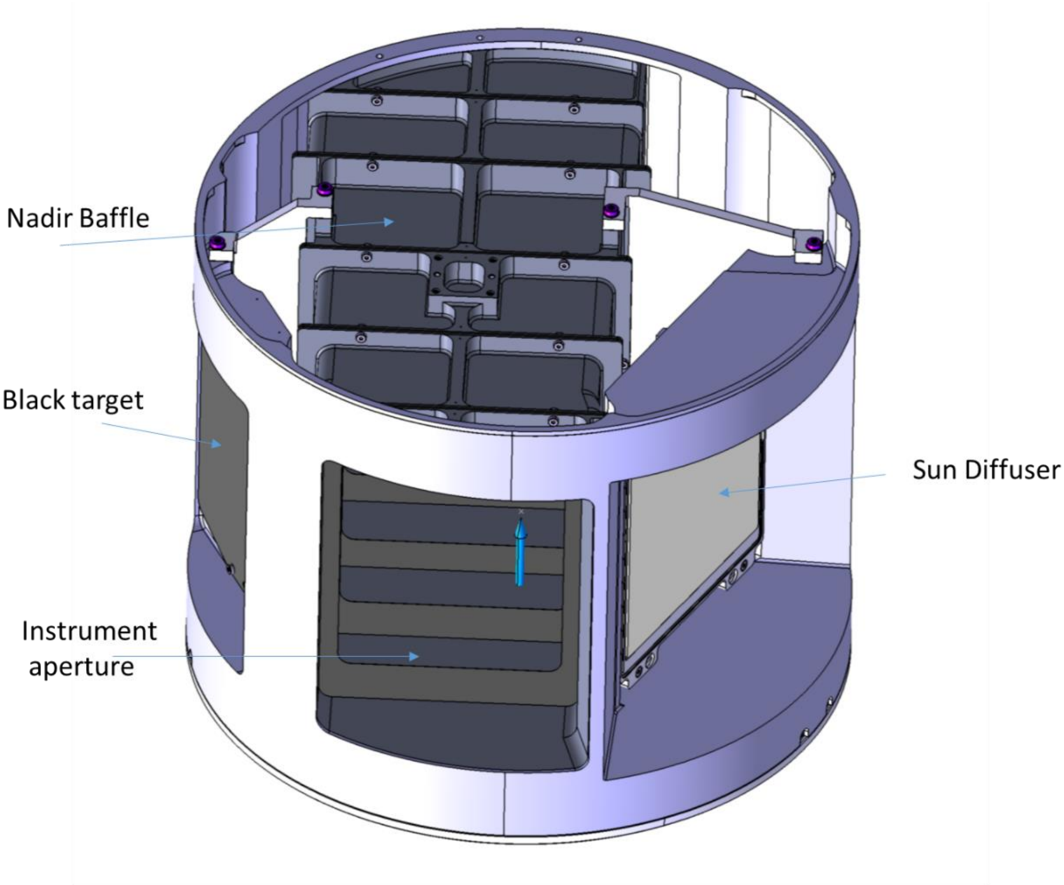

Figure 26: rotor assembly, lateral view

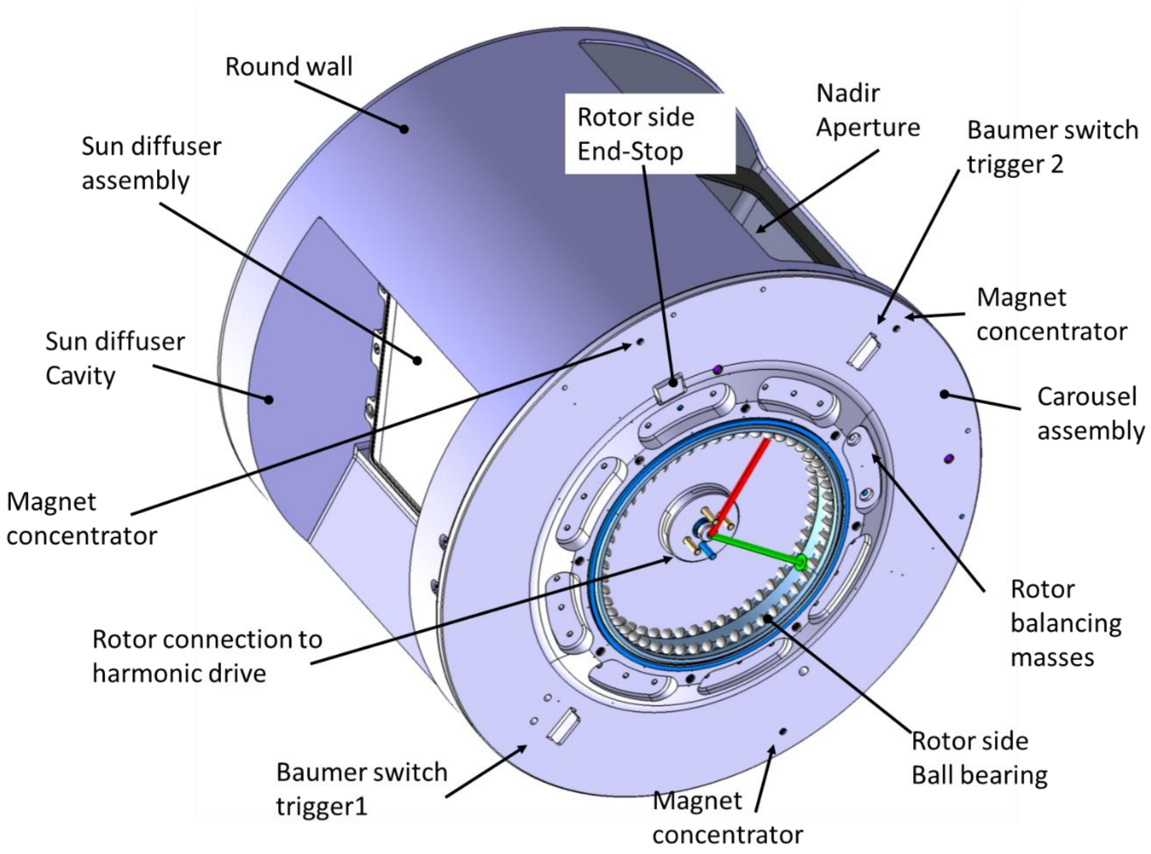

Figure 27: Rotor bottom view

The carousel hosts:

- the ball bearing outer ring and related balls
- 2x Baumer Switch trigger
- 1x End Stop (which will limit the rotation of the rotor and defines the two extremes positions.
- Location for tunable mass counter weights. These masses are located at the far bottom of the carousel assembly in order to reduce the z-position of the rotor CoG with respect to the bearing middle plane. These masses are adjusted during the rotor equilibration phase. By design 1 single mass is present.
- Magnet concentrator (holes for the concentrator tip are reported in Figure 27)

5.4.3.1 Carousel and Round Wall assembly

The carousel sub assembly is shown in Figure 28.

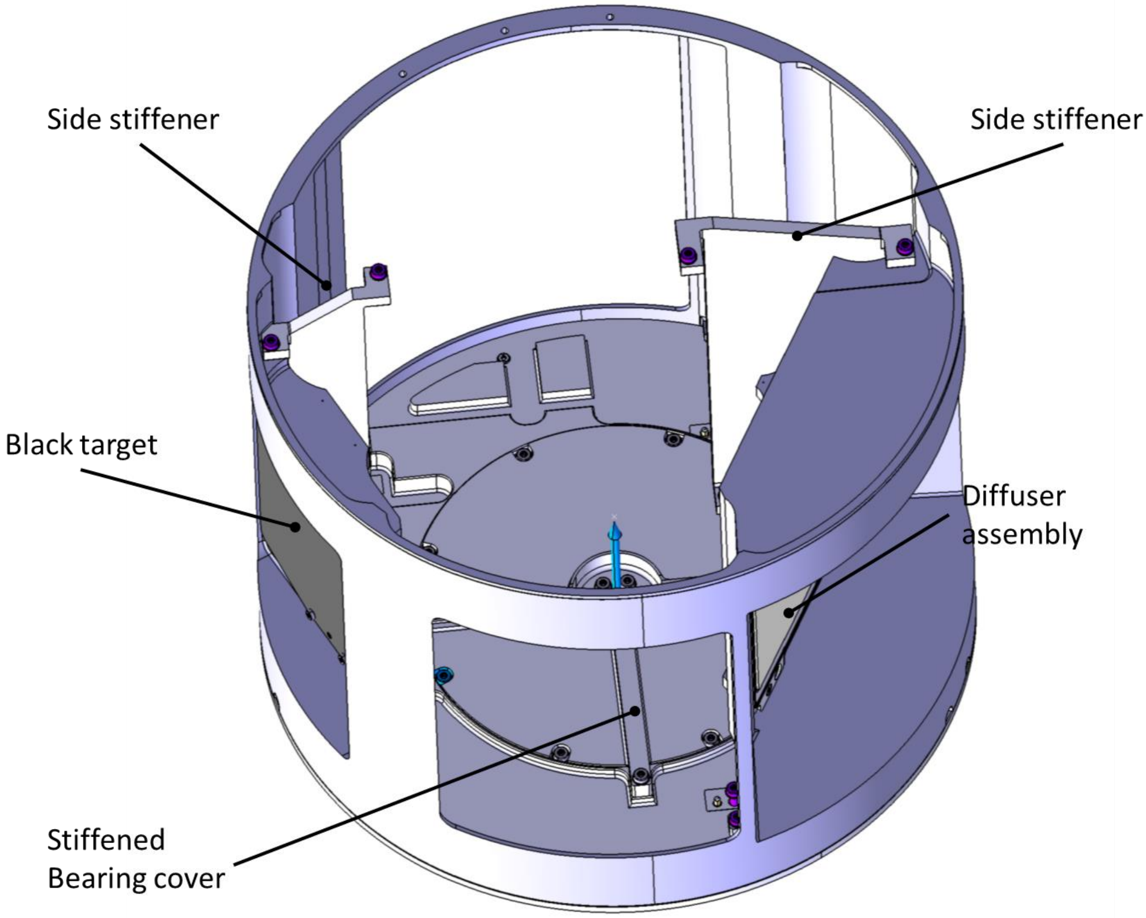

Figure 28: Carousel sub assembly

It presents the following elements:

- Sun diffuser

  The sun diffuser is located in its frame on the right hand side of the nadir baffle (looking along the observation direction). It presents provisions for a protective cap (not shown) with the double function of contamination protection and alignment since a mirror is located on the cap external surface.

  The diffuser is placed in an insulated cavity in such a way that contaminants or stray light reflected from all the directions cannot come directly in contact with the diffuser.

- Black target

  The black target is located in its frame on the left hand side of the nadir baffle (looking along the observation direction). It presents provisions for a protective cap (not shown) with the double function of contamination protection and alignment since a mirror is located on the cap external surface.

The black target is placed in an insulated cavity in such a way that contaminants or stray light reflected from all the directions cannot come directly in contact with the black target.

- Ball bearing cover

  It separates, avoiding contamination, the rotor upper volume from the lower volume where the bearing and the harmonic drive are located. Because of its fine adjustment no type of contaminant can reach the upper part of the rotor.

  The bearing cover is stiffened in order to reduce mechanical loads to the connected harmonic drive

- Nadir baffle side stiffeners

  These thin wall structures connect the nadir baffle to the round wall contributing to the bending stiffness of the whole rotor.

5.4.3.2 Nadir Baffle

The nadir baffle subassembly design is shown in Figure 29.

