A Small Parallel Manipulator for the Active Alignment and Focusing of the Secondary Mirror of the VLTI ATS

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ABSTRACT

The paper describes the mechanism made for the 140-mm secondary mirror of the VLTI Auxiliary Telescopes. This mechanism consists of an hexapod parallel manipulator, capable of orienting its mobile base along all six degrees of freedom by means of six independent linear actuators.

The six linear actuators are attached to a base plate along the vertices of a regular hexagon. Each actuator pushes/pulls from the base plate an oblique leg to which it is linked by a flexible pivot. At the other end, the six legs are linked pairwise by flexible pivots to three points of the mirror cell, which can therefore be displaced to any position and angle by the combined motion of the six actuators.

An advantage of this configuration is that the vertical motion (used to procure the focus adjustment of the telescope) is obtained by a direct 1:1 action of all six actuators, without any coupling nor intervening lateral forces. Each actuator consists of a closely integrated system comprising a motor, a resolver (for the angular incremental measurement), a high precision screw with planetary rollers, and a bearing. A LVDT position detector provides the absolute position of each actuator. A standalone multi-axis digital controller board controls the hexapod.

Keywords: Parallel manipulator, hexapod, M2 unit, linear actuator

1. INTRODUCTION

In the framework of the Very large telescope (VLT) project, the European Southern Observatory (ESO) is building on Cerro Paranal (Chile) a multi-telescope optical interferometer called VLTI (VLT Interferometer) which will combine the capabilities of four giant 8-m telescopes with several (presently three) auxiliary 1.8-m optical telescopes on mobile bases.

The Belgian company AMOS is in charge of procuring the first three auxiliary telescopes and CSEM has been contracted for the development and supply of the mechanism required to position and align the secondary mirror (diameter 140 mm) of these telescopes (see Figure 1). This actively controlled mechanism shall provide a positioning capabilities along five degrees of freedom (the three linear axes plus tip and tilt angles) with a range up to 3 mm and an absolute accuracy of a few micron. The mechanism must be included within a cylindrical volume of 140 mm diameter and 200 mm height, and must also have high stiffness.

This mechanism produced consists of an hexapod parallel manipulator, capable of orienting its mobile base along all six degrees of freedom by means of six independent linear actuators. The particular configuration of this hexapod is called a type 6-3 parallel manipulator. An advantage of this configuration is that the vertical motion (used to procure the focus adjustment of the telescope) is obtained by a direct 1:1 action of all six actuators, without any coupling nor intervening lateral forces.

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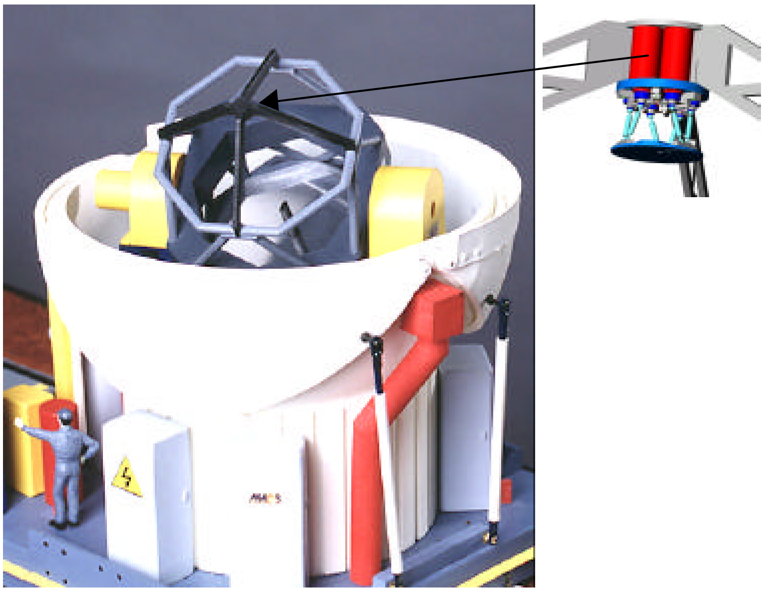

Figure 1 Picture of model showing the VLTI auxiliary telescope and the location of the secondary mirror which will be supported by the CSEM mechanism (by courtesy of AMOS).

