SAT

AdV Plan for R&D, SR Construction and Short SA Upgrade

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INTRODUCTION

The AdV *Superattenuator* subsystem (SAT) concerns the modifications of the existing Superattenuators, the construction of the suspension of the new signal recycling cavity mirror (SR) and the upgrade of the short towers of the actual VIRGO baseline suspending the injection and detection benches (IB and DB) and the Input Mode Cleaner end mirror (MC). The present document aims to give a detailed presentation of the whole preliminary SAT plans for the R&D activities, the SR construction and installation, and the IB, DB and MC upgrades. It represents the initial step to setup the requirements for the operation and the integration of all the involved items. Further versions of the present document will be delivered as new information and specifications will be acquired.

SAT R&D Program

While the passive attenuation of the seismic vibrations in the detection band should be enough for AdV it is still appropriate to try to reduce the maximum compensation force on the payload, at the *Marionett*e level, during adverse meteorological conditions. Indeed, when strong windy days occurs, the tilt of the ground affects the inertial loop designed to reduce the mirror swing in the *Superattenuator* (SA) resonance range *Inertial Damping* (ID). The required compensation range at the level of the optical payload implies a noise floor (proportional to the range) that is comparable with the AdV sensitivity in the 10-20 Hz region. As detailed in this document a straightforward solution to reduce the mirror swing (and thus the compensation force) during adverse meteorological conditions would be the development of a tilt control system, based on very sensitive tilt-meters and piezoelectric actuators. Since the concerning R&D is very challenging other upgrades of the SA are also under study so to guarantee a good (even if reduced) safety margin in the 10-20 Hz region sensitivity even during windy days.

For this purpose the SAT group has established an R&D activity on tilt-meters and piezoelectric actuators, and the study of a few upgrades of the *Inverted Pendulum* (IP), *Filter Zero* (F0), accelerometers and suspension electronics.

SR Construction, Assembly and Integration Plans

The proposed conceptual design of the AdV baseline is that of a non-degenerate dual-recycled interferometer (ITF) with the implementation of a new SR cavity. SAT is called to define the plans for the construction, assembly and integration of the new SR SA.

Short Suspensions Upgrade

The sensitivity requirements of the new AdV baseline would presumably imply the upgrade of the attenuation specifications for the VIRGO short SAs suspending MC, IB and DB. While the addition of one extra filter could be sufficient for the MC the same could not be for the IB and DB SAs. According to the preliminary results of simulations, the adoption of non-degenerate recycling cavities in AdV will require the installation of some optics of the PR and SR over the IB and DB benches, with probably more stringent attenuation requirements. If more than one extra filtering stage is really needed than also the height of these SAs will have to be changed. In this case the interventions will concern not only the upgrade of the first SA stage (F0), of the IP flexible joints and partially of cabling, but also the substitution of the whole IP, the upgrade of the safety structure, the installation of a long mechanical filter chain, and the complete cabling reshuffling.

At the moment, being the attenuation specifications not yet completely established, the main case of adding only one extra filter in MC, IB and DB SAs with also the implementation of the tilt control is being planned in more detail. A more general evaluation of the IB and DB height change case is also considered together with the estimated costs.

This document is organized in five sections. The SA general specifications are presented in Section 1, while the specifications and required upgrades for AdV SA are outlined in Section 2, compared with the present performance. The SAT R&D plans are described in Section 3, and for each activity the manpower, the responsibilities (labs and people), the present status, the planning, the possible scenarios and the cost estimates are reported. Section 4 is devoted to the description of the SR construction, assembly and integration management plans. Finally, in Section 5, the executive plan for the upgrade of the short SAs is presented.

SECTION 1

SUPERATTENUATOR DESIGN AND SPECIFICATIONS

1.1 VIRGO Superattenuator Overall Design

VIRGO *Superattenuators* (see Fig.1.1) are electro-mechanical systems designed to achieve two main purposes. The first one is to achieve by a chain of mechanical filters a passive attenuation of seismic vibrations so to make the residual seismic displacement of the mirror along the beam well below the interferometer sensitivity in the detection band (i.e. above 10 Hz). The second one is to reduce the large swing of the mirror in the low frequency range (occurring below a few Hz because of wide seismic noise amplified by filter chain resonances) to allow a low noise control of the optical payload.

A complete SA chain [1] is a five-stage pendulum (Fig.1.1), where each stage is replaced by a special mechanical filter designed to attenuate the seismic vibration in all degrees of freedom. In an N-stage pendulum the horizontal motion of the suspension point, at a frequency f much higher than the frequencies of the normal modes is transmitted to the suspended mass with a reduction factor proportional to f^{2N}. In order to decrease the frequency detection threshold it is necessary to reduce the resonant frequencies of the chain and thus to increase the length of the pendula. The VIRGO chain of pendula has all its horizontal normal modes below about 2 Hz and should provide the required attenuation starting from about 4 Hz so to guarantee a good safety margin in the detection band (i.e. above 10 Hz). Vertical vibrations would be also partially transferred to the laser beam (horizontal) direction because of the unavoidable mechanical couplings between different degrees of freedom (a few %) and because of the curvature of Earth that make widely separated pendula non parallel to each other (misalignment of $3\cdot10^{-4}$ rad for 3 km-long arms). A detailed description of the VIRGO mechanical filter, exhibiting the required vertical elasticity, is given in the following Section 4.1.

The top stage of the chain is formed by another mechanical filter named *Filter Zero* (F0) suspended (by three thin wires) from a three legs elastic structure called *Inverted Pendulum* IP. The elasticity is given by a flexural joint on which the leg is based. By keeping the horizontal resonance frequency of the inverted pendulum at 30-40 mHz a significant attenuation in the horizontal direction is achieved also in the pendulum chain resonance range (100 mHz – 2 Hz).

From the last filter of the chain is suspended the payload, a system composed by the *Marionette*, the mirror and the mirror *Reference Mass* (RM). The *Marionette* allows the steering of the mirror in three degrees of freedom: the displacement along the beam direction and the rotation about other two axes. The *Marionette* supports the mirror in a cradle formed by a couple of 1.9 m long thin wires. The *Marionette* control is performed by four coils each placed at the end of a long cylinder extending from the last stage of the SA (and thus isolated from the seismic noise) acting on permanent magnets mounted on the *Marionette* arms. For this reason the last mechanical filter, named F*ilter 7* for historical reasons, exhibits four cylindrical legs displayed in Fig.1.1. The final control of the mirror displacement along the beam direction will be obtained by four coils acting on magnets glued directly on the back of the mirror. The coils are supported by RM suspended to the same marionette. The RM recoils against the mirror, keeping at rest the common center of mass.

Once suspended to the SA the mirrors will oscillate at low frequency (i.e. below the detection band) with amplitude of the order of ten microns, mainly because of the pendulum chain resonances. This wide motion, even if well below the detection band, con not been tolerated. Indeed, a too large compensation force at the level of the optical payload would be necessary. Since the noise floor of the electro-mechanical actuation system is proportional to the maximum available force, this large compensation would induce a spurious mirror displacement affecting the detection band sensitivity. In particular the electro-mechanical noise floor is mainly due to the finite dynamics of the DAC system. The 10 V range corresponds to a noise floor of about 300 nV/ $Hz^{1/2}$. The DAC board is connected to the coils, by resistors (via Coil Driver boards). Increasing the resistor the noise floor can be reduced at the price of limiting the force range. This makes important to reduce the low frequency seismic mirror swing as much as possible.

The mirror oscillation in the resonance range is maintained by the seismic noise injected at the suspension point. By applying at the level of the top stage a feedback force proportional to the velocity measured by LVDT sensors (based on the safety frame, connected to ground), through a coil-magnet actuator one can perform a “viscous” damping, reducing the quality factor of the suspension normal modes. However, the measurement of the displacement would be performed with respect to a ground and thus to a noisy structure. For this reason in VIRGO the damping of the SA resonances is performed by a control system, named *Inertial Damping* [2] (Fig.1.2), in which the error signal is referred to an inertial frame by means of accelerometers. The sensors and actuators are all placed in a pinwheel configuration. It is important to stress that the high compensation required on the top stage, implies a large noise floor. However, the induced spurious vibrations are suppressed by the entire filter chain suspended below. As shown in Fig.1.2 the sensor signals are digitized by an analog to digital converted (ADC – 16 bit) and then processed by a digital signal processor (DSP) that computes the correction signals to be sent via digital to analog converter DAC (20 bit system) to the coil magnet actuators. The DSP handles the signal of all sensors and actuators, recombines them by means of matrices, creates complex feedback filters with high precision pole/zero placements and performs calculation at a high sampling rate (10 kHz).

The damping of the vertical resonances of the filter chain is compensated at the level of the *Filter Zero*. A vertical accelerometer placed on the filter movable part (*crossbar*) is used to measure vertical motion of the suspension point. The compensation of the measured vertical displacement is made by a couple of coil-magnet actuators acting on the filter crossbar.

1.2 Passive Attenuation

The goal is thus to reduce the transmission of ground vibrations to the mirror level so to make its residual seismic noise smaller than other noise mechanisms limiting the antenna sensitivity. This result has to be achieved in the entire detection band, starting from about 10 Hz. In VIRGO, between a few Hz and a few tens of Hz, the sensitivity is limited (after seismic noise suppression) by the mirror pendulum thermal noise [3]. Indeed each mirror undergoes a spurious thermal displacement whose linear spectral density is about $2 \times 10^{-15} f^{-5/2}$ m $\mathrm{Hz}^{-1/2}$ (where f is the frequency expressed in Hz). In AdV the interferometer noise floor will be about one order of magnitude smaller (see Fig.1.3). On the other hand, the linear spectral density of the ground seismic displacement typically measured at the EGO site is approximated, from 1 Hz to tens of Hz, by the function $10^{-7} f^{-2}$ m $\mathrm{Hz}^{-1/2}$ in all directions. Enhancements of this spectral value by a few units are observed in special days in different frequency bands, above a few Hz [4]. As a consequence, the SA has to provide an attenuation of several orders of magnitude in the very low frequency range. The ratio between the two previous spectral densities (ground seismic noise vs. thermal noise) provides the attenuation specification at any frequency.

The expected residual seismic noise at the mirror level (inferred by a stage by stage measurement of the SA transfer function – see next section) is reported in Fig.1.4 and compared with the thermal noise floor in VIRGO. As previously mentioned, residual mechanical couplings, and geometric factors due to the Earth curvature, transfer along the beam the residual motion of the optical payload. A strong attenuation (of the same order of magnitude) is thus necessary in all the degrees of freedom. As shown in Fig. 1.4, the SA makes the residual mirror seismic displacement completely negligible also with the AdV configuration, where the sensitivity is just one order of magnitude below the thermal noise depicted in the graph.

1.3 Low Frequency Swing Reduction

In the resonance range, namely below the detection band, the seismic noise is amplified by the chain normal modes. The goal of the ID is to reduce the mirror peak to peak displacement keeping the interferometer locked using a limited force, so to make the corresponding electro-mechanical noise floor (proportional to the maximum force that can be applied to the optical payload) well below the detector sensitivity curve.

In order to reduce as much as possible the actuation range at the mirror level, in addition to the ID, a “hierarchical control strategy” is adopted. The larger motions (hundreds of microns) takes place below ten of mHz (tidal effects) and are compensated at the level of the top stage. As for the case of ID the compensation implies a high electro-mechanical noise floor that is filtered by the entire SA chain. The residual motion in the resonance range (around one micron) is compensated at the level of the marionette and the corresponding noise floor is filtered just by the mirror pendulum. The noise from the RM acts directly on the mirror and for this reason only small force can be applied at this level (nanometer compensations) at frequencies larger than a few Hz.

As mentioned above the DAC board noise floor is about 300 nV $Hz^{-1/2}$ (with a range of 10 V), resulting in a dynamic range of $3 \cdot 10^7$ $Hz^{-1/2}$. Using the marionette transfer function (from DAC Voltage to displacement), and requiring that noise introduced by the DAC is below the sensitivity, one can deduce the maximum displacement that can be corrected acting on the *Marionette*. This turns out to be a few microns in VIRGO. If the seismic swing of the mirror in the low frequency range exceeds this threshold a larger compensations is necessary to keep the interferometer locked. As a consequence the DAC actuation range has to be increased and the noise floor affects more the VIRGO sensitivity. Since the electromechanical noise force is proportional to the maximum force one can apply at the marionette level, it is straightforward to compute the specification also for AdV. The maximum force allowed at the marionette level corresponds to a few tenths of micron mirror position compensation. The noise due to the RM actuation range can be computed by the same argument and turns out to be negligible even in AdV.

1.4 References

[1] G.Ballardin et al., Rev. Sci. Instrum. 72, 3643 (2001).

[2] G.Losurdo et al., Rev.Sci.Instrum. 72 (9), 3653 (2001).

[3] http://wwwcascina.VIRGO.infn.it/senscurve/

[4] F.Acernese et al., Class. Quantum Grav. 21 (2004), S433-S440.

1.4 Figures

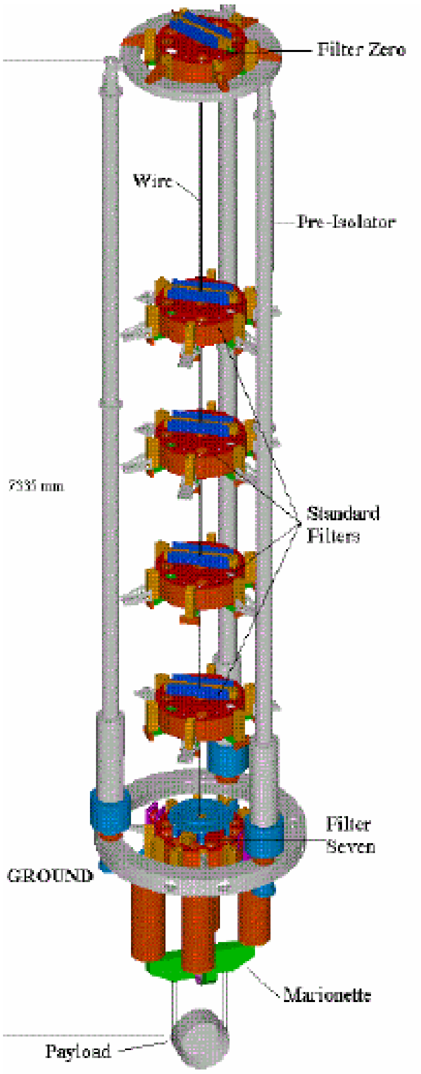


Figure 1. 1

The VIRGO Superattenuator: the mechanical filter chain to attenuate seismic vibration in the detection band, the three-leg Inverted Pendulum pre-isolator, the top filter of the chain (Filter Zero) and the Marionette are well visible. The Inertial Damping acts on the top stage to suppress the mirror swing in the range of suspension resonances (below 2Hz).

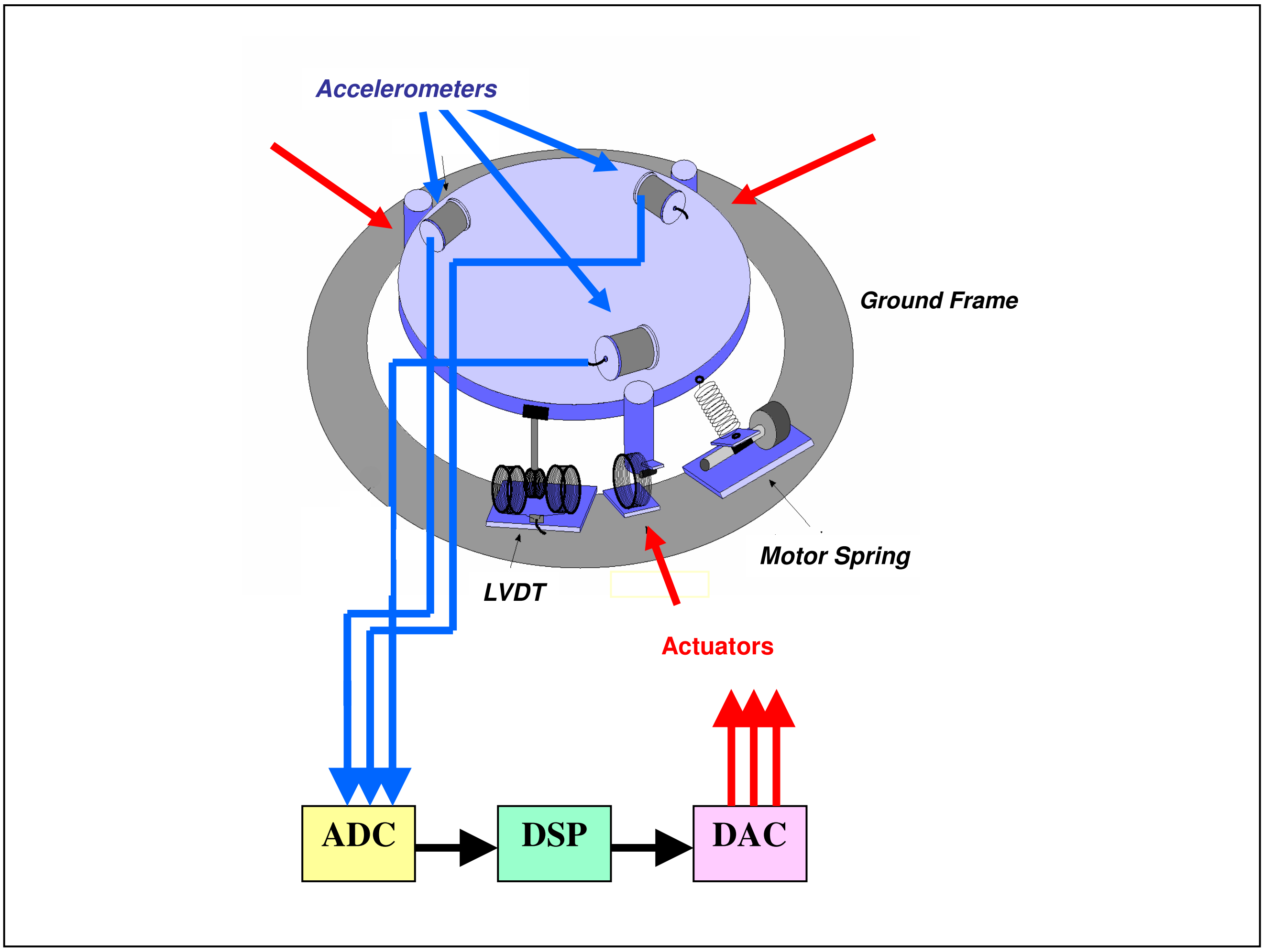


Figure 1. 2

Scheme of the Inertial Damping loop to chill suspension resonance motion. The displacement of the suspension top-stage in the horizontal plane is read by 3 accelerometers (and 3 LVDT sensors, in the ultra-low frequency range). The correction signals (computed by the electronics chain) are sent to three coil-magnet actuators.

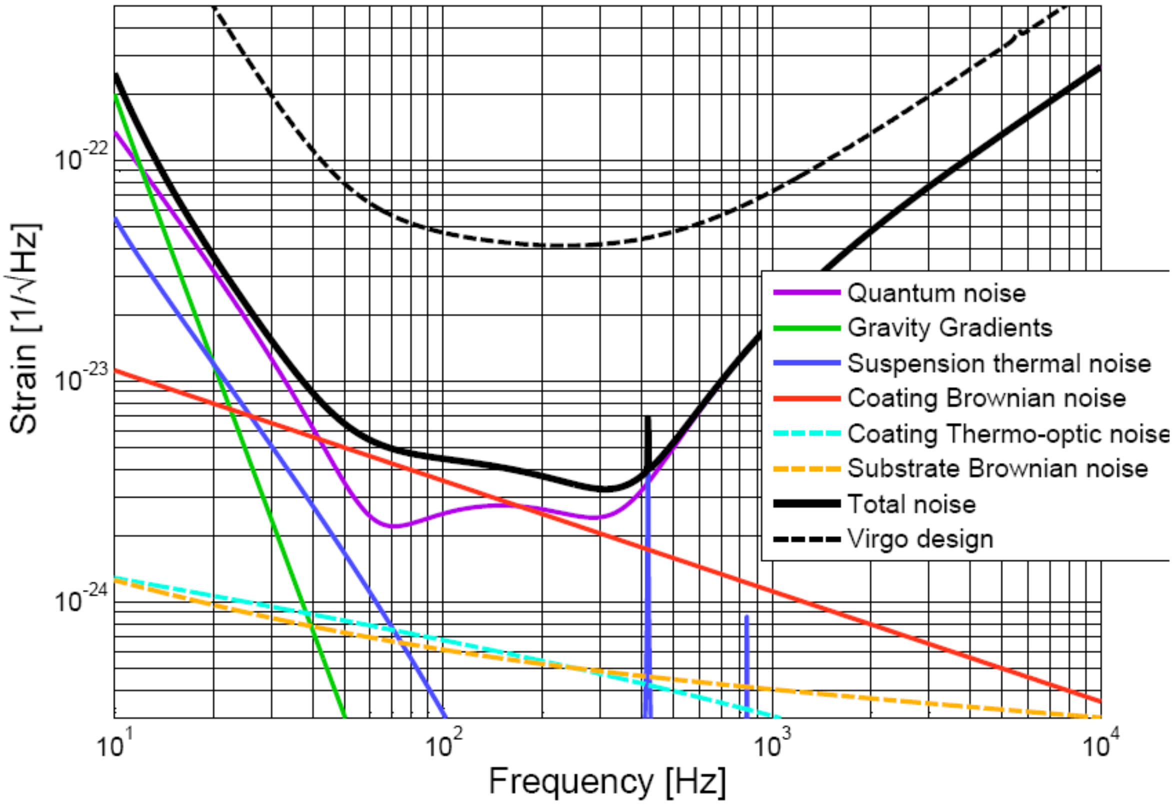


Figure 1.3

VIRGO and AdV sensitivity curves one

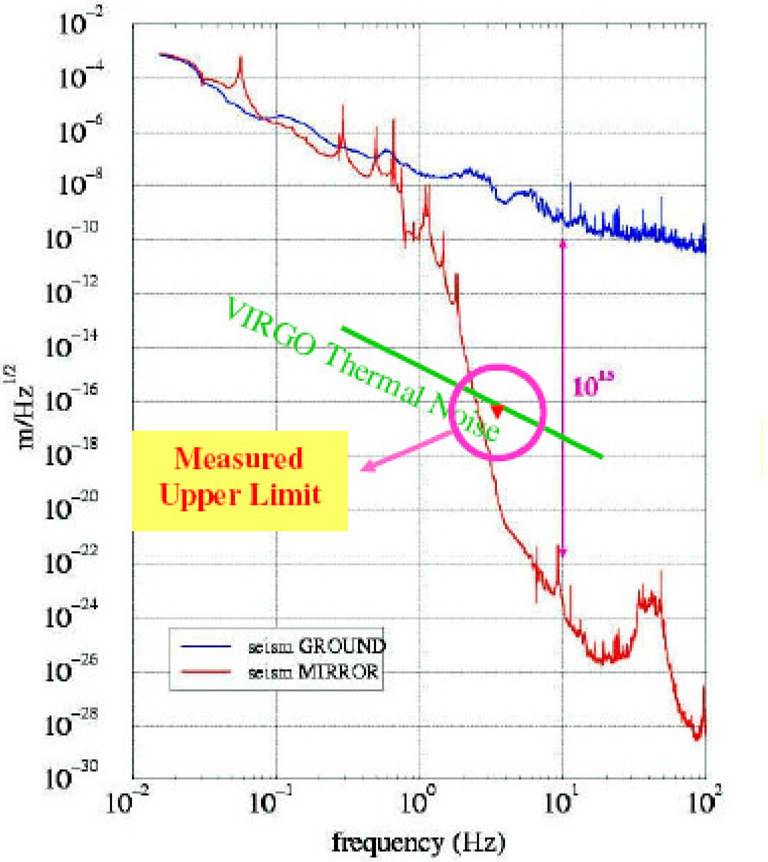


Figure 1. 4

Linear spectral density of the ground seismic displacement (blue), almost isotropic, and of the expected mirror residual seismic displacement along the beam (red). Seismic noise is expected to be well below the thermal noise starting from a few Hz. In the detection band (i.e. above 10 Hz) the residual seismic displacement is many orders of magnitude below the sensitivity curve. This means that the SA is adequate also for AdV, whose sensitivity is about one order of magnitude smaller than the VIRGO one. The measured residual seismic noise upper limit (see next section) is also displayed and turns out to be below the VIRGO sensitivity curve.

SECTION 2

Present SA Performance and Requirements for AdV

2.1 Passive Attenuation

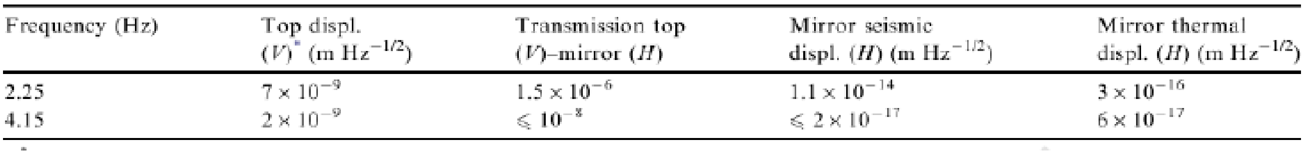
The attenuation performances of the SA filter chain have been measured in two ways. The first method [1] consists in exciting one stage of the filter chain and then to measure the residual motion on the next one. By a suitable combination of single stage mechanical transfer functions one can infer the transfer function of the entire chain. This work was repeated in a more detail in [2], considering the single stage 6 d.o.f. transfer function matrix, connecting input and output filter displacements in all the degrees of freedom. In this manner a full knowledge of the SA dynamics and the characterization of its normal modes have been obtained.

The attenuation performance of the SA was also directly measured at special frequencies [3]. This was performed by applying sinusoidal currents to the ID coil-magnet actuators located on the suspension top-stage and using the Central Interferometer [4] as a sensor of the residual mirror displacement. The measurement has been done providing both vertical and horizontal excitation lines. As shown in Fig. 2.1, despite the high displacement sensitivity of the interferometer and the long measurement time (hours), the excitation at 4 Hz was not detectable at the mirror level. Thank to this measurement an upper limit in seismic vibration transmission has been set. This demonstrated that the attenuation is enough, already at 4 Hz, to reduce the mirror residual seismic vibrations at least below the VIRGO thermal noise floor. As shown in the next table the upper limit of the residual seismic noise is already comparable with the AdV displacement sensitivity, about a factor ten smaller than the VIRGO one (indicated in table column 5).

