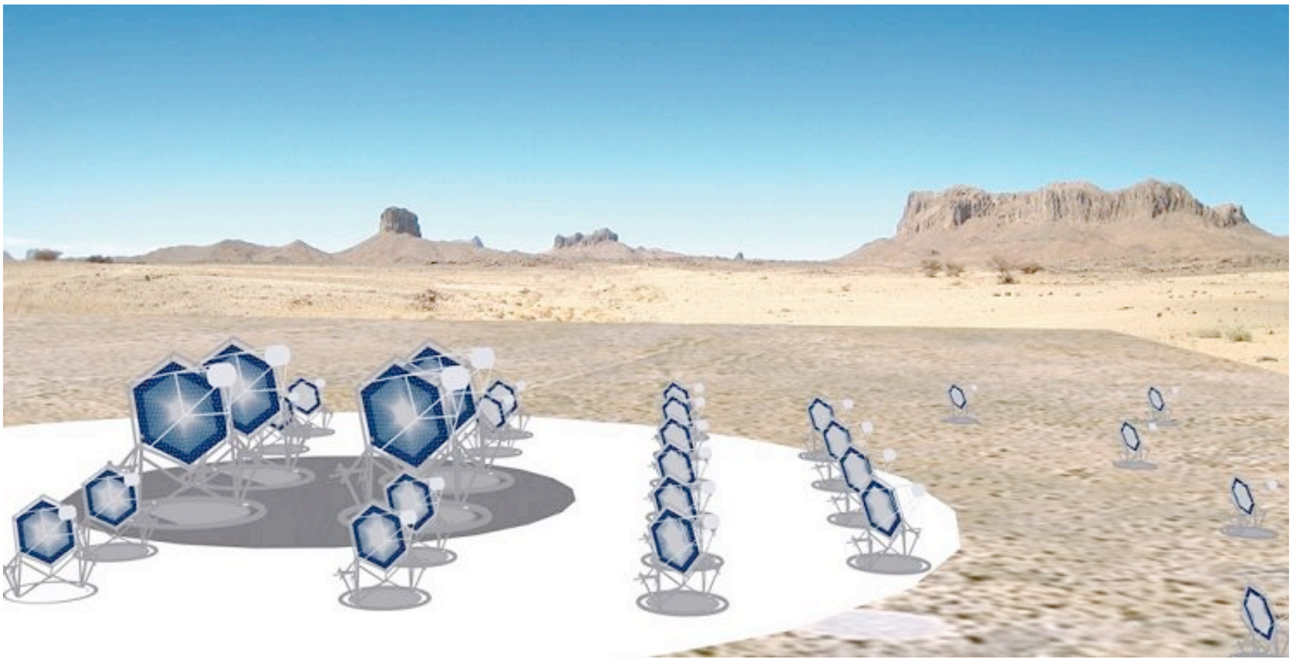
PROGRESS REPORT ON THE MECHANICAL DESIGN OF THE SST-DM TELESCOPE



Prepared by:	Name: Rodolfo Canestrari INAF-OAB	Signature:	Date:	15-12-2011
Reviewed by:	Name: Stefano Vercellone INAF-IASF Palermo	Signature:	Date:	16-12-2011
Approved by:	Name:	Signature:	Date:	

TABLE OF CONTENTS

DISTRIBUTION LIST

ASTRI mailing list	astri@brera.inaf.it
Piergiorgio Picozza	piergiorgio.picozza@roma2.infn.it
Michèle Lavagna	lavagna@aero.polimi.it
Caterina Petrillo	caterina.petrillo@pg.infn.it
Giovanni Bignami	presidente@inaf.it
Gianpaolo Vettolani	vettolani@inaf.it
Gabriele Villa	villa@inaf.it

