



Accelerator Division

SECTION B: TECHNICAL SPECIFICATION FOR LOT 2

*GOVERNING THE CONTRACT FOR THE SUPPLY OF TWO TURN KEY IN -
VACUUM UNDULATORS FOR THE ALBA STORAGE RING*

14th June 2007

CELLS

Campus UAB, E-08193 Bellaterra, Barcelona (Spain)

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1. Introduction

The synchrotron radiation facility, ALBA, a 3.0 GeV low emittance electron storage ring able to run in top up mode is currently under construction in Cerdanyola del Valles, in the province of Barcelona, Spain. The facility will use a linac to accelerate electrons to 100 MeV, inject into a booster synchrotron in which it will be accelerated to an electron energy of 3 GeV, and finally injected, accumulated and stored in a storage ring with a current of up to 400 mA. High intensity photons will be delivered to experimental stations from insertion devices installed in the straight sections of ALBA.

In the first phase overall 6 insertion devices will be installed at ALBA. The layout of ALBA with the different beam lines and insertion devices is given in Fig. 1. The layout within the area around the insertion devices with the tunnel, booster, storage ring, front end, and shielding wall is given in Fig.2. For the two beam lines “Macromolecular Crystallography (XALOC)” and “Non-Crystalline Diffraction (NCD)”, each will use an in vacuum undulator as a photon source.

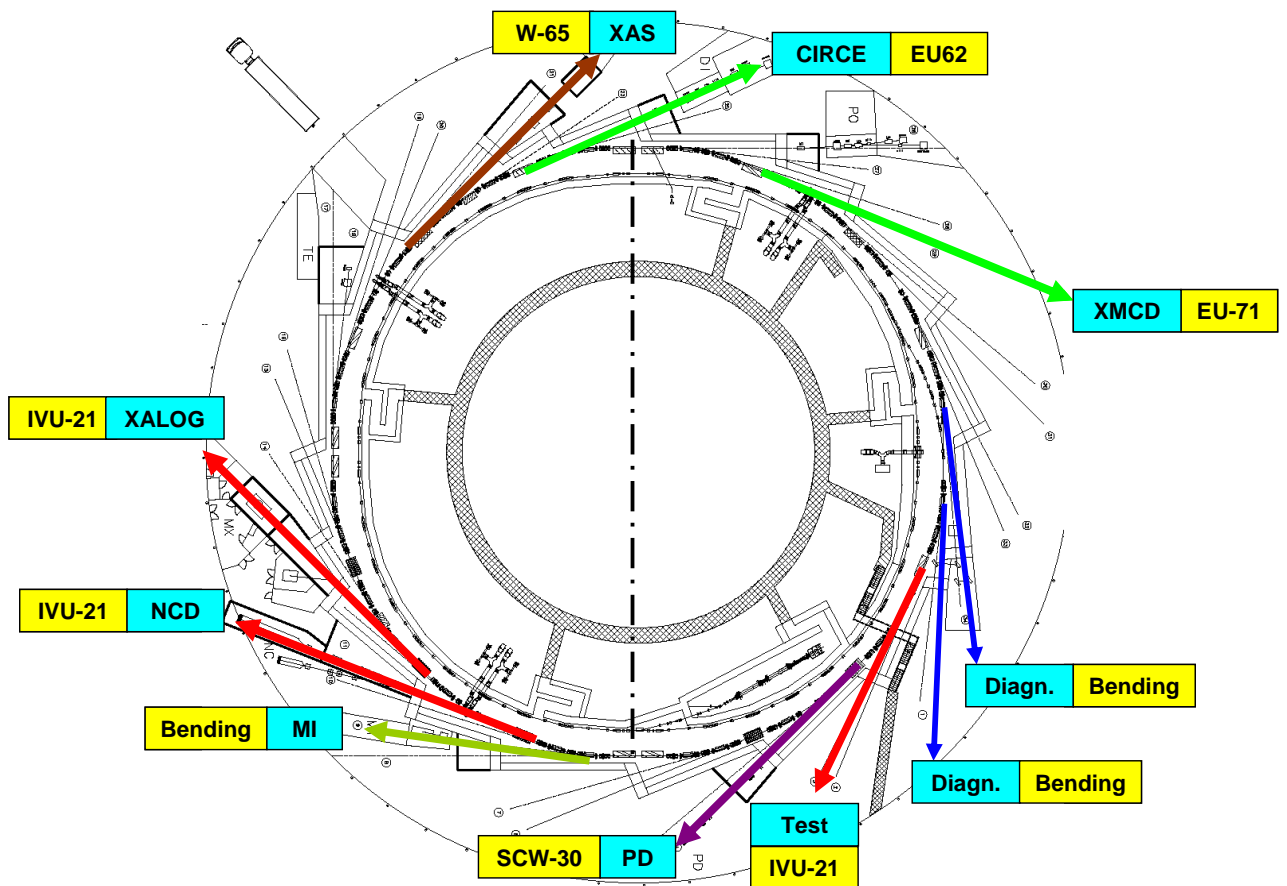


Figure 1: ALBA storage ring layout

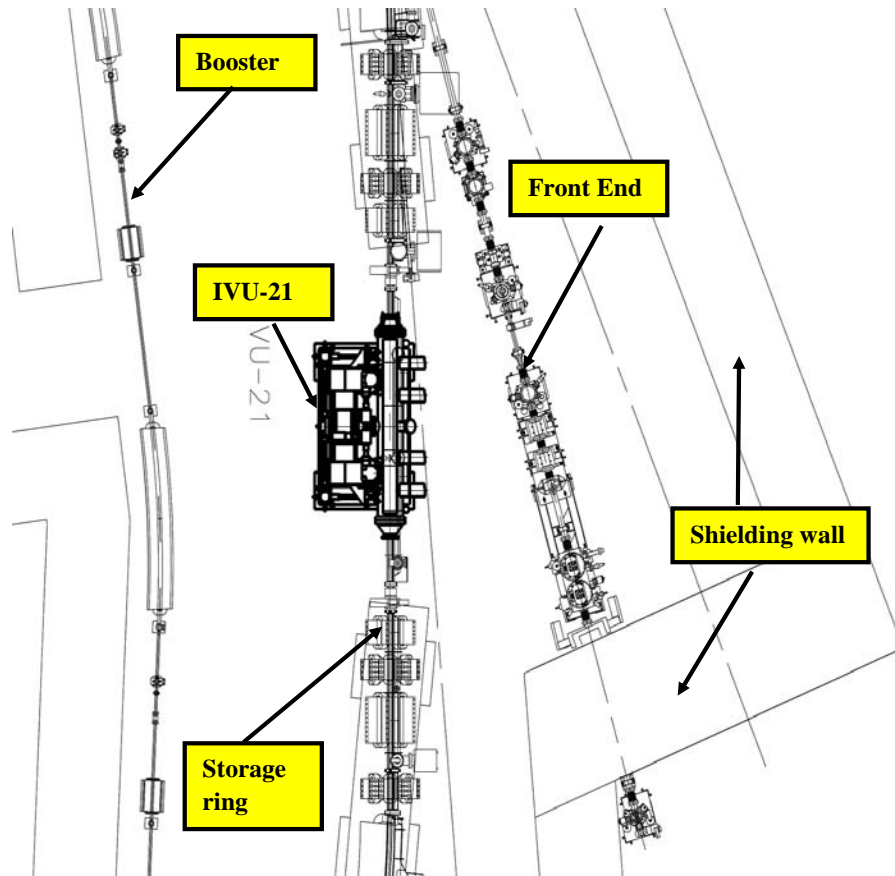


Figure 2: Layout of the tunnel area around the location of the insertion device

Both beam lines XALOC and NCD needs in vacuum undulators with a length of 2 m. the undulators will be used to produce high brilliance x-rays with energies between 5 to 15 keV by using the 3rd to the 7th harmonics. Very tight tolerances are required on the magnetic assemblies and on the girder deformations to preserve a small RMS phase angle error at all gaps.

To achieve the aforementioned requirements CELLS requires in-vacuum undulators. Based on the performance CELLS requires **two** in-vacuum undulators with identical characteristics. For these two in vacuum undulators CELLS made a so called reference design. The CELLS reference design is the basis of this Technical Specification. This reference design can be available for the bidder by contacting CELLS.

2. Scope of Contract and Deliverables

The purpose of this document is to contract a company for the production of 2 complete in-vacuum undulators hereafter referred to individually as Undulator #1 & Undulator #2 and collectively as In-Vacuum Undulators (IVUs). All clauses in this Specification apply to both Undulator #1 and Undulator #2 unless otherwise stated. Each IVU shall be a complete in-vacuum undulator procured, manufactured, assembled, magnetically shimmed, vacuum conditioned, and delivered for direct installation into the ALBA storage ring. The layout of CELLS reference design is given in the Fig. 3, 4, 5, and 6.

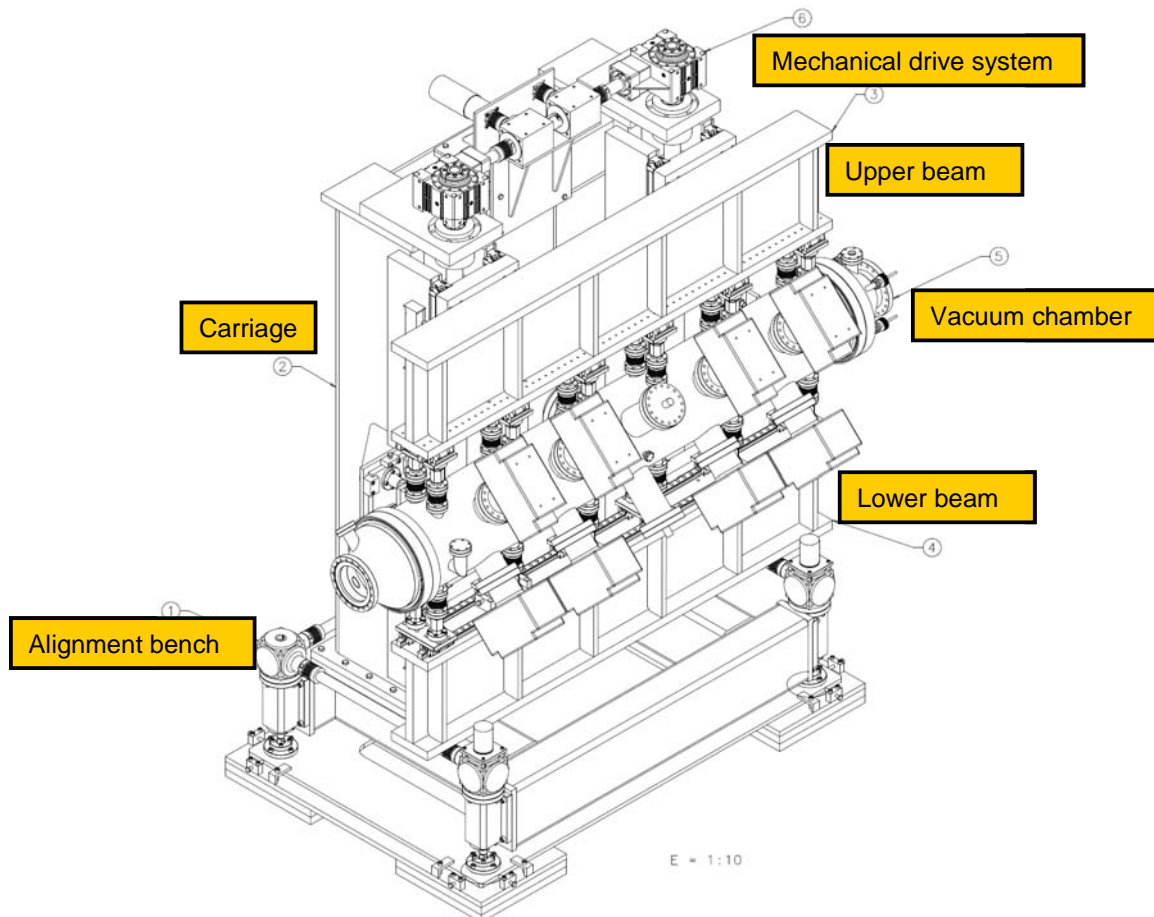


Figure 3: 3D-model of the reference design of the CELLS in vacuum undulator

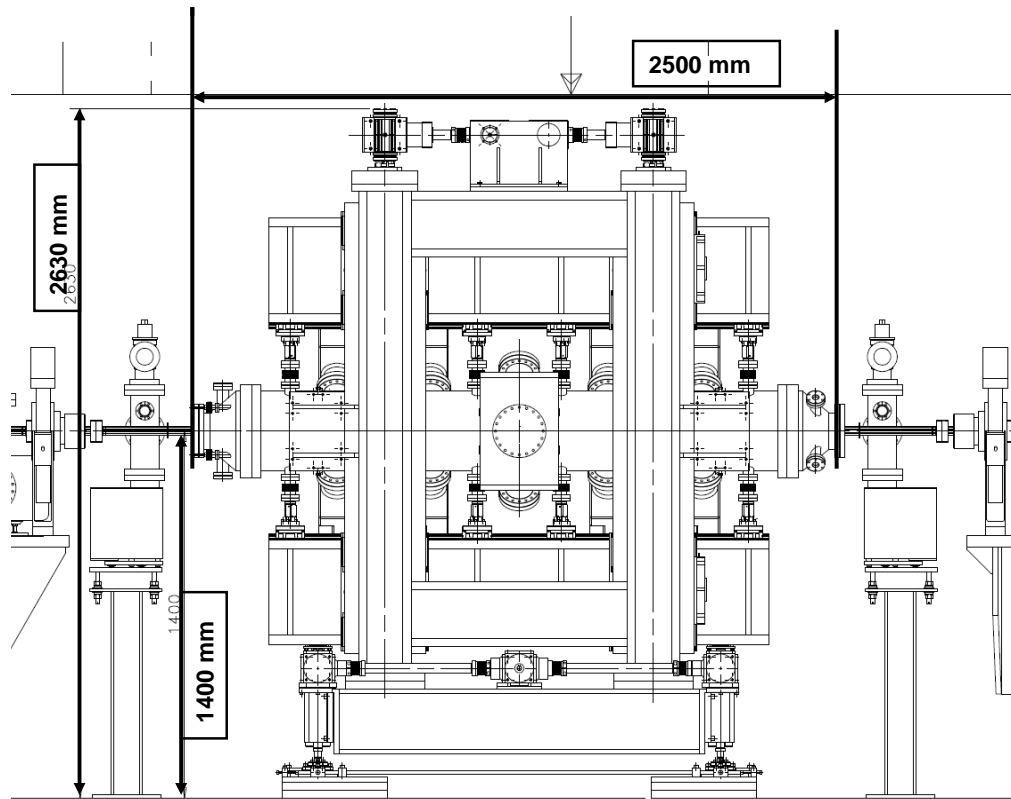


Figure 4: Layout of the CELLS in vacuum undulator (reference design) located in the middle straight section of the ALBA storage ring (back view).

