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VST Project: Mechanical Design Optimization

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ABSTRACT

The VLT Survey Telescope (VST) is a cooperative program between the European Southern Observatory (ESO) and the INAF Capodimonte Astronomical Observatory (OAC), Naples, for the study, design, and realization of a 2.6-m wide-field optical imaging telescope to be operated at the Paranal Observatory, Chile. The VST has been specifically designed to carry out stand-alone observations in the UV to I spectral range and to supply target databases for the ESO Very Large Telescope (VLT). The telescope design, manufacturing and integration are responsibility of TWG and have been carried out on the base of a model of optimized design not only for mechanics but for all telescope subsystems. The paper is an overview on the telescope mechanical design and optimization.

Keywords: mechanical design, Finite Element Analysis, integrated design

1. INTRODUCTION

The VLT Survey Telescope (VST) is a cooperative program between the European Southern Observatory (ESO) and the INAF Capodimonte Astronomical Observatory (OAC), Naples, for the study, design, and realization of a wide-field optical imaging facility to be operated at the ESO Paranal Observatory in Chile. The telescope, expected to be installed at Paranal within the year 2003, has been designed, manufactured and integrated by the Technology Working Group of the Astronomical Observatory of Capodimonte, Italy. The enclosure and civil work at the VLT environment at Paranal are responsibility of ESO. The VST camera, a CCD mosaic named OmegaCAM, is being built by a European consortium which includes the Netherlands, Germany, Italy, and the European Southern Observatory. The data reduction pipeline is under construction by the OmegacCAM Consortium and by OAC. The VST telescope features are: modified Ritchey-Chretien optical layout, 2.6 m aperture, f/5.5 focal ratio, three lenses wide-field corrector with optional atmospheric dispersion compensation, active primary mirror, hexapod driven secondary mirror, and alt-azimuth mounting. The design is optimized for high quality, seeing limited wide-field astronomical imaging on a 1 degree x 1 degree corrected field of view, mapped by a 16k x 16k pixel CCD mosaic with 0.21 arcsec/pixel scale, in the wavelength range from 320nm/365nm to 1014 nm. High image quality performance is guaranteed by an active control of the optics, acting on both primary and secondary mirror. The telescope structure and all the related subsystems have been designed in order to satisfy contemporary both opto-mechanical constraints and the required performances in terms of natural proper frequencies. The frequencies are related to the expected necessary bandwidth of the control system to compensate for wind buffeting effects and general high frequency disturbances. The optimization of the structural frequencies have been achieved by modeling carefully the structure and all the interfaces toward the rest of the mechanical subsystems and toward the field. The optimization allowed to increase the weight to stiffness ratio, giving as a result a light and compact structure.

2. MECHANICAL DESIGN

The VST model in 1:20 scale is shown in Fig.1 together with a wireframe drawing. In the wireframe drawing come electronic cabinets are represented. They have been disconnected physically by the telescope and positioned on the dome floor. Fig.2 allows to identify the main mechanical telescope subsystems. It is an Alt-Az 2.65-m class wide field telescope, designed for Cassegrain operations. The corrected field - of - view diameter is 1.47 degree. Optical switching

Large Ground-based Telescopes, Jacobus M. Oschmann, Larry M. Stepp, Editors,
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correctors are installed very close to the main mirror. The thickness of the main mirror was chosen to be 14 cm in order to optimize both thermal and optical behaviors. The M1 (Mirror#1) sag is controlled by means of 84 axial pads and 24 radial pads. As for M1 also the secondary mirror is actively controlled by means of two dedicated positioning system (Hex#1 and Hex#2) to compensate for thermal and gravitational structure deformations. In order to actively control both M1 and M2 (Mirror#2) an on line Shack Hartman wavefront sensor is present in the M1 cell. The M1 cell supports all the axial and radial pads, a very precise two stage switching optical support for the correctors, and it is provided with two large rotating flanges to support instrumentation and the guide probe. A co-rotator is fixed to the M1 cell base to support the instrument electronics. The Instrument and telescope optics and mechanics have been designed together in order to optimize the entire assembly. One of the guidelines is in fact to consider the telescope and camera as a whole system. Interfaces and performance are so optimized. As an example the detector window has been studied and optimized as one of the component of the telescope optical train. The telescope is designed to produce sharp images. For this reason a detailed study of the thermal behavior of the telescope subsystems and active control systems has been performed to maintain the temperature of the active subsystems in a tight range around the ambient temperature, so avoiding any influence on the surrounding ambient and on the telescope structure itself. For the same reason the ventilation of the telescope is guaranteed by the open design of the enclosure, avoiding air stagnation around the telescope. Air flow is allowed all around the main mirror being the mechanical structures of the mirror cell and of the Center Piece separated. The motors are cooled by means of a cooling jacket having as a reference temperature the telescope structure temperature, so avoiding concentrated losses in the mechanical structure. The same strategy is at the base of the electronic cabinets cooling system design, that measures the ambient temperature around the cabinet. The stability of the telescope in terms of response to external disturbances has been also optimized in order to guarantee for a satisfactorily compromise between attended performance and general cost of the project. One delicate section of the telescope is located in the M2 box. Two very precise positioning systems are present: Hex#1 and Hex#2. The first one is a hexapod optimized in terms of quality, backlash, linearity. But its resolution is not sufficient during tracking to guarantee the stability of the spot on the focal plane as required by optics. For this reason a second stage Hex#2 provides movements in a tight range but with an higher precision and resolution in respect to Hex#1. The telescope general design has been carefully analyzed in order to prevent the necessity to apply large balancing masses on the structure. At the end the finest compensation could also be obtained by modifying some structural components in the mechanical design if possible. The VST design philosophy meets the above constraints within the available budget. The major guidelines of the VST mechanical design can be summarized as follows:

