NTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

LIGO Laboratory / LIGO Scientific Collaboration

LIGO- T070157-00-E *LIGO* January 2007

Chronicles of the HAM chamber seismic Isolators (HAM-SAS) construction

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The SAS pre-isolator prototype for the HAM chambers has been completed and is traveling to LASTI for qualification tests.

The SAS pre-isolator is a fully-in-vacuum, predominantly passive system, which has been designed to meet the cumulative requirements of the HEPI hydraulic and the two in-vacuum active pre-attenuation stages for the optical benches in the LIGO chambers.

The HAM SAS is designed for the HAM vacuum chambers, supporting and isolating an un-modified HAM optical table. For installation, a custom elevator-translator cart allows the optical table to slide horizontally over the SAS structure, already pre-populated with most or all of its optical components.

In addition to its passive attenuation capabilities, active static controls based on voice coils and LVDT position sensors are designed to maintain the optical bench positioning and alignment.

Although the SAS seismic attenuation is designed to be a primarily passive instrument, active attenuation can be implemented, at minimal cost, using the static controls actuators, to supplement its performance up to the sensitivity of available accelerometers or seismometers. For this optional, it is particularly useful the fact that SAS internally performs vertical (and tilt) attenuation independently from the horizontal (and yaw) attenuation. The vertical and horizontal modes are naturally decoupled to a very high level, providing a natural diagonalization into two 3-degrees-of-freedom control loops. Its rigid internal platforms, supported by extremely soft spring suspensions are also ideal for active controls.

A fully assembled and pre-tuned SAS structure has been built, pre-assembled, and then disassembled, UHV cleaned, baked in flowing N_2 atmosphere to temperatures as high as 200^{o}C, typically for a day, before being re-assembled in UHV-compatible conditions, by Galli & Morelli in Lucca Italy.

The finished structure has then been re-baked with a temperature profile equivalent to more than 48 hours ate 120^{o}C in flowing N_2 atmosphere. This thermal treatment is intended to both eliminate any possible contamination from the assembly and tuning process, and to burn out any possible creep in the springs.

During the production of this prototype, several procedures had to be developed or optimized, ranging from coil coating, kapton wire stripping, welding of intricate base structure, magnet assembly, et c.. For each problem a fully satisfactory procedure was found. Several parts had to be re-worked or re-made, to satisfy the tight UHV cleanliness requirements. These developments, as well as the process infrastructure accounted for close to half of the prototype costs (both in part production and assembly manpower costs).

The SAS structure has been shipped to LASTI and is presently in the US waiting for customs clearance.

In early January installation and commissioning at LASTI will start.

Testing will confirm if the SAS system satisfies the Ad-LIGO requirements to support the Ad-LIGO multiple pendulum suspensions and if it is suitable to replace the baseline hydraulic and in-vacuum seismic pre-attenuators.

The following is a photo gallery illustrating the assembly process.

To perform the SAS assembly a complex infrastructure was necessary and built. This infrastructure includes a 450 sq feet clean room provided with specialized tooling, including a large (3 m diameter) and a small, neutral atmosphere baking ovens.

Small Bakeout Oven with its neutral atmosphere box (pre-purging)

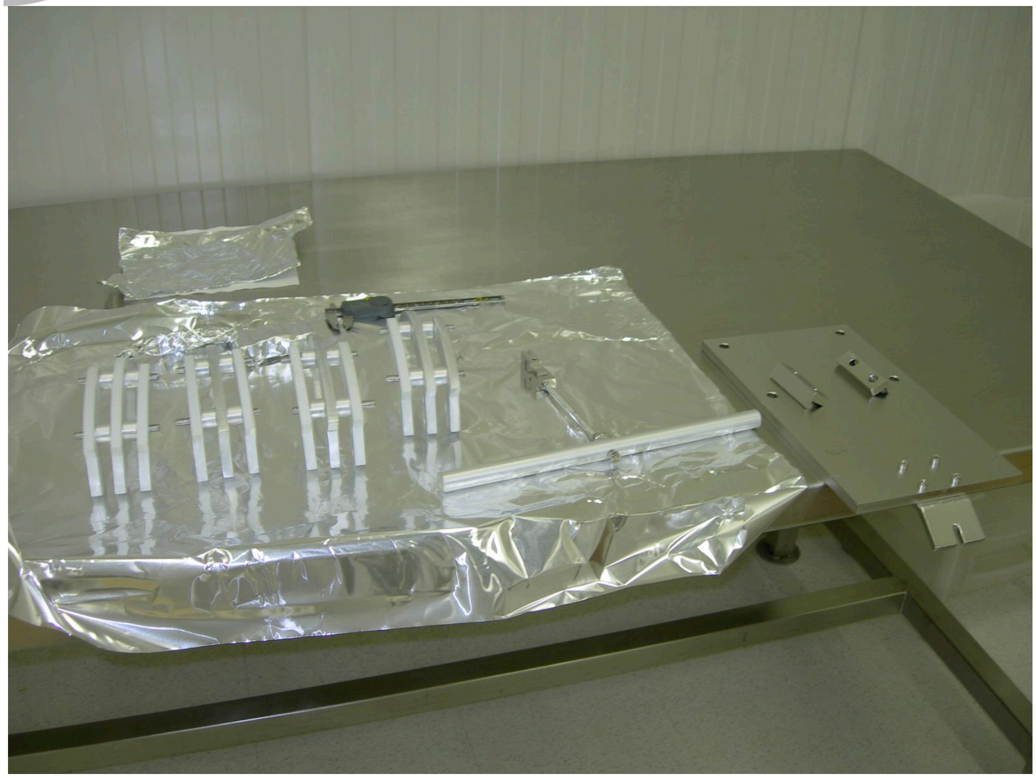

Small parts being loaded in the small oven.


The large (3 m diameter) clean Bake-out oven entering the grey room.

The large Oven cap is provided with internal eye-bolts, used to handle large parts while being shielded from the crane dirt by the cap, and cleanly deposit them inside and outside the oven.

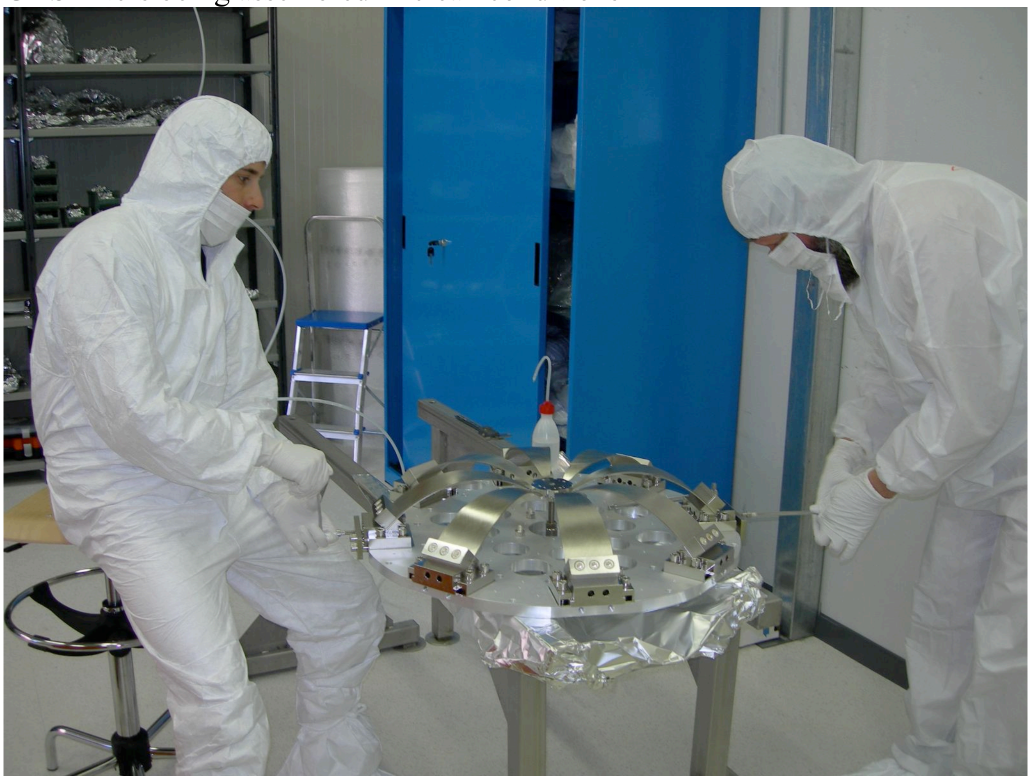
SAS base structure lowered in Oven for pre-bake-out.

Clean-room-class A-frame crane, support and leveling horses and various tuning structures being readied in the clean room.

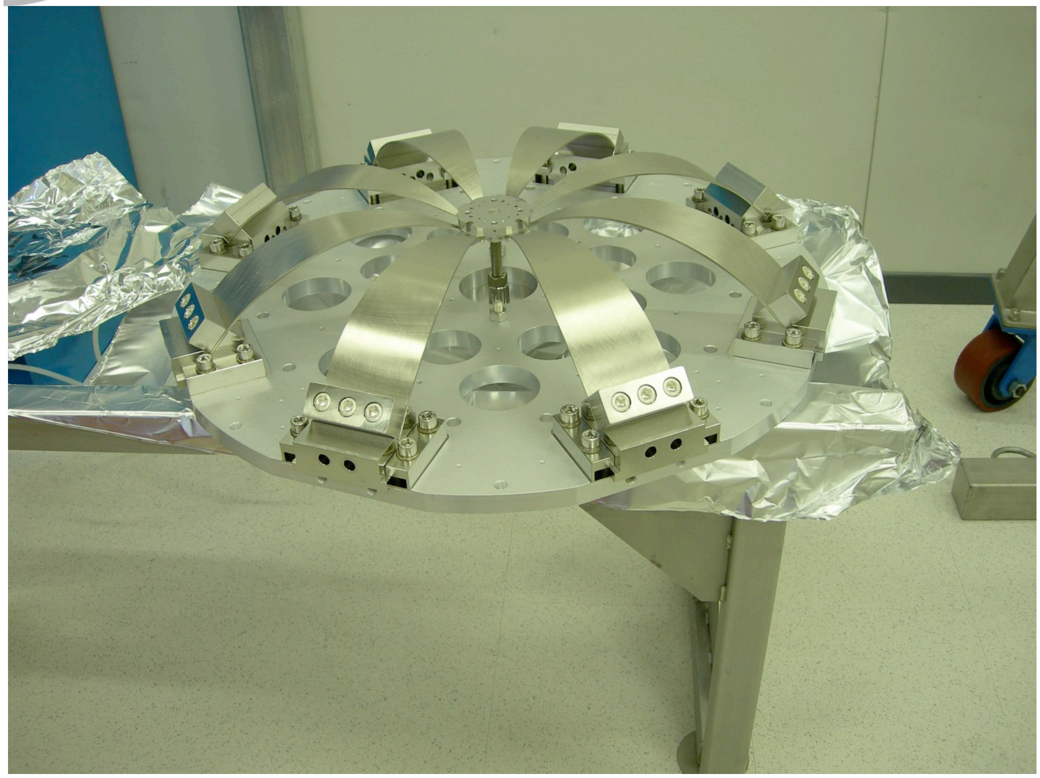


Clean GAS-Filter-blade pre-stressing tools.
The SAS vertical attenuation is provided by a set of four Geometric Anti Spring (GAS) Filters