Even if no problem is expected in the AdV configuration concerning seismic noise suppression in the detection band, the measurement will be repeated. The use of the VIRGO + interferometer (much more sensitive than the central one) should give the opportunity to reduce by more than two orders of magnitude the present upper limits and to perform in a small integration period a more systematic check, injecting noise in all the interesting frequencies on all towers. These new upper limits should confirm that even in AdV the mirror residual seismic noise is completely negligible all over the detection band.

Frequency (Hz)	Top stage displ.* ($m\,Hz^{-1/2}$)	Transmission top-mirror	Mirror seismic displ. ($m\,Hz^{-1/2}$)	Mirror thermal displ. ($m\,Hz^{-1/2}$)
2.25	2×10^{-10}	5×10^{-6}	10^{-15}	3×10^{-16}
4.1	7×10^{-11}	$\leqslant 6 \times 10^{-8}$	$\leqslant 4 \times 10^{-18}$	6×10^{-17}

Table 1 - HORIZONTAL EXCITATION: Column 1: Excitation frequency at which the experiment is performed – Column 2: Linear Spectral Density of the top stage displacement when no excitation is applied – Column 3: Mechanical transmission between the top-stage horizontal displacement and the mirror one (while at 2 Hz the line is detected at 4.1 Hz only upper limit can be given) – Column 4: Linear Spectral density of the residual seismic motion of the mirror along the beam (product of the previous two columns) – Column 5: Linear Spectral density of VIRGO thermal noise mirror displacement (a factor ten smaller in AdV).



Frequency (Hz)	Top displ. (V)* ($m\,Hz^{-1/2}$)	Transmission top (V)–mirror (H)	Mirror seismic displ. (H) ($m\,Hz^{-1/2}$)	Mirror thermal displ. (H) ($m\,Hz^{-1/2}$)
2.25	7×10^{-9}	1.5×10^{-6}	1.1×10^{-14}	3×10^{-16}
4.15	2×10^{-9}	$\leqslant 10^{-8}$	$\leqslant 2 \times 10^{-17}$	6×10^{-17}

Table 2 - VERTICAL EXCITATION: Same meaning of the column. The transmission between the vertical excitation and the horizontal beam displacement already includes the coupling factor between different degrees of freedom.

2.2 Low Frequency Swing Reduction

The capability of the ID to reduce the mirror swing [5] is usually sufficient. Indeed, in normal weather condition, the maximum peak to peak displacement at the level of the *Marionette* does not exceed a few tenths of micron. Nevertheless, as shown in Fig.2.2, an enhancement of the mirror swing (and thus of the force to be applied to the mirror) is necessary in adverse meteorological condition. The problem is due to the effects of the ground tilt seismic noise (entirely transmitted by the IP to the top stage) which shows itself with bad weather conditions (wind activity). Ground tilt motion, important below 200 mHz, is large when wind is strong enough (a few % of working time). As shown in [6], it is unavoidable that an inclination of the top stage is misinterpreted by the accelerometer sensor as a longitudinal acceleration with opposite sign. This induces a wrong correction in the ID loop and thus an additional spurious displacement of the top stage in the horizontal plane, proportional to the ground tilt. While the reference mass control force is not affected by environmental condition, during windy days a higher dynamics for the *Marionette* control force is required to keep the mirror in the working position. In VIRGO the required force range set on the

DAC-coil driver control system to keep the interferometer locked acting on the *Marionette* provides an electromechanical noise that is below the design sensitivity (see Fig. 2.3). A recent optimization study [7] (based on a wide statistics of environmental conditions) has proved that we can already reduce by a further factor 5 the present *Marionette* actuation range with only a negligible reduction of the duty cycle (around 1%). In these conditions the corresponding electronic noise curve is reduced to a level that is comparable with AdV design sensitivity in the 10-20 Hz region (see Fig. 2.4) and negligible at higher frequency

2.3 Conclusions

The unique open point on the SA is thus reduce the control noise when windy days take place. A tilt control system implemented on the SA would be the straightforward solution to reduce by at least one order of magnitude the mirror motion in 0-200 mHz range and fulfil AdV specifications with a wide safety margin in all weather conditions. This means to develop sensitive *tiltmeters* measuring ground tilt motion and to compensate tilt by piezoelectric actuators (*piezos*) located below the three IP feet. Other suspension electronics upgrades can be thought to mitigate the impact of the large swing motion taking place during windy days (see next section). Even if a failure of the tilt control R&D program will take place, this upgrades should allow to operate the required large compensation with a noise floor below the AdV sensitivity even during windy days.

2.4 References

[1] G.Ballardin et al., "*Measurement of the VIRGO superattenuator performance for seismic noise suppression*", *Rev. Sci. Instrum.* 72 (2001), 3643.

[2] P.Ruggi, Grad. Thesis Pisa Univ., "*L'attenuazione del rumore sismico nel rivelatore di onde gravitazionali VIRGO*" (http://wwwcascina.virgo.infn.it/theses/Tesi_Ruggi.doc).

[3] S.Braccini et al., "*Measurement of the seismic noise attenuation performance of the VIRGO Superattenuato*r", *Astropart. Phys.* 23 (2005), 557.

[4] F.Acernese et al., "*First Locking of the VIRGO Central Area interferometer with suspension hierarchical control*", *Astropart. Phys.* 20 (2004), 629.

[5] G.Losurdo et al., "*Inertial Control of the mirror suspensions of the VIRGO interferometer for gravitational wave detectio*n", *Rev. Sci. Instrum.* 72 (2001), 3653.

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[7] S.Braccini: http://wwwcascina.virgo.infn.it/advirgo/biweekly/2008/2008-10/braccini_161008.ppt

2.5 Figures

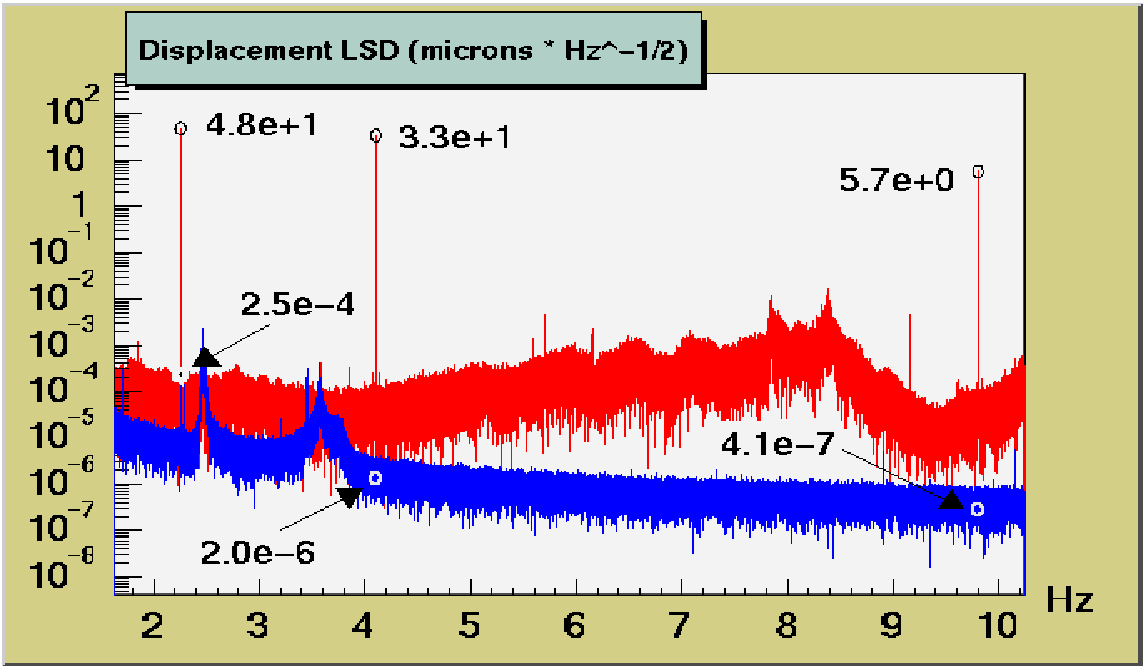

Figure 2. 1

Linear Spectral Density of the top stage horizontal displacement as measured by the LVDT sensors (red) and mirror one (blue), expressed in μm Hz$^{-1/2}$. The excitation around 2 Hz is detected at the mirror level (even if strongly attenuated by the filter chain), while the line at 4.1 Hz cannot be distinguished from the interferometer noise floor. At this frequency only upper limit on the transmission of the horizontal seismic noise can be given. Similar results were obtained when the filter chain suspension point is excited along the vertical direction (see table 1 summary).

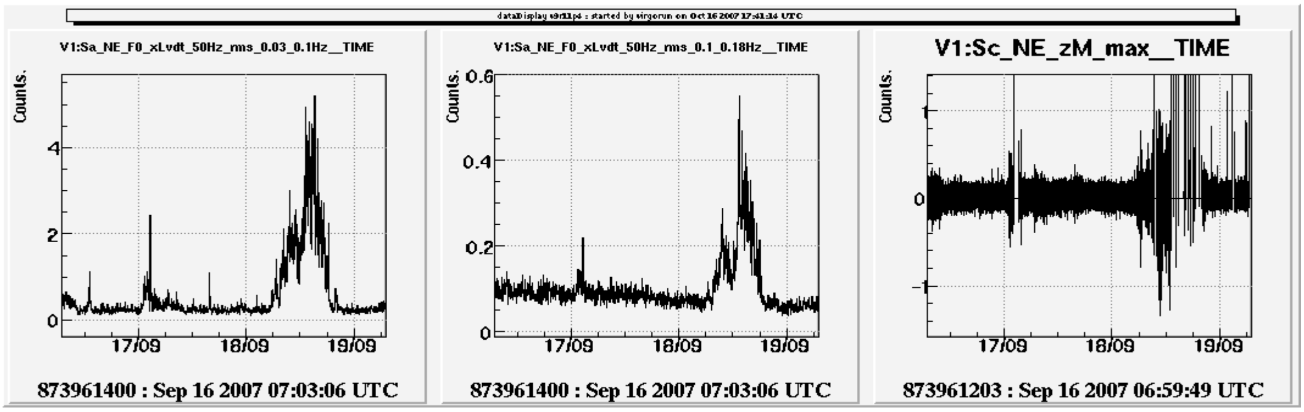

Figure 2. 2

The signals in the first two plots (time evolution of the rms values of the top stage LVDT sensors in given frequency bands) indicate the wind and sea activity respectively. In the third plot the time evolution of the maximum value of the marionette compensation voltage computed each 1 s (measured using 20 kHz data) to keep the interferometer locked is displayed. With bad weather condition the maximum correction reaches 1 V, corresponding to a *Marionette* displacement around 4 microns. After a few hours the interferometer unlocks (third plot out of range). The time is expressed in days.

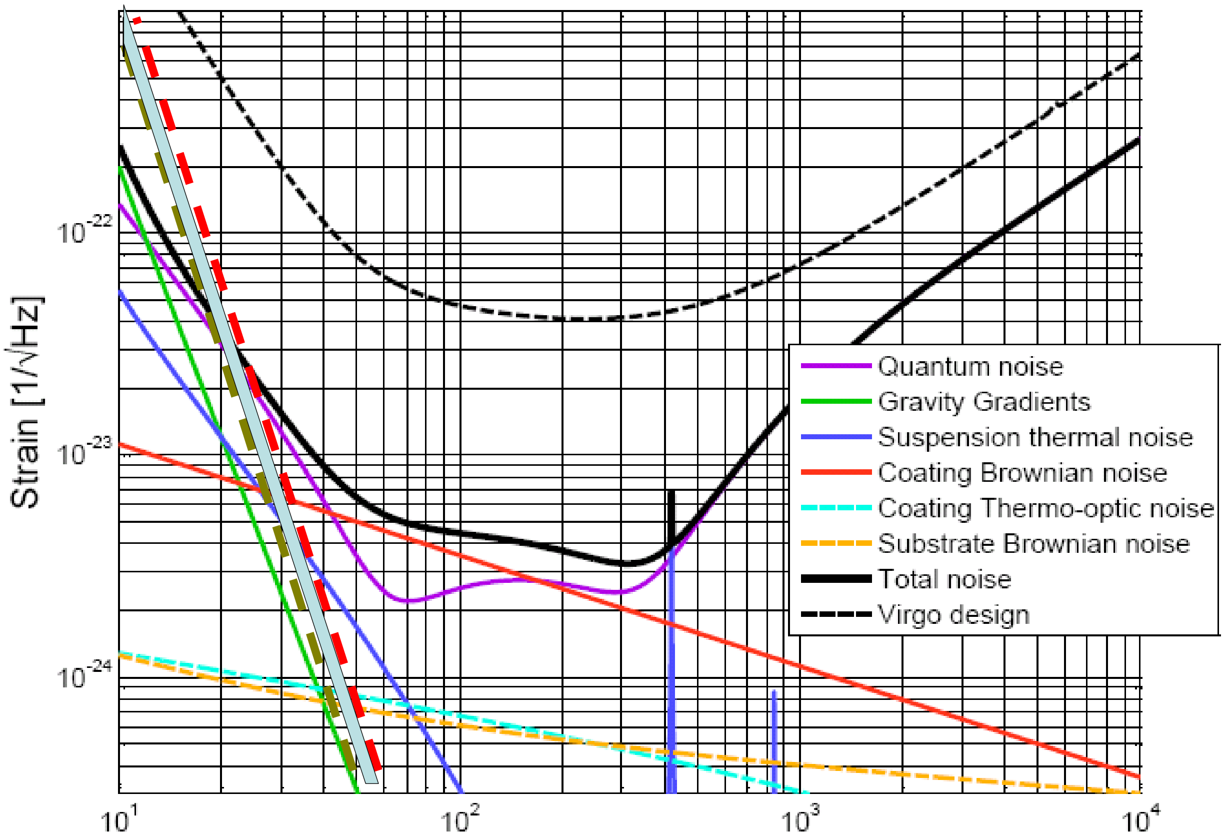

Figure 2. 3

Linear spectral density of the marionette electro-mechanical noise, with the present actuator force range, without DAC non-linear noise (thick-dashed green) and with DAC non linear noise (thick-dashed red), compared with the VIRGO (dashed) and AdV (continuous) sensitivities. The induced noise is below the VIRGO sensitivity curve but affects the AdV sensitivity in the 10-20 Hz region.

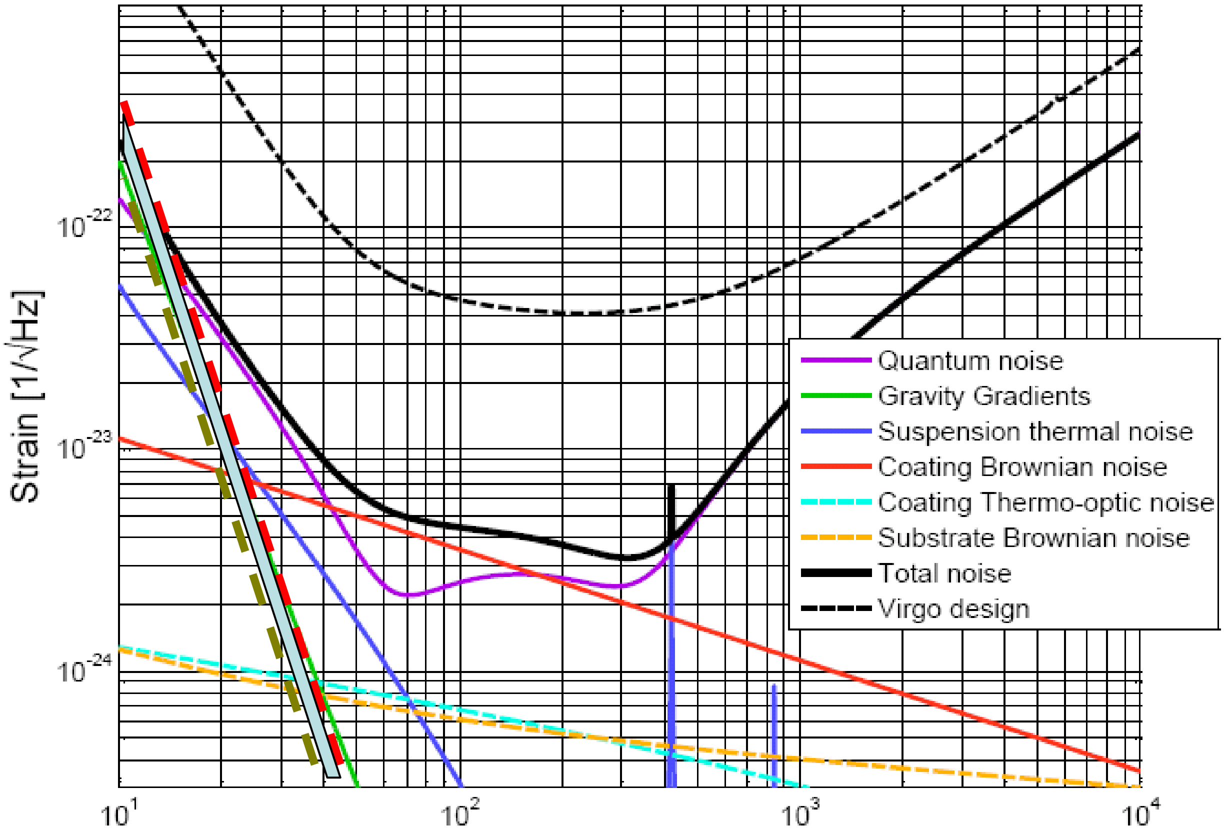

Figure 2.4

The reduction by a factor 5, already applicable for VIRGO, would lower the DAC noise to almost the level of AdV sensitivity in the 10-20 Hz range.

SECTION 3

SAT Suspension System R&D

3.1 SAT R&D Guidelines

As mentioned in the previous section, a tilt control system implemented on the SA would be the straightforward solution to reduce by at least one order of magnitude the mirror swing in 0-200 mHz range and fulfil AdV specifications with a wide safety margin in all weather conditions [1]. This means to develop sensitive *tilt-meters* measuring ground tilt motion (10^{-8} rad $Hz^{-1/2}$ in the tens of mHz region - a challenging target), and to compensate tilt by piezoelectric actuators (*piezos*) located below the three IP feet. Piezos could be useful even without tilt-meter since coarse information of the ground tilt motion could be provided by combining information coming from accelerometers and LVDT sensors on different towers. The possibility to perform a tilt control was already foreseen in VIRGO suspension and thus a location for tilt-meters and piezos is available. This makes the impact in the AdV construction plan negligible.

Other suspension electronics upgrades are possible to reduce the noise induced by the large mirror swing compensation occurring during windy days. This should allow achieving an acceptable safety margin even if the tilt control R&D program will not provide satisfactory results. In particular: *i*) A selection of DAC chips, with a higher number of bits and higher sampling frequency to decrease the noise content is in progress. The first selection (LIGO DAC) was tested [2], providing only a slight improvement (factor 1.5 noise reduction). However a reduction of a few units in DAC noise could be expected. *ii*) To split the control action (presently on the cavity end mirrors) on two mirrors per cavity should be not a challenging task, reducing by a factor 2 the control noise. A test will be performed during VIRGO+ commissioning. *iii*) Improvements in the control noise filtering (emphasis de-emphasis) can also be thought, even if saturation effects limit the possible reduction factor to a few units. *iv*) New coil-driver boards [3] with the possibility to remotely tune the voltage partition (and thus tune the force dynamics with atmospheric condition) were prepared. They were tested on the ITF in the control loop acting at the level of the coils mounted on a *Reference Mass*. During normal days, the marionette control could be tuned in “low noise” configuration, with a floor well below the AdV sensitivity. When strong wind takes place a “high noise” configuration is set. This means that only for a few % of working time the ITF will operate with a control noise at the limit of the AdV sensitivity in the 10-20 Hz range.

Use of IP monolithic legs would help to make the piezo action safer, avoiding dangerous yielding in the junctions. In addition the new legs would displace to higher frequency the leg main flexural resonance (from 9 to 20 Hz), allowing to increase ID gain. Even if the filter chain would remain assembled, the leg replacement has an impact of about 2 weeks per tower. A new IP prototype was already designed simulated, built and it is under assembly on site. A decision about its implementation on AdV will be taken after the test (spring 2009).

The noise of present accelerometers is adequate for AdV, as can be seen by measuring ID performance when tilt noise is small. Some electronics upgrades are in any case necessary to increase their robustness (PID digital control). An R&D on higher sensitivity accelerometers is in progress in Naples-Salerno (University funds). Only if much better performance will be achieved a replacement of all accelerometers could be thought (with no strong impact in AdV construction plan).

A study to increase the thickness of top filter centering wires so to displace its internal resonances at higher frequency (and its impact on the construction plan) is in progress. This upgrade could allow increasing the ID gain by a few units.

The ADC-DSP-DAC architecture (100% duty cycle in VSR1) was the key element for the approaching of the VIRGO design sensitivity in the low frequency range. The new DSP board under test in VIRGO+ will solve the memory saturation problems expected with the control strategy increasing complexity. Some technical improvements on digital and analog boards are also scheduled (see AdV Suspension Electronics Plan).

The SAT R&D plan for the SA upgrade was divided in six items: Tilt-meters, Piezoelectric actuators, Inverted Pendulum, Filter 0, Suspension electronics and Accelerometers.

3.2 Tilt-Meters

The tilt-meter design (see Fig. 3.1) makes use of a pivoting bar (a balance) accommodated inside a rigid box. The sensitivity depends on the capability to reduce as much as possible the balance angular resonance frequency. Above its angular resonance the balance is freely rotating around the pivot bar and its displacement, relative to the tilting box, is read by two displacement LVDT sensors. The goal is to reach an angular sensitivity of about 10^{-8} rad $Hz^{-1/2}$ in the tens of mHz region. Two of these sensors, aligned along the main axis of the interferometer, will be installed within the vacuum vessel of each SA on top of the ring platform (Fig. 3.2) supporting the IP legs.

The mechanical set-up of this instrument is quite challenging and it exhibits a high feasibility risk.

Involved Labs: INFN Roma 2 (Roma Tor Vergata) and INFN Pisa.

Responsible: A. Giazotto.

Manpower: A. Giazotto, Y. Minhenkov, F. Frasconi, R. Simonetti, G. Gennaro, INFN-Pisa Electronics Group for cabling and electronics.

Concerning R&D: The tilt-meter prototypes are presently developed in the framework of the *"Interferometer Sensitivity at Low Frequencies"* R&D, already approved and supported by EGO [1].

Present Status: Two Prototypes have been already assembled. No problem appeared in the electronics chain, while serious problems took place in the yielding of the flex joints. The prototypes were upgraded two times to reduce pre-stresses in the flex-joints, but again they break during operations. One of these prototypes has been equipped with stiffer flex joints and further modified with special care, also to guarantee a more reliable fine tuning of the pivoting bar. Tests are in progress and will continue in the next months.

Planning for Possible Scenarios:

- **Short Term Plan:**
  Continue tests up to summer 2009
- **Long Term Plan:**
  - **Satisfactory R&D Results:**
    - Operate two tilt-meters the VIRGO central area in the second half of 2009
      - Setup the apparatus
      - Monitor the ground tilt noise
      - Study a possible feed-forward tilt noise compensation
    - Install two tilt-meters in SAFE by the beginning of 2010
      - Define the assembly procedures
      - Verify the high vacuum compatibility
      - Study the tilt noise compensation performances
      - Validate by spring 2010
    - If accepted for AdV VIRGO
      - Quantity: **22 pieces** (14 for 6 long SA + SR , 6 for 3 short SA, 2 spares)
      - Call for tender by summer 2010
      - Production of electrical and mechanical components by the end of 2010
      - Prepare the installation by spring 2011
        - Clean the mechanical components
        - Assembly
        - Characterization and validation tests
        - Inventory and storage
  - **Unsatisfactory R&D Results:**
    - Optimization of the actual ID performances

- Study of possible upgrade of the actual suspension control strategy in SAFE, using the IP piezo-actuators to compensate the low frequency tilt error signal from the accelerometers.

3.3 Piezoelectric Actuators

The most suitable piezoelectric actuators available on the market turned out to be the piezoelectric actuators P-239.30 (by *Physik Instrumente*). They provide a force of 4500 N, and a dynamic range of 430 microns. An experimental set-up made of an IP base ring and three LVDT sensors to monitor its displacement with respect to the ground will be set-up in SAFE in the next months. The mechanical structure of the IP was designed taking into account the possibility to implement a tilt control: an elastic element was embedded within its feet (see Fig 3.2).

The behavior of this special IP base springs need also to be better investigated. Problems in terms of noise due to e.m. pick up could come from the required high voltage power supply. As mentioned above the impact of the piezoelectric actuators installation is small since their implementation was already foreseen in the present design.

It is possible to conceive the use of these actuators to compensate the excess of vertical seismic noise on the suspension top stage, presently exciting the angular payload motion.

If the R&D will be satisfactory these piezoelectric actuators will be installed in all the AdV SAs.

Involved Labs: INFN Pisa.

Responsible: F.Frasconi.

Manpower: F.Frasconi, C.Magazzù.

Concerning R&D: *“Interferometer Sensitivity at Low Frequencies”* R&D, already approved and supported by EGO.

Present Status: Piezoelectric actuators P-239.30 have been purchased. The driving board is being prepared.

Planning for Possible Scenarios

- **Short Term Plan:**
  Install in SAFE by the end of 2008
- **Long Term Plan:**
  - Validation and characterization in SAFE R&D by the end of 2009:
    - Assembly and tests:

  - Define the assembly procedures
  - Verify of the IP base springs behavior
  - Verify of the high vacuum compatibility
  - Measurement and compensation of possible e.m. noise coupling
  - Implement into the ID strategy (with/without tilt-meters)
  - Validate.
- **Satisfactory SAFE R&D Results, and Accepted for ADV:**
  - Quantity: **33 pieces** (21 for 6 long SA + SR, 9 for 3 short SA, 3 min. spares)
  - Call for tender
  - Characterization and validation test
  - Inventory and storage
  - Installation
- **Unsatisfactory SAFE R&D Results:**

  Piezoelectric actuators will not be adopted in AdV.

