Innovative Relocation System for Enclosures for MROI Array Telescopes.

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ABSTRACT

Magdalena Ridge Observatory Interferometer (MROI) comprises an array of up to ten (10) 1.4m diameter mirror telescopes. Each of these ten telescopes will be housed inside a Unit Telescope Enclosure (UTE) which can be relocated, with the telescope inside, to any of 28 stations arranged in a "Y" configuration. These stations comprise fixed foundations with utility and data connections. There are four standard array configurations, the most compact of which one has less than 350 mm of space between the enclosures.

This paper describes the relocation systems that were evaluated, including a rail based system, wheels or trolley fixed to the bottom of the enclosure, and various lifting mechanisms, all of which were analyzed to determine their performances related to the requirements. Eventually a relocation system utilizing a modified reachstacker (a transporter used to handle freight containers) has been selected. The reachstacker is capable of manoeuvring between and around the enclosures, is capable of lifting the combined weight of the enclosure with the telescope (40tons), and can manoeuvre the enclosure with minimal vibrations. A rigorous testing procedure has been performed to determine the vibrations induced in a dummy load in order to guarantee the safety of optics that must remain on the nasmyth table during the relocation.

Finally we describe the lifting system, constituted by hydraulic jacks and locating pins, designed to lift and lower the enclosure and telescope during the precise positioning of the telescopes in the various stations.

Keywords: dome, array, interferometer, relocation, transporter.

1. INTRODUCTION

The Magdalena Ridge Observatory is sited on South Baldy, part of the Magdalena Ranger District of the Cibola National Forest in central New Mexico. A part of the observatory will be a long-baseline imaging interferometer, the Magdalena Ridge Observatory Interferometer (MROI). This will comprise an array of up to 10×1.4m-diameter "unit" telescopes that can be arranged in four different configurations. All the configurations are "Y" shaped, they differ in arm length.

The unit telescope will utilise an elevation-over-elevation mounting, and will deliver a collimated beam of starlight of diameter 95mm, which will be fed out horizontally towards a beam-combining laboratory located near the centre of the array.

Each unit telescope will be housed within a Unit Telescope Enclosure (UTE). The MROI UTE will have not only the purpose to protect the telescope from the surrounding environment, but also to allow its change of location along the array as it will be directly involved into the relocation activities.

The UTE indeed shall be capable of being relocated to any of 28 fixed stations, whose pattern can be seen in Figure 1. Moreover during the relocation, the telescope will be attached to the enclosure and retained within it until the whole enclosure/telescope system has been moved to a new location. This is so as to protect the telescope from the environment during also the relocation procedure and to avoid the delays and risk to both the telescope and the enclosure which would be entailed in removing the telescope from the enclosure at the beginning of the relocation and re-inserting the telescope back into to the enclosure at the end of the relocation procedure.

It is to be noticed that the length of the array arms varies from about 23m minimum in the close-packed array up to about 200m in the widest array configuration.

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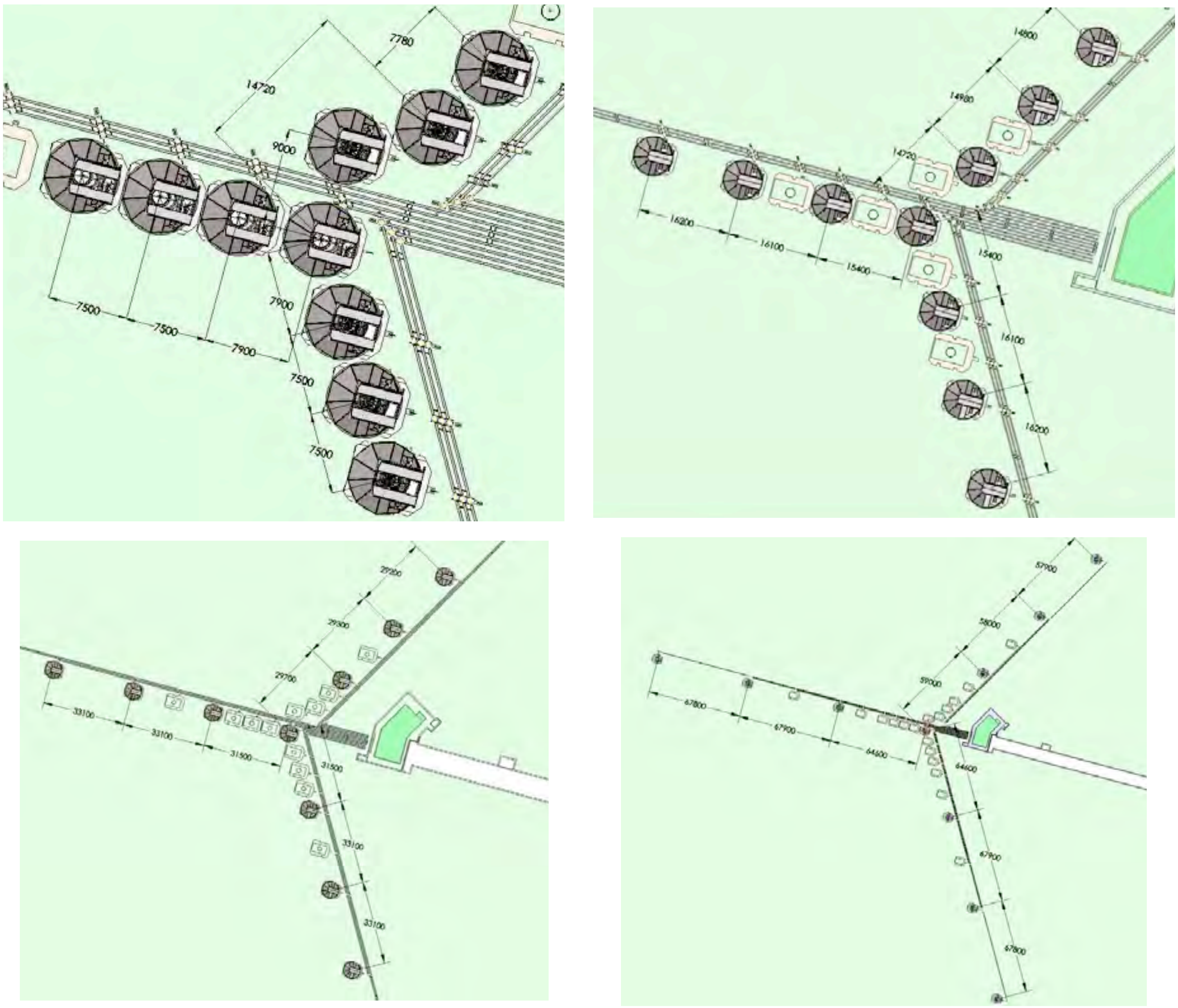