GAS filters being assembled in clean conditions

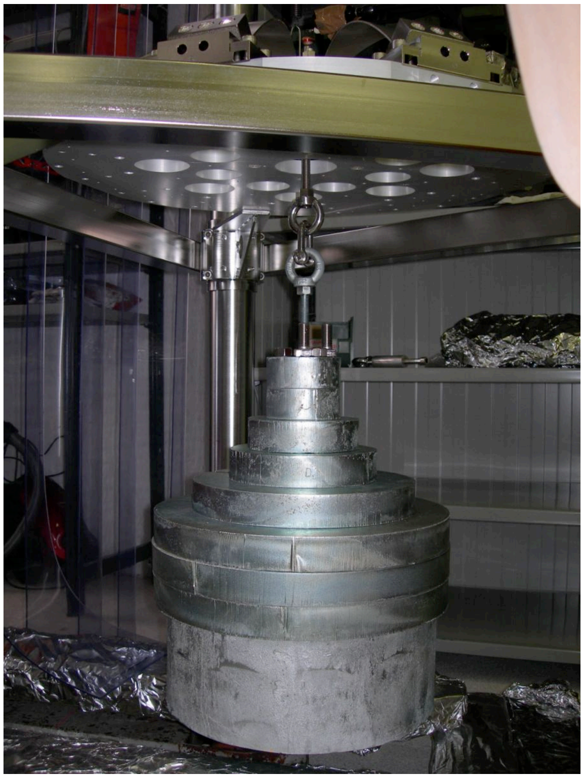


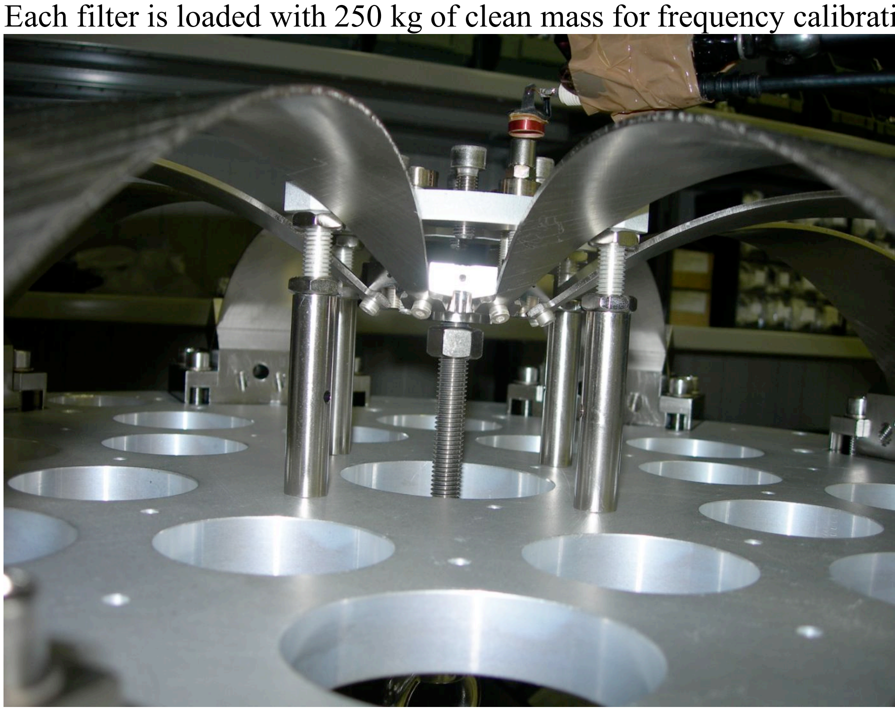
The GAS filters are tuned to 200 mHz vertical mechanical resonant frequency by means of radial compression of its arched cantilever springs.



Finished, naked, GAS spring. The central keystones of four filters supports the optical bench, thus providing vertical suspension and seismic attenuation.

The four GAS Springs awaiting calibration and installation in the spring box.


Each filter is loaded with 250 kg of clean mass for frequency calibration.

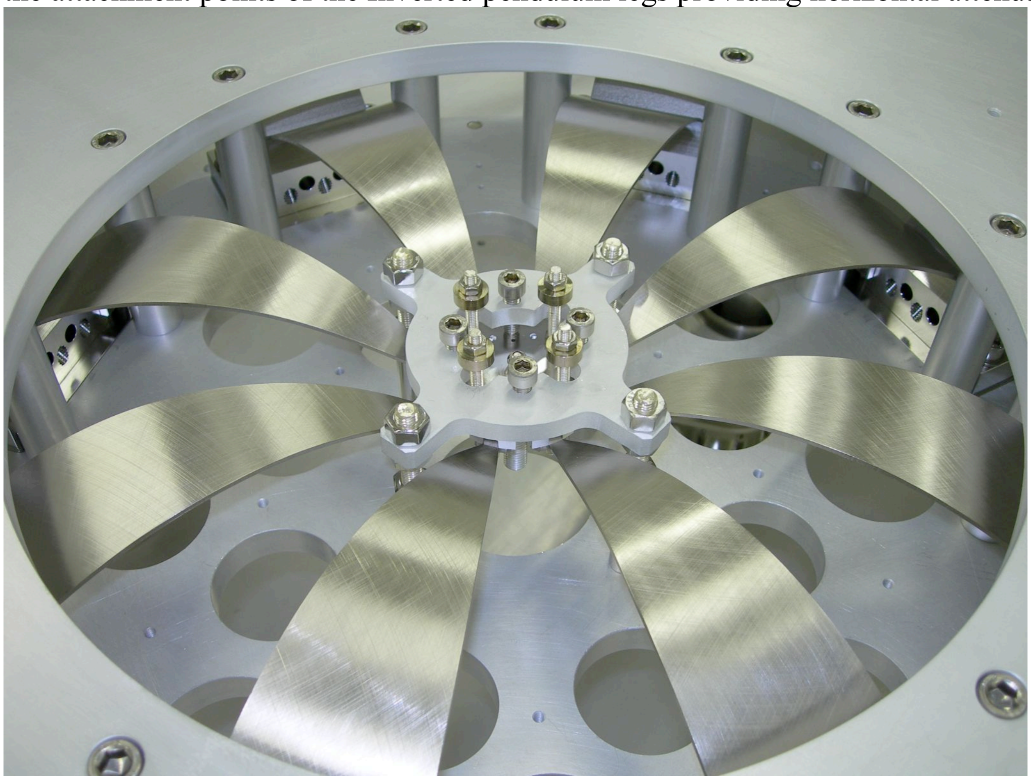

A coil picks up the field from a magnet sitting on the GAS filter keystone. The collected signal is used to measure the vertical resonance frequency.

The mechanical resonant frequency is tuned to below 200 mHz by acting on the radial compression. GAS filter calibration results for the four units in the table.

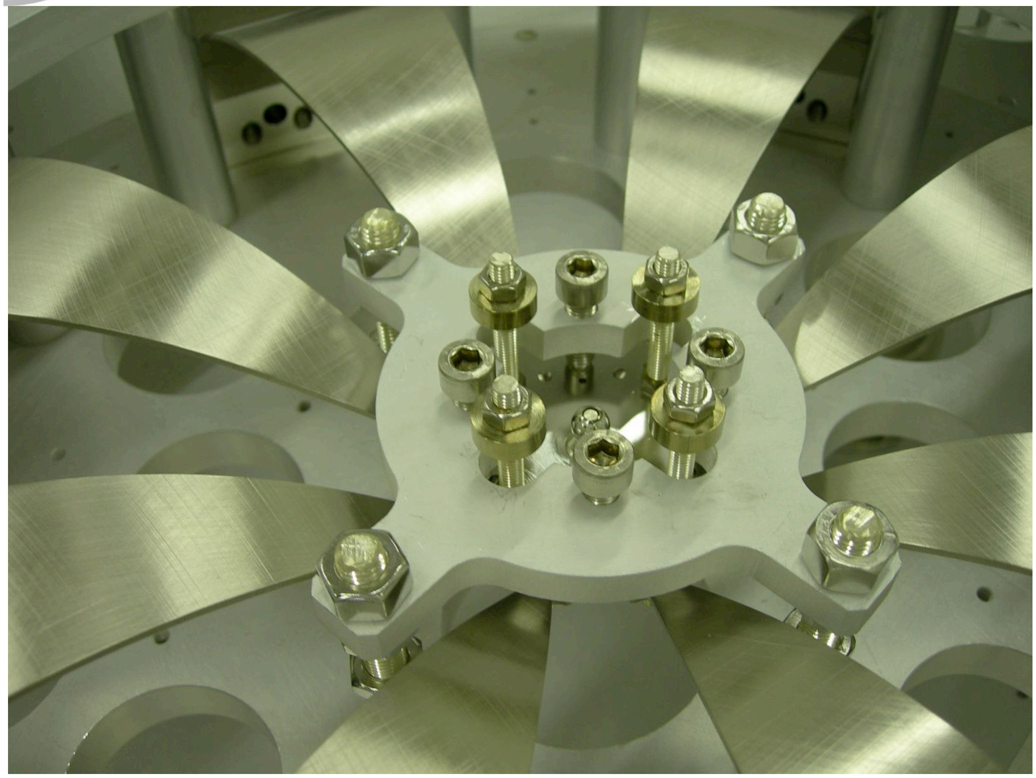
Filter	Frequency [mHz]	Optimal Load [Kg]	Height [mm]
A	192	276.21	19.46
B	180	275.42	19.95
C	188	276.34	20.15
D	180	276.45	20.03

Mounting the GAS filters in the spring box. A second aluminum plate will then complete the box and give it its rigidity.

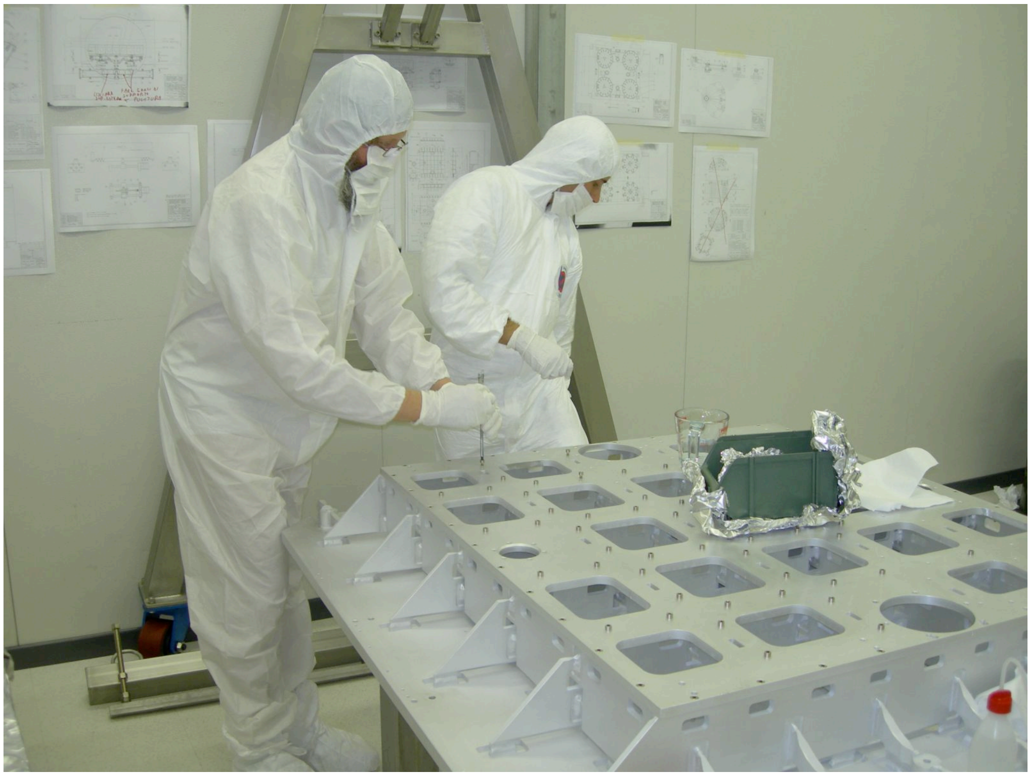
The four GAS filters attached to the spring-box. Visible at 45° from the filters are also the attachment points of the Inverted pendulum legs providing horizontal attenuation.



Detail of a GAS filter in the spring box.