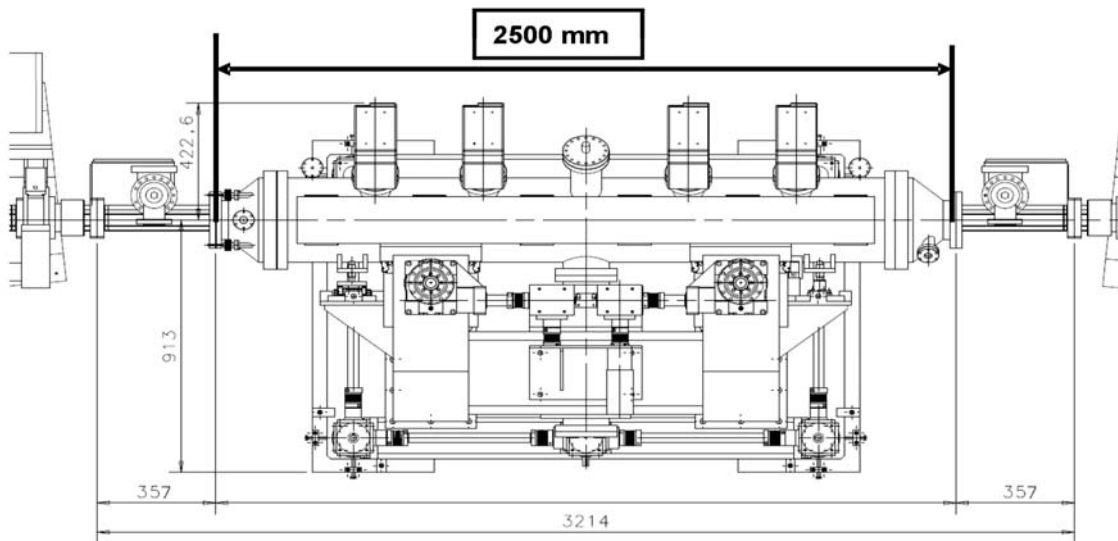


Figure 5: Top view of the Cells reference design

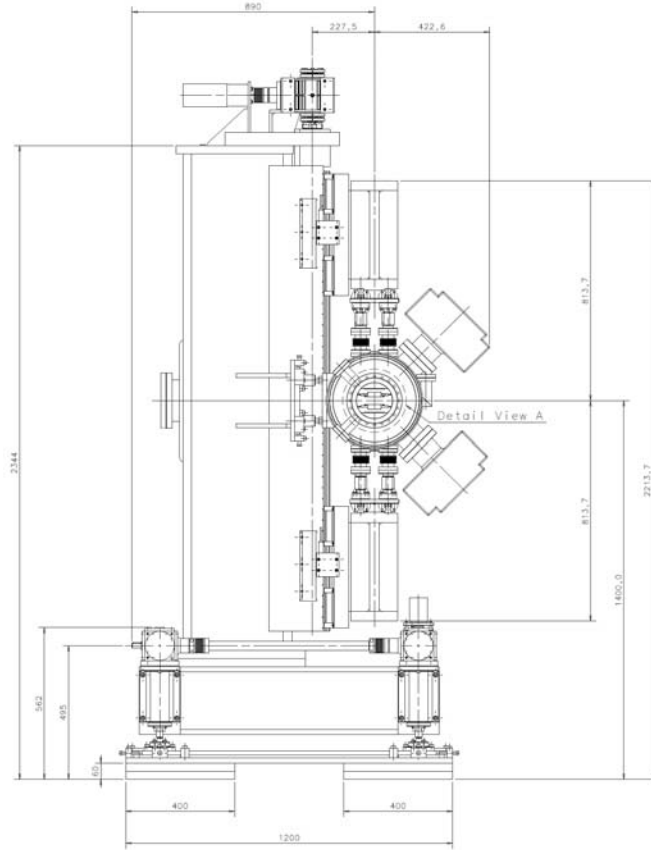


Figure 6: Side view of the Cells reference design

The length of the magnetic structure is 2m, with a period of 21.3 mm. The overall length of the in vacuum undulator from flange to flange is (see Fig.5) is 2500 mm. The height of the center line above the floor is 1400 mm and the overall height should be smaller as 2600 mm.

2.1 Scope of Work for the Complete In-vacuum Undulators:

2.1.2 Design

- 1) 3D magnetic design of a Pure Permanent Magnet Halbach undulator structure meeting the required parameters of this Technical Specifications.
- 2) Design of a UHV system including the main chamber, flexible transition chamber, and fixed transition chamber sealing and maintaining the magnetic undulator and in-vacuum beams under UHV conditions as specified in the appendix.
- 3) Design of a mechanical support structure acting as a carriage for the magnetic assembly, vacuum system, and mechanical chain conforming to functional requirements and technical specifications of appendix.
- 4) Design of a 2-axis mechanical gap drive system operating as specified in the appendix.
- 5) Design of water cooled flexible taper (including the upstream and downstream photon absorbers) as specified in the appendix.
- 6) Design of water cooling system for magnet arrays and flexible taper as specified in the appendix
- 7) Design bake-out system as specified in the appendix
- 8) Design of auxiliary and electrical systems as specified in the appendix
- 9) Design of survey and alignment system for support structure as specified in the appendix

2.1.2 Production, Test, and Delivery

- 1) Procurement and manufacture of all parts required for a successful completion of the in vacuum undulator
- 2) Production of documentation, manufacturing drawings, assembly drawings and procedures required for construction, assembly, and commissioning of the complete IVUs
- 3) Production of the whole IVUs
- 4) Factory Acceptance Tests (FAT)
- 5) Delivery of IVUs to ALBA site
- 6) Quality assurance documentation for all parts and processes
- 7) Training and manuals for operation and maintenance

2.3 Scope of Supply for the Complete In-vacuum Undulators

- 1) IVUs manufactured, assembled, tested, delivered, and tested at CELLS
- 2) Complete set of 3D and 2D manufacturing and assembly drawings in the form of 2 paper copies and one electronic copy which will be provided on a CD
- 3) Quality assurance documentation for all parts and processes
- 4) FAT & SAT (Site Acceptance Tests) reports
- 5) A complete body of documentation for the IVUs including the elements in the Scope of Work §2.1
- 6) All tooling, jigs, gauges, and sensors necessary for assembly of IVUs

2.4 Elements outside the scope of supply:

- 1) Standard vacuum components including pumps, gauges, controllers, vacuum valves, and residual gas analyzers, the associated controllers, and controllers for temperature sensors. Unless otherwise stated, CELLS will only provide equipment that will be permanently connected to the IVU. Temporary equipment for the purpose of assembly, mounting, testing, or any equipment which is not a part of the operational IVU will be provided by the Supplier.
- 2) CELLS will provide the control system (see the description within the appendix)
- 3) Supplier shall quote on stepper motor drivers(s) as an option
- 4) The Supplier shall provide their own dry Nitrogen purge cart, vacuum roughing cart, RGA, and Helium leak detector for the purpose of performing the FAT.

3. Specification of In-vacuum Undulators

3.1 Design Parameters

The design parameters of both IVUs as required by CELLS are given in Table 2. Table 3 outlines the general operational requirements placed on the in-vacuum undulators over their full gap range of 5.0 mm to 30 mm.

Undulator type	In-vacuum
Magnetic configuration	Planar PPM Halbach structure
Magnetic material	Sm ₅ Co ₁₇
Period length	21.6 mm
Number of periods	92
Maximum length of magnetic structure	2.1 m
Average magnetic gap	5.7 mm
Minimum gap	5.0 mm
Gap range	5 mm to 30 mm
Minimum effective K-value at 5.5 mm gap	1.60

Table 2: In-vacuum undulator parameters

Operational vacuum pressure (without beam)	$\leq 1 \times 10^{-9}$ mbar
Maximum gap velocity	≥ 1 mm/s
Minimum incremental gap step	≤ 0.001 mm
Minimum bi-directional reproducibility of gap	≤ 0.001 mm
Minimum phase angle error on x=0, y=0	2.5 degrees RMS
Maximum first field integral on x=0, y=0	$I_x \leq 30 $ Gcm, $I_y \leq 7 $ Gcm
Maximum second field integral on x=0, y=0	$JI_x \leq 6000 $ Gcm ² , $JI_y \leq 600 $ Gcm ²
Maximum integrated multipoles over x < 15 mm, y=0	
Dipole (Normal)	$\leq 30 $ Gcm
Dipole (Skew)	$\leq 7 $ Gcm
Quadrupole (Normal)	$\leq 50 $ G
Quadrupole (Skew)	$\leq 5 $ G
Sextupole (Normal & Skew)	$\leq 20 $ Gcm ⁻¹
Octupole (Normal & Skew)	$\leq 10 $ Gcm ⁻²

Table 3: In-vacuum undulator requirements over full gap range 5.5 mm to 30 mm

3.2 Detailed Technical Specifications

The relevant technical specifications for:

- Magnets
- Mechanical Support Structure
- Tolerances
- Alignment
- Mechanical Chain
- Controls
- Auxiliary Systems
- Vacuum
- Factory Acceptance Test

which accompany this document are contained in the Appendix.

3.3 Request for Modification and Standardization

CELLS assumes that the different bidders have previously manufactured in vacuum undulators and the bidders have knowledge and experiences with build in vacuum undulators. In order to get a cost effective solution CELLS requested the different bidders to make proposals for some modifications to use their so called “standard design” and meet the specifications of CELLS.

4. Time Schedule and Phasing of the Contract

CELLS proposes the following phases and time schedule to the Supplier.

Phase I	
to	Signature of the Awarding Letter
t1	Signature of Contract
t1 + 2 weeks	Kickoff Meeting
t1 + 4 weeks	Preliminary Design Review Meeting
t1 + 3 months	Final Design Review Meeting
Phase II	
t1 + 13 months	Start of FAT
t1+ 16 months	End of FAT & Delivery of IVUs to CELLS
t1+ 16 months	SAT, Installation, and Commissioning

Table 4: Time schedule proposed by CELLS

Phase I will finish with the acceptance of the Final Design Report. The contents of which shall be agreed upon at the preliminary design review meeting. The Phase II can only start after the approval of the conceptual design report by CELLS. The procurement of long lead time items, which could have an influence upon the time schedule, should be discussed at the preliminary design review meeting. For the phase II the bidder should present the times schedule for the two insertion devices.

5. Services available to Supplier at CELLS

5.1 Water cooling

Water conductivity 0.2 $\mu\text{S}/\text{cm}$
Inlet Temperature $23^{\circ}\text{C}\pm 1^{\circ}\text{C}$
Maximum temperature variation 10°C
Inlet pressure 10 bar
Minimum outlet pressure 4 bar

The materials in the cooling circuit shall be compatible with the use of demineralised water. Any material other than stainless steel and EPDM (for the o-rings) must be identified in the design report.

5.2 Electrical mains network

The AC distribution board is fed from a 2MVA, 25kV/400V – 5% distribution transformer, via power switches with magneto-thermal protection. The 400V secondary star mi-point is earthed at the transformer and the neutral is directly distributed to the equipment. Thus, the neutral must not be earthen at any other point.

CELLS 400VAC network characteristics:

Line voltage 400V rms $\pm 10\%$ (TNS neutral mode: three phases + neutral +PE)
Frequency 50Hz $\pm 1\%$
Voltage harmonic distortion 5% rms
Phase imbalance $\pm 1.5\%$
Conductor distribution 3 phases + neutral + PE
Short circuit capacity <40 MVA
Peak main surges 1200V rms for 0.2 ms & 600V rms for 10 ms

5.3 Alignment

CELLS is responsible for the alignment of the IVUs into the ALBA storage ring.

6. Tendering

6.1 Adjudication of Bid

CELLS shall adjudicate bids according to the Administrative Clauses.

6.2 Documentation Required with the Tender

The Bidder shall provide sufficient tendering documentation as described in 6.2.1 to 6.2.9 to allow an evaluation of the bids.

6.2.1 Conformity

A conformity sheet that addresses, in writing, each clause in this specification by either confirmation, request for clarification, or propose a deviation from this specification. For proposals of deviation the Supplier shall provide the technical and cost impact of their proposal.

6.2.2 Technical Design Solutions

The technical design solutions required to complete the IVUs to this set of specifications in the form of a preliminary conceptual design which includes (but is not limited to):

- a) Design of magnetic undulator system
- b) Design of the mechanical frame and linear guides to support the undulators beams, vacuum vessel, and mechanical chain under magnetic load
- c) Design of mechanical chain, gear boxes, spindles, motors (torque/velocity curves, resistance, and inductance), and encoders
- d) Design of link rods

- e) Design of vacuum system (pumps, gauges, temperature sensors, and their distribution), main vacuum vessel chamber, flexible transition chamber, and fixed transition chamber
- f) Design of flexible taper
- g) Design of bake-out system including the design of cooling system for the magnet arrays and flexible taper and design of slide system for differential thermal expansion of in-vacuum beams with respect to the out vacuum beams.

6.2.3 Principle Components

The Bidder shall include a list of the principle components of the insertion device in the tender and their specifications.

6.2.4 Previous Projects

The Bidder shall include a list of previous similar or comparable projects (in size and scope), for other synchrotron light sources.

6.2.5 Draft Schedule

The Bidder shall include a draft schedule showing the timeline for design, procurement & manufacturing, assembly and testing of the IVUs with long lead time items clearly identified. CELLS assume that there is a shift in the production, the shimming, the factory acceptance test and the delivery for the two insertion devices. The bidders are requested to shoe this shift in the time schedule

6.2.6 Work Packages

The Bidder shall include a list of work packages from the IVUs that will be subcontracted and the names of the subcontractors.

6.2.7 Specification of Facilities

The Bidder shall include the specifications for their relevant facilities and equipment that shall be used to manufacture, assemble, and perform the measurement and acceptance tests. The facilities may include (but are not limited to) the clean room, Helmholtz coil, Hall probe bench, flip coil bench.

6.2.8 Quality Assurance Plan

The Bidder shall include the details of their Quality Assurance scheme.

6.2.9 Critical Procedures

The Bidder shall include a general description of the critical procedures used in constructing the IVUs including:

- a) Welding plan
- b) Procedure for cleaning, conditioning, and testing the vacuum vessel and vacuum subassemblies
- c) Procedure for manufacturing the frame
- d) Procedure for manufacturing of the vacuum system
- e) Procedure for alignment of the in-vacuum beams before shimming after assembly of the vacuum vessel and procedure for alignment of undulator to the storage ring
- f) Method for measurement and verification of gap tolerances stated in Appendix

7. Contract Management

All interested Bidders are strongly encouraged to contact CELLS and discuss the details of this specification so to ensure that the Bidder understands completely the requirements and implications of the specification before making an offer (see also paragraph 3.3). Enquiries of a technical nature shall be directed to Mr. Drew Bertwistle, CELLS, tel: 34-93-592-4348, e-mail dbertwistle@cells.es. Enquiries of a contractual nature shall be directed to Mr. Mariano Sazatornil, CELLS, Tel: 34-93-592-4307, email alba.concursos@cells.es.

7.1 Design Reviews & Acceptance Tests

The Design Reviews and Acceptance Tests are milestones in the schedule. CELLS shall verify in writing that the Supplier has met the requirements of each Review and Acceptance test. If the requirements are satisfied then the Supplier may begin the next phase. The milestones are as follows:

- a) Preliminary Design Review (PDR)
- b) Final Design Review (FDR)
- c) Factory Acceptance Test (FAT)
- d) Site Acceptance Test (SAT)

7.2 Preliminary Design Review (PDR)

For the PDR the Supplier shall submit to CELLS the items specified in this section (see 7.2.1 to 7.2.6) to be agreed upon with CELLS in writing. The Supplier shall provide CELLS with a description of the critical procedures, plans and specifications used in construction of the IVUs. All elements discussed and agreed upon in the PDR shall be included in a full design report delivered 2 weeks before the final design review.

7.2.1 General Requirements

- a) The procedures, plans, and designs must be consistent with the technical clauses of this specification.
- b) The Supplier shall be responsible for specifying the utility requirements and interfaces of the IVUs (compressed air, water, electrical power, vacuum) for operation in the ALBA storage ring. The Supplier shall inform CELLS of the required utilities and CELLS shall agree to those requirements in writing.
- c) Time schedule
- d) Performances (test reports, calculations, etc.)
- e) Complete list and specification of components and subassemblies

7.2.2 Mechanical Support Structure

- a) The Supplier shall provide CELLS with the detailed mechanical design for the support structure, mechanical chain, link rods, alignment system, and mechanical subassemblies
- b) Design and location of the survey fiducials on the support structure
- c) Design of the water cooling system for the in-vacuum beams and flexible taper including specification of the water mass flow rate and velocity. The Supplier will provide the expected temperature rise of the in-vacuum beams and flexible tapers during bake-out and storage ring operation with and without cooling water.
- d) Procedure for relating the undulator fiducials to the shimmed undulator centreline and alignment of the centerline in the ALBA storage ring straight section
- e) Procedure for aligning the in-vacuum beams and adjusting their planarity and taper with respect to the link rods before application of magnetic load, after application of magnetic load, and when shimming is completed and the in-vacuum beams are reinstalled in the vacuum chamber.
- f) Procedure for adjusting link rods for in-vacuum beam planarity
- g) Manufacturing process and material certificates
- h) Procedure for assembly of the mechanical support structure

7.2.3 Magnetic Design and Measurement

- a) Detailed magnetic design of the undulator, mechanical assembly of magnets, mechanical mounting of magnets on in-vacuum beams, mechanical holders, and correction coils
- b) Procedure for alignment and mounting of the magnets on the in-vacuum beams
- c) Specification of magnetic materials, coating, and dimensions
- d) The specification and calibration data for the Hall probe bench, Hall probe sensors, flip coil bench, and calibration dipole magnet used in the magnetic shimming and final FAT

7.2.4 Vacuum System

- a) Vacuum design for the vacuum system including the design of the three chambers
- b) Specification and location of all flanges, ports, vacuum windows, and all vacuum feed throughs
- c) Drawings of flanges to be used for the manufacture of the IVUs
- d) Required pumping speed, the type of pumps, their specification, and the specification of their respective controllers
- e) A list of all vacuum instrumentation, gauges, and their specifications
- f) Procedures for cleaning all vacuum chambers and their associated subsystems
- g) Design of bake-out system and the bake-out procedure
- h) Procedure for vacuum testing
- i) Procedure for dimension testing and specification of tooling used
- j) Manufacturing process and material certificates
- k) Detailed welding plan
- l) List and specification of free issued components required by the Supplier and provided by CELLS, together with a proposed schedule for the free issuing.

7.2.5 Control System Hardware Interface

- a) The Supplier shall provide all detailed electrical wiring for the IVUs and the electrical layout of the IVU patch panel with all electrical signals appropriately labeled with respect to CELLS convention. The signals of all electrical instruments associated with the IVUs shall be tabulated against their identifier with respect to contact points and signal type.
- b) The Supplier shall provide the electrical specification and pin-out for all instrumentation including but not limited to motors, sensors, power supplies, correction coils, pumps, switches, encoders, and gauges.