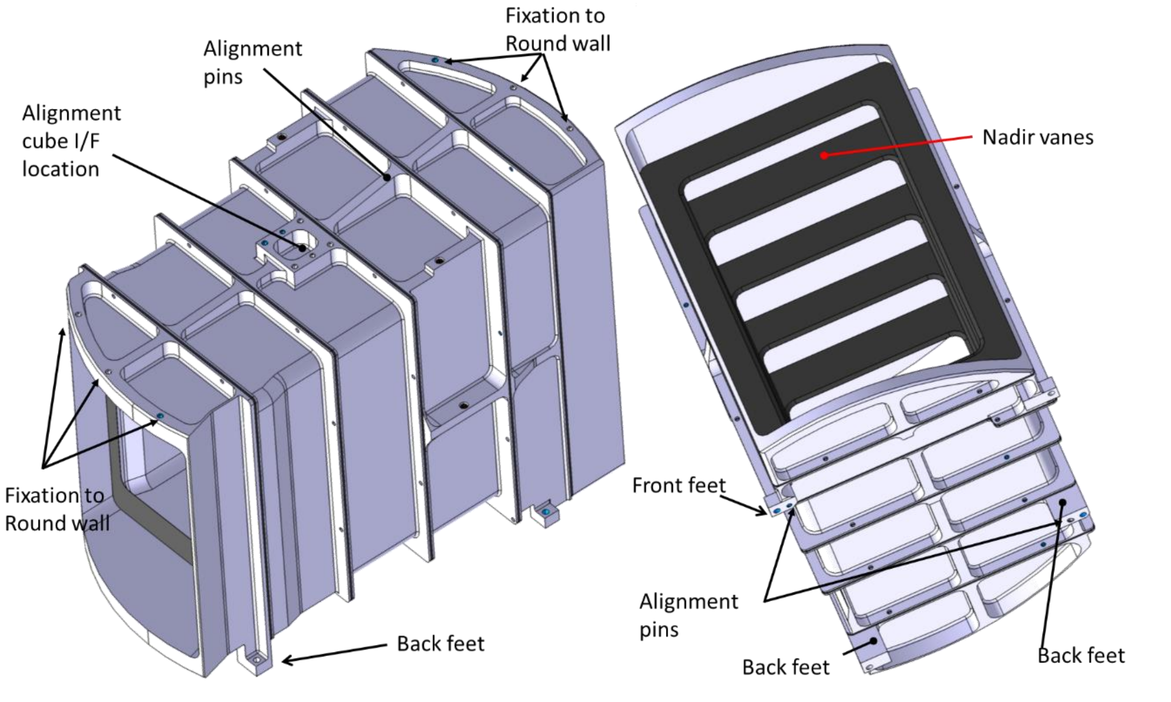

Figure 29: Nadir baffle, back and front-bottom view.

The nadir baffle is assembled in the same way of the sun baffle. The vane axial alignment is guaranteed by successive partial assemblies during the machining phase and the vane in plane alignment is guaranteed by the use of two lines of alignment pins located in the baffle stiffeners.
Moreover, the front feet are directly machined on the inter-vane part, the back feet are connected with the relative inter-vane parts by means of alignment pins.

The feet are connected also by alignment pins and screws on the carousel base. On the upper part, the baffle is connected directly to the round wall in order to prevent light propagation on the inside of the rotor cavity and to ensure mechanical continuity and stress path closure with the round wall.

5.4.3.3 Sun diffuser assembly

The sun diffuser in encapsulated between the bottom and top frame as reported in Figure 33. The top frame is attached by means of 8 screws from the back side of the bottom frame. This solution minimizes the number of screws heads on the functional side of the assembly reducing the possibility of spurious light reflections.

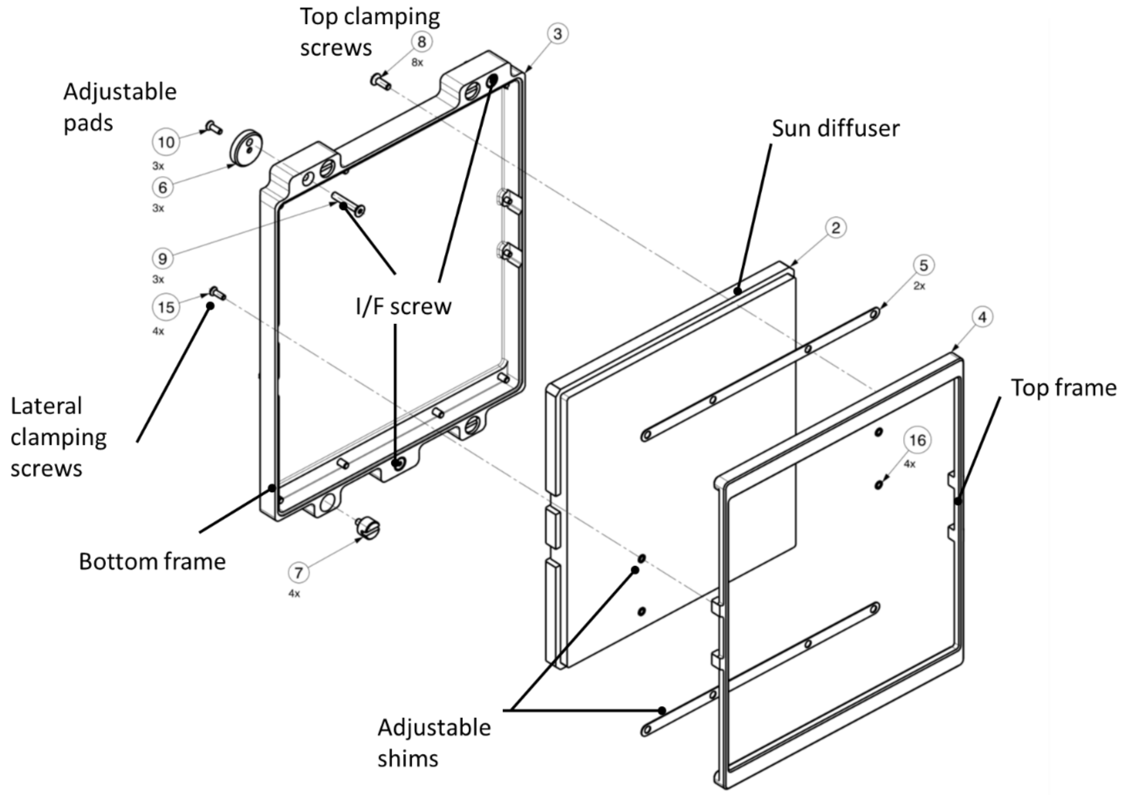

Figure 30: Diffuser assembly design

The back side of the bottom frame is equipped with 3 adjustable pads which can be polished during assembly of the diffuser assembly on the rotor assembly in order to recover possible angle misalignment of the diffuser. The pads are also screwed independently on the frame in order to ensure their correct positioning during diffuser mounting/dismounting at PFM level.

Three fixating screws from the front side of the diffuser are used to lock in place the diffuser assembly after alignment.

The diffuser geometry presents a stepped shape in order to allow the lateral side of the frame to contain the diffuser itself. This solution avoids misalignment during dynamic loads. The diffuser functional dimension are: 102.4mm x 96.6mm which is compliant to requirement FLO-CU-URD-REQ-0590. The overall dimensions are 106.4mmx100.6mm. The overall thickness is 8 mm and the reduced thickness is 5mm. Once mounted the diffuser protrudes from the top frame plane by 0.2mm as reported in Figure 31.

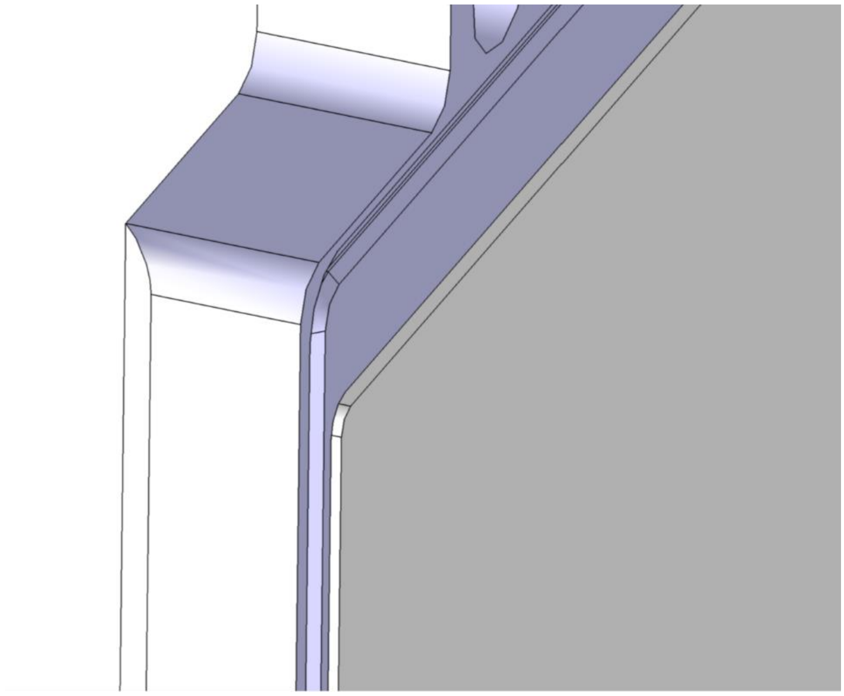

Figure 31: Sun diffuser protrusion outside from the top frame

This protrusions allows for covering a part of the diffuser manufacturing tolerances on the thickness and reduces the effect of the top frame on the reflected light.

5.4.3.4 Black target

The black target has dimensions 92mm x 107mm and presents stiffeners on the back side as reported in Figure 35.

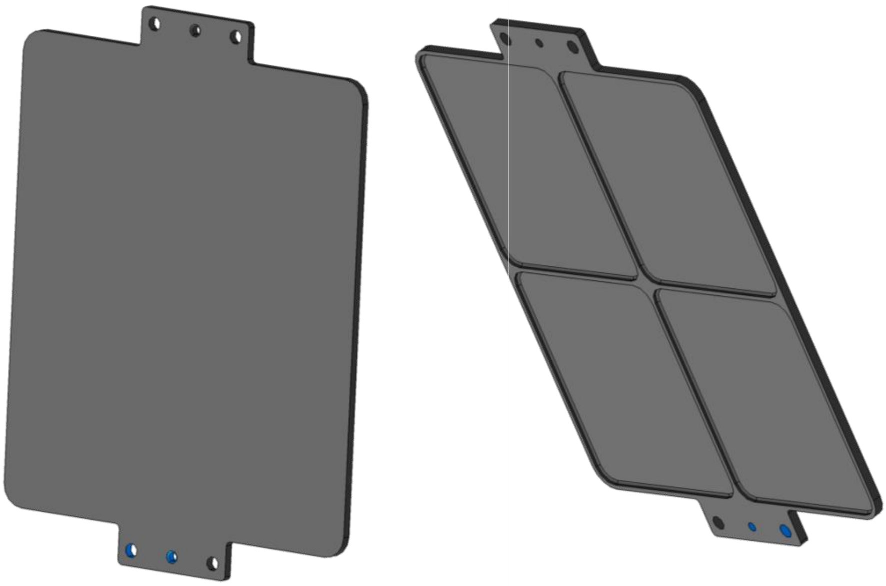

Figure 32: black target geometry.

5.4.4 Functional Description

This sections describes the functionalities of the current CU designs. In particular the following aspects are discussed:

- Observation position
- Dark calibration position
- Sun calibration position
- Contamination control
- Stray-light control

5.4.4.1 Observation Position

A cut view of the observation position is reported in Figure 33.