Fig 1. MROI Array configurations

The close-packed configuration represented a critical issue in the development of the design due to the narrow span between adjacent enclosures, which clearly had impacts on the accessibility of the enclosures as well as on the safety, during relocation manoeuvres and above all on the mutual optical obstruction.

Besides the standard performances that are usually required to an enclosure (i.e. structural resistance, structural stiffness, thermal insulation, air treatment during daytime etc.) the driving issues in the design of the MROI-UTE have been its transportability and the mutual optical obstruction when the array is in the close-packed configuration.

Both these aspects have led to an innovative compact and light-weight enclosure design, so to shrink its overall dimensions as adherent as possible to the telescope.

The present paper focuses specifically on the relocation process challenges necessary to move a UTE with its telescope in another station of the array. In particular it highlights all the hardware elements employed during the relocation process: the transporter, the lifting system, the damping system and the safety device.

2. RELOCATION ENVIRONMENTAL CONDITIONS

The “Telescope Relocation Environment” is the environment in which a telescope and enclosure can be transported from one array location to another and in which the allowable mechanical, thermal and electrical stresses in all elements of the enclosure, telescope and relocation system are not exceeded. The condition are listed here below:

	TELESCOPE RELOCATION ENVIRONMENT
Time of day	Sun > 5 degrees above horizon
Air temperature	-5°C to +25°C
Air temperature rate of change	Unconstrained
Mean wind speed	0 m/s to 10m/s
Maximum wind gust	25 m/s
Wind gust profile	Unconstrained
Altitude	0m to 3,231m (0ft to 10,600ft)
Relative humidity	10% to 100%
Snow and ice load	Combined snow load and ice load < 50 kg/m2; Combined snow and ice load center of gravity <1.5m from center of enclosure.
Precipitation	< 2mm/hr
Earthquake load	Maximum acceleration less than 0.2g along any axis, in the frequency range 0.5 Hz to 100 Hz.

3. TRANSPORTER

3.1 Preliminary trade-offs

The first analysis performed by European Industrial Engineering (EIE) to choose the most suitable means to relocate the UTE with the telescope inside took into account important aspects such as safety, costs and technical requirements.

The safety regards the personnel involved during operations and, of course, the hardware. Obviously the environmental and site conditions affect safety because they have a practical influence during relocation operations. Road size, level and smoothness, wind speed and temperature can easily introduce further risks during relocation activities in a site like the one foreseen for the MRO Interferometer.

Costs involve not only the direct ones of the hardware necessary for relocation activities but also the costs necessary to prepare and carry out every single relocation process.

Technical requirements impose that the telescope needs to be protected as well as not exposed to a certain level of vibrations which could cause optical misalignment. In addition, during the positioning on the new station it is required precision during manoeuvres and certainly a good motion accuracy. Finally, the time to remove the telescope and install it in a different station without include the transport from old to new station should be within 1 hour which is very challenging.

The options examined as transporter means included five different design concepts. The four options discarded on the trade-off are reported below:

- tyre-motorized trolley,
- rail motorized trolley,
- motorized UTE on rail system,
- truck with trailer (2 options).