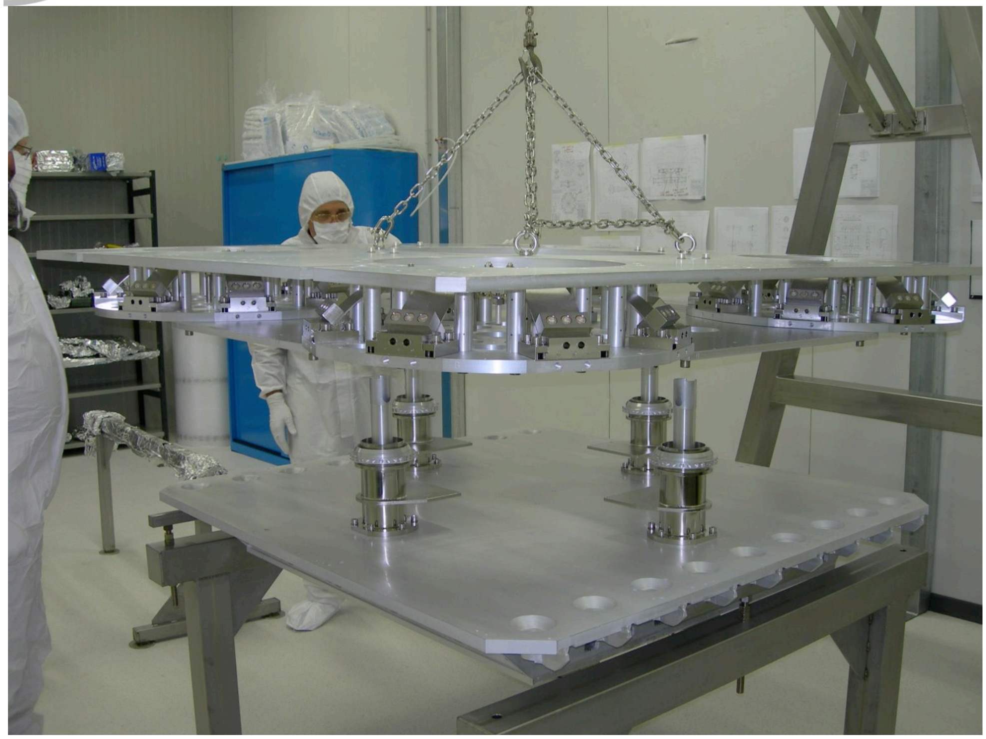


View of the GAS filter nose, which supports the optical bench.
A standard LIGO optical bench is used, not requiring new benches to be built.

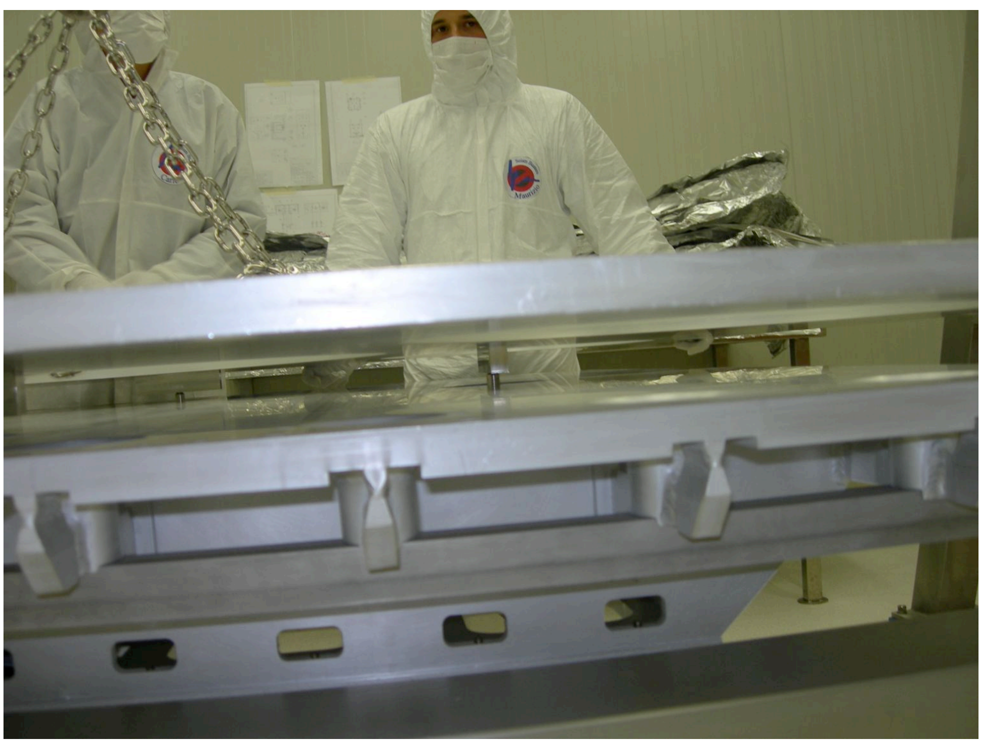


Base structure being assembled. It is composed of honeycomb weldment closed by a bolted bottom plate for cleanliness and machining precision. On the bottom right side is visible the shelf that will fit over the HAM cross pipes.


IP parts ready for assembly on the base structure.



The finished spring box is lowered over the Inverted pendulum legs, that provide the horizontal seismic attenuation. The IP legs are surrounded by a safety structure, which limits the spring-box horizontal to its 1 cm earthquake travel. Rotating the ring at the top of each safety structure immobilizes the spring box for access and maintenance

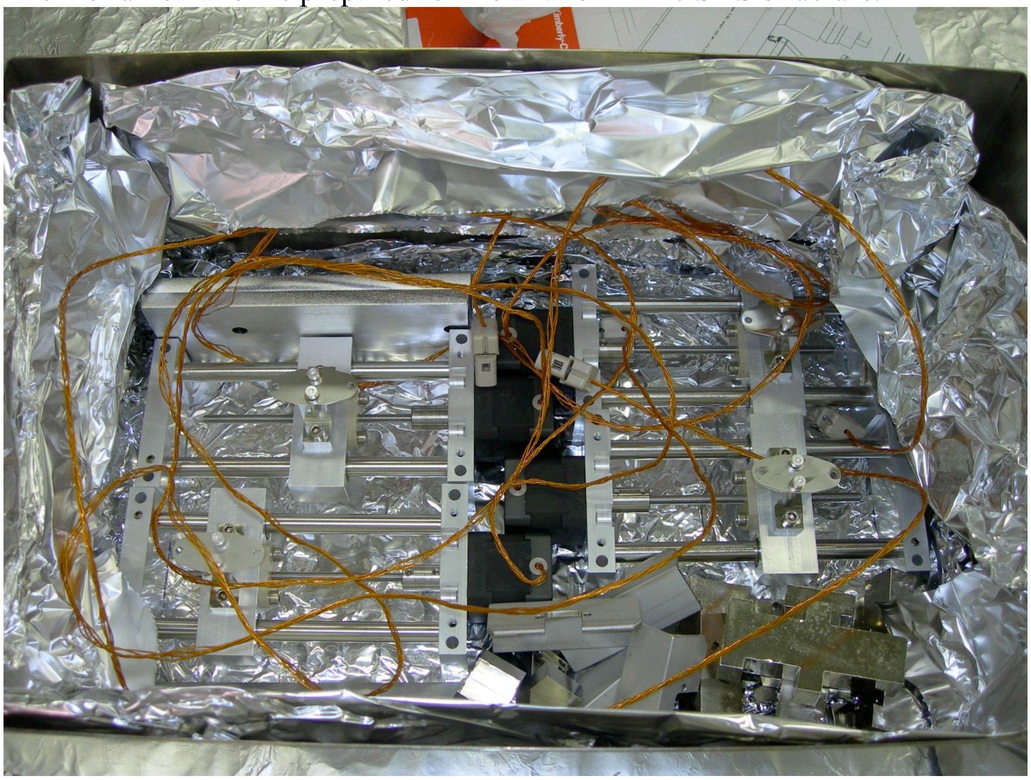


The footing of the IP legs had been pre-positioned to match the position of the IP head in the spring box. This step avoids cradle effects in the x-y movement.

Positioning the spring box over the IP legs.

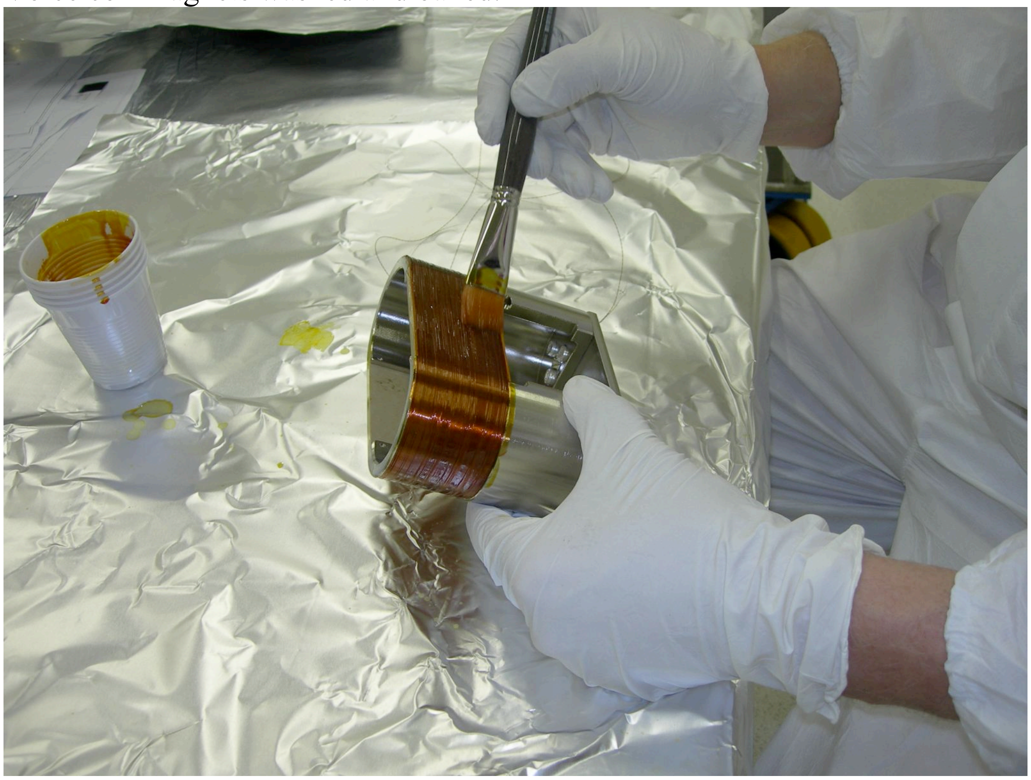
Finished, naked ,SAS structure, ready for instrumentation with LVDT sensors, Voice-Coil actuators and static positioning tuning motorized sleds.

The instrumentation is prepared for installation in the SAS structure.

