13.Transport and integration

13.1 Transport

For cost and schedule reasons. the design of OWL takes in to account transport constraints and is based on the following principles:

- Avoid oversized special transport.
- Use of standard containers for critical parts.
- Redundancy in case of partial loss.

13.1.1 Design provisions

13.1.1.1 Mechanics

Most of the mechanical parts can be transported within standard dimensions. Critical parts such as Bogies. Tracks. Actuators Structural nodes (see Figure 13-1) can be transported in 20 or 40 feet containers. Other parts such structural truss elements can be transported without special precaution (see Figure 13-2).

Due to the high degree of design standardization. partial loss of a shipment does not represent a major draw back in the flow of the site integration activities. Lost or damaged parts can be immediately exchanged with others. while the repairing or re-manufacturing takes place.

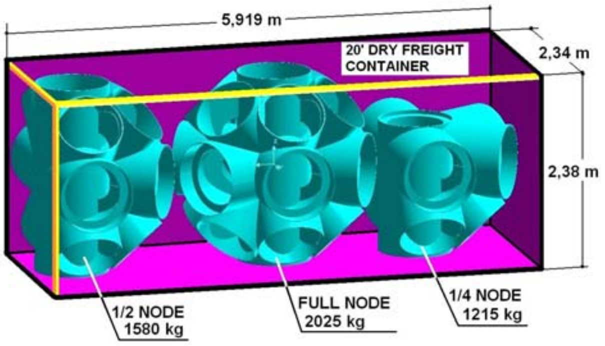

Figure 13-1: Structural nodes container

Figure 13-2: Pipe elements shipping

13.1.1.2 Optics

Optical units are the most critical parts to be transported. They can be classified according to the hazard involved:

- Mirror segments. The size of each segment allows transport in standard size containers. Inner fittings would have to be mounted for safety. The segments transport is not considered as critical..
- M3 and M4 Units. These mirror units. which are similar to the VLT primary mirror. are the most critical parts to be transported. Special transports have to be organised and no redundancy exists. thus the risk associated to this transport is most severe. Nevertheless VLT primary mirror transports and handlings have demonstrated that this can be achieved.
- M5 and M6 Units. Special transports have to be organised and no redundancy exists. Their reduced size makes the transport somehow less demanding then the M3 and M4 units.

13.2 Site integration

The design of OWL takes in to account integration requirement and constraints and it incorporates the following principles:

- Avoid oversize and heavy parts.
- Avoid tight assembling tolerances.
- Maximize standardization of parts.
- Redundancy of handling devices.
- Self standing structure.
- Avoid scaffolding structures.
- Avoid complex metrology and alignment systems.
- Avoid complex welding processes.
- Allow day and night shifts. with tasks tailored to the environmental condition.

13.2.1 Design provisions

13.2.1.1 Mechanics

13.2.1.2 Alignment metrology

By design the structural alignment tolerances of OWL are fairly generous and easy to achieve. The metrology used during the integration does not require high level of accuracy (see sections 13.2.1.3 to section 13.2.1.3.7). Real time measuring systems can be used to align time consuming sub-systems lsuch as:

- Annular azimuth tracks

  Figure 13-3 shows a hydrostatic levelling system which can be used for azimuth tracks alignment. This system assures a rapid convergence to the track flatness requirement. over a total developed length of about 5 km.

Figure 13-3: Azimuth tracks alignment metrology.

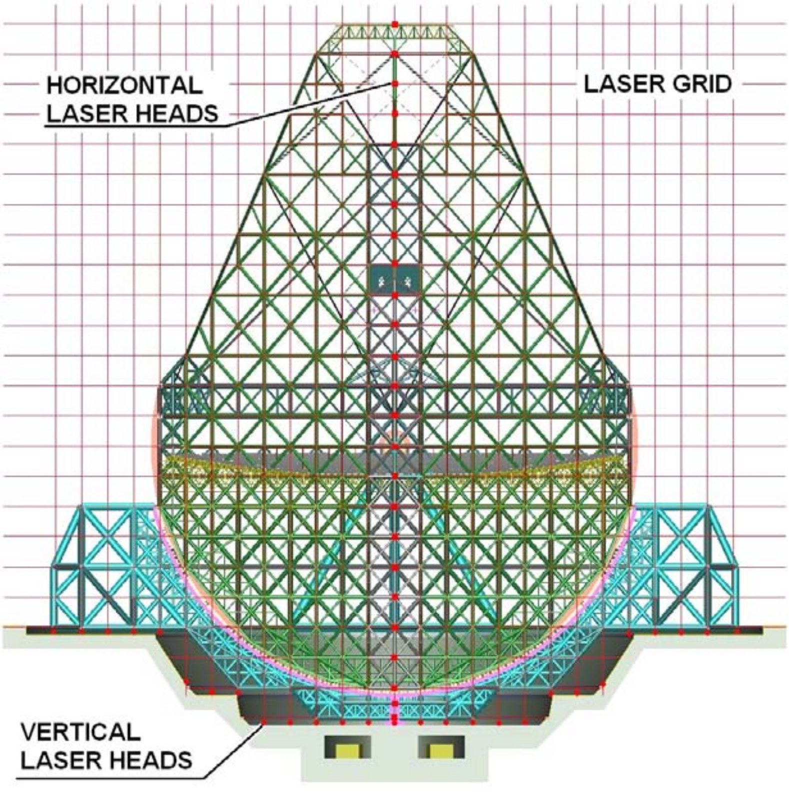

Figure 13-4: Structural elements alignment.