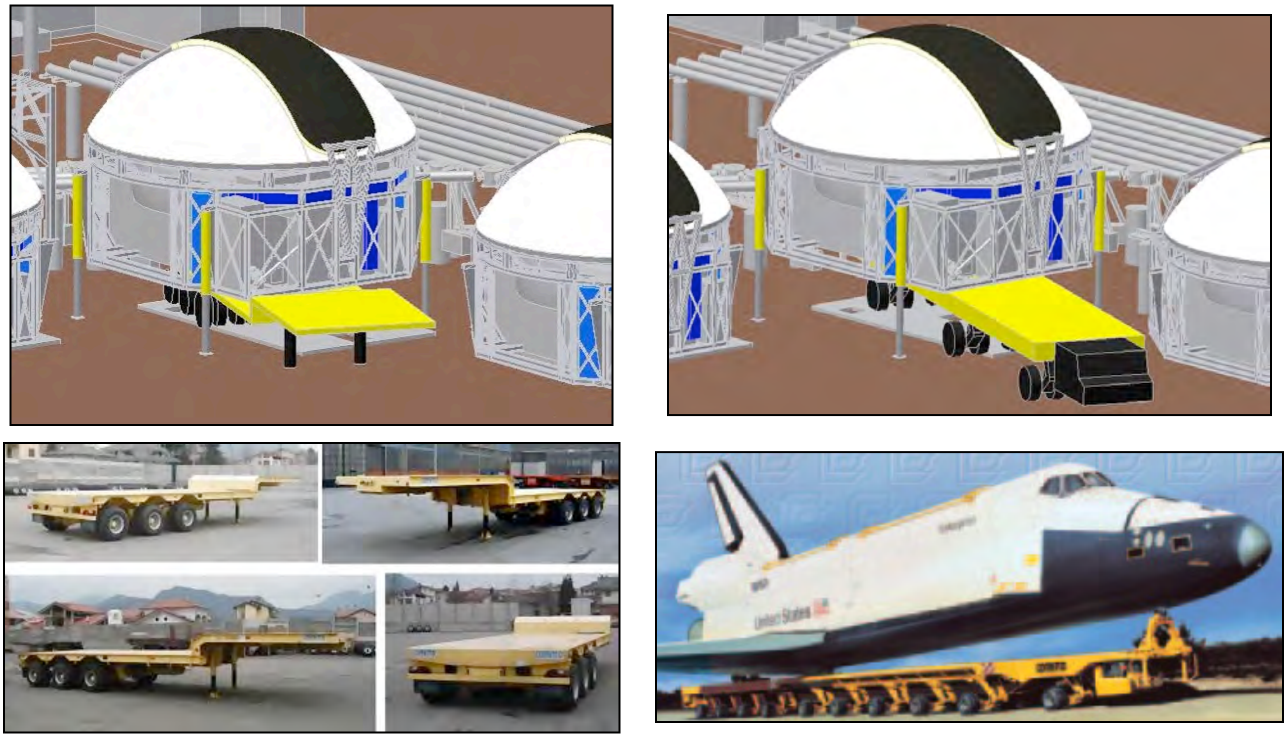

Fig 2. Packed array configuration, truck with trailer relocation studies

The first three options were discarded mainly for cost reasons. The tyre motorized trolley solution indeed would have needed an entirely custom design tailored while the railed solutions would have implied long alignment procedures although their precision would have been high. Finally, the truck with trailer highlighted serious manoeuvres limits.

3.2 Final choice

After examining all the relocation systems previously presented, the option with the a container handler commonly used on harbour (also known as reachstacker) with a tailored relocation frame has been selected as the most effective and safe for this specific application. On this base, several aspects have been analyzed regarding the use of this system and the main results are reported in the next paragraphs.

- **Handling capabilities**

The relocation of the various telescopes has been analyzed for all the stations of the array, identifying the approaching trajectories and the lifting manoeuvres needed. The following figures show part of the handling studies performed for several relocation manoeuvres.

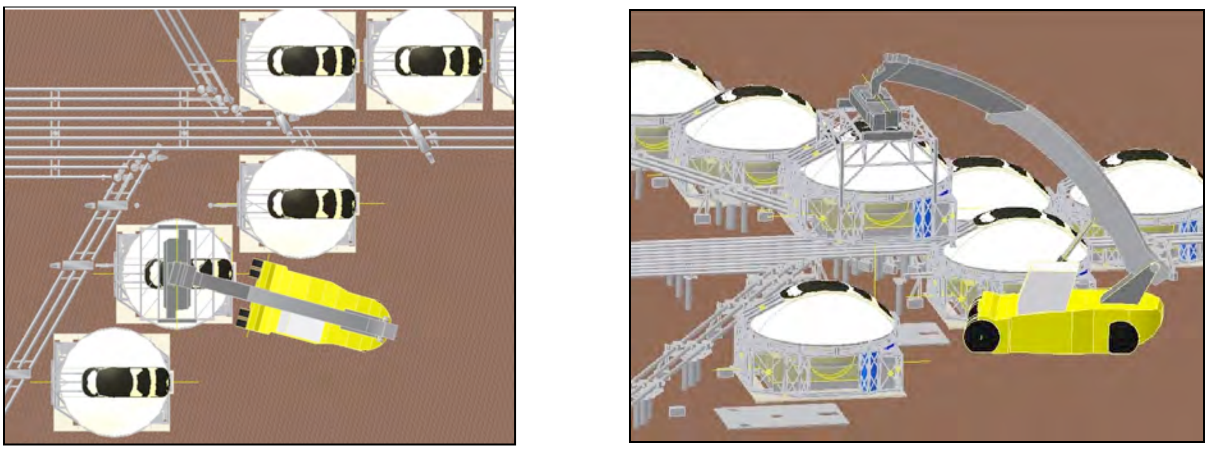

Fig 3. Packed array configuration, reachstacker relocation studies and relocation frame

The load capacity of this kind of transporter allows to handle and move the telescope within the enclosure along all 28 array stations. In particular the handling capabilities, permits to rotate and translate the UTE in order to obtain the best configuration for transport (in terms of centre of gravity of the assembly UTE,UT and transporter) and also to move the enclosures into the really narrow spaces of the array closed packed configuration.

- **Positioning capabilities**

The analyzed reachstacker, thanks to its frontal stabilizers, is capable to align and lower the UTE and UT with the suitable accuracy. Moreover, it is possible to easily interface the main control system of the transporter with a videocamera-based alignment system (dedicate inputs are already foreseen).
Due to the fact that all the translation are driven by hydraulic units commanded by proportional valves, the speeds of translation and tilt can be set and regulated.

- **Driving capabilities**

The hydrostatic transmission of the driving wheels allows to program the travel speed as well as the acceleration and deceleration ramps. This aspect improves the relocation operation in terms of safety because the human error is reduced simply setting the best configuration. The hydraulic transmission permits also to have different controlled speeds on the two driving wheels and this determines a reduction of the steering radius of the transporter. The absence of a gearbox allows continuous variation of the translation speed, avoiding problems of unwanted accelerations peak transmitted to the UTE and consequently to UT. This kind of transmission includes also braking capabilities so to prevent offhand stops even in case of emergency.

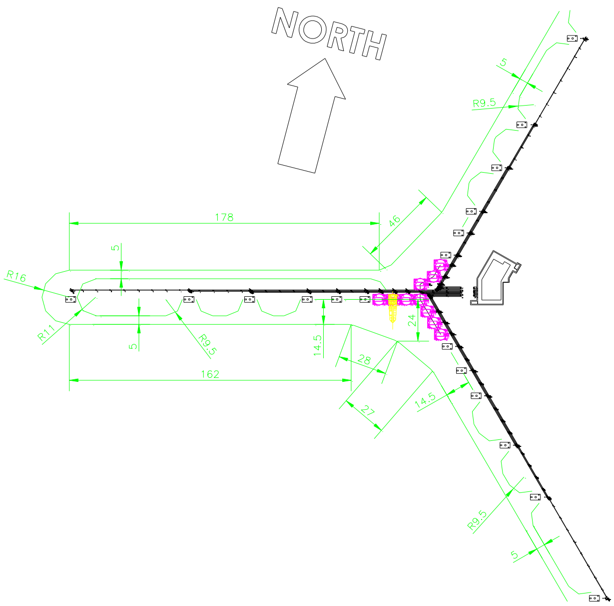

Fig 4. Relocation path along the array (green) based on reachstacker performances

- **Shock loads transmitted**

The reachstacker is equipped with a double damping system installed on the axles and on the boom. During the lifting and lowering of the UTE and UT, the use of the stabilizers permit to have the correct stiffness to avoid unwanted movements, but during the translation, the damping system will works to reduce the dynamic loads transmitted to the UTE and UT assembly.
Regarding the magnitude of the shock loads transmitted by the transporter to the UTE, due to difficult modelling of the transport process, a test has been performed with a simulated load. This, has been indeed the best way to assess the vibrations transmitted to the telescope. Moreover these tests allowed to assess the suitable road conditions, to keep shocks below the prescribed thresholds.