2. MAIN SPECIFICATIONS

The main requirement for the secondary mirror mechanism are summarized in the following table.

Kinematic requirtements	**Specification**
Focus (z) range	± 1.5 mm for zero tilt and center, or ± 1.2 mm for any tilt or centering location within the respective ranges
Focus resolution	≤ 0.6 µm
Focus accuracy	≤ 6 µm
Focusing speed	≤ 6 µm/s
Center (x,y) range	± 0.7 mm
Center resolution	≤ 5 µm
Center accuracy	≤ 20 µm
Centering speed	≤ 10 µm/s
Tip-tilt range	± 300 arcsec
Tip-tilt resolution	≤ 5 arcsec
Tip-tilt accuracy	≤ 20 arcsec
Tip-tilt speed	≤ 10 arcsec/s
Cross-coupling	< ± 0.5 arcsec tilt by a 6 µm focusing step
Other requirements	
Envelope	Ø 140 x 200 mm cylinder
Mass	< 8 kg approximately
First eigenfrequency	> 220 Hz approximately

Table 1: Main specifications for the ATS secondary mirror mechanism

3. DESIGN DESCRIPTION

The fundamental choice for a kinematic mechanism capable of handling 5 DoF's is between a serial manipulator, in which each stage moves one DoF, and a parallel manipulator, i.e. an hexapod. Here the parallel manipulator solution is dictated essentially by two requirements:

– the small volume available for the mechanism
– the need of a very stiff and stable device.

Parallel manipulators can take a number of different configurations. The most conventional hexapod type comprises six legs with embedded linear actuators and had been initially considered - see the figure below.

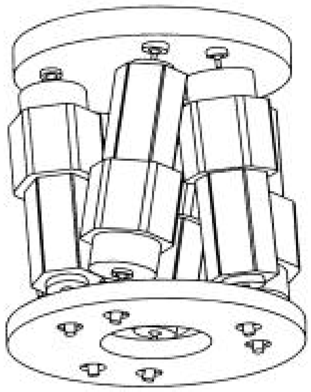

Figure 2 Conventional hexapod arrangement

However, this configuration has significant drawbacks for the present application. Because of the severe volume constraint, the arrangement of the six units would not be efficient with respect to kinematic characteristics because of the small angle at which they could be placed with respect to the vertical axis. Moreover, in this configuration the entire mass of the actuators is attached between its two hinges, thus affecting negatively the dynamic characteristics. These considerations lead to the configuration illustrated in figure 3.

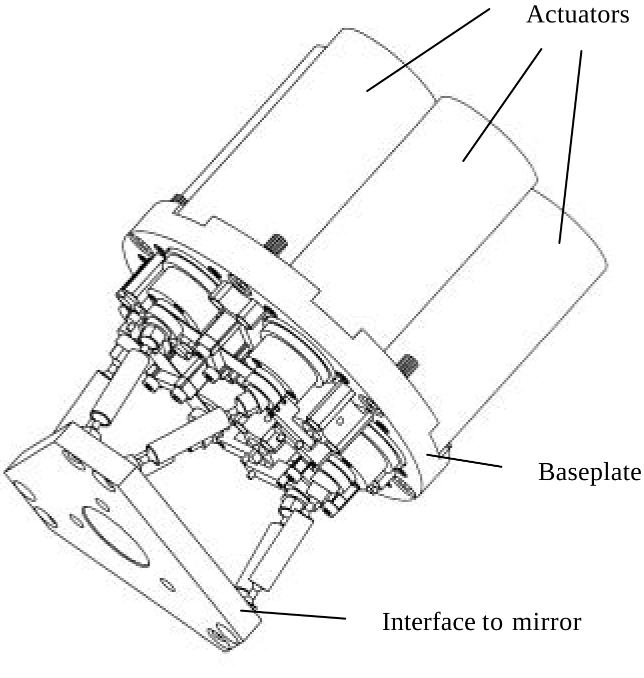

Figure 3 Design of the hexapod parallel manipulator.

