The M1 Cell-M3 Tower of the VLT Design Overview and Manufacturing Progress

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Introduction

The primary mirror cell and the primary support system of the VLT have to fulfil stringent requirements. The thin meniscus blank demands a high-precision support system and good structural stiffness. Despite its moderate thickness, the weight of the primary mirror exceeds 23 tons. To be compatible with the overall VLT telescope design, which has been optimised to give a high first eigenfrequency of the tube, the design of the M1 cell must be a light but stiff structure. In addition, the primary mirror support system has to be able to cope with the inevitable deflection associated with the large dimensions. Preliminary studies showed that a space frame of approximately 10 tons weight, together with an appropriate hydraulic support system, would be suitable to support the primary mirror of the VLT.

The M1 cell forms part of the subassembly called M1 Cell-M3 Tower, and comprises, in addition to the primary cell and tertiary mirror supporting tower, the safety and handling support system of the primary mirror, the cooling system for the primary mirror, and the complete control electronics.

In April 1993, following preliminary feasibility studies, ESO awarded competitive design and development contracts to two European consortia, leading to a complete design of the M1 Cell-M3 Tower, and to a reduced scale mock-up of the M1 support system with actual size prototypes. The design of the French consortium composed of GIAT Industries – Branche Gitech, and SFIM Industries was finally selected by ESO, and a contract for the construction of this unit was awarded to the same consortium in February 1995. The major characteristics are described here, together with the summary of the manufacturing status.

M1 Cell Design and Construction

The design of the M1 cell is based on the possibilities offered by laser cutting and welding technology of which GIAT Industries is a leader in Europe. The technology allows the manufacture of very complicated structures starting from thin metal sheets. It is possible to obtain large beams with very thin walls and internal reinforcements which is not possible when using standard profiles. This possibility is extensively exploited in the M1 cell design to generate the variable section profiles used in the 12 radial rafters, and the complicated structures on which the mirror supports are mounted. The various faces of the structural beams and boxes are cut out from selected metal sheets in the desired shape by a computer guided infrared laser beam. The precision of the cuts is such that, after manually pre-assembling the beams, it is possible to weld them in an automatic mode along the seam without any fillet material. A minimum amount of heat is introduced into the metal, and the residual stresses are low, which is advantageous for the dimensional stability.

In summary, the laser technology results in the following advantages for the design and the construction:

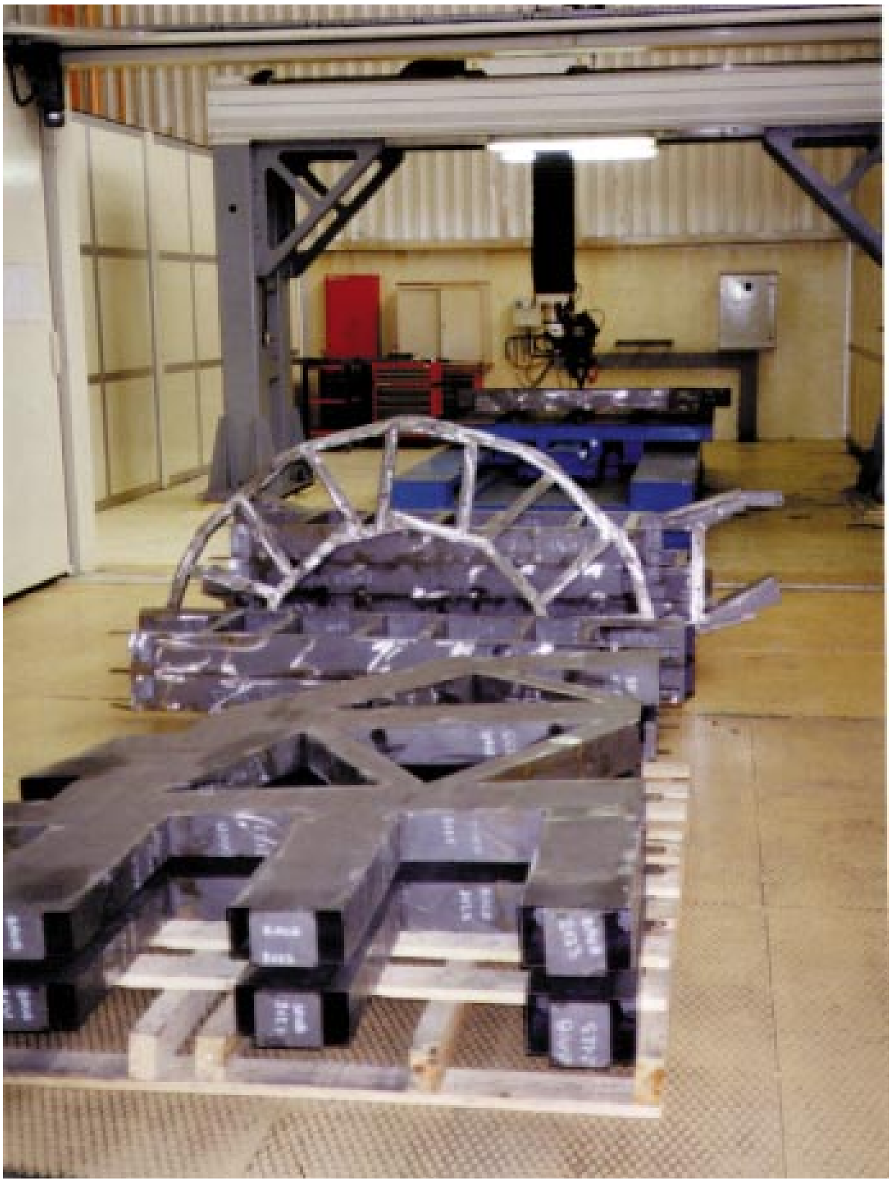

Figure1: GIAT laser welding shop with preassembled parts of the cell.

Figures 2a and 2b: The M1 cell.

• absence of complex structural nodes requiring complicated cuts and welding,

• optimum utilisation of the steel with the use of thin sheets and tapered sections,

• excellent dimensional stability,

• larger internal space for the installation of equipment and better access than in a conventional space frame structure,

• the laser cutting and welding process, being computer controlled, is more economical for building four units of the M1 cells than standard construction methods. (See Fig.1.)

The M1 cell resembles a truncated cone with the upper surface having a diameter of approximately 10 m, and a thickness of 2.8 m. There are twelve tapered radial rafters, each of which extends from one of the attachment points to the telescope at the edge to three annular belts (rings) at the centre. Two of these belts are used for the M3 tower and its rotating stage, and the third for the Cassegrain instrumentation. All the assemblies have internal reinforcements to stiffen the thin walls. The top surface of the M1 cell is made of 7 concentric rings which have been manufactured using laser technology and are used for mounting the axial and lateral

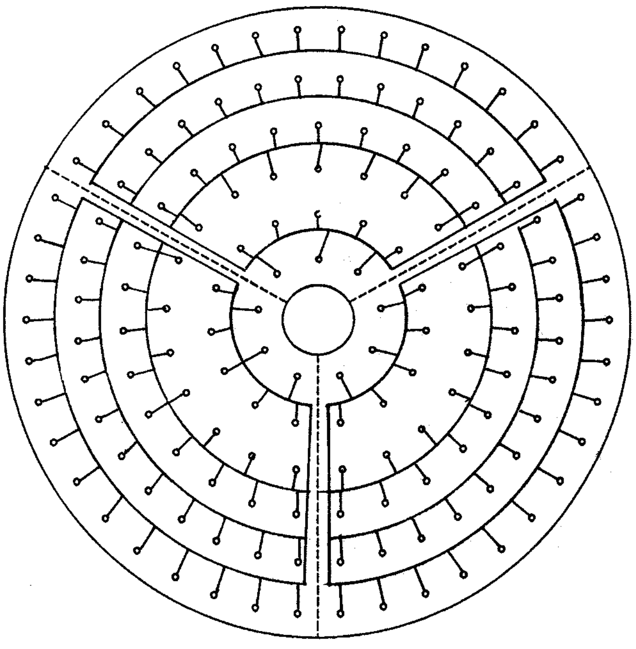

Figure 3a: Topology of axial support hydraulic circuits.

Figure 3b: Passive axial support prototype.

supports. The most external ring is used as base for the lateral M1 supports, while the 6 internal rings, resembling ladders, are used for the M1 axial supports, and for the safety and handling system supports. The thickness of the plates used in the ladders and their cross sections are variable, increasing from the centre to the periphery. (See Figs. 2a and 2b.)