7.2.6 Auxiliary Systems

- a) Specification of water cooling system for use during bake-out
- b) Specification of the correction coil power supplies
- c) Specification and placement of the thermocouples used during bake-out and operation of the IVUs
- d) Procedure for assembly of RF flexible taper and CuNi foil

7.3 Final Design Review

All design changes agreed upon in writing between CELLS and the Supplier shall be implemented in a Final design report and issued to CELLS 2 weeks before the Final Design Review Meeting (FDR).

7.3.1 Detailed Design & Procedures

The Supplier shall include the detailed design and procedures in the final design report. It will include the elements described in the Scope of Work §2.1.

7.3.2 Drawings

The Supplier shall provide CELLS with the complete set of detailed 3D and 2D functional and assembling drawings for the IVUs and two complete paper copy of the drawings and one electronic copy on CD or DVD. The preferred format for the drawings is DWG or DXF, non-scalable formats are not acceptable, for the 3D models the preferable format is IGS, STEP or VDA. The final format of the drawings and 3D models shall be agreed upon with CELLS in writing. The drawings form a part of the final design report.

7.4 Factory Acceptance Test

The General Requirements of the FAT are stated in the Appendix. The Supplier shall propose to CELLS, in detail, the factory acceptance tests and procedures necessary to demonstrate that the IVUs meet the technical clauses of this specification, the tests shall be agreed upon with CELLS in writing. Within a week following the conclusion of the FAT the Supplier shall issue to CELLS the detailed results of the FAT in the form of a report.

7.5 Site Acceptance Test

CELLS is responsible for conducting the site acceptance tests. The Supplier is responsible for supervising the SAT and verifying the SAT results. The Supplier is responsible for insuring that the results conform to the technical clauses of this specification. The General Requirements of the SAT are stated in the Appendix. The Supplier shall propose to CELLS, in detail, the site acceptance tests and procedures necessary to demonstrate the IVUs meet the technical clauses of this specification, the tests shall be agreed upon with CELLS in writing. Within a week following the conclusion of the SAT the Supplier shall issue to CELLS the detailed results of the SAT in the form of a report.

8. Responsibilities of the Supplier

8.1 Detailed Technical Design and Technical Drawings

The contracted Supplier is required to perform a detailed technical design including technical as well manufacturing drawings. CELLS has performed a reference conceptual design for the IVU and mechanical reference drawings intended to communicate to the Supplier CELLS performance requirements (see chapter 3).

8.2 Production Schedule

Within one month of signing of the contract the Supplier shall issue a detailed technical design with corresponding production schedule showing in detail the design, procurement, manufacturing, and testing of the IVUs. The Supplier's production schedule shall be agreed upon with CELLS. Within the scope of the production schedule CELLS and the Supplier shall agree upon a series of technical and progress review meetings.

8.3 Monthly Progress Reports

After the production schedule is frozen the Supplier shall issue a monthly progress report to CELLS describing the state of the IVUs, next steps in production, and indicate any issues which may possibly cause delay in the schedule or deviation from the clauses of this specification.

8.4 Technical Responsibilities

The Supplier is completely responsible for the design study, design, production, detailed manufacturing drawings, assembly drawings, assembly procedures, procurement of parts, manufacturing of parts, assembly, assembly tools, testing tools, quality control, testing and quality assurance such that the IVUs meet the technical and administrative clauses of this specification.

8.5 Design Choices and CELLS Approval

The Supplier shall be responsible for the final design, production methods and the correct performance of all the items supplied, independent of whether they have been chosen by the Supplier or suggested by CELLS.

CELLS approval of the design or selection of components does not release the Supplier from their responsibilities in this respect.

8.6 Deviation from Technical Specification

If, after the order is placed, the Supplier discovers that the specification has been misinterpreted, this will not be accepted as an excuse. Consequently, CELLS will insist that the manufacturer delivers the IVUs with any and all deviations corrected to conform with this specification at no extra cost to CELLS.

If the Supplier proposes any deviations from this specification then they shall be submitted to CELLS in writing; the implementation of said changes shall only occur with written approval from CELLS.

If CELLS proposes a deviation from the specification then it will be sent to the Supplier through the CELLS purchase office.

In either case the Supplier shall provide a reply in writing with an evaluation of the technical merit, impact on cost, and impact on delivery of the IVUs.

8.7 Access to Premises of Supplier

CELLS shall be granted access to the premises of the Supplier, and also to the premises of any subcontractor, for the purpose of progress meetings and inspection visits. Access and visits to the site of a subcontractor shall be made in the presence of a technical representative from the Supplier with 10 days notice provided by CELLS.

8.8 Subcontracting

If the Supplier subcontracts any work package of the IVUs to a subcontractor then the Supplier remains responsible for quality control and production of said work package and it's adherence to the clauses of this specification.

9. Norms and Standards

The system must comply with all harmonized European standards as well as details regarding the appropriate EMC regulations. A basic separation between the power and signal cables should be provided

10. Transportation

- a) The Supplier is responsible for the proper transport and packaging of the device CELLS.
- b) In preparation for transportation to CELLS the water channels of the IVUs shall be blown to insure there is no water remaining in the lines. The vacuum chamber shall be backfilled with 99.99% pure Nitrogen to above atmospheric pressure and sealed.
- c) The crate for transportation shall be designed such that it can be moved by a standard forklift.
- d) The undulator shall be protected by a plastic sealed envelope from which the maximum amount of air has been removed. This cover shall be water tight.
- e) Shock and tilt indicators shall be fitted on the equipment and on the crate. The presence of these shall be notified to the carrier in writing with a copy to CELLS. On delivery, CELLS shall inspect the shock indicators and inform the Supplier in case of a problem.
- f) The specific details of delivery and transportation of the IVUs will be discussed with CELLS and agreed upon in writing.



Accelerator Division

Appendix
to the
Technical Specifications for LOT 2
(In-Vacuum Undulator)

Specification of :

Magnets
Mechanical Support Structure
Tolerances
Alignment
Mechanical Chain
Controls
Auxiliary Systems
Vacuum
Factory Acceptance Test

14th of June 2007

CELLS

Campus UAB, E-08193 Bellaterra, Barcelona (Spain)

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1. Magnetic Specification for an In-Vacuum Undulator

1.1. Definition of Coordinate System

The nominal height of the electron beam in the ALBA storage ring is 1400 mm above the concrete slab. The magnetic centerline of the undulator shall coincide with the nominal electron beam path through the ALBA straight section. The origin of the coordinate system shall be fixed to the middle of the undulator magnetic centerline. The longitudinal coordinate is referred to as the S-axis, it lies parallel to and coincides with the magnetic centreline (see Fig.1). The vertical coordinate anti-parallel to gravity is referred to as the Y-axis, and the transverse coordinate is radially outward with respect to the storage ring and is referred to as the X-axis. With respect to the support structure or support structure components, roll is defined as rotation about the S-axis, pitch is defined as rotation about the X-axis, and Yaw is defined as rotation about the Y-axis. The coordinate system must be used in mechanical design and magnetic measurements.

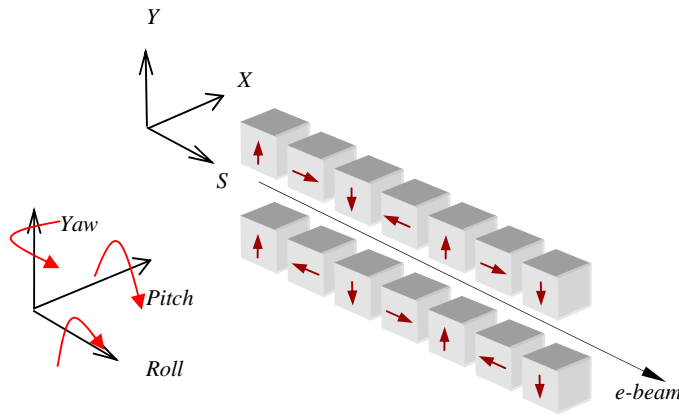


Figure 1: Undulator coordinate system

1.2. Magnetic Structure

The undulator magnetic structure shall use Pure Permanent Magnets, hereafter PPM, technology to construct a periodic arrangement of horizontally and vertically polarized blocks known as a HALBACH undulator.

1.3. Period Length and Number of Periods

Each undulator shall have a magnetic period of 21.6 mm with 92 full size periods. The total length of magnetic material shall not exceed ~ 2.1 meters, including the terminations, and magic fingers.

1.4. Minimum Magnetic Gap and Maximum Gap

The average minimum magnetic gap of the undulator shall be 5.7 mm and the absolute minimum shall be 5.0 mm. This is defined by the minimum physical vertical aperture in the ALBA storage ring for an IVU of 2.1 meters length. The gap of 5.5 mm shall be the beam stay clear of the insertion device. The maximum magnetic gap of the undulator shall be 30 mm.

1.5. Maximum Effective K value

The effective K value shall have a value of 1.60 or greater at a gap of 5.7 mm.

1.6. Magnetic Modules

On each in-vacuum beam there will be blocks (see Fig.2) that are vertically magnetized (parallel or anti-parallel to the Y-axis) and horizontally (parallel or anti-parallel to the S-axis) magnetized. The direction of block magnetization shall rotate about the X-axis in 90-degree steps from adjacent block to adjacent block. The sense of rotation is opposite between upper and lower magnet arrays.

On each in-vacuum beam the magnet blocks shall be grouped into M3 and M1 modules. Figure 2 shows schematically how the blocks shall be grouped:

- Each M1 module consists of a horizontally magnetized block
- Each M3 module consists of three blocks. One block magnetized parallel to the Y-axis, one magnetized horizontally (parallel or anti-parallel to the S-axis depending on which beam it is on), and one magnetized anti-parallel to the Y-axis. The horizontally magnetized block shall be between the vertically magnetized blocks.
- There are terminations at the end of each undulator beam that shall be grouped together in their own special holder. The termination shall consist of a vertically magnetized block and a horizontally magnetized block with special dimensions described in §2.3 (table 2). CELLS has performed a magnetic conceptual design for the IVU and the Supplier is encouraged to refer to it.

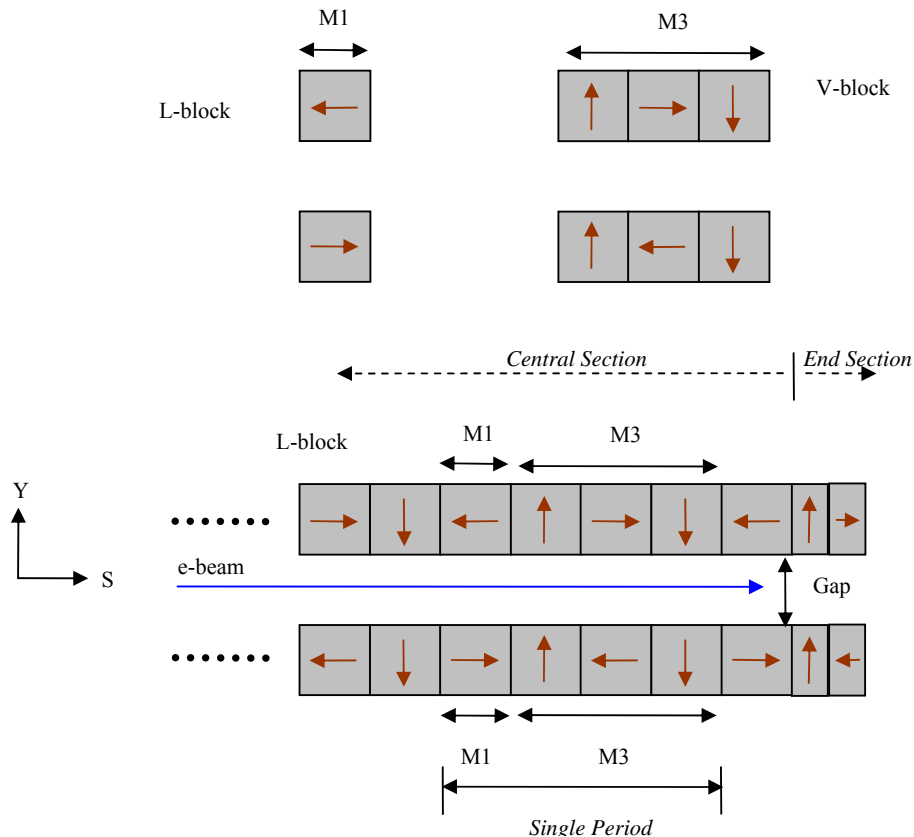


Figure 2: Schematic of M3 and M1 modules and their mounting arrangement on the upper and lower in-vacuum beams

1.7. Module Height Adjustment

The proposed procedure of CELLS is that each M1 and M3 module will be mounted onto the in-vacuum beam on 0.1 mm shims (an alternative material may be proposed by the Supplier). The shims shall allow good thermal contact between the in-vacuum beams and the magnet arrays. The M1 and M3 modules shall have the capability of being shimmed in the vertical direction ± 0.100 mm with respect to their nominal height. No magnet block in a undulator beam shall be more than 0.100 mm above or below the

nominal height of the magnet blocks in that beam. Adjustments in height shall be made by using colour coded shim stock with thicknesses of 0.010 mm, 0.030 mm, 0.050 mm, and 0.100 mm. The supplier can suggest an other procedure which has to be agreed by CELLS.

1.8. End Sections

The periodicity of the magnetic field at either end of an undulator jaw shall be terminated with an ESRF type 'B' termination. A separate holder is required for the end section allowing for mechanical adjustments independent of the periodic part of the undulator. The longitudinal spacing between the individual blocks of the termination and the adjacent period shall be made adjustable by the insertion of 10 micron thick shims to a maximum stroke better than 1.0 mm. The vertical height of each magnet block in an end section shall be made vertically adjustable in 0.010 mm steps with a maximum stroke of 0.100 mm.

1.9. Multipole Correction – Magic Fingers

A multipole correction module shall be used for the correction of the undulator magnetic field, first field integral, and integrated multipoles. The module shall be mechanically independent from other modules mounted on the in-vacuum beam.

1.10. Total Number of Modules Required

The total number of M1, M3, end section, and corrector modules required to construct a single 92 period undulator is 186, 184, 8, and 8 respectively. For each complete undulator CELLS requires at least 20 percent additional M1 and M3 modules. Also, CELLS requires double the number of required end sections. The additional modules shall be used in the sorting and when the undulator is complete they shall serve as spares. Table 1 summarizes the required quantities.

Module Type	Number Required	Spares	Total
M1 Modules	186	37	223
M3 Modules	184	37	221
End Section Modules	8	8	16
Corrector Modules	8	0	8

Table: 1 Required quantities of magnet block modules for one complete undulator

1.11. Tolerances on the Undulator Magnetic Field Content

After the undulator magnet arrays are mounted onto the support structure and have been shimmed they shall not exceed the tolerances of sections 1.11.1 to 1.11.4. The measurement of the first field integral, second field integral, and integrated multipole content shall take place in the best determined magnetic midplane. The integration shall take place along continuous straight lines parallel to the S-axis starting and end ending at points downstream and upstream of the undulator where undulator contribution to the measured field is less than 1% of the earth's magnetic field.

1.11.1. Tolerance on Multipole Content

Over a transverse width of ± 15 mm and over a full gap range of 5 mm to 30 mm the integrated multipole components are toleranced as:

- Normal integrated dipole less than $|30| G \cdot cm$
- Skew integrated dipole less than $|7| G \cdot cm$
- Normal integrated quadrupole less than $|50| G$
- Skew integrated quadrupole less than $|5| G$
- Normal integrated sextupole less than $|20| G \cdot cm^{-1}$
- Skew integrated sextupole less than $|10| G \cdot cm^{-1}$

1.11.2. Tolerance on First and Second Field Integral

The first field integral shall vary by no more than $I_x \leq |30|$ Gcm and $I_y \leq |7|$ Gcm, at $(x=0, y=0)$ for the full gap range of the undulator.

The second field integral shall vary by no more than $J_x \leq |6000|$ Gcm² and $J_y \leq |600|$ Gcm² at $(x=0, y=0)$ for the full gap range of the undulator.

1.11.3. Tolerance on Phase Angle Error

The RMS phase angle error measured on the centreline shall be 2.5 degrees or less over the full gap range of the undulator.

1.11.4. Tolerances on Averaged Angular & Displacement Trajectory

The deviation of the averaged angular trajectory as measured along the length of the undulator, on the best determined magnetic centreline, shall be $I_x, I_y \leq |50|$ G-cm at $(x=0, y=0)$ for the full gap range of the undulator.

The deviation of the averaged displacement trajectory as measured along the length of the undulator, on the best determined magnetic centreline, shall be $J_x, J_y \leq |5000|$ G-cm² at $(x=0, y=0)$ for the full gap range of the undulator. The average angular and displacement trajectory are calculated by filtering out the periodic component of the trajectory with a moving average window having a width equal to the undulator period.