3.3 Transporter tests

In this specific matter the danger during transportation regards mainly the telescope. So, the telescope designer imposed the following vibration limits:

- 45 mg/($Hz^{1/2}$) for X and Y directions,
- 100 mg/($Hz^{1/2}$) for Z direction.

The tests performed were done by sampling vibrations with a series of accelerometer located in strategic points on the reachstacker.

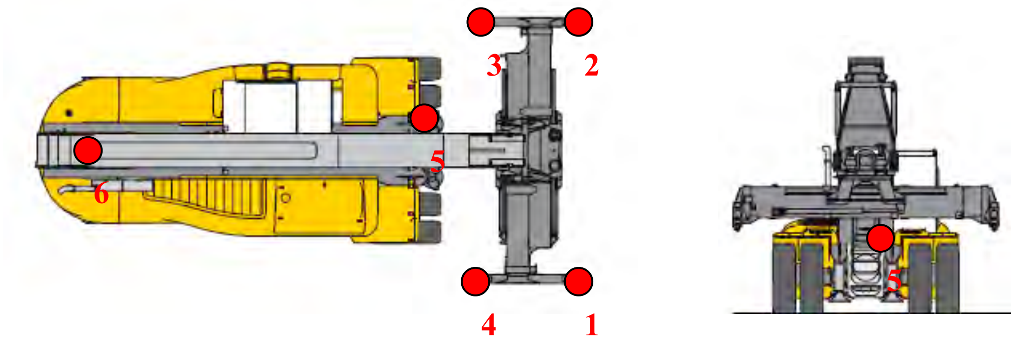

Fig 5. Accelerometer position during test performed

Different kind of tests were carried out in order to observe background noise during various motions and vibrations due to motion with full UTE/UT load.
Road smoothness and level conditions were tested to understand the entity of the impacts that could have been critical for relocation operations.

The following tests have been performed:

1. Tests without dummy load:
   - Background level: reachstacker engine on – no load – no handling operation;
   - Spreader lifting and lowering (1 meter) at minimum speed – no load;
   - Spreader lateral moving (1 meter) at minimum speed – no load;
   - Spreader arm extension and retraction (0,5 meters) minimum speed – no load;
   - Spreader clockwise and counter-clockwise rotations (30 deg) at minimum speed – no load;

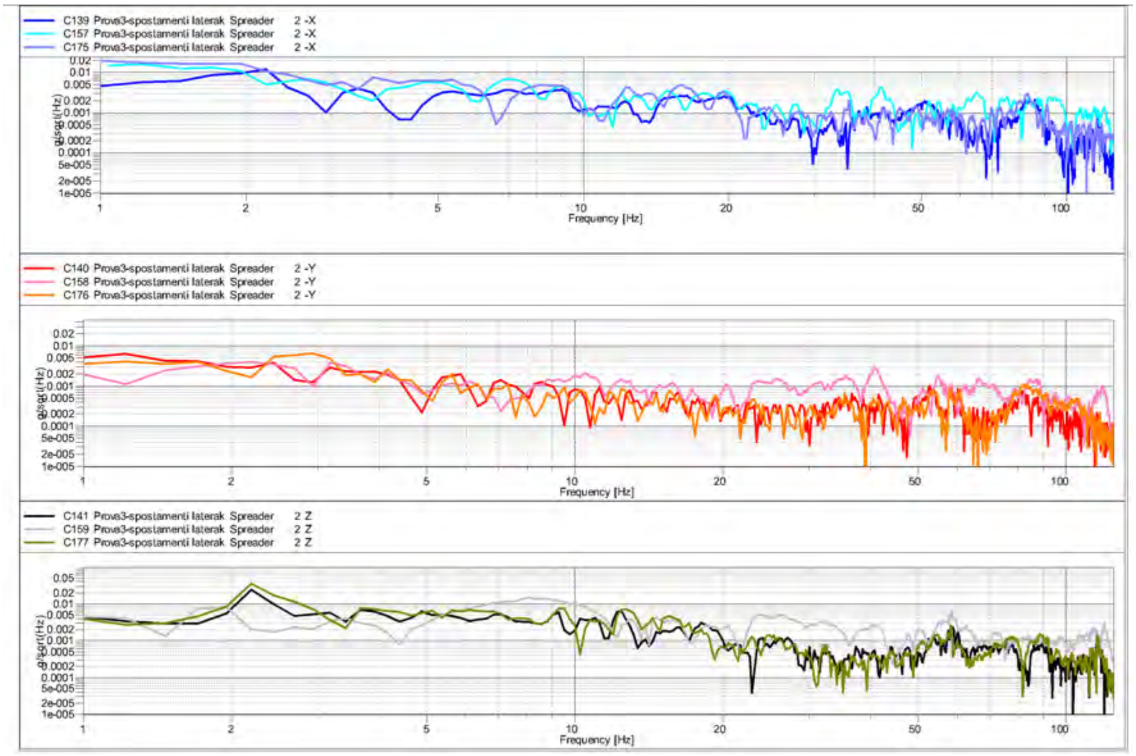

Figure 6. Point 2 instantaneous PSD square root during unloaded spreader lateral transition.