- extremely compact and light structure (<50T) in order to reduce the size, cost and improve general performance;
- high proper frequencies (> 10 Hz), namely stiffness maximization not at the expense of excessive weight in order to optimize structural dynamic behavior and avoid thermal delays;
- whole optimization by Finite Element Techniques and novelties in system design and modelization;
- structure supported by Hydrostatic bearing system (20 GNm/rad) stiff namely telescope capable of smooth and precise rotation around the azimuth and altitude axes (special bearings) in order to restrict the error amplitudes, measured as RMS image motion at the focal plane, to less than 0.05 arcsec;
- telescope structure designed to permit smooth air flow and to maintain stiff optical alignment for wind velocities up to 10msec;
- temperature differences between the telescope active subsystems and the surrounding air kept in the range of +/-1 degree.

An Alt-Az mounting has been designed to satisfy the above guidelines that require essentially high stiffness and a compact overall structure. The mechanical design has been implemented on the base of the experience of the designer and to satisfy the optomechanical constraints. All the structural solution behavior have been validated by means of careful use of FEA tools. The following pictures and tables reports all the main information of the telescope structure and design. The drive system, for both the altitude and azimuth axes, is provided with an adaptive preload system for backlash removal from the telescope shaft gears. The desired tracking performance is guaranteed by high quality customized servo-drives. A Hydrostatic Bearing System is used in the AZ axis for excellent smoothness and low friction during axis rotation. High quality state of the art encoder system guarantee the telescope tracking performance. A large use of ESO standards both for hardware and software design has been considered in order to guarantee maintenance at any level on site. All the control sections and components have been distributed in cooled cabinets installed on the telescope structure. The misalignment due to thermal deformations elastic and no-elastic gravitational flexures has been taken under control also if is a intrinsic behavior of the Alt-Azimuth structure design. The weight/stiffness ratio has been taken under control with a good iteration with the results of FEA analysis. Materials, processes and standard parts used for the construction and indicated herein are conform to specifications and standards selected in accordance with UNI standard codification.