2. Specification for Undulator Magnet Blocks

2.1. Definition of Magnet Block Types

The specification includes 2 types of magnet blocks H-block and V-block. The geometry and magnetization of each type of magnet block is included in the specification drawings as given in Table 2. The cross-section of the end section magnet blocks shall be the same as those of the central section. Their longitudinal thickness shall be optimized to minimize the beam offset of the central orbit and the first and second field integral.

2.2. Magnet Geometry and Dimensioning Tolerances

Each type of magnet block is listed in Table 2 with their respective geometry and contour (see Fig.3) given by their drawing. We specify a negative tolerancing in the machining on each surface of a block. To be clear, each magnet block after coating will have a thickness less than their nominal thickness within a tolerance of 0.040 mm (with coating) as specified in their respective drawing.

Block Type	Quantity	Thickness nominal (mm)	Width nominal (mm)	Height nominal (mm)	Tolerance (mm)
V-Block	442	5.400	50	16	0-0.040
H-Block	444	5.400	50	16	0-0.040
VE-Block	16	X	50	16	0-0.040
HE-Block	16	X	50	16	0-0.040

Table 2: Magnet block dimensions and tolerances

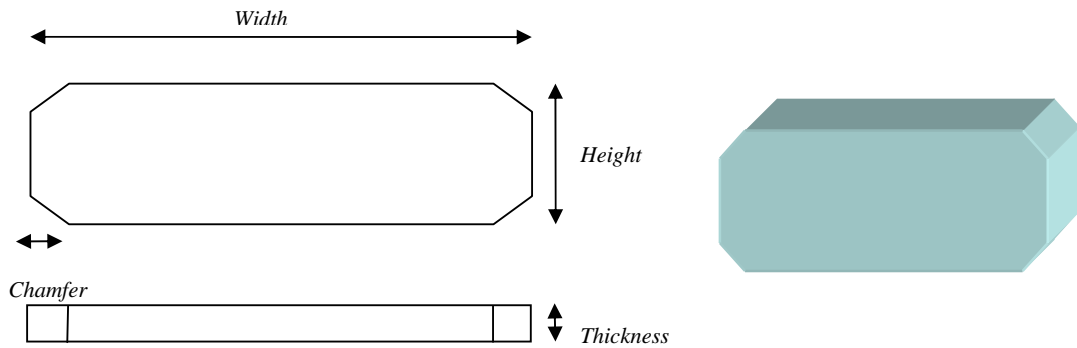


Figure 3: Geometry and contour of the permanent magnet blocks

2.3. Manufacturing Process

At present, the method of transverse die pressing, application of the polarizing field in a direction perpendicular to the pressing direction, produces blocks with the highest homogeneity and minimum error in the geometric alignment of the average dipole moment. The method of transverse die pressing shall be applied to both the H-blocks and the V-blocks such that the blocks achieve the highest remanence possible for the material specification whilst maintaining the specified material coercivity, minimum alignment error of the average dipole moment, and a maximum uniformity of the magnetic material.

2.4. Magnet Identification

Each magnet shall be inscribed with a magnet identifier defined in Table 3, followed by a serial number. The magnetization orientation will be inscribed on each magnet and must be clearly visible. The method for inscribing the label onto the magnets surface shall be compatible with UHV conditions. The method of ink deposition is not acceptable. The engraving shall not alter the integrity of the coating.

- Blocks in the magnetization stage, where the magnetizing field is parallel/anti-parallel to the S-axis, will be labelled as 21H
- Blocks in the magnetization stage, where the magnetizing field is parallel/anti-parallel to the Y-axis, will be labelled as 21V
- Each aforementioned identifier is followed by a unique 3 digit serial number, XXX, associated with the block's magnetic data
- An arrow shall be inscribed at the same position on each block and it shall indicate the direction of magnetization for each block

Magnet Name	Identifier
H-block	HXXX
V-block	VXXX

Table 3: Magnet identifiers for U21 undulator

2.5. Remanent Strength of Magnet Blocks

The material used for the magnet blocks will be $\text{Sm}_2\text{Co}_{17}$. The magnetic remanence shall be precisely parallel to their respective nominal easy axis for all types of blocks and shall not be less than 1.05 T.

2.6. Tolerance in Error of Magnetization Strength

From a set of manufactured magnet blocks the absolute difference in magnetization from block to block of a particular type shall be less than 1.5 % for the set of H-blocks and the set of V-blocks.

2.7. Tolerance in Error of Magnetisation Direction

Each block shall have a magnetization vector that is parallel to the direction defined in their respective drawing. The maximum tolerable deviation angle is 1.5 degrees.

2.8. Intrinsic Coercivity

For this undulator the maximum coercive field has been calculated to be $\sim 1000 \text{ kA} \cdot \text{m}^{-1}$ therefore we require the intrinsic coercivity of each magnet block shall not be less than 1600 kA/m at 20 degrees Celsius. To achieve high vacuum the magnetic material will be baked out at a maximum temperature of 100 degrees Celcius for a minimum of 3 days. The demagnetization curves for $\text{Sm}_2\text{Co}_{17}$ are non-linear in the region of curve's 'knee' and a manufacturer's linear temperature coefficient is insufficient to estimate the intrinsic coercivity of the material at 120 degrees Celcius. We therefore require the magnetic material to be in its linear region of the demagnetization curve and will not experience any irreversible losses to a maximum temperature of 120 degrees Celcius.

2.9. Segmentation of Permanent Magnet Blocks

No magnet will be built by gluing elementary blocks.

2.10. Magnet Block Coating

All the magnet blocks will be coated with an Aluminum layer by Aluminum Vapor Desposition (compatible with Ultra High Vacuum operation). The coating thickness shall be less than or equal to but no greater than 0.010-0.015 mm. The coating thickness should be clearly mentioned in the offer.

No observable surface defects will be tolerated (e.g. bubbles, holes, cracks, chips, loose particles, dog bones).

2.11. Magnet Block Cleaning

The ALBA storage ring will operate the IVUs to a minimum gap of 5.7 mm with a 3.0 GeV electron beam and a maximum average current of 400 mA. After manufacturing the magnet blocks must be completely compatible with the Ultra High Vacuum ALBA storage ring environment.

Considering the magnet production, the following steps will be respected:

- Before the Aluminum coating, all the blocks will be carefully degreased by using a cleaner and/or slightly etched by an acid (+ drying). The detailed process must be described by the manufacturer.
- For the magnetization process, the necessary tools will be cleaned with a solvent, or the magnets will be kept in their polyethelene bags

After the magnet coating is applied, it must never come in contact with oil or grease. They must be handled with latex gloves to avoid touching with barehands and leaving finger prints.

2.12. Radiation Resistance

The permanent magnets shall be radiation resistant, thermally stabilized at 120°C, and experience negligible irreversible losses over a 20 year lifetime in the ALBA storage ring.

3. Mechanical Support Structure Requirements

3.1. Overview

The Supplier shall construct two IVUs of the same period length that will deliver photons to the MX and NCD beamlines. Each IVU shall have a magnetic period of 21.6 mm and will be of the Pure Permanent Magnet (PPM) type.

3.2. Lifetime

The lifetime of the IVUs and their subcomponents shall be at least 20 years of continuous service in the ALBA storage ring environment. The Supplier shall satisfy this requirement by specifying routine maintenance and replacement of a limited number of wearing parts.

3.3. Basic Components

The support structure consists of 3 basic components, they are as follows (see Fig.3 of the Technical specifications):

- An alignment bench, alignment shoes, and a mover system for the carriage to adjust the carriage structures 6 degrees of freedom
- The carriage which supports the mechanical chain, in-vacuum beams, out-vacuum beams, linear guides, vacuum chamber, vacuum pumps etc...
- The out-vacuum beams supporting the in-vacuum beams and their connecting link rods

3.3.1. Alignment Bench and Alignment Shoes

- The alignment bench shall have four alignment shoes mounted underneath its body evenly supporting its weight. The shoes shall be used to perform rough global adjustments of the support structure in the 6 degrees of freedom during mechanical tests, magnetic measurement, and installation into the storage ring.
- The mover support system shall rest on the four alignment shoes. The mover shall be capable of globally translating the support structure in the vertical direction to perform fine alignment during mechanical tests, magnetic measurement, installation into the storage ring and storage ring operation. The mover system shall be stepper motor driven and remotely controlled.

3.3.2. Carriage

- The carriage consists of two columns bolted to the base frame. They shall be of welded steel and form a C-frame providing the support to hold the magnetic assemblies, mechanical chain, and vacuum system.

3.3.3. Out-Vacuum Beams

- The out-vacuum beams are the mechanical interface between the mechanical chain and the link rods which support the in-vacuum beams.
- The out-vacuum beams shall be made of normal welded steel St37 and shall be bolted to the nuts of the mechanical chain by 90 degree mouting plates in a three part system.
- The magnetic forces in the undulator gap will introduce local beam bending deformations along the longitudinal length of the in-vacuum girder due to the point like support of the link rods. The out-vacuum beams, link rods, and in-vacuum beams are a coupled system and shall, as a system, have a sufficient moment of inertia to reduce the gap deformations to within tolerance of 0.005 mm as specified in §4.5. For this reason the out-vacuum beams CELLS recommends they are I-beam type to provide sufficient moment of inertia with the minimum quantity of material.

3.3.4. Slides

- The link rods provide a rigid connection between the in-vacuum beams and the out-vacuum beams. During bake-out of the in-vacuum beams there will be a differential thermal expansion with respect to the out-vacuum beams. To accomadate the longitudinal expansion slides mounted on cross roller bearings shall support a connection for each pair of link rods.
- To insure alignment of the top in-vacuum beam with respect to the bottom in-vacuum beam all slides of the out-vacuum beams, shall be mechanically lockable (unlockable) to fix (unfix) their respective positions of the out-vacuum beam during bake out.
- The bearings of the slides shall be preloaded cross-roller bearings so as not to deform under the gap dependent magnetic forces.

3.3.5. Link Rods

- The link rods provide the mechanical connection between the in-vacuum beams and the out-vacuum beams. There shall be 6 pairs of link rods that support the lower in-vacuum beam and 6 pairs that support the upper in-vacuum beam.
- Each link rod shall be sealed in UHV-bellows.
- Each link rod shall be made of stainless steel 316 L and have an adjustable length with the use of differential screws. The link rods shall have the capability of adjusting the planarity of the inner surface of each in-vacuum beam to within a tolerance of 0.010 mm.
- The longitudinal spacing between pairs of link rods shall be optimized to minimize the gap dependent deformation due to magnetic forces

3.3.6. In-Vacuum Beams

- The in-vacuum beams shall support the magnet assemblies and provide a rigid moment of inertia to resist the gap dependent deformation due to magnetic forces in the undulator gap (see chapter 4.5).
- The in-vacuum beams shall be made of Aluminum and designed for high stiffness and high thermal conductivity.
- The in-vacuum beams shall be of the I-beam type and have a sufficient moment of inertia to minimize the gap dependent deformation due to magnetic forces.
- The in-vacuum beams shall be water cooled during bake out to maintain the temperature of the magnet blocks lower as 100 °C and during storage ring operating around 23 °C.
- The surface of the in-vacuum beams facing the gap shall be machined to a flatness of 0.020 mm over the entire length of the beam.

3.3.7. Linear Guides

- The magnetic forces in the undulator gap produce a torque on the support structure causing the frame to bend in towards the undulator gap. Linear guides provide a restoring force to reduce the torque and to guide the out-vacuum beams shall be foreseen.
- There shall be 8 linear guides in total separated into 4 pairs.
- The linear guides shall be dimensioned and positioned to limit the roll of the in-vacuum beams to less than 0.050 mrad.

3.3.8. Spindles

- The motion of the gap is made by ball screw spindles driven by a mechanical chain. They are a precision leadscrew shaft mounted in the columns of the frame.
- The ball screw spindles are right-handed on the upper section and left-handed on the lower section to provide equal but opposite vertical motion of the upper and the lower out-vacuum beams.
- The ball screw spindles must resist whatever residual side forces that result from gap motion.
- In virtually all IDs, the ball screw spindles rotate in preloaded ball or tapered-roller bearings.

3.3.9. Magnetic Load

- Based on the the magnetic design given in the magnetic load between the in-vacuum beams and acting on the support structure is 13.0 kN at the minimum gap of 5 mm and 10.5 kN at the average minimum magnetic gap of 5.7 mm.

3.3.10. Installation support

- The complete IVUs shall be capable of being lifted by an overhead crane from a single point. The Supplier shall provide lifting eyes and associated spreader bar/lifting bars with the system. In all cases international standards and CE markings must be fulfilled. All lifting equipment should be suitably tested to indicate a “safe working limit”. CELLS requires all lifting equipment to be document and will supply an alphanumeric code to enable the information to be added to the database. This information will be provided on or before the FDR meeting.

- The complete IVUs shall be capable of being supported by removable wheels for the purpose of installing the device into the ALBA storage ring straight section. Four wheels shall either be attached or detached by the use of jacks provided by the Supplier or by the alignment shoes included with the IVUs for alignment. Once at the point of installation the wheels shall be removed and the mechanical structure shall be supported by its alignment shoes.

3.3.11. Springs

- The Supplier may consider the use of Belleville springs to buck the magnetic force at small gaps to reduce the load on the motor and at larger gaps where the force of gravity on the girder exceeds the magnetic force.

3.4. Manufacturing

3.4.1. Material Creep and Stress Relieving

- All sub-assemblies shall be stress relieved before final machining to minimize material creep.
- The welded out-vacuum girders shall be stress relieved after welding, rough machined, again stress relieved and then given the final machining.

3.4.2. Surface Treatment

Materials that are subject to surface corrosion shall be anodized, passivated, or painted wherever possible.

3.4.3. Dimensions of the Complete Undulator

- Each IVU shall have a maximum envelope 2630 mm high, 2500 mm long, and 1335 mm wide

4. Functional Tolerances and Specification of the Undulator Gap

The inner surface-to-surface distance between the magnet arrays, unless otherwise stated, is defined as the gap. CELLS places tolerances on gap which in turn determines the tolerances on other parts of the support structure which include (but are not limited to) frame, mechanical chain, and linear guides. The tolerances apply to the IVUs after machining, and mounting of the in-vacuum beams and after magnetic arrays will be mounted onto the in-vacuum beams over a gap range 5 mm to 30 mm for the full range of magnetic force acting on the support structure. Table 4 provides a summary of the functional tolerances.

Tolerance	Unit	Tolerance Value	Definition
Gap range	mm	5-30	4.1.1
Gap reproducibility	mm	≤ 0.001	4.1.2
Gap speed	mm/s	1	4.1.3
Maximum Force	kN	13.0	4.2
Taper angle	mrad	≤ 0.0025	4.3.1
Variation of taper angle	mrad	≤ 0.005	4.3.2
Locking of taper angle	mrad	≤ 0.001	4.3.3
Reproducibility of taper angle	mrad	≤ 0.004	4.3.4
Roll angle	mrad	≤ 0.050	4.4.1
Variation of roll angle	mrad	≤ 0.050	4.4.2
Reproducibility of roll angle	mrad	≤ 0.050	4.4.3
In-vacuum girder deformation	mm	≤ 0.005	4.5

Table 4: Summary of functional tolerances and specification of undulator gap

4.1. General Requirements of Undulator Gap

4.1.1. Gap Range

The gap range will be continuously adjustable from an absolute minimum gap of 5 mm to a maximum gap of 30 mm.

4.1.2. Gap Reproducibility

CELLS requests a reproducibility of 1.8 eV with respect to the photon energies produced by the IVUs. The maximum energy gradient with respect to the gap on the 7th harmonic is approximately 2.0 keV/mm. The support structure must be designed such that it has bidirectional repeatability of the gap corresponding to an energy band tolerance of 1.8 eV. This gap reproducibility corresponds to a gap of reproducibility of 0.001 mm. CELLS, requires a bidirectional reproducibility of undulator gap better than 0.001 mm.

4.1.3. Gap Speed

The mechanical and electrical system for the IVUs will allow for a maximum gap speed of at least $1 \text{ mm} \cdot \text{s}^{-1}$.

4.2. Forces

At an average minimum magnetic gap of 5.7 mm the magnetic force acting on *each* magnet array is approximately 11.0 kN, at the minimum gap of 5.0 mm the forces are roughly 13.5 kN, and exponentially to near zero at a gap of 30 mm.

4.3. Taper Angle of Gap

4.3.1. Tolerance on Taper Angle of Gap

The taper angle shall be less than 0.001 mrad. Figure 4 shows a sketch of the taper angle which assumes each in-vacuum beam is rotated symmetrically with respect to the mid-plane.