DOCUMENT HISTORY

Version	Date	Modification
1	15-12-2011	first version

LIST OF ACRONYMS

ASTRI	Astrofisica con Specchi a Tecnologia Replicante Italiana
CTA	Cherenkov Telescope Array
FEA	Finite Element Analysis
INAF	Istituto Nazionale di AstroFisica
HESS	High Energy Stereoscopic System
KOM	Kick Off Meeting
MAGIC	Major Atmospheric Gamma-ray Imaging Cherenkov telescope
OAB	Osservatorio Astronomico di Brera
PDR	Preliminary Design Review
PV	Peak to Valley
rms	root mean square
SST	Small Size Telescope
WBS	Work package Breakdown Structure
WP	Work Package

APPLICABLE DOCUMENTS

[AD1] ASTRI Governance document

[AD2] CTA-TC_PR1-110331 *"Level A: Preliminary CTA System Performance Requirements"*

REFERENCE DOCUMENTS

[RD1] ASTRI-PR-IFSI-5000-007, Vallania P.

[RD2] ASTRI-IR-OAB-3100-009, Canestrari R. et al *"The optical layout of the ASTRI prototype: 4 meter Schwarzschild-Couder Cherenkov telescope for CTA with 10 degrees of field of view"*

[RD3] ASTRI-SPEC-OAB-3100-002 Canestrari R. et al *"Error Budget Tree for the ASTRI prototype: structure and mirrors"*

[RD4] MAN-PO/111118 *"Review of the CTA Small Size Telescopes", Chapter 5*

[RD5] ASTRI-SOW-OAB-3100-002 Canestrari R. et al *"Statement of the Work for the engineering structural design of a dual-mirror Cherenkov telescope prototype for the ASTRI project"*

[RD6] ASTRI-SOW-OAB-3100-003 Canestrari R. et al *"Statement of the Work for the engineering designs of mechanical subsystems for a dual-mirror Cherenkov telescope prototype for the ASTRI project"*

[RD7] ASTRI-MIN-OAB-3100-011 Fiorini M. *"Kick-Off meeting per la struttura e la meccanica del prototipo di SST-2M"*

[RD8] SST-STR_review Greenshaw T. et al *"Summary report of the SST-STR working group activities", Chapter 4.1 (The ASTRI end-to-end prototype)*

[RD9] ASTRI-SPEC-OAB-3100-003 Canestrari R. *"ASTRI SST design loads"*

[RD10] ASTRI-ES-BCV-3110-008 (aka p2652_rep_4_2 and p2652_rep_4_1_allegati) BCV progetti srl *"AZIONI PER DIMENSIONAMENTO ORGANI MECCANICI"*

[RD11] ASTRI-PR-OAB-3120-003 Canestrari R. *"Progress Report on the development of the manufacturing technology for the M1 mirror segments"*

1. INTRODUCTION

This document is the deliverable R2 required by the ASTRI governance document [AD1].

The aim of this document is to provide the state of the art of all the activities related to the design of the mechanical structure of the dual-mirror telescope prototype under study. The activities here reported are mainly related to the WP 3110 of the ASTRI WBS.

2. THE OPTICAL DESIGN

The optical system is a wide filed, aplanatic, double-reflection Cherenkov telescope based on the Schwarzschild-Couder configuration (see Fig. 1 left panel).

The design is done taking into account both the segmentation of the primary mirror M1 and the arrangement of detection units into the detector DET. The secondary mirror M2 is considered to be monolithic, this being the baseline for the ASTRI prototype.

The optimization as been done in order to have the largest Field of View that keeps at least the 80% of the energy within 2x2 physical pixels along the entire field angle (see Fig. 1 right panel).

The design has been performed using the commercial software for optical system design ZEMAX. Moreover, a crosscheck to validate the robustness of the results has been performed by means of MonteCarlo simulations using the simulation tool sim_telarray, developed by the HESS collaboration for the simulation of their telescopes (optical ray tracing, photon detectors, electronics, noise, etc). sim_telarray is now the standard simulation tool adopted in CTA. Details are reported in [RD1].

A detailed description of the optical layout and its performances can be found in [RD2]. A summary is hereafter reported for completeness.