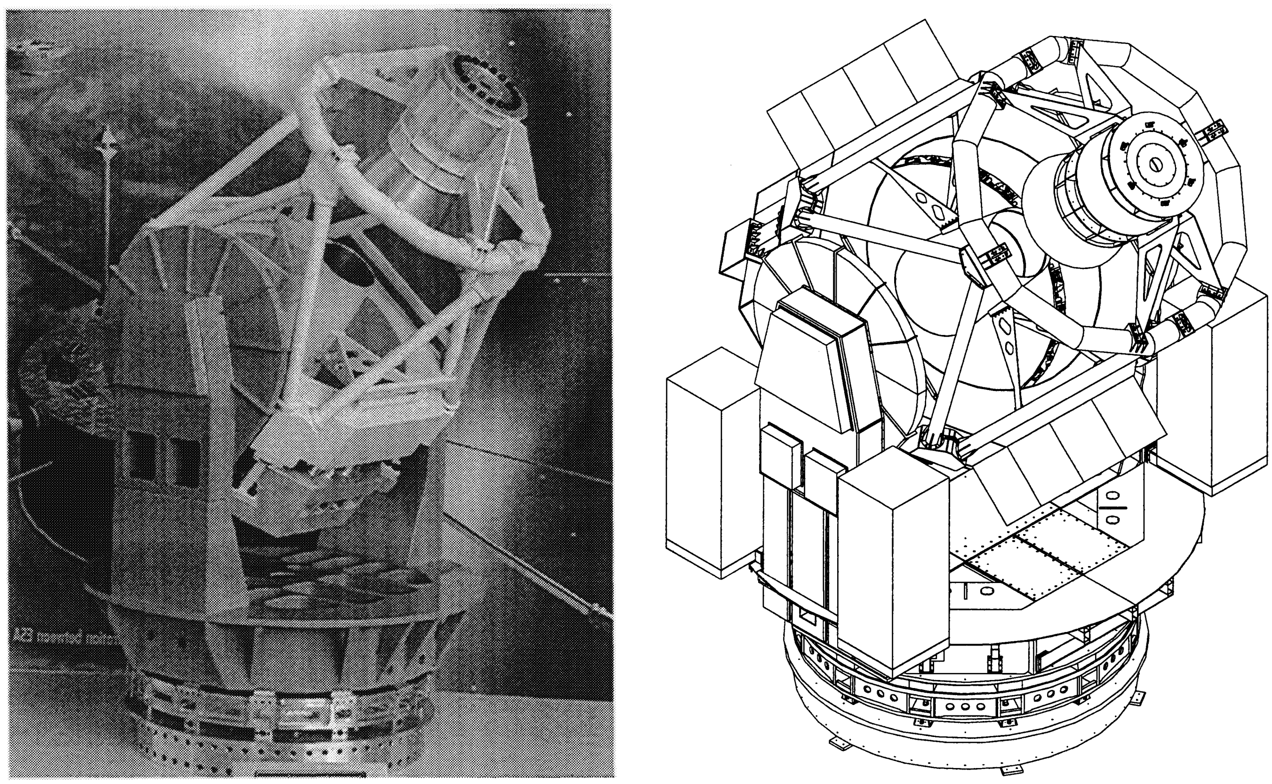

Fig.1 – Two images representing the VST. In the first one (left) the model in scale of the VST is shown. The right image is a wireframe one of the complete assembly. The electronic switchboards are now fixed on the dome floor.

3. MAIN TELESCOPE SUBSYSTEMS

1. Top assembly

The Top assembly consists essentially of a supporting structure that sustains the secondary mirror and all the related auxiliary sub-systems. The Top Assembly is divided in the following sub-assemblies:

- Top Ring Assembly
- Spider Assembly
- M2 Mirror Assembly
- M2 Box Assembly
- M2 Support Assembly
- M2 Hexapod 1
- M2 Baffle Assembly
- M2 Astatic Assembly
- M2 Hexapod 2
- Serrurier Assembly

The Top Ring is a welded structure obtained as a polar array of short standard profiles. The Top Ring has a circular section to allow a consistent reduction of the wind disturbance effects. Eight dedicated interface are realized and machined on the top ring connect to the Serrurier and spider assemblies. Four additional saddles with handles are placed on the top ring to permit the lifting of the structure during maintenance (Top Assembly removal for M1 maintenance operation). On the top ring four calibration lamps locations are also placed. A schematic representation of the top ring assembly is shown in Fig. 3.