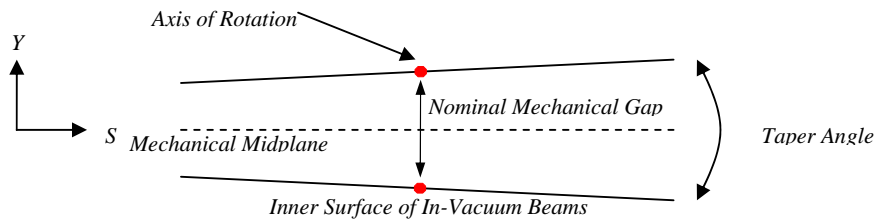


Figure 4: Schematic illustrating the taper of the in-vacuum beams

4.3.2. Requirement for Adjustment and Locking of Taper Angle of Gap

It is foreseen that the taper of the in-vacuum beams will change under magnetic force after the mounting of magnet assemblies. We will take the aforementioned possible case into account by requiring a method for adjustment and locking of the taper angle of the in-vacuum beams, individually, or simultaneously over the full gap range of 4 mm to 30 mm.

4.4. Roll Angle of the Gap

4.4.1. Tolerance on Roll Angle of the Gap

It is assumed that the rotation of the individual beams about the S-axis is equal in magnitude but opposite in direction, as shown in Figure 5. The roll angle of the in-vacuum beams shall be better than $0.050 \pm .005$ mrad.

4.4.2. Tolerance on Reproducibility Variation of the Roll Angle of the Gap

The bi-directional reproducibility of the roll angle shall be better than 0.050 mrad.

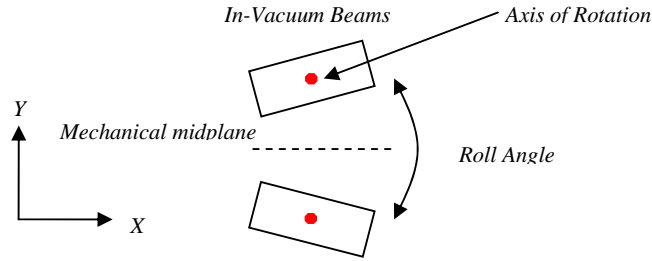


Figure 5: Schematic illustrating the roll angle of the in-vacuum beams

4.5. Deformation of Gap Due to Magnetic Force

The link rods act on the in-vacuum beams as a point like support against the magnetic force between the magnet arrays. It is foreseen that they produce local, gap dependent, deformations on the in-vacuum beams. The resulting deflection of the magnetic arrays will produce a weaker or stronger magnetic field that is locally gap dependent. Such effects cannot be fixed by static shims. An illustrative example of such an error is shown in Figure 6.

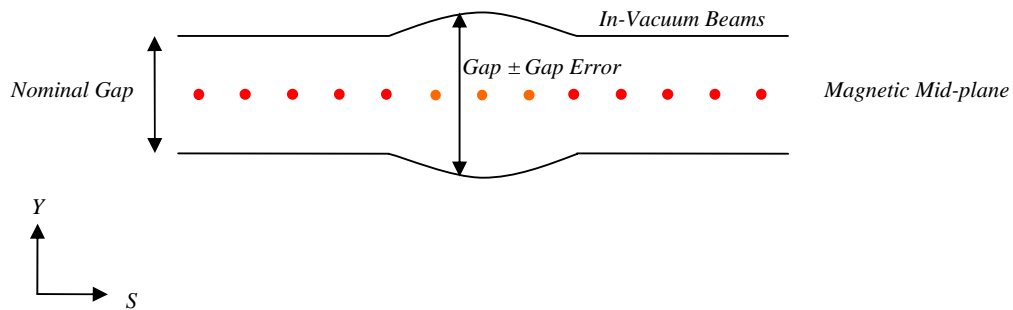


Figure 6: Schematic illustrating the deformation of in-vacuum beams due to magnetic force

We consider a gap error that is independent of pitch, roll, yaw of the in-vacuum girders, after the magnetic structure is mounted on to the in-vacuum beams, a magnetic load is applied, and after accounting for the deformation of all girders in the undulator system. The surfaces facing the electron beam of both the upper and lower in-vacuum beams shall have a gap variation of less than ± 0.0025 mm.

5. Technical Specification of Undulator Alignment

Following the shimming of the magnetic arrays the magnetic midplane, coordinate system of the undulator with respect to the magnetic midplane, and best determined magnetic centreline of the undulator will be defined. After installation into the storage ring the undulator will be aligned with respect to the storage ring.

5.1. Survey

The Supplier is required to fix survey features, fiducials, on the support structure. The survey fiducials shall allow for surveying of the support structures 6 degrees of freedom in 3D space with respect to the ALBA storage ring.

After the magnetic arrays are assembled, mounted on the in-vacuum beams, and shimmed to within specification, the magnetic centerline will be defined at minimum gap. The magnetic centreline shall be determined by Hall probe measurement. At 10 mm gap the Supplier shall make Hall probe measurements at $x = 0, y = -2, -1, 0, 1, 2$ mm. Determine the peak field and find the vertical position of the minimum in the resulting parabolas for each pole and fit a straight line to the minimum positions. The Supplier shall also make Hall probe measurements for $x = \pm 10, \pm 7.5, \pm 5, 0$ mm with $y = 0$ and determine the horizontal pole positions. It is the best determined vertical and horizontal coordinates of the centreline that shall be

related to the fiducials and surveyed into the ring. The Supplier shall provide CELLS with the coordinates of the so-determined centerline with respect the fiducial positions at the carriage

The Supplier shall provide a procedure compatible with the tools (Laser Tracker) and methods employed by the CELLS Survey and Alignment Group.

5.2. Global Alignment

The global alignment of the support structure shall be made by using the support structure fiducials.

5.2.1. The range of alignment in any coordinate direction shall be ± 10 mm.

5.2.2. Rough Vertical Alignment of the Magnetic Centreline

The complete support structure shall be globally aligned to the storage ring in the vertical direction using the alignment shoes beneath the support structure. They shall have an alignment resolution of 0.100 mm or less.

5.2.3. Rough Transverse Alignment of the Magnetic Centreline

The complete support structure shall be globally aligned to the storage ring in the transverse direction using the alignment shoes beneath the support structure. They shall have an alignment resolution of 0.2 mm or less.

5.2.4. Rough Longitudinal Alignment of the Support Structure

The complete support structure shall be globally aligned to the storage ring in the longitudinal direction using the alignment shoes beneath the support structure. They shall have an alignment resolution of 1.00 mm or less.

5.2.5. Fine Vertical Alignment of the Magnetic Centreline

The in-vacuum undulator has a narrow gap and is therefore sensitive to the relative position of the electron beam with respect to the inner side of the in-vacuum beams. To minimize beam losses CELLS requires that the complete support structure be globally aligned in the vertical direction by a single stepper motor. The minimum adjustment step of the support structure shall be 0.010 mm with a range of 5 mm or greater. The fine vertical alignment shall be done by optimizing the losses of the stored electron beam as a function of position and the position shall be measured by an absolute encoder.

5.3. Alignment of the In-vacuum Beams

After the magnetic beams are shimmed to within specification they will be disconnected from the link rods, removed, the vacuum chamber will be mounted on the support structure, and the in-vacuum beams shall be remounted inside the chamber and connected to the link rods. The Supplier shall provide a procedure for insuring that the taper, roll, and longitudinal position of the in-vacuum beams after remounting is within the tolerances of §5.

6. Mechanical Chain Specification and Functional Requirements

Figure 7 shows a schematic of the proposed CELLS mechanical chain. It shows a 2-axis mechanical chain where each axis is driven by independent motors. It permits the dynamic feedback and correction of the taper angle between the two in-vacuum beams. Initially, CELLS foresees driving both axes of the mechanical chain with a single motor and later driving with two motors if dynamic correction of the taper is necessary. Therefore, CELLS requires that the axes may be driven in Master/Slave mode or independently.

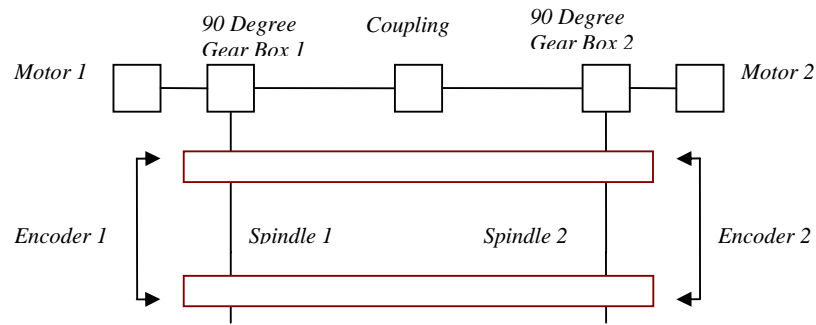


Figure 7: Schematic of mechanical chain to drive the gap

6.1. Motors

6.1.1. Motor Type

CELLS requires a minimum of two motors as the driving component for the mechanical chain. All motors used by for the IVUs shall be a two phase stepper motors. The selection of motors shall be agreed upon in discussion with CELLS.

6.1.2. Motor Electrical Compatibility

Each motor shall be electrically compatible with the CELLS control system given in §7 and CE and EMC electrical regulations.

6.1.3. Motor Operation in Master/Slave Mode

It is foreseen that CELLS will initially use only one out of the two motors and drive the spindles in a master/slave mode. In this case the single motor will be required to reach the same gap specifications as given in §5 but at twice the torque. In this case the Supplier will insure the single motor is capable of driving the gap.

6.1.4. Motor Brake

If the power is cut to the motor the mechanical chain shall not be driven by the magnetic load in the undulator gap. Each motor shall have a brake and the default mode of that brake shall be ON when motor power is cut.

6.1.5. Motor Encoder

All motors shall be equipped with absolute rotary encoders.

6.2. 90 Degree Gearboxes

6.2.1. 90 Degree Gearbox Type

The 90 degree gearboxes will transmit the rotational motion of the motor to the spindles and consequently cause the axial linear motion of the nuts. Each 90 degree gearbox shall be of the worm gear type so that it may not be back driven by the load and will have zero backlash.

6.3. Spindles

6.3.1. Spindle Type

The ball screw spindles shall be right-handed on the upper section and left-handed on the lower section to provide equal but opposite vertical motion of the upper and the lower out-vacuum beams.

6.3.2. Variation in Travel

The variation in travel for each spindle shall be less than 0.001 mm over the useful travel range.

6.3.3. Forces Acting on the Spindle

Almost all spindles are designed for axial load but the action of radial forces or torques may result in shorter life time, reduced position accuracy, acoustic and material vibrations, or breakage of the Spindle

ends. Therefore the spindles shall be mounted into the frame support such that they experience zero radial forces and torques.

6.4. Nuts

6.4.1. Type and Quantity of Nuts

On each Spindle there are 2 nuts giving a total of 4 nuts for linearly translating the undulator gap due to rotation of the Spindles. CELLS recommends nuts using planetary roller screws for high load carrying capacity and rotation speed. Each Nut shall be preloaded to have zero backlash and no axial play by using a split nut.

6.5. Shaft Couplings

6.5.1. Coupling Type

All coupling connections between shafts shall be of the stainless steel bellows type using clamps and not keys.

6.6. Gap Encoders

Four linear absolute encoders shall be used to measure the undulator gap and taper at the upstream and downstream ends each out-vacuum undulator beam. They shall have a resolution better than 0.0001 mm. The encoders shall be shielded with lead to minimize radiation damage to the electronics.

6.7. Spindle Encoders

Two incremental rotary encoders shall be used to measure the undulator gap and taper at the upstream and downstream ends of the undulator by being mounted on the free ends of the spindles. They shall have a resolution better than 0.0001 mm. The encoders shall be shielded with lead to minimize radiation damage to the electronics.

6.8. Limit Switches

The frame shall support 6 adjustable electromechanical soft limits to prevent the mechanical chain from driving the gap below or above a predefined value for protection for the magnetic arrays. Four of the soft limits shall be mechanically referenced to the minimum and maximum gaps of the undulator and shall be capable of stopping the gap from closing smaller than a settable gap value between 1 mm and 30 mm. Two of the limit switches are for the global vertical alignment of the IVUs which is stepper motor driven. They shall be mechanically referenced to the slab and the best determined magnetic centreline of the IVUs and be capable of limiting global movement of the in-vacuum beams with respect to the storage ring electron beam. The type and location of limit switches used shall be agreed upon with the CELLS at the time of the PDR

6.8.1. There shall be two limit switches for minimum gap that shall be mounted on the upstream and downstream ends of the out-vacuum girders. The limit switches shall have a binary (OPEN/CLOSED) sensitivity to 0.001 mm of gap motion, they shall be easily adjustable for gap sizes from 4.0 mm to 8.0 mm, and they shall have a reproducibility of 0.001 mm.

6.8.2. There shall be two limit switches for maximum gap that shall be mounted on the upstream and downstream ends of the out-vacuum girders. The limit switches shall have a binary (OPEN/CLOSED) sensitivity to 0.001 mm of gap motion, they shall be easily adjustable for gap sizes from 30 mm to 22 mm, and they shall have a reproducibility of 0.001 mm.

6.8.3. There shall be two limit switches for maximum and minimum global position of the IVUs. The limit switches shall have a binary (OPEN/CLOSED) sensitivity to 0.001 mm of gap motion, they shall have an easily adjustable range of at least 10 mm, and they shall have a reproducibility of 0.001 mm.

6.9. Hard Stops

The frame shall support 4 adjustable hard stops to prevent the mechanical chain from driving the gap below a predefined value in the event of soft limit switch failure.

6.9.1. There shall be two hard limits for minimum gap that shall be mounted on the upstream and downstream ends of the out-vacuum beams. The hard stops shall have an adjustment resolution of

0.100 mm using precision thread screws and have an adjustment range of 4.0 mm to 8 mm minimum gap.

6.9.2. There shall be two hard limits for maximum gap that shall be mounted on the upstream and downstream ends of the out-vacuum beams. The hard stops shall have an adjustment resolution of 0.100 mm using precision thread screws and have an adjustment range of 31 mm to 22 mm minimum gap.

6.10. Inclinometers

The Supplier shall consider the use of inclinometers as a part of the interlock system to insure the undulator beams do not exceed a user defineable pitch angle.

7. Control systems and interface

7.1. General

7.1.1. The in-vacuum undulators shall be operated remotely.

7.1.2. The control system for the in-vacuum undulators is not a part of the scope of Supply of this contract. CELLS shall provide their control system to the site of the Supplier for the purpose of the FAT. At the FAT, the Supplier shall provide their control system, outside of the scope of supply, to perform the FAT. CELLS control system shall be used as an independent test.

7.1.3. The Supplier shall perform a series of tests to demonstrate that the IVUs motion control systems and routine operation functions are fully compatible with CELLS control system interface requirements CCD-BLCT-CC-0001.

7.1.4. The CELLS control system is based on Suse Linux (currently v10.2, kernel 2.6). It will consist of a Compact PCI and IOCs. The IOC is connected to the ALBA network (Ethernet 100BaseT or 1000BaseT). The preferred remote control link for eventual subsystems is Ethernet (this is the case for

the motor controller). Other field buses like RS485, RS232 and GPIB can be used under certain conditions. It will be installed in the CPCI crate.

7.1.5. The Supplier is responsible for the integration of the different subsystems (i.e. power supplies, and vacuum systems, interlocks, etc...). The Supplier shall provide a well-documented protocol for the remote control of the different subsystems. Example programs shall be included.

7.1.6. The Supplier shall provide a PLC for interlocking the in-vacuum undulator subsystems. The choice of PLC shall be decided in discussion with the CELLS controls group at the PDR.

7.1.7. The Supplier shall provide temporary racks, outside of the scope of supply, for the purpose of the FAT. The racks should correspond to DIN 41494/IEC 297. The specific number and type of racks need shall be discussed with the CELLS controls group by the time of the PDR.