- Structural nodes

  Figure 13-4 shows a grid made by laser beams. This grid defines the X-Y-Z location of each node of the structure. Each node can be equipped with a reference target. Thus the alignment of the complete mechanical structure does not required complex calculations. but only simple visual checks of the target with the laser beams. Convergence time. risks and costs associated to complex metrology can thus be avoided.

13.2.1.3 Telescope truss structure integration

The following design provisions related to site integration. are embedded in OWL concept:

- The telescope structure and its sub-system can be integrated in parallel by several integration teams. using several light cranes with a maximum payload of 3 tons. thereby allowing for redundancy.
- The structural design allows self-supporting “floors” to be to built up progressively. Each floor serves as platform for the next one. Therefore scaffolding is limited and serves for access but not for supporting structural elements.
- Due to the large excursion of temperature during day time (see section 5.4.1.3) the following procedure will be adopted for all part which whose dimensions may be significantly altered under solar exposure:

1.	Day time	Transport to final location.
2.	Day time →	Rough alignment.
3.	Night time →	Fine alignment.
4.	Night time →	Spot welding or other preliminary joining techniques.
5.	Day time →	Final weld and local annealing
6.	Night time →	Final dimensional check.

The following section describes in more detail the various integration phases. The integration teams can cover different disciplines. such as Welding. Metrology. Electrical. Electronic and Control engineering. Each team can be specialized. Electronic and Control Engineering will be more intensive during the final phases.

The manpower required for the telescope integration. is a large part of the total 400 people planned on the site integration for a period of 10 years.

13.2.1.3.1 Phase 1

Integration steps - The first Phase is divided in the following integration and alignment steps:

- Azimuth central bearing. which defines the reference zero of the complete structure.
- Annular track pre-alignment
- Annular track joints (Welded or bolted joints)
- Annular tracks fine alignment Only the vertical DoF has to be aligned (Z axis).
  - Typical flatness accuracy per each track is 5 mm over the largest track diameter.
  - The vertical track to track distance ± 5 mm.
  - Cylindricity and concentricity tolerances 10 mm.

Manpower - Up to one integration team per track can work simultaneously.

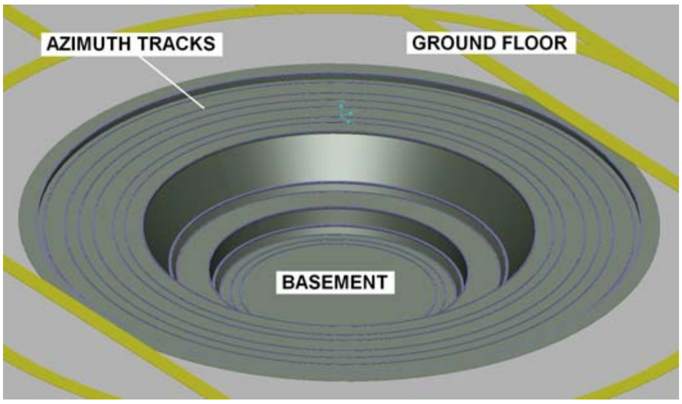

Figure 13-5: Azimuth tracks integration

13.2.1.3.2 Phase 2

Integration steps- The second phase is divided in the following integration and alignment steps:

- Define the location of the "master nodes" where the alignment laser beam can be installed and aligned. Tolerance ± 2 mm related to the azimuth central bearing.
- Place base blocks. To be exchange in phase 4 by azimuth bogies.
- Integrate the truss structure up to the ground level. Tolerance ± 5 mm related to the azimuth central bearing.
- Start of painting activities.
- Start of cabling activities.

Manpower - Up to 6 integration teams can work simultaneously.