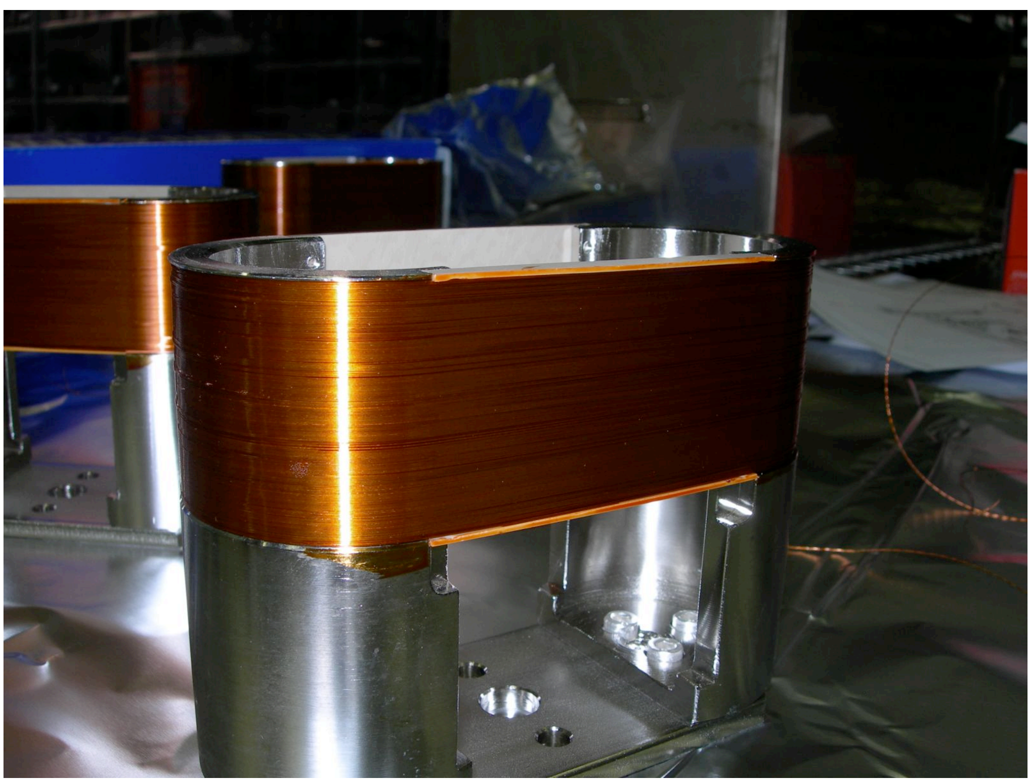


Parasitic tuning spring motorized sleds are assembled and baked

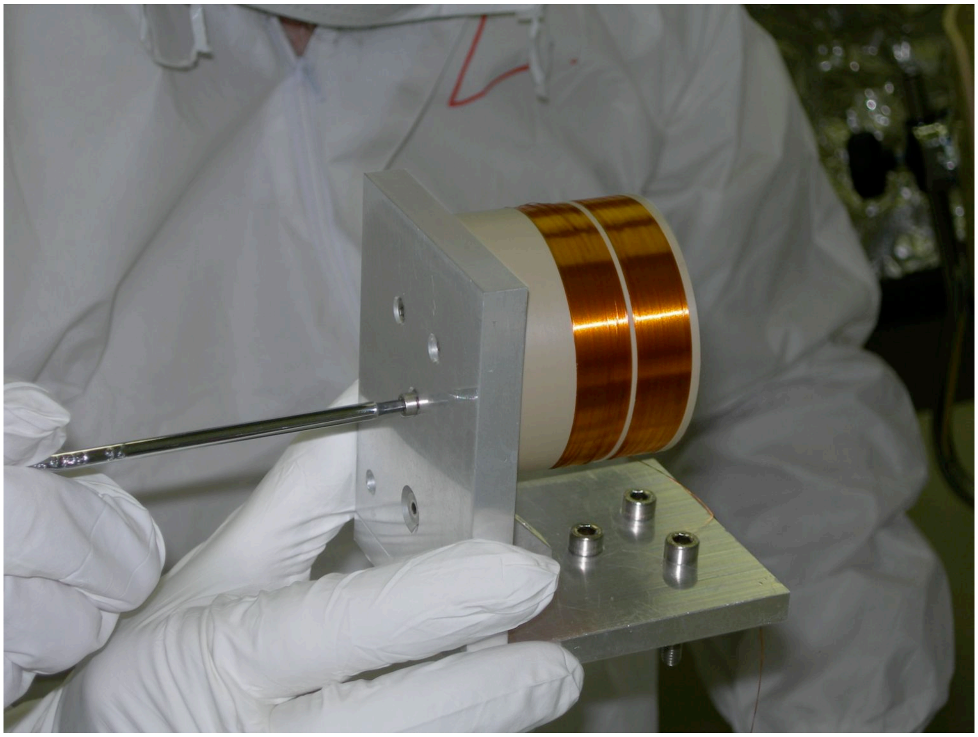
Voice coil magnets washed and baked.



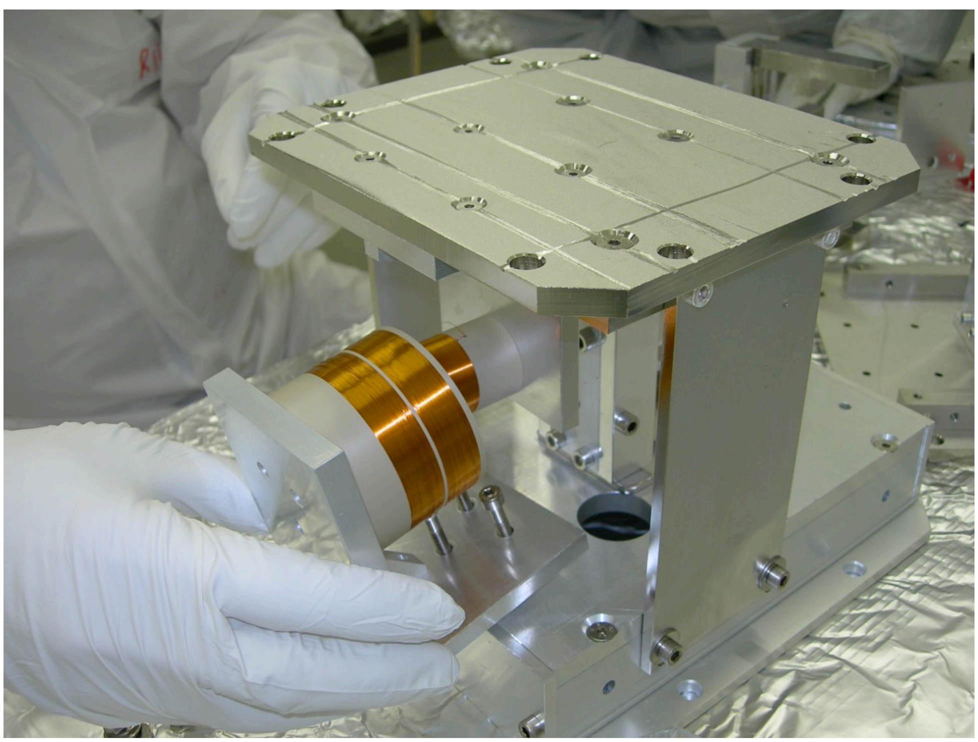
Voice coil actuators are coiled, then kapton painted and baked.



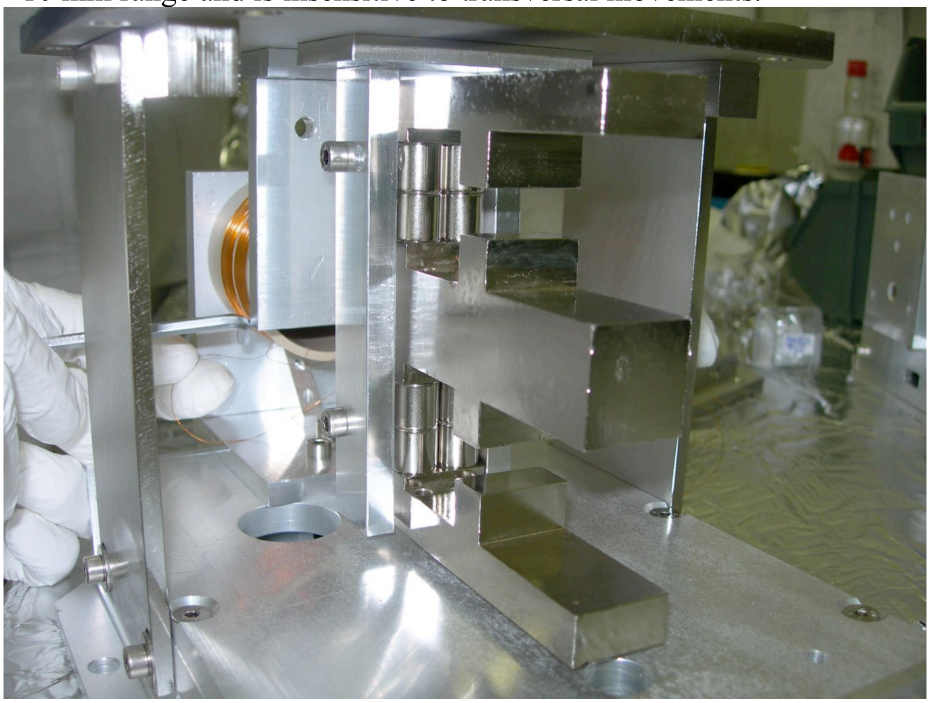
Finished racetrack coil for horizontal actuator.



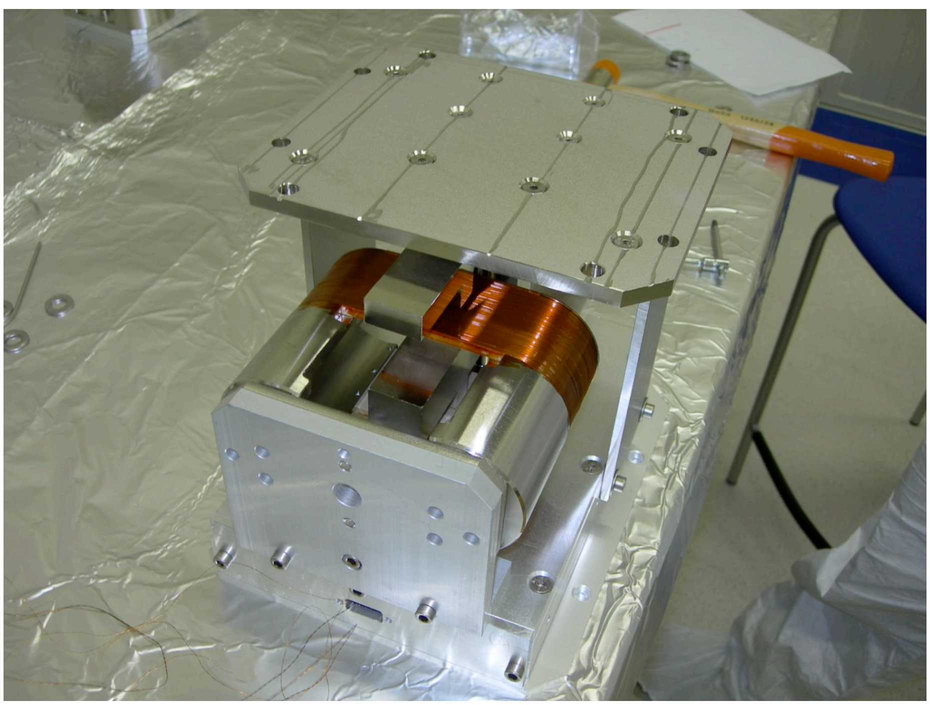
Horizontal LVDT secondary coils being assembled.



The LVDT secondary coil assembled mounted around its primary, while the structure is being held rigidly by a couple of transport plates. This non contacting position sensors has a resolution of better that 10^{-8} m/√Hz with less than a percent non linearity over its ±10 mm range and is insensitive to transversal movements.



The magnetic jaws of the coaxial, co-located voice-coil actuator are mounted in the same structure housing the LVDT position sensors.

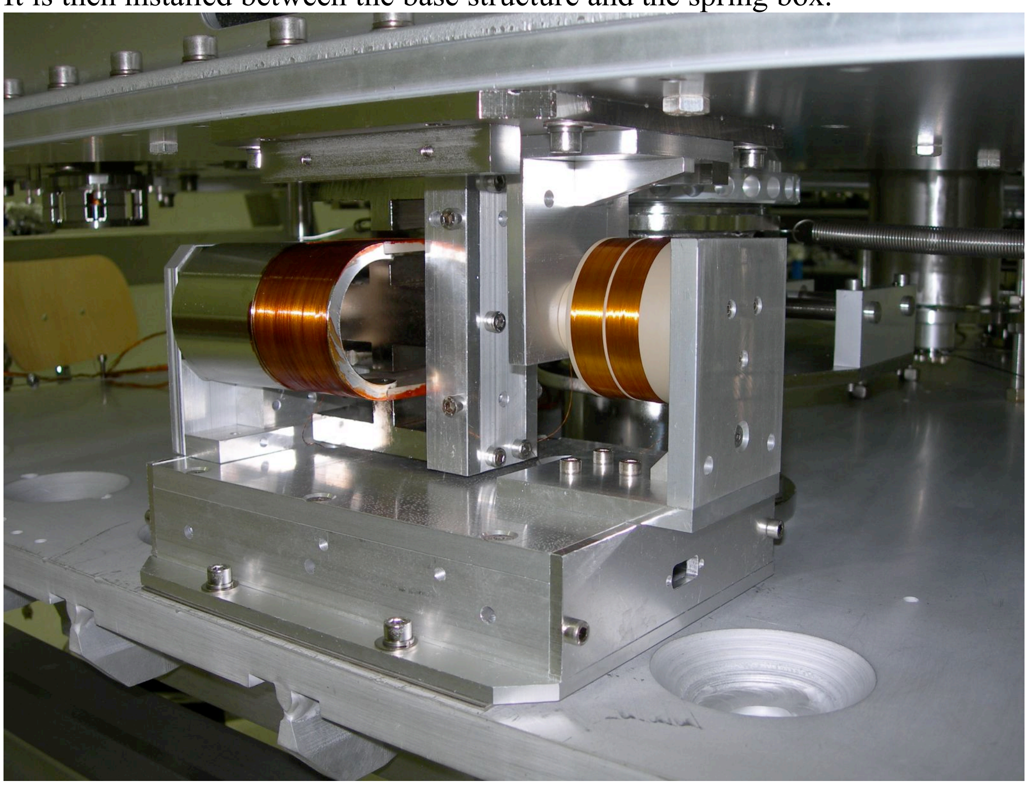


The corresponding racetrack coils are installed.

