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# The EMIR detector translation unit: a cryogenic high-precision 3-DoF parallel mechanism

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## ABSTRACT

The paper describes a 3-DoF translational (XYZ) mechanism for the main detector of the EMIR multi-object spectrograph, developed for the GTC telescope. This mechanism is designed for the cryogenic environment (77 K) and consists of a parallel manipulator with flexure joints, actuated by three identical and symmetrically located linear actuators.

**Keywords:** Parallel manipulators, hexapods, cryogenics, linear actuators, GTC

## 1. INTRODUCTION

Following a call for tender by the Institute of Astrophysics of the Canaries (IAC), CSEM was granted a contract for the procurement of a high precision 3-axis translation stage that will be a main component of the EMIR infrared spectrograph currently being developed for the GTC 10.4-m telescope on the island of La Palma.

As for all modern infrared instruments, the optical train of EMIR is entirely confined in a large cryostat that will maintain it at a temperature close to 80 Kelvin (about –200 C). The core component of EMIR is its infrared detector, which needs to be adjusted and moved during the instrument operation over a range of a few millimeters along three orthogonal axes, and with an accuracy of about 100 nanometers.

The translation mechanism specified for this function, hereafter called DTU (Detector Translation Unit), has to provide three translation axes (X,Y,Z) but also avoid any tilt and rotation cross-coupling. This latter requirement, in particular, led to the design of a 3-axis parallel mechanism, based on kinematic principles similar to those of the Delta manipulator.

## 2. DESCRIPTION

The parallel mechanism that translates the actuators' action into orthogonal motion of the target plate is a novel design developed by CSEM. The specific geometry of the parallel mechanism was chosen to provide optimal translational accuracy at the detector support based on the achievable performance of the actuators. The mechanism is actuated by means of three stepper-motor leadscrew actuators. The actuators use a combination of commercial and custom components, and were specially designed, built and tested under cryogenic conditions by the company Energen, Inc. in the USA.

All kinematic links are consist of flexures, and strict manufacturing tolerances ensure optimal analytical predictibility between the motion of actuators and that of the detector support.

A suite of dedicated control electronics drives the mechanism. The core of this electronics suite is a Microchip dsPIC processor, which handles the closed-loop behaviour of the three actuators as well as all of the kinematic transformations. The DTU control unit communicates by serial line with the main CPU of the EMIR.

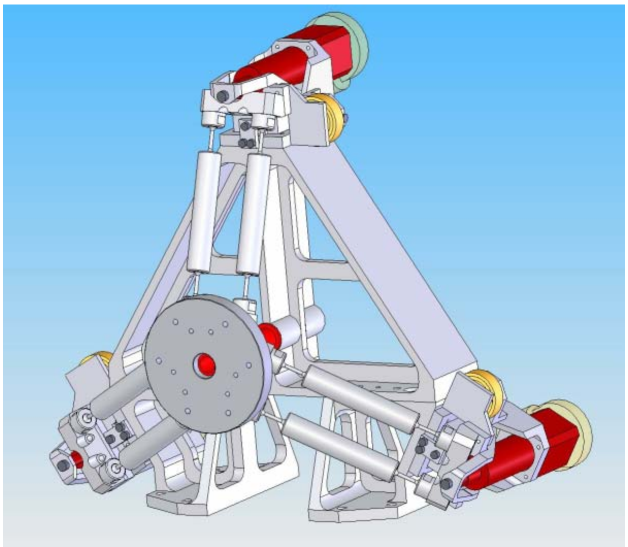

Fig. 1. CAD view of the DTU: the three actuator axes are parallel to one another. The kinematic structure translates independent displacements of the actuators into purely translational XYZ displacement of the mobile target.

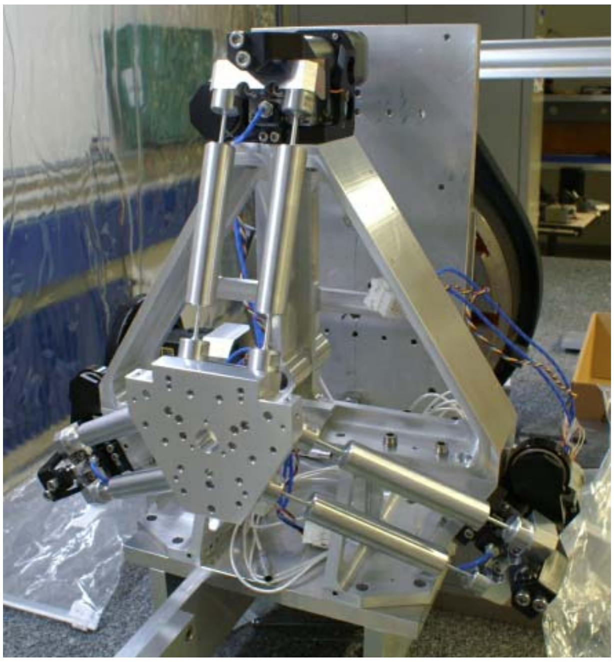

Fig. 2. First assembly of the DTU. The parts were subsequently anodized black to minimize light reflection during operation of the EMIR.