Parameter	***Value***
M1 diameter (max)	4306 mm
M2 diameter	1800 mm
F/number	0.5
Equivalent focal length	2150 mm
Plate scale	37.5 °/mm
Pixel size	0.16 °
Corrected Field of View	9.6 °

ID	***Diameter [mm]***	***Radius of Curvature [mm]***	***Shape***	***Distance to… [mm]***
M1	4306	- 8223	Even asphere	M2: 3108.4
M2	1800	+ 2180	Even asphere	DET: 519.6
DET	360	+ 1000	Sphere	##

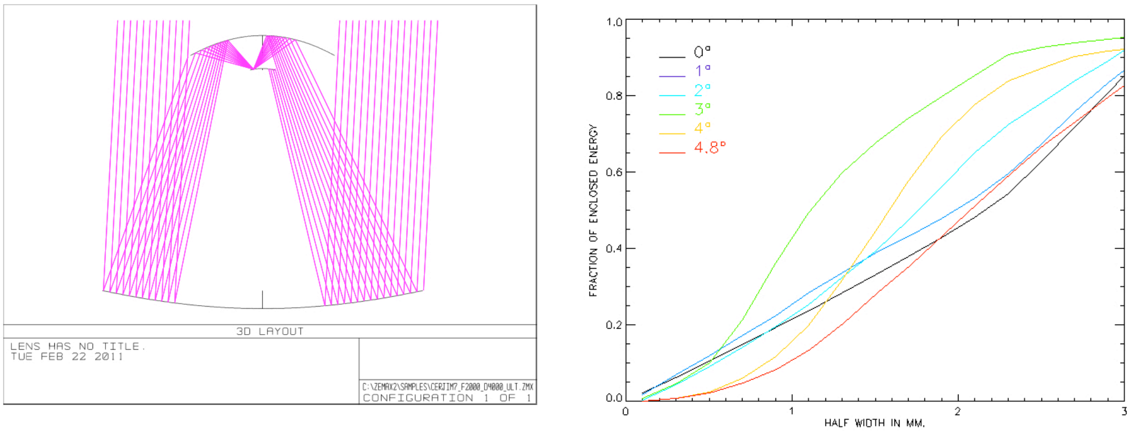


Fig. 1: The Schwarzschild-Couder optical design (left). Ensquared energy for various field angles (right).

2.1 The Error Budget Tree

A detailed error budget has been compiled and is reported in [RD3]. This document is a living document. This means that the numbers adopted for each parameter can be subject of changes depending from the outcomes of the structural analyses and/or technological developments.

The analysis has been performed in such a way the global effect of all contributions keeps the energy concentration (ensquared energy) better then (or equal to) 70%.

This can be translated in a PV error budget equal to 120 µm and slope error budget equal to 60'' rms.

It worth to be noted that the release of this document was also suggested by the CTA-SST review committee as reported in [RD4].

3. THE TELESCOPE PRELIMINARY DESIGN

The telescope structure will be an alt-azimuthal design in which the azimuth axis will be moved by means of two pinions drive system. The elevation axis will be moved by means of a linear actuator with a gear box and preloaded ball screw. The azimuth axis will admit a rotation range between -270° and +270°.

The mirror cell, which will be light and stiff to support the segmented M1 mirror and to allow the maintenance of the segments, will be fixed on a fork. Rotation around the axis will be possible from -5° up to +95°. Fixed on the mirror cell will be the structure (quadrupod) that will support the M2 mirror cell in which another structure will support the camera and, to balance the torque due to the overhang of the M1 cell with reference to the rotation axis, two structures supporting the counterweights. A view of the telescope is shown in Fig. 2.

The telescope design will be carried out by the firms Tomelleri Srl for what concern the mechanical design and by BCV progetti Srl for structural design and FEA. Details of the contractual activities, milestones, schedules and expenses are reported in [RD5], [RD6] and [RD7].