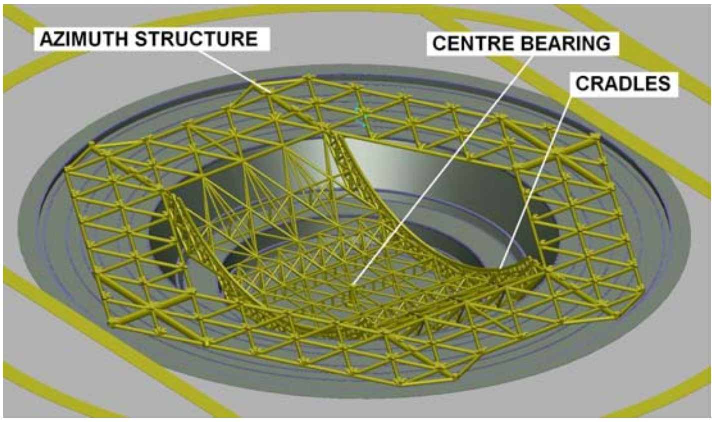

Figure 13-6: Azimuth Basement integration.

13.2.1.3.3 Phase 3

Integration steps - The third phase is divided in the following integration and alignment steps:

- Integrate the truss structure up to the first floor (12.8 m above ground level). Tolerance ± 5 mm related to the azimuth central bearing.
- Start of the altitude cradle integration

Manpower - Up to 6 integration teams can work simultaneously.

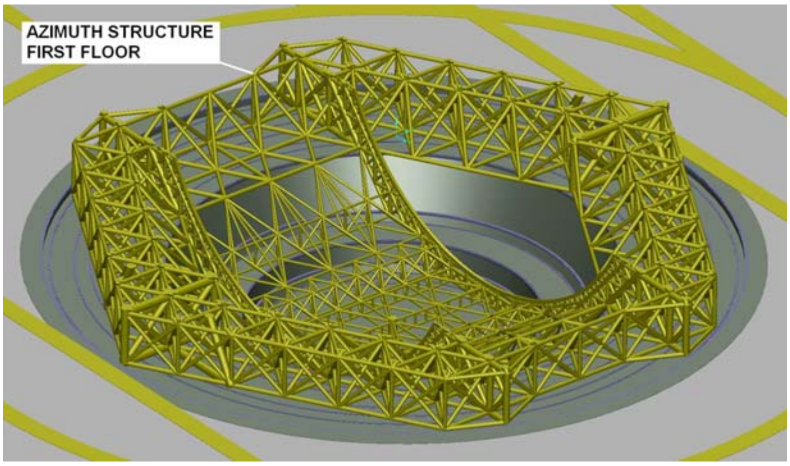

Figure 13-7: Azimuth first floor integration

13.2.1.3.4 Phase 4

Integration steps - The fourth phase is divided in the following integration and alignment steps:

- Complete integration of the truss structure up to the third floor (38.49 m above ground level). Tolerance ± 5 mm related to the azimuth central bearing.
- Complete the altitude cradle integration.
- Complete painting activities.
- Integration of azimuth cable wrap.
- Integration of altitude bearings.
- Complete cabling activities.
- Integration of azimuth bogies.
- Integration of azimuth control electronics.
- Functional test of the azimuth structure.
- Qualification of the azimuth axis.

Manpower - Up to 6 integration teams can work simultaneously.

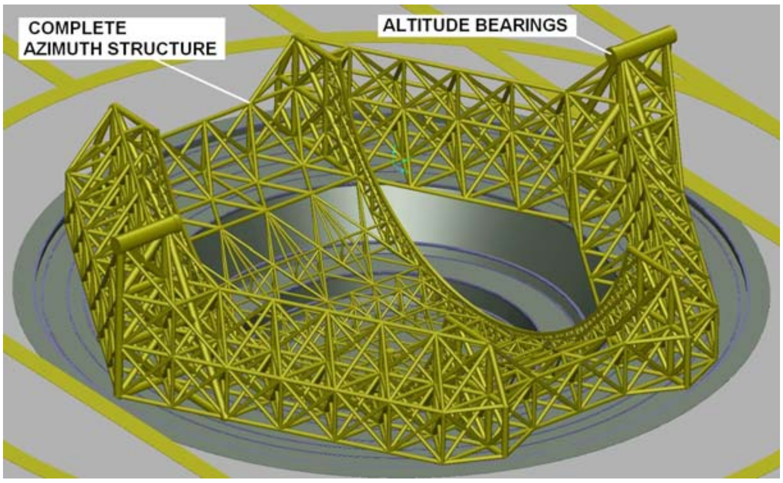

Figure 13-8: Azimuth structure complete integration

13.2.1.3.5 Phase 5

Integration steps - The fifth phase is divided in the following integration and alignment steps:

- Reposition the azimuth structure on base blocks
- Place base blocks on the altitude cradle. To be exchange in phase 7 by altitude bogies.
- Install a provisional supporting structure between the concrete foundation and the location where the altitude structure lower part ahs to be integrate.
- Integrate the truss structure up to the first floor (12.8 m above ground level). Tolerance ± 5 mm related to the azimuth central bearing.
- Start of painting activities.

Manpower - Up to 6 integration teams can work simultaneously.