2. Tests with dummy load (20" loaded container, total weight of about 32 metric tons to simulate the weight of the telescope, enclosure and relocation interface frame):
   - Container locking, lifting, lateral moving, rotation, lowering;

3. Driving test on simulated different terrains with dummy load;
   - Driving tests on asphalt at different speed values;
   - Driving tests on gravel;

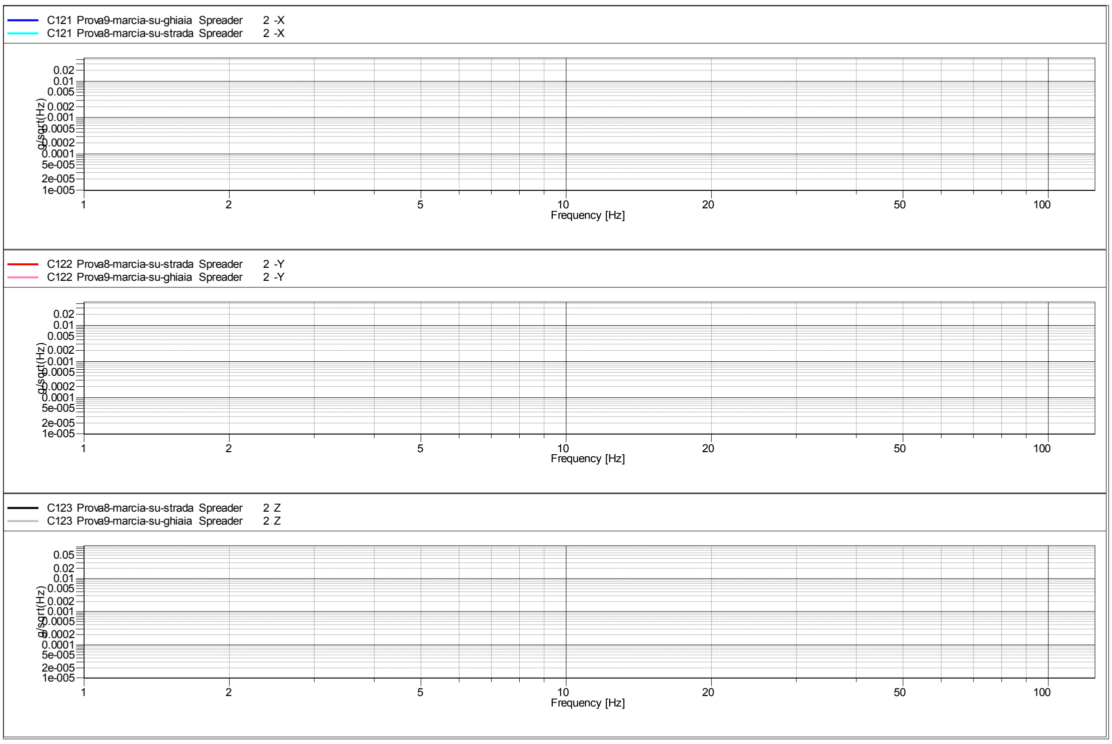

Figure 7. Point 2 average PSD square root during driving tests at minimum speed on gravel.

- Driving tests on simulated obstacles;

Fig 8. Series of obstacles positioned to assess road acceptable conditions

4. Lateral displacement tests.

The recorded data showed that the vibration level remains well below the prescribed limit in all the considered cases. Particularly tests pointed out that:

- in case of concentrated irregularities of the road which presents the height (in case of bumps) or the depth (in case of holes) lower than 20 mm, the effect on the vibrations measurements will be compatible with the requirements imposed. This is obviously valid if the driving speed will be lower than the limits which will be imposed (about 0,5 km/h during relocation).
- The driver will be necessarily properly trained. As a matter of fact, during the tests a change on the measurements has been recorder with different operators and thus, different skills.

- Using the reachstacker on a compacted soil is compatible with the requested performances for the relocation process; nevertheless a certain consistence shall be ensured by compacting the terrain with a steamroller. This is to avoid heavy degradations of the surface during the steering manoeuvres of the wheels over the road surface.

- At least one week before the relocation process a careful inspection of the reachstacker and the relocation path should highlight critical problems.

- The characteristics of the ground shall take into account also the payload induced on the surface by the transporter. In the actual configuration, the reachstacker has a total mass of about 73 metric tons and considering the load distribution when the UT plus UTE will be carried on, it is probable that the load on the four front wheels will exceed the 85 metric tons.

Fig 9. Reachstacker during tests without dummy (left) and with dummy load (right)

3.4 Finite Element Analysis

The relocation frame was deeply analyzed and optimized through finite element analysis (FEA). In particular a general model and some detail models were created to have the required confidence that the structure is able to guarantee safe relocation process in all environmental conditions.

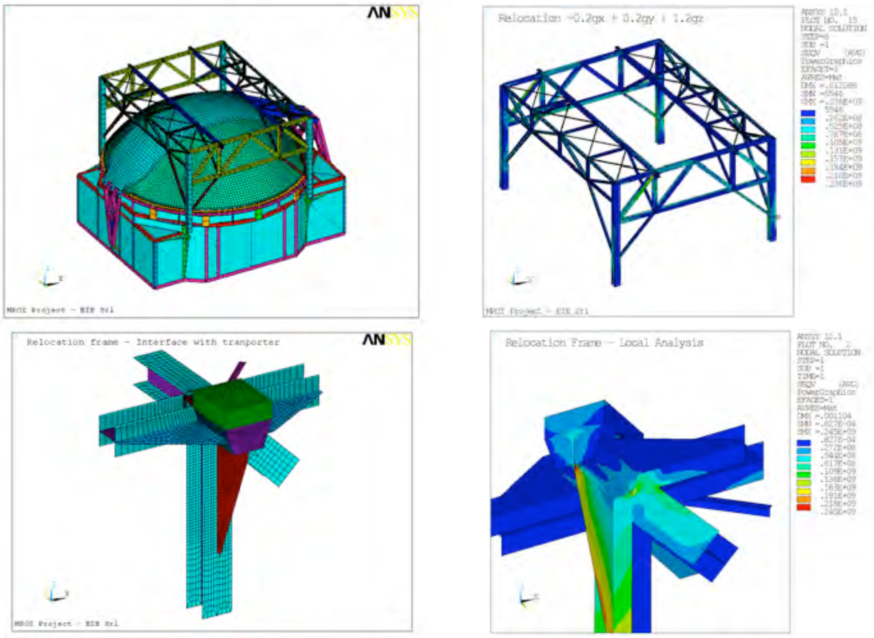

Fig 10. Relocation frame finite element analysis models and post processing

4. LIFTING SYSTEM

The very first stroke (150mm) of the lifting procedure represents one of the critical phases of the relocation operations as well as the last stroke (150mm) of the lowering phase. That is why a dedicated lifting system has been designed so to ensure a safer and more accurate process with adequate slow speeds during the lifting/lowering of the UTE from/to an array station.