7.2. Hardware architecture

7.2.1. Figure 8 shows the hardware architecture diagram for the CELLS ID control.

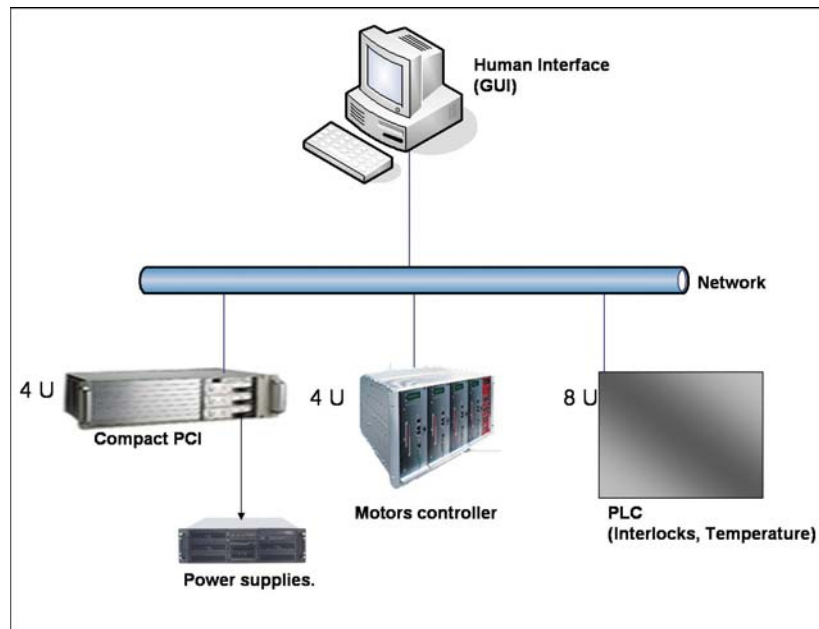


Figure 8 CELLS proposed hardware architecture

- 7.2.2. The Supplier must define and implement signals and logic for interlocks to ensure correct and safe operation of the device. These shall be managed by PLC. The Supplier is responsible for the design of the logic in the PLC. The Supplier shall also provide fully documented source code and development tools to CELLS. The structure of the interlocks must be proposed by the Supplier and agreed by CELLS.
- 7.2.3. Temperature sensors are read by a PLC. CELLS will inform the Supplier about the preferred model of the PLC. The final choice shall be agreed with CELLS.
- 7.2.4. IOCs, motor controller and PLC are connected to the network. Human-machine interfaces (monitor, control and archiver) will run in the control room and will access to IOCs through the network. For acceptance tests, the Human interface will run in a computer connected to the network.
- 7.2.5. The standards of connectors and signals shall be agreed upon by the PDR through discussion with CELLS controls group.

7.3. Control Signals and Power Cabling

- 7.3.1. All electrical cabling performed by the Supplier for the IVUs shall conform to CELLS standards document “Equipment Naming Conventions and Naming of the Signal” END-PM-QA0505, and “Control and Powering Cables and Racks” END-GDEL-EN-004.
- 7.3.2. All electrical signals, connectors, cabling, and soft interfaces used by the Supplier shall conform to the terms defined in document CCD-BLCT-CC-0001.
- 7.3.3. The Supplier shall cable all control and power signals from each IVU directly to terminal blocks in a patch panel mounted on the backside of each support structure. For the FAT the Supplier shall complete the cabling from the patch panel to the control system racks. For the SAT CELLS shall perform the cabling from the patch panel to the CELLS control system racks. The cabling shall be discussed with CELLS on or before the PDR and finalized with CELLS, in writing, on or before the FDR.
- 7.3.4. Each signal terminated in a terminal block shall be clearly labelled with its associated identifier.
- 7.3.5. The Supplier shall place an easily accessible emergency abort button on the downstream column of the undulator on the in-vacuum beam side and near the patch panel on the support structure back side. The abort button shall normally be closed and shall open when activated. When activated the abort button shall cut power to the motor.
- 7.3.6. Control level signals and electrical power level signals shall be separately cabled to the patch panel.
- 7.3.7. All wiring diagrams, cable types, and tabulated system I/O shall be provided to CELLS on or before the PDR meeting and subsequently agreed upon in writing between CELLS and the Supplier.
- 7.3.8. The I/O labelling standard in wiring diagrams, schematics, and on the components shall be agreed upon with CELLS in writing on or before the PDR.

7.4. Motion control

The stepper motors used for motion control shall be compatible with the specifications given in this document. Any derivation from these standards must be explained and agreed with CELLS.

- 7.4.1. The motor connection (including the limits switches) will be with metallic compatible ITT cannon 14-12 pin male. Table 5 shows the pin out of this connector, and an example is TNM OU 1400-12P1L. If a four phases motor is used, the phases will be connected in series or in parallel in agreement with the CELLS staff.


Connector	Pin	Signal	Description
	A	Home	Mechanical reference
	B	Phase A+	Motor power
	C	Phase A-	
	D	n/c	
	E	Phase B+	Motor power
	F	Phase B-	
	G	n/c	
	H	Limit switch+	Travel limit
	I	Limit switch-	
	J	Disable	Remote disable
	K	+5 V power	Auxiliary power supply
	L	GND	

Table 5 Motor phases and signals pin out

CELLS has defined a color code for the motor cables.

Motor phases:

- phaseA+: yellow
- phaseA-: green
- phaseB+: white
- phaseB-: brown

Motor signals:

- GND: black
- Disable: pink
- Limit+: orange
- Limit-: blue
- Home: grey
- +VCC: red

The motor controller could deliver a maximum power of 330 W, with a maximum current of 8 A and maximum voltage of 78 V.

7.4.2. A motor brake signal will be delivered by the motor controller. This signal is LVTTTL.

7.4.3. The relative encoders will be with a 15 pin sub-D male, with a pinout showed in the following picture (Table 6).

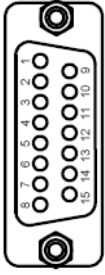
Connector	Pin	Signal		Type/Direction	Description
		Incremental	SSI		
	1	Encln A+		RS422	Encoder Signal
	9	Encln A-			
	2	Encln B+		RS422	Encoder Signal
	10	Encln B-			
	3	EncAux+	Data+	RS422	Auxiliary Encoder Signal
	11	EncAux-	Data-		
	4		CLK+	RS422	Clock SSI Interface
	12		CLK-		
	5			n/c	
	13			n/c	
	6			n/c	
	14	5V sense+			Sense signals
	7	5V sense-			
	15	+5 VDC power		power supply	Auxiliary Power Supply
	8	GND		power ground	

Table 6 Encoder pinout

The signals for the encoder signals will be RS422 standard.

If an absolute encoder is used, only SSI protocol is supported. Other protocols have to be agreed with CELLS staff. The SSI protocol has a clock signal provided by the controller in pins 4 (CLK+) and 12 (CLK-), and the data signal will be in the pins 3 (DATA+) and 11 (DATA-). The signal levels are always RS422 standard.

The preferred option is to receive digital signals from the encoder, but if the output is analogue, it shall be 1 Vpp differential. The supply voltage for the encoder shall be 5 V. The pin-out shall be agreed upon with CELLS.

- 7.4.4. The limit switches could be either dry-contacts, or active with a open drain output.
- 7.4.5. Whenever possible, fast digital timing signals (electrical) interconnecting modules or devices should use LVTTTL logic levels, capable of driving 50 Ohms cables with RC loads. Other logics like NIM or PECL will be also supported. The standard connector is a compatible with the Lemo Series 00 of contact type female.
- 7.4.6. Regarding optical signals, it will be supported the HFBR-1528 and HFBR-1414 (high speed) optical link outputs.
- 7.4.7. For analogue control signals 4-20 mA or ± 10 V shall be used. As both signals have their advantages and disadvantages, the final selection shall be done in agreement with ALBA
- 7.4.8. For control, 24 VDC shall be used for digital signals (with unshielded twisted pairs ([2x0.5 mm2])). The usage of 48 VDC or AC signals is not acceptable.
- 7.4.9. The preferred connectors are 50 Ohms BNC female connectors (panel or feed through) (with RG58 cables), or compatible with the Lemo Series 00 (with RG174 cable). High frequency signals will be connected with SMA (with RG223) or N connectors. Also screw clamp connectors, DB 9 or DB25 could be used. Other connectors like miniDIN or multipin Lemo compatible connectors have to be agreed with CELLS.
- 7.4.10. Application where maximum RF shielding and minim noise radiation is required, triax connectors and cables could be used. The triax connector (like triax BNC or any Lemo) has to be agreed with CELLS.
- 7.4.11. When video signals are transmitted, the connector will be 75 Ohms BNC female panel connectors (with RG59 cable).
- 7.4.12. Interlocks and controls should be designed to be failsafe. A safe state shall be indicated by a closed contact sending +24 VDC signals. An unsafe state shall be indicated by an open contact that blocks the +24 VDC. On power failure, the system should indicate an unsafe state.
- 7.4.13. The high voltage signals will be defined when the controller and pumps will be chosen by the vaccum group. The cable will be connected with something like the RG213 or the HTC-50-3-2 from Draka (up to 10 A).
- 7.4.14. All NIM bins will supply ± 6 VDC. The delivered power is 150 W.
- 7.4.15. For connecting any controller to the control system, ALBA prefers the following controller interfaces in the order, TCP/IP over Ethernet, RS-232 / RS-422, GPIB
- 7.4.16. All connectors or connection points and internal cabling provided by the supplier shall be EMC compatible and mounted on metallic patch-panels. Those panels shall be electrically and mechanically connected to the equipment according to the EMC recommendations.
- 7.4.17. The equipment (girders or vacuum components) shall provide, either foot or top side, two holes, one M8 and the other M10, both 15 mm deep. The M8 hole shall contain the appropriated screw to fix a terminal spade, crimped with either a bared copper 29 mm² cable or a green/yellow jacket isolated copper 25 mm² cable according to the current country safety rules. This cable shall be connected directly to the ground (or on the cable tray ground) according to the current safety rules. The M10 hole shall contain the appropriated screw to fix a terminal spade, crimped with an EMC ground strap. This EMC ground strap shall be connected to the closest ground (or massif equipment connected to the ground eg Cable trays), to be ECM compatible. The EMC ground strap shall be copper laminated or braided but it shall be completely tinned to provide corrosion resistance. The EMC ground strap shall be 50x5 mm² or with a maximum length shorter than 13 times the width.
- 7.4.18. This electrical connections are required when the device are not electrically connected. If a girder and a magnet are electrically connected through the mechanical connections, they could be considered a single equipment, and any electrical connection is required between them.

7.5. Equipment Protection System

7.5.1. The Supplier shall provide the wire diagrams, signal specification, and control logic for integration of the relevant IVU instrumentation (thermocouples, vacuum gauges, limit switches, flow switches etc...) into an Equipment Protection System. CELLS is responsible for integration of the instrumentation controls signals into the Equipment Protection System.

7.6. Software architecture

7.6.1. From the software point of view (see Fig.9), the architecture is distributed. The subassemblies and low level hardware provided by the Supplier shall be integrated into the CELLS control system. The specific low level software protocols and the associated hardware shall be determined in discussion with the CELLS controls group to insure ease of integration and compatibility with the CELLS control system. Figure 13 shows the scheme of the CELLS control system.

7.6.2. The Power supplies will be controlled through a field bus. CELLS will provide a standalone tool to control the power supplies.

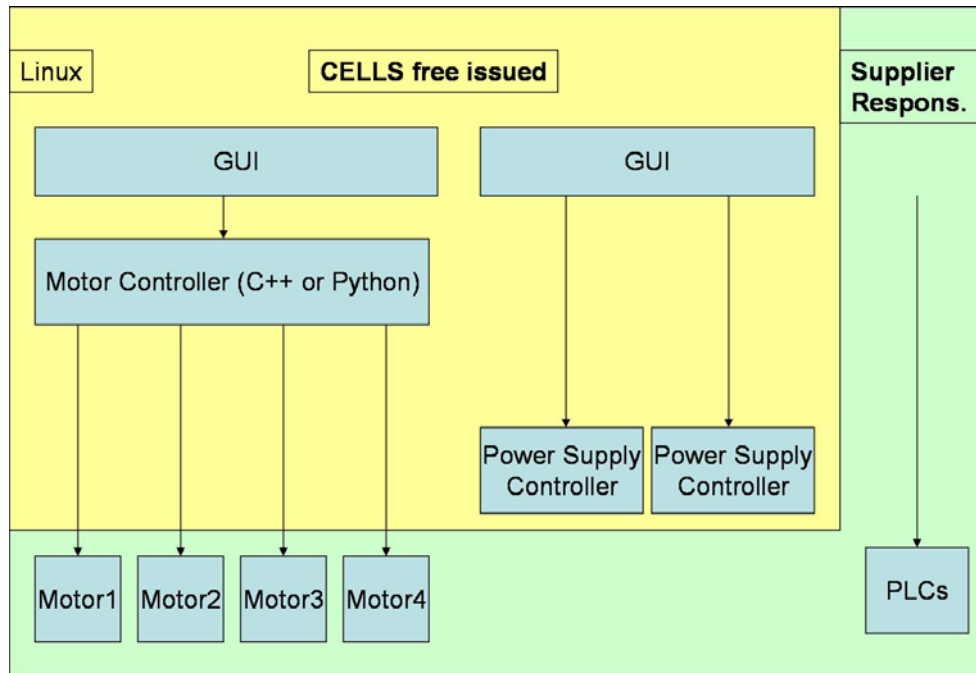


Figure 9: Proposed software architecture for factory test (in the case there are 4 motors).

7.7. Rack specifications

7.8. IP Protection

All the facility space is considered a safe environment. Due to this no IP protection will be requested for the cabinets.

7.9. Dimensions

The cabinet will handle standard 19'' racks according to DIN 41494/IEC 297.

The dimensions of the cabinet should be 2000x600x800mm³. It can be considered a slight variation in the height although it is required that 42U units of electronic equipment can be installed.

The cabinet will need to have supports in order to stand directly on the concrete floor and not on the false-floor of the facility. These supports shall be provided by the contractor. The external envelope of the ensemble shall be defined by the side walls of the rack (i.e. the supports shall not stick out). The total height of the false floor is 500mm. The cabinets and/or the support shall have some mechanism to balance the height of the feet so little irregularities of the floor could be compensated and the racks can be properly aligned.

The rack and its supports must be mechanically fixed to each other in order to guarantee safe operation. The method proposed shall guarantee that no mechanical interference arises between adjacent racks and allow for safe rack operation.

The eventually fixation of the racks to the floor shall allow for errors in the position of floor drilled holes of ± 10 mm.

The supports shall be considered as an integral part of the rack. CELLS strongly prefers that the supports can be dismount from the racks. The contractor will have full responsibility on the functionality of the ensemble rack-support.

All the cabinets shall be supplied with eye holders. They will be used for the installation of the cabinets inside the facility using the crane that is available inside the facility.

7.10. Total Weight

The maximum weight of the rack including the installed electronically equipment 400 kg.

All the cabinets shall be supplied with four eye holders. They will be used for the installation of the cabinets inside the facility using a crane.

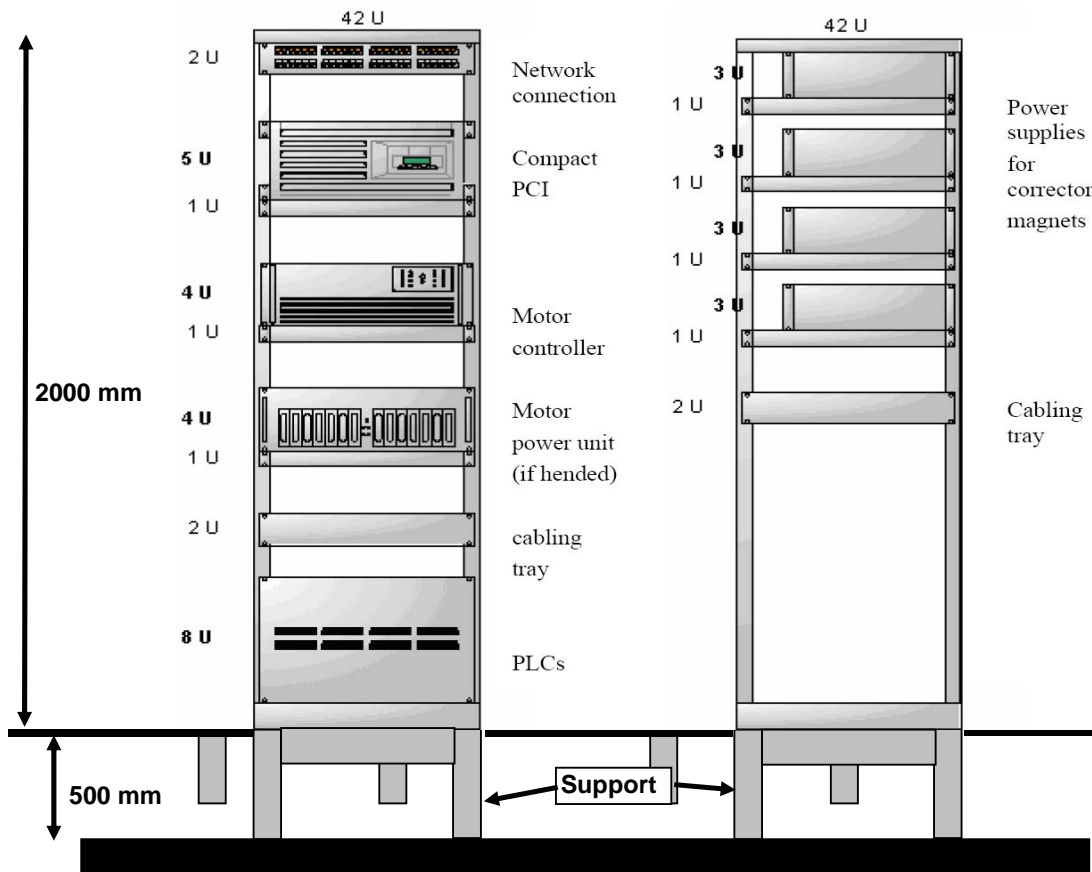


Figure 10. Lay out of the cabinets with the supports dedicated to ID control

7.11. Accessory Trays

There will be three types of fixing that will be used to handle the equipment inside the cabinet:

1. Slide Rails – Used for “light” 19” standard equipment whose weight will not be bigger than 25kg. This support has to occupy a maximum of 1U in the cabinet and the vertical space that uses has to be available for the equipment.
2. Light Shelf – In this support it will be installed “light” non standard 19” equipment. It has to support a maximum weight of 25kg.
3. Heavy Shelf – In this support will be installed the heavy equipment. It has to support a maximum weight of 75kg.