The magnetic jaws and the racetrack are designed to yield constant force within better than a percent independently of the relative positioning (in all 3 d.o.f.) of the two halves of the actuator. This arrangement is chosen to avoid coupling ground vibrations to the payload via spatial force gradients.

The LVDT voice-coil/actuator unit is cabled to its UHV connector.

It is then installed between the base structure and the spring box.



After installation between the base structure and the spring box, the transport plates are removed and the LVDT is free to measure the relative motions between these structures.

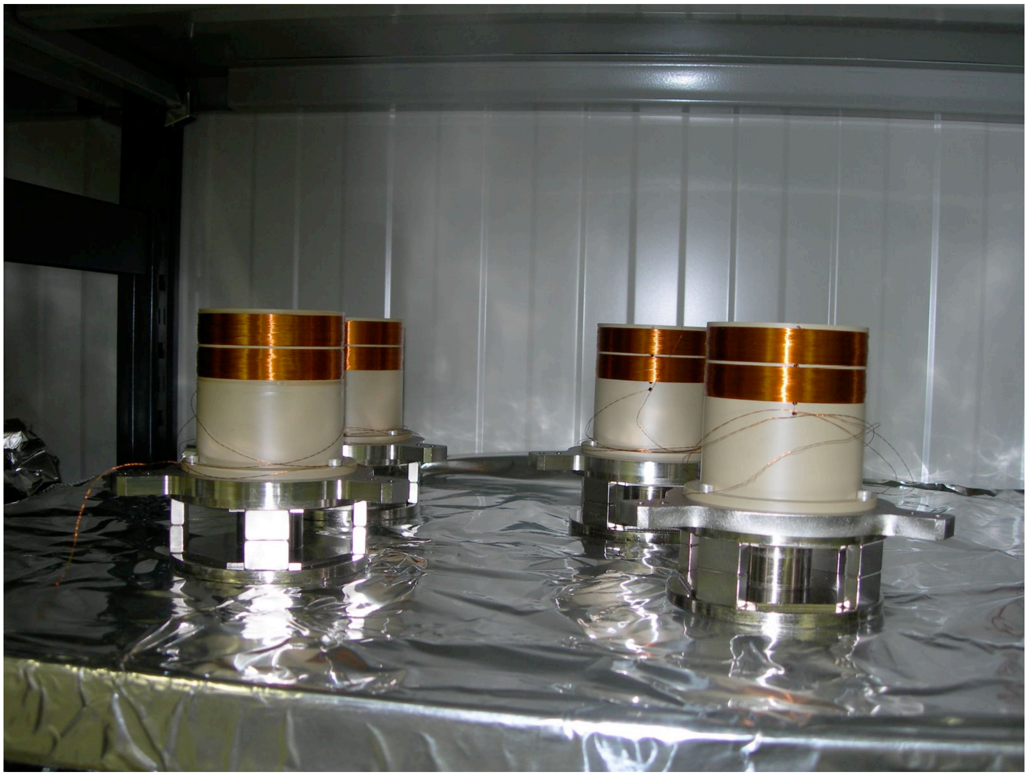
These units represent the sensors and actuators for the horizontal direction defined by the IPs.

The vertical degrees of freedom are completely decoupled from the horizontal one by mechanical construction. The horizontal controls are therefore a relatively simpler 3 degree of freedom control problem, separated from the vertical one, which is dealt with using the GAS filters sensors and actuators in the spring box.

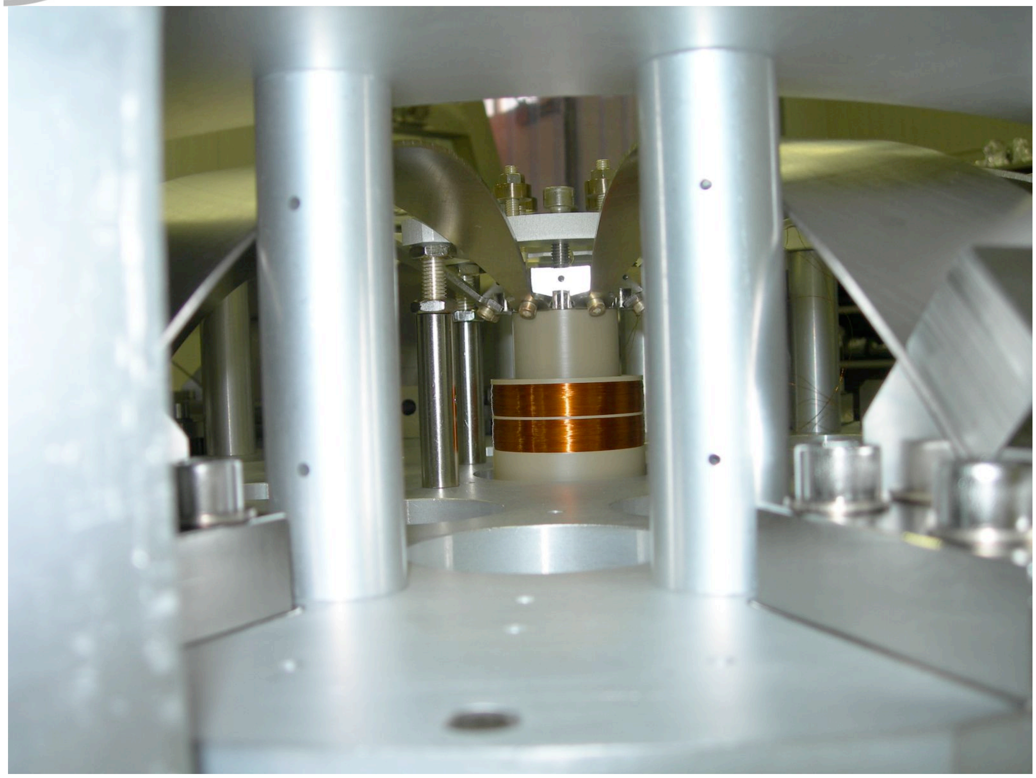
Similarly for the vertical degrees of freedom, sensor and actuators are mounted, coaxially into each GAS filter.

The LVDT primary and actuator coil cylinder is mounted on a GAS filter Key-stone .

The vertical Actuator coil, wound around the same peek cylinder, sticks out from the bottom of the filter base structure.



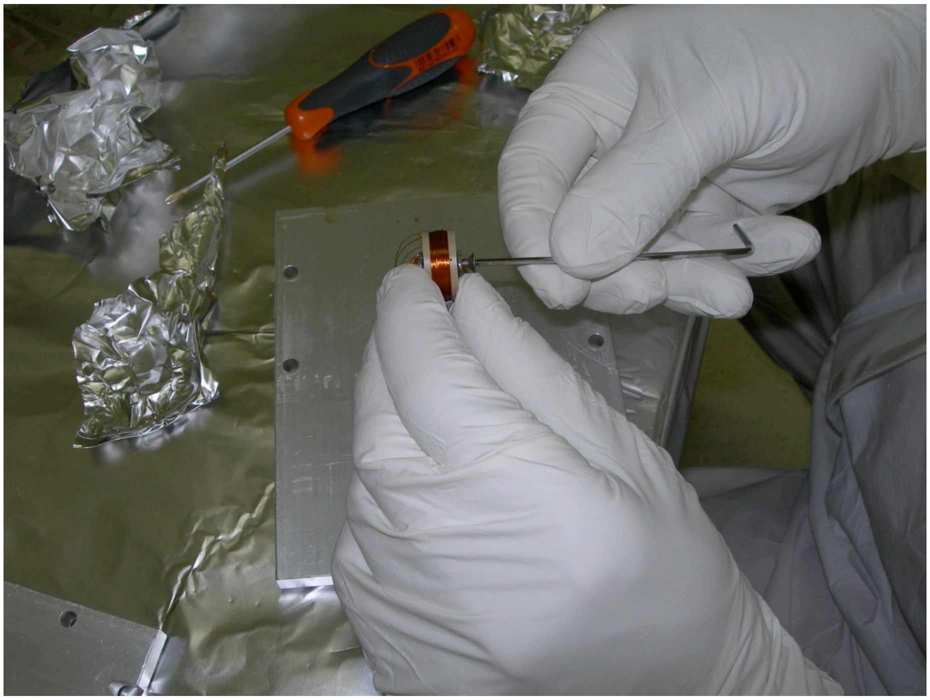
Vertical LVDT coils and actuator magnetic yoke are pre-assembled together.



Then they mount on the bottom plate of each filter to complete the vertical sensor actuator unit.

View of the completed vertical actuator coil inside its magnetic yoke. The screws on the side are for electrical zero tuning.

The SAS prototype is provided with additional witness LVDT (not part of the feedback loop) mounted at the center of the structure, between the optical bench plate and the base structure.   They monitor both vertical and horizontal movements.

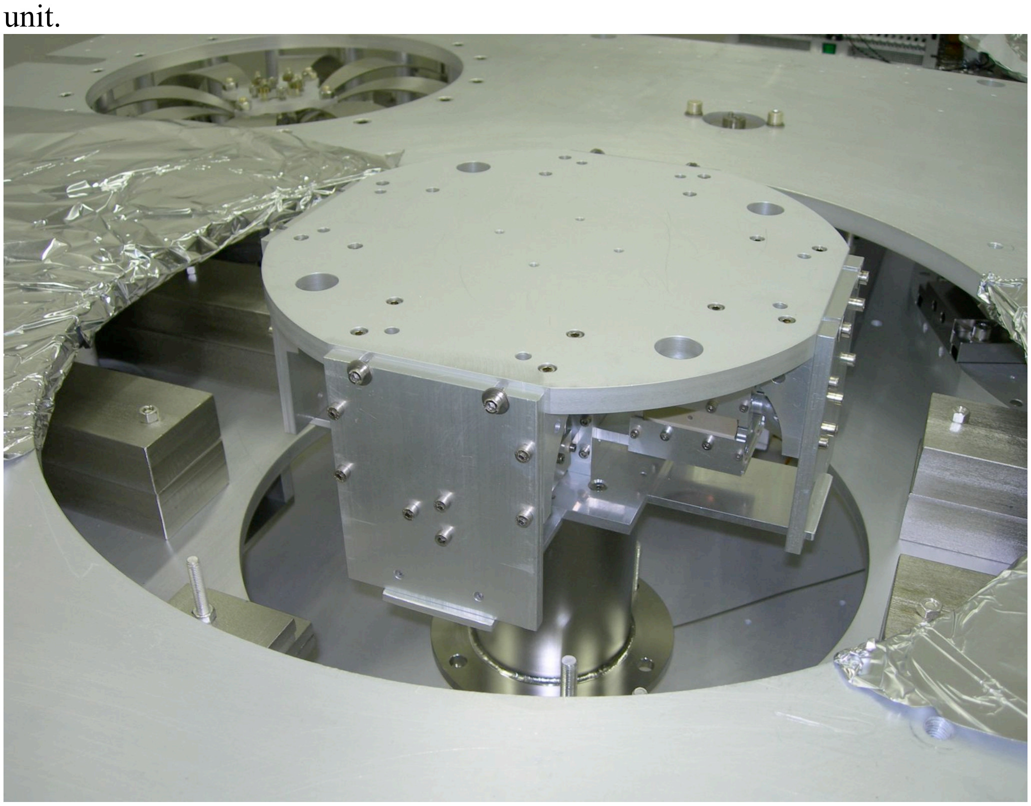


Primary coil being mounted on its plinth.