4.1 Lifting devices

The accuracy and the smoothness required for the positioning of the UT and UTE over their foundation, highlights that the transporter can not be used for the first phase of the lifting and for the final phase of the lowering.
The lifting system consists in four hydraulic jacks which are positioned below UTE frame and controlled by an electric powered pumping unit. All the jacks are double effect type and the pumping unit permit to send the same flow rate to all the jacks, even when the loads supported by the four jack are different, so to ensure uniform movements in the four lifting point.
The safety of this specific system has been increased also by introducing non-return driven valves on each jack to avoid, even in case of a big oil leakage (eg due to a hose failure), a sudden lowering of the UTE with possible damages or shocks.
The stroke of this lifting system is 150 mm in order to implement suitable centring devices on the UTE (pins and bushes).
The four jacks have to be installed under the UTE frame before relocating the telescope, inside the dedicated foundation pits (see following picture). Than, the jacks can be adjusted in height to bring them all in contact with the lower UTE frame surface.

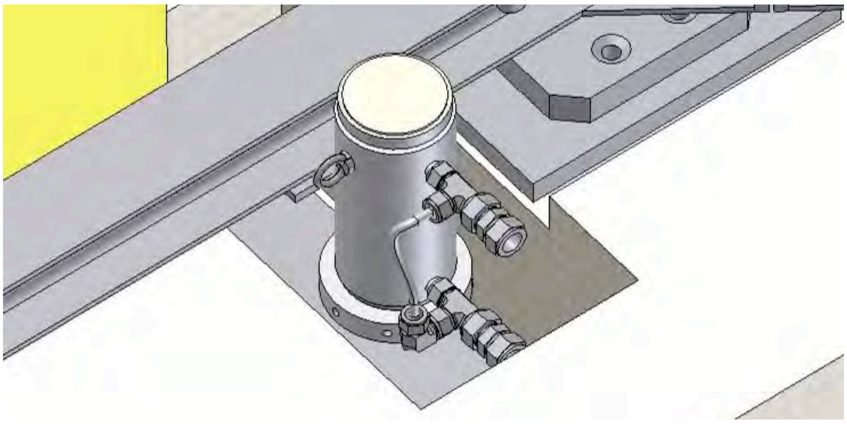

Fig 8. Hydraulic jack and insertion pit

4.2 Centring devices

The correct positioning of the UTE and UT on the foundations will be ensured by means of two centring pins attached to the foundations; their positions are shown in the following picture.

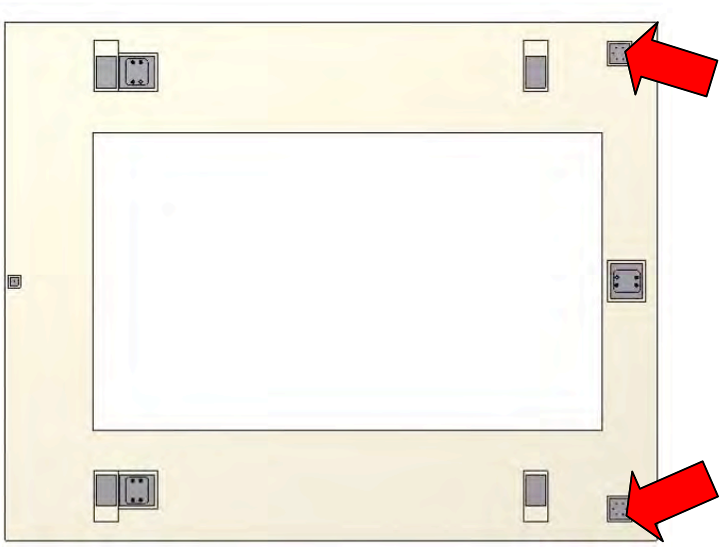

Fig 9. Centring pins interface plates

These pins have the scope to guide the UTE in the correct position during the lowering phase, with an approximation compatible with the correct functioning of the centring plug of the telescopes.
The centring phase for UTE has been studied in order to guarantee the adequate positioning of the telescope; for this reason UTE is provided with two pins (marked in the following picture in green) properly designed to guide the whole system in order to allow the telescope to engage properly its centring plug (following picture in blue and red).

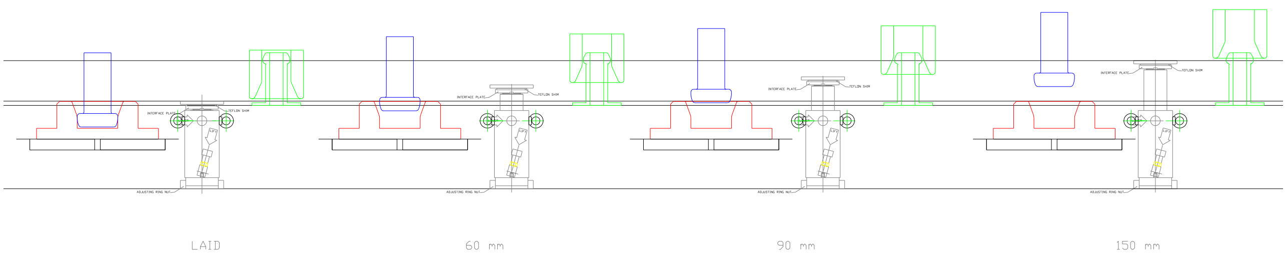

Fig 10. Centring phases represented by the functioning of the centring devices of the UTE and of the UT

The positioning accuracy of the reachstacker will permit to lay the UTE over the jacks with a precision of about +/- 15 mm, with a portion of the centring pins already inserted in the UTE bushes (see pictures below).