The six linear actuators are attached to a base plate along the vertices of a regular hexagon. Each actuator pushes/pulls from the base plate an oblique leg to which it is linked by a flexible pivot. At the other end, the six legs are linked pairwise by flexible pivots to three points of the mirror cell, which can therefore be displaced to any position and angle by the combined motion of the six actuators. This particular configuration is called a type 6-3 parallel manipulator and has the advantage that the vertical motion (used to procure the focus adjustment of the telescope) is obtained by a direct 1:1 action of all six actuators, without any coupling nor intervening lateral forces.

An important and novel feature of this hexapod are special flexure blades which guide the parallel motion of the actuators, thus greatly increasing the lateral bending stiffness of the actuators and relieving the rod and screw sections inside the actuator cylinder from bending stresses and lateral forces.

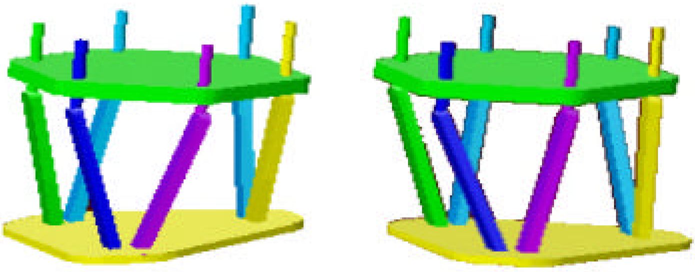

Figure 4 Computer simulations of the kinematics of the manipulator. The short vertical rods on the top represent the six actuators. Each actuator pushes/pulls from the base plate an oblique leg which has flexural hinges at both extremities.

The linear actuator used here was evolved from a previous application and consists of a closely integrated system comprising a motor, a resolver (for the angular incremental measurement), a high precision screw with planetary rollers, and a bearing. Additionally, a LVDT position detector on the hexapod baseplate provides the absolute position of each actuator. These linear actuators are also marketed separetely by CSEM as they provide an unique combination of advanced performances:

Linear range	4 mm
Absolute accuracy:	< 5 µm (without LVDT)
Resolution	≤ 0.2 µm
Stiffness	> 45 N/µm
Continuous load	100 N
Peak load	250 N
Backdriving load	> 150 N

Table 2: Actuator main performance values

Each actuator consists of a closely integrated system comprising a brushless motor, a high precision screw with planetary rollers, a bearing and an angular resolver/encoder on the screw shaft.

Figure 5 Linear actuator

4. CONTROL

For verfication purposes, the parallel manipulator as delivered by CSEM, is controlled by a multi-axis DSP-based Delta Tau PMAC board interfaced via a serial line to a PC. The PMAC board manages the actuator control while the software in the PC includes the kinematic model which convert high-level commands in the mechanism axes into actuator commands, and vice-versa for positions.

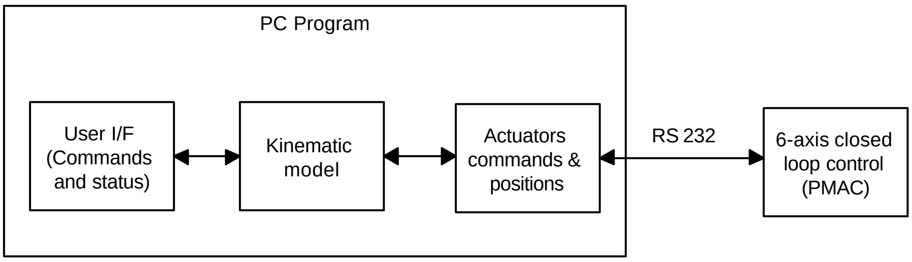

Figure 6 Actuator control

The controller programmed on the PMAC will be of PID type. The control logic will take advantage of the presence of both a motor sensor (encoder) on the motor axis and position sensor (LVDT) on the load. Tests with an actuator prototype have shown in particular that a position loop with the LVDT signal will ensure compliance of the command within the LVDT accuracy and with a resolution of 200 nm. Placing the feedback sensor on the motor provides stable and accurate control of motor position. However, backlash prevents the actuator to reach the exact same position each time. Alternatively, closing the loop on the load sensor avoids backlash, but the dynamic behavior due to the backlash may make the system unstable.

To circumvent this issue the dual loop approach - Figure 7 - is chosen: the inner loop gets its feedback from the encoder and the outer loop from the LVDT. The PID functions are divided between the two loops: the function P and I apply to the outer loop, while D works on the inner loop.