Secondary coil pairs being assembled. Note the different orientation of the vertical and horizontal sensing coils.

Primary and secondary coils structure being held fast by four transport plates.

Roll Bar, controlling the table tilt stability, being mounted coaxial to the witness LVDT unit.



Witness LVDT unit installed on the base structure, in the center of the spring box, waiting for the optical table support plate to be installed.

Optical table support plate being installed. It sits on a modified kinematic mount on the four filter key-stones. The optical bench slides over and bolts on this plate

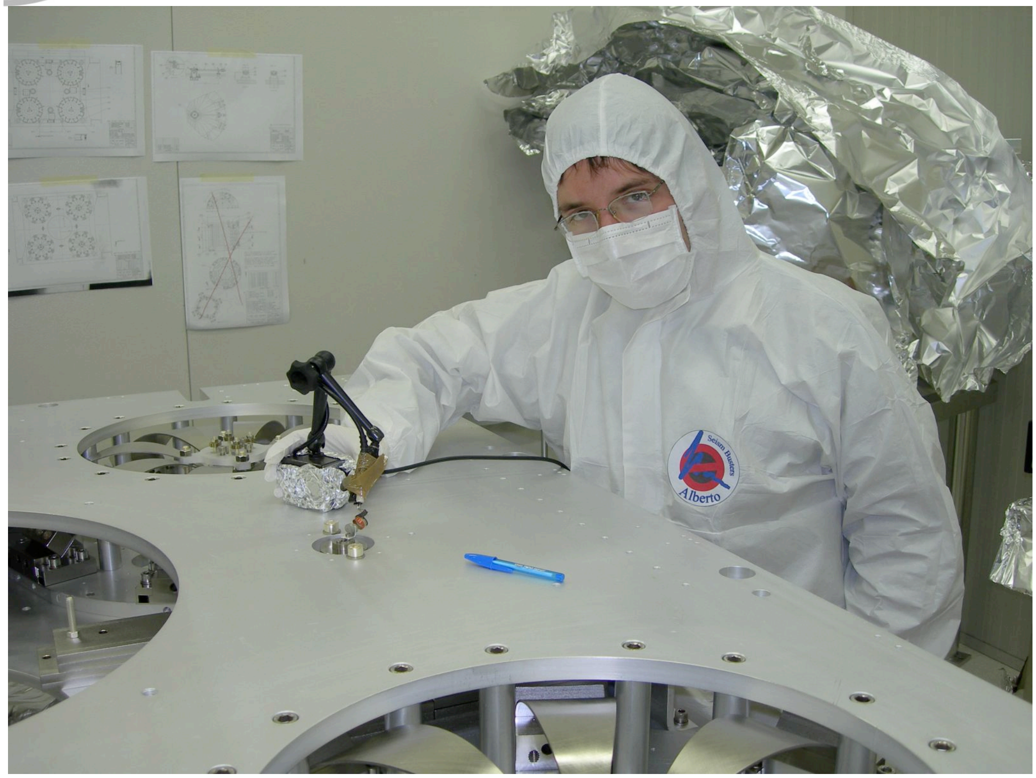
Witness LVDT being fastened to the optical table support plate.

Witness LVDT being fastened to the optical table support plate.

Witness LVDT being then fastened to the base structure. The double nuts provide vertical adjustment.

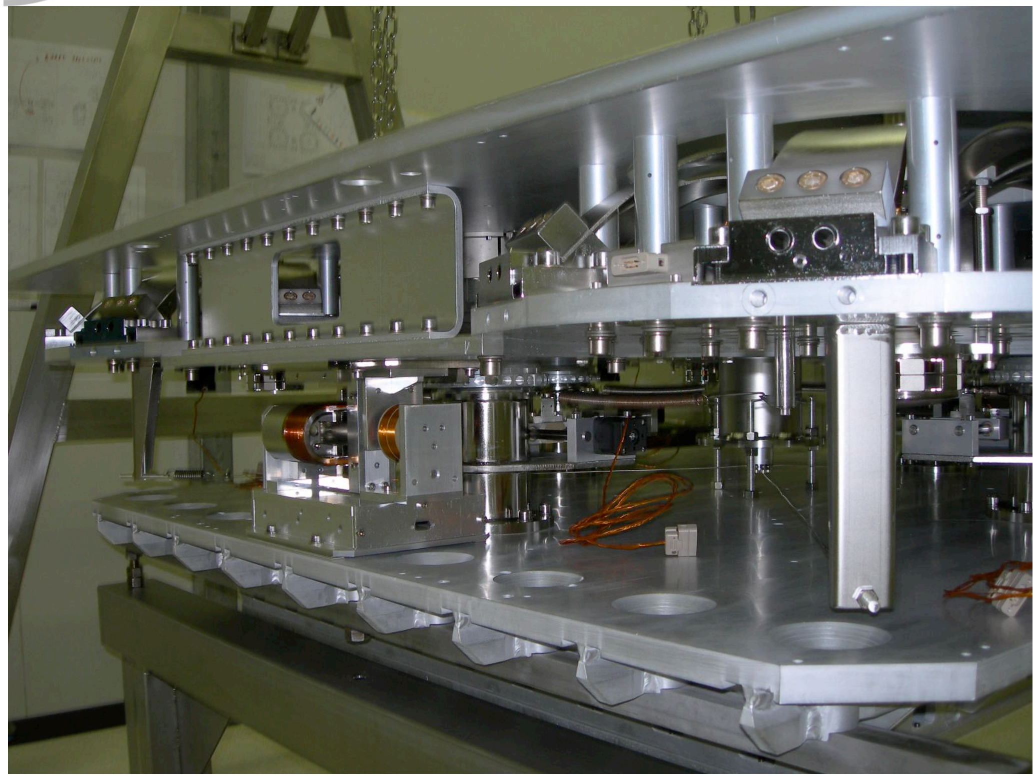
Roll Bar sticking through the witness LVDT structure connected to the four tilt stabilization springs.

Transport plates of the witness LVDT being removed.

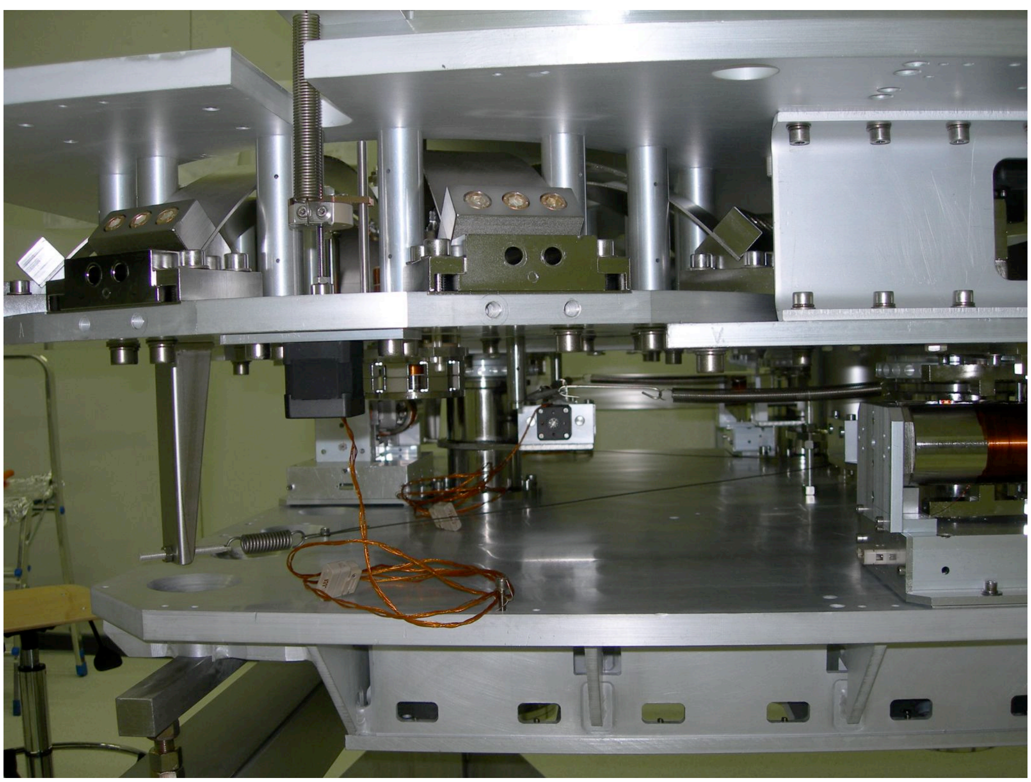


Testing the load sharing on the IP legs measuring the leg rigid body first resonance.

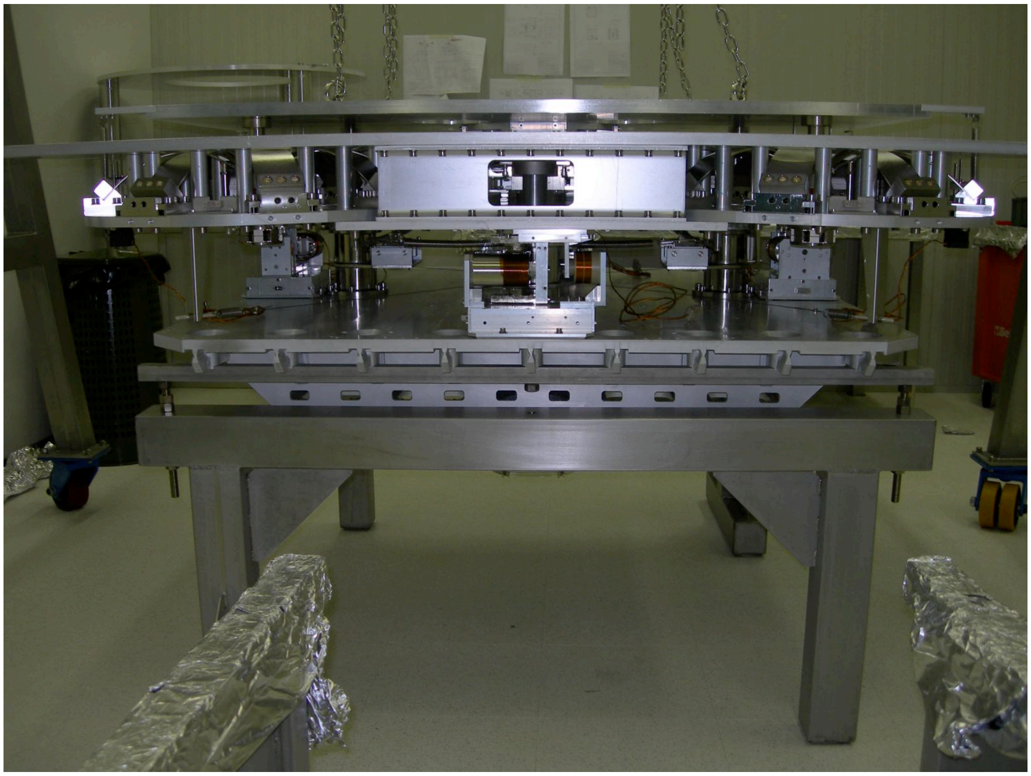
Magnetic dampers eliminating the leg rigid body first resonance.