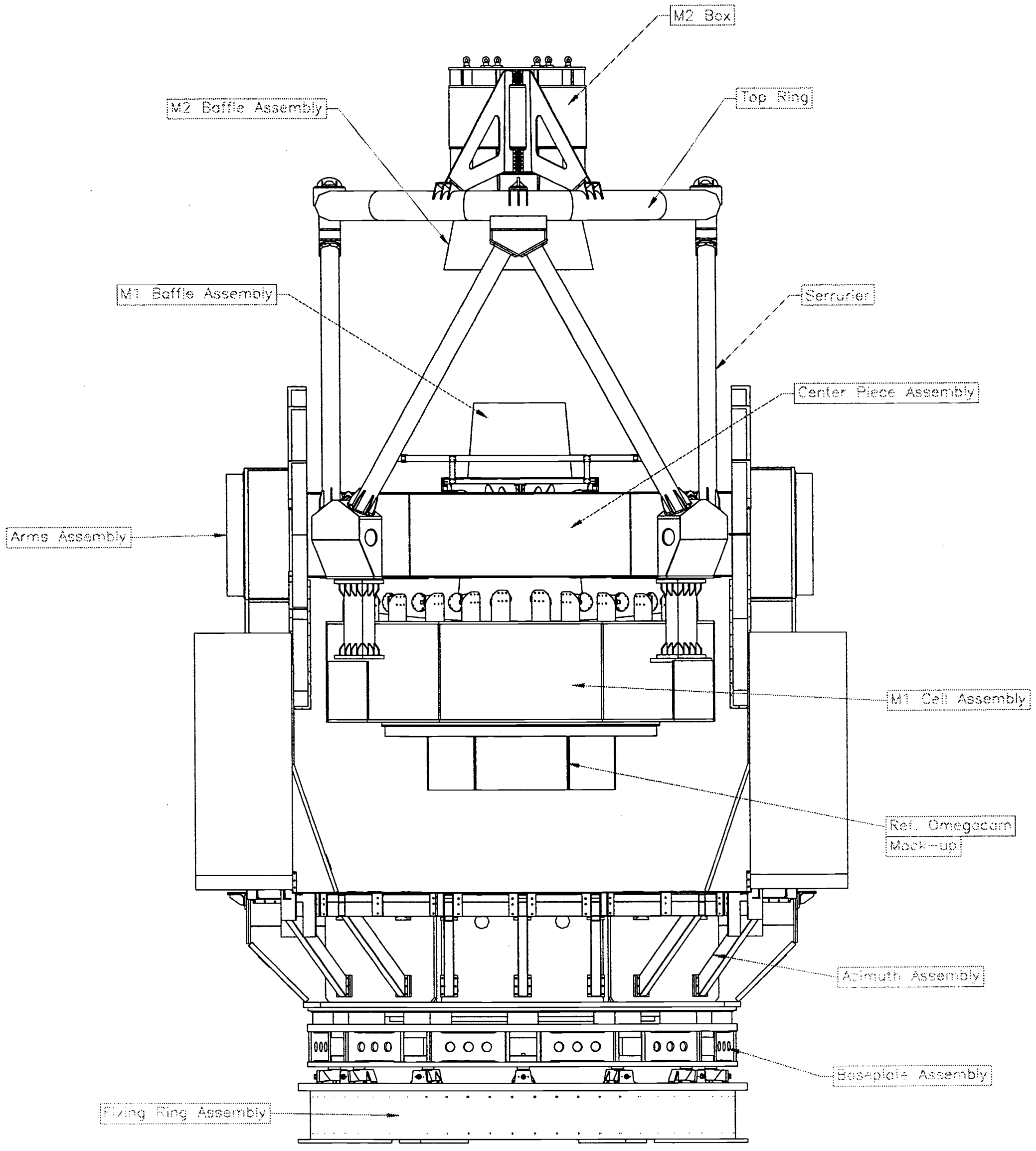

Fig. 2 – Main assemblies identification

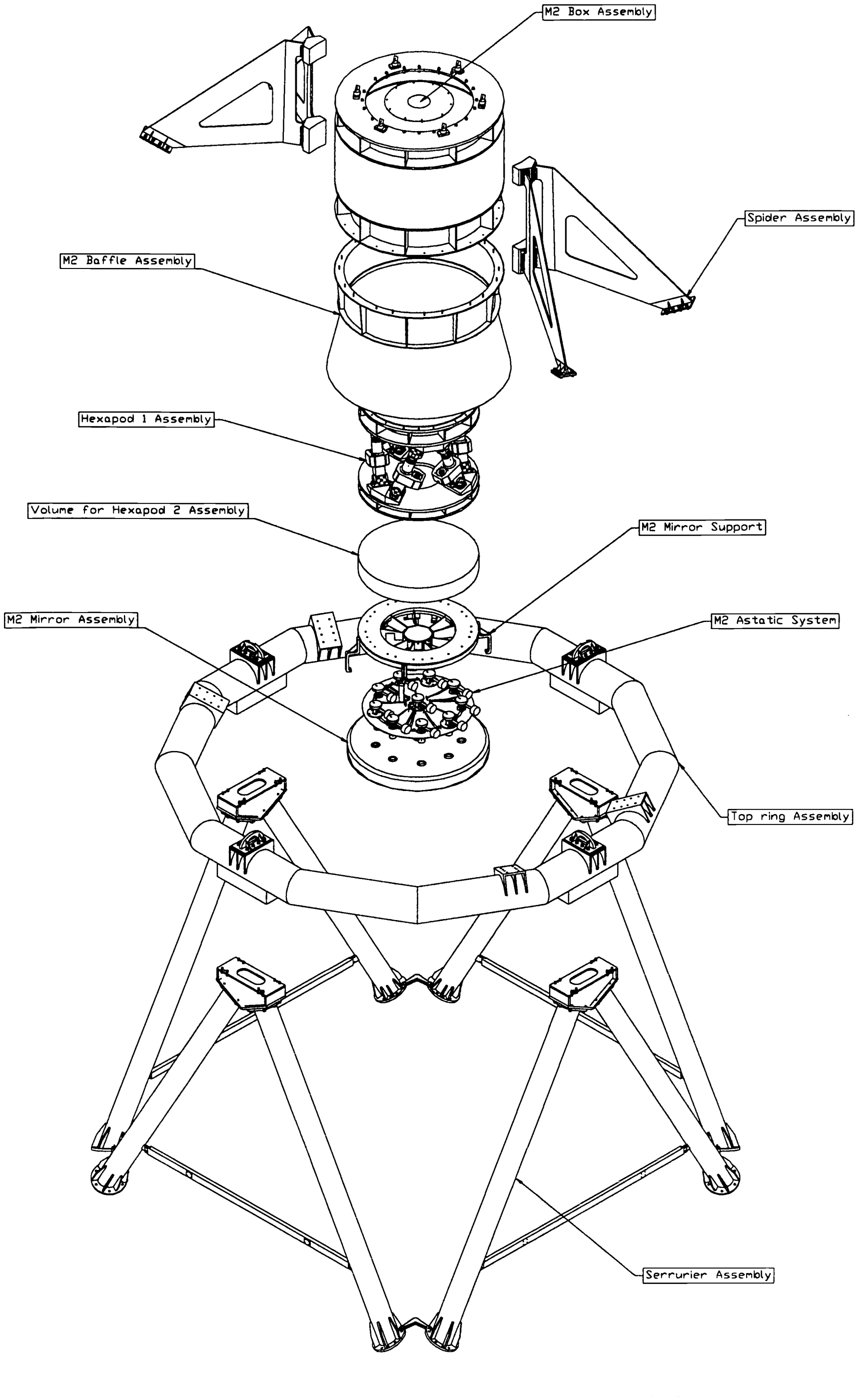

Fig. 3- VST Serrurier and Top Assembly Exploded view

The secondary mirror is provided with ten calibrated holes where special insert sleeves are glued. Slotted rings are glued on the border of the holes. The external slotted rings are glued on three holes located at 120° . The central slotted ring is used to define the radial correct position of the mirror while the lateral slotted rings are used to define the axial position. The axial and lateral regulators are included in the astatic system assembly. Any insert sleeve is used to fix the astatic lever arm and to define the correct connection between the astatic system and the mirror to permit to apply the correction displacements by a reaction force transmit from the astatic lever arm. In order to correct any misalignment in the telescope optical system during pointing an alignment active system (Hexapod #1) is placed in the M2 box. Hexapod #1 is used to compensate for the gravitational and thermal effects on the structure. This assembly is composed by six linear actuators which are placed between two reinforced interfaces allowing to fix it into the M2 box. The second interface is necessary to support a second M2 positioning system (Hexapod #2). Any Hexapode#1 leg is provided with special industrial selected components coupled in order to be backlash free. The Hexapode#1 performance depend almost exclusively by the quality of the leadscrew and then by the quality of the rest of the components and of the entire assembly. For this reason a high quality/low error leadscrew has been chosen on the base of experience.

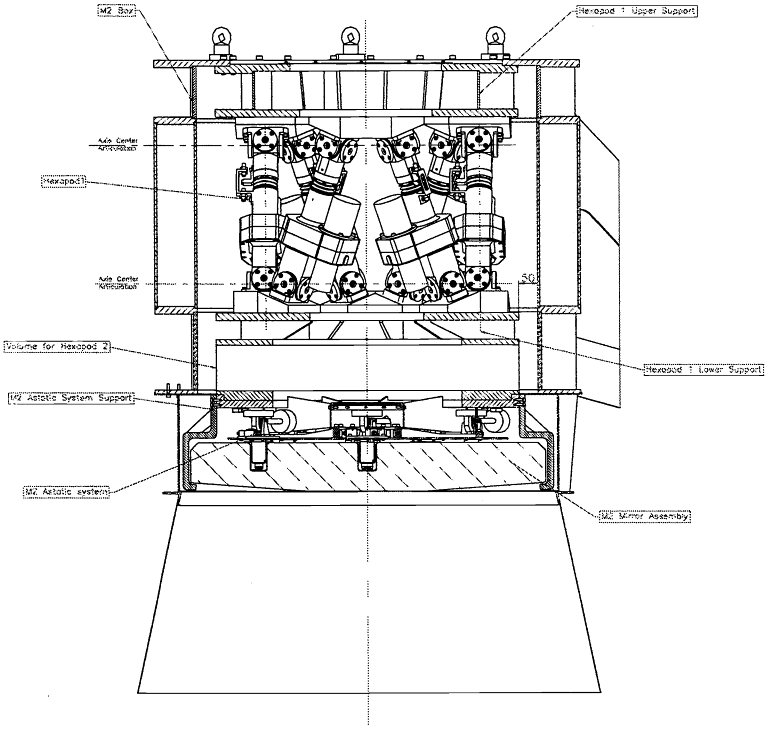

Fig. 4 – A M2 box section view