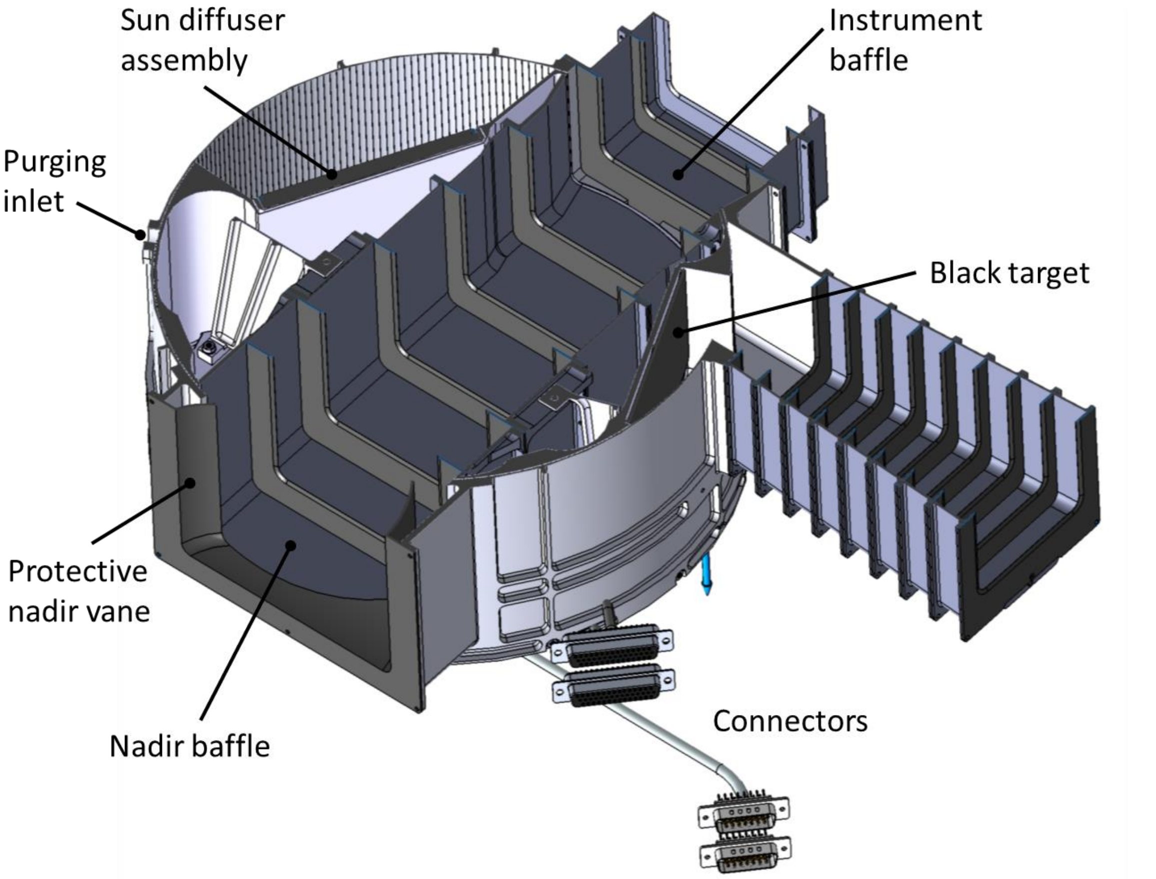

Figure 33: Observation position, cut view.

In this position the following considerations can be performed:

- the protective nadir vane do not obstruct the nadir field of view.

  Its contamination protective function in this position is not used. However, because of its particular shape, it contributes to protect the gap between rotor and stator from multiple ray reflection.

- The sun diffuser is completely hidden inside the CU stator

  Any external contamination shall travel a long path before reaching the sun diffuser from the nadir aperture. In addition, it is placed on the other side of the instrument aperture meaning that external contamination from the sun port is not possible.

- The black target is partially exposed to the sun port

  This exposition cannot be avoided as it will be clear by the comparison with the dark calibration position. The choice of protecting the most sensitive element, the sun diffuser, was privileged as driving factor.

- The purging inlet is not aligned to the diffuser

  In this position the purging inlet points directly to the rotor round wall.

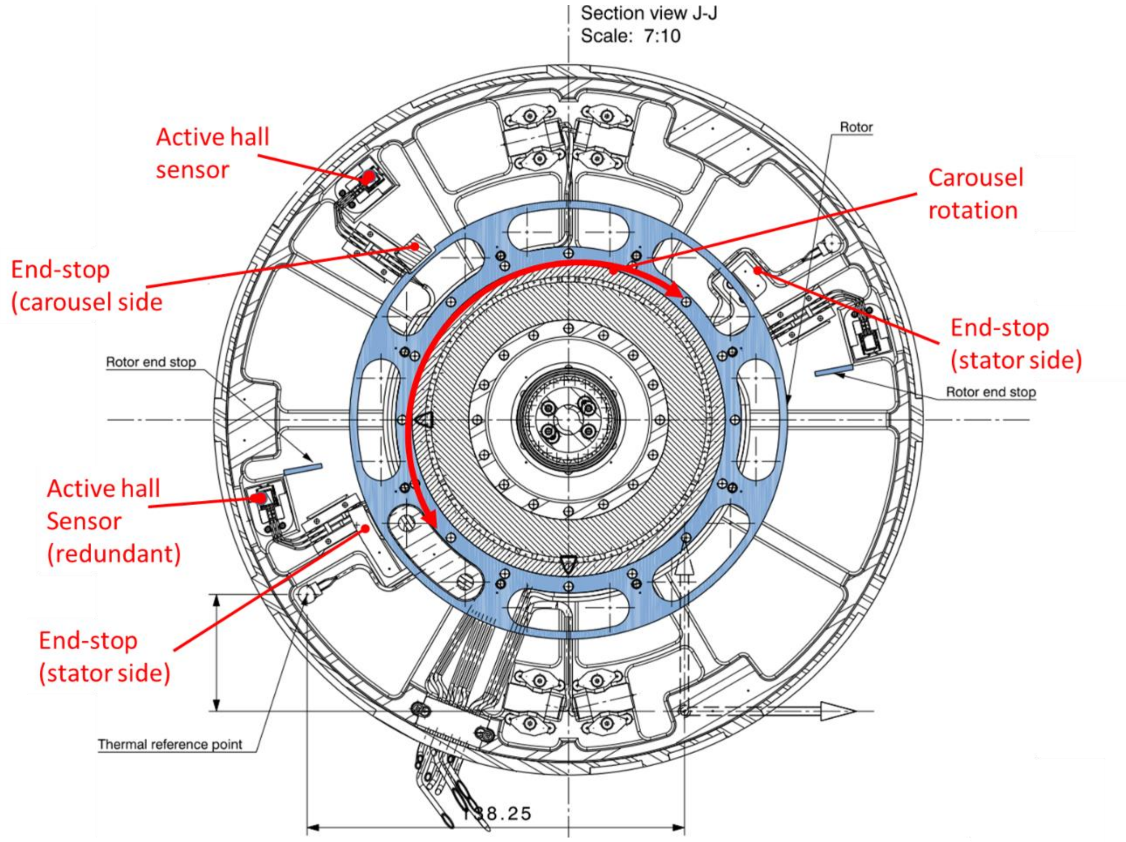

Figure 34: Observation position: Active Hall sensors location

In Figure 34 the active hall sensors detecting the position are also shown. As it can therein be seen 2 magnets (red dots) are in this position superposed to two hall sensors (one main and the other redundant). The other hall sensor is inactive and do not have magnet superposed to their positions. In this position switches are not activated. The rotor end-stops is not in contact with the ones on the stator.

5.4.4.2 Dark Calibration Position

A cut view of the dark calibration position is reported in Figure 35.

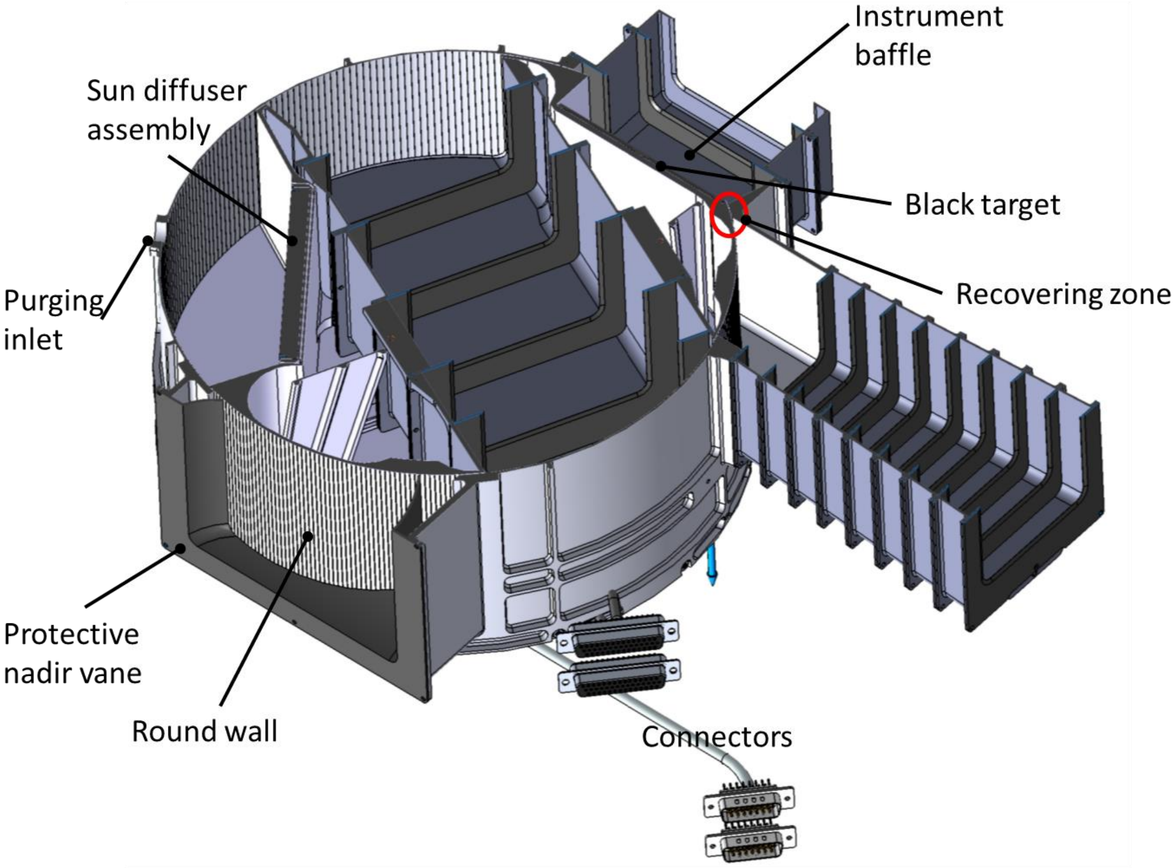

Figure 35: Dark calibration position, cut view.

In this position the following considerations can be performed:

- Both nadir and sun aperture are obstructed by the rotor round wall
- The sun diffuser is protected by the instrument exterior.
- The superposition of the rotor round wall with stator internal surface
- The protective vane which is almost tangent to the stator.
  It can be seen that the distance between a contaminant potentially able to enter into the diffuser cavity is increased by the use of the protective vane.
- The nadir baffle is also protected by the instrument exterior
  In particular, the advantage of having the nadir baffle protected is twofold. Firstly, no contamination can reach the interior of the housing. Second there is no possibility to contaminate the vanes which can result in instrument decrease of performances.
- The purging inlet faces the sun diffuser

More details of Figure 35 reported from Figure 36 to Figure 39.