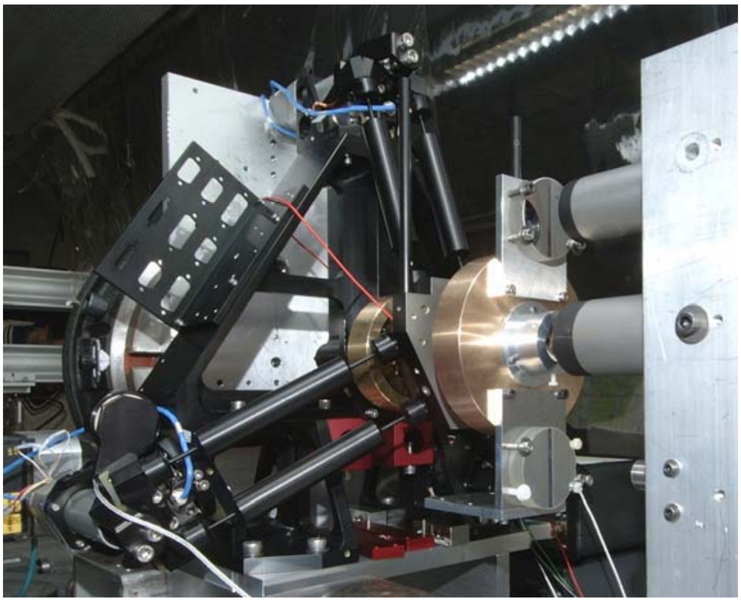

Fig. 3. The DTU during kinematic tests at ambient temperature: two autocollimators, a corner cube/rectitude sensor and an interferometer are used for concurrent monitoring of all 6 degrees of freedom of the mobile target.

At the time of writing this paper, testing was still in progress. The following performance values are expected.

| **Kinematic requirements** | **Performance** |
|---|---|
| Focus (z) range | ± 2 mm, |
| Focus resolution | ~ 1 µm |
| Focus repeatability | ≤ 5 µm |
| Focusing speed | > 1000 µm/s |
| Center (x,y) range | ± 0.4 mm |
| Center resolution | 3 µm (large displacements), 0.3 µm (for displacements < 50 µm) |
| Center repeatability | ≤ 9 µm (large displacements), ≤ 1 µm (for displacements < 50 µm) |
| Centering speed | > 400 µm/s |
| Cross-coupling | < 200 µrad tilt over the entire XY range, negligible rotation |
| Other requirements | |
| Envelope | Ø 450 x 450 x 230 mm |
| Mass | approximately 11 kg |

## 3. ACTUATORS

The actuators for the DTU consist of three linear translation systems qualified for high accuracy and 77 K operation by Energen, Inc.. Each translation stage is a load-bearing one-dimensional linear system, with capacitance position sensors and computer control through a serial interface.

The motion is guided by a linear guide, on cross roller bearings that are dry-lubricated to ensure smooth motion, with extremely small crosstalk errors and reliable cryogenic operation.

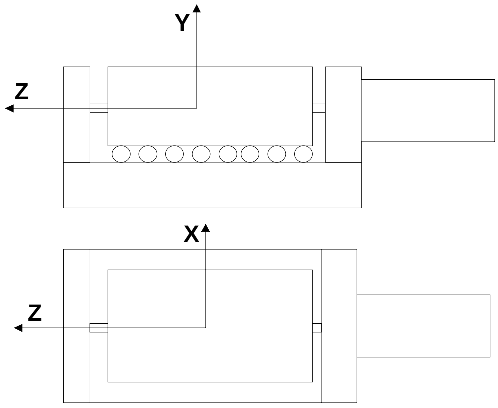


Fig. 4. Concept for the DTU linear actuator.

The actuators are driven by a commercial off-the-shelf integrated stepper motor and leadscrew, provided by UltraMotion, Inc.. The mechanical interface is designed to be compatible with the load and base.

Capacitance position sensors are used to measure and control the position of the stages. These sensors are cryogenic temperature capable and have a resolution better than 0.25 µm. Additionally, two Baumer My-Com A precision contact switches limit the operating range within the desired 7 mm.

Cabling is suited for cryogenic environment using PTFE insulated silver plated copper wires.