None of these accessories shall be telescopic.

7.12. Cable Routing

All the cables from the outside of the cabinet will enter through the bottom side of the cabinet to cable trays. Special brush accessories will be needed to ease the route of these cables. The general policy will be that the main cable routing will be done in the rear side. In order to do this the equipment installed in the cabinet will be fixed as close as possible to the front door producing a valuable space for routing cables in the rear side. In order to fit the cable trays the distance between the two vertical axis (front and rear) shall be the distance most next to 450 mm without exceeding it. And the distance from the front axis to the door shall be 100mm. Finally the total length from the rear axis to the rear door will be 250 mm (see Figures 23).

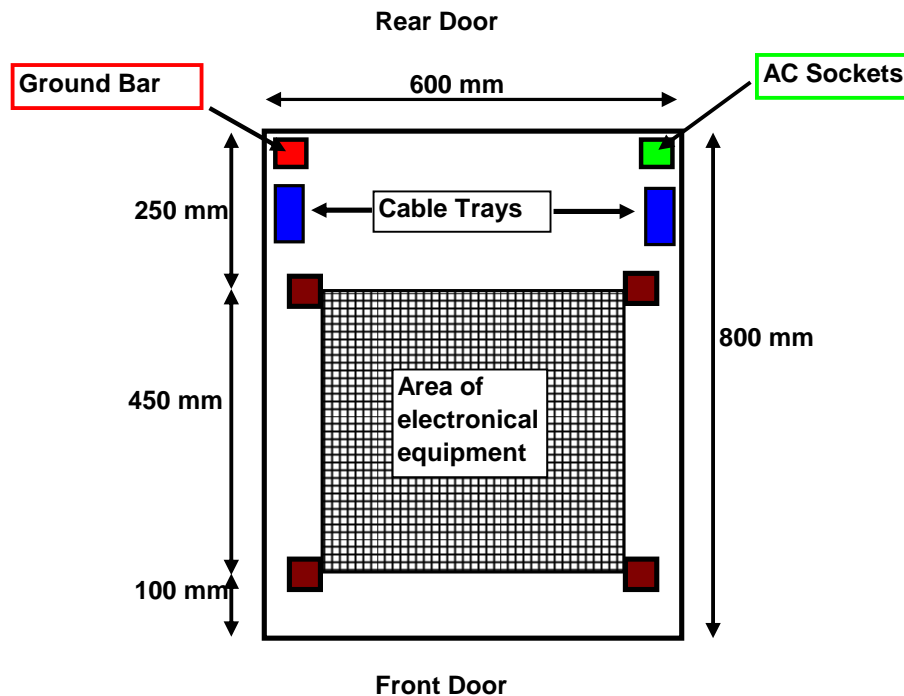


Figure 12. Rack layout.

In the rear side it has to be installed two vertical cable trays in order to route all the cables. The lengths of the trays have to be as large as possible.

In the front side the vertical cable management will be done using little cable hoops that have to be fixed in the front axis or in any part of the cabinet but not in the side panel. This cable hoop section has to be larger than 10 cm². Little plastic parts of very easy mounting will be preferred (no screw).

In some cases a horizontal cable distributor accessory is needed to route the cables from the equipments to this cable hoops.

Also it will be needed a cabling guide tray in order to route the cables from the front to the rear side. For every cable tray will be reserved a maximum space of 2U.

The contractor is invited to suggest any extra accessory that would improve the cable management inside the cabinet.

7.13. Doors and side covers.

The cabinets have to incorporate a door in the front and the rear side. It shall be used a glazed doors on the front and a steel door in the rear side. The doors should be equipped with a button for opening.

7.14. Fan System

In the case of the racks that will be installed with glass doors it will be needed to be installed a fan system in order to ventilate the cabinet. This system has to be installed in the top of the cabinet without occupying any U and without affecting the exit of the cables. The system has to be operated at 220V.

The preferred system would be a modular one with 1, 2 or 3 fans. Each fan should have a minimum flow rate of 120 m³/h.

The contractor is invited to suggest any other solution that would improve the ventilation inside the cabinets that uses glazed doors.

7.15. Grounding System

All the electronically units of the cabinet shall be connected electrically to the general ground. In order to do this connection all necessary accessories shall be provided by the contractor. Moreover a standard M8 general ground connection of the cabinet shall be provided to connect the cabinet to the facility ground.

The cabinet has to provide also a general earth connection to the equipment. This connection has to be done from the bottom side. For doing this connection properly two connections of ground shall be possible: the first one is the direct contact of the equipment to the metallic axis of the cabinet, and the second one is using a ground bar that has to be installed vertically in the rear side next to the cable trays. This bar shall include some metric holes (preferably M6) in order to connect each individual equipment ground.

It is also necessary to have the possibility to shield individual cables to the cabinet (like shielding brackets). In this case one accessory have to be provided for connecting the shield of different control signal cables (Ø up to 15mm) directly to the cabinet.

7.16. Socket Strips

The AC distribution of the equipments has to be smartly connected using socket strips installed inside the cabinet in the rear side. These sockets should be installed vertically beside the right cable tray.

The sockets have to be standard Schuko connectors (DIN 49440) and the socket strip will need to be connected also in a standard Schuko connector. The total number of sockets inside a cabinet has to be greater or equal than 16. The maximum number of strips that have to be possible to be installed inside each cabinet has to be at least 24. The socket strips have preferably to have installed a thermal magnetic breaker and a main suppression noise filter. The sockets should not have a manual on/off switch and allow a connection of equipments up to 16A.

It has to be possible to distribute inside one cabinet two different AC sources (8 plugs each minimum).

At ALBA there are four different types of electrical supplies, which will be identified by colour codes. The contractor will receive the detailed information on the colours to be used for the sockets of each rack during

the initial stages of contract execution. Each rack will receive a maximum of two different types of supply (i.e. colours for the sockets), among the total of FOUR types of supply (i.e. colours for sockets) existing at ALBA.

7.17. Units marks

In the front side of the cabinet has to be installed labels all along vertical axis that indicates the height in U units from 1(bottom) to 42U(up).

8. Auxiliary Systems

8.1. Bake-Out System

A bake-out system is necessary to vacuum condition the undulator vessel and its sub-assemblies to meet the UHV requirements of the ALBA storage ring. The Supplier will propose, design, and implement a bake-out system that shall be agreed upon and accepted by CELLS in writing. The Supplier will also include in the proposal a cold water circuit for cooling critical mechanical components that may be damaged by thermal expansion.

- The Supplier shall provide the bake-out system, power supplies, controller, thermal sensors, and cooling system for conditioning of the vacuum vessel by baking.
- The bake-out system shall be capable of raising the temperature of the vacuum vessel to $200^{\circ}C$ for 48 hours or a length of time sufficient to vacuum condition the vessel.
- The magnet arrays may be baked for 48 hours using pressurized hot water or gas. A higher temperature may cause irreversible partial demagnetization of the magnet material and thus shall not exceed $100^{\circ}C$.
- The Supplier shall provide a cold water circuit as necessary to cool the critical mechanical parts of the undulator such as linear slides and UHV bellows.

8.2. Corrector Coils

The first and second field integrals of the electron beam trajectory through the undulator should ideally be zero but will not be due to magnetic field errors from the undulator and the ambient field in the ALBA storage ring. The Supplier shall specify, design, and implement correctors capable of adjusting the first and second field integrals of the undulator to zero.

- The Supplier shall propose a set of corrector coils, long loop and short loop, for meeting the specification of this section. The final design and placement of the corrector coils shall be agreed upon with CELLS. CELLS suggests the use of air coils without water cooling but will consider alternative proposals made by the Supplier.
- Long loop air coils shall provide a horizontal and vertical uniform dipole field over the length of the undulator to compensate the ambient magnetic field. The field produced by the coils shall be bipolar and shall be adjustable in minimum steps of at least $1\text{ G}\cdot\text{cm}$ for a maximum of at least $\pm 300\text{ G}\cdot\text{cm}$ with a stability better than $0.1\text{ G}\cdot\text{cm}$.
- Short loop air coils shall provide a local uniform dipole field at the upstream and downstream ends of the undulator system such that the correction field produced is applied within the vicinity of the magnetic undulator end sections. The field produced by the coils shall be bipolar and shall be adjustable in minimum steps of at least $1\text{ G}\cdot\text{cm}$ for a maximum range of at least $\pm 200\text{ G}\cdot\text{cm}$ with a stability better than $0.1\text{ G}\cdot\text{cm}$.
- The undulator magnetic system shall meet the specification §1.11 and §4 for gap dependent integrated multipoles independent of the use of the correction coils.
- The vertical correction coils, either long loop or short loop, shall add only a normal integrated dipole to the undulator magnetic midplane. All other integrated multipoles measured in the magnetic midplane, as specified in §1.11 and §4, shall not be exceeded by the addition of the vertical corrector coil field over its full operational range.
- The horizontal correction coils, either long loop or short loop, shall add only a skew integrated dipole to the undulator magnetic midplane. All other integrated multipoles measured in the

magnetic midplane, as specified in §1.11 and §4, shall not be exceeded by the addition of the horizontal corrector coil field over its full operational range.

- If the Supplier proposes placing corrector coils inside the vacuum, their outgassing must not degrade the vacuum at the highest coil operating currents. If necessary, the water cooling system available to the in-vacuum beams may include the capacity to cool the correction coils.

8.3. Water Cooling

A water cooling system shall be used to stabilize the temperature of the magnet arrays to within $\pm 1^\circ\text{C}$ at 23°C . (100°C during bake-out).

8.4. In-Vacuum Beam Mounting

The in-vacuum beams require a mounting stand to guide them into plane when mounting them into the support structure. The structure shall be provided by the Supplier.

8.5. Thermocouples

K-type Kapton covered thermocouples shall be used to monitor the temperature of the vacuum vessel and the magnet arrays. Five thermocouples shall be in thermal contact with the the vacuum vessel, 5 shall be in thermal contact with and equally spaced along the upper in-vacuum beam, 5 shall be in thermal contact with and equally spaced on the lower in-vacuum beam and there shall be one thermocouple for each flexible taper, and one on each corrector coil winding.

9. Flexible Taper

At the upstream and downstream end of the magnet arrays shall be a flexible taper. It has the function of bridging the electron beam image currents carried on the upper and lower magnet arrays to the fixed transition chamber and finally to the ALBA storage ring. As the ALBA storage ring is sensitive to impedance discontinuities the flexible taper must provide a smooth electrical transition with a minimum impedance discontinuity over the entire full gap range (4 mm to 30 mm).

- The Supplier shall provide the water cooled flexible taper and Cu-Ni foil to CELLS.
- The flexible taper shall be machined from Beryllium-Copper (Be-Cu), similar to a ribbon cellular radiator, that can follow the ID gap motion in the range of 4 mm to 40 mm. The side facing the electron beam shall be a smooth surface.
- To prevent buckling, RF springs as well as a suspension design shall be designed to allow a longitudinal movement of the flexible tapers during bake-out.
- The flexible taper shall be water cooled using Cu tubes to remove the excess heat due to resistive heating.
- A foil consisting of 0.050 mm thickness of Cu and 0.050 mm thickness of Ni shall lie flat on surface of each magnet array facing the gap. The Ni layer shall stick to the magnet arrays while the Cu shall provide a continuous path for the electron beam image current. The foil shall provide a continuous electrical path cross the magnet arrays and to the upstream and downstream flexible taper. The Cu-Ni foil will have a tendency to bunch or ripple and shall require a mechanism for adjusting and maintaining the foil tension.

10. Vacuum

The IVUs consists of three main chambers, a cylindrical vessel for containing and permitting the vertical motion of the in-vacuum beams, a water cooled flexible transition section for conducting the electron beam image currents to accommodate gap motion, and a fixed taper section for mating with the ALBA storage ring. The three joined chambers shall be referred to as the undulator vacuum system which includes all subassemblies within the chambers.

10.1. Main Vacuum Vessel

The main vessel is cylindrical in shape and has longest chamber which contains the largest inner surface area of the vacuum system. Within the chamber are the in-vacuum undulator beams and the magnet arrays that rest upon them. The in-vacuum beams have link rod connections which penetrate the chamber wall and shall be sealed by UHV bellows that allow for linking of the in-vacuum beams to the out-

vacuum mechanical chain. The inner diameter of the vessel shall allow for gap motion of 4 mm to 30 mm.

The main chamber is part of the whole vacuum system must be cleaned and maintained by good UHV practices, baked, and UHV compatible for installation with the ALBA storage ring. All subassemblies within the chamber must be cleaned and baked in conformance to good UHV practices.

10.2. Flexible Transition Chamber

There is a flexible transition chamber upstream and downstream of the main vacuum vessel (see also chapter 9). It holds the water-cooled flexible taper which at one end is fixed to the lower and upper in-vacuum beams and on the other end mates to the fixed transition chamber by flexible RF fingers. The flexible taper shall provide a smooth electrical transition which minimizes the impedance discontinuity for the conduction of the electron beam image current between the adjustable vertical aperture (4 mm to 30 mm gap) of the in-vacuum beams and the fixed transition to the ALBA storage ring. The water cooling removes the excess heat from the electrical resistance of the transition. Placed on top of each in-vacuum beam and terminated at the upstream and downstream flexible tapers shall be a Cu-Ni foil for conducting the electron beam image currents across the undulator.

10.3. Fixed Transition Chamber

There is a fixed transition chamber upstream and downstream of the main vacuum vessel before and after the flexible transition chambers. The fixed transition chamber is the mating section between the storage ring vacuum system and the in-vacuum undulator providing a smooth and low impedance path for the electron beam image current.

10.4. Vacuum Feedthroughs

The Supplier shall provide all vacuum feedthroughs electrical, thermocouple, and coolant connections.

The type and location of each feedthrough shall be agreed upon with CELLS in writing and specified on or before the PDR. The specific feedthroughs shall be clearly labelled and tabulated against their identifier and specific location on the vacuum vessel. The tabulated information shall be provided to CELLS on or before the PDR.

10.5. Undulator Vacuum System Requirements

- 10.5.1. After the complete vacuum system is cleaned and baked, and installed into the ALBA storage ring vacuum system, it shall achieve a vacuum pressure of less than 1×10^{-9} mbar at all gaps when exposed to the ALBA electron beam under normal operating conditions.
- 10.5.2. The undulator vacuum system must be cleaned and maintained by good UHV practices, baked, and UHV compatible for installation in the ALBA storage ring.
- 10.5.3. No water-to-vacuum joints are permitted.
- 10.5.4. The Supplier must avoid all virtual leaks and trapped volumes.
- 10.5.5. Welded bellows must be baked in clean vacuum at 200°C for 6 hours before use.
- 10.5.6. No liquids or sealants may be used to test or repair leaks.
- 10.5.7. Any roughing pumps used by the Supplier shall be oil-free.
- 10.5.8. The different chambers shall be connected by Conflat® flanges with small clearance to the beam (Spigot type); the supplier must provide CELLS with the drawings of these flanges. And the are subject to CELLS approval.
- 10.5.9. All pumps, diagnostics, and valves shall use Conflat® flanges; where the CF flanges are manufactured in house, the supplier will send to CELLS a drawing for each type of flange used together with the full material specification for CELLS approval. Where the CF flanges are purchased from another company CELLS approval at the proposed flange supplier must be sought prior purchase.
- 10.5.10. The chambers shall contain branches for vacuum pumps, vacuum diagnostics, and thermocouples.
- 10.5.11. All chambers and their flange connections shall allow bake-out to 250° C .