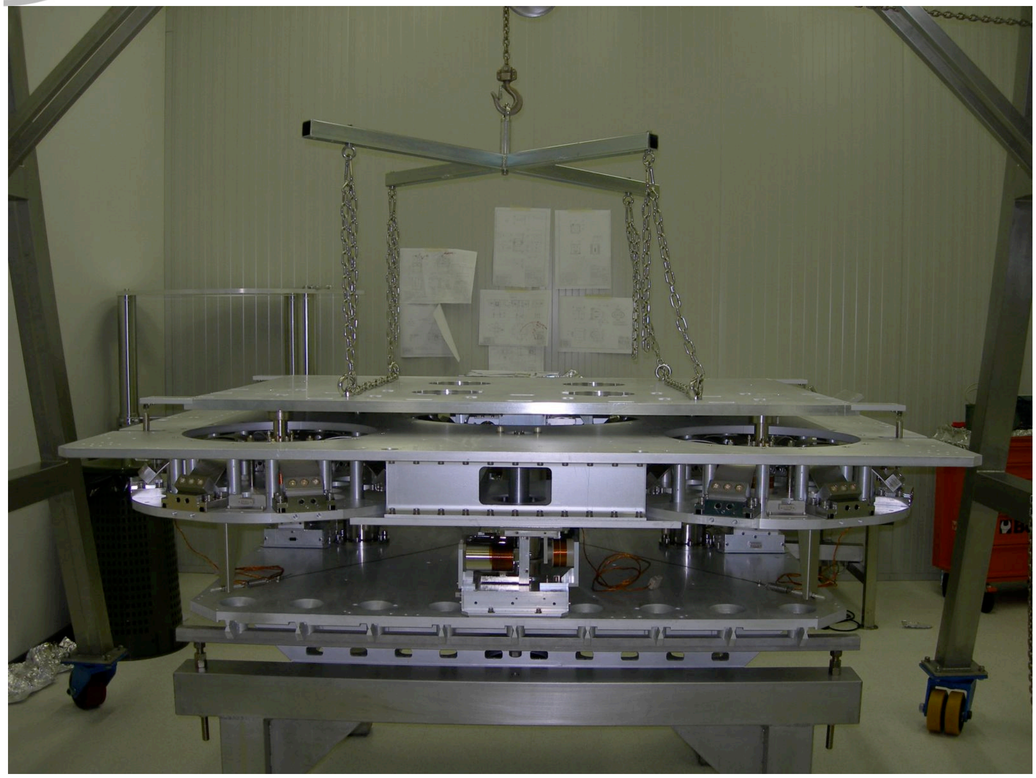
Finished assembly of the SAS structure, sensor actuator view. The horizontal tuning springs and the tilt control ones are visible in the background.



Finished assembly of the SAS structure, view of vertical actuator and static tuning sled, roll bar spring tuning visible on the left.

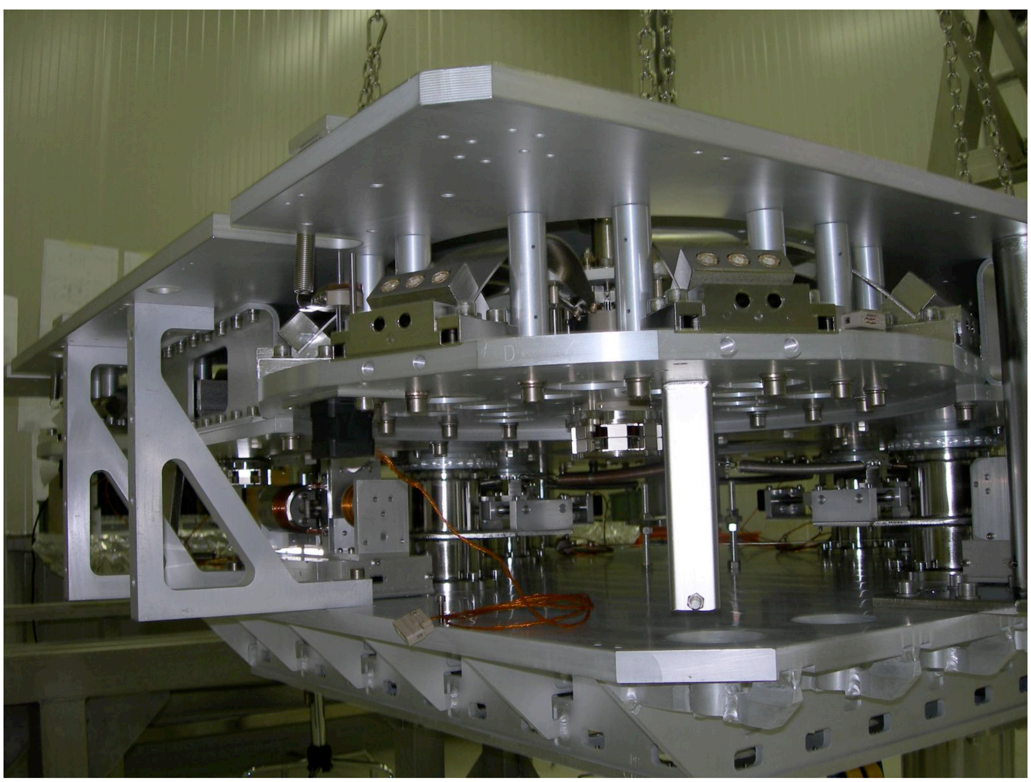


Finished assembly of the SAS structure.



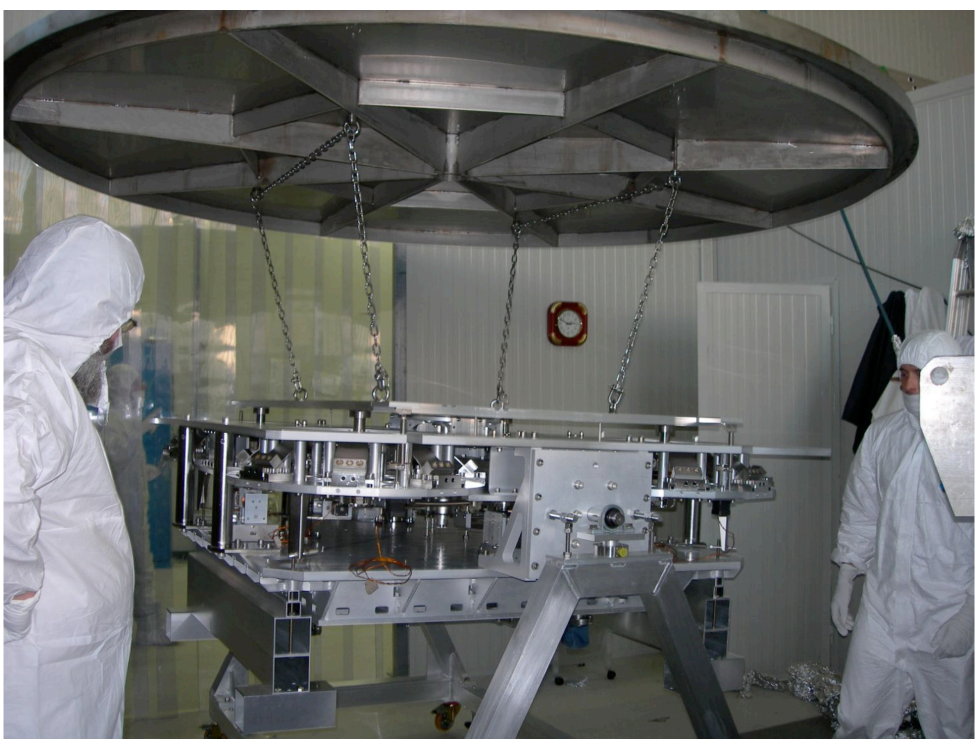
Preparing to lift the finished assembly of the SAS structure, .

Transport tubes immobilizing the structure for transport.

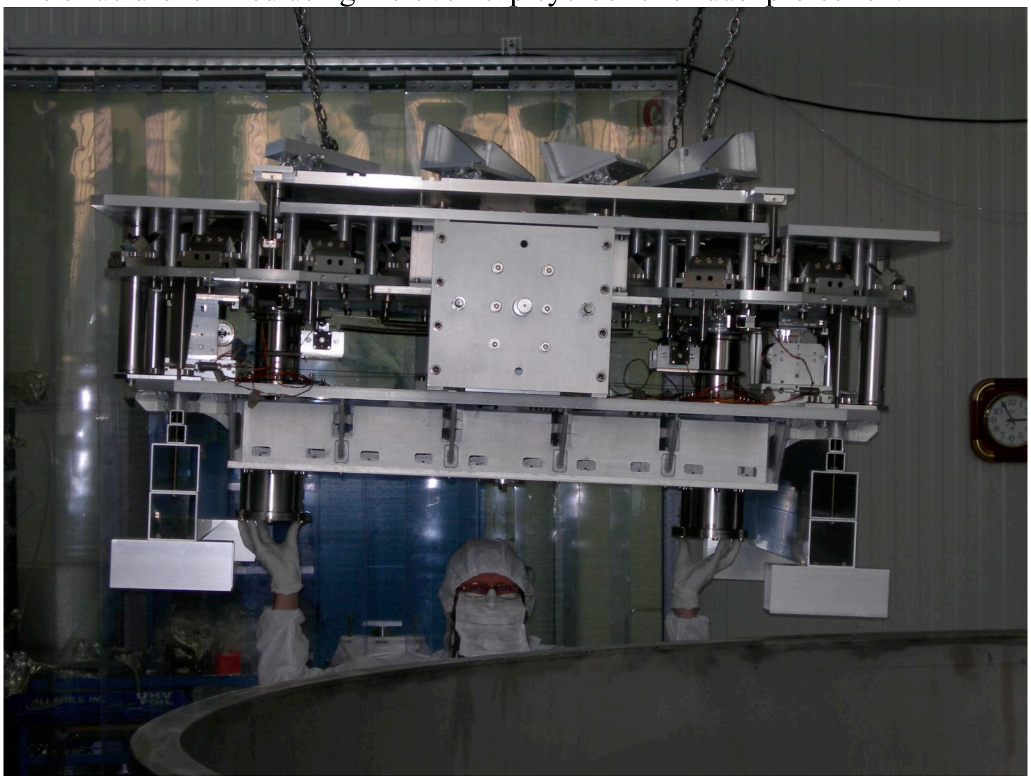


Transport brackets immobilizing the structure for transport.

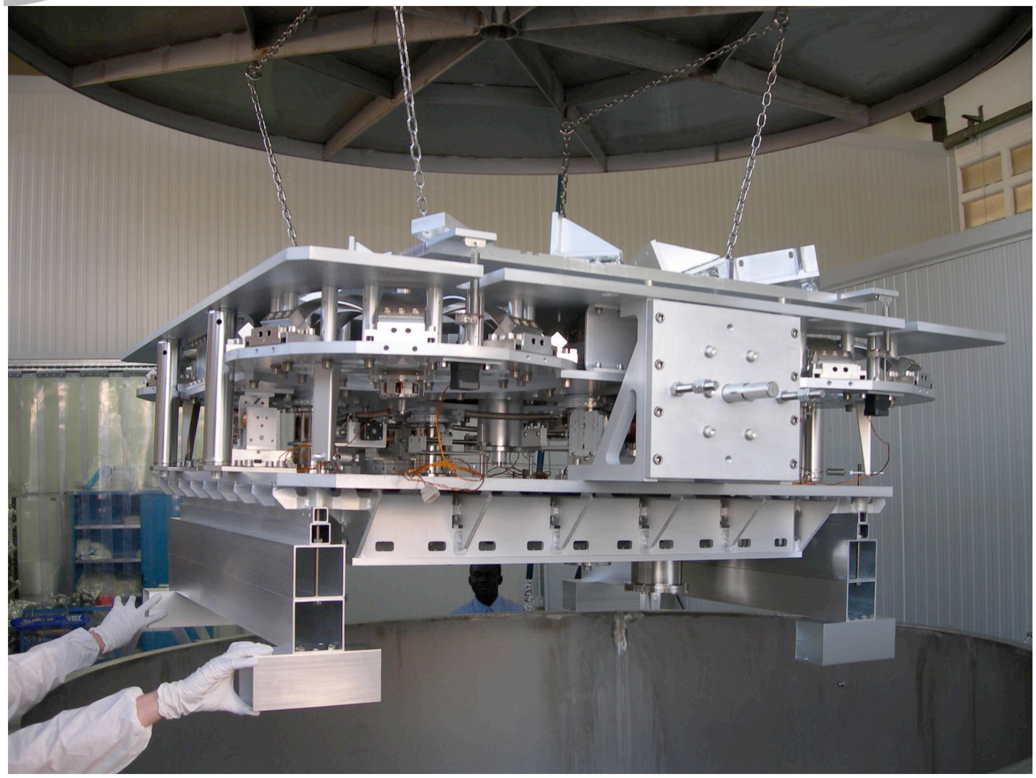
The SAS structure traveled from the clean room to the grey room supported from the transport brackets in the foreground, on a custom transport cart that allows 90^{o} rotation of the structure to pass through doors at LASTI. The SAS structure is then lifted using the eye-bolts below the oven cap.