The main activities related to [RD6] are:

- design of the mechanisms for the two principal movements requested for the telescope, i.e. the azimuth and the elevation;
- design, calculation and test of the engines and position-measuring devices used for the telescope pointing/tracking, evaluation of the power consumption including peaks;
- design of the safety systems in case of motor failures and/or power cuts (dampers and stow pins for the two axes, emergency manual driving systems);
- telescope assembling/disassembling procedures and related safety aspects;
- design and study of solutions to minimize operations during mounting/dismounting of mirror panels and their actuators;
- cost estimation for the construction of a prototype including all mechanical and electrical subsystems with the exclusion of the optical parts;
- cost estimation for the construction of all telescopes required by the CTA SST array including all mechanical and electrical subsystems with the exclusion of the optical parts;
- manufacturing and testing of one M1 segment support and alignment system.

The main activities related to [RD5] are:

- FEA to study the deformations of the structures and of the mirror supports arising from gravity load, operative winds, operative temperatures and other eventual loads;
- FEA to study the stress of the main structures due to gravity load, to survival winds, to survival temperatures, seismic loads and to other eventual loads;
- evaluation of the eigenfrequencies in different configurations, such as different pointing orientation, different stow/parking positions.

- design of the concrete foundations;
- definition of the materials to be used for the construction;
- structural checks;
- technical specifications;
- detailed drawings of the telescope structures.

A more detailed report of the solutions under investigation is available in [RD8].

The PDR of the activities related to [RD5] and [RD6] is foreseen for late January 2012. At that time more detailed results will be available and some decisions could be taken in case of different solutions studied.

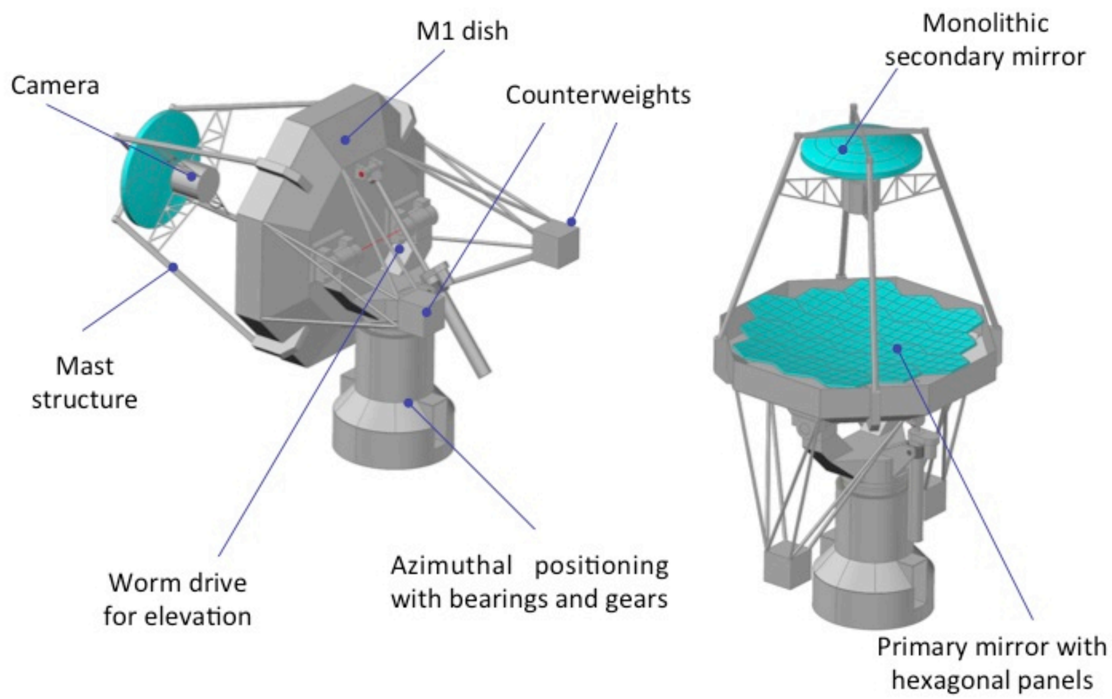


Fig. 2: Picture of the preliminary design of the telescope structure. The main elements are shown and labeled.