- 10.5.12. A vacuum leak test shall be performed after a bake-out of the vessel to 200° C . A Helium leakage rate of $Q_L < 1 \times 10^{-10}$ mbar · L · s⁻¹ and a specific desorption rate of $Q_{sp} < 1 \times 10^{-12}$ mbar · L · s⁻¹ · cm⁻² is to be demonstrated.
- 10.5.13. All undulator vacuum chambers, forgings for flanges, and milled pieces shall be fabricated from stainless steel grade 316 LN. the supplier may propos other grades of steel in additionto the specified grade according to this specification.
- 10.5.14. The flanges, and other milled pieces shall be manufactured from forgings. The structure of these forgings shall be homogeneous, free from porosity and fully austenitic with less than 1% ferrite. The presence of sigma phase of precipitated carbide is not permitted.
- 10.5.15. The Supplier shall be responsible for the detailed specification of the welding procedures and shall make test pieces and trials as are necessary and record the details in the welding procedure specification.
- 10.5.16. The Supplier shall be responsible for the detailed specification and installation of a bake-out system, and they are subject to CELLS approval.
- 10.5.17. The Supplier shall provide material certificates for all manufactured chambers, flanges, and subassemblies. The certificates are subject to CELLS approval.
- 10.5.18. CELLS's approval of the design and components does not release the manufacturer from his responsibilities to correct errors, oversights and omissions to ensure conformance to the specifications of this document.
- 10.5.19. All forgings have to be forged in all axes in order to arrive to grain sizes < 3.5 according to ASTM E 112-88. After forging the forgings are to be quenched in water. The material shall have a maximum of 1 inclusion of type A, B, or C and a maximum of 1.5 inclusions of type D according to ASTM E 45-87. Every tenth forging (apart from the standard flanges) shall be tested by ultra-sound testing over the entire volume according to ASME V 23, SA-745. For acceptance, the acceptance criteria QL 1 and QA1 will be used. In case of non-compliance the follow-up has to be decided together with CELLS.
- 10.5.20. Alls welds shall be internal. Where vacuum sealing welds made externally must have full penetration leaving a smooth surface on the vacuum inside, and must be done with argon purge on the inside to prevent oxidation. Any later brushing or other finish work on the welds is prohibit.

10.6. Cleaning

- 10.6.1. The Supplier is responsible for the detailed specification of the cleaning procedure. This procedure shall be submitted and agreed upon with CELLS before implementation.
- 10.6.2. The undulator vacuum system shall be compatible with the UHV requirements of the ALBA storage ring and thus the Supplier shall use a high degree of cleanliness at all stages of production to produce an acceptable low out-gassing rate and weld integrity.
- 10.6.3. After final machining and subsequent cleaning of the undulator vacuum system the vacuum surfaces shall not come in contact with oily or greasy objects (including bare hands).
- 10.6.4. If a vacuum surface is contaminated with an oily or greasy surface then the contaminated area will be thoroughly cleaned.
- 10.6.5. All in-vacuum components shall be wrapped in Aluminium foil and kept separately in polyethylene bags. All components shall be identified with their drawing numbers.
- 10.6.6. The assembly and storage of all components for the in-vacuum undulator shall take place in a clean facility. The clean facility shall be kept free from any contamination.
- 10.6.7. Final machining after welding of the vessel body shall be carried out in an clean and protected area.
- 10.6.8. All machining components shall be water soluble and sulphur free.

10.6.9. The cleaning process should not include an acid etch or treatment.

10.6.10. The Supplier shall provide a detailed description of their cleaning procedure for the undulator vacuum vessels and their subassemblies with the tender. All cleaning procedures must be submitted to and agreed upon with CELLS before implementation.

10.7. Vacuum Pumps and Instrumentation

10.7.1. In the CELLS reference design we suggest the use of four NEG pumps, eight $75 \text{ L}\cdot\text{s}^{-1}$ Diode ion pumps, and one $500 \text{ L}\cdot\text{s}^{-1}$ Diode ion pump. CELLS specification of the number of pumps is only conceptual. The Supplier shall specify the required pumping speed and quantities of standard vacuum components which are required to meet the specified vacuum performance.

10.7.2. For the use of Non Evaporable Getter pumps (NEG) CELLS is responsible for the NEG cartridges and the pump flange which includes heater for NEG activation and thermocouple. Each NEG pump shall be connected to one NEG pump controller.

10.7.3. The Supplier shall specify the necessary size and type and location of vacuum equipment to reach, maintain, and measure the ultimate vacuum pressures of this specification. CELLS will determine the manufacturer of the vacuum equipment and shall free issue all vacuum pumps, gauges, and associated controllers which are needed for the final assembly of the undulator to the Supplier, CELLS will supply any equipment needed for the manufacturing or testing

10.8. Vacuum Gauges

10.8.1. CELLS shall use two types of vacuum gauges for the measurement of vacuum: Pirani Vacuum Gauge (Atmosphere to 1×10^{-3} mbar), Cold Cathode Gauge (inverted magnetron type) (1×10^{-11} mbar to 1×10^{-3} mbar), and Ion Gauge (5×10^{-12} mbar to 1×10^{-4} mbar). The Supplier shall specify the number and type of gauges and submit to CELLS for written acceptance and agreement. The Suppliers specification shall include Residual Gas Analyser (RGA) for identifying the residual gases inside the system and perform leak checks.

11. Factory Acceptance Tests

The FAT is a milestone in the schedule. A CELLS representative shall verify each test either by witness in person or by the transmission of data to CELLS as specified for each test clause. Production of the IVUs shall not continue until CELLS has accepted in writing the results of each test clause (see section 7.4 of the Technical Specifications).

11.1. Measurement of Magnet Blocks

11.1.1. General Requirements

The Supplier shall perform a set of measurements on each magnet block and record the measurements in a database against the magnet block identifier. The Supplier shall provide CELLS with any conversion factors, data corrections, or conversion equations used to arrive at the final measurement values. All sorting and shimming procedures implemented by the Supplier shall be discussed and agreed upon with CELLS before commencement. The magnet block tests are specified as follows:

- a) The three orthogonal average magnetizations of each magnet block shall be measured with a Helmholtz coil system and tabulated in database. The Supplier shall report measurements in units of Tesla with their corresponding measurement errors. The precision and reproducibility of the measured components shall be 0.01 % or better. During the Helmholtz coil magnet block measurements the environment shall be maintained at the same constant temperature with a variation less than $\pm 1^\circ\text{C}$. Before and during the Helmholtz coil measurements all magnet blocks shall be in thermal equilibrium with the Helmholtz coil measurement environment. The volume of each magnet block shall be recorded in the database against the magnet block identifier.
- b) The calibration constant of the Helmholtz coil used to measure the blocks shall be recorded in the database.

- c) Each magnet block shall be visually inspected to insure there are no chips, cracks, surface contaminants (UHV), or coating defects. Blocks with these defects shall be rejected by the Supplier and will not be included in the quantities specified in §2.2.
- d) The Supplier shall measure the length, width, and height of each magnet block (excluding the chamfer) with a precision of 0.005 mm and record them into the database against the magnet block identifier. Blocks with dimensions exceeding specification §2.2 will not be included in the quantities specified in §2.2.
- e) Before magnetization of the blocks the Supplier shall perform an out-gassing test on 20 of the blocks (out of the entire set) after baking. The results of the out-gassing tests shall be submitted to CELLS prior to acceptance of the magnet blocks.

As part of this acceptance test CELLS shall witness the magnetic and mechanical measurements of a sample of the magnet blocks from the Supplier and at the same time shall visually test the block for surface imperfections. Furthermore, the Supplier shall transmit the database which includes the results of tests 11.1.1 a-e to CELLS by email for evaluation and acceptance of the complete lot of magnet blocks. A paper copy and soft copy on CD of the acceptance tests shall accompany the shipment of the IVUs to CELLS. The complete production of all the magnet blocks shall not proceed without written acceptance from CELLS.

11.2. Measurement of Magnet Block Arrays

11.2.1. Requirements of Hall Probe Bench

- a) The Hall probe shall be capable of being placed anywhere in the volume of ± 1500 mm in length, ± 50 mm in width, and ± 20 mm in height centered on the in-vacuum undulator.
- b) For the field scan the position of the Hall probes shall have an uncertainty within $\Delta y = \pm 0.0005$ mm, $\Delta x = \pm 0.005$ mm, and $\Delta s = \pm 0.001$ mm.
- c) The reproducibility of the first field integral shall be better than 1 G·cm.
- d) The Hall probe shall allow a determination of the vertical and horizontal field within a relative uncertainty of $2 \cdot 10^{-4}$ (rms) (short term drift (15 min): ≤ 0.02 G; long term drift (8 hr): < 1 G. the Supplier shall demonstrate that the difference between 2 consecutive scans is within these tolerances.

11.2.2. Requirements of the Flipping Coil Bench

The Supplier's magnetic measurement equipment shall include a flipping coil bench or a stretched wire bench. The minimum length of the wire or coil shall be 3.0 meters. The motorized stages shall be positioned with a sensitivity below 0.002 mm in the range of $x = \pm 30.0$ mm and $y = \pm 20$ mm vertically. The flipping coil measurements shall have a repeatability better than 1 G·cm.

11.2.3. General Requirements

After mounting and shimming of the magnet block arrays the Supplier shall perform a set of final magnetic field measurements to characterize the field quality of the undulator system.

For the tabulated Hall probe scans the Supplier shall include the raw data measured in Volts and the post-processed data in units of Tesla that has been corrected for planar Hall effect, angular misalignment, offset misalignments, removal of ambient background field, and removal of Hall voltage drift & offset. All Hall probe measurements of the three magnetic field components shall be made with respect to a single virtual point on the probe. The Supplier shall provide the conversion equations and calibration data used to process the raw Hall voltage measurements into its final form. The Hall probe used in the measurements shall be uniquely identified and referenced to the measurements.

For the tabulated flipping coil measurements the Supplier shall include the raw data measured in V·s and the post-processed data in units of G·cm that has been corrected for voltage drift, ambient background field, and misalignment errors. The Supplier shall provide the conversion equations that were used to process the raw measurement data into its final form. The measurement procedure described below shall be applied when the shimming is finished and the passive correction of the field integrals with magic fingers has been applied.

The Supplier shall measure the field integral signatures of each module and provide them to CELLS.

The required measurements are as follows:

- a) The Supplier shall measure the undulator horizontal and vertical first field integral as a function of transverse position (integrated multipoles). A set of flipping coil measurements shall be taken in the best determined magnetic midplane, beginning at the magnetic centreline, and include measurements taken at regularly spaced 2 mm horizontal steps from the magnetic centreline over a horizontal range of ± 30 mm. The set of flipping coil measurements shall be repeated at gaps 5 mm through 10 mm including 5.7 mm gap at 1 mm intervals and from 10 through 20 mm at 2 mm intervals and at 30 mm. The measured horizontal and vertical field integrals shall be recorded and tabulated against the X and Y position of the flip coil.
- b) The Supplier shall measure the vertical, horizontal, and longitudinal magnetic field profile of the undulator system. In the best determined magnetic midplane Hall probe scans shall be used to measure B_x , B_s , B_y , components of the magnetic field along straight lines parallel to the S-axis. Measurement along the straight lines shall begin before the undulator fringe field and terminate after the undulator fringe field. The set of Hall probe scans required shall be made on the magnetic centreline. The B_x , B_s , B_y of the magnetic field shall be sampled longitudinally at equidistant points of 0.100 mm along the straight lines. The set of hall probe measurements shall be repeated at gaps 5 mm through 10 mm including 5.7 mm gap at 1 mm intervals and from 10 through 20 mm at 2 mm intervals and at 30 mm. Additionally, the Supplier shall make a set of Hall scans taken at regularly spaced 2 mm horizontal steps from the magnetic centreline over a horizontal range of ± 30 mm, in the magnetic midplane, at 5.7 mm gap and 10 mm gap.
- c) The Hall probe measurement data shall be recorded and tabulated against the X, S, and Y position of the Hall probe.
- d) From measurement 11.21 (b) the Supplier shall calculate the electron beam trajectory along the centreline and the phase angle error as a function of gap for an electron beam energy of 3 GeV. The phase error shall be evaluated on the best determined magnetic centreline.
- e) From §11.2.1 (a) the Supplier shall calculate the integrated dipole, quadrupole, sextupole, octupole, and decupole as a function of gap.
- f) The Supplier shall record the final configuration of the magic fingers (there vertical position and sign with respect to the best determined magnetic midplane).
- g) The Supplier shall measure the first and second field integral along the centreline and calibrate the corrector coils to zero the integrals. This shall be repeated at gaps 5 mm through 10 mm including 5.7 mm gap at 1 mm intervals and from 10 through 20 mm at 2 mm intervals and at 30 mm

As part of the acceptance test CELLS shall witness the magnetic measurements and characterization of the undulators arrays. The complete production of the undulator system shall not proceed until the measurements have been completed. Furthermore, the Supplier shall transmit the measurements of this acceptance test by email to CELLS for evaluation and acceptance.

11.3. Test of Control Interfaces

- a) The Supplier shall test the motion control system functional requirements.
- b) The Supplier shall perform a test on the functionality of all IVU associated instrumentation including sensors, switches, encoders, gauges, and thermocouples.
- c) The Supplier shall perform a test of communication between all hardware receiving control commands and insure that they act as specified under the constraint of routine functional operation as described in the terms of this set of technical specification documents.

11.4. Measurement of Vacuum System General Requirements

- a) Visual inspection (internal and external) of the chamber, particular attention shall be paid to the form and state of the vacuum surfaces, the quality of welded joints and the sealing surfaces of flanges. Inner surfaces will be controlled in order to detect any surface, e.g. incrustation, grooves, traces of pollution, dust... etc
- b) Dimension check of the vacuum chambers and afterwards the final cleaning
- c) The vacuum system without magnet arrays shall be baked out to a temperature of 250°C without the magnet arrays at least once
- d) After FAT of the magnetic arrays has been completed they will be dismantled and the vacuum system and magnet arrays will be mounted on the support structure
- e) Water circuits will be connected and operational before bake-out of the IVU

- f) The vacuum pumps and instrumentation will be mounted and connected to the vacuum vessel and the system will be vacuum sealed
- g) The vacuum system shall be pumped down and the pressure will be monitored and recorded as a function of time. After pumping down a Helium leak check and an RGA scan shall be performed.
- h) The vacuum chamber shall be ramped up to a maximum temperature of 200°C for a minimum of 24 hours and then finally cooled by convective cooling. The temperature of the vacuum vessel, magnet arrays, and pressure of the IVU will be monitored continuously during the bake-out with interlock to eliminate the possibility of overtemperature.
- i) Once the vacuum vessel has cooled and the vacuum vessel pressure has reached a level of 2×10^{-11} mbar or better the vessel will be Helium leak checked with a sensitivity of 2×10^{-10} mbar·L·s⁻¹ and an RGA spectrum will be taken, the results of the residual gas analysis must show that the hydrocarbon contamination (defined by the sum of all masses above 28 excluding 44) must be less than 1 % of the total pressure.
- j) The outgassing rate must be measured after cooling down the vessel and the it must be less than 1.10^{-12} mbar.l/sec.cm².

11.5. FAT Report

The Supplier shall provide a FAT report detailing the results.

12. Site Acceptance Test

The Supplier shall provide personnel to perform the unloading, unpacking, testing, and installation of the IVUs into the ALBA storage ring. The Supplier shall propose the procedure and implement the procedure for the SAT to be agreed upon in writing with CELLS. The proposal shall also include an estimate of the manpower and equipment required to perform the SAT.

The installation of the IVUs into the ALBA storage ring is the responsibility of CELLS but shall be supervised by the Supplier and is part of this specification's SAT.

The SAT procedure should include the following:

- a) Unloading of the container at CELLS site
- b) Unpacking of the equipment
- c) The equipment shall be visually inspected for any damage caused during transport
- d) The IVU will be transported to the CELLS vacuum lab for vacuum testing
- e) The vacuum pumps will be installed in the CELLS vacuum lab. The vacuum instrumentation will be installed for pressure monitoring, temperature monitoring of the in-vacuum beams and temperature monitoring of the vacuum vessel.
- f) Water circuits will be connected and operational before bake-out of the IVU
- g) The vacuum system shall be pumped down and the pressure will be monitored and recorded as a function of time. After pumping down a Helium leak check and an RGA scan shall be performed.
- h) The vacuum chamber shall be ramped up to a maximum temperature of 200°C for a minimum of 24 hours and then finally cooled by convective cooling. The temperature of the vacuum vessel, magnet arrays, and pressure of the IVU will be monitored continuously during the bake-out. The gauges, RGA, and ion pumps shall be degassed and flushed. The NEG pumps shall be activated.
- i) Once the vacuum vessel has cooled and the vacuum vessel pressure has reached a level of 2×10^{-11} mbar or better the vessel will be Helium leak checked with a sensitivity of 2×10^{-10} mbar·L·s⁻¹ and an RGA spectrum will be taken.
- j) The undulator system, under vacuum, is moved to the storage ring for installation
- k) Before installation and bake-out the undulator system will be connected to the CELLS control system and the mechanical chain and motion control system shall be tested with the encoders
- l) The undulator system will be surveyed and aligned into its operating position with respect to the storage ring fiducials
- m) Water circuits will be connected, tested, and operational before bake-out of the IVU

- n) A temporary tent will be built around the straight section installation area and a positive pressure of dry Nitrogen gas will be applied in the tent volume. The vacuum system will be let up with dry Nitrogen and the downstream and upstream sealing flanges will be removed and the vacuum chamber of the IVU will be connected to the storage ring vacuum system bellows. Steps (g-i) will be repeated.

12.1. SAT Report

The Supplier shall provide a SAT report detailing the results.