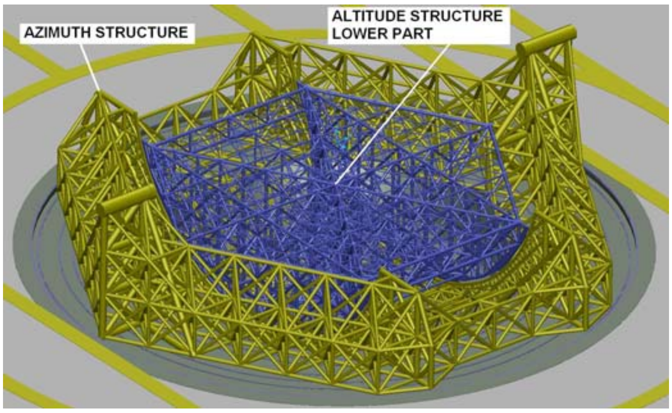

Figure 13-9: Altitude lower part integration.

13.2.1.3.6 Phase 6

Integration steps - The sixth phase is divided in the following integration and alignment steps:

- Integrate the truss structure up to the M1 cell (38.49 m above ground level).and the complete corrector and focal station central tower (102.64 m above ground level). Tolerance ± 5 mm related to the azimuth central bearing.
- Start altitude cradle track integration.
- Start of painting activities.

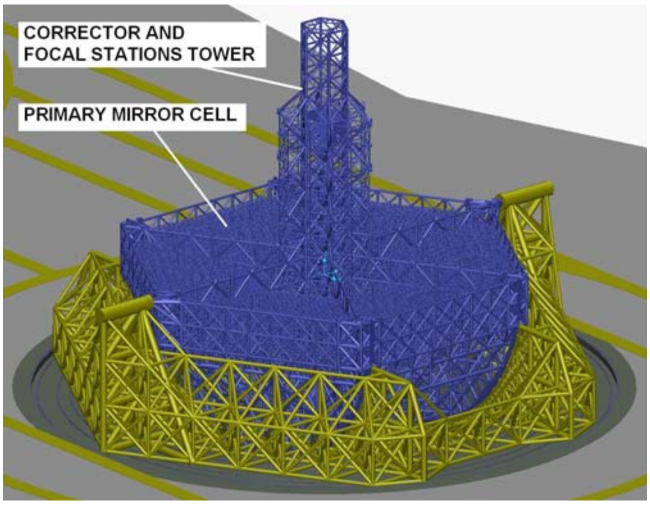

Figure 13-10: Altitude M1 cell and central tower integration.

Manpower - Up to 6 integration teams can work simultaneously. Only one integration team can work on the central tower

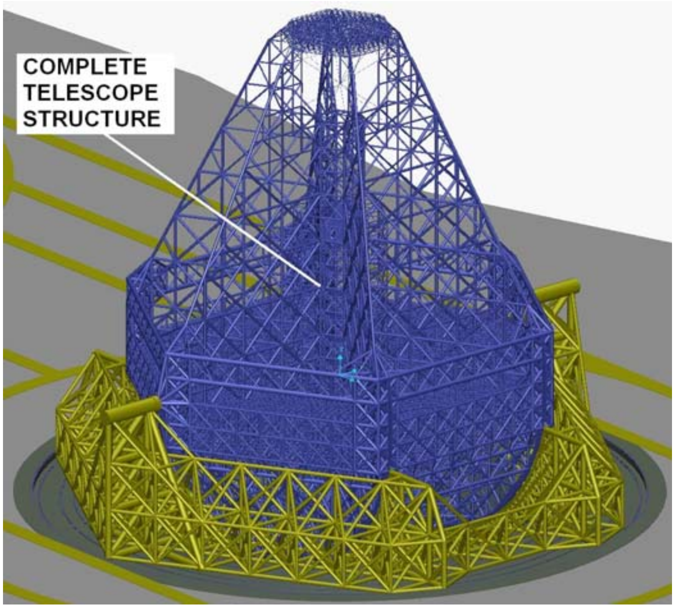

Figure 13-11: altitude structure complete integration.

13.2.1.3.7 Phase 7

Integration steps - The seventh phase is divided in the following integration and alignment steps:

- Complete integration of the altitude truss structure (128.3 m above ground level). Tolerance ± 5 mm related to the azimuth central bearing.
- Complete the altitude cradle track integration. Cylindricity and concentricity tolerance ± 2 mm related to the altitude central bearings
- Complete painting activities.
- Integration of altitude cable wraps.
- Complete integration of altitude bearings.
- Complete cabling activities.
- Integration of altitude bogies.
- Integration of optical unit dummies.
- Integration of altitude control electronics.
- Functional test of the altitude structure.
- Safety inspection. In particular dedicated to parts which may damage the telescope optics or personel.
- Qualification of both azimuth and altitude axes (Pointing and tracking)
- Functional tests of the mirror covers
- Qualification of the mirror covers
- Functional test of the segment handling facilites with segment dummies.
- Qualification of the segment handling facilities.
- Functional test of all the built-in access and lifting facilities.