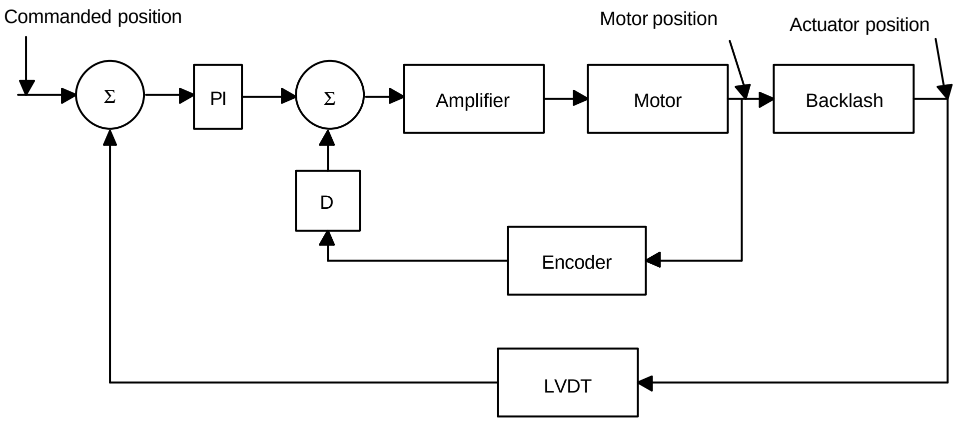

Figure 7 Dual loop control of single actuators

5. INITIAL TESTS

At the time of submitting the present paper only initial tests have been performed on the first assembled and calibrated mechanism (Figure 8).

Figure 9 presents some measurements of the absolute accuracy in focus over the entire range, with various initial alignment configurations.

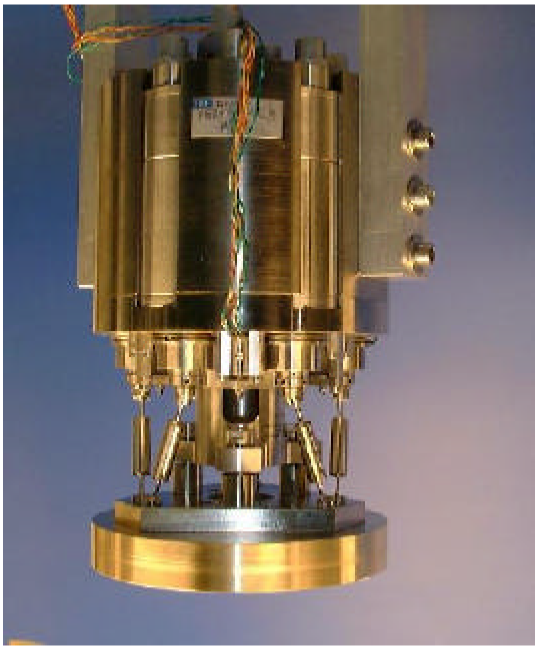

Figure 8 The assembled M2 Support parallel manipulator mechanism

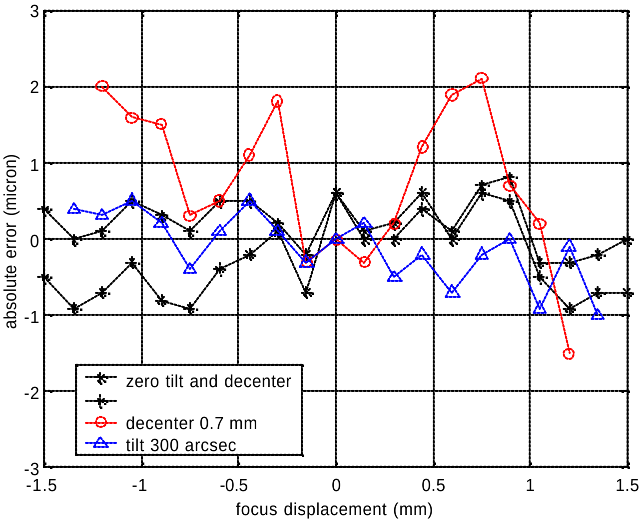

Figure 9 Typical absolute accuracy of focus positioning with various initial alignment configuration

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