3.4 Inverted Pendulum

Starting from the present design, and reducing the impact of the changes at the minimum level, a new IP has been conceived. The new monolithic legs (Fig. 3.3) will be about 6 m tall (identical to the present SA ones). The sectional area will be increased, passing from a cylinder with an outer diameter of 130 mm diameter to a new one of 160 mm, while the thickness goes from 2.5 mm to 5 mm.

A prototype having its structural modes at frequencies higher than the actual IP was constructed. The new IP should work as it has been designed. The impact on the AdV assembly is not negligible since it should be installed in all the 6 existing long towers and on the new SR chain. As a consequence the main scopes of this R&D are two: to test the feasibility of a better designed IP to increase the gain of ID longitudinal loops, and to understand, at the same time, if its implementation is strictly necessary.

Involved Labs: INFN Pisa.

Responsible: F.Frasconi.

***Manpower*:** F.Frasconi, R.Passaquieti, C.Bradaschia, 2 INFN-Pisa technicians.

Concerning R&D: The implementation of the new IP is part of the *“Interferometer Sensitivity at Low Frequencies”* R&D.

Present Status: The simulation to study its performance is available. The construction of the new IP prototype is done and it is on site ready for installation in SAFE.

Planning for Possible Scenarios:

- **Short Term Plan:**

  Install this new IP at EGO West 1500 m building by the end of 2008
- **Long Term Plan:**
  - Validation and Characterization in SAFE R&D by the end of 2009
    - Define the assembly procedures
    - Cleaning of components
    - Verification of the high vacuum compatibility
    - Tuning of the main longitudinal modes
    - Measurement of the seismic noise attenuation performance
    - Measurement of the ID performance
    - Validate
  - **Satisfactory SAFE R&D Results, and Accepted for ADV:**
    - Quantity: **9 pieces**: (6 long SA + SR, eventually 2 upgraded IB and DB)
    - Call for tender by spring 2010
    - Prepare the installation
      - Cleaning of components
      - Test
      - Inventory and storage of components
    - Installation of new IP from 2011
  - **Unsatisfactory SAFE R&D Results:**

    Monolithic IP will not be adopted in AdV.

3.5 Filter Zero

The F0 design is being presently reviewed to move to higher frequency the resonances of its movable part adopting a more rigid mechanical structure. This could help to extend the bandwidth and the gain of the vertical ID. The reduction of the total mass supported by the F0 *crossbar* (two vertical accelerometers and the heavy screw endless gear mechanism for the chain vertical positioning) is likely to be important in achieving that goal. Preliminary studies show that a sufficient increase of the crossbar resonant frequencies could be obtained stiffening the four centering wires, constraining the crossbar to move only along the vertical direction. Other more relevant modifications that would imply the substitution of all the F0s require a deeper understanding and strong evidence of their benefits. Other less invasive solutions, involving the optimization of the vertical ID control, are being also studied.

Involved Labs: INFN Pisa.

Responsible: R.Passaquieti.

Manpower: R.Passaquieti, S.Braccini.

Concerning R&D: The design of a new F0 is part of the *"Interferometer Sensitivity at Low Frequencies"* R&D.

Present Status: The assembly of the simulation algorithms is in progress.

Planning for Possible Scenarios:

- **Short Term Plan:**
  - F0 Upgrades Simulation and Design/Strategy Definition by spring 2009:
    - Setup the filter model
    - Study the model inner modes
    - Evaluate the effects on the suspension ID
- **Long Term Plan:**
  - Test of F0 Upgrades in SAFE by spring 2010:
    - Build the components
    - Install the new F0
    - Verify ID performance
    - Validate
  - **Satisfactory SAFE R&D Results, and Accepted for ADV:**
    - Quantity of modified parts: **10 sets** (6 long SA + SR, 3 upgraded MC, IB, DB short SAs)
    - Call for tender by the second half 2010
    - Installation of the new F0s from 2011
  - **Unsatisfactory SAFE R&D Results:**
    F0 will remain unchanged in AdV.

3.6 Suspension Electronics (detailed in AdV Susp. Electronics Plan)

The detailed plan for Suspension Electronics will be agreed with the AdV electronics system and circulated in another document. In this document we will provide just a short description of the activities of the INFN-Pisa Suspension Electronics group for AdV.

3.6.1 Control Digital Electronics

As mentioned above ADC-DSP-DAC architecture was very important to approach the VIRGO design sensitivity in the low frequency range. This solution was adopted also in the control of the injection system, replacing the old design electronics. No noise excess or unlocks was ascribed to digital suspension electronics during VSR1 (i.e. the duty cycle can be assumed around 100%). The new DSP, under test in VIRGO+ commissioning, should widely solve the problem of memory saturation one can expect in the increasing of the control strategy complexity. Indeed the new board (with a 6 DSP architecture, see [4]) will exhibit a very high computing power respect to the old Virgo single DSP board. Moreover the new Photodiode Readout Scheme (and the new Global Control Architecture) both based on more recent CPUs and faster digital optical links, allows a better conditioning and a higher frequency band of the error signals. Thanks to these changes it is possible to perform better control strategies and to design more effective digital filters. No major change is foreseen on the processing board for AdV. Nevertheless a daughter-board has to be developed to manage the digital signals exchanged with the suspension electronics equipped with digital input or output. The architecture should be very similar to the one already implemented for the global control signal in Virgo and in Virgo+, but in this case it refers also to local control signals. Digital data link was already studied in INFN Pisa.

Some improvements could be achieved for the analog/digital converters, ADCs and DACs, in particular about the effective number of bits, in order to reduce the quantization noise introduced during both the sensing and the driving. The ADC of the control electronics, in the Virgo and Virgo+ configuration, are located in the same unit of the processing electronics and are used mainly to convert signals coming from the suspension electronics, located close to the respective tower. In AdV some of these converters will be placed directly in the suspension electronics. Independently of their location, an improvement of their performances (mainly in terms of quantization noise reduction) should be achieved. A candidate ADC converter was already selected and tested together with a DAC converter and a PLL circuitry capable of letting the two converters operate at different rates synchronously with VIRGO timing signal. Such studies were partially integrated in the R&D activity for the upgrade of Virgo control electronics together with new DSP design.

As mentioned in the introduction of the present chapter, the DAC noise is more critical that ADC board one (probably already compatible with AdV specifications). As shown in Fig.2.4, the current performance is still a limiting factor for the achievement of the AdV sensitivity in the low frequency region, due to the direct coupling with the coils actuating on the test masses. As already mentioned specific R&D is dedicated to the selection of a suitable chip, with a higher number of bits respect to now and higher sampling frequency to decrease the noise content.

3.6.2 Front-End Suspension Electronics

The Coil Driver boards were upgraded for Virgo+ and their current performances, in terms of noise, linearity and frequency band are already compliant with the AdV requirements [3]. R&D related to the development of an engineered version of coil driver prototypes is now closed. What still remain to be studied is the use of high power – low noise modes with marionette actuators. INFN Pisa will carry on some test during VIRGO+ commissioning phase. The major upgrade in AdV is related to the introduction of a digital input, through a fast optical link connected to an on board DAC and to a selection of a new DAC converter (the one in use is obsolete). The digital link is particularly important since the actuation signals of the coil are the most critical for the ITF sensitivity, and a connection between the control and processing electronics that is virtually unaffected by environmental interferences is strongly desirable.

The LVDT sensors actually used to measure the position of the top stage of the suspended chain in the very low frequency band are enough sensitive for AdV. However their conditioning electronics needs to be upgraded for two main reasons. The first one is the age of the electronic components used in the driver, that are now obsolete and difficult to maintain. The second one concerns the possibility to implement a digital output on the driver by using an onboard ADC to immediately digitize the position signal, and sending it to the processing and control electronics through a digital link. This solution has the clear advantage to greatly reduce the possible interferences and electrical pick-ups from the electromagnetic noise present in the environment. Finally it is foreseen to use such new drivers also to manage the LVDT sensors used inside the accelerometers of the top stage; this solution will avoid the development of hybrid electronic board and will make more logical and easy to maintain the full suspension electronics. INFN Pisa is being studying a new design for LVDT electronics since a few years.

As mentioned in the previous sections, the accelerometer sensitivity is adequate for AdV VIRGO. During calm days (when tilt is small) the accelerometer noise is low enough to make the residual top-stage residual motion small enough for AdV. However a few upgrades to make the system more robust will be implemented in AdV. The main one concerns the driving electronics: apart from the use of an external LVDT driver and the introduction of a digital output for the acceleration signal, as already stated in the previous section, the replacement of a digital feedback instead of the analog one currently in use will be made. The implementation of such digital system would allow the design of more effective feedback for the internal loop, resulting in a wider frequency band, in an improved robustness and in improved noise perfomance. Of course for this aim some suitable additional electronics has to be hosted on the driver, namely an ADC to digitize the position signal coming from the LVDT, a DSP for the digital filtering, and a DAC for the actuation on the internal coil. In addition to the studies carried on for ADC and DAC converter mentioned in the previous section, a few different options for the digital controller implementation were investigated by INFN Pisa. Such controller could be implemented with either a devoted DSP processor or with one of the multi-DSP boards developed by INFN Pisa handling several sensors at a time or with fast FPGA.

Involved Labs: *INFN Pisa*

Responsible: A. Gennai

Manpower: E&S Pisa group with contributions by *EGO* personnel (see detailed document by A.Gennai)

Concerning R&D: All these activities are already financed by EGO.

Present Status: The DSP and the coil drivers will be tested in *VIRGO+*.

Planning for Possible Scenarios: The specifications for AdV were already defined.The plan for DSP and Coil Driver is defined in the *VIRGO+* general plan.

- **Short Term Plan:**
  - **Installations for VIRGO+:**
    - Installation and validation of new DAC boards
    - Installation of new DSP
    - Installation of new coil drivers
- **Long Term Plan:**
  - **Suspension electronics upgrades :**
    - DSP
    - ADC
    - DAC
    - LVDT boards
    - Motor drivers

3.7 Accelerometers

The sensitivity of the present accelerometers (better than 10^{-9} (m/s^2/√(Hz)) in the range 0-2Hz) seems to be adequate for AdV. We have discussed in the previous paragraph the electronics upgrades to increase their robustness. Moreover backup items are also necessary to favourite an immediate replacement if a malfunctioning occurs. Indeed the accelerometers presently in action on VIRGO towers are working since many years and ageing effects could be figured out.

The INFN Naples group is developing, in collaboration with the Salerno University, a special monolithic accelerometer [5], based on an existing model developed at the Pisa University. If the developed instrument will exhibit better performance a replacement of all accelerometers could be considered.

Involved Labs: INFN Pisa in collaboration with INFN Naples

Responsible: A.Gennai

Manpower: E&S Pisa group with contributions by EGO personnel (TBD)

Concerning R&D: This upgrade, coordinated by the INFN Pisa group, will be partially financed by EGO. The activity of the INFN Naples and Salerno University groups is presently financed by independent channels.

Present Status: The accelerometer exhibited a 100% duty cycle during the run. When the weather is good the measured performance seems to be enough, even if a better analysis will be necessary. An excess of noise below 200 mHz takes place because of tilt, masking instrument noise floor. The INFN Pisa electronics group will perform some measurements to characterize the accelerometer noise. This should enable to understand if major improvements are really necessary.

Planning for Possible Scenarios:

- **Short Term Plan:**
  - Characterization of the accelerometer noise.
- **Long Term Plan Options:**
  - Maintenance of actual accelerometers and construction of 3longituidinal + 2 vertical accelerometers for the SR chain.
  - Replacement of all the accelerometers:
    - **33 horizontal** (3x (6 Long SA+SR), 3x3 Short SA, 3 sp.)
    - **22 vertical** (2x (6 Long SA+SR), 2x3 Short SA, 2 sp.)

3.8 SAT R&D Implementation Plan and Deliverables

Table 3.7a – AdV SAT: R&D Activities Implementation Plan

Tasks and Deliverables	**2008**		**2009**		**2010**		**2011**		**2012**	
IP prototype install. and test in SAFE		■	■	■			░	░		
Piezos install. and test in SAFE		■	■	■			░	░		
Tilt-meter tests		■	■	░			░	░		
Tilt-meter install. and test in CITF				■			░	░		
Tilt-meter install. and test in SAFE			■	■	■		░	░		
F0 simulation and design		■	■	░			░	░		
New F0 installation in SAFE			░	■	■		░	░		
Accelerometers Upgrade		■	■	■	■		░	░		
Suspension Electronics Upgrade		■	■	■	■		░	░		
Deliverables:										
IP prototype validation			░	🟩			░	░		
Piezoelectric actuators validation			░	🟩			░	░		
Tilt-meter validation			░	🟩	🟩		░	░		
F0 design validation			🟩	░			░	░		
F0 performance validation			░	🟩	🟩		░	░		
Accelerometer upgrade design			░	░	🟩		░	░		
Susp. Electronics upgrade design			░	░	🟩		░	░		
Upgrade Production			░	░		🟩	🟩	░		
Installation Preparation			░	░			🟩	░		

3.9 SAT R&D Manpower Estimate

Table 3.8a – Manpower for SAT R&D Activities

Task	Eng/Physicists									Mech.Technit.			Electr. Technit.			
IP	A	B						H		J						
Piezoelectric Act.		B								J			M			
Tilt-meter		B	C	D							K	L		N		P
F0 upgrade	A				E					J						
Accelerometers						F	G		I					N	O	P
Susp. Electronics						F	G			J				N		P
Total	9									3			4			

Legend

A: R. Passaquieti [1]

B: F. Frasconi [1]

C: A. Giazotto [1]

D: Y. Minenkov [2]

E: S. Braccini [1]

F: A. Gennai [1]

G: D. Passuello[1]

H: C. Bradaschia[1]

I: INFN Napoli-Università Salerno

J: INFN Pisa technician

K: R. Simonetti [2]

L: G. Gennaro (PROMEC)

M: C. Magazzù [1]

N: INFN Pisa Electronics

O: INFN Napoli Electronics

P: EGO Electronics Dept.

1) **INFN Pisa**
2) **INFN Roma 2 (Tor Vergata)**

3.10 SAT R&D Costs Estimate

In this table we report, in case of R&D success, the costs of the implementation of the upgrades.

Table 3.9a - Summary of Required Components and Costs for R&D Installation in AdV

ITEM	6 Long SA + SR	Short SA (IB – DB)*	Spare	Tot Quantity	Unit Cost k€	Total Cost k€
IP Long SAs	6+1	0	0	7	25	175
IP other SAs	0	2*	0	2*	25	50*
Piezoelectric Actuators	18+3	9	3	33	2	66
Tilt-meters	12+2	6	2	22	6	132
Upgraded Filter 0	6+1	3	0	10	4	40
Long + Vert. Accel.(opt.1)	3 + 2	0	3+2	6 + 4	6	60
Long + Vert. Accel.(opt.2)	21 + 14	9 + 6	3+2	33 + 22	6	330
Sum (opt.1)						473 (523)*
Sum (opt.2)						743 (793)*

* Case of IB an DB SAs elongation

Opt.1: maintenance of actual accelerometers and construction of **only** the ones for AdV SR

Opt.2: replacement of all the VIRGO accelerometers **and** construction of the new ones for AdV SR

3.11 References

[1] a) SAFE proposal: VIR-047A-07, b) Addendum after internal review:VIR-048A-07 (2007).

[2] A.Gennai: http://wwwcascina.virgo.infn.it/commissioning/weekly/2008/Jan2008/GennaiNewCD0108.ppt

[3] A.Gennai, *"New Coil Driver Measurements"*, VIR-010C-08 (2008).

[4] A.Gennai, *"New DSP final design document"* VIR-SPE-PIS-4900-120

[5] F Acernese *et al* 2008 *J. Phys.: Conf. Ser.* 122, 01201

3.12 Figures

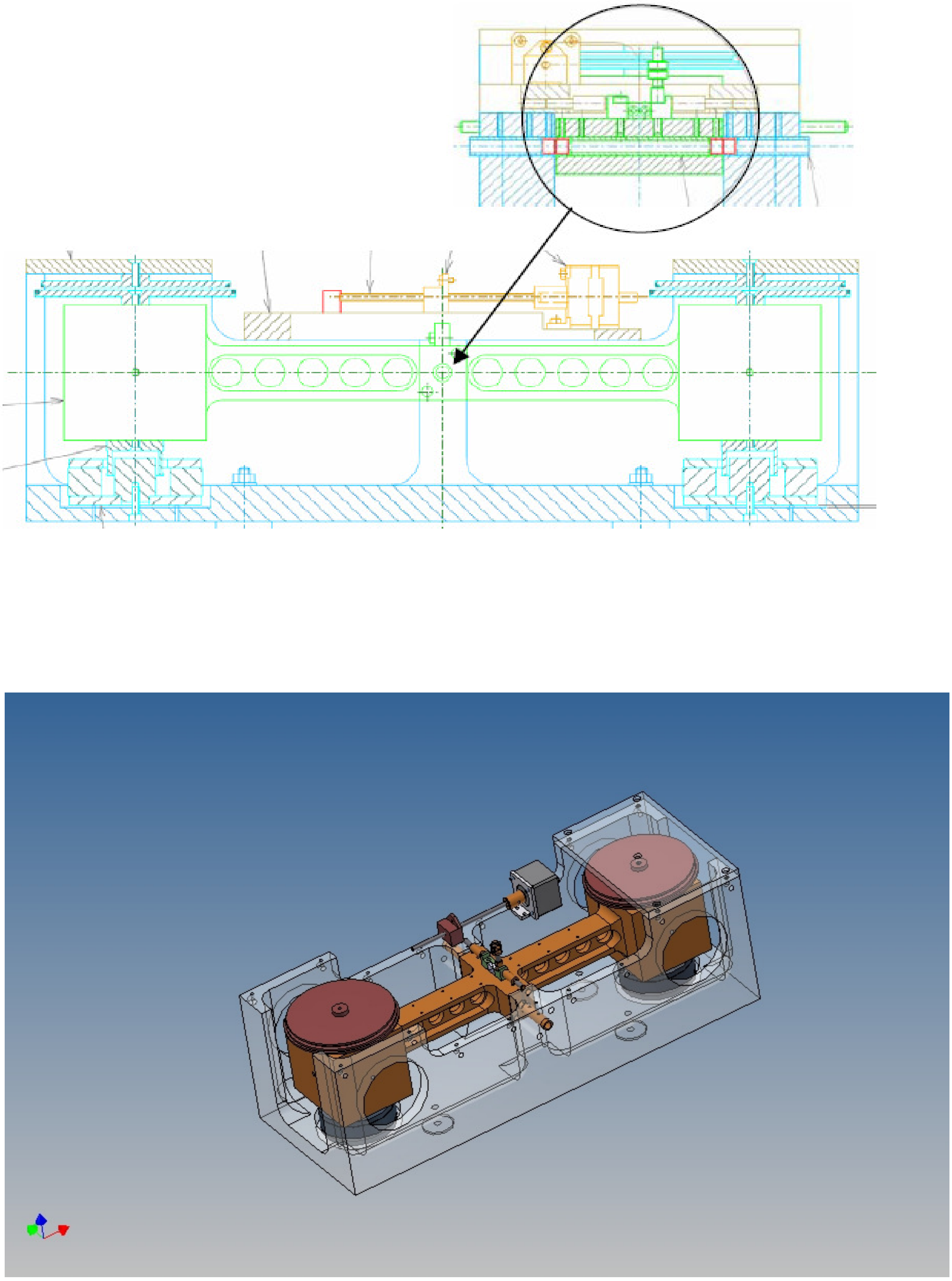

Figure 3. 1

Tilt-meter technical drawing and 3D rendering

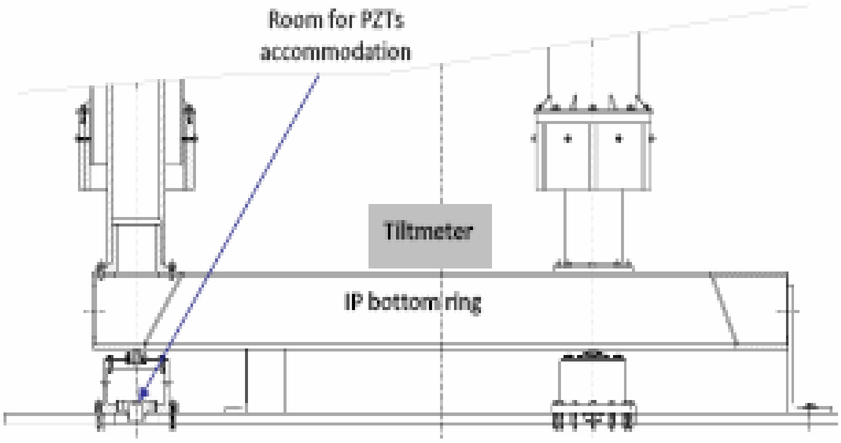

Figure 3. 2

The IP bottom part is visible. A section of a foot supporting the IP bottom ring and the last part of IP leg is visible on left side. A schematic box representing the tilt meter accommodation is also shown.

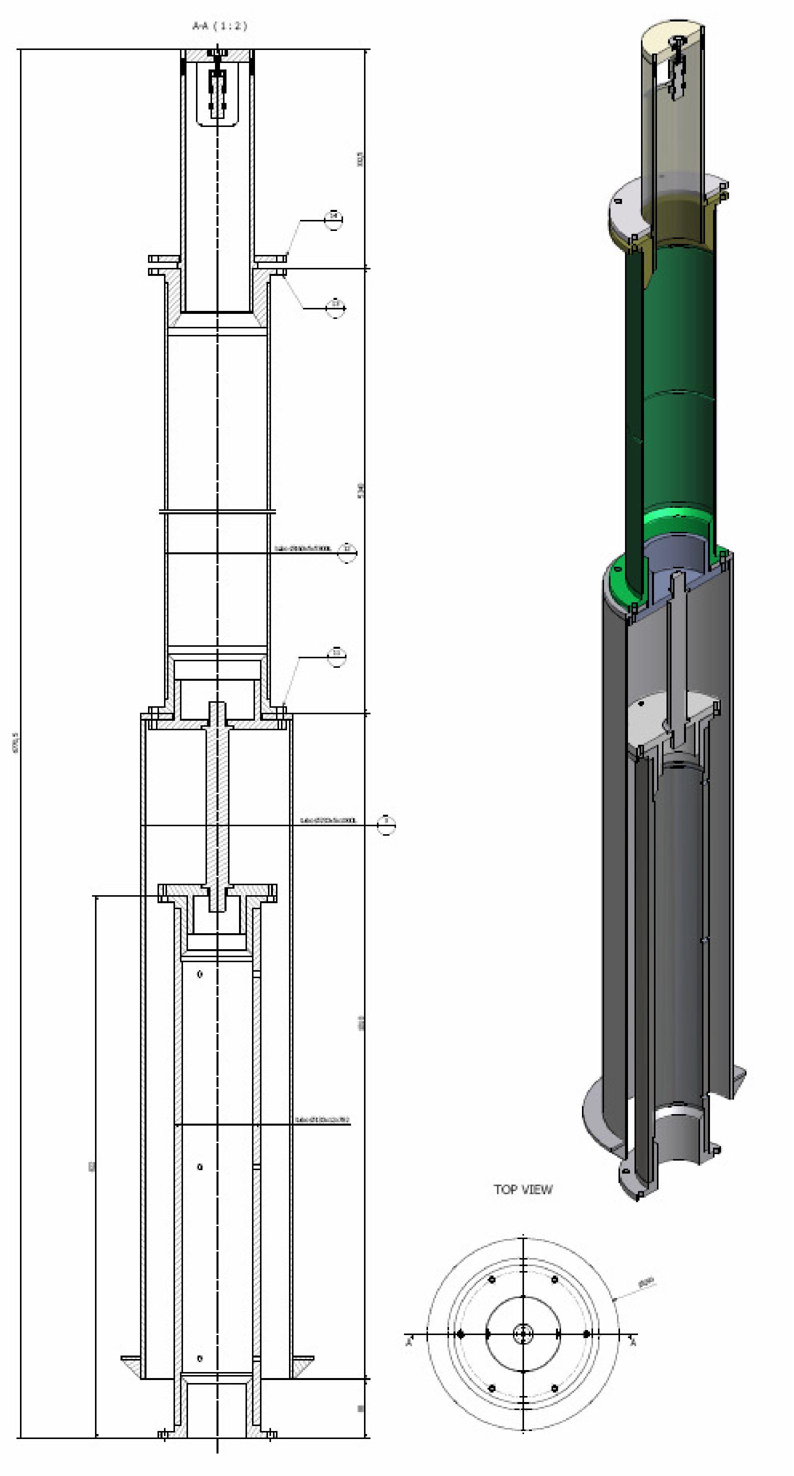

Figure 3. 3

Technical drawing of the new IP, based on monolithic legs with increased sectional area.

SECTION 4

Signal Recycling Mechanics Management Plan

This section is intended as a preliminary reference plan for the management of the SR *Superattenuator* mechanics construction. The document is organized in the following paragraphs:

4.1 SR Superattenuator System Description

The work concerning the realization of the SR SA is outlined.

4.2 SR Project Engineering Descriptions

The main SR SA items and sub-items are described.

4.3 SR Product Breakdown Structure (PBS)

The three levels (Items, Sub-items, and Components) of the SR SA system are individuated and described.

4.4 SR Work Breakdown Structure (WBS)

The WBS is outlined on the basis of the project description and PBS. The work of each item production is described and responsible tasks are defined. At the end of the section an estimate of the production time and manpower requirements is presented.

4.5 SR Superattenuator Assembly and Integration

A summary of the SR SA assembly and integration with the requirements of manpower is outlined.

4.6 Summary of SR Superattenuator Costs

This end section summarizes the whole construction and assembly costs of the SR SA.

4.1 SR Superattenuator System Description

According to the AdV proposal the SR SA chain should be a complete five-stage pendulum. Preliminary simulation results are confirming this requirement [1]. Essentially, the SR chain will reproduce the geometry of the actual VIRGO SA [2], apart from the possible implementation, as for all other VIRGO suspensions, of the SAT R&D upgrades (see Section 3). Also the AdV payload will be upgraded, as outlined in a separate planning for AdV PAY subsystem [3, 4].