The transmission of the torque is obtained with an off axis brushless motor coupled to the leadscrew with a gear ratio 1:2 by means of a preloaded gearbox. Also the encoder is coupled to the leadscrew through the same gearbox in order to reduce the length of the Hexapod leg. The resolution of the encoder is 20000 pulse per turn allowing a numerical resolution of about 0.25E-5mm per encoder pulse to better resolve very small movements. The Hexapode#2 system is composed by four parallel plates that allow combined relative movements. The movements are obtained by means of preloaded piezoactuators. The movements are allowed by four brass flat plates springs for the X and Y displacements and by 3 preloaded membranes for tilt movements. The movement ranges are defined by some mechanical stops. In order to maintain the contact between the two plates through the piezoactuator, a preload is provided by means of conic washers. The relative movements are within 180 microns. The mechanical stops are regulated to allow a maximum displacement of 0.3 mm. The zero active position is obtained with the piezoactuators powered in the middle of the voltage range. The zero mechanical position of all the M2 system is reached by means of the Hexapode#1. A schematic representations of the Hexapode#1, Hexapode#2 integrated in the M2 box together with the astatic levers is shown in Fig.4.

2. Arms assembly

The design of the arms allows to test the drive system also if the telescope is not still integrated. In fact it results possible to mount and test all the device inside the arm. The mounting procedure allows to fix the gear separately on the Alt axis and to test the quality of the transmission and of the adaptive preload behavior. This kind of assembly allows also to verify the quality of the contact between pinions and gear. Only one arm is provided with the axis encoder. For this reason and to increase the general reliability and flexibility at the system. Each motor to provided with dedicated interface for standard angular encoder for maintenance and test. One of the arms is visible in Fig.5. Fig.6 shows a section drawing of the arm integrated with the main gear, the bearings, the servo drive and the axis encoder.