3.1 The design loads

A detailed enumeration of the design loads and loads combinations has been performed and reported in [RD9]. The list has been compiled on the basis of the information given by [AD2] and in accordance with the appropriate EUROCODEs.

In case of lack of critical information, such as the case of the seismic loads because the CTA site is not yet decided, mitigation strategies will be carried out in order to minimize the risks (i.e. evaluation of two different seismic load cases compatible with typical North-Argentinean sites and South-African sites).

A preliminary evaluation of the torques and momentum of inertia has been done [RD10].

3.1 The Finite Element Analysis

Simplified FEA have been carried out in the early stages of the project in order to support the preliminary evaluations leading us to the telescope configuration presented in [RD8] and summarized in this document. Extensive numerical structural analyses by means of FEA calculations are ongoing in order to verify the structural design and compare different solutions.

In particular, the structural behaviors of the two solutions for the dish (see next paragraph), the mast and the M1 mirror segments are under investigation.

When the structural configuration of the SST will be frozen, a global FEA of the whole assembly is foreseen in order to optimize the design of the structural members and in order to study the global behavior of the structure. Refined local FEA calculations will be used, if necessary, to assess local effects such as stress peaks in complex nodes.

3.2 The mechanical structure

The main structural SST components are shown in Fig. 2. Here we list these elements, starting from the ground level (see [RD8] for details):

a. <u>Foundation</u>: it will be realized in reinforced concrete. The telescope structure will be fixed to the foundations by steel anchor bolts embedded in the concrete mass. Shear devices could be also used in order to assure the transmission of the lateral forces to the foundations.

b. <u>Tower</u>: it will consist mainly of a steel tube, with section variations along its height. Openings to allow access to internal devices and proper stiffeners, mostly at the inter- faces and around the openings, are envisaged. It is connected at the base flange to the foundation by anchor bolts and perhaps also a shear device.

c. <u>Azimuth fork</u>: it rotates around azimuth and supports the elevation assembly through the linear actuators and the bearings at the fork top ends. It is composed of welded steel box sections. All steel structures are protected against corrosion by paint.

d. <u>Elevation assembly</u>:

   i. <u>Dish</u>: it supports the primary mirror segments and accommodates also the structural interfaces with the counterweight and quadrupod. Two options are under evaluation: a plate and a truss dish (see Fig. 3). After preliminary evaluations we report a similar overall structural behavior between the two. The plate concept, despite a slightly higher dead weight, has the advantage to strongly reduce the number of components to be assembled (both at the factory and on-site). On the other hand, the truss concept permits a better airflow on M1 and a faster thermalization. Whether this is a real need for the telescope is now uncertain. More refined thermal analysis and lab measurements are ongoing to help the understanding of the problem.

ii. Counterweights: they balance the elevation assembly around the elevation axis.

iii. Quadrupod: structure supports the secondary mirror and the camera, maintaining the alignment of the optical components of the telescope in the allowable range.