Manpower - Up to 6 integration teams can work simultaneously.

13.2.1.4 Segment integration

After the kinematics test and verification. the integration of the segmented mirror can start.

Segment support structure

Each segment support structure (Figure 13-12) has to be aligned with its central axis converging toowards the M1 center of curvature. Then the 6 legs can be adjusted and interfaced to the mirror cell. The typical alignment tolerance is ± 2 mm (the reference being the nominal spherical shape of the primary mirror). This tolerance is rather generous because the segment position actuators (see 9.4.6.3) coarse range can compensate for large piston and tip-tilt misalignments.

Each segment support structure of the flat secondary mirror has to be aligned with its central axis parallel to the altitude structure main optical axis.

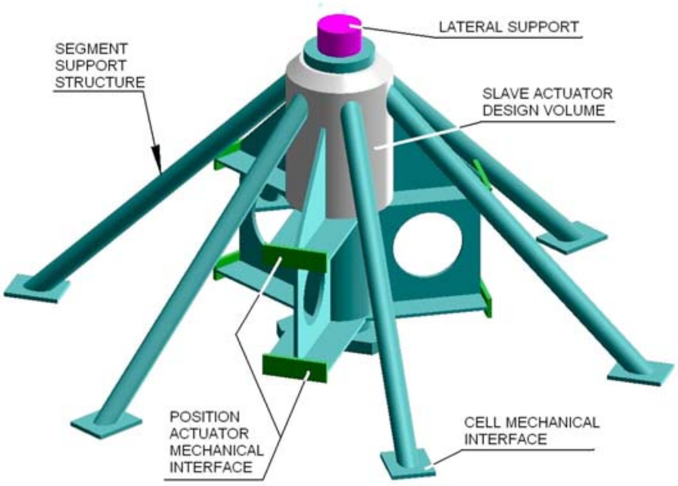

Figure 13-12: Segment Support Structure.

Hexagonal segments integration - To complete the segment integration (see Figure 13-13) the following preparatory steps will be performed:

- On the telescope primary and secondary mirror cell:
  - Integration of 3 Position Actuators per segment.
  - Integration of the slave actuator.
  - Integration of the central membrane attached to the slave section actuator.
- In the integration laboratory:
  - Integration of the Position sensors around the segment.
  - Integration of the waffle tree on the segment.

Primary mirror segments integration - The integration of the spherical segments on the primary mirror :

- Transport from the integration laboratory to the M1 maintenance cover (see section 15.1.1.4)
- Docking of the maintenance cover over one of the six primary mirror sectors.
- Automated handling of each segment to its segment support structure (see Figure 13-13 and Figure 13-16).

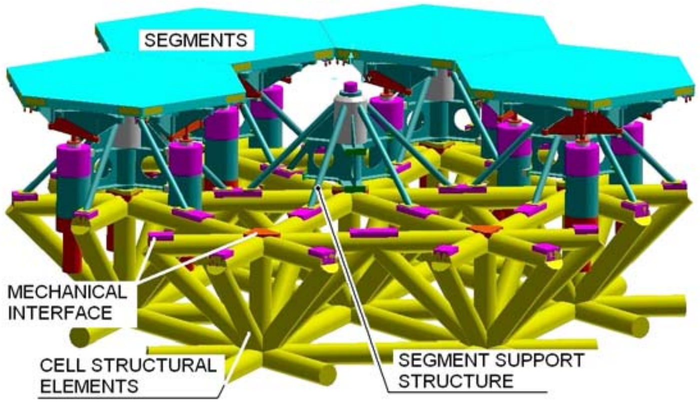

Figure 13-13: Segments integration.

Secondary mirror segments integration

The integration of the flat segments on the secondary mirror is made according to the following sequence:

- Transport from the integration laboratory to OWL horizontal parking configuration (see section 15.1.1.6).
- Docking of the maintenance facilities on the secondary mirror (see section 15.1.1.6).
- Automated handling of each segment to its segment support structure (see Figure 13-13 and Figure 13-16).