The basic layout of a VIRGO SA is shown in Fig. 4.1 and 4.2. Each stage is constituted by a special mechanical filter designed to attenuate the seismic vibration in all degrees of freedom. Fig.4.3 shows the design of one *Standard Filter* which is essentially a rigid steel cylinder supporting a set of springs. This is formed by a series of steel cantilevered triangular blades which are clamped to the outer circumference of the filter body (see Fig. 4.2, 4.3 and 4.4). The tip of each blade is attached to a metal central column through a piano wire acting as a hinge. The central column moves freely in the vertical direction constrained by two systems of four centering wires, respectively mounted on the top and on the bottom of the filter. In this way a chain of springs is obtained also in the vertical direction. The central column supports the load of the lower filters through a wire clamped as close as possible to the center of mass of the cylinder.

A special magnetic antispring system is used to reduce the vertical resonant frequency of the filter, increasing the vertical attenuation in the VIRGO detection band. The working principle of the antispring system can be explained considering two permanent ferrite magnets facing each other with opposite horizontal magnetic moment (namely in a repulsive configuration) and constrained to move only along the vertical axis (see Fig. 4.5.a). When the magnets are aligned the repulsive force has a zero vertical component. If one of the magnets is moved in the vertical direction, a vertical component of the repulsive force appears. This arrangement is thus equivalent to a vertical spring with a negative elastic constant (antispring). The antispring is placed in parallel to the vertical blade spring mounting two matrices of magnets (see Fig.4.5.b) on the moving part of the filter, along the so called *Crossbar* (thus connected to the next stage), and two facing matrices on the rigid part of the filter (see Fig.4.2).

The top stage of the chain is formed by the *Filter Zero* (F0) rigidly connected to a top ring (see Fig. 4.6 and 4.7). The adjustment of the vertical position of the chain suspension point is performed by changing the position of the moving part of the F0 with a special motor placed over the filter crossbar (see Fig. 4.6 and 4.7) driving and end-less screw. For these reasons, as discussed below, the design of this filter exhibits slight differences from those of the standard filters.

The suspension top ring, as shown in Fig 4.6, is also suspended, by three thin wires, from the three legs elastic structure of the *Inverted Pendulum* (IP). The IP elasticity is given by a flexural joint on which each leg is based (see Fig. 3.3 and 4.8). The entire system is surrounded by a structure named *Safety Frame* designed to allow the SA installation and to setup safety stops of each moving element in case of accidents (see Fig. 4.2 and 4.9).

The top ring itself is kept horizontal by the *Inertial Damping* (ID) (see Section 1 and 2). By keeping the horizontal resonance frequency of the entire structure below 100 mHz a significant passive attenuation in the horizontal direction is achieved. This softness results also in low forces that need to be applied to the top ring to compensate for the horizontal ground slow motion.

To freeze the suspension point the ID of the top stage longitudinal and rotational movement is operated mixing the signal of 3 LVDT displacement sensors and 3 horizontal accelerometers [5, 6] placed over the top ring in a 120^o triangular configuration (see Section 1.2 and 2.2, see Fig. 4.6 and 4.7). The inertial control of the translation of the suspension point along the vertical axis is performed by reading the signal coming from two vertical accelerometers over the F0 crossbar and compensating the measured vertical displacement by two voice coil actuators operating on the opposite sides of the same crossbar (see Fig. 4.6 and 4.7).

The last sixth stage of the SA chain is constituted by the *Filter 7* (F7) (see picture in Fig.4.10). From this filter is suspended the VIRGO payload (see Fig. 4.17) that is actually composed by the *Marionette* (Fig. 4.11) which supports the mirror and its *Reference Mass* (RM) by means of two couples of 1.9 m long wires(see picture in Fig. 4.18).

The F7 position with respect to ground has to be monitored quite accurately to avoid any interference with the vacuum vessel structure that would short-cut the chain to the ground motion, affecting destructively the SA anti-seismic filtering performances. The angular rotation, around the two horizontal axes, is monitored by commercial dual-axes miniature electrolytic tilt-meter, placed over the filter body (see picture in Fig. 4.12), which has a resolution of about 0.1 μrad. The adjustment of the F7 tilt is operated by driving a stepping-motorized balancing system placed nearby the tilt-meter (see picture in Fig. 4.13). The F7 rotation around its vertical axe, and its longitudinal displacements, are monitored by a set of three horizontal LVDTs displaced around the filter body in a 120^o triangular configuration (see picture in Fig. 4.14). Each of these LVDTs implements also a Maxwell pair coil-magnet actuator, with the magnet embedded inside the LVDT primary and the coils shared with the LVDT secondary windings (see picture in Fig. 4.15). These actuators are intended to recover the F7 position in case of strong excitations of the low frequency rotational modes of the SA below 1 Hz which, due to their high Q, are characterized by long decay times. The F7 vertical position is monitored by a virtual sensor obtained summing up the signals of each SA filter crossbar LVDT. Finally the static angular positions of the F7 with respect to the rest of the upper SA chain, and of the payload with respect to the F7, can be adjusted operating two stepping-motorized rotation systems placed on the top and on the bottom of the filter body.

In VIRGO the *Marionette* has been conceived for steering the suspended optical component of the interferometer through magnet-coil systems. The *Marionette* control is actually performed by four coils each placed at the end of a long cylinder extending from the F7 (and thus isolated from the seismic noise), acting on permanent magnets mounted on the *Marionette* arms (see Fig. 4.10 and 4.17). The final control of the mirror position is operated by a set of coil actuators carried by the RM acting upon magnets directly glued on the back of the mirror (see picture in Fig. 4.18).

As anticipated in AdV the full payload system will undergo some major modifications after the results of the AdV PAY R&D activity. The main tasks of PAY is the design and construction of the new *Marionette*, of the marionette reference mass (MRM) and of the new mirror RM, the selection and realization of new test mass actuators, the realization of the monolithic payload, the sensing/actuation for local controls. According to the proposed design the MRM will be installed, as an additional suspended element, within the UHV chamber between F7 and marionette replacing the F7 legs (see Fig 4.19). It will also host the actuator coils for steering the new *Marionette*. Thus, quite presumably, it will be necessary to review the F7 interface with this new AdV payload.

4.1.1 References

[1] G. Vajente, "*Requirements for the Advanced Virgo Length Sensing and Control System",* VIR-083-A, 2008.

[2] The VIRGO collaboration: VIRGO Final Design, 1997.

[3] The VIRGO collaboration: Advanced Virgo Conceptual Design, VIR-042A-07, 2007.

[4] The VIRGO collaboration: AdV Cost Plan and Project Execution Plan, VIR- 043A-07, 2007.

[5] G. Losurdo et al., Rev. Sci. Instrum, 72 (9) (2001) 3653.

[6] S.Braccini et al., Rev. Sci. Instrum, 68 (3) (1995) 2672.

4.2 SR Project Engineering Descriptions

On the basis of the VIRGO SA design the nine main items indicated in Tab. 4.2.a have been individuated.

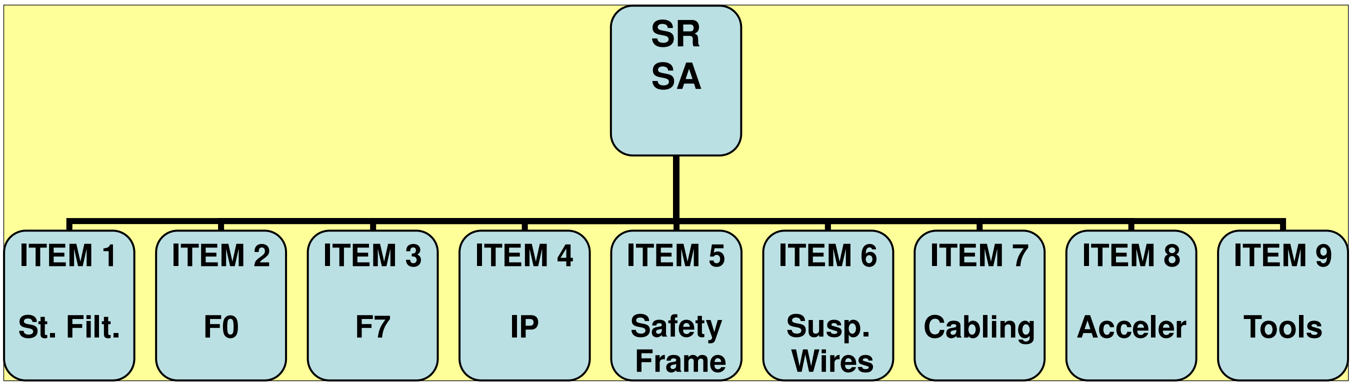

Table 4.2.a: Scheme of the SR SA system items subdivision

Each item contains some specific sub-items that will be listed and presented in the following paragraphs. Other three items are being investigated in the framework of the SAT R&D program: the new monolithic IP, the piezoelectric actuators, and the tilt-meter. Their description and plans are outlined in Section 3. These items will not be considered in this section since their design is not yet frozen.

4.2.1 ITEM 1: Standard Filters

Fig. 4.20 shows the technical drawing of the mechanical *Standard Filter* body (70 cm in diameter and 18.5 cm in height) supporting a ring of springs blades. The blades are triangular shaped maraging steel cantilevers which are clamped to the outer circumference of the filter body. The tip of each blade is attached to a metal central column through 1.0 mm diameter piano wire which acts as hinge.

As mentioned in the previous section, the central column moves freely in the vertical direction and it is constrained to just vertical motion by two systems of four centering wires mounted on the top and on the bottom of the filter respectively (*Centering System*). The central column supports the load of the lower filters through a wire clamped as close as possible to the center of mass of the cylinder; the central column is bolted to a crossbar carrying a series of magnets, necessary for the antispring effect described below.

The vertical working position of the crossbar (measured by an LVDT displacement sensor) can be varied by changing, through a lever arm acting on metal blades, the inclination of some of them. A special system (*Fishing Rod*), based on a motor controlled blade acting on the crossbar, is also used for the fine vertical adjustment of the moving part of the filter.

All the steel blades have a thickness of 3.5 mm, a length of 385.5 mm, while the width of the triangular base changes according with the load to be supported. The number of blades ranges from 12 (in the first filter of the chain) to 4 (in the last filter) according to the suspended load (see Section 5.4.1.5). Once properly loaded, the main vertical resonance of the blade system is around 1.5 Hz. A damper is located in the middle of each blade (*Blade Damper*) (see picture in Fig. 4.2) in order to damp its first internal mode, while another special damper will be accommodated on the crossbar to suppress a mode which involves the crossbar (*Crossbar Damper*) (see Fig. 4.25).

A further reduction of the main vertical resonant frequency of the filter can be obtained by softening the vertical spring strength around their working point through the magnetic antisprings (see Fig 4.3 and 4.21). The required antispring stiffness, and hence the number of magnets used for reducing the vertical resonant frequency, depends on the filter load.

On the basis of the available design this item is shared in the sub-items of Tab. 4.2.1a:

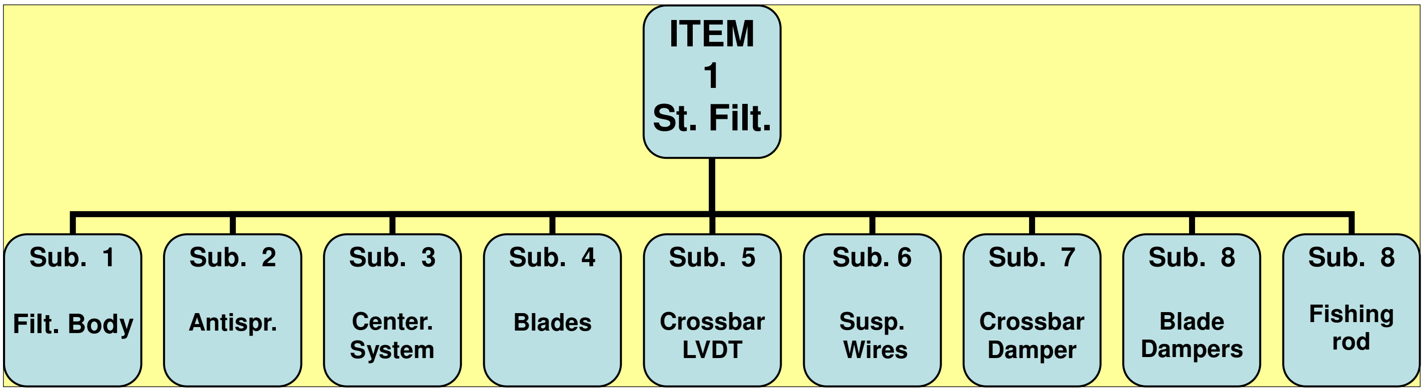

Table 4.2.1a: Scheme of the Item Standard Filters sub-structure

4.2.1.1 SUB-ITEM Filter Body

The filter body is a stainless steel AISI 304L cylindrical element of about 80 cm in diameter and 20 cm in height. As shown in Fig. 4.20, it is a cylindrical drum closed on the bottom and top by two lids stiffened by 12 internal ribs. Clamps for holding a maximum of twelve blades are welded on the outer diameter of the cylinder. The components attached to the filter body and the corresponding materials are listed in [1].

Reference Documentation on the filter body

[1] A.Gaddi, F.Raffaelli: "Standard filters specifications" (November, 1996). (VIRGO Internal Report - VIR-SPE-PIS-4600-105).

4.2.1.2 SUB-ITEM Antispring System

Each of the four magnetic matrix mounted on the filter (Fig.4.21) is made of two or four lines of Philips ferroxdure (FXD 330) magnets (6 x 2 x 1.5 cm^3) producing a nominal magnetic field of 0.36 Tesla in the direction parallel to the 1.5 cm dimension [1]. Each line of magnets in the matrix has the sense of the magnetic field opposite both to that of the neighboring line, in the same matrix, and to that of the line facing on the opposite matrix. This configuration allows minimizing the total magnetic dipole of the system, thus reducing the coupling with the external magnetic field.

As mentioned before, the number of magnets in each line is decreased from the top to the bottom filter to match roughly the need of antispring elastic constant. Fine tuning of the antispring force is obtained by setting the horizontal separation of the magnetic matrices. A vertical frequency of 0.4 Hz on the filter can be attained with a separation between the magnetic matrices of about 1 cm.

A full characterization of the antispring system (dependence on the positioning, on the temperature and on the number of magnets) has been given in [2,3,4,5]. This work has shown that large tolerances are allowed in the assembly of the antispring matrices.

The antispring ferrite magnets have been tested under vacuum after the baking outgassing treatment. They exhibit a negligible outgassing rate at room temperature.

The supports are made of titanium, a not ferromagnetic material showing the same thermal dilation coefficient of the magnets.

The glue proposed for attaching the magnets on the supports is VAC-SEAL. This glue has shown a very low outgassing rate [7].

The ferrite magnets and the entire antisprings system can undergo heating until 200 ^{0}C without effects on the magnetic and mechanical performances [8].

Reference Documentation on the antispring system

[1] PHILIPS, Datasheet of Ferroxdure 330 (FXD 330) in the "Handbook of PHILIPS Components" (1991).

[2] R.Del Fabbro: "Magnetic antisprings" (1993) (VIRGO Internal report - PJT93/025).

[3] S.Braccini et al.: "An improvement in the VIRGO Superattenuator for interferometric detection of gravitational waves: the use of magnetic antisprings" (1993). Rev.Sci.Instrum. 64 (2), 1993.

[4] S.Braccini, C.Casciano, R.De Salvo, L.Holloway, G.Losurdo: "Extending the VIRGO detection band down to few *Hz*: metal blade springs and a magnetic antispring system" (February, 1997). Published on N.I.M., A394 (1997) 397-408.

[5] V.Dattilo: "Direct characterization of the antispring system". (VIRGO Internal Report)..

[6] S.Braccini, C.Casciano, R.De Salvo, F.Fidecaro: “Temperature Stabilization requirement of the

VIRGO towers” (July, 1996). (VIRGO internal report - NTS032/1996).

[7] M.Bernardini, C.Bradaschia, H.B.Pan, A.Pasqualetti, R.Poggiani, Z.Zhang: "Outgassing measurement of VAC-SEAL vacuum epoxy" (April - July, 1996). (VIRGO Internal Report - VACPISA 048P).

[8] S.Malik, S.Braccini, R.De Salvo: "Effect of heating on the antispring system (magnets & glue)" (February, 1997). (VIRGO Internal Report - VIR-NOT-PIS-4600-115).

4.2.1.3 SUB-ITEM Centering System

The centering wires are made of piano wires steel. They will be protected from rust formation by chemical electroless nickel plating. All the centering wires will be set on the bench at a frequency 150±20 Hz, just sufficient to keep the moving part of the filter aligned.

The relevant point is that a large tension of the centering wires induces an extra vertical stiffness on the moving part of the filters, causing a reduction of the vertical attenuation performances [1]. In this condition, the tension of the wires is sufficient to keep the central column aligned and it is small enough to avoid overstress (and thus creep) inside the material. The end of each of the 8 centering wires is strongly clamped in a steel mandrel. This system has shown in VIRGO to be satisfactorily stable on the long term.

Reference documentation on the centering system

[1] S.Malik, S.Braccini: "Role of the centering wires in determining the main resonant frequency of the mechanical filter" (December, 1996). (VIRGO Internal Report - VIR-SCH-PIS-4600-112).

4.2.1.4 SUB-ITEM Metal Springs Blades

As mentioned in Section 4.2.1.1, the steel blades (see Fig. 4.22 and 4.23) of the mechanical filters [1] have a thickness of 3.5 mm, a length of 385.5 mm, while the width of their base changes according to the load to be supported. The triangular shape gives the blades a rest and stressed shape with a single curvature radius and allows distributing uniformly the stress in the material under load. Bending curvature and dimensions are such that in a loaded cantilever the internal stress is always kept well below 2/3 of the elastic limit.

The studies that have been performed for the VIRGO design [2,3,4] have shown that the maraging steel 18% Ni C-250 (Marval 18) steel has to be used to avoid creep in the blades. The following thermal treatment of the Marval 18 has provided the best results in terms of creep, and ultimate tensile strength (UTS):

1. **Solubilization:** 840 ^{0}C for 1 hour in neutral environment (Ar flux);

2. **Aging:** 435 ^{0}C for 100 hour in neutral environment (Ar flux).

The yielding and UTS measured are about 1950 MPa [4]. All the blades will be protected from rust formation by a thin layer of chemical electroless nickel plating. After the chemical plating process the blades will undergo a thermal dehydrogenation treatment of 24 hours at 200 ^{0}C, to avoid hydrogen embrittlement.

The blades under load exhibit a 1.5 Hz pendulum mode and the first flexural mode at ≈ 100 *Hz*. These blades have been heated under load at 80 ^{0}C without significant effects in their mechanical performances. The mechanical performance in VIRGO has been satisfactory.

Reference documentation on the metal springs or blades

[1] F.Raffaelli: "VIRGO blade springs mechanical aspects" (June, 1992, reprinted in 1997). (VIRGO internal report - VIR-SCH-PIS-4600-111).

[2] S.Braccini, C.Casciano, R.De Salvo, F.Paoletti, F.Fidecaro: "Evidence of creep in the superattenuator mechanical filters" (July, 1996). (VIRGO internal report - NTS044/1996).

[3] R.Valentini: "Acciai ad alta resistenza nel progetto VIRGO" (April, 1996). Private communication (available).

[4] S. Breaccini et al.: "The Maraging–steel blades of the VIRGO super attenuator", Meas. Sci. Technol. 11 (2000), 467-476.

4.2.1.5 SUB-ITEM Crossbar LVDT Sensors

The design of the LVDT sensor mounted on the chain filter is reported in Fig. 4.24. A 10 kHz AC-signal flows in the internal coil, while the external coil, which is the passive element, is composed of two parts wrapped in opposite direction (clockwise and anti-clockwise). When the external coil moves with respect to the symmetric position the combined output signal at the passive coil extremities is proportional to the difference between the signals induced on both parts. A 10 kHz signal, whose amplitude is proportional to the relative displacement between the two coils, is induced on the passive elements [1].

This system provides a displacement sensitivity of 10^{-10} m/√(Hz) in the entire band. The electronic performances and the vacuum compatibility of the materials have been validated in VIRGO.

Reference Documentation on the LVDT sensors

[1] H. Tariq et al. "*The linear variable differential transformer (LVDT) position sensor for Gravitational Wave Interferometer low-frequency controls*", NIM, A 489, 2002, 570-576.

4.2.1.6 SUB-ITEM Crossbar Dampers

In the VIRGO filters there is a resonant mode involving the crossbar. This internal mode is due to the fact that the suspension wire connecting the crossbar to the next filter acts as a spring. The resonance, around 60-80 Hz, is suppressed by using an iron cylindrical mass of 2.5 kg resting on three viton columns at the center of the crossbar (see Fig.4.25). The mass oscillates in the vertical direction while the viton columns act as damping springs. The length of the columns is chosen to tune the damping system on the frequency of the crossbar mode. This system is able to reduce of one order of magnitude and more the peak of the vertical transfer function within a tolerance of ± 1 mm in the tuning of the viton columns.

Reference Documentation on crossbar dampers

[1] S.Braccini et al.:"Seismic vibrations mechanical filters for the gravitational waves detector VIRGO" (1996). Rev.Sci.Instrum. 67 (8), 1996.

[2] S.Braccini, C.Casciano, R.De Salvo, L.Holloway, G.Losurdo: "Extending the VIRGO detection band down to few *Hz*: metal blade springs and a magnetic antispring system" (February, 1997). N.I.M., A394 (1997) 397-408. (VIRGO Internal Report - VIR-NOT-PIS-1390-068).

[3] S.Braccini, C.Casciano, R.De Salvo: "Crossbar and blades dampers" (October, 1996). (VIRGO Internal Report - VIR-NOT-PIS-4600-108).

4.2.1.7 SUB-ITEM Blade Dampers

The first flexural mode of each blade (around 100 Hz) can be suppressed by attaching at the point of its maximum oscillation, close to the center of the triangular surface, a short viton with a light mass accommodated near its extremity (see picture in Fig. 4.2). The mass oscillates in the vertical direction inducing a flexure of the viton rod with opposite phase to that of the blade's displacement. The frequency of the viton oscillator can be tuned on the blade first flexural mode by varying the position of the mass along the rod. In this way, the energy of the blade flexural mode is transferred to the dissipative viton oscillator and a strong attenuation is obtained.

Reference Documentation on blade dampers

[1] S.Braccini, C.Casciano, R.De Salvo: "Crossbar and blades dampers" (October, 1996). (VIRGO Internal Report - VIR-NOT-PIS-4600-108).

4.2.1.8 SUB-ITEM Fishing Rod

The fishing rod depicted in Fig. 4.26 is able to tune the position of the crossbar with a precision of few microns and with a dynamic range of few mm. The MARVAL 18 triangular blade has a width of 40 mm, a flexural length of 254 mm, a maximum load of 20 N, a curvature radius of 823 mm and a stiffness of 255 N/m. The blade is connected through a Maraging steel wire (0.6 mm diameter and 200 mm length) to the crossbar. The adopted motor is a commercial ultra high vacuum compatible AML stepping motor chosen on the basis of the mechanical and outgassing tests [1].

Reference documentation on the fishing rods

1] M.Bernardini, C.Bradaschia, H.B.Pan, A.Pasqualetti, R.Poggiani, G.Torelli, Z.Zhang: "Outgassing measurements of a third AML motor", VACPISA 041P, VACPISA (April - July, 1996).

4.2.2 ITEM 2: Filter 7

In VIRGO, as mentioned in the Section 4.1, the F7 (Fig. 4.27) is directly connected to the payload steering the *Marionette* to set the mirror longitudinal and angular position (see Fig. 4.17 and 4.18). As anticipated (see Section 4.1) the eventual adoption in AdV of the MRM carrying the *Marionette* steering coils will bring as immediate consequence to the suppression of the F7 legs from the filter design (see Fig. 4.19). This section will describe the F7 mechanics of the actual VIRGO model.

The position of F7 with respect to the separating roof pots and conductance holes (see VIRGO Final Design) is controlled in all the degrees of freedom by the *Position Monitoring System*. The vertical position is monitored by a virtual sensor combining the signals from the crossbar LVDT sensors of all the SA filters. The course positioning is performed adjusting the suspension point of the entire chain. The fine setup is made adjusting the position of each filter crossbar, driving the respective *Fishing Rod*. The F7 horizontal position is monitored by a system of three horizontal LVDT sensors placed in a 120° triangular configuration around the filter (see Fig. 4.14). The correct working point is found adjusting the horizontal position of the top ring at which the entire chain is suspended. The angular tilt around the horizontal axes is monitored by dual-axes precision tilt-meter placed on the top of the filter body. Balancing of the filter is achieved by means two motorized sliders with masses that act as counterweights on the horizontal plate on the top of the filter body (see Fig. 4.13). In VIRGO these adjustments are quite infrequent and occur out of the data-taking.

In order to achieve the correct angular positioning with respect to the vertical axis, the F7 has a modified standard filter body to allow vertical rotations of the filter itself with respect to the suspension wire and to the wire suspending the *Marionette*. Two vacuum compatible ceramics ball bearings allow rotations steered by two stepping motors placed respectively above and below the filter body.

On the basis of F7 VIRGO design this item contains the sub-items indicated in Tab. 4.2.2.a

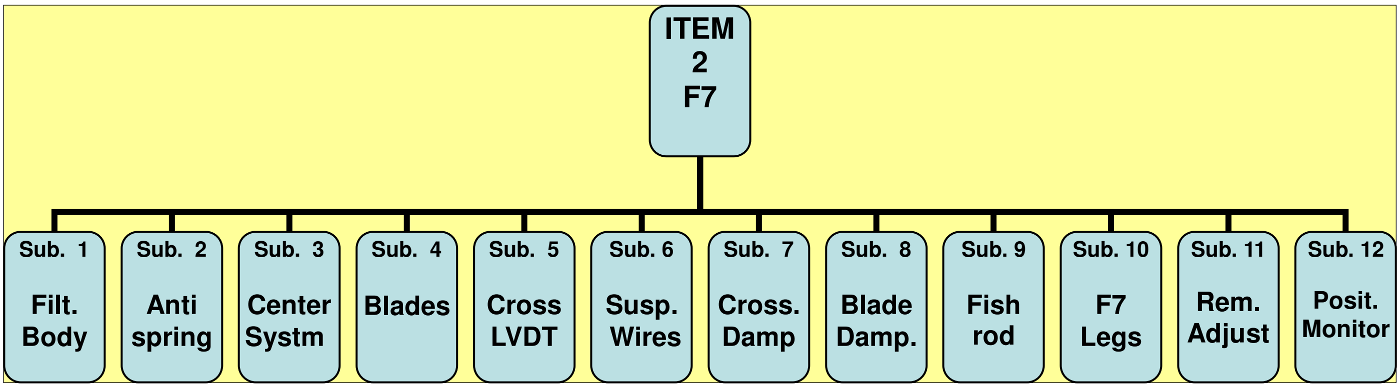

Table 4.2.2.a: Scheme of the Item F7 sub-structure.