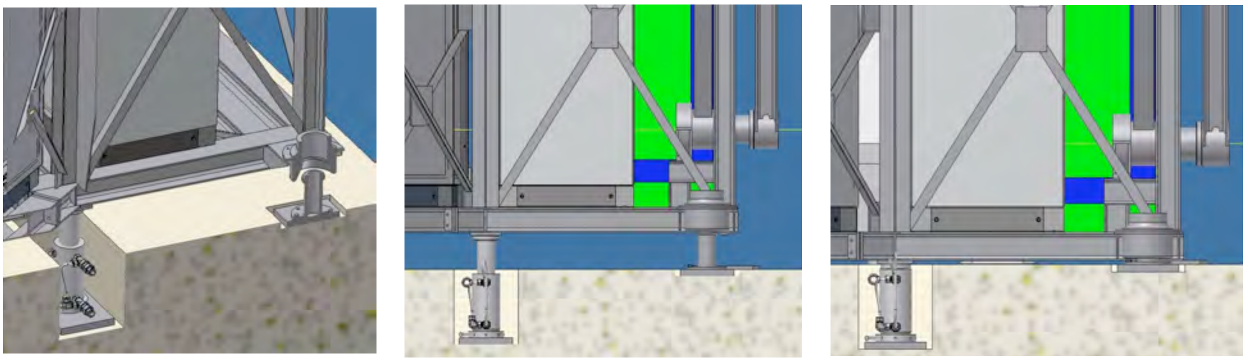

Fig 11. Isometric and side view of the hydraulic jack and UTE centring pin

5. DAMPING SYSTEM

The damping system has the scope to connect the UT to the UTE and at the same time to limit the vibrations induced by the transporter motion to the telescope. This system counts on four bumpers which are intended to bear the vertical loads and by four stabilizing bars which help to sustain the horizontal ones. The four dampers are located at telescope fork on the bottom sides; the four stabilizing bars are linked on dedicated interfaces placed over the telescope centre of gravity. All these components have been modelled and introduced in the global Finite Element Analysis (FEA) model in order to verify their effectiveness. The following picture shows the location of these devices inside UTE.

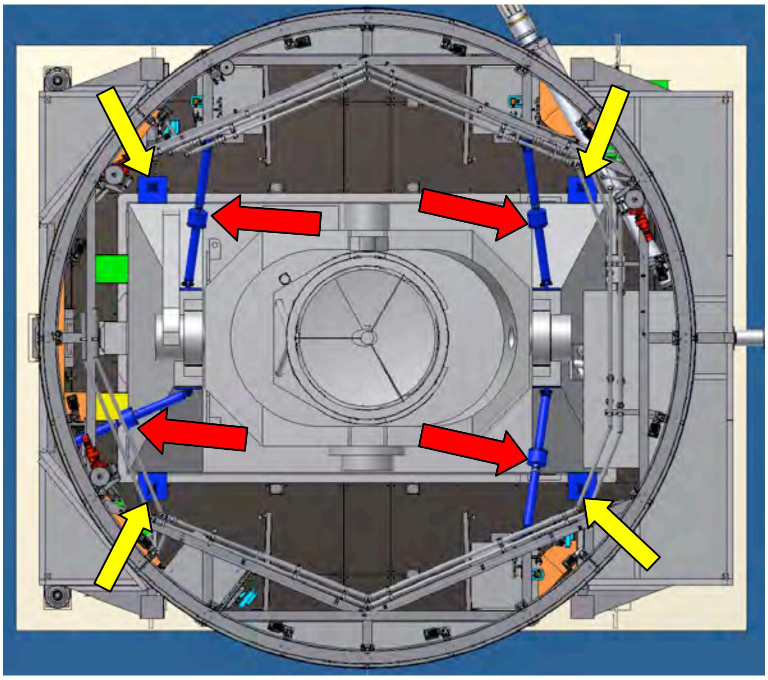

Fig 12. Dampers (yellow arrows) and stabilizing bars (red arrows)

5.1 Supporting dampers

Considering the level of the vibrations measured during the tests on the reachstacker the relocation interface structure, this device provide an adequate reduction of the shock loads applied to the telescope during the relocation.
This dampers are installed by means of interface plates and dedicated brackets shown in the following picture.

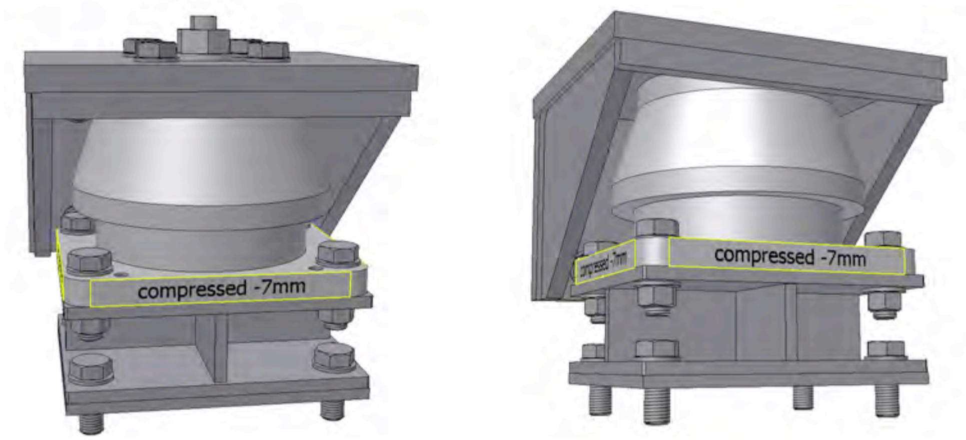

Fig 13. Damper with fixing plate and bracket

The damper has a preloading system in order to regulate the load borne by the damper itself and to limit its stroke. The damper preload is set to avoid any vertical displacement during the lifting of the UTE and UT.