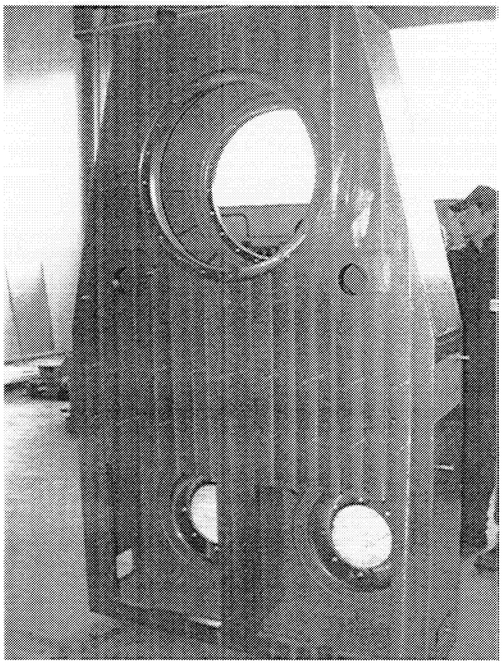

Fig.5 – One of the two arms manufactured for the VST

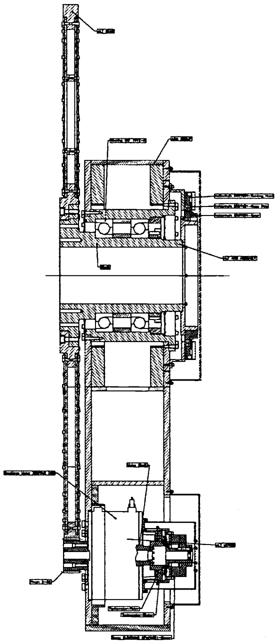

Fig.6 – A section view of one arm integrated with the main gear, the bearings, the servo drive and the axis encoder.

3. Azimuth assembly

The Azimuth Box is the heaviest part of the telescope. It has divided in a rotating part (AZ Box) and in a fixed part (Baseplate). The AZ box is visible in Fig.7. The two assembly are divided by the Hydrostatic Bearing System (HBS) (12 pads) (shown in Fig.8) and are coupled by a central oblique contact ball bearing. The central bearing has the task to guarantee both the radial centering of the rotating part in respect to the Baseplate and to preload the AZ Box against the Baseplate to guarantee the necessary stiffness of the Hydrostatic Supporting System. The HBS Track is coupled to the AZ box lower face. The AZ Box is provided with a segmented floor. The AZ motors are placed into the AZ box through four trapdoors while the encoder and the radial bearing are reachable through a central trapdoor.

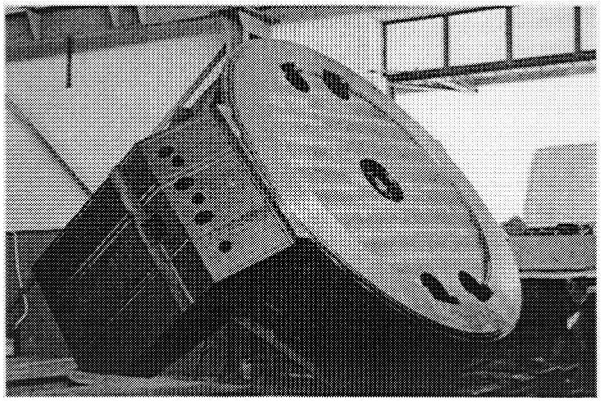

Fig.7 – The Azimuth Box (rotated around the longitudinal axis). The hydrostatic track is visible

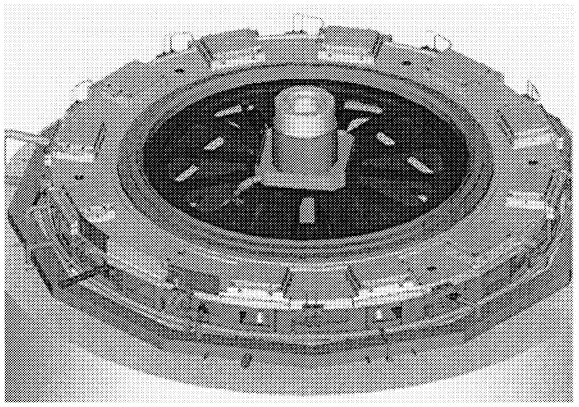

Fig.8 – (Render picture). The baseplate with the hydrostatic pads and piping integrated

4. The M1 cell

The mirror cell is a welded structure that supports the following subassemblies:

- Mirror#1 through the axial and radial pads
- Optical correctors (ADC + 1 lens and 2 lenses corrector) by means of a dedicated switching support
- Instrument and probe rotators
- Instrument electronics Co-rotator (UD).

The M1 axial and radial pads supporting areas are reinforced in order to avoid any misalignment during telescope rotation. The cell is supported by the center piece by means of the flexion bars computed to compensate for the top ring and M2 flexures along Y reference axis. Fig.9 shows the M1 cell just before the final manufacturing. Fig. 10 shows the prorotype of the axial pads.