Reference Documentation on Filter 7

[1] P.Ruggi, F.Frasconi, S.Braccini - Measurements of the Filter 7 prototype. (VIRGO Intern. Rep.).

[2] G.Ballardin et al.: Rev.Sci.Instrum. 72 (9), 3635-3642 (2001).

4.2.2.1 SUB-ITEM F7 Position Monitoring System

The F7 *Position Monitoring System* is devoted to monitor the position of the filter with respect to the separating roof pots and conductance holes. The angular position about the two horizontal axes is monitored by a dual-axes commercial tilt meter (CODEVINTEC). This sensor is high vacuum compatible and consists of two orthogonal electrolytic precision bubbles contained in an aluminum case (see Fig. 4.12). The high sensitivity dynamical range is of 16 mrad and the resolution is of about 0.1 μrad. The tilt adjustment is performed operating two sliders, carrying the counterweight masses, with precision AML stepping motors.

The F7 monitoring of the horizontal displacements is performed by a set o three angular LVDT sensors placed around the filter in a 120° triangular set-up. The primary LVDT winding is rigidly connected to the filter body while the two anti-phase secondary LVDT windings, arranged on two separated aluminum coils, are co-axially fixed over the IP platform (see Fig. 4.14). This setup is conceptually analogous to that implemented for the top stage LVDTs.

Actually these F7 horizontal LVDTs allow a large linear swinging of about ± 15 *mm* along their axe without limiting the filter dynamics. In VIRGO the filter rotation range is presently limited by the interference with the pots that contain the F7 legs supporting the four *Marionette* steering coils. While the F7 linear displacement range is limited to a few mm by the narrow conductance pipe crossed by the *Filter 7-Marionette* suspension wire and electric cable links.

The same horizontal LVDT system represents an original system of three *collocated* coil-magnet actuators. The magnets are placed inside the LVDT primary winding while the actuator coils are made by the same secondary LVDT windings. Practically, the two secondary anti-phase LVDT windings are driven, at frequencies below a few Hz, as a Maxwell pair coil-magnet actuator, which is characterized by a large linear dynamics (see Fig.4.15). The matching of the actuation signal with the high frequency LVDT driving signal is based on the fact that the two drivers work at different frequency bands. A conceptual scheme of the analog conditioning and filtering electronics is visible in Fig. 4.16. This actuation system is used to recover the F7 position damping the excess of angular and rotational motion caused by the excitation of the high Q SA resonances in the low frequency region below 1*Hz*.

4.2.3 ITEM 3: Filter Zero

The *Filter Zero* is a modified standard filter with 12 blades supported by a steel rigid ring (see Fig. 4.6 and 4.28).The vertical position of the crossbar with respect to the F0 body is measured by means of a standard LVDT sensor. An end-less screw controlled by stepping motor is employed to adjust in a remote way the height of the chain suspension point with a dynamics of ± 35 mm.

SAT R&D planning foresees the study of possible solutions to have a stiffer crossbar having higher inner mode resonances above 10 Hz. This could help extending the ID control bandwidth. As described in Section 3.4 and 4.1, a final decision will be taken only after a deep study of the benefits that any designed solution will imply. As a consequence the F0 design, concerning its movable components, could be slightly modified for AdV.

On the basis of the VIRGO design this item contains the sub-items of Tab. 4.2.3.a.

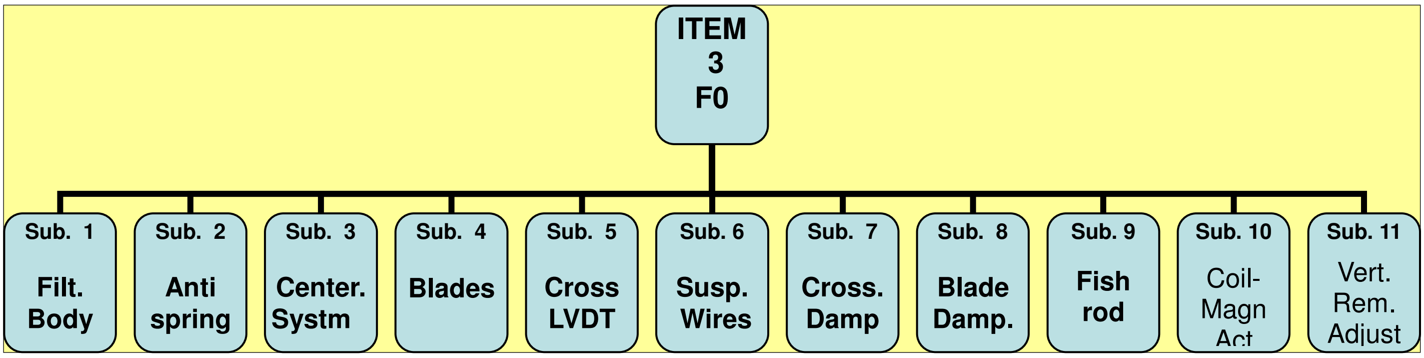

Table 4.2.3.a: Scheme of the Item F0 sub-structure.

4.2.4 ITEM 4: Inverted Pendulum

An ideal *Inverted Pendulum* (Fig. 3.3 and 4.8) is made of a massless (light) vertical beam of length l, connected to ground by means of an elastic joint of stiffness k, and supporting a mass M on its top. In such a pendulum the gravity acts as an antispring and the resonant frequency

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{k}{M} - \frac{g}{l}}$$

can be lowered up to mechanical instability by adding load. Thus, an IP can be operated at very low frequency (30 mHz) acting as a pre-isolator stage for the SA. Moreover, due to the very low overall stiffness of the IP little forces are needed to move it. For this reason the IP, provided with coil-magnet actuators, is suitable to act as a positioning stage for the SA suspension point.

As described in Section 4.1 the VIRGO IP is a 6 m high system made of three aluminum legs supporting a top table. The top table, which supports the F0, is suspended from the top of the IP legs by three thin maraging steel wires. The legs are provided with counterweights to compensate for the center of percussion effect. The system stands on a rigid ring platform. The IP top table is provided with a complete set of sensors (3 LVDT displacement sensors, 3 horizontal accelerometers), and actuators (3 coil-magnet actuators and three motor controlled ones) to perform the low frequency control of its position and the *Inertial Damping* of the SA resonances.

The SAT R&D activity foresees the study of a modified IP with stiffer monolithic aluminum legs (see Fig 3.3). The prototype has been already built and is being installed in SAFE. This new system will be equipped with piezoelectric actuators and tilt-meters (see Fig 4.2) to verify the possible upgrade of the ID performances.

On the basis of the VIRGO design this item contains the sub-items of Tab. 4.2.4.a

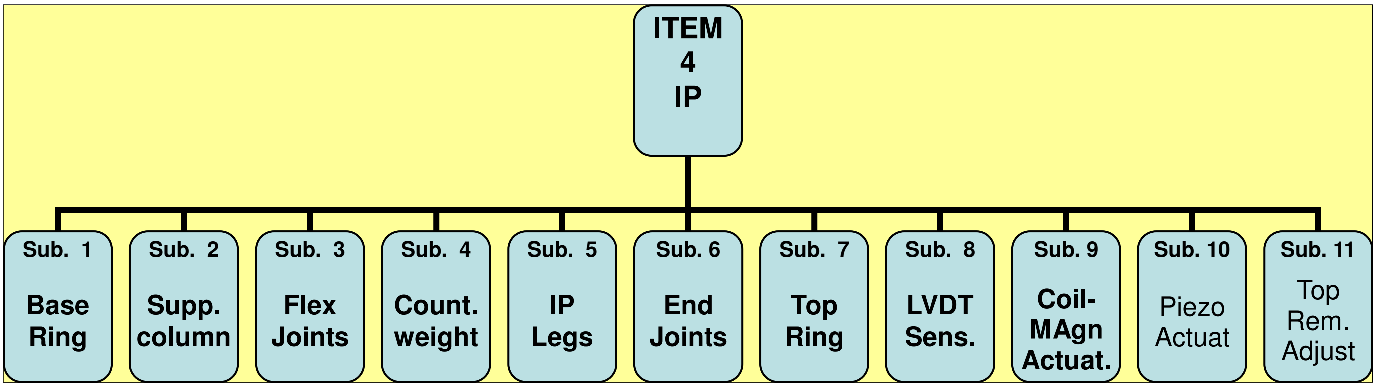

Table 4.2.4.a: Scheme of the Item F0 sub-structure.

Reference Documentation on the inverted pendulum

[1] G.Losurdo et al.: *Rev.Sci.Instrum. 70* (5), 2507-2515 (1999).

[2] A.Gennai, A.Giazotto, S.Mancini, D.Passuello, "Seismic noise on the inverted pendulum", VIR-NOT-PIS-1390-086, 1997.

[3] R.De Salvo, A.Gaddi, G.Losurdo, "The new design of the inverted pendulum preisolator stage", VIR-NOT-PIS-4600-98, 1997.

4.2.5 ITEM 5: Safety Frame

The *Safety Frame* (or *Inner Structure*) is made of three beams with a C profile connected by rings (see Fig. 4.9). Suitable bolts connect the structure to the viroles. According with the vertical position of each filter there are three shelves which support an internal ring. This ring has a safety function for the breaking of one of the suspension wires. Removable connections between the shelves and the concerning filter are foreseen so as to keep the filter hooked at the internal structure during the assembly and tuning procedures.

On the basis of this design this item contains the sub-items of Tab. 4.2.5.a

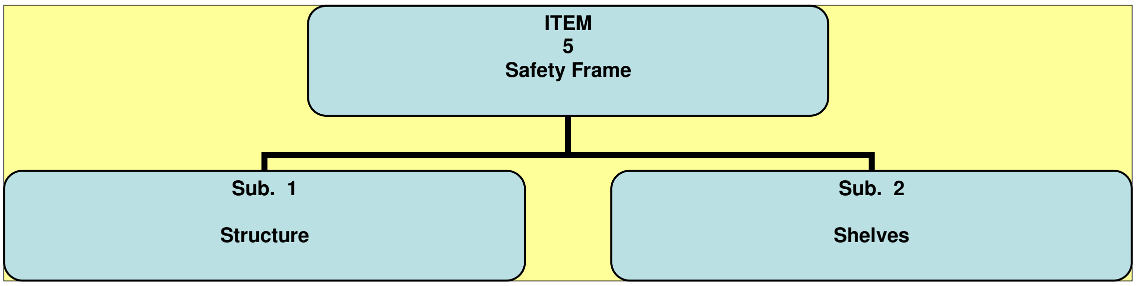

Table 4.2.5.a: Scheme of the Item Safety Frame sub-structure.

Reference Documentation on the Safety Structure

[1] A.Gaddi: "Safety Frame Specifications". (VIRGO Internal report, VIR-SPE-PIS-4600-82, 1996).

4.2.6 ITEM 6: Suspension Wires

The VIRGO suspension wires, as like as the filter spring blades, are of maraging steel 18% Ni C-250 (MARVAL 18) material to minimize the creep processes and hysteresis effects. The suspension wires have a double nail-head obtained from a cylindrical bar with a larger diameter using a special grinding machine. Thermal treatments and Nickel plating procedures are the same adopted for the filter spring blades (Section 4.2.1.4).

The nail head is mounted inside a screw head by means of a split cup washer. The resulting wire headings are then simply screwed in two tapped bridges attached to the upper and lower suspension points of the lower and higher filters.

The distance between the attach points of the two wires is only 5 mm in order to keep the rocking frequency of the filter below 1 Hz. The chosen diameters of the suspension wires allow having all the rotational frequencies of the chain below 1 Hz.

In order to make possible the removing of a given filter from the chain, and to avoid too long suspension wires (with difficult machining), the wire connecting two contiguous filters are split in three parts operating small and light junctions. Each junction box is essentially a small Ti brick (few cm^3) where two holes with the same shape of the connection wire-filter is placed. This means that the attach mechanism of the wire with the junction is identical to the wire-filter one. In order to maximize the resonant frequency of the violin mode of the suspension wire it is mandatory to place the junctions as close as possible to the filter body and to make them as light as possible (few tens of grams). The technical design of the suspension wires is provided in Fig.4.29.

On the basis of this design this item contains the sub-items of Tab. 4.2.6.a

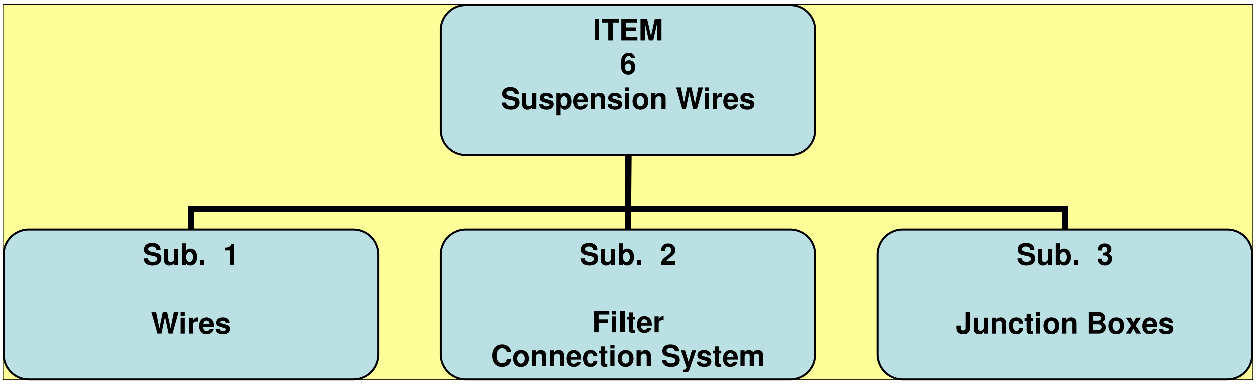

Table 4.2.6.a: Scheme of the Item Suspension Wires sub-structure.

Reference Documentation on the suspension wires

[1] S.Braccini, R.De Salvo, G.T.Feng, F.Paoletti, G.Gennaro: "Behavior measurement and analysis for VIRGO suspension wires" (January, 1997). (VIRGO Internal Report - VIR-SCH-PIS-4600-114).

[2] S.Malik, S.Braccini, R.De Salvo: "Measurements of creep in the suspension wires". (VIRGO Internal Report - VIR-NOT-PIS-4600-116).

4.2.7 ITEM 7: Cabling

The cabling is used for the electrical connection between the equipment inside the towers and the one outside. The most part of the equipment in the tower vacuum environment is mounted on the SA elements or on the optical benches. Cables start their path from the front-end electronics in racks placed sideways each tower, enter in the vacuum environment through a set of electrical feedthroughs mounted on few tower flanges, and reach the top stage, all mechanical filters and the payload.

The vacuum cabling of VIRGO is subjected to several constraints which must be taken into account on the selection of the components, on the assembling tools and on clamping. The main design requirements can be summarized as follows:

- **Vacuum Compatibility.**

All the materials used for cabling have to be clean and with a low outgassing rate, to match the VIRGO vacuum specifications [1]. Also if the temperature in vacuum will be around the ambient one, in some conductors there will be a temperature rise due to the current across them: hence some cabling components have to be vacuum compatible also at a temperature above the nominal one. Besides the components installed in the lower part of the tall towers have to be compatible with the 150° C bake-out 100 hours long. This process will be performed in order to speed up the outgassing of water from the chamber surface; components at the level of F7 have to be compatible with intermediate temperatures, during bake-out.

- **Seismic Isolation Compatibility.**

The cabling has not to reduce the attenuation performances of the SA. Particularly, for the cables attached to the SA is required a high mechanical flexibility and a clamping performed at suitable points, in order to prevent vibration transmission or generation of new resonances.

- **Electrical compatibility.**

Depending on the type of application, some ratings have to be made. These are current, crosstalk, electrical disturbances and impedance.

Current ratings are based on the conductor sizes, on the amount of current that will produce certain rises in the temperature of conductors and contacts, on the thermal capacity and heat transfer capability (in vacuum) of the electrical insulation.

Impedance ratings come from the considerable length of the cables (up to 25 m): in fact, in this case, the cable impedance may become comparable with the load impedance, thus reducing the driving capability.

Crosstalk is the electrical pickup caused in a conductor by near conductors, while electrical disturbances come from external electromagnetic field or from ground loops. Cables connected to the mirror coils and to the accelerometers are particularly sensitive to these effects (in particular to inductive coupling): hence they should be suitably shielded and driven.

Finally, cabling should not introduce additional noise, such as microphonics and triboelectric effects in cables or contact noise in connectors.

Cables can be classified on the basis of their function:

- *Readout cables*. These cables bring back the signals from:
  - LVDT secondary coils
  - Thermal probes
  - LVDT secondary coils of accelerometers

    End stroke of motors
- *Control cables*. These cables have to power:
  - Coils
  - Stepping motors
  - Accelerometer coils
- *Driving cables*. These cables provide the driving signal for:
  - LVDT primary coils
  - LVDT primary coils of accelerometers

Due to the large number of conductors needed for each tower (about 350 conductors), it is necessary to use multi-pole cables. For our applications flat cables are preferred to round cables. The latter exhibit a lower mechanical flexibility and a higher air entrapment inside the insulation.

The immunity to electrical disturbances is critical for cables connected to the accelerometers, to some LVDTs, to the mirror actuators (i.e. coil-magnet systems), to the optical bench devices

In order to minimize cable mechanical effects on filter performances, the links of cables between two adjacent filters have to be very slack, large bend shaped and with at minimum a 90° cable rotation in each link. A clamp at suitable points is also fundamental to avoid any possible friction. Another improvement in cable flexibility is achieved by using stranded conductors and braided shields, except in the last SA stages, where solid conductors are preferred in order to avoid mechanical friction among the wires of the stranded conductors.

Cables are terminated by mainly using three types of connectors:

- 25 pin type-D subminiature connectors to mate with the electrical feedthroughs
- 32 pin circular connectors (MIL-C-26482) to mate with the electrical feedthroughs
- multipin LEMO connectors to mate with the devices.

The type-D connectors and circular connectors have PEEK insulation and gold plated copper alloy contacts, UHV temperature rated to 200°C. The same connector may be shared between two cables.

The LEMO connectors belong to a multipin series having push-pull and bias features; have

PEEK insulation and a nickel plated brass shell, with gold plated brass contacts. At the device side, each cable is ended with several LEMO connectors, whose quantity and number of pins depends on the type of connected devices.

All the connectors include crimp contacts. For the VIRGO vacuum side cabling, the crimping has to be preferred to the soldering because it is cleaner, reproducible and practical.

The connection between F7 and *Marionette* is performed by a 1.85 mm diameter suspension wire with a length of about 1130 mm. In the case of the SR tower, where the separating roof is present, the only possible passage for electrical wires is through the conductance pipe.

The arrangement of these wires and the suspension wire has to be done taking into account some constraints [3]:

1. to minimize the effective section of the conductance pipe;
2. to leave the possibility of a relative motion of ±5 mm in the horizontal plane between separating roof and wires;
3. to avoid any movement or friction among components of the assembly in order not to deteriorate the quality factor;
4. to avoid an excessive lowering of the violin mode of the suspension wire;
5. UHV compatible with a bake-out up to 150°C;
6. possibility to be easily connected and disconnected in the SA.

The basic idea is to put all the wires in a small metal tube and then completely fill it with an UHV compatible material. Then terminate the wires with round connectors small enough to go through the conductance pipe.

The tube is made of INOX 304, has an inner diameter of 6.2 mm (slightly larger than the 6 mm diameter of the nail heads), a length of 500 mm (longer than the conductance pipe), a thickness of 0.1 mm (to minimize the weight).

Inside the 6.2 mm tube are hosted 7 wires for the balancing motor in the marionette (terminated with a 7 pin connector), 4 twisted pairs for the 4 coils on the reference mass (terminated with a 8 pin connector), the suspension wire. Particular care is needed during the filling in order to avoid air entrapment in the metal tube that would produce virtual leaks. It is foreseen to use special UHV glue as filling material: a kind of Araldite with a working time of about one hour and with very low viscosity when heated. The filling is performed by plunging one end of the metal tube in the glue and by means of a vacuum pump connected to the other end which aspire the glue; during the filling the tube and the glue are heated to about 100°C.

A technical report concerning the cabling was performed for VIRGO assembly [2]. In this report one can find the list of the components, the cable arrangement inside the towers and the technical choices for the purchasing of each component.

On the basis of this design this item contains the sub-items of Tab. 4.2.7.a

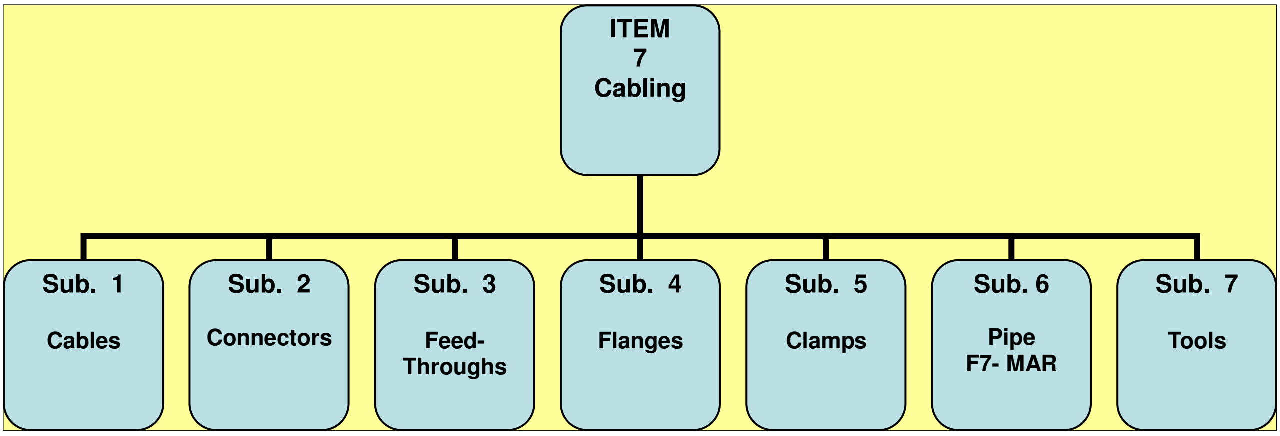

Table 4.2.7.a: Scheme of the Item Cabling sub-structure.

Reference Documentation on cabling

[1] V.Dattilo: "State of the work and definition of the aspects related to cabling interfaces (July, 1997). (VIRGO Internal Report, VIR-MOM-PIS-4600-81).

[2] V.Dattilo: “VIRGO vacuum cabling”. (VIRGO Internal Report, VIR-TRE-PIS-4600-145).

[3] C.Bradaschia, V.Dattilo, F.Frasconi, P.Mugnier, Z.Zhang: “Conductance pipe for the VIRGO IVC”. (VIRGO Internal Report, VIR-TRE-PIS-3400-171).

4.2.8 ITEM 8: Accelerometers

The horizontal accelerometers [1] are based on a mass suspended by means of a low resonant frequency spring system (Fig. 4.30). A feed back loop keeps the mass on a reference position. Acceleration is derived from the correction signal applied to the accelerometer. The vertical accelerometer is based on the same principle as the horizontal one. The mechanics is different to achieve a low resonant frequency while compensating for the acceleration of gravity (Fig.4.31). These accelerometers show a high sensitivity level in the low frequency region down to about 10 mHz. A measured value of the acceleration spectral sensitivity of about $7x10^{-10}$ ($m/s^{2}/\sqrt{(Hz)}$) below 10Hz was reported[1].

These sensors are being investigated in SAT R&D. Another monolithic accelerometer type, based on an existing model developed at the Pisa University, is being tested by the INFN-Napoli

Group in collaboration with the Salerno University [2].

On the basis of the VIRGO accelerometers design this item contains the sub-items of Tab. 4.2.8.a.

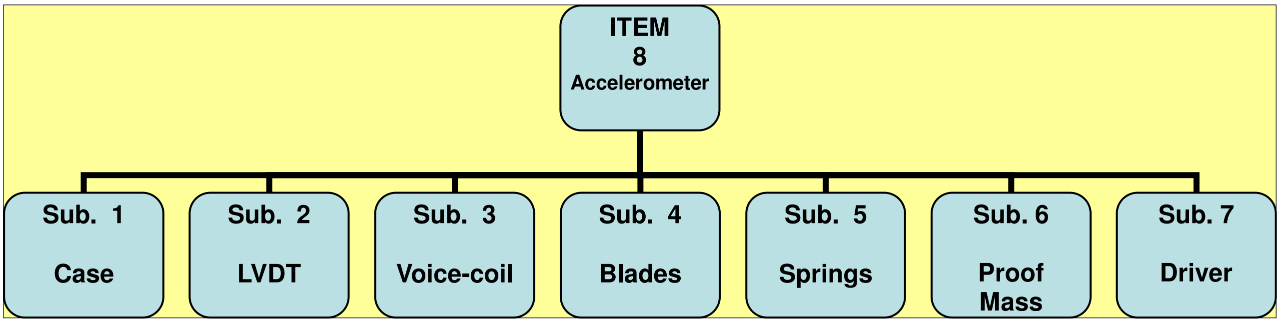

Table 4.2.8.a: Scheme of the Item Accelerometers sub-structure.

Reference Documentation

[1] S.Braccini et al., Rev. Sci. Instrum, 66 (3) (1995) 2672.

[2] F Acernese *et al* 2008 *J. Phys.: Conf. Ser.* 122, 012012

4.2.9 ITEM 9: Tools

Special tools are necessary for the production and the quality control of the SA chains.

Here we list all the necessary tool sub-items followed by a brief description.