The axial supports are positioned in the cut-outs of the ladders by interfaces allowing the fine adjustment of the support position. The position of the cross beams connecting the rafters and contributing to the general stiffness of the M1 cell has been optimised, as far as possible, to leave free space for the various pieces of electromechanical equipment. These include the electronic cabinets of the M1 Cell-M3 Tower and the Cassegrain instrumentation, and the various hydraulic components of the M1 hydraulic support system. It is worth mentioning here that the final mass of the M1 cell is approximately 10.5 tons, while its first elastic mode, once fully loaded and mounted onto the telescope exceeds 14 Hz. Its stiffness is such that the rigid displacement of the primary mirror when moving from zenith to horizon is only a few tenths of a millimetre.


Figure 4: Active axial force actuator.

The M1 Support System

The axial support system comprises 150 axial support points on 6 concentric rings, which combine a passive hydraulic pad and an electromechanical force actuator. The hydraulic pads, connected in three hydraulic sectors, act like astatic levers, supporting the mirror weight while removing the gravity deflection. The force actuators are used for active optics correction by adding or subtracting a force to the fraction of the mirror weight carried by each hydraulic pad. The lateral support system acts at the outer rim of the mirror by means of passive hydraulic pads.

The axial force is applied to load spreaders at the mirror back by means of a dedicated flexure, which also exercises a safety function against overload. The lateral supports use the same hydraulic pad design as the axial ones, but the load is carried by means of a special lever connected to the mirror by a cardan joint.

A considerable effort has been spent on the definition and the testing of the passive supports. The version finally selected makes use of two hydraulic chambers, one supporting the weight of the mirror, the other compensating the hydrostatic pressure generated when the telescope is tilted. The passive axial support is largely astatic to cope with the M1 cell deflection, and free from dangerous friction or hysteresis. The stiffness of the support is such that the first rigid axial mode of the primary mirror M1 on its supports exceeds 25 Hz, which is important for the dynamics of the telescope and for the resistance to wind buffeting.

During the design phase, much attention was dedicated to the study of the topology of the hydraulic circuits of the passive supports. The topology, together with the pipe diameter and the viscosity of the fluid used, influences the dynamics of the active correction and the resistance to wind buffeting on the primary. A good compromise was sought to be able to perform active optics correction with fast settling time as well as to be able to damp the effect of wind on the primary. A parallel connection between the passive supports was chosen together with the possibility of adapting the degree of connection between the hydraulic sectors to match the prevailing wind condition. The selected topology was chosen on the basis of dynamic simulations which included the dynamics of the mirror and of the M1 cell. (See Figs. 3a and 3b.)

As most of the wind energy is located in frequencies above 1 Hz, it is interesting in case of wind to reduce the bandwidth of the system to below this frequency. This is done by means of remotely operated valves installed in the external circumferential pipes which slow the movement of the oil as occurring during astigmatic deflection of the primary. In the event of wind excitation, this has the effect of stiffening the primary mirror by coupling it in the astigmatic mode to the M1 cell for high temporal frequencies without violating the principle of a kinematic mount.

Given the moderate thickness of the blank, the force actuators used for active optics correction must be extremely accurate. Their force resolution is 0.05 N as determined by the minimum amount of astigmatism which must be corrected. The required force range of 500 N pull and 800 N push force depends on various factors, including the final polishing accuracy of the primary mirror, the effort required to bend the primary mirror to Cassegrain shape, and the active optics forces.

Each of the 150 force actuators has its own microcomputer to control its function and to communicate with the Local Control Unit of the M1 Cell-M3 Tower by means of a dedicated bus. This minimises the cabling and increases the reliability of the system. The individual actuators are composed of an electromechanical part and an electronic part. The electromechanical part generates a force by the compression of a spring and transmits it to the shaft of the passive hydraulic support through a load cell of high resolution and linearity. The electronic boards are assembled inside a mechanical casing ensuring thermal conduction and electromagnetic shielding. The few watts of power dissipated are transferred by heat pipes from the casing to the M1 cold plate to minimise heat dissipation to the surrounding (see Fig. 4) .

The M1 Safety and Handling Support System

The behaviour of the M1 cell during an earthquake is influenced by the dynamics of the telescope structure. Response spectra analyses carried out with the complete telescope model have shown that a dedicated safety support system must be used in case of earthquake to restrain safely the primary mirror. The system uses radial and axial elastomer pads, mounted onto hydraulic jacks, which are pressurised if an earthquake is detected by an independent accelerometer.