13.2.1.4.1 Segment handling tool

The integration of the segments into the primary and secondary mirrors will be realized with the help of a dedicated handling tool (Figure 13-14 and Figure 13-15) Its main characteristics are:

- 3 pairs of axial clamps. with clamp / unclamp kinematic function
- 3 radial constrains with on / off kinematic function
- 3 air bags for safety against handling tool failures.
- 6 sensors units. with 150 mm stroke and accuracy of ± 1mm.
- 36 sensors with stroke of 3 mm and accuraxy of ±1 μm

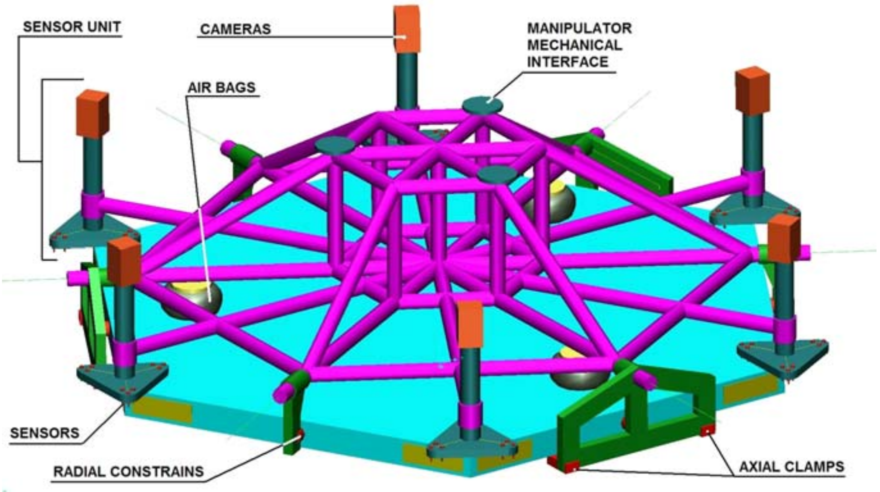

Figure 13-14: Segment handling tool. notional design.

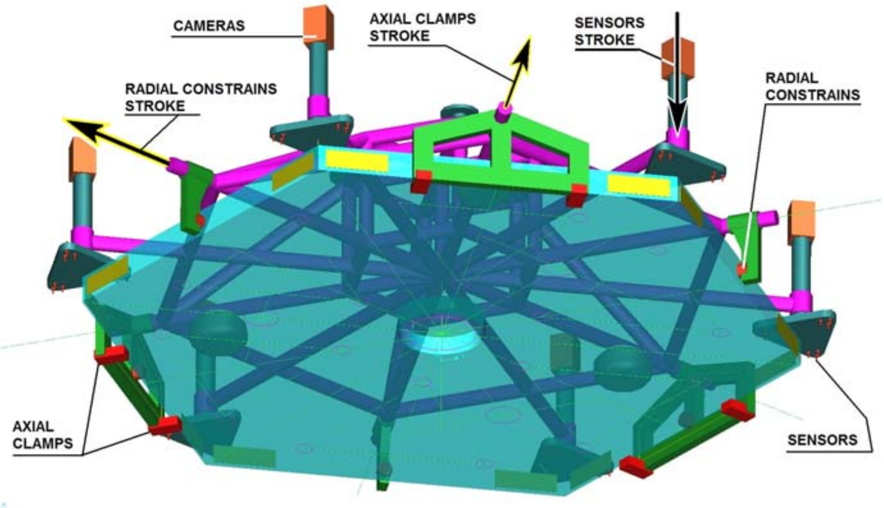

Figure 13-15: Segment handling tool. notional design

Segment docking operation.

An operator located in the M1 cover or in the secondary mirror handling facilities operates the handling tool which is attached to a manipulator integrated in the primary mirror cover (see section 15.1.1.4) or in the secondary mirror handling facilities (see section 15.1.1.6). The manipulator places the segment on the segment support assembly with the extractor in the open configuration. The segment optical surface is 150 mm above the mirror optical surface. The manipulator kinematic allows a fine translation of the segment in the 3 DoF and a fine rotation around the segment optical axis. The typical required position accuracy of the segment with respect to the segment support assembly is ± 0.5 mm. Cameras located on the sensors units help the operator to align the segment against fixed targets placed on the mirror cell.

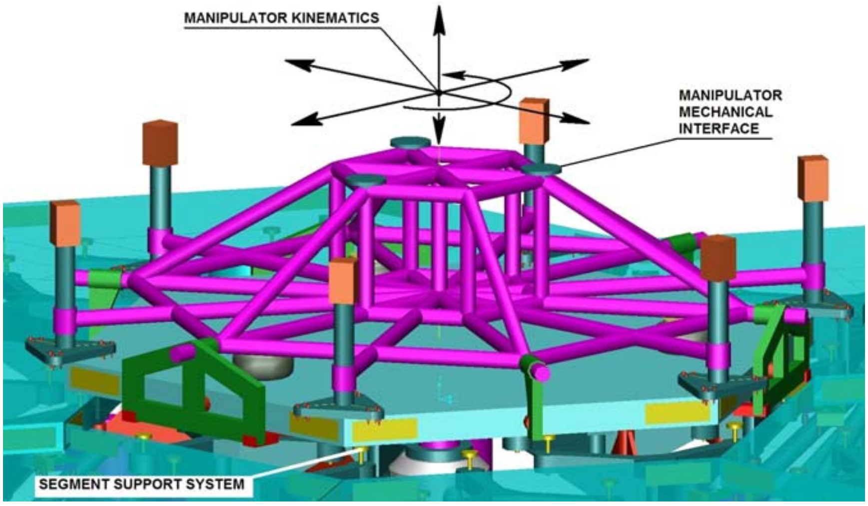

Figure 13-16: Handling of segment on the extractor.