5.2 Stabilizing bars

At an higher level of the structure of the telescope, four stabilizing bars are foreseen in order to avoid unwanted rotation of the UT during the relocation process. The configuration adopted for the stabilizing bars is shown in the next picture.

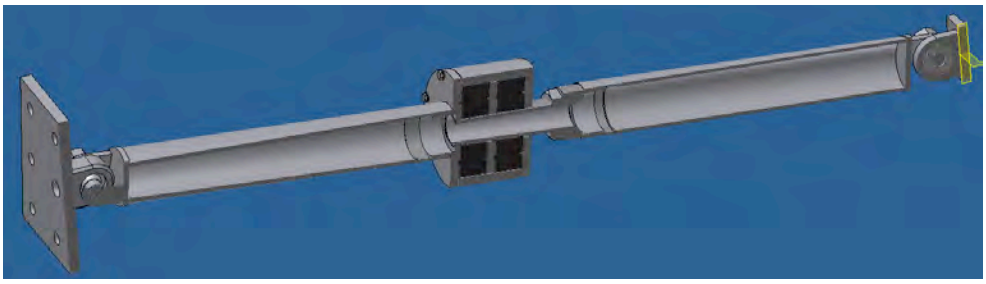

Fig 14. Cross section of the stabilizing bar

As design approach adopted, the bars have not been considered to support the telescope, but only to avoid excessive movements of the telescope inside the UTE. To reach this scope, all the four bars have a suitable damper system in its central area. During the installation of the bars, the threading permit to adjust the length of each bar in order to match the available space between the interfaces on the telescope and on the UTE.

6. SAFETY DEVICE

The safety device allows to safely lay down the UTE on the soil in case an emergency occurs during the relocation operations (possible unexpected failures, wind gust speed sudden increase, etc.). This safety device is constituted by three rubber pads on which the UTE can temporarily lay while a recovery solution is being planned.

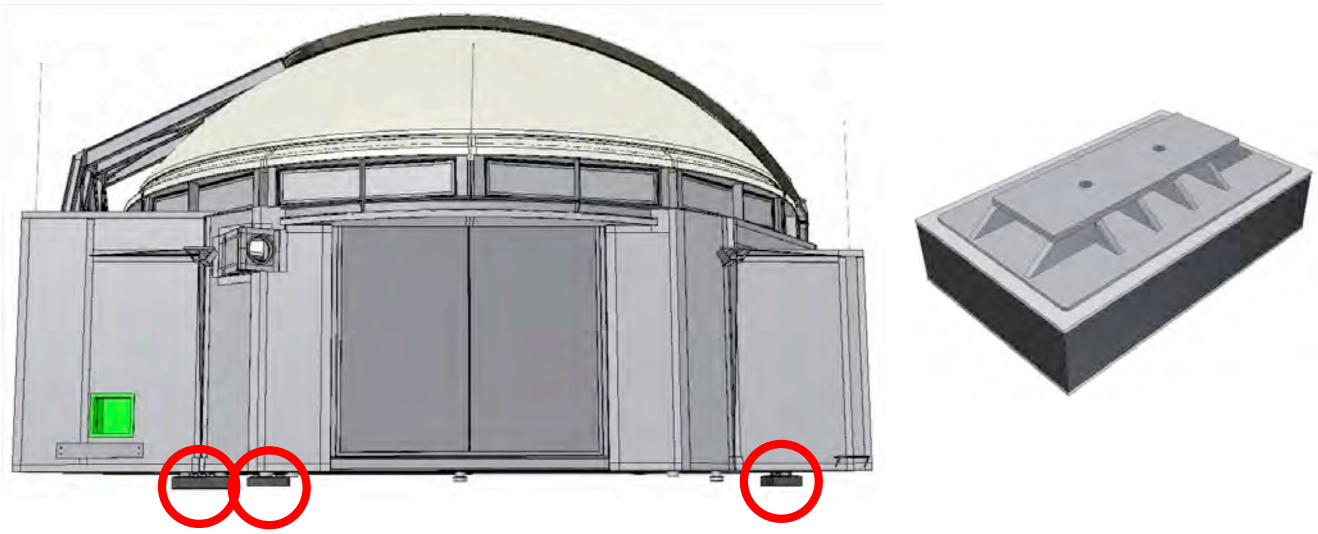

Fig 15. Safety pads mounted in correspondence of the UTE interfaces with the station

The total height of the pads (145 mm) has been dimensioned to avoid contacts of the centring pin of the telescope with the soil. In any case, it is convenient to check the area under the UTE before to completely lower it over the ground.
It has to be underlined that if the problem that determine the lowering of the UTE is not linked to a failure of the transporter, it is possible to keep a portion (50% for example) of the weight of the UTE + UT with the transporter itself in order to increase the stability of the UTE when laid on the ground.

7. CONCLUSIONS

The design of the relocation system for the Unit Telescope Enclosure presented some difficult challenges due to the harsh environmental conditions and the narrow space between the enclosure in the compact array configuration of the Magdalena Ridge Observatory Interferometer.
The study of the relocation process required an initial trade-off among several options where the solution with the container handler presented the best cost/benefit compromise under the point of view of the handling, positioning accuracy and shock load transferred to the telescope. In particular for this specific matter a test campaign have been carried out in order to have the best real feedback for the reachstacker behaviour. The results highlighted the suitability of this means for this peculiar application.
While the reachstacker practically picks up the UTE to bring it in the new station, the lifting system provides the first very precise lifting to "unplug" the telescope from its foundation and the last lowering to "plug" telescope again. This is an hydraulic system capable to guarantee a synchronized as well as smooth motion during lifting/lowering.
The telescope is linked to the UTE by means of the damping system which assure a further vibrations reduction during the relocation operations.
Finally, the safety device allows to save the hardware in case of unexpected failures during the transportation of the UTE.
The studies described in this paper allows to state that these sub-systems altogether permits to carry out the least riskful and the most accurate relocation process as fast as possible.

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