4.2.9.1 SUB-ITEM Wire Breaking Machine

The suspension wires can be checked by measuring stress-strain curves that allow extrapolating the yield and breaking points. All wires have to be checked, since they undergo a treatment to produce nail-heads at their extremities.

4.2.9.2 SUB-ITEM Blade Stress Machine

Each metal spring undergoes mechanical and thermal treatment. The resulting elastic constant has to be measured and the uniformity of strain has to be verified by a hydraulic machine capable of applying a known stress. Metal springs can be also cycled to check as better as possible their mechanical properties.

4.2.9.3 SUB-ITEM Cleaning Tools

For the cleaning of all the items and components of the SA few ultrasonic cleaning machines are necessary with suitable dimensions.

4.2.9.4 SUB-ITEM Oven for the mechanical filters

A large oven is necessary for the mechanical procedures during the production of the filters.

4.2.9.5 SUB-ITEM Oven for blades and suspension wires

An oven (able to operate in a protected atmosphere under Ar flux) is also necessary for the thermal treatment of the maraging AdV blades and suspension wires. The system is already available at EGO 1.5 km W-labs.

4.2.9.6 SUB-ITEM Plating tools

A tank with the opportune chemical products is necessary to operate the Nickel plating of the Maraging steel components.

4.2.9.7 SUB-ITEM Hardness measurement tool

To perform a quality test on maraging blades a standard hardness measurement tool is necessary. Experience in VIRGO has shown that the measurement of the hardness is an exhaustive quality test of the thermal treatment.

4.2.9.8 SUB-ITEM Filter quality test set-up

An experimental set-up with a single filter and a tunable mass must be available to tune a seismic filter with its real load. This will allow tuning the metal spring and crossbar dampers and to measure the filter transfer function.

4.2.9.9 SUB-ITEM Magnetic force measurement machine

A special measurement machine able to measure the force and the torque between two facing magnetic plate of the antispring system.

4.2.9.10 SUB-ITEM Gaussmeter

A commercial gauss-meter is necessary to measure the magnetic field of the magnets. This tool could be used to check the field of all the magnets mounted on the SA.

4.3 SR Product Breakdown Structure

Items	**Subitems**	**Components**
1 - Standard Filters		
	1.1 - Body, crossbar and central cylinder	
	1.2 - Antispring system	
		1.2.a - Supports
		1.2.b - Magnets
		1.2.c - Glue
		1.2.d - Sealing
		1.2.e - Cage
	1.3 - Centering system	
		1.3.a - Wires
		1.3.b - Clamps
		1.3.c - Clamp supports
	1.4 - Metal springs (or blades)	
		1.4.a - Blades
		1.4.b - Base clamps
		1.4.c - Tip wires
		1.4.d - Tip clamps
		1.4.e - Setting systems
		1.4.f - Thin maraging plates
	1.5 - Filter LVDT sensor	
		1.5.a - Ceramic support
		1.5.b - Wire
		1.5.c - Resin
		1.5.d - Mechanical support
	1.6 - Crossbar damper	
		1.6.a - Viton
		1.6.b - Springs
		1.6.c - Mass
		1.6.d - Plate support
	1.7 - Blade dampers	
		1.7.a - Viton
		1.7.b - Supports
	1.8 - Fishing rod	
		1.8.a - Blade
		1.8.b - Motor
		1.8.c - Mechanic.structure
		1.8.d - Flex joint
		1.8.e - Wire
	1.9 - Plated screws for standard filters	

Items	**Subitems**	**Components**
2 - Filter 7		
	2.1 - Body, crossbar and central cylinder	
	2.2 - Antispring system	
		2.2.a - Supports
		2.2.b - Magnets
		2.2.c - Glue
		2.2.d - Sealing
		2.2.e - Cage
	2.3 - Centering system	
		2.3.a - Wires
		2.3.b - Clamps
		2.3.c - Clamp supports
	2.4 - Metal springs (or blades)	
		2.4.a - Blades
		2.4.b - Base clamps
		2.4.c - Tip wires
		2.4.d - Tip clamps
		2.4.e - Setting systems
		2.4.f - Thin plates
	2.5 - Filter LVDT sensor	
		2.5.a - Ceramic support
		2.5.b - Wire
		2.5.c - Resin
		2.5.d - Mechanical support
	2.6 - Crossbar damper	
		2.6.a - Viton
		2.6.b - Springs
		2.6.c - Mass
		2.6.d - Plate support
	2.7 - Blade dampers	
		2.7.a - Viton
		2.7.b - Supports
	2.8 - Fishing rod	
		2.8.a - Blade
		2.8.b - Motor
		2.8.c - Mechanic. structure
		2.8.d - Flex joint
		2.8.e - Wire
	2.9 - Plated screws for filter 7	
	2.10 - Filter 7 legs	
		2.10.a- Legs
		2.10.b- Thermal insulator
		2.10.c- Connection plate
	2.11 - Remote adjustment	
		2.11.a- Motors
		2.11.b- Rotat.mechanics
		2.11.c- Tilt mechanics

Items	**Subitems**	**Components**
		2.11.d- Balancing system motors
	2.12- Position Monitoring System	
		2.12.a- Tilt-meter support
		2.12.b- Tilt-meter
		2.12.c LVDT-Coil-Magnet supp.
		2.12.d- LVDT-Coil-Magnet coils
		2.12.e- Magnets
		2.12.f- Wire
		2.12.g- Connectors
3 - Filter Zero		
	3.1 - Body, crossbar and central cylinder	
	3.2 - Antispring system	
		3.2.a - Supports
		3.2.b - Magnets
		3.2.c - Glue
		3.2.d - Sealing
		3.2.e - Cage
	3.3 - Centering system	
		3.3.a - Wires
		3.3.b - Clamps
		3.3.c - Clamp supports
	3.4 - Metal springs (or blades)	
		3.4.a - Blades
		3.4.b - Base clamps
		3.4.c - Tip wires
		3.4.d - Tip clamps
		3.4.e - Setting systems
		3.4.f - Thin maraging plates
	3.5 - Filter LVDT sensor	
		3.5.a - Ceramic support
		3.5.b - Wire
		3.5.c - Resin
		3.5.d - Mechanical support
	3.6 - Crossbar dampers	
		3.6.a - Viton
		3.6.b - Springs
		3.6.c - Mass
		3.6.d - Plate support
	3.7 - Blade damper	
		3.7.a - Viton
		3.7.b - Supports
	3.8 - Fishing rod	
		3.8.a - Blade
		3.8.b - Motor
		3.8.c - Mechanic. structure

Items	**Subitems**	**Components**
		3.8.d - Flex joint
		3.8.e - Wire
	3.9 - Plated screws for the filter zero	
	3.10 -Coil-magnets actuators	
		3.10.a- Coils
		3.10.b- Magnets
		3.10.c- Supports
	3.11 -Vertical remote adjustment	
		3.11.a- Mech.System
		3.11.b- Motor
		3.11.c- Encoder
	3.12 -Mechanical connection filter zero - top table	
4 - Inverted Pendulum		
	4.1 - Feet	
		4.1.a - Mechanics
		4.1.b - Piezoelectrics
	4.2 - Platform ring	
	4.3 - Support columns	
	4.4 - Flexural joints	
	4.5 - Counterweight	
	4.6 - Pendulum legs	
	4.7 - Terminal joints	
		4.7.a - Top of the legs
		4.7.b - Wires
		4.7.c - Clamps
	4.8 - Top table	
		4.8.a - Ring
		4.8.b - Connections filter 0
		4.8.c - Motors mech.conn.
	4.9 - Long LVDT sensors (horiz.)	
		4.9.a - Ceramic support
		4.9.b - Wire
		4.9.c - Resin
		4.9.d - Mechanical support
	4.10 -Coils -magnets actuators	
		4.10.a- Maxwell coils
		4.10.b- Magnets
5 - Safety Structure		
	5.1 - Structure	
		5.1.a - Columns
		5.1.b - Rings
	5.2 - Shelves	
		5.2.a - Shelves
		5.2.b - Safety connections

Items	**Subitems**	**Components**
6 - Suspension wires		
	6.1 - Wires	
		6.1.a - Steel Wire
		6.1.b - Heads
	6.2 - Filter connection system	
		6.2.a - Split heads
		6.2.b - Special screw
		6.2.c - Clamp special tool
	6.3 - Junctions	
		6.3.a - Split heads
		6.3.b - Special screw
		6.3.c - Clamp special tool
7 - Cabling		
	7.1 - Cables	
	7.2 - Connectors	
		7.2.a - Pins
		7.2.b - Sockets
		7.2.c - Cases
	7.3 - Feed-throughs	
	7.4 - Flanges	
	7.5 - Mechanical interfaces & clamps	
	7.6 - Accessories	
		7.6.a - Gaskets
		7.6.b - Solding tin
	7.7 - Tools	
		7.7.a - Crimping tool
		7.7.b - Solding machine
8 - Accelerometers		
	8.1 - support for horizontal accelerometers	
	8.2 - support for vertical accelerometers	
	8.4 - maraging blades	
	8.5 - springs	
	8.6 - LVDT	
	8.7 - voice-coil	
	8.8 - brass masses	
	8.9 - connectors	
	8.10 - driver	
9 - Tools		
	9.1 - Wire breaking machine	
	9.2 - Blade stress machine	
	9.3 - Cleaning tools	
		9.3.a - Washing machines
		9.3.b - Outgassing chamber
		9.3.c - Soaps

Items	**Subitems**	**Components**
	9.4 - Oven for mechanical filters	
	9.5 - Oven for blades	
	9.6 - Plating tools	
		9.7.a - Tanks
		9.7.b - Chem. Components
	9.7 - Hardness measurement tool	
	9.8 - Filter quality tests set-up	
	9.9 - Magnetic force measurement machine	
	9.10 -Gaussmeter	

4.4 SR Work Breakdown Structure

4.4.1 Items Production

4.4.1.1 General Working Procedures for Mechanical Filters

Work Description:

1. **Check of the raw material for filter body**
    a. Control of the material type and producer documentation
    b. Measure of the material hardness
2. **Laser cut and cleaning of filter AISI 304L plates**
    a. Laser cut
    b. Degrease with alkaline solution (1hour at room temperature)
    c. Rinsing with de-ionized water
    d. Pickling with nitric and fluoride acid solution (40 min. at room temperature)
    e. Rinsing with de-ionized water
    f. Drying with filtered compressed air
    g. Storage with clean polyethylene packaging
3. **TIG welding and machining of the bare filter body**
    a. Test of the welding procedure (quality, outgassing, strength)
    b. Accept of the welding procedure
    c. Welding of the filter body
    d. Visual inspection of the quality of all the welds
    e. Verify the design dimensions on the welded parts
    f. Machining of the filter body
    g. Visual inspection of all the machined parts
    h. Verify the dimensions on the manufactured parts
4. **Welding and machining stress release of the bare filter body**
    a. Thermal treatment for stress release of the welds and machining (8 hours at 450 ^{0}C)
5. **Control of the filter components**
    a. Verify the dimensions
    b. Weight all components
    c. Label all components
    d. Edit the database for the filter components.
    e. Cleaning and storage in clean environment (step 6 or 7 or 8 or 9)

6. **Cleaning and storage**
    a. Bare filter body and of all AISI 304L steel parts
        i. Degreasing in alkaline solution (1hour at room temperature)
        ii. Rinsing in de-ionized water
        iii. Pickling in nitric and fluoride acid solution (40 min. at room temperature)
        iv. Rinsing with de-ionized water
        v. Passivation bath (1hour at room temperature)
        vi. Rinsing with de-ionized water
        vii. Drying with filtered compressed air
        viii. Packaging with clean polyethylene
        ix. Storage in a clean environment
    b. Maraging
    Cold ultrasonic bath in isopropyl alcohol (15 min.)
    c. Nickel plated parts
    Cold ultrasonic bath in isopropyl alcohol (15 min.)
    d. Viton
    Baking (150 ^{0}C for 24 hours)
7. **Filter Assembly (in a clean environment)**
    a. Install the movable parts:
        i. Crossbar and centering wires
        ii. Blade tips links and centering wires
    b. Install the crossbar LVDT
    c. Install the *Fishing Rod* system
    d. Install the movable blade clamps
    e. Clamp all the maraging cantilever blades
    f. Install the superior and inferior maraging wires
    g. Install the crossbar damper
    h. Install the blade dampers
    i. Edit the filter assembly database
8. **Filter tuning and characterization**
    a. Suspend of the filter from a dedicated suspending frame
    b. Apply the filter nominal load
    c. Balance the filter tilt around horizontal axes
    d. Adjust the tension of the fishing rod blade to its mid range

   e. Adjust the movable blade clamps to set the vertical working point
   f. Tune the upper and lower centering wire frequencies
   g. Measure the main vertical resonance
   h. Install the magnetic antispring system
   i. Measure the main vertical resonance with antisping
   j. Tune the magnetic antispring system (vert. resonance down to ~ 400 *mHz*)
   k. Measure the crossbar displacement with different loads
   l. Measure the main inner resonances
   m. Tune the crossbar damper
   n. Tune the blade dampers
   o. Edit the filter characteristics database

9. **Clean polyethylene packaging and storage of the assembled filter**
10. **Filter installation in the *Superattenuator* chain:**
    a. Before load application:
       i. Deposit filter over the safety frame from F7 to F0
       ii. Connect the filter to its previous SA stage
       iii. Connect the LVDT and fishing rod electric cables
       iv. Fix the SA cabling clamps
       v. Fine balancing of the filter static tilt
    b. After load application
       Fine tuning of the movable blade to compensate for little load mismatch

Specifications:

Filter machining, cleaning and assembly procedures should satisfy the same requirements that were adopted for the VIRGO SA.

Previous Experience on VIRGO:

The operation of the VIRGO filters has shown a satisfactory level of the performances and has confirmed the adopted procedures. The experience for the SA filters construction suggest that the each phase of the preparation to the final installation has to be closely checked and require the supervision of one scientist and the direct involvement of at least one well trained technician.

4.4.1.2 ITEM 1: Standard Filters

Responsible: one scientist (named **A**).

Responsible Tasks

1. Edit the components database and production schedules (see Section 4.4.1.1)
2. Check the efficiency of the required tools
3. Check each step the production phase
4. Check the production quality with planned measurements and tests on raw materials and finished parts
5. Perform the filter characterization tests
6. Validate the final product
7. Check the storage and the cleanliness of the environmental conditions
8. Assist the filter assembly in AdV
9. Assist the commissioning of the SR in AdV

Technical Designs

The SR standard filter technical design is the same one adopted for VIRGO. Old drawings are already available and electronically archived at EGO.

Specific Working Procedures

1. Select the proper spring blades for each filter type according to the design specifications (see Table 4.4.1.5a)

Acceptance Criteria

Each production phase has to be carefully checked to verify the satisfaction of those criteria that were adopted for the VIRGO SA.

1. **Raw Materials**
   a. All the used materials have to match exactly the design requirements concerning the type grade, residual magnetization, and aging status
2. **Welding Procedure**
   a. All the welds have to be of TIG type without cracks and unwanted discontinuities
   b. Tests on welded samples have to be executed to measure their strength
3. **Cleaning Procedures**
   a. Tests on samples have to be executed to verify that the cleaning procedure does not

affect the mechanical strength (excess of pickling can damage the welds)

  b. After cleaning the surfaces and interstices have to be free of grease and other contaminants

4. **Machining**
    a. Check the exact correspondence of machined parts with the design geometry
    b. Check that all the threads are through all and well machined
5. **Assembly**
    a. Check the cleaning of the assembly environment
    b. Check that the screws are not blocked and verify their tightening strength with dynamometric wrench
    c. Check that the tension of the crossbar centering wires is equally shared
    d. Check that the moving components are free to swing vertically
    e. Check the tightening of all the clamps
    f. Check the correct radial distribution of the blade tips
    g. Check the assembly of the antispring system
    h. Check the assembly of the fishing rod system
    i. Check the assembly of the crossbar LVDT sensor
6. **Characterization**
    a. Measure the main inner modes of the assembled filter
    b. Setup the vertical position of the movable part of the loaded filter to mid swinging range
    c. Measure and tune the main vertical mode to the design value (~ 400 *mHz*)

Production Time Schedule and Deliverables:

Table 4.4.1.2.a: SR Standard Filters - SR Production Schedule and Deliverables

Production Phase	**Month 1**		**Month 2**		**Month 3**		**Month 4**		**Month 5**		**Month 6**		**Month 7**		**Month 8**		**Month 9**	
Laser cut	■	■	■	■														
Components product.	■	■	■	■	■	■	■	■	■	■	■							
Filter sheets welding			■	■	■	■	■	■	■	■								
Filter machining					■	■	■	■	■	■	■	■						
St. Filter 1 assembly									■	■								
St. Filter 1 tuning										■	■							
St. Filter 2 assembly											■	■						
St. Filter 2 tuning												■	■					
St. Filter 3 assembly													■	■				
St. Filter 3 tuning														■	■			
St. Filter assembly															■	■		
St. Filter 4 tuning																■	■	
Deliverables																		
Material procurement	■																	
St. Filter 1 validation											■							
St. Filter 2 validation													■					
St. Filter 3 validation															■			
St. Filter 4 validation																	■	

Manpower Plan:

Table 4.4.1.2.b: SR Standard Filters – Manpower Plan

Production Phase	Physicist/Engineer				Mechanics Technician		
Laser Cut	A				J		
Components production	A				J		
Filter sheets welding	A				J		
Filter bodies machining	A				J		
St. filter 1 assembly	A				J		
St. filter 1 tuning	A	B			J		
St. filter 2 assembly	A				J		
St. filter 2 tuning	A	B			J		
St. filter 3 assembly	A				J		
St. filter 3 tuning	A	B			J		
St. filter 4 assembly	A				J		
St. filter 4 tuning	A	B			J		
Total	2				1		

Costs:

Table 4.4.1.2.c: SR Standard Filters – Costs

Item	Quantity	Unitary Cost (k€)	Total Cost (k€)
Standard Filter 1 parts	1	7	**7**
Standard Filter 2 parts	1	7	**7**
Standard Filter 3 parts	1	7	**7**
Standard Filter 4 parts	1	7	**7**
St. Filter Assembly	4	2.5	**10**
Total			**38**

4.4.1.3 ITEM 2: Filter Zero

Responsible: one scientist (named **A**).

Responsible Tasks:

The same of the *Standard Filters* item (see Section 4.4.1.2)

Technical Drawings:

The preliminary SR F0 technical design is the same one adopted for VIRGO. Old drawings are already available and electronically archived at EGO. Some slight modifications concerning the filter movable components could come as consequence of the SAT R&D studies. Eventually, the modified component drawings will be soon produced at the end of this activity for the prototype production in 2009 (see Sections 4.4 and 4.7 Table 4.7a).

Specific Working Procedures:

1. Select the proper spring blades according to the design specifications (Table 4.4.1.5a)
2. Assemble the support of the two vertical accelerometers
3. Install the two vertical accelerometers
4. Assemble the supports of the voice-coil actuators
5. Install the two voice coil actuators
6. Install the SA vertical adjustment endless screw system with motor

Acceptance Criteria:

The same of the *Standard Filters* item (see Section 4.4.1.2).

Production Time Schedule and Deliverables:

Table 4.4.1.3.a: SR Filter Zero - Production Schedule and Deliverables																
Production Phase	**Month 1**		**Month 2**		**Month 3**		**Month 4**		**Month 5**		**Month 6**		**Month 7**		**Month 8**	
Laser cut	■	■														
Components production	■	■	■	■	■	■	■	■								
F0 welding			■	■												
F0 machining					■	■										
F0 assembly							■	■								
F0 tuning								■	■							
Deliverables																
Material procurement	■															
F0 validation									■							

Manpower Plan:

Table 4.4.1.3.b: SR Filter Zero - Manpower Plan							
Production Phase	**Physicist/Engineer**				**Mechanics Technician**		
Laser cut	**A**				**J**		
Components production	**A**				**J**		
F0 sheets welding	**A**				**J**		
F0 machining	**A**				**J**		
F0 assembly	**A**				**J**		
F0 tuning	**A**	**B**			**J**		
Total	**2**					**1**	

Costs:

Table 4.4.1.3.c: SR Filter Zero – Cost			
Item	**Quantity**	**Unitary Cost (k€)**	**Total Cost (k€)**
F0 components	1	9	**9**
F0 assembly	1	3	**3**
Total (without IVA/VAT)			**12**

4.4.1.4 ITEM 3: Filter 7

Responsible: one scientist (named **A**).

Responsible Tasks:
The same of the *Standard Filters* item (see Section 4.4.1.2)

Technical Drawings:
The preliminary SR F7 technical design is the same one adopted for VIRGO. Old drawings are already available and electronically archived at EGO.

At the moment there is an AdV PAY R&D activity concerning the construction of the SA payload (see Fig. 4.19). According to the proposed payload design the MRM will be installed, as an additional suspended element, within the UHV chamber between the F7 and the *Marionette*. This new MRM will also host the actuator coils for steering the *Marionette,* replacing the F7 legs which will be than suppressed from the F7 design.

Specific Working Procedures:

1. Select the proper spring blades according to the design specifications (Table 4.4.1.5.a)
2. Assemble the upper and lower motorized rotational systems
3. Install the Filter 7 monitoring system:
    a. Install the balancing sliders
    b. Install the filter dual-axes tilt-meter sensor (Section 4.2.2.1)
    c. Install the 3 horizontal LVDT primary windings on the outer shell

Acceptance Criteria:
The same of the *Standard Filters* item (see Section 4.4.1.2).

Production Time Schedule and Deliverables:

Table 4.4.1.4.a: SR Filter 7 – SR Production Schedule and Deliverables

Production Phase	**Month 1**		**Month 2**		**Month 3**		**Month 4**		**Month 5**		**Month 6**		**Month 7**	
Laser cut	■	■												
Components production	■	■	■	■	■	■	■	■						
F7 sheets welding			■	■										
F7 machining					■	■								
F7 assembly							■	■						
F7 tuning								■	■					
Deliverables														
Material procurement	■													
F7 validation									■					

Manpower Plan:

Table 4.4.1.4.b: SR Filter 7 - Manpower Plan

Production Phase	**Physicist/Engineer**				**Mechanics Technician**			
Laser cut	**A**				**J**			
Components production	**A**				**J**			
F7 sheets welding	**A**				**J**			
F7 machining	**A**				**J**			
F7 assembly	**A**				**J**			
F7 tuning	**A**	**B**			**J**			
Total	**2**				**1**			

Costs:

Table 4.4.1.4.c: SR Filter 7 – Cost

Item	**Quantity**	**Unitary Cost (k€)**	**Total Cost (k€)**
F7 components	1	12	**12**
F7 assembly	1	3	**3**
Total (without IVA/VAT)			**15**

4.4.1.5 Typical SA Filters Characteristics

Table 4.4.1.5.a – Typical SA Filters Characteristics							
E maraging 18%Ni C250 (MARVAL 18) = 186000 N/mm^2							
Filters		**Filt – 0**	**Filt. St. 1**	**Filt. St. 2**	**Filt. St. 3**	**Filt. St. 4**	**Filt. 7**
Mass (kg)		-	152+7	147 +7	141+7	125+7	192+7
Load on blades (kg)		TBD	=	=	=	=	=
Fixed blades		8	8	6	4	4	2
	Base width (mm)	180	152	146	138	133.5	110
	Length (mm)	354.5	=	=	=	=	=
	Thickness (mm)	3.5	=	=	=	=	=
	Material	Marval 18	=	=	=	=	=
	Load /Blade (kg)	TBD	=	=	=	=	=
	Rad. of curv. (mm)	TBD	=	=	=	=	=
Movable blades		4	4	4	4	2	2
	Base width (mm)	160	=	=	=	=	=
	Length (mm)	354.5	=	=	=	=	=
	Thickness (mm)	3.5	=	=	=	=	=
	Material	Marval 18	=	=	=	=	=
	Load /Blade (kg)	TBD	=	=	=	=	=
	Rad. of curv. (mm)	TBD	=	=	=	=	=
Fishing Rod blade		1	=	=	=	=	=
	Base width (mm)	40	=	=	=	=	=
	Length (mm)	254	=	=	=	=	=
	Thickness (mm)	1.5	=	=	=	=	=
	Material	Marval 18	=	=	=	=	=
	Load Max. (N)	20	=	=	=	=	=
	Rad. of curv. (mm)	823	=	=	=	=	=
	σ (N/mm^2)	338.6					
	K (N/m)	255	=	=	=	=	=
Crossbar wire		4	=	=	=	=	=
	Material	Piano wire	=	=	=	=	=
	Length (m)	1	=	=	=	=	=
	Diameter (mm)	1	=	=	=	=	=
	Load Max. (N)	650	=	=	=	=	=
Fishing Rod wire		1	=	=	=	=	=
	Material	Marval 18	=	=	=	=	=
	Length (m)	0.2	=	=	=	=	=
	Diameter (mm)	0.6	=	=	=	=	=
	Load Max. (N)	20	=	=	=	=	=
Blade tips wire		12	12	10	8	6	4
	Material	Marval 18	=	=	=	=	=
	Total Length (m)	2.5	2.5	2.1	1.7	1.3	0.9
	Diameter (mm)	1	=	=	=	=	=
	Load in VIRGO (N)	928	747	718	678	656	474
	σ in VIRGO (N/mm^2)	1182	951	915	863	835	603

4.4.1.6 ITEM 4: Inverted Pendulum

Work Description:

1. **Control of the raw material**
    a. Check of the material type and producer documentation
    b. Measurement of the material hardness
2. **Laser cutting and cleaning of IP platform and top ring AISI 304L plates**
    a. Laser cut
    b. Degrease with alkaline solution (1hour at room temperature)
    c. Rinse with de-ionized water
    d. Pickling with nitric and fluoride acid solution (40 min. at room temperature)
    e. Rinse with de-ionized water
    f. Drying with filtered compressed air
    g. Storage with clean polyethylene packaging
3. **TIG welding and machining of the IP platform and top rings**
    a. Test of the welding procedure (quality, outgassing, strength)
    b. Acceptance of the welding procedure
    c. Platform and top rings welding
    d. Visual inspection of the quality of all the welds
    e. Verify the dimensions on the welded parts
    f. Platform and top rings machining
    g. Visual inspection of all the machined parts
    h. Verify the dimensions on the manufactured parts
4. **Welding and machining stress release of the IP platform and top rings**
    a. Thermal treatment for stress release of the welds and machining (8 hours at 450 ^{0}C)
5. **Control of the all the IP leg components**
    a. Verify of the design dimensions on the manufactured parts
    b. Check the coaxiality of top and bottom flanges of the IP Aluminum legs
    c. Check the coaxiality of top and bottom flanges of the IP steel legs
    d. Edit of the database for the IP leg components
    e. Cleaning and storage in clean environment (step 6 or 7 or 8 or 9)
6. **Cleaning and storage**
    a. AISI 304L steel parts
        i. Degrease in alkaline solution (1hour at room temperature)

        ii. Rinse in de-ionized water
        iii. Pickling in nitric and fluoride acid solution (40 min. at room temperature)
        iv. Rinse with de-ionized water
        v. Passivation bath (1hour at room temperature)
        vi. Rinse with de-ionized water
        vii. Drying with filtered compressed air
        viii. Packaging with clean polyethylene
        ix. Storage in a clean environment
    b. Aluminum and Titanium parts
        i. Degrease with isopropyl alcohol
        ii. Packaging with clean polyethylene
        iii. Storage in a clean environment
    c. Maraging:
        i. Cold ultrasonic bath in isopropyl alcohol (15 min.)
    d. Nickel plated parts:
        i. Cold ultrasonic bath in isopropyl alcohol (15 min.)
    e. Viton:
        i. Baking (150 ^{0}C for 24 hours)

7. **IP tuning and characterization**
    a. Assembly of the IP maraging flex joints, legs and top ring
    b. Gradual loading on the IP top ring and measuring of the main longitudinal and rotational mode frequencies
    c. Verify the IP joint elasticity with nominal load applied
    d. Edit of the IP characteristics database

8. **Clean polyethylene packaging and storage of the IP components**
9. **IP installation in the SR tower**
    a. Before load application:
        i. Install the IP steel platform supports with piezoelectric actuators
        ii. Install the IP steel platform
        iii. Install the 3 IP steel leg base and maraging flexible joints
        iv. Install the 3 IP counterweight Aluminum cylindrical support
        v. Install the 3 IP Al legs

        vi. Install the 3 IP Ti terminations
        vii. Install the steel top ring with the 3 maraging connection wires and Ti supports
        viii. Clamp of the IP legs the springs of the 3 horizontal motorized-sliders placed over the *Safety Frame*
        ix. Install the 3 LVDTs primary winding support over the IP top ring
        x. Install the 3 horizontal accelerometers over the IP top ring
        xi. Install the 3 magnets supports of the coil magnet actuators over the IP top ring
        xii. Install the IP safety stops over the Safety Frame
    b. After load application (all SA filters and payload)
        i. Install the IP counterweights
        ii. Check of the IP legs parallelism
        iii. Check of the IP orthogonality with respect to the Platform
        iv. Setup of the SA suspension point with the motorized sliders placed over the *Safety Frame*
        v. Tune of longitudinal and angular modes adding mass to the IP top ring.