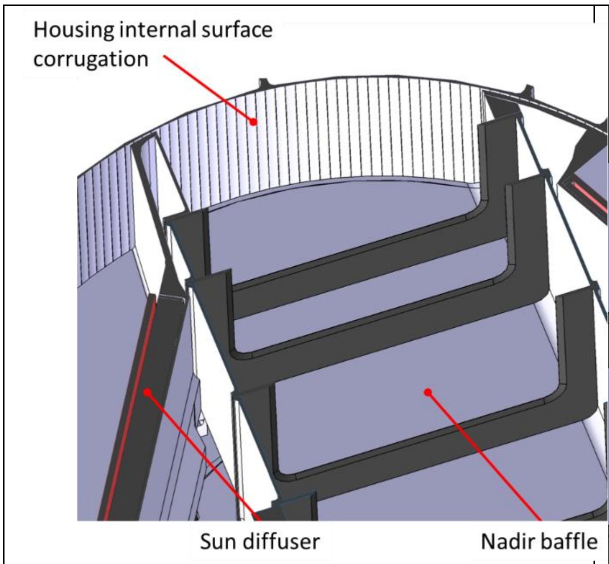

Figure 36: detail of Figure 35

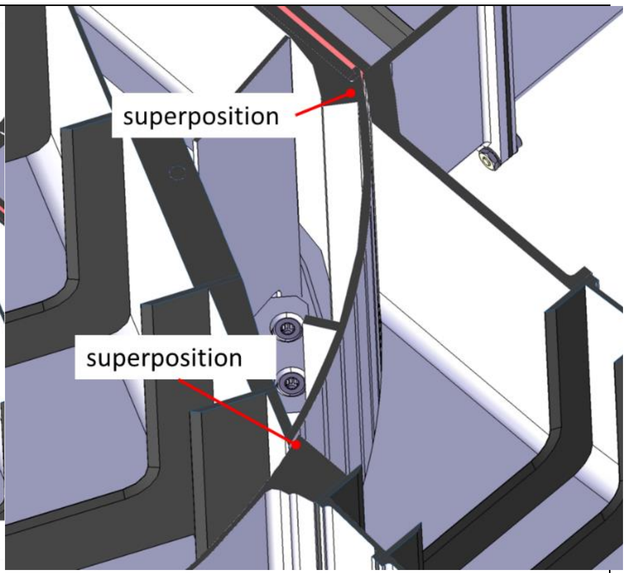

Figure 37: detail of Figure 35

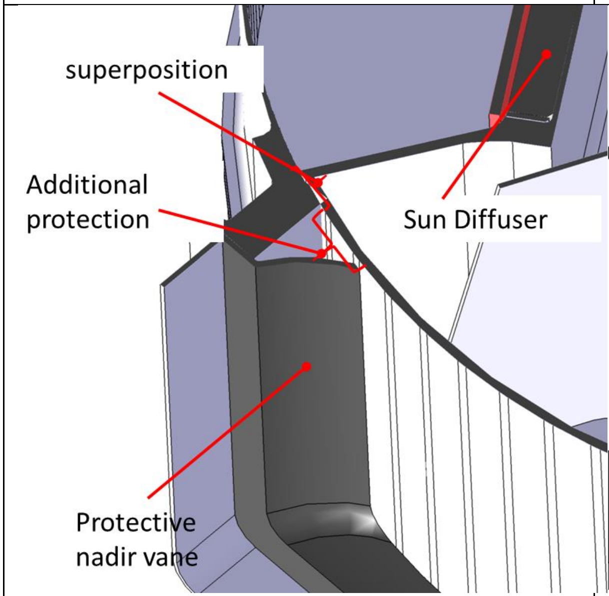

Figure 38: detail of Figure 35

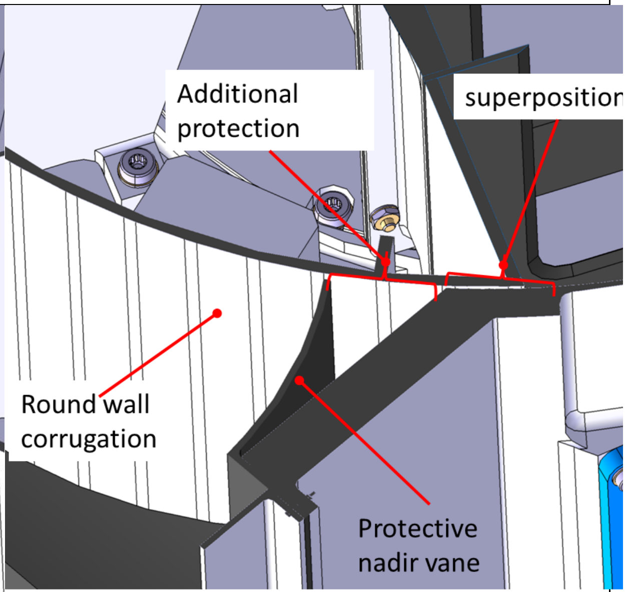

Figure 39: detail of Figure 35

In Figure 40 the active hall sensors detecting the position are shown. As it can therein be seen 2 magnets (red dots) are, in this position, superposed to two hall sensors (one main and the other redundant). The other hall sensors is inactive and do not have magnet superposed to their positions.

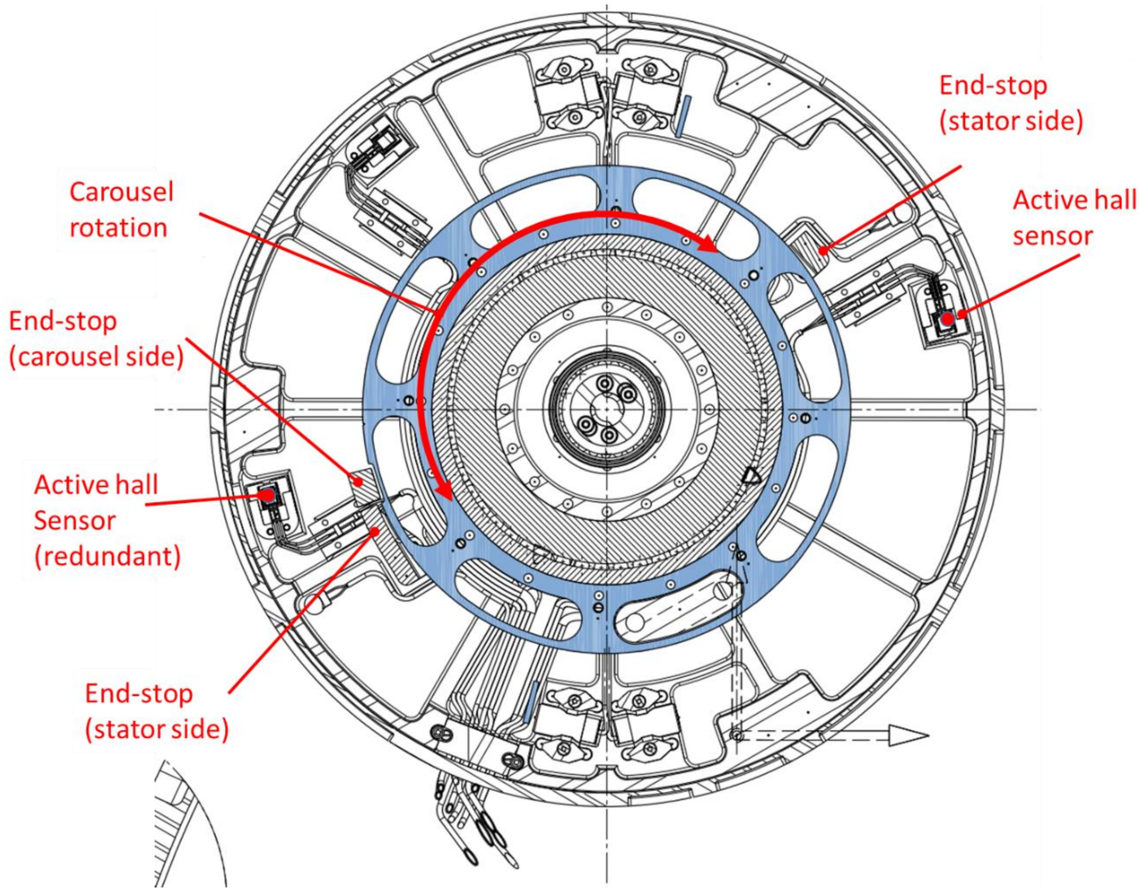

Figure 40: Dark calibration position: Active Hall sensors location

Figure 40 reveals the relative position of the end stops and switch. In this position, Baumer switches are not activated in order to avoid possible reset switch damage during launch. The distance between the Baumer switch head and the reset trigger is ~1.3mm.

The end stop on the rotor side and the one on the stator are also at the same distance.

5.4.4.3 Sun Calibration Position

A cut view of the Sun calibration position is reported in Figure 41.

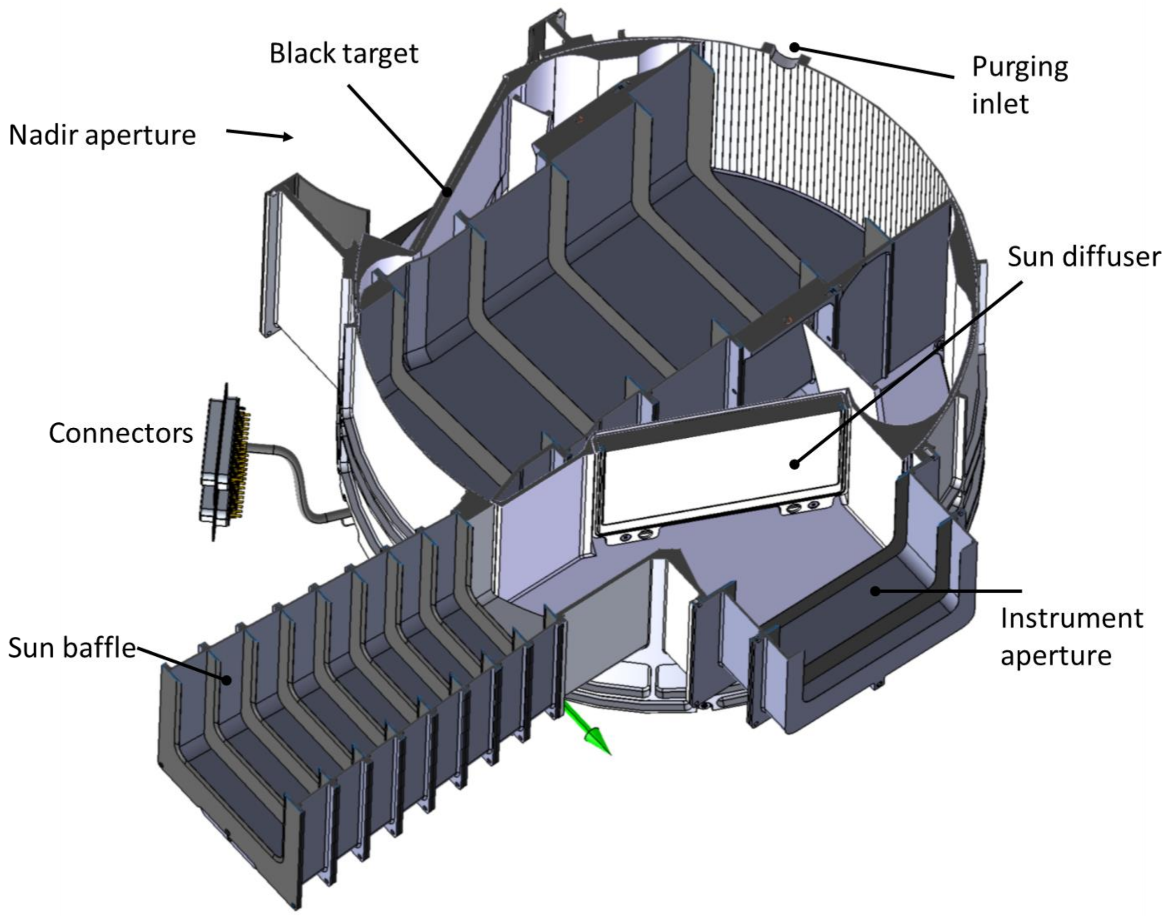

Figure 41: Sun calibration position: cut view.

In this position the following considerations can be performed:

- The black target is exposed to the exterior of the instrument by the Nadir aperture As previously discussed, this condition cannot be avoided since the protection of the sun diffuser is privileged.
- The nadir baffle is completely protected
- The purging inlet points directly on the nadir baffle
- The diffuser is aligned with an angle of 25 degrees with respect to the nadir direction.

In Figure 42 the active Baumer switch sensors detecting the position are shown. The hall sensors are inactive and do not have magnet superposed to their positions.