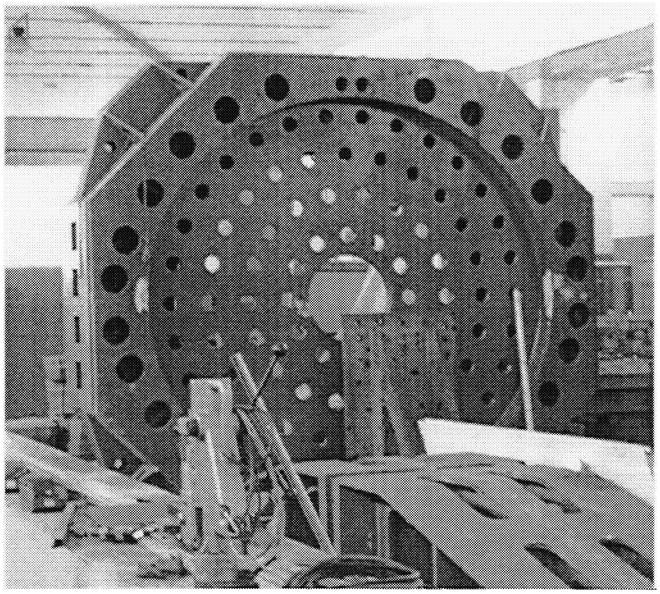

Fig. 9 – The M1 cell before final manufacturing

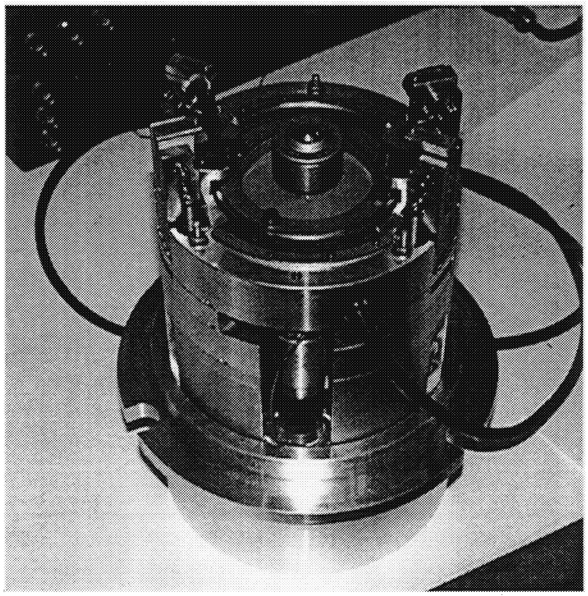

Fig. 10 – The axial pad prototype

4. STRUCTURAL ANALYSIS

A finite element analysis (FEA) of the whole telescope has been done and the results have been used as a feedback for the mechanical design optimization. In particular the FEA has been done with the following aims:

- compute the telescope main resonance frequencies
- test the effect of the wind and gravity loads on mirrors relative tilt decentring and defocusing
- compute the actual stiffness between the various part of the telescope to be used in the telescope model for the control system
- verify that no elements in the structure are stressed over their proper limits

Fig.11 shows the telescope structural model. The ball bearings of the elevation axis are introduced in the model exploiting the options "sliding surfaces" of the MSC-NASTRAN code. It allows relative movement of nodes laying on surfaces in contact (in this case the internal one of the hole of the fork and the external one of the hub of the elevation axis), avoiding any penetration of the nodes belonging to one surface into the other one. The ball bearings of the azimuth axis have been modeled taking into account the displacements of the nodes on the surface of baseplate hole that have been linked rigidly to the displacements of a fictitious node in the center of the hole itself. Another node has been created in the center of the hole of the cylinder fixed to the pillar, and the nodes on the surface of the hole have been linked to this one in the same way. The two fictitious nodes have been linked rigidly. The fictitious nodes have been left free of any movement, so allowing the baseplate and the fixed cylinder for free relative rotations but not for relative translations. Doing so the presence of the ball bearings is correctly simulated. The fixed part has been linked rigidly to the pillar in twelve points simulating the connecting bolts. The rotating stiffness around the azimuth axis is guaranteed by four springs connecting eight points, four on the baseplate and four on the fixed cylinder. The spring stiffness is four times the stiffness of a single tooth to tooth connection, in order to take into account the contribution of four motors, with two couple of teeth matching for each pinion. Eight spring elements connected to ground are present in the model in order to introduce the stiffness of the elevation axes motor gears. The primary mirror has been modeled together with its support