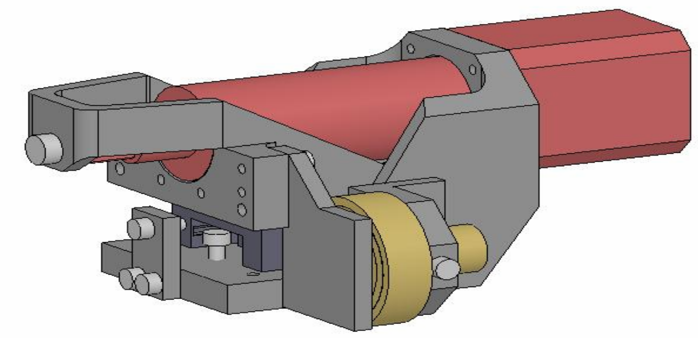

Fig. 5. CAD view of the DTU actuator. Note the capacitance sensor, located off the actuator axis.

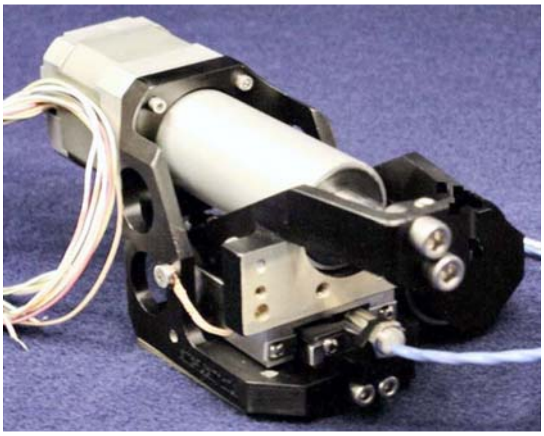

Fig. 6. Photograph of a DTU actuator.

| | |
|---|---|
| Linear range | 8 mm |
| Absolute accuracy: | < 2 µm |
| Resolution | 0.5 µm |
| Stiffness | ~ 5 N/µm |
| Continuous load | > 30 N |

Table 1. Actuator performance, as verified under both ambient and cryogenic conditions.

## 4. CONTROL

A dedicated suite of control electronics drives the mechanism. Its core is a Microchip dsPIC processor, which handles both closed-loop control of the three actuators and all kinematic transformations. The DTU control unit communicates by serial line with the main CPU of the EMIR, and has one RS-422 differential input channel for synchronization.

This controller uses the capacitance sensors for feedback control of the translation stages.

One controller has the ability to both address each stage individually and operate the three stages simultaneously. Its embedded software also handles inverse and forward kinematic calculations, which allow the user to command either direct actuator displacements or the resultant XYZ displacement of the EMIR detector.

Limit switches of each actuator are monitored to avoid overrun conditions along the Z direction and a lateral end stop mechanism is integrated to limit the lateral travel. The temperatures of all actuators are also periodically monitored .

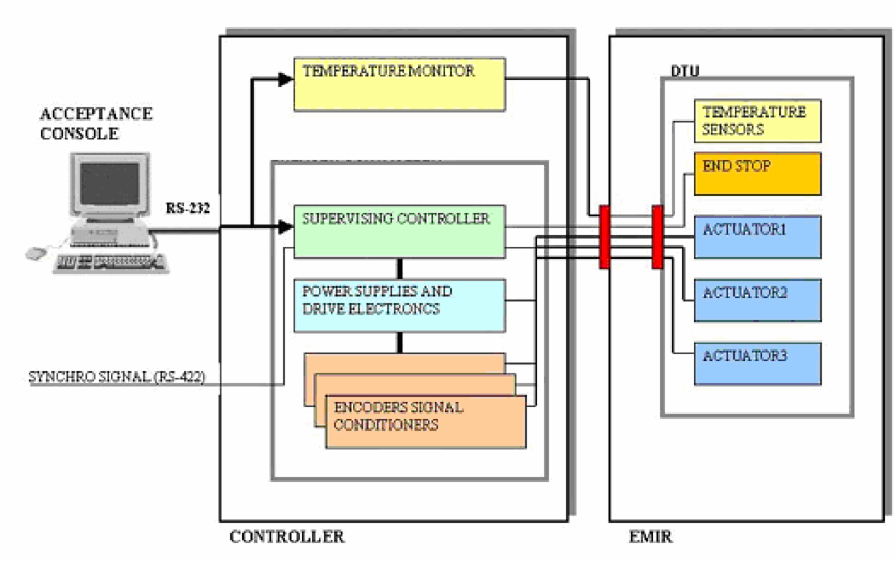


Fig. 7. General schematic of the DTU control.

## 5. ACKNOWLEDGEMENTS

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