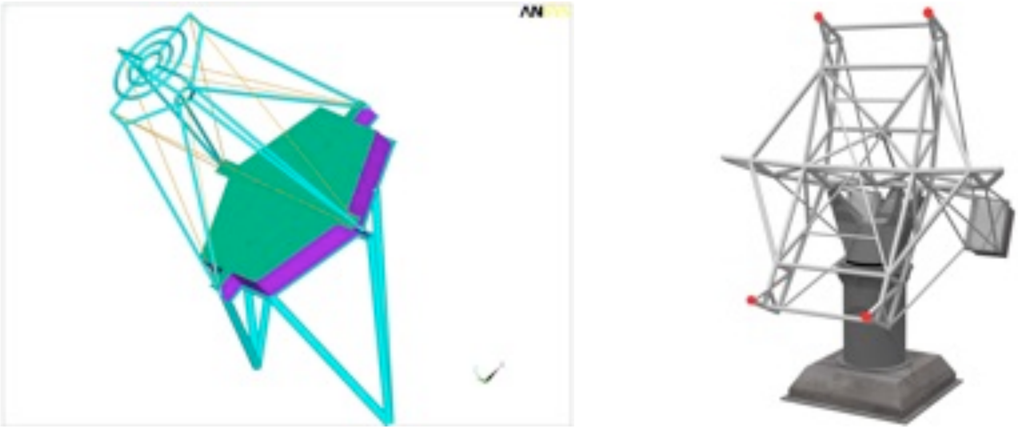


Fig. 3: Plate concept for the M1 dish (left). Truss concept for the dish (right). The quadrupod, which is not shown, will be connected to the four corners indicated by red dots.

3.3 The drives and safety concepts

A list of the baseline solutions concerning the drives and control systems and the safety concepts are hereafter reported (see [RD8] for details.):

a. Preloaded bearings on the azimuth and altitude axes are under evaluation. In particular:

   i. two different solutions for the bearing system of the azimuth axis (two ball bearings axially preloaded by an adjustable spacer (see Fig. 5 left panel) or one slewing ring ball or roller bearing inner preloaded);

   ii. The bearing system of the altitude axis will use four tapered roller bearings to which the fork of the M1 cell will be connected. The bearings will be axially preloaded by suitable threaded bushes in order to ensure there is no backlash.

b. Direct measuring systems on the azimuth and altitude axes (see Fig. 5 right panel);

c. High performance control system of the azimuth and altitude axes will be achieved implementing three closed loops for each of the two axes: the torque closed loop; the velocity closed loop and the position closed loop;

d. Cable accommodation for reliable connection between base, fork and M1;

e. Stiff drive systems with anti-backlash solutions on the azimuth (a solution with two pinions seems preferable) and altitude axes (a linear actuator is adopted with a gear box);

f. A software manager will monitor the telescope/instrument/structure status and evaluate operational limits based on environmental and operational parameters.

g. Safety systems solution on the azimuth and altitude axes will be done both by a software limit switch and by electromechanical limit switches. Two emergency limit switches will cut the power supply to the motor and a dumper system is foreseen to stop the axis mechanically (if needed).

h. Stow pins on the azimuth and altitude axes;

i. High Reliability, Availability, Maintainability and Safety (RAMS) of all subsystems;

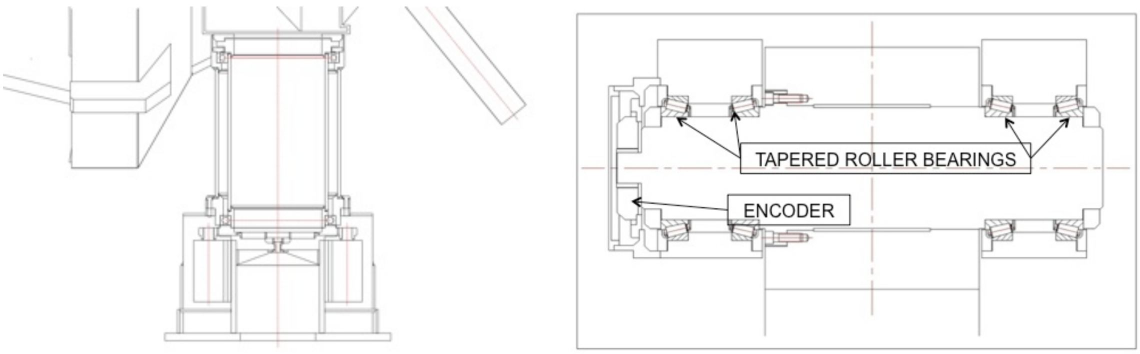


Fig. 5: Bearing system on the azimuth axis using two preloaded ball bearings (left). Direct measuring system on the altitude axis (right).