Specifications:

IP machining, cleaning and assembly procedures should satisfy the same requirements that were adopted for the VIRGO SA.

Previous Experience on VIRGO:

The operation of the VIRGO IP has shown a satisfactory level of the performances and has confirmed the adopted procedures. The experience made suggests that the each phase of the preparation to the final installation has to be closely checked and require the supervision of one scientist and the direct involvement of at least one well trained technician (named **K**).

Responsible: one scientist (named **C**).

Responsible Tasks:

1. Edit the components database and production schedules
2. Check the efficiency of the required tool
3. Check each step the production phase
4. Check the production quality with measurements and tests on materials and finished parts
5. Perform the IP characterization tests
6. Validate the final product

7. Check the storage and the cleanliness of the environmental conditions
8. Assist the IP assembly in AdV
9. Assist the commissioning of the SR in AdV

Technical Drawings:

The preliminary SR IP technical drawings are the same of VIRGO. Old drawings are already available and electronically archived at EGO.

At the moment there is an AdV SAT R&D activity concerning the construction of a new IP with stiffer monolithic aluminum legs and implementing piezoelectric actuators at the base of the platform ring. Actually only the prototype drawings are ready and the system is being assembled in SAFE. Tests will follow to validate the system.

Acceptance Criteria

Each production phase has to be carefully checked to verify the satisfaction of those criteria that were adopted for the VIRGO SA.

7. **Raw Materials**
   a. All the used materials have to match exactly the design requirements concerning the type grade, residual magnetization, and aging status
8. **Welding Procedure**
   a. All the welds have to be of TIG type without cracks and unwanted discontinuities
   b. Tests on welded samples have to be executed to measure their strength
9. **Cleaning Procedures**
   a. Tests on samples have to be executed to verify that the cleaning procedure does not affect the mechanical strength (excess of pickling can damage the welds)
   b. After cleaning the surfaces and interstices have to be free of grease and other contaminants
10. **Machining**
    a. Check the exact correspondence of machined parts with the design geometry
    b. Check that all the threads are through all and well machined
    c. Check the assembly of the crossbar LVDT sensor
    d. Check the IP legs parallelism
    e. Check the IP orthogonality with respect to the Platform

Production Time Schedule and Deliverables:

Table 4.4.1.6.a: SR Inverted Pendulum - Production Schedule and Deliverables

Production Phase	Month 1		Month 2		Month 3		Month 4		Month 5		Month 6		Month 7		Month 8	
Components production	■	■	■	■	■	■	■	■								
Laser cut	■	■														
Ring plates welding			■	■												
Ring bodies machining					■	■	■	■								
IP pre-assembly								■	■							
IP test									■	■						
Deliverables																
Material procurement	■															
IP validation										■						

Manpower Plan:

Table 4.4.1.6.b: SR Inverted Pendulum - Manpower Plan

Production Phase	Physicist/Engineer				Mechanics Technician		
Components production	C				K		
Laser cut	C				K		
Ring plates welding	C				K		
Ring bodies machining	C				K		
IP pre-assembly	C				K		
IP test	C	B					
Total	2				1		

Costs:

Table 4.4.1.6.c: SR Inverted Pendulum –Cost

Item	Quantity	Unitary Cost (k€)	Total Cost (k€)
Inverted Pendulum	1	25	**25**
Total (without IVA/VAT)			**25**

4.4.1.7 ITEM 5: Safety Frame

Work Description:

1. **Control of the raw material**

   Check of the material type and producer documentation
2. **Cutting and Cleaning of the AISI 304L plates**
   a. Laser or flame cut
   b. Degrease with alkaline solution (1hour at room temperature)
   c. Rinse with de-ionized water
   d. Pickling with nitric and fluoride acid solution (40 min. at room temperature)
   e. Rinse with de-ionized water
   f. Drying with filtered compressed air
   g. Storage with clean polyethylene packaging
3. **TIG welding and machining**
   a. Test of the welding procedure (quality, outgassing, strength)
   b. Accept the welding procedure
   c. U shaped column flanges welding
   d. Visual inspection of the quality of all the welds
   e. Verify of the design dimensions of the welded parts
   f. Safe structure rings and flanges machining
   g. Visual inspection of all the machined parts
   h. Verify of the design dimensions on the manufactured parts
4. **Welding and machining stress release**
   a. Thermal treatment for stress release of the welds and machining (8 hours at 450 ^{0}C)
5. **Control of the all the Safe Structure components**
   a. Verify of the design dimensions on the manufactured parts
   b. Check the assembly of parts
   c. Edit of the database for the Safe Structure components
   d. Clean and storage in clean environment (step 6 or 7 or 8 or 9)
6. **Cleaning and storage**
   a. AISI 304L steel parts
      i. Degrease in alkaline solution (1hour at room temperature)
      ii. Rinse in de-ionized water
      iii. Pickling in nitric and fluoride acid solution (40 min. at room temperature)

            iv. Rinse with de-ionized water
            v. Passivation bath (1hour at room temperature)
            vi. Rinse with de-ionized water
            vii. Drying with filtered compressed air
            viii. Packaging with clean polyethylene
            ix. Storage in a clean environment
    b. Aluminum parts
        i. Degrease with isopropyl alcohol
        ii. Packaging with clean polyethylene
        iii. Storage in a clean environment

7. **Clean polyethylene packaging and storage of the Safe Structure components**
8. **Safe Structure installation in the SR tower**
    a. Install the Safe Structure platform
    b. Install the Safe Structure U shaped columns, the intermediate and top rings
    c. Install the Safe Structure U shaped shelve support and ring shelves

Specifications:

IP machining, cleaning and assembly procedures should satisfy the same requirements that were adopted for the VIRGO SA.

Previous Experience on VIRGO:

The operation of the VIRGO *Safety Frame* has shown a satisfactory level of functionality. Each phase of the preparation to the final installation has to be closely checked and require the supervision of one mechanical technician (named **C**).

Responsible: one scientist (named **K**).

Responsible Tasks:

1. Edit the components database and production schedules
2. Check the efficiency of the required tools
3. Check each step the production phase
4. Check the production quality with planned measurements and tests on raw materials and finished parts
5. Validate the final product

6. Check the storage and the cleanliness of the environmental conditions
7. Assist the *Safe Structure* assembly in AdV

Technical Drawings:

The preliminary SR *Safe Structure* technical design is the same one adopted for VIRGO. Old drawings are already available and electronically archived at EGO.

Acceptance Criteria:

Each production phase has to be carefully checked to verify the satisfaction of those criteria that were adopted for the VIRGO SA.

11. **Raw Materials**
    a. All the used materials have to match exactly the design requirements concerning the type grade, residual magnetization, and aging status
12. **Welding Procedure**
    a. All the welds have to be without cracks and unwanted discontinuities
    b. Tests on welded samples have to be executed to measure their strength
13. **Cleaning Procedures**
    a. Tests on samples have to be executed to verify that the cleaning procedure does not affect the mechanical strength (excess of pickling can damage the welds)
    b. After cleaning the surfaces and interstices have to be free of grease and other contaminants.
14. **Machining**
    a. Check the exact correspondence of machined parts with the design geometry
    b. Check that all the threads are through all and well machined
    c. Check the assembly of the contiguous parts
    d. Check the U shaped columns alignment
    e. Check U shaped columns orthogonality with respect to the Platform

Production Time Schedule and Deliverables:

Table 4.4.1.7.a: SR Safety Frame - Production Schedule and Deliverables

Production Phase	**Month 1**		**Month 2**		**Month 3**		**Month 4**		**Month 5**		**Month 6**		**Month 7**	
Components production	■	■	■	■	■	■								
Plates cut	■	■												
Flanges welding			■	■										
Flanges machining					■	■	■	■						
Pre-assembly							■	■						
Deliverables														
Material procurement	▒													
Safety Frame validation								■						

Manpower Plan:

Table 4.4.1.7.b: SR Safety Frame - Manpower Plan

Production Phase	**Physicist/Engineer**				**Mechanics Technician**			
Components production					**K**			
Plates cut					**K**			
Flanges welding					**K**			
Flanges machining					**K**			
Pre-assembly	**C**				**K**			
Total	**1**				**1**			

Costs:

Table 4.4.1.7.c: SR Safety Frame – Cost

Item	**Quantity**	**Unitary Cost (k€)**	**Total Cost (k€)**
Safety Frame	1	14	**14**
Total (without IVA/VAT)			**14**

4.4.1.8 ITEM 6: Suspension Wires

Work Description:

1. **Control of the raw material (maraging 18%Ni C2500– MARVAL 18)**
    a. Control of the material type and producer documentation
2. **Wire machining**
    a. Test of the machining procedure (quality, strength)
    b. Accept of the machining procedure
    c. Verify the dimensions on the produced wires
3. **Thermal treatments solubilization**
    a. Solubilization at 840 ^{o}C for 1 hour in neutral environment (Ar gas flux), cooling in air down to 100 ^{o}C and quenching in water and ice solution at 0 ^{o}C
    b. Aging at 435 ^{o}C for 100 hour in neutral environment (Ar gas flux)
4. **Nickel chemical electroless plating**
5. **Dehydrogenation thermal treatment**
    a. 100 hours at 200 ^{o}C
6. **Acceptance Test**
    a. Test the strength of a production sample in the wire pulling machine tool
7. **Checking of the wire Ti junction boxes and carbon steel semi-cups**
    a. Verify of the design dimensions of the manufactured parts
    b. Verify of the complete junction box and wire assembly
8. **Cleaning**
    a. **Maraging, titanium and carbon steel cleaning**
    Degrease with cold ultrasonic bath in isopropyl alcohol (15 min.)
9. **Editing the suspension wire production and test database**
10. **Clean polyethylene packaging and storage**

Specifications:

The suspension maraging wires are critical components of the SR chain. These elements will be designed once the payload weight will be exactly defined. In fact, the applied stress need to be well below the ultimate breaking strength, and it is determined by the applied load and the wire geometry. The critical point of the suspension wires is in correspondence of the radial joint of the terminal heads, where the maximum combination of maximum share stress and tensile stress is applied. The maraging Young modulus after the adopted thermal treatments is of about 1800 MPa and yield is about 1950 MPa. These values have to be verified in traction tests operating the wire pulling machine tool on selected samples from the production line.

Previous Experience on VIRGO:

The operation of the VIRGO suspension wires has been satisfactory. Each phase of the wire production and final installation has to be checked and require the supervision of one scientist (named **D**).

Responsible: one scientist (named **D**).

Responsible Tasks:

1. Edit the wires and junction boxes database, the production and test schedules
2. Check the efficiency of the required tools
3. Check each step the production phase
4. Perform tensile strength tests on samples from the production line
5. Validate the final product
6. Check the storage and the cleanliness of the environmental conditions
7. Assist the suspension wire installation in AdV

Technical Drawings:

The preliminary suspension wires technical design is the same one adopted for VIRGO. Old drawings are already available and electronically archived at EGO. The final design will come after the exact definition of the payload weight.

Acceptance Criteria:

Each production phase has to be carefully checked to verify the satisfaction of those criteria that were adopted for the VIRGO SA.

1. **Raw Materials**

   All the used maraging and titanium rods have to match exactly the design requirements concerning the type grade, and aging status

2. **Thermal treatments**

   Solubilization and aging thermal treatments have to be executed in a proper oven, in neutral environment, under controlled Ar flux

3. Nickel Plating

Only the approved electroless nickel plating procedures have to be applied

4. Dehydrogenation

Wire dehydrogenation need to be executed in a proper clean oven within 1 hour from chemical Nickel plating bath

5. Cleaning Procedures

Only the approved cleaning procedures have to be applied

6. Machining

Check the exact correspondence of machined parts with the design geometry

7. Tests

Wire tensile strength tests have to verify the foreseen strength value

Production Time Schedule and Deliverables:

Table 4.4.1.8.a: SR Suspension Wires - Production Schedule and Deliverables

Production Phase	**Month 1**		**Month 2**		**Month 3**		**Month 4**		**Month 5**		**Month 6**		**Month 7**	
Wire production	■	■	■	■										
Thermal treatment			■	■	■	■								
Nickel plating			■	■	■	■								
Tensile strength tests					■	■	■	■						
Deliverables														
Material procurement	■													
Validation					■	■	■	■						

Manpower Plan:

Table 4.4.1.8.b: SR Suspension Wires – Manpower Plan

Production Phase	**Physicist/Engineer**				**Mechanics Technician**		
Wire production	**D**						
Thermal treatment	**D**						
Nickel plating	**D**						
Aging	**D**						
Tensile strength tests	**D**						
Total	**1**				**0**		

Costs:

Table 4.4.1.8.c: SR Suspension Wires – Costs

Item	Quantity	Unitary Cost (€)	Total Cost (€)
Top Ring wires	3	100	**300**
Filter 0 – short wires	2	300	**600**
Filter 0 – long wires	2	400	**800**
F. St. 1 – short wires	2	300	**600**
F. St. 1 – long wires	1	400	**400**
F. St. 2 – short wires	2	300	**600**
F. St. 2 – long wires	1	400	**400**
F. St. 3 – short wires	2	300	**600**
F. St. 3 – long wires	1	400	**400**
F. St. 4 – short wires	2	300	**600**
F. St. 4 – long wires	1	400	**400**
Filter 7 – short wires	2	300	**600**
Filter 7 – long wires	1	400	**400**
Ti Junction boxes	16	150	**2400**
Steel Semi-cups	50	100	**5000**
Total (without IVA/VAT)			**14100**

4.4.1.9 ITEM 7: Cabling

Work Description:

1. **Cabling design (electrical schemes and pin-outs included)**
2. **Material procurements**
3. **Components preparation in cabling lab (clean room class 100)**
    a. Cut the cables
    b. validate the crimping procedures
    c. Crimp the connectors on cables
    d. Verify the connectors continuity
    e. Labeling
    f. Cleaning and UHV treatment

    g. Realization of the special cabling assembly used along the conductance pipe
    h. Edit the technical and production cable database
4. **Storage in clean plastic bags**
5. **Clean the aluminum clamps and heat-shrinkable tubes in isopropyl alcohol (15 min.)**
6. **Clean the flanges in isopropyl alcohol (15 min.)**
7. **Mount the panel LEMO connectors on the electrical devices of the suspension**
8. **Install of cables and flanges**
9. **SR cabling testing**
10. **Edit the SR cabling technical documentation**

Specifications:

Cable specifications will be the same adopted for the VIRGO assembly.

Previous Experience on VIRGO:

From the past experience it is confirmed that cabling preparation require a clean room and the adoption of a strong care in maintaining satisfactory cleaning conditions. Continuity tests on cable connectors have to follow each cable preparation. The work requires the supervision of an electronics engineer (named **F**) and the involvement of one electronics technician (named **M**).

Responsible: one electronics engineer (named **F**)

Responsible tasks:

1. Edit the cables production database and test schedules.
2. Edit the cable technical database.
3. Check the efficiency of the required tools.
4. Check each step the production phase.
5. Check the storage and the cleanliness of the environmental conditions
6. Validate the final product.
7. Assist the cabling installation.
8. Edit the SR cabling database.
9. Assist the SR commissioning

Technical drawings:

Electric cabling schemes will be derived from the ones adopted for the VIRGO SA assembly. The old cabling schemes are available.

Acceptance Criteria:

The acceptance criteria will be the one adopted for the VIRGO SA assembly

1. Cables and connectors have to be prepared in a clean cabling lab (class 100)
2. Cabling has to match the VIRGO outgassing specifications
3. Cables impedance has to be measured
4. Conduction Pipe continuity has to be verified after its construction and installation
5. SR Cabling electrical and technical schemes have to be delivered

Production Time Schedule and Deliverables:

Table 4.4.1.9.a: SR Cabling - Production Schedule and Deliverables

Production Phase	**Month 1**		**Month 2**		**Month 3**		**Month 4**		**Month 5**		**Month 6**		**Month 7**	
Cables preparation	■	■	■	■										
Test		■	■	■	■	■								
Deliverables														
Material Procurement	■													
Validation						■								

Manpower Plan:

Table 4.4.1.9.b: SR Cabling - Manpower Plan

Production Phase	**Physicist/Engineer**				**Electronics Technician**			
Design	**E**				**L**			
Material procurement	**E**							
Cables preparation	**E**				**L**			
Test	**E**				**L**			
Total	**1**				**1**			

Costs:

Table 4.4.1.9.c: SR Cabling - Costs			
Item	**Quantity + Spare**	**Unitary Cost (k€)**	**Total Cost (k€)**
Flat cable (m)	300 +100	-	**26**
12" CF flanges *	2	9	**18**
Lemo conn.-multipin	100	-	**4.5**
Heat shrinkable tube	-	-	**0.5**
Conduction pipe components	-	-	**1.5**
Total (without IVA/VAT)			**50.5**
* Feedthroughsand circular peek plugs are included			

4.4.1.10 ITEM 8: Accelerometers

Work Description:

1. **Control of the raw material**
   a. Control of the material type and producer documentation
2. **Control of the accelerometer components**
   a. Check the accelerometer parts dimensions
   b. Label of all components
   c. Edit of the database of accelerometer components
   d. Check the LVDT position sensor assembly
   e. Measure the LVDT position sensor impedance
   f. Measure the LVDT position sensor response
   g. Measure the voice coil impedance
   h. Measure the voice coil response
   i. Perform thermal treatment of MARVAL 18 blades (see procedure Section 4.4.1.8)
   j. Measure the spring stiffness
   k. Edit the accelerometer electromechanical database
3. **Cleaning of accelerometer components**
   a. Aluminum, brass and maraging parts
      Degrease with isopropyl alcohol.
4. **Storage of accelerometer components**

    a. Packaging with clean polyethylene
    b. Storage in a clean environment

5. **Accelerometer assembly (in a clean environment)**
6. **Tuning and characterization**
7. **Edit the accelerometers technical database**
8. **Clean polyethylene packaging and storage of the assembled accelerometers**

Specifications:

Accelerometers for the SR will match the same specifications of all other AdV accelerometers with an acceleration spectral sensitivity of about $7x10^{-10}$ $(m/s^2/\surd(Hz))$ in the 0.01-10 Hz region.

Previous Experience on VIRGO:

The operation of the VIRGO accelerometers has been satisfactory. Each phase of the production and final installation has to be checked and require the supervision of one scientist (named **F**) and the involvement of one electronic technician (named **M**).

Responsible: one scientist (named **F**).

Responsible Tasks

1. Edit the accelerometer components database, the production and test schedules
2. Edit the accelerometer technical database
3. Check the efficiency of the required tools
4. Check each step the production phase
5. Perform tests on electromechanical components
6. Measure the accelerometer response
7. Validate the final product
8. Check the storage and the cleanliness of the environmental conditions
9. Assist the installation on the SR chain
10. Assist the commissioning of the SR chain

Technical Drawings:

The preliminary vertical and horizontal technical designs are the same one adopted for VIRGO. The old drawings are already available and electronically archived at EGO.

SAT is studying the possible upgrade of these devices considering other performing models and considering some minor interventions on the electromechanical components of the present ones. Eventual design of the upgraded accelerometers will come after the SAT R&D activity in 2010 (see Section 4.6 and 4.7 Table 4.7a).

Acceptance Criteria:

Each production phase has to be carefully checked to verify the satisfaction of those criteria that were adopted for the VIRGO SA.

1. **Raw materials**

   All the used aluminum, brass, maraging and insulation materials have to match exactly the design requirements concerning the type grade, and aging status

2. **Maraging blades thermal treatments**

   Solubilization and aging thermal treatments of maraging blades have to be executed in a proper oven, in neutral environment, under controlled Ar flux

3. **Maraging nickel plating**

   Only the approved electroless nickel plating procedures have to be applied

4. **Maraging dehydrogenation**

   Wire dehydrogenation need to be executed in a proper clean oven within 1 hour from chemical Nickel plating bath

5. **Cleaning procedures**

   Only the approved cleaning procedures have to be applied

6. **Machining**

   Check the exact correspondence of machined parts with the design geometry

7. **Characterization Tests**

   Tests of electromechanical components and response measurements have to match the foreseen specifications

Production Time Schedule and Deliverables:

Table 4.4.1.10.a: SR Accelerometers - Production Schedule and Deliverables

Production Phase	**Month 1**	**Month 2**	**Month 3**	**Month 4**	**Month 5**	**Month 6**	**Month 7**	**Month 8**	**Month 9**
Components production	■	■	■						
Blade therm. treatments	░	■	■						
Blade Nickel plating		■	■	░					
Electromech. tests			■	■	░				
Assembly			■	■	░				
Characterization			■	■	■				
Deliverables									
Validation			■	■	■				

Manpower Plan:

Table 4.4.1.10.b: SR Accelerometers - Manpower Plan

Production Phase	**Physicist/Engineer**			**Electronics Technician**		
Components production	**F**					
Blade therm. treatments	**F**	**D**[*]				
Blade Nickel plating	**F**	**D**[*]				
Electromech. tests	**F**			**M**		
Assembly	**F**			**M**		
Characterization	**F**			**M**		
Total	**2**			**1**		
*** Expert in maraging thermal treatments and nickel plating**						

Costs:

Table 4.4.1.10.c: SR Accelerometers – Costs

Item	**Quantity**	**Unitary Cost (k€)**	**Total Cost (k€)**
Vert. Accelerometer	2	6	**12**
Horiz. Accelerometer	3	6	**18**
Total (without IVA/VAT)			**30**

4.4.1.11 ITEM 9: Tools

The special tools that are foreseen for the SR construction and assembly are listed below. For each of them is given the present status and the list of responsibles.