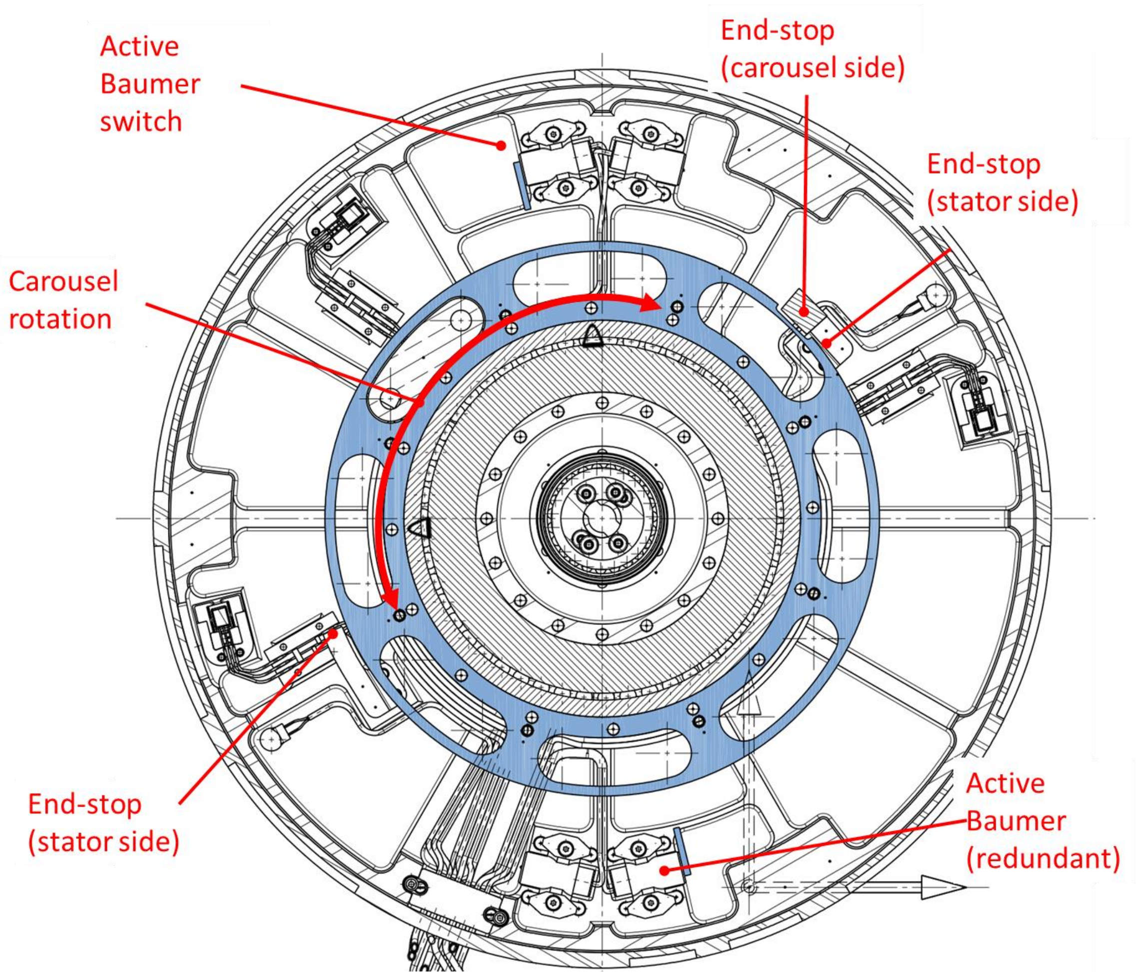

Figure 42: Sun calibration position: active Sensors location.

In this position, 2 triggers are in contact to the Baumer switches heads. The end of the activation range is ensured by the end stop located on the stator and rotor side.

5.4.4.4 Reset position

The reset position is 1° further the dark calibration position. This choice was necessary to avoid any possible contact during the launch phase between the rotor end-stop and the stator end-stop locating the reset switches. The result of such addition rotation is negligible. In fact the CU is still completely closed even if with less margins especially on the sun aperture close to the nadir baffle intersection.

A cut view of the CU in reset position is reported in Figure 43.

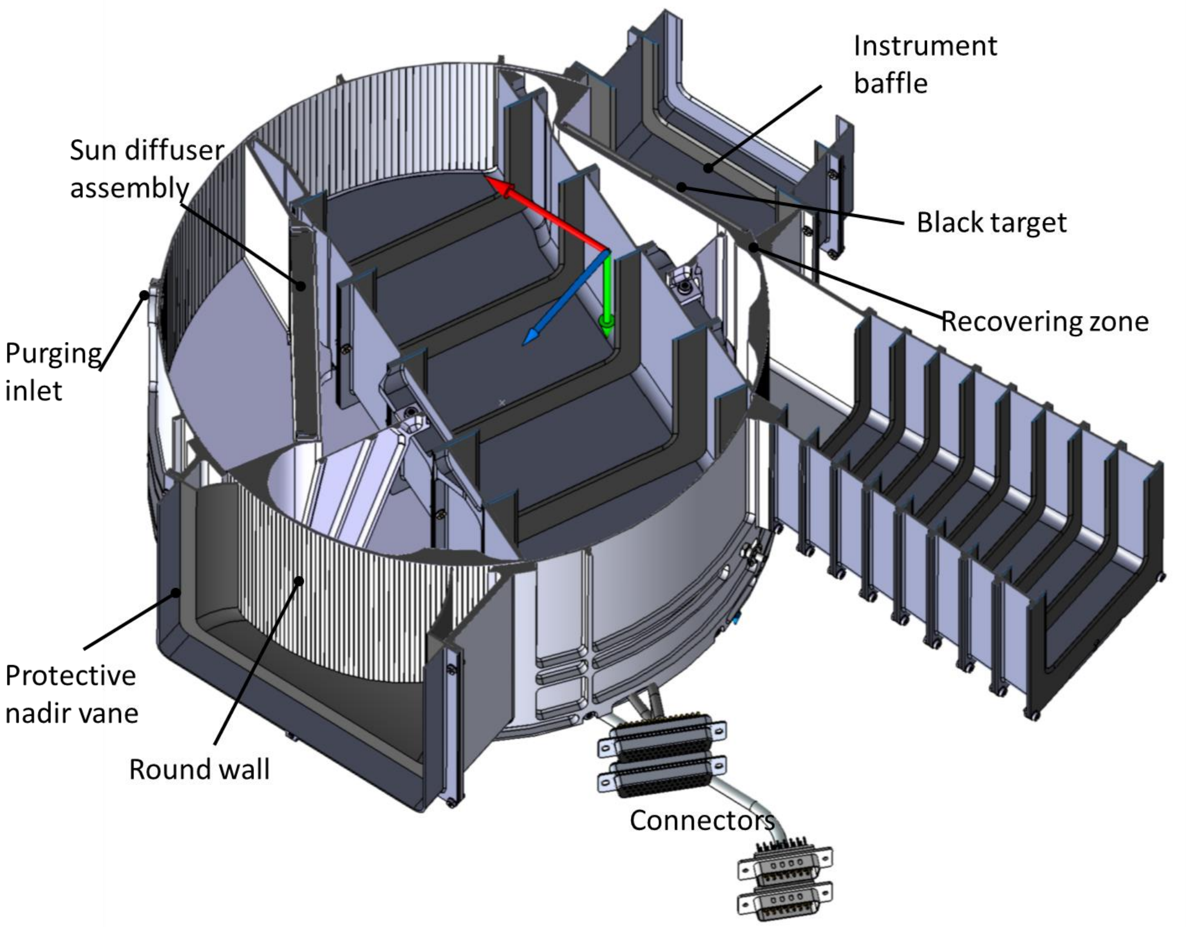

Figure 43: Calibration unit in reset position

In Figure 44 the corresponding sensor configuration is also reported.

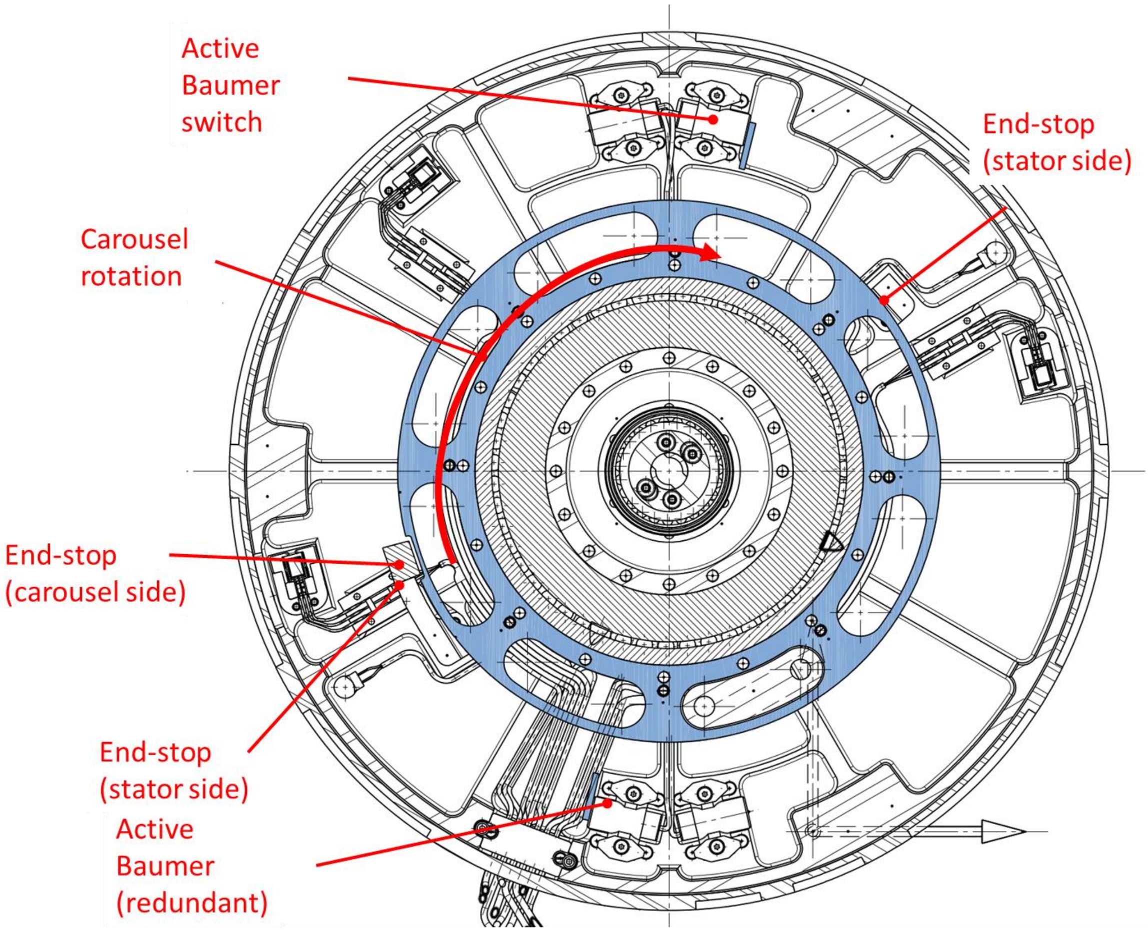

Figure 44: Reset position: active sensors configuration.

5.4.4.5 Contamination Control

Part of the design phase was deputed to the analysis and implementation of the contamination control means to ensure that external and internal contaminant are not able to reach the sensitive optical parts.

This sections presents more details on the contaminations controls means put in place in order to isolate the contaminations generating elements (ball bearing, harmonic drive) from the optical elements.

The design choice to compact all the polluting elements in a single cavity reveals its importance at this stage. This solution is shown in Figure 45 and Figure 46 and detailed here after.

In the upper part of Figure 45 and Figure 46 shaded in light green the optical cavity is outlined. The cavity is separated by the mechanical cavity by the carousel plate, the bearing cover, the housing and the CU base plate.

The only openings that put in communication the two cavities are the gaps between the rotor and stator (housing/round wall) and between carousel plate and CU base. The width of this gap is 0.7mm and 0.25 mm respectively.