The structure is lifted using the oven cap eye-bolts for dust protection.



The structure moves to the nearby oven. Note the temporary baking square pipe support making the function of the HAM cross pipe support.

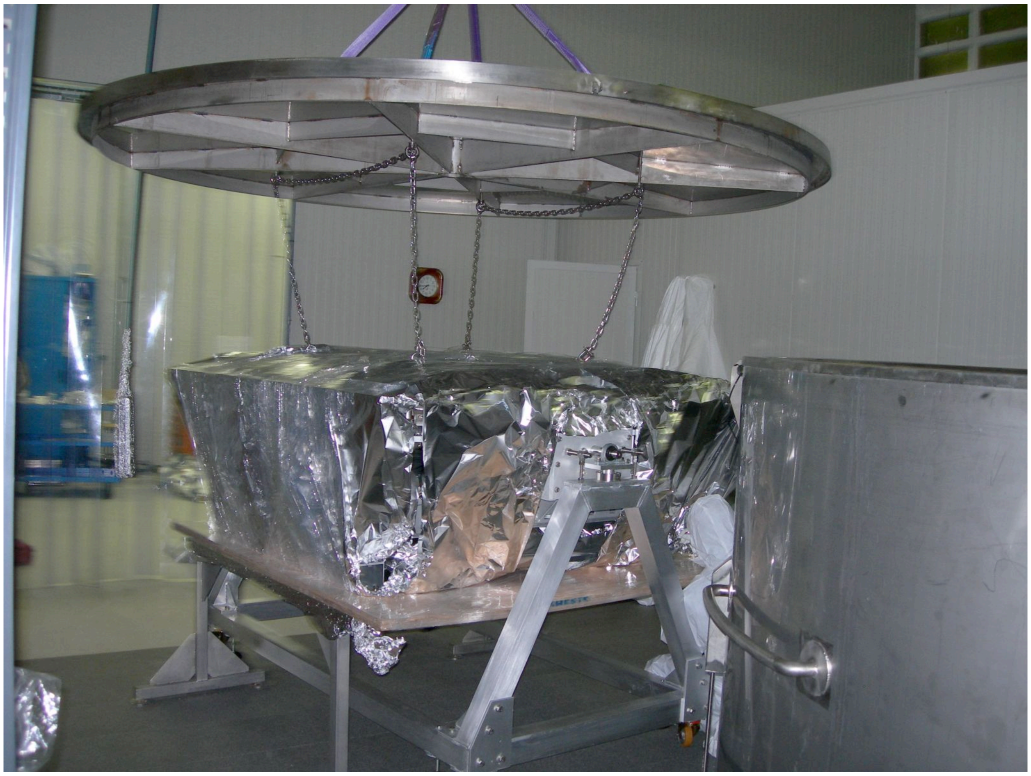


The structure is lowered in the oven and baked without disconnecting the clean lifting chains, to minimize chances of pollution.

The oven is then closed.

After bake-out the structure is wrapped in aluminum foil while still hanging below the oven cap.

The aluminum foil is added in sections and stabilized with clear stretchable polyethylene film which never touches the structure.



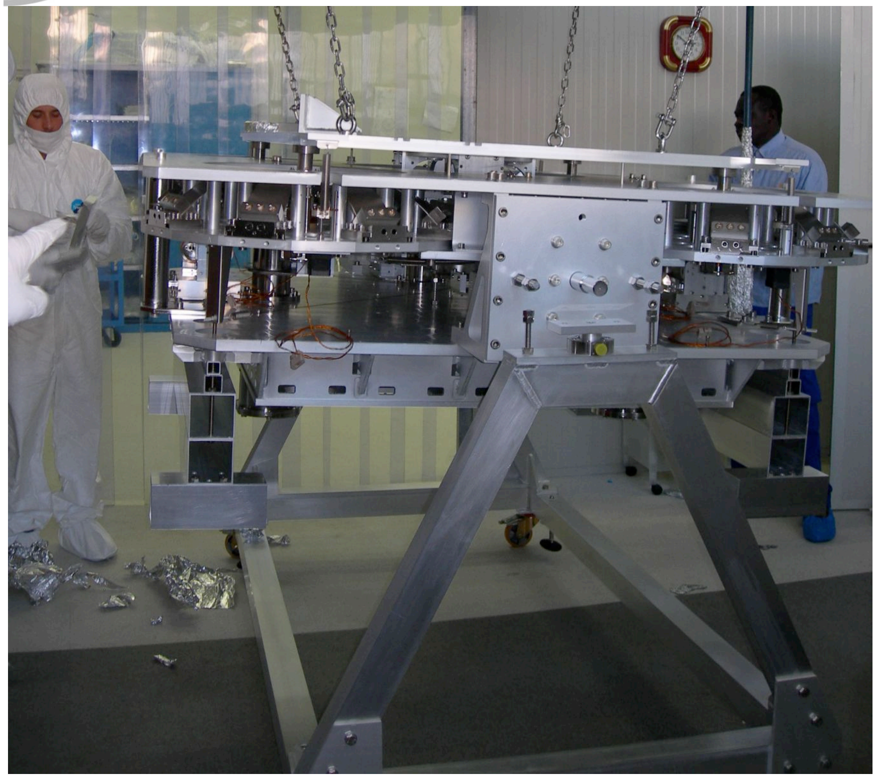
More aluminum foil sectors are added.   Then a polyethylene film coated base plate is bolted to the temporary square pipe supports.

A final polyethylene wrapping precedes the assembly of the shipping crate.

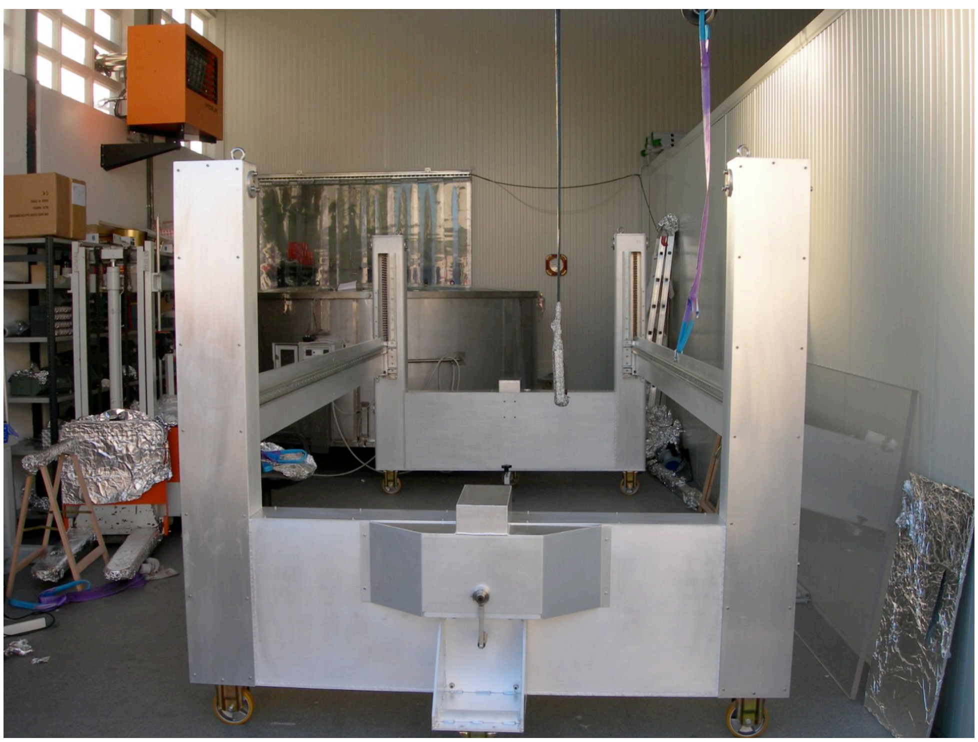
The crate bottom is screwed below the base plate, with a weldable plastic film imprisoned in between.

An air-tight weldable plastic film cap is welded to the base one, a window with a dust filter is applied on the bag to allow for air expansion during flight.

The sides and the top of the crate are added on.
All crate panels are pre-wrapped in plastic film to insure cleanliness.
The wrapping is imprisoned between the screwed together panels, leaving a good protection inside the box, while the external wrapping can be cut away.
The crate is ready for shipping.

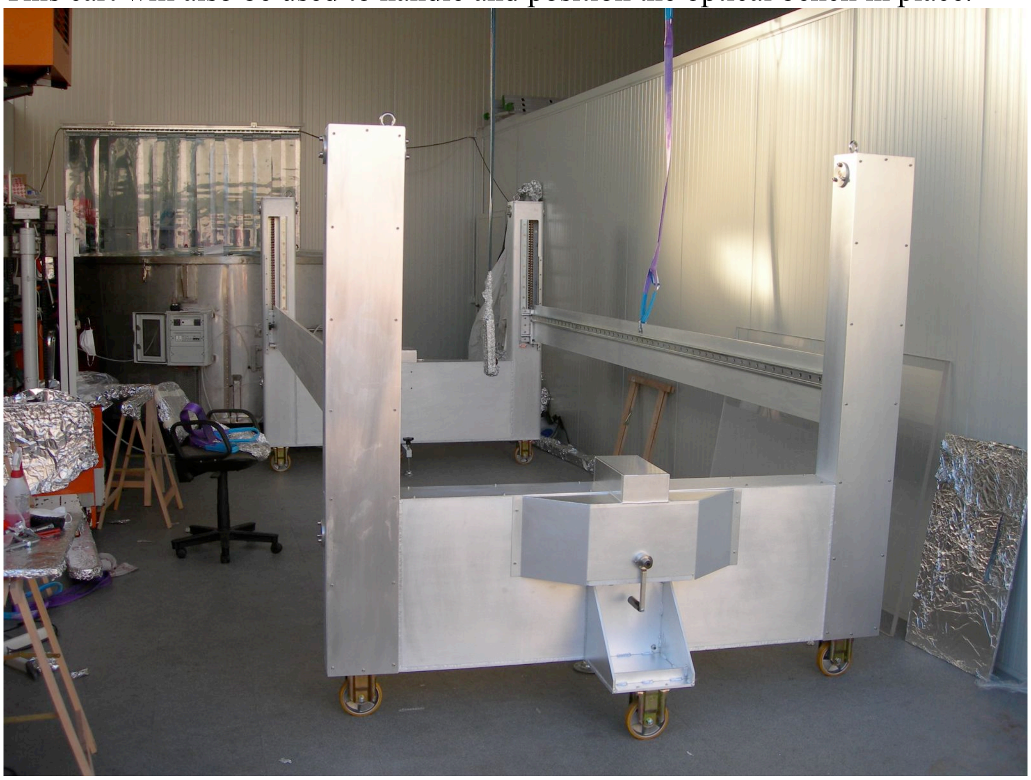


At LASTI the structure will travel on this cart.



SAS will be installed in the HAM chamber using this elevator-transfer cart, straddling the HAM chamber, half inside and half outside.

The transport cart carrying the SAS will move below this elevator/translator cart, transfer its load to it, which then will shift inside the HAM chamber and be lowered in place. This cart will also be used to handle and position the optical bench in place.



Side view of the elevator cart.

All of the above was possible thanks to the dedication and technical abilities of the SEISMBUSTERS team.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