Segment integration

An operator located in the mirror cell performs the following tasks

- Take the manual control of the handling tool.
- Connects the segment with the 3 position actuator units.
- Connects the segment to the lateral support and torsion bar.
- Connects the edge sensors.

- Sends the command to the handling tool for the unclamping operation (see also Figure 13-17 and Figure 13-18).
- Lowers the segment into the mirror using the extractor (stroke -150 mm).

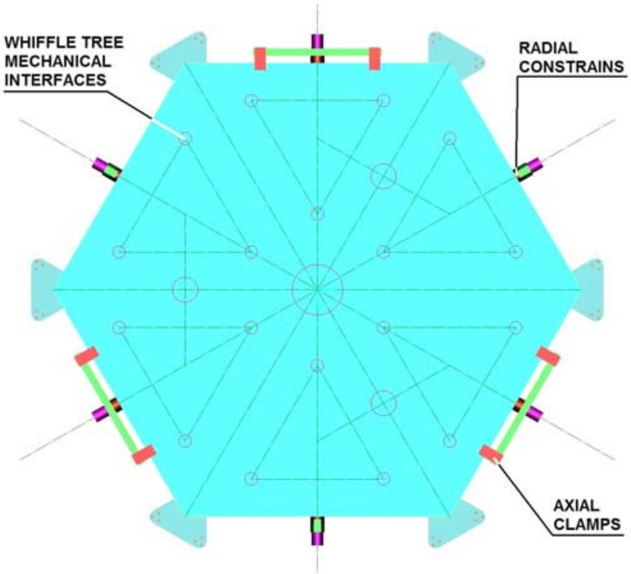

Figure 13-17: Clamped and constrained segment.

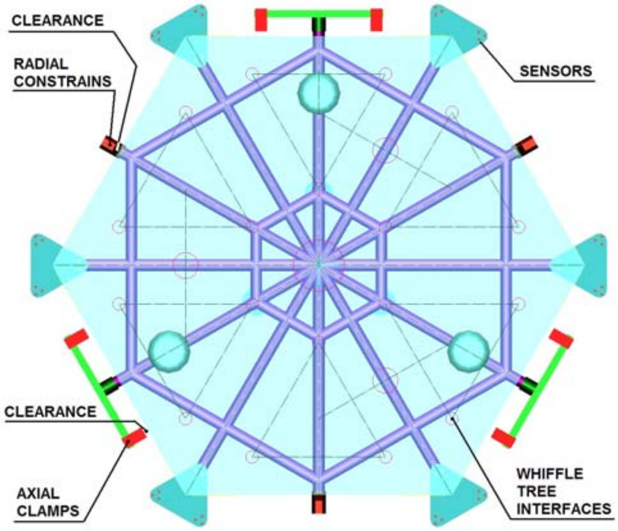

Figure 13-18: Un-clamped and un-constrained segment.

Segment pre phasing

Once the segment has reached its final location with a coarse accuracy of ± 1 mm. the following operation are performed:

- Lower the 6 sensor units until the sensors are in contact with the segment optical surface and the adjacent phased segments (see Figure 13-19)
- Fine pre-phasing of the segment within an accuracy of ± 0.01 mm (see Figure 13-20)
- Withdraw the sensor units.
- Return the handling tool control to the manipulator operator.
- Remove the handling tool using the manipulator.