3.4 The mirrors and mirrors interfaces

The primary mirror M1 is segmented into 18 tiles; the central tile position is not used because it is completely obstructed by the secondary mirror. The segmentation requires three types of segments having different surface profiles. The segments have hexagonal shape with an aperture of 849 mm face-to-face.

The manufacturing technology exploits the concept of replication of a master shape. In particular, we propose to adopt a modified version of the cold-glass slumping technology formerly developed by INAF-OAB and adopted for the 17 m MAGIC II telescope. For this project the glass shells will undergone a pre-shaping process at high temperature. A more detailed description of the technology and the status report of the activities are left to the deliverable R3 [RD11].

Each segment will be supported in an isostatic way by one fixed support and two controlled supports placed at a suitable distance, see Fig. 4. The tilting of the segments will be achieved by the control of two axial actuators, by counting the steps of suitable stepper motors. The required accuracy will be guaranteed by coupling the motor with a gearbox with low backlash. The reliability requirement is critical given the number of actuators. The manufacturing and tests of a prototype of the supporting and alignment system of one segment of M1 is part of the activities requested in [RD6].

The secondary mirror M2 is monolithic (baseline choice) and equipped with three actuators. The implementation of the third actuator makes available also the piston/focus adjustment for the entire optical system. Despite known technical difficulties in the manufacture of large aspherical mirrors, we intend to pursue this route because of a number of clear advantages. As examples, it will be possible to implement a simpler and lighter mechanical structure, use less actuators and avoid a non-trivial alignment system for double-segmented surfaces. This should lead also to a reduction of the costs. However, a risk mitigation strategy is under definition for a backup solution and different structural configurations will be investigated (monolithic and segmented mirror).

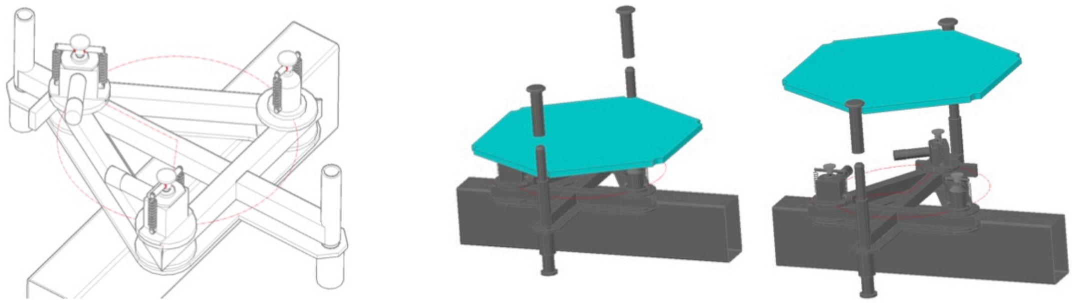


Fig. 4: The M1 segment supporting and alignment system (left). The M1 segments mounting/dismounting system (right).

4. INDUSTRIAL CONTRACTS, SCHEDULE AND COSTS

The designs activities [RD5] and [RD6] are conducted through industrial contracts with leading Italian firms. The contracts have been placed following the procedures given by the Italian law "Decreto legislativo 12 aprile 2006 nr. 163" with particular reference to the "art. 57 comma 3 lettera a".

Various firms have been contacted and a technical Committee (DD nr. 56/11) has evaluated the offers.

The KOM took place in INAF-OAB on September 27th 2011 [RD7].

The schedule foresees a timeframe of 9 months to carry out the designs up to the executive level. The breakdown of the main deliverables is:

- 3 months from the KOM: PDR of the telescope structure
- 5 months from the KOM: executive design of the mirror segment supporting/alignment structure demonstrator
- 6 months from the KOM: general design and cost evaluation of the telescope structure
- 8 months from the KOM: manufacturing of the mirror segment supporting/alignment structure demonstrator
- 9 months from the KOM: executive design and documentation of the telescope structure, test of the mirror segment supporting/alignment structure demonstrator

Monthly reports/updates can be requested to the firms.

The total amount of money committed to these activities is of the order of 360 k€.

More refined information are available in [RD8].