The path that the contaminant shall travel to reach optical sensitive elements depends on the distance of the latter from the carousel. It is underlined here that black target and sun diffuser are also located in a pertinent cavity which is separated by walls from the optical cavity.

The volume occupied by the harmonic drive is delimited by the bearing cover the CU base and the motor. This volume is vented directly outside of the optical bench as reported in the Figure 45 by the red arrow.

The volume inside the harmonic drive is vented directly on the previous volume by holes machined on the rotor shaft. The venting path is reported in Figure 46 by the light blue arrow.

The entire volume beneath the carousel, and which contains the bearings is principally vented outside of the instrument through the optical bench. The venting path is reported in Figure 46 by the green arrow. Part of the volume will be also vented towards the sun and the nadir aperture which are the only opening communicating with exterior. However, during launch this openings will be closed by the rotor round wall therefore no significant contamination flux is expected towards the black target and sun diffuser (insulated by the round wall and their own cavity walls).

In addition, the volume around the bearing is insulated by a labyrinth, therefore this smaller volume is vented directly to the exterior of the instrument as reported by the yellow arrow in Figure 45.

The optical cavity is vented by the top side of the Rotor through the nadir and sun apertures. The air flux during venting, since passing through a thin gap will take presumably more time than the rest of vented volumes. This conditions is beneficial since the rotor/stator gap will longer be in overpressure conditions with respect to the external environment decreasing the chances for external contamination to infiltrate along the gap. The venting path during the launch configuration from the optical cavity are described in Figure 47. As described two fluxes of different intensities are expected depending on the geometries of the gaps. Low intensity flux are reported in dashed arrows and higher intensity fluxes are reported in full arrows in Figure 47.

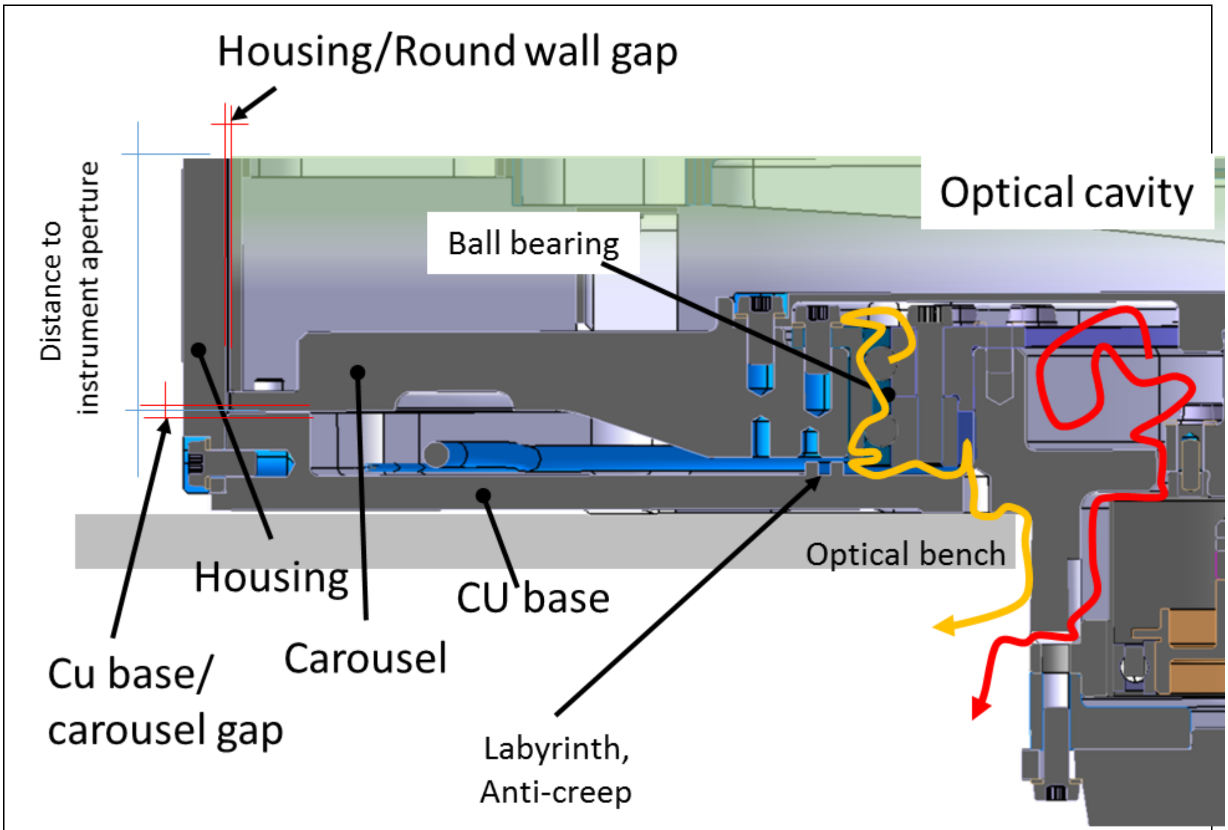

Figure 45: vertical section, mechanical cavity venting.

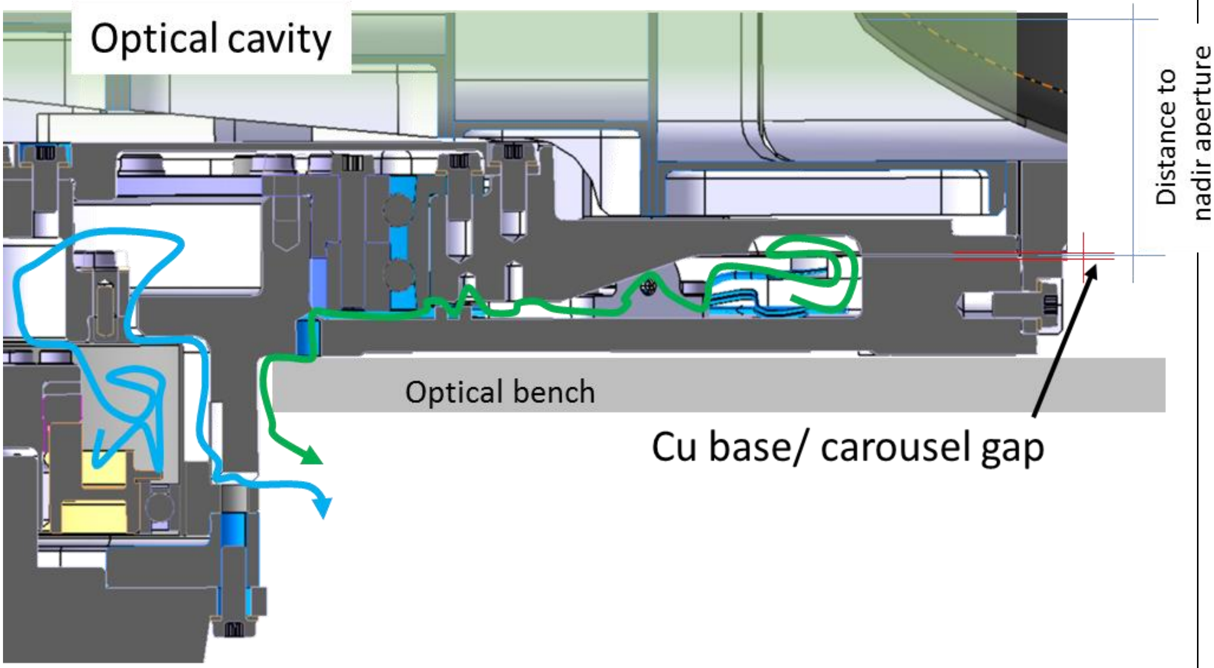

Figure 46: vertical section, mechanical cavity venting.

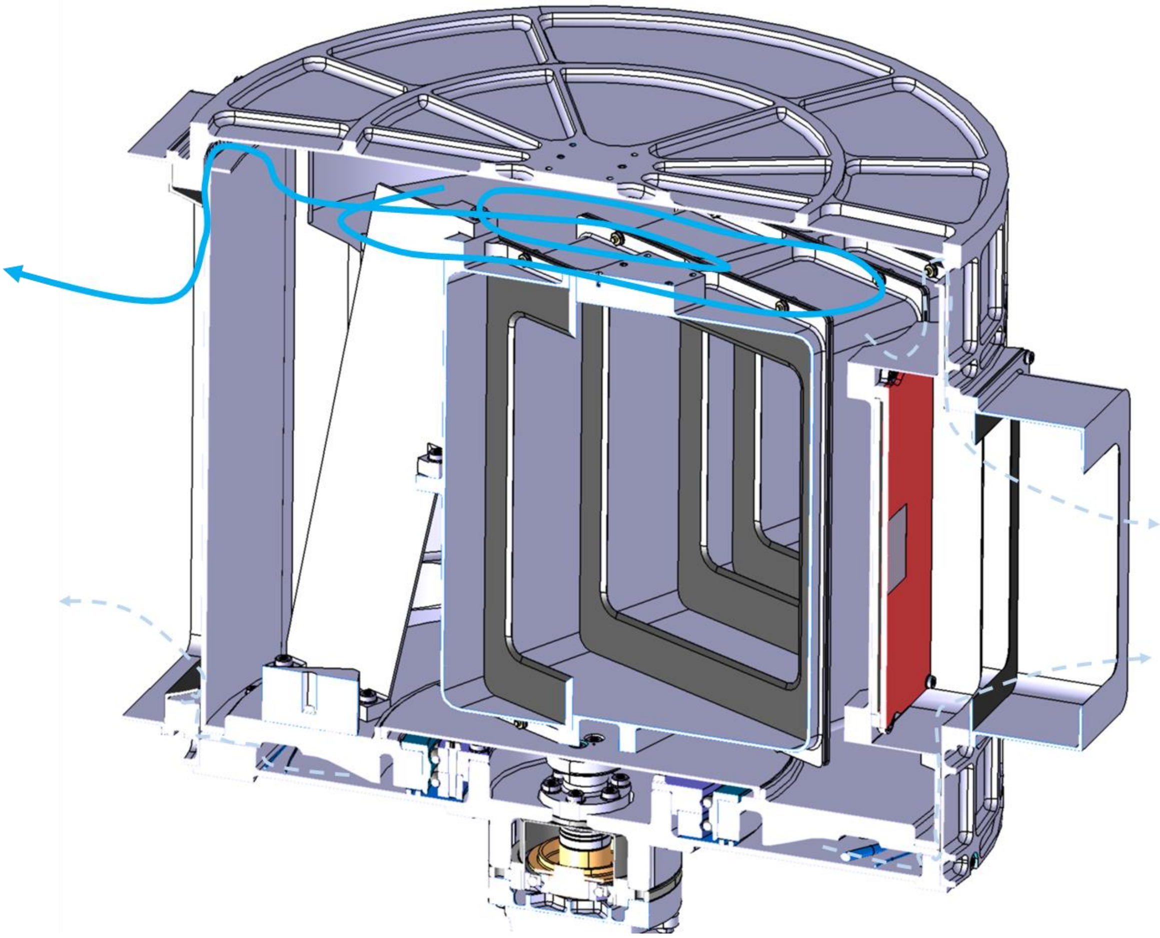

Figure 47: venting path: strong venting flux (solid arrow), mild venting flux (dashed arrows).

5.4.4.5.1 Conclusions

The following conclusions can be drawn:

- The optical cavity is optimally insulated from the mechanical cavity
- Ball bearing and harmonic drive are vented directly to the exterior of the instrument without passing through the optical cavity.
- Labyrinth avoid the propagation of contaminants outside of the mechanical cavity
- Venting fluxes from the mechanical cavity through the nadir and sun port is geometrically discouraged
- Optical elements are further insulated from the optical cavity by their own cavity

For all these reasons the design is judged compliant to the higher cleanliness requirements.

5.4.4.6 Stray Light Control

As reported before multiples means are introduced to ensure stray-light control and light tightness. In this section the implementations of such design choices is reported. In particular, for the launch configuration, dark calibration position, the gap's channel lengths on the side of sun and nadir apertures are illustrated in Figure 48 .