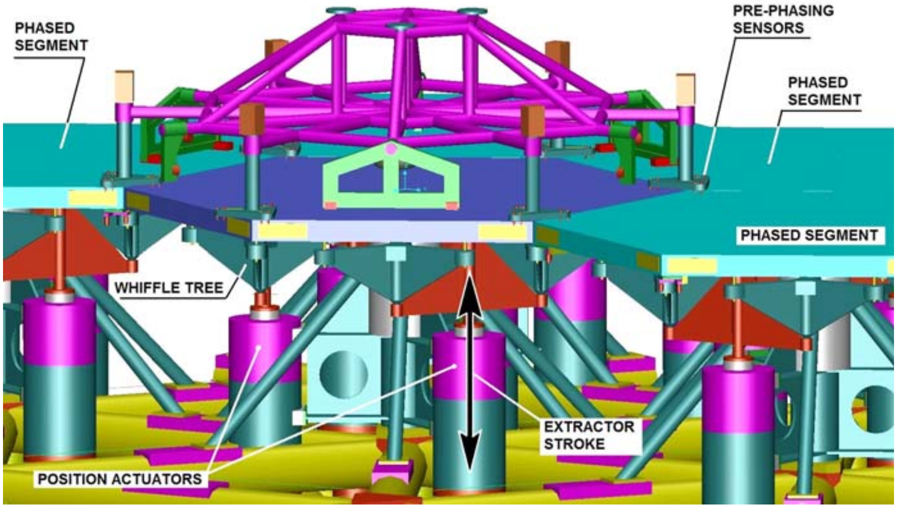

Figure 13-19: Segment coarse pre-phasing

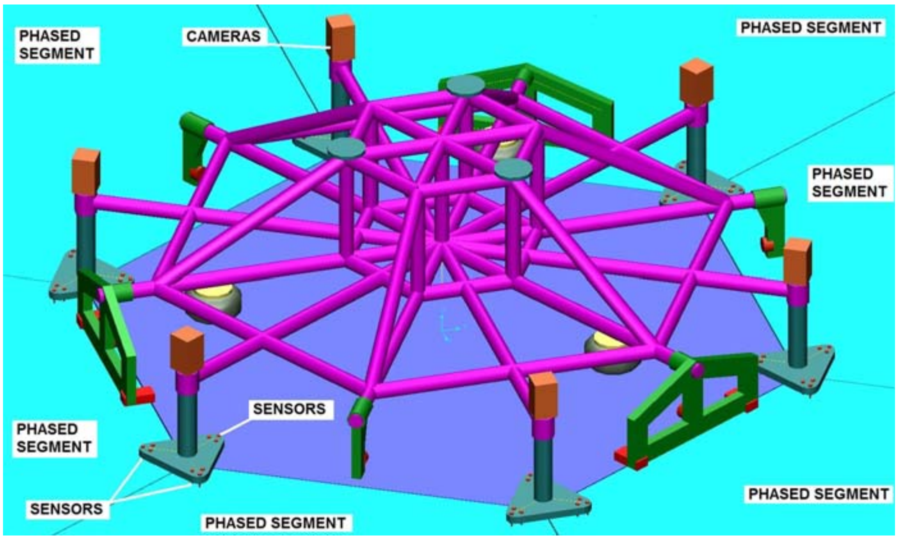

Figure 13-20: Segment fine pre-phasing

13.2.1.5 Optics

13.2.1.5.1 Initial alignment

This section describes the progressive integration of the segments and the corrector.

In a perfectly aligned telescope the optical axes of all mirrors are congruent with the mechanical axis of the adapter. Initially. at the end of the installation. the mirrors will be misaligned with respect to the axis of the adapter. the flexible meniscus mirrors will be deformed. and the segments will be misaligned both in piston and in tip/tilt. With the following steps the errors can be brought within the ranges of the control systems.

1. By autocollimation M6 would be aligned with the axis of the adapter. This would require an additional optical device at the center of M6.
2. The segmented mirrors would be aligned with the help of the edge sensors. These must be glued to the rims of the mirrors with an accuracy of approximately 200 micrometers with respect to the front surface of the segment. By moving individual segments and measuring when adjacent sensors go out of range. the differential displacements between the mirrors at the locations of each pair of sensors can be detected. From the data of all sensor pairs the optimum movement of all segments to minimize the rms of the differential

displacements can be calculated and applied. At the end of these procedure the rms. excluding the undetectable focus mode. should be of the order of 200 micrometers. The correction of defocus could be left to the stage of automatic corrections. In the case of the flat M2 it may also be feasible to measure it with a laser across the M2 surface.

3. The distance between the mirror surface and the support structures of M1 and M2 can then be measured by the fibre extensiometer.
4. All other mirrors could be aligned starting from M6 with the help of a fibre extensiometer. This requires fibre links between specified locations on all pairs of successive mirrors.
5. Finally. a second round of aligning the segments in tip-tilt could be done by stacking the images of individual segments or by using the Shack-Hartmann sensor.

At this stage one major error will be that low order aberrations in individual mirrors may compensate mutually but generate additional field aberrations. The other error will be caused by piston misalignments of the segmented mirrors.

From this point on the remaining errors can be calculated from simultaneous measurements by a few wavefront sensors distributed in the field and corrected by the actuators under all mirrors.

13.2.2 Safety

During the early erection. there are few difference with respect to erecting large scale structures. Once the telescope main axes are functional. more stringent safety rules shall be implemented. as done on Paranal:

1. Anybody entering a potentially dangerous area shall be directed to a specific corridor with safet station equipped with emergency push buttons and safety card reader at locking/emergency stations. That inhibits the telescope main axes rotation.
2. In addition the following surveillance and emergency devices are implemented:
    - Transceiver (GPS localizer).
    - Signal reflectors embedded in the clothes of the personnel. similar to those for avalanche rescue.
    - WEB camera. thermal cameras and infrared sensors.
    - Audio devices: Microphone. Loudspeakers.
    - Optical devices: Emergency and flash lights.

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