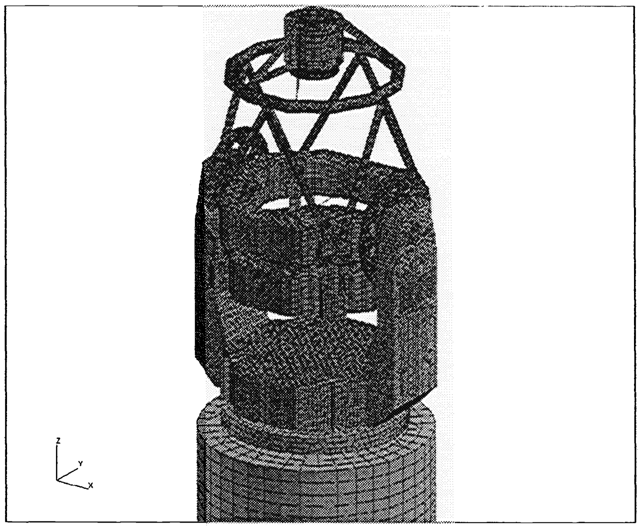

Fig. 11 – The Telescope structural model

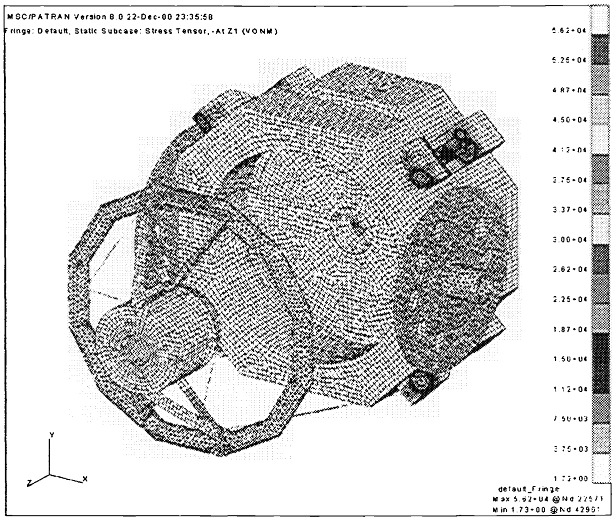

Fig. 12 – Element stress for gravity load applied along y axis, telescope at 90°.

system: for the mirror 2D solid plate (CTRIA3 elements from NASTRAN source code) elements have been used, while for the support system the BAR2 elements have been chosen, capable to bear only axial loads. The instrumentation has been introduced as suspended masses, with appropriate inertia moments with respect the x, y and z-axes. The pillar has been modeled with solid hexahedral 2°order p-elements, and has been fixed to the ground. The pads under the baseplate have been modeled as springs: twelve springs whose stiffness has been computed in order to give the same tilt stiffness with respect to the baseplate of the real hydrostatic system. The secondary mirror and its support structure has been modeled as it has been designed, while the two hexapod system has been introduced as a cylinder of appropriate stiffness. The rest of the structure has been modeled as much as possible similar to the mechanical design. The telescope model is mainly composed of plates elements (CQUAD4), capable of bending and membrane behavior. The whole model consists of 66224 nodes and 81180 elements. The gravity load has been considered with the telescope at 0° and 90°, while the wind has been considered as acting at the worst case, i.e. telescope at 45° with wind screens at ALT axis. Fig.12, 13, 14 show some of the results of the structural analysis.

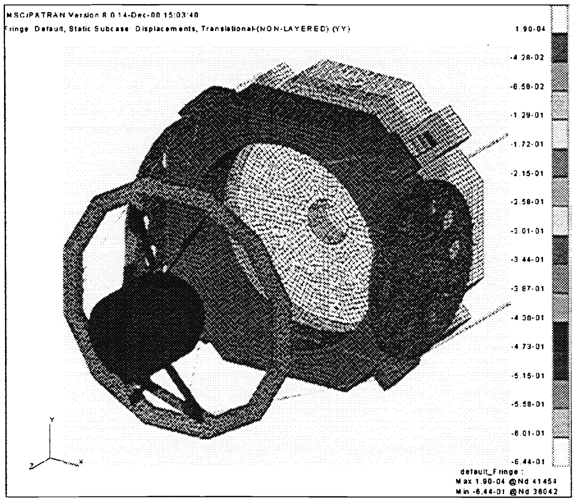

Fig. 13 – Deformation along y axis for a gravity load applied along the same axis-units are mm

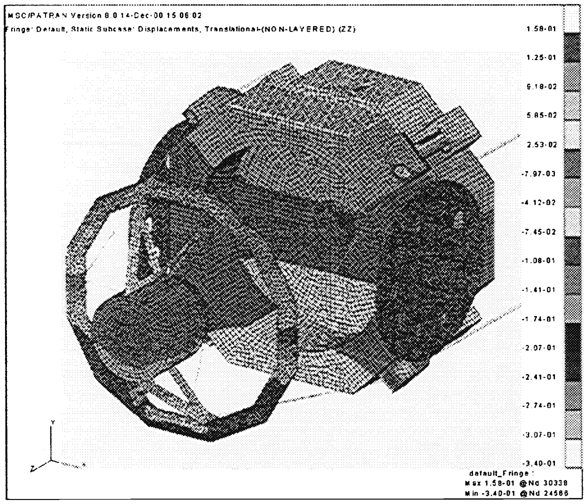

Fig. 14 – Deformation along z axis for a gravity load applied along the y axis-units are mm

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