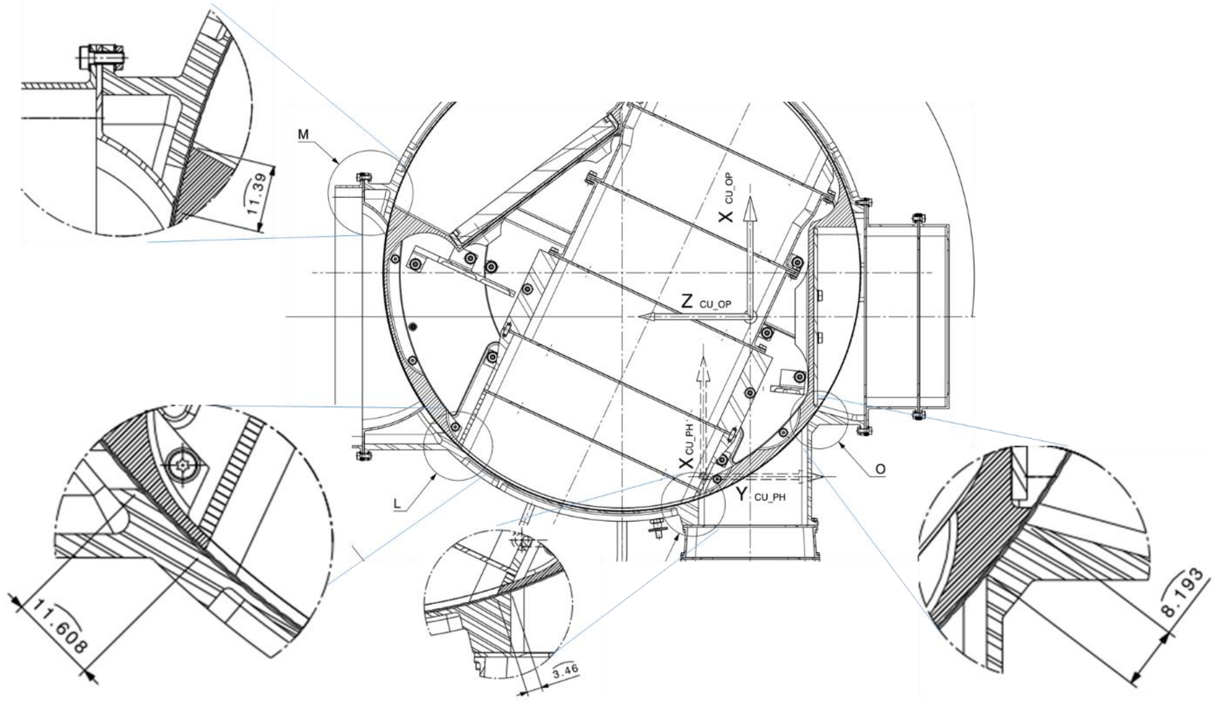

Figure 48: gap's channel lengths on the side of sun and nadir apertures

In this position most critical is the gap between the sun port and the instrument port. It arc length is 8.19mm. This length is lower than the one proposed during the offer since the nadir baffles dimensions has been modified in last version of URD. The stray light cutout effect will be investigated further in the project. However, the double corrugation of the two superposed walls constituting the gap channel will reduce greatly the light propagation path.

5.5 Grounding Scheme

The grounding scheme is shown in Figure 49.

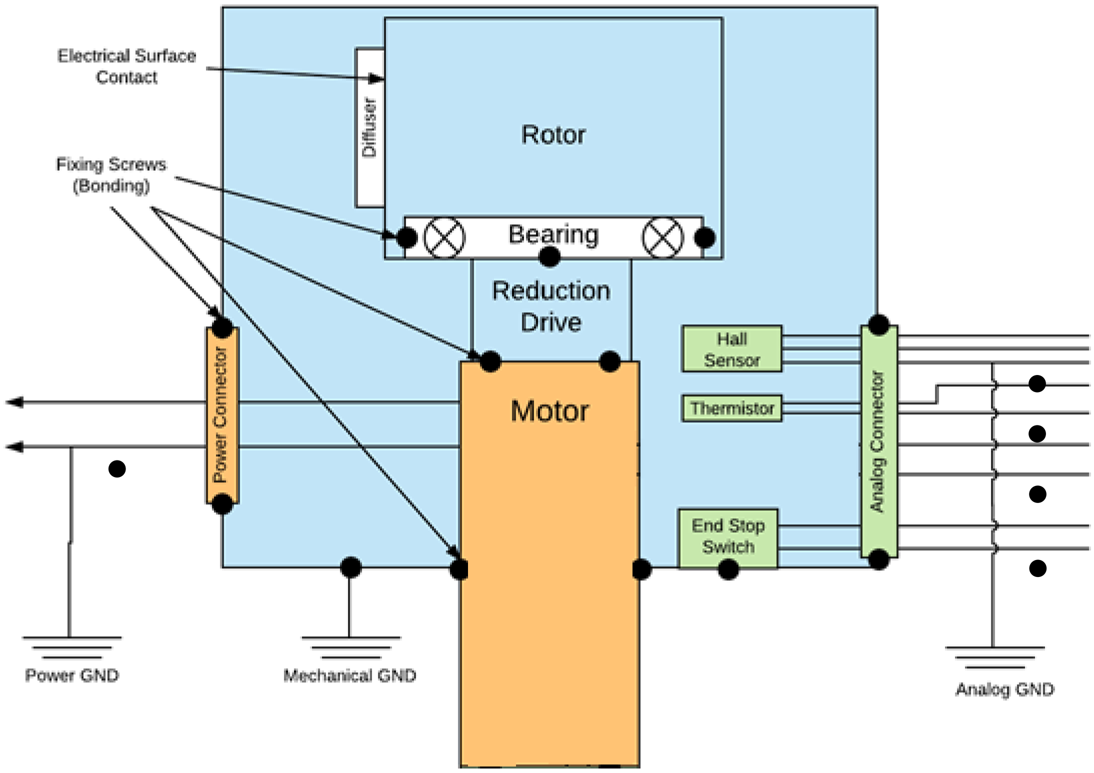

Figure 49: CU Bonding and Grounding Scheme

All mechanical elements are connected electrically by screws (bonding) and direct metallic contact. The Rotor is grounded through the bearing and the reduction drive. Calculated resistance through the bearing and the reduction drive is less than 2.5mOhm.

All cables and wires are routed inside the Calibration Unit. The Calibration Unit acts as a Faraday Cage as it is a fully metallic enclosure.

All sensors (Hall and Thermal, main and redundant) are galvanically isolated from the Calibration unit. They need to be grounded through the ICU. The End Stop housing is metallic and therefore grounded to the mechanical ground.

Motor housing is bonded through screw to the mechanical ground. Power and signals need to be grounded the PGND resp. AGND through the ICU.

As baseline surface coating is Black Anodizing and Alodine 1200S. For Black anodized surfaces, the contact surfaces will need to be masked during coating process or need to be machined after coating and locally treated with Alodine.

The only large non-conductive and isolating material and surface inside the Calibration Unit is the Spectralon Sun Diffuser. The Diffuser is in direct contact to metallic surface. In fact the surface behind the Sun Diffuser frame is Alodine 1200S Aluminum. This should provide enough electrical conductive surface in order to dissipate any possible charging of the diffuser.

Further details on the grounding are reported in the EICD [RD11]

5.6 Galvanic Coupling

Structure Materials are Aluminum 6000 series alloys with Alodine 1200S, Passivated Stainless Steel (Bearing, Reduction Drive, End Stop Switch) and Passivated Titanium grade 5 (Motor housing). Further, all fasteners (Screws, washers, nuts) are made of passivated stainless steel/ Titanium, thread inserts are bronze.

5.7 Cleanliness Measures

For PFM, all AIV/T activities are performed in ISO 5 clean room environment. Transportation and storage will be performed in ultra clean N_2 purged clean enclosures or, if not possible differently, in an ultraclean N_2 purged double bagging. Purity level of N_2: ≥99.9999 % mol.

Further, cleanliness witness samples are following the CU and its critical Sub-Systems and Elements during all AIV/T activities. These elements will be of same material and coating as the CU and its elements.

For Contamination Control see cleanliness and contamination control plan.

5.8 Specification Tree

The procurement specifications reported in TT have been prepared for the project.

Spec Reference	issue	title
FLX-RS-ALM-CU-0001	1	Hall Effect Sensor Procurement Specification
FLX-RS-ALM-CU-0002	1	Ball bearing procurement specification
FLX-RS-ALM-CU-0003	1	Harmonic Drive Procurement Specifications
FLX-RS-ALM-CU-0004	1	Phytron Motor Procurement Specifications
FLX-RS-ALM-CU-0005	1	EGSE specifications
FLX-RS-ALM-CU-0006	1	Sun diffuser Procurement Specifications
FLX-RS-ALM-CU-0008	1Draft	Light tightness test specifications

5.9 Description of Interfaces

5.9.1 Mechanical Interface

The mechanical interfaces are given in FLORIS Calibration Unit MICD [RD10]

5.9.2 Electrical Interface

The Electrical interfaces are given in FLORIS Calibration EICD [RD11].

6 Technical Budget, Margin and Deviations

6.1 Mass

6.1.1 Budget

As per requirement FLO-CU-URD-REQ-0390, the CU total mass with harness and including margin shall be lower than 7.5 kg.

6.1.2 Breakdown

Table 5: CU mass breakdown, summary.

Sub Assembly	without contingency [gr]	Cont.	with Contingency [gr]
Rotor			
Mechanical parts	3626.67	1.2	4352.0
Fasters	134.95	1.05	141.7
Stator			
Mechanical parts	2740.64	1.2	3288.8
Fasters	135.96	1.05	142.8
Harness Int+ harness Ext+ motor	518.15	1.05	544.0
Total	**7169.4**		**8469.3**

6.1.3 Mass budget conclusions

- As reported in the above sections the design is compliant without margins (RFD issued see Section 6.4).

6.2 Power

6.2.1 Budget

As per requirement FLO-CU-URD-REQ-0405, the Cu power consumption shall be:

- Less than 9.2 W average for the motor and 10W as peak (time less than 15 sec including margin)
- Less than 1W average for the other lines (including margin)

6.2.2 Breakdown

The detailed calculation of the power budget is reported in the Functional Analysis [RD06].

It is therein reported that:

- sensors lines are compliant with prescribed margin
- Instantaneous motor power consumption is non-compliant (RFD issued see Section 6.4)
- Average motor power consumption over one orbit is compliant.
- Peak motor consumption is compliant to requirement.

6.3 Mechanism Architecture

The stepper motor is rigidly connected to a harmonic drive gear with reduction of 1:100 as reported in Figure 50. The gear activates the carousel whose maximum rotation is 152°, to be achieved in the worst case in less than 15 seconds.

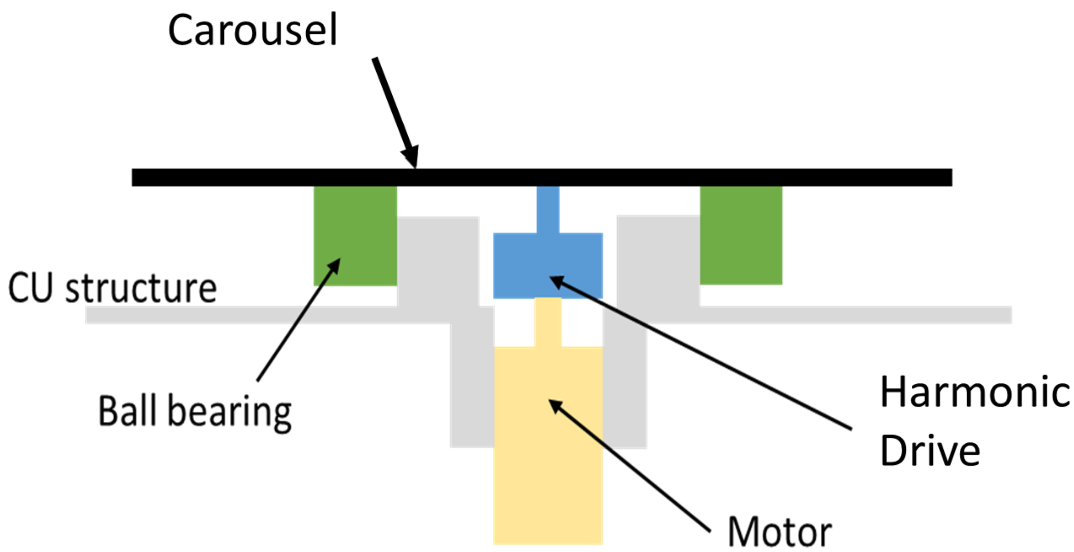

Figure 50: mechanism scheme.