The axial pads mounted below the primary mirror can also be used to lift the primary mirror above the M1 cell when removal is necessary for periodical recoating. This is done when the M1 cell with the primary mirror has been transported to the maintenance building using a special transportation carriage. Once the mirror has been lifted from its support system, an overhead handling crane installed in the Mirror Maintenance Building takes the primary and places it in the coating plant.

Primary Mirror Cooling

To reduce the mirror seeing, the primary mirror can be cooled to allow the temperature of the mirror to be as close as possible to the temperature of the ambient air at the beginning of the night and to follow its evolution during the night. The cooling is performed by means of a radiation cold plate located just below the M1 mirror and mounted on the M1 cell. The cold plate is realised by means of rolled aluminium plates on which copper tubes are fixed by brazing. The cooling fluid is provided through the telescope structure. The cold plate located approximately 20 cm away from the rear surface of the mirror is supported on the M1 cell by elastic dampers to avoid any vibration. The cold cavity between mirror and cold plate is closed by a soft rubber seal without contact to the mirror. Small fans in the cavity can be operated to move the air around mylar obstacles to avoid stratification and improving the cooling. Temperature sensors are fixed to the cold plate and to the M1 in order to control the cooling process.

Given the statistical distribution of the air temperature of the clear nights during the year at Paranal, it is expected that the M1 cooling system used in conjunction with the air conditioning in the enclosure and temperature prediction models will allow the temperature of the front mirror surface to be maintained within –1.0° C / +0.2° C from ambient for over 80 % of the total observation time.

The M3 Tower

The tertiary mirror of the VLT is installed on a tower which is attached to the M1 cell. The mechanical system of the M3 tower allows the focus of the telescope to be selected. The M3 tower is divided in two parts. The lower part, containing the rotating stage to shift between the Nasmyth A and B, is mounted on the M1 cell. The upper removable part extends through the central hole of the primary mirror and is connected to a flange of the rotating stage. The rotating stage makes use of a pre-stressed bearing and a worm gear drive.

A sophisticated control law copes with the friction in the system and ensures a good repeatability of the positioning. Once in the desired position, the tower is locked with a pneumatic brake. This solution, in conjunction with the use of aluminium for the superior part, allows considerable stiffness to be attained and assures the stability of the M3 position. The first elastic mode of the tower exceeds 20 Hz.

Given the dimensions of the VLT and the obvious difficulty of gaining access to the tertiary mirror, a motorised support system for the tertiary mirror has been included to fine tune its position remotely. In addition, the M3 can be moved outside the beam by a remotely operated stowing mechanism to allow the use of the Cassegrain focus. An Atmospheric Dispersion Compensator, when required by the Cassegrain instrumentation, can be installed inside the lower part of the rotating stage.

Manufacturing Status

The first M1 cell has now been completed. The cell was assembled on a dedicated jig at the St-Chamond factory of GIAT. The laser welded subassemblies, after having been annealed, were assembled from top to bottom on the jig and manually welded together. The manual welds were shot peened to avoid any risk of cracking. Once completely assembled, the M1 cell was turned and the various interfaces and reference points measured with the help of theodolites. Finally the flanges of the M3 tower and of the Cassegrain rotator adapter were machined. The M1 cell was then sand blasted and painted.

The second M1 cell is now in production. Most of the laser subassemblies have already been produced and assembly will start as required by the delivery plan.

Two M3 towers have been manufactured in parallel. The first one is ready to be integrated in the M1 cell while the second unit is used to perform parallel testing of the LCU. The support system of the primary mirror is now in serial production. The force actuators are produced by SFIM Industries in Paris while the passive supports are produced by GIAT in Tarbes. The first batch of supports is now available to start the system integration in the GIAT assembly hall at St-Chamond. The cold plate of the primary mirror and the heat pipes to cool the force actuator are also in production.

A complete cycle of testing is foreseen in Europe for the M1 Cell-M3 Tower. The testing foresees the use of a concrete dummy primary mirror to check the complete functionality. To install the mirror in the M1 cell, the M1 Handling Tool, to be eventually installed in the Mirror Maintenance Building in Chile, will be used. The tool has been designed by GIAT and its installation in the assembly hall is presently underway.

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