To achieve 152° rotation of the carousel, the number of revolutions of the motor is:

$$Motor, shaft, rotation = \frac{152° \times 100}{360°} = 42.2$$

The selected motor has 200 steps per revolution. One motor step is equivalent to 1.8° rotation of the motor and to 0.018° rotation of the carousel.

6.3.1 Position Accuracy, Resolution, Repeatability and Knowledge of Position

The calculation of the mechanism resolution, repeatability and position accuracy and knowledge of position are reported in the functional analysis [RD06].

The following summary is reported here after:

- Position accuracy, resolution and repeatability are in compliant to requirement
- Sun diffuser knowledge of position is compliant to requirement
- Black target and nadir knowledge of position are slightly non-compliant

All the requirements applicable to FLEX CU movement are gather in the Table 6.

Table 6: Requirement summary table.

Requirement N°	Budget	Status	Verification means	Current design
FLO-CU-URD-REQ-0055		C		
FLO-CU-URD-REQ-0190	resolution: $<0.1°$ Repeatability: $<\pm0.1°$	C		$0.072°$ $\pm0.0026°$
FLO-CU-URD-REQ-0200	$<\pm0.2°$	C	given by harmonic drive repeatability, HD back-driving torque, HD no load running torque	$\pm0.04461°$ BOL
FLO-CU-URD-REQ-0210	NA	C	This document	
FLO-CU-URD-REQ-0240	Sun calibration position knowledge: $\leq \pm0.04°$ Black calibration and observation position knowledge: $\leq \pm0.1°$	C NC	Baumer switch Hall sensors	$0.013° \pm 0.0005729°$ $\pm0.119°$ $\pm0.164°$ **RFD Issued**
FLO-CU-URD-REQ-0610	±0.1	C		

6.4 List of RFDs

The complete list of RFDs is reported in [RD13] latest issue

7 Design Constraints

7.1 Constraints for Production

7.1.1 Geometrical Envelop

The analysis of the envelope is of primary importance in order to understand the system constraints. The superposition of the provided envelope on the proposed design is reported in Figure 51.

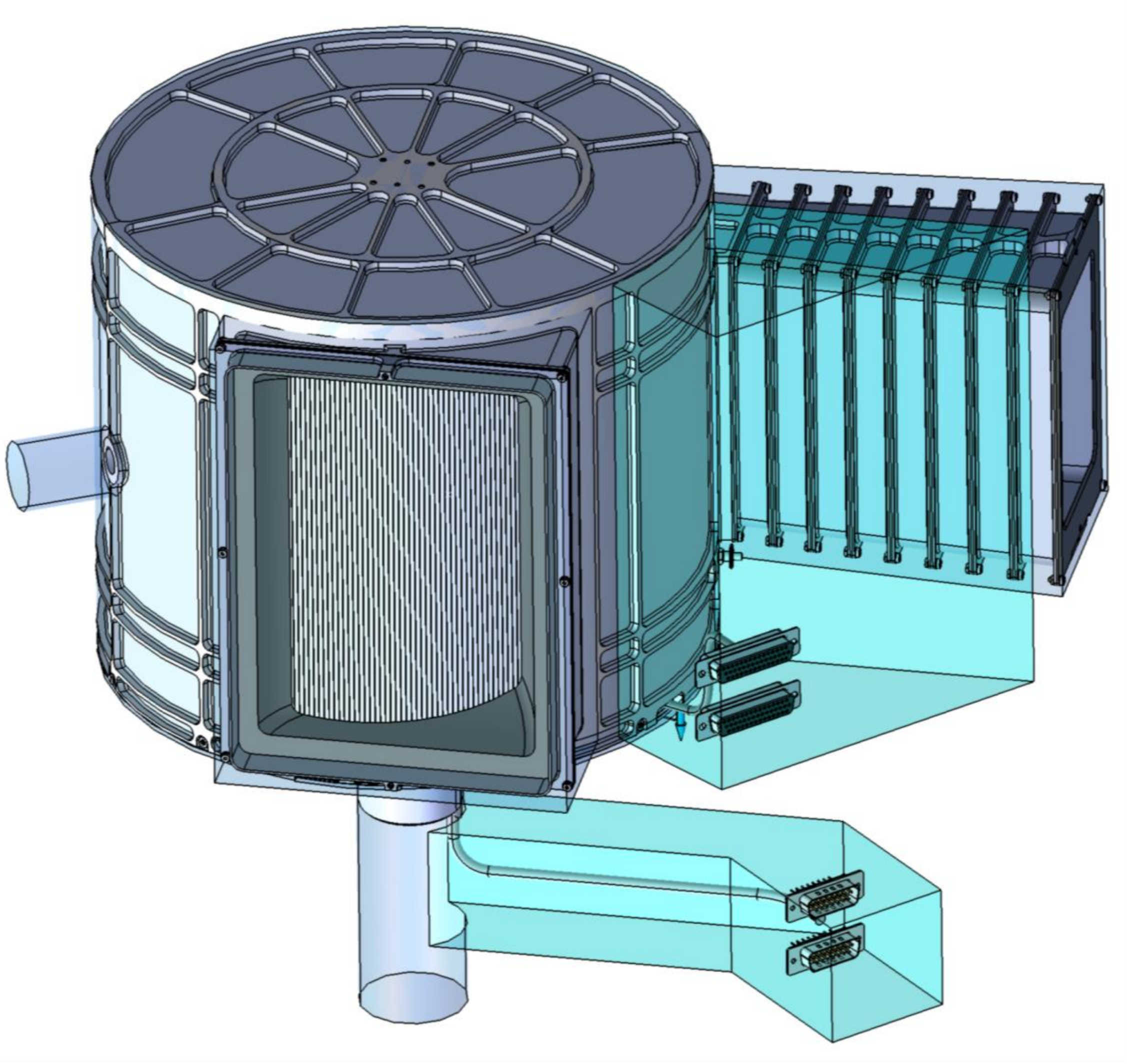

Figure 51: superposition of provided envelope with CU proposed design.

One deviation with respect to the allowable volume is identified w.r.t envelop provided by FLX-DW-FNM-IOMS-002_RevD:

- Instrument side baffle

  The baffle on the instrument side is by its definition larger than the last available version of the envelope. Nothing can be done from Almatech side to cope with this violation. A request of update is already in place. The detail of the violation is reported in Figure 52

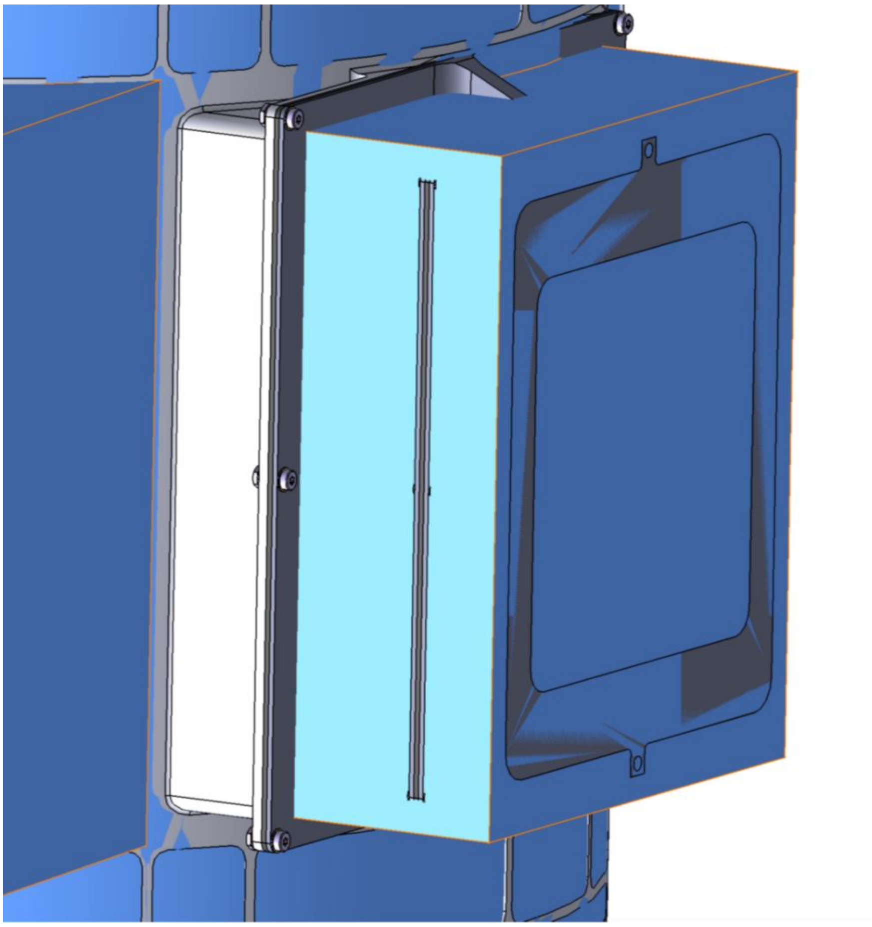

Figure 52: Detail of the CU I/F, pad heights

7.2 Constraints for Operation

This section provides constraints induced by the system or product design definition on the implementation of the operations e.g. operational allowable envelopes, restrictions on operating modes, and exclusion zones.

The following points are identified:

- Once the flight diffuser is installed into the CU the molecular contamination will be out of specification in few days without Sun Diffuser Cover the efficiency of the sun diffuser can be compromised depending on the duration of storage.

7.3 Constraints for Transport and Storage

This section provides constraints induced by the system or product design definition on the transportation activities and during the periods of storage of the product e.g. allowable envelopes, restrictions on transportation and storage, exclusion zones, packaging, shock levels, temperature environments, humidity, cleanliness, regulations, and dangerous materials.

The following points are identified:

- Transport and storage container shall provide means to keep CU cleanliness level adequate to the model.
- The CU PFM model shall be transported and stored in a container with adequate nitrogen flushing provision
- CU PFM and EQM shall be transport and storage container shall provide means for humidity, temperature and shock measurement
- Storage and transport container shall be opened only under Almatech supervision

7.4 Constraints for Maintainability

This section contains constraints induced by the system or product design definition on the maintenance activities and procedures e.g. operational allowable envelopes, accessibility, tooling, support materials, parts availability, and deliveries.

The following points are identified:

- Periodic control of storage container shall be performed to ensure that the logger for temperature humidity and shock are functioning, acquiring data, and that maximum values are not passing the maximum prescribed ones.
- Control if the flushed environment is still active.

8 Conclusion

The Cu design is presented and the following point have been discussed in details:

- Analysis of requirement driving the design
- Description of sensing configuration
- Description of functional position
- Unit physical description and product tree
- Budget verification
- Verification of design constraint

The CU proposed design is compliant with functional requirements. However, small deviation from the power budget point of view and from the knowledge of position are detected (see also Functional Analysis [RD06]).

The power budget is linked to the motor selection and cannot be overcome unless the motor is powered with lower current level. The latter solution will influence the entity of the motorization margins, however, depending on test results, could be a viable solution.

The knowledge of position uncertainty shall be verified by test and further development could be necessary in order to comply with specifications.