- **Wire Breaking Machine**

This tool is already available in the INFN-Pisa mechanics laboratory

Responsible: one person (**D**)

- **Blade Stress Machine**

This tool is already available in INFN-Pisa mechanics laboratory

Responsible: one person (**D**)

- **Cleaning Tools**

Almost all these tools are already available at EGO

Responsible: EGO

- **Oven for the Mechanical Filters**

This device can be found in some known workshops that have already worked for VIRGO

Responsible: one person (**A, B**)

- **Oven for Maraging Blades and Suspension Wires**

This tool is already available at the 1.5 Km W-building of the EGO facility

Responsible: one person (**D**)

- **Nickel Plating Tool**

This instrument can be found in some known workshops that have already worked for VIRGO

Responsible: one person (**D**)

- **Hardness Measurement Tool**

This instrument can be found in some known workshops that have already worked for VIRGO

Responsible: one person (**A, B**)

- **Filter Quality Test Setup**

This set up is already available and stored at EGO

Responsible: one person (**A, B**)

- **Magnetic Force Measurement Machine**

This machine is already available at INFN- Pisa mechanics laboratory

Responsible: one person (**E**)

- **Gaussmeter**

This tool is already available at EGO

Responsible: one person (**E**)

Production Time Schedule and Deliverables:

Table 4.4.1.11.a : SR Tools - Production Schedule and Deliverables

Tool Preparation	**Month 1**	**Month 2**	**Month 3**	**Month 4**	**Month 5**	**Month 6**	**Month 7**
Wire Breaking Machine	■	■	■				
Blade Stress Machine	■	■	■				
Cleaning Tools	■	■					
Filter Oven	■	■	■				
Maraging pieces oven	■	■					
Nickel Plating	■	■					
Hardness Measurement	■	■					
Filter quality test setup	■	■					
Magnetic force Meas.	■	■	■				
Gaussmeter	■	■					
Deliverables							
Validation		■	■				

Manpower Plan:

Table 4.4.1.11.b: SR Tools Manpower Plan

Tool Preparation	**Physicist/Engineer**					**Electronics Technician**			
Wire Breaking Machine	**D**					**J**			
Blade Stress Machine	**D**					**J**			
Cleaning Tools		**EGO**							
Filter Oven			**A,B**						
Maraging pieces oven	**D**								
Nickel Plating	**D**								
Hardness Measurement			**A,B**			**J**			
Filter quality test setup			**A,B**						
Magnetic force Meas.				**E**			**L**		
Gaussmeter				**E**			**L**		
Total	**4**					**2**			

Costs:

Table 4.4.1.11.c: SR Tool – Costs

Tool Preparation	**Quantity**	**Unitary Cost (k€)**	**Total Cost (k€)**
Wire Breaking Machine	1	-	**1.5**
Blade Stress Machine	1	-	**1.5**
Cleaning Tools	1	-	**1**
Filter Oven	1	-	**1.5**
Maraging pieces oven	1	-	**0.5**
Nickel Plating	1	-	**1**
Hardness Measurement	1	-	**1**
Filter quality test setup	1	-	**2**
Magnetic force Meas.	1	-	**2**
Gaussmeter	1	-	**-**
Total (without IVA/VAT)			**12**

4.4.2 Production of special parts of the items

4.4.2.1 Metal Spring Blades

Work Description:

1. **Control of the raw material (maraging 18%Ni C2500– MARVAL 18)**
   Control of the material type and producer documentation
2. **Blade machining**
   a. Laser cut and drilling of the maraging plate
   b. Bend each blade up to the requested radius of curvature
   c. Label with a punch tool
   d. Preliminary sandblasting for surface oxides layer removal
   e. Verify the design dimensions on the produced wires
   f. Cleaning with cold ultrasonic bath in isopropyl alcohol (15 min.)
3. **Thermal treatments and tests**
   a. Solubilization at 840 ^{o}C for 1 hour in neutral environment (Ar gas flux), cooling in air flow down to 100 ^{o}C and final quenching in water and ice solution at 0 ^{o}C
   b. Check and eventual adjusting of the radius of curvature
   c. Aging at 435 ^{o}C for 100 hour in neutral environment (Ar gas flux)
   d. Checking with microscope the special samples treated with the blades
   e. Mechanical pulling test of the samples treated with the blades
   f. Hardness test of the blades
   g. Editing of the blade database
   h. Sandblasting of blades for surface oxides layer removal
4. **Nickel chemical electroless plating**
   Checking the nickel plating thickness on samples plated with blades
5. **Dehydrogenation thermal treatment**
   100 hours at 200 ^{o}C
6. **Acceptance Test**
   a. Measuring the elasticity and applied load in flat blade configuration operating the blade pulling machine
   b. Editing the blade technical database
7. **Cleaning with cold ultrasonic bath in isopropyl alcohol (15 min.)**
8. **Clean polyethylene packaging and storage**

Specifications:

The maraging blade Young modulus after the adopted thermal treatments is of about 1800 MPa. The designed blade elasticity depends on its geometry and pre-bending radius of curvature. The final design of the filter blades will follow after the definition of the AdV payload weight. The blade nominal load in flat horizontal configuration will be verified operating the blade pulling machine tool on all the produced blades. The blade hardness of each blade will also be measured with a proper hardness measuring instrument. Selected samples of the blade plates will undergo the same blade processes and will be tested measuring the hardness, the nickel plating layer, and the elongation strength.

Previous Experience on VIRGO:

The operation of the VIRGO suspension blades has been satisfactory. Each phase of the blades production and test has to be checked and require the supervision of one scientist (named **D**).

Responsible:

One scientist (named **D**).

Responsible Tasks:

1. Edit the blade production and technical database, the production and test schedules
2. Check the efficiency of the required tools
3. Check each step the production phase
4. Perform tests and measurements on blades and samples from the production line
5. Validate the final product
6. Check the storage and the cleanliness of the environmental conditions

Technical Drawings:

The preliminary maraging blades technical design is the same one adopted for VIRGO. The old drawings are already available and electronically archived at EGO. The final design will follow the exact definition of the payload weight. The fishing rod blade design is the same one adopted for VIRGO and is considered fixed.

Acceptance Criteria:

Each production phase has to be carefully checked to verify the satisfaction of those criteria that were already adopted for the VIRGO SA.

1. **Raw Materials**

All the used maraging plates have to match exactly the design requirements concerning the type grade, and aging status

2. **Thermal treatments**

Solubilization and aging thermal treatments have to be executed in a proper oven, in neutral environment, under controlled Ar flux

3. **Nickel Plating**

Only the approved electroless nickel plating procedures have to be applied

4. **Dehydrogenation**

Dehydrogenation process has to be executed in a proper clean oven within 1 hour from chemical Nickel plating bath

5. **Cleaning Procedures**

Only the approved cleaning procedures have to be applied

6. **Machining**

Check the exact correspondence of machined parts with the design geometry

7. **Tests**

Hardness and nominal load have to match the foreseen design values

Production Time Schedule and Deliverables:

Table 4.4.2.1.a: SR Metal Spring Blades - Production Schedule and Deliverables

Production Phase	**Month 1**	**Month 2**	**Month 3**	**Month 4**	**Month 5**	**Month 6**	**Month 7**	**Month 8**	**Month 9**
Blades production	■	■							
Thermal treatment	■	■	■	■					
Nickel plating		■	■	■	■				
Tests			■	■	■	■			
Deliverables									
Material Procurement	■								
Validation			■	■	■	■			

Manpower Plan:

Table 4.4.2.1.b: SR Metal Spring Blades - Manpower Plan

Production Phase	**Physicist/Engineer**					**Mechanics Technician**			
Blades production	**D**								
Thermal treatment	**D**								
Nickel plating	**D**								
Tests	**D**								
Total	**1**					**0**			

Costs:

Table 4.4.2.1.c: SR Metal Spring Blades - Costs

Item	**Quantity + Spares**	**Unitary Cost (€)**	**Total Cost (€)**
Type A	8+2	250	**2500**
Type B	8+2	-	**2500**
Type C	6+2	-	**2000**
Type D	4+2	-	**1500**
Type E	4+2	-	**1500**
Type F	2+2	-	**1000**
Type G	18+4	-	**5500**
Type H	2+2	-	**1000**
Fishing rod blade	6+2	150	**1200**
Total			**18700**

Reference: Section5.4.5, Table 5.4.1.5a (3.5 mm thick maraging (MARVAL 18)

Type A- Base width 180mm	**Type B-** Base width 152 mm	**Type C-** Base width 146 mm
Type D- Base width 138 mm	**Type E-** Base width 133.5 mm	**Type F-** Base width 152 mm
Type G- Base width 160 mm	**Type H-** Base width 110 mm	

4.4.2.2 Antisprings and Magnets

Work Description:

1. **Control of the raw material (Ti and ferrite magnets)**

   Check the material type and producer documentation
2. **Ti plates machining**
   a. Cutting and drilling the Ti plates
   b. Check geometrical dimensions of machined parts
   c. Label with a punch tool
   d. Cleaning with cold ultrasonic bath in isopropyl alcohol (15 min.)
   e. Storage in clean polyethylene bags
3. **Magnets preparation**
   a. Select magnets after visual inspection of any crack or defect
   b. Dry Sandblasting of magnets
   c. Remove the residual ferrite powder layer
   d. Bake the magnets (48 h at 150 ^{o}C in vacuum)
   e. Check the magnets polarity
   f. Storage in clean polyethylene bags
   g. Edit of the magnets database
4. **Magnets gluing**
   a. Fix the Ti support plates on a dedicated frame
   b. Glue one column of 4 magnets per time in controlled environment under laminar filtered air flux
   c. Fix the magnet column to the Ti support with a thin Ti safety plate tightened with screws
   d. Repeat the process up to completing the designed magnet matrix disposal
   e. Curing of the glue of the assembled magnets matrix (2 h at 100 ^{0}C in air)
   f. Edit the antispring database
5. **Storage**

   Storage each assembled Ti plate with magnets in labeled double clean polyethylene bags

Previous Experience on VIRGO:

The operation of the VIRGO antisprings has been satisfactory. Each phase of the production has to be checked and require the supervision of one scientist (named **E**).

Responsible: one scientist (named **E**).

Responsible Tasks:

1. Edit the production and technical database, the production and test schedules
2. Check the efficiency of the required tools
3. Check each step the production phase
4. Perform tests and measurements on samples from the production line
5. Validate the final product
6. Check the storage and the environmental cleaning

Technical Drawings:

Technical design is the same one adopted for VIRGO. The old drawings are already available and electronically archived at EGO.

Acceptance Criteria:

Each production phase has to be carefully checked to verify the satisfaction of those criteria that were already adopted for the VIRGO SA:

1. Check visually and instrumentally the geometry of the antispring assembly
2. Check the polarity of the magnets along the antispring magnetic matrix
3. Check the outgassing of samples from the production line

Production Time Schedule and Deliverables:

Table 4.4.2.2.a: Production Schedule and Deliverables

Production Phase	**Month 1**	**Month 2**	**Month 3**	**Month 4**	**Month 5**	**Month 6**	**Month 7**
Components production	■	■	■				
Antispring assembly			■	■			
Characterization			■	■			
Deliverables							
Material Procurement	■						
Validation			■	■			

Manpower Plan:

Table 4.4.2.2.b: SR Antisprings - Manpower Plan

Production Phase	Physicist/Engineer			Electronics Technician		
Components production	E					
Antispring assembly	E			L		
Characterization	E			L		
Total	1			1		

Costs:

Table 4.4.2.2c: SR Antisprings – Cost

Items	Quantity +Spare	Unit Cost (k€)	Total Cost (k€)
Magnets	456	Available	**0**
Magn. Sanding and Cleaning	-	-	**1**
Machined Ti Plates	24	6	**10**
Special Glue	Min. order	-	**2**
Ti Plates Assembly	-	-	**2.5**
Accessories	-	-	**1**
Total (without IVA/VAT)			**16.5**

4.4.2.3 Crossbar and Top Stage LVDT Sensors

Work Description:

1. **Control of the raw material**

   Check the material type and producer documentation
2. **Check the dimensions of all machined components**
3. **Clean components with isopropyl alcohol**
4. **Assemble the top stage LVDT secondary support**
5. **Assemble the top stage LVDT primary support**
6. **Control of the crossbar and top stage LVDTs**
   a. Measure the primary and secondary impedance
   b. Label
   c. Measure the LVDT response

   d. Edit the LVDT technical database

7. **Storage**
   a. Packaging with clean polyethylene
   b. Storage in a clean environment

Specifications:

Filter crossbar and top stage LVDTs of the SR will show a displacement spectral sensitivity of about $10\mathrm{x}10^{-10}$ *(m/√(Hz))* in the entire sensor frequency band.

Previous Experience on VIRGO:

The operation of the VIRGO LVDTs has been satisfactory. Each phase of the production and final installation has to be checked and require the supervision of one scientist (named **G**) and of one electronics technician (named **N**).

Responsible: one scientist (named **G**).

Responsible Tasks:

1. Edit the production and test schedules
2. Check the efficiency of the required tools
3. Check each step the production phase
4. Measure the LVDT response
5. Validate the final product
6. Edit the accelerometer technical database
7. Check the storage and the cleanliness of the environmental conditions
8. Assist the installation on the SR chain
9. Assist the commissioning of the SR chain

Technical Drawings:

The technical design of the SR filter crossbar and top stage LVDTs are the same one adopted for VIRGO. The old drawings are already available and electronically archived at EGO.

Acceptance Criteria:

Each production phase has to be carefully checked to verify the satisfaction of those criteria that were adopted for the VIRGO SA.

1. Raw materials

All the used cupper wire, aluminum, glass, and MACOR materials have to match exactly the design requirements concerning the type grade, and aging status

2. Cleaning procedures

Only the approved cleaning procedures have to be applied

3. Machining

Check the exact correspondence of machined parts with the design geometry

4. Characterization Tests

Impedance and response measurements have to match the design specifications

Production Time Schedule and Deliverables:

Table 4.4.2.3.a: SR LVDT - Production Schedule and Deliverables

Production Phase	**Month 1**	**Month 2**	**Month 3**	**Month 4**	**Month 5**	**Month 6**	**Month 7**
Components production	■	■	■				
Top Support assembly			■	■			
Characterization			■	■			
Deliverables							
Material Procurement	■						
Validation			■	■			

Manpower Plan:

Table 4.4.2.3.b: SR LVDT – Manpower Plan

Production Phase	**Physicist/Engineer**			**Electronics Technician**		
Components production	**G**					
Top Support assembly	**G**			**N**		
Characterization	**G**			**N**		
Total	**1**			**1**		

Costs:

Table 4.4.2.3.c: SR LVDT – Costs

Item	Quantity +Spare	Unit Cost (k€)	Total Cost (k€)
Crossbar LVDT	6+2	Available	**0**
Top stage LVDT	3+1	1.5	**6**
Total (without IVA/VAT)			**6**

4.4.2.4 F0 Voice Coil and Top Stage Coil-Magnet Actuators

Work Description:

1. **Control of the raw material**

   Check the material type and producer documentation
2. **Check the dimensions of all machined components**
3. **Cleaning with isopropyl alcohol**
4. **Assembly of the top stage actuator magnets support**
5. **Assembly of the top stage actuator coil support**
6. **Nickel plating of the F0 voice coil jokes**
7. **Label all actuators**
8. **Control the top stage actuators**
   a. Measure the coil impedance
   b. Measure the actuator response
   c. Edit the top stage actuators technical database
9. **Control of the F0 voice coil actuators**
   a. Measure the actuator response
   b. Edit the F0 voice coils technical database
10. **Storage**
    a. Packaging with clean polyethylene
    b. Storage in a clean environment

Specifications:

The same specifications adopted for VIRGO will be applied

Previous Experience on VIRGO:

The operation of the VIRGO F0 and top stage actuators has been satisfactory. Each phase of the production and final installation has to be checked and require the supervision of one scientist (named **E**) and of one electronics technician (named **L**).

Responsible: one scientist (named **E**).

Responsible Tasks:

1. Edit the production and test schedules
2. Check the efficiency of the required tools
3. Check each step the production phase
4. Measure the actuators response
5. Validate the final product
6. Edit the actuators technical database
7. Check the storage and the cleanliness of the environmental conditions
8. Assist the installation on the SR chain
9. Assist the commissioning of the SR chain

Technical Drawings:

The technical design of the SR F0 and top stage actuators are the same one adopted for VIRGO. The old drawings are already available and electronically archived at EGO.

Acceptance Criteria:

Each production phase has to be carefully checked to verify the satisfaction of those criteria that were adopted for the VIRGO SA:

1. **Raw materials**

   All the used cupper wire, aluminum and magnets have to match exactly the design requirements concerning the type grade, and aging status

2. **Cleaning procedures**

   Only the approved cleaning procedures have to be applied

3. **Machining**

   Check the exact correspondence of machined parts with the design geometry

4. **Characterization Tests**

   Impedance and response measurements have to match the design specifications

Production Time Schedule and Deliverables:

Table 4.4.2.4.a: SR F0 and Top Stage Actuators - Production Schedule and Deliverables

Production Phase	**Month 1**	**Month 2**	**Month 3**	**Month 4**	**Month 5**	**Month 6**	**Month 7**	**Month 8**	**Month 9**
Coil Magn Comp Prod.	■	■	■						
Coil Winding		■	■	■					
Assembly top actuator			■	■					
F0 VC supports prod.	■	■	■						
F0 VC Nickel plating		■	■						
Act. Characterization			■	■					
Deliverables									
Material Procurement	■								
Validation			■	■					

Manpower Plan:

Table 4.4.2.4.b: SR F0 and Top Stage Actuators - Manpower Plan

Production Phase	**Physicist/Engineer**			**Electronics Technician**		
Components production	**E**					
Characterization	**E**			**L**		
Total	**1**			**1**		

Costs:

Table 4.4.2.4.c: SR F0 and Top Stage Actuators –Cost

Item	**Quantity +Spare**	**Unit Cost (k€)**	**Total Cost (k€)**
F0 voice coil and support	2	-	**1.5**
Top Stage coil-magnet	3	3	**9**
Total (without IVA/VAT)			**10.5**

4.4.2.5 Filter 7 Monitoring System

This system (see Section 4.2.2.1) consists of a dual axes tilt-meter, two motorized balancing sliders, three horizontal LVDT/Coil-magnet devices.

Work Description:

1. **Control of the raw material**

   Check the material type and producer documentation.
2. **Check the dimensions of all machined components**
3. **Cleaning of the aluminum and PEEK components**

   Cold ultrasonic bath in isopropyl alcohol (15 min.)
4. **Label of all devices**
5. **Assemble the balancing sliders**
6. **Check the functionality of the sliders**
7. **Assemble the dual axes electrolytic tilt-meter support**
   a. Install the dual axes tilt-meter over the support
   b. Adjust the vertical offset with a precision bubble
8. **Test the dual axes tilt-meter**
   a. Measure the dual axes tilt-meter response
   b. Edit the dual axes tilt-meter technical database
9. **Control of the LVDT/coil cupper windings**

   Measure the impedance of each coil
10. **Assembling the LVDT/Coil-magnet device**
    a. Assemble the LVDT primary supports
    b. Setup the magnets inside the LVDT primary winding
    c. Assemble the secondary LVDT/Coil system
11. **Test the LVDT/Coil system**
    c. Measure the LVDT response
    d. Measure the actuator response
    e. Edit the LVDT/Coil system database
12. **Storage**
    c. Packaging with clean polyethylene
    d. Storage in a clean environment

Specifications:

The same specifications adopted for the VIRGO construction and operation will be observed.

Previous Experience on VIRGO:

The operation of the Filter 7 monitoring system has been satisfactory. Each phase of the production and final installation has to be checked and require the supervision of one scientist (named **E**) and of one electronics technician (named **L**).

Responsible: one scientist (named **E**).

Responsible Tasks:

1. Edit the production and test schedules
2. Check the efficiency of the required tools
3. Check each step the production phase
4. Measure the sensors and actuators response
5. Validate the final product
6. Edit the sensors and actuators technical database
7. Check the storage and the cleanliness of the environmental conditions
8. Assist the installation on the SR chain
9. Assist the commissioning of the SR chain

Technical Drawings:

The technical design of the SR F7 monitoring system is the same one adopted for VIRGO. Old drawings are already available and electronically archived at EGO.

Acceptance Criteria:

Each production phase has to be carefully checked to verify the satisfaction of those criteria that were adopted for the VIRGO SA.

1. **Raw materials**

   All the used copper wire, aluminum and magnets have to match exactly the design requirements concerning the type grade, and aging status

2. **Cleaning procedures**

   Only the approved cleaning procedures have to be applied

3. **Machining**

   Check the exact correspondence of machined parts with the design geometry

4. **Characterization Tests**

   Impedance and response measurements have to match the design specifications

Production Time Schedule and Deliverables:

Table 4.4.2.5a: SR F7 Monitoring System - Costs Production Schedule and Deliverables

Production Phase	**Month 1**	**Month 2**	**Month 3**	**Month 4**	**Month 5**	**Month 6**	**Month 7**	**Month 8**	**Month 9**
Components production	■	■	■						
Sliders Assembly			■	■					
Sliders test				■	■				
Tilt-meter Assembly				■	■				
Tilt-meter Test				■	■				
LVDT/Coil Assembly				■	■				
LVDT/Coil Test				■	■				
Deliverables									
Material Procurement	■								
Validation				■	■				

Manpower Plan:

Table 4.4.2.5.b: SR F7 Monitoring System - Costs Manpower Plan

Production Phase	**Physicist/Engineer**			**Electronics Technician**		
Components production	**E**					
Sliders Assembly	**E**			**L**		
Sliders test	**E**	**A**		**L**		
Tilt-meter Assembly	**E**			**L**		
Tilt-meter Test	**E**	**A**		**L**		
LVDT/Coil Assembly	**E**			**L**		
LVDT/Coil Test	**E**	**A**		**L**		
Total	**2**			**1**		

Costs:

Table 4.4.2.5.c: SR F7 Monitoring System – Costs			
Item	**Quantity +Spare**	**Unit Cost (k€)**	**Total Cost (k€)**
Dual axes tilt-meter	1	2.5	**2.5**
Signal Conditioner	1	2	**2**
LVDT/Coil-magn. act	3	2	**6**
Accessories	-	-	**0.5**
Total (without IVA/VAT)			**11**

4.4.2.6 Stepping Motors

The adopted motor of VIRGO SA is a commercial ultra high vacuum compatible AML stepping motor. These motors were chosen for because exhibit a very low outgassing rate. In VIRGO these motors undergo a special baking outgassing treatment for 24 hours at 200 ^{O}C.

Responsible: one scientist (named **C**).

Responsible Tasks:

1. Perform the baking outgassing process (24 h at 200 ^{o}C)
2. Perform tests operating the motors cyclically under load
3. Edit the motors technical database

Acceptance Criteria:

Motors have to show an optimum functionality before and after the baking treatment. The outgassing rate has been already accepted for VIRGO.

Production Time Schedule and Deliverables:

Table 4.4.2.6.a: SR Stepping Motors - Production Schedule and Deliverables

Production Phase	**Month 1**	**Month 2**	**Month 3**	**Month 4**	**Month 5**	**Month 6**	**Month 7**	**Month 8**	**Month 9**
Outgassing treatment	■	■							
Test		■	■	■					
Deliverables									
Procurement	■								
Validation				■					

Manpower Plan:

Table 4.4.2.6.b: SR Stepping Motors - Manpower Plan

Production Phase	**Physicist/Engineer**			**Electronics Technician**		
Procurement	**B**					
Outgassing treatment	**B**					
Test	**B**			**L**		
Total	**2**			**1**		

Costs:

Table 4.4.2.6.c: SR Stepping Motors – Costs

Item Location	**Type**	**Quantity**	**Unit Cost (€)**	**Total Cost (€)**
F0 Vertical Hoist	VEXTA- PK264-E2.0A	1	450	**450**
Trolley IP Control	AML - C17.1	3	950	**2850**
Fishing Rods	AML - B23.1	6	1500	**9000**
Trolley F7 Control	AML - C17.1	2	950	**1900**
F7 Rotations	AML - C17.1	2	950	**1900**
Horiz. Accelerometer	AML - C14.1	3	910	**2730**
Vert. Accelerometer	AML - C14.1	2	910	**1820**
Total (without IVA/VAT)				**20650**

4.4.3 SR Production and Manpower Schedule

The SR Superattenuator construction will imply the coordination and the integration of the identified items and special components realization. The SR construction period is outlined in Table 5.4.3a where the construction time, individuated by the month number, is associated to each item production phase conclusion. Labels indicate the scientists and technicians involved

Table 4.4.3a: SR Superattenuator Production and Manpower Schedule

<table>
<tr><th>ITEM</th><th>Month 1</th><th>Month 2</th><th>Month 3</th><th>Month 4</th><th>Month 5</th><th>Month 6</th><th>Month 7</th><th>Month 8</th><th>Month 9</th><th>Month 10</th><th>Month 11</th><th>Month 12</th></tr>
<tr><td>1</td><td>▨</td><td>▨</td><td>▨</td><td>▨</td><td>▨</td><td colspan="4">A, B / J</td><td></td><td></td><td></td></tr>
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<tr><td>4</td><td>▨</td><td>▨</td><td>▨</td><td>▨</td><td>C/K</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>5</td><td>▨</td><td>▨</td><td>C / K</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>6</td><td>▨</td><td>▨</td><td colspan="2">D</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>7</td><td>▨</td><td>▨</td><td colspan="2">E / L</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>8</td><td>▨</td><td>▨</td><td colspan="3">F, D /M</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>9</td><td>▨</td><td colspan="2">A, B, D, E</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>S5</td><td>▨</td><td>▨</td><td>A,E/L</td><td>A,E/L</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Labels: Scientist, Support Scientist **/Technician** as involved in each item description Section.

IT 1: St. Filters - IT 2:F0 - IT 3: F7 - IT 4: IP - IT 5: Safety Structure - IT 6: Suspension Wires
IT 7: Cabling - IT 8: Accelerometers - IT 9: Tools
IT S1: Blades – IT S2: Antisprings - IT S3: Crossbar and Top Stage LVDT Sensors
IT S4: F0 Voice Coil and Top Stage Coil-Magnet Actuators - IT S5: F7 Monitoring System

The SR construction requires a period of about 9 months, with the intervention of at least 7 scientists (physicists or engineers) and 5 technicians.

4.5 SR Superattenuator Assembly and Integration

The SR assembly will proceed according to the following sequence:

1. **Install the Safety Structure**
2. **Install the Inverted Pendulum**
    a. Install the IP steel platform supports with piezoelectric actuators
    b. Install the IP steel platform
    c. Install the 3 IP steel leg base and maraging flexible joints
    d. Install the 3 IP counterweight aluminum cylindrical support
    e. Install the 3 IP Al legs
    f. Install the 3 IP Ti terminations
    g. Install the steel top ring with the 3 maraging connection wires and Ti supports
    h. Clamp the IP legs to the springs of the 3 horiz. sliders placed over the *Safety Frame*
    i. Install the IP safety stops over the *Safety Frame*
3. **Install the filters of the chain**
    a. Place filters over the safety frame shelves
    b. Fix the F0 over the IP top ring
    c. Suspend Filter Standard 1 to F0
    d. Suspend Filter Standard 2 to Filter Standard 1
    e. Suspend Filter Standard 3 to Filter Standard 2
    f. Suspend Filter Standard 4 to Filter Standard 3
    g. Suspend dummy payload to Filter 7
    h. Suspend Filter 7 and to Filter Standard 4
4. **Install the two tilt-meters on the IP platform (if SAT R&D is positive)**
5. **Install the top stage accelerometers**
6. **Install the top stage LVDT**
7. **Install the top stage actuators**
8. **Check the SA signals from LVDTs, tilt-meters and accelerometers in air**
9. **Check the top stage actuators in air**
10. **Cabling**
11. **Clamp the descending cables to the filter bodies**
12. **Check the cables connections**
13. **Balance the filters tilt adding masses**
14. **Tune the filter crossbar vertical position with respect to the body**
15. **Tune the IP modes adding mass to the IP top ring**

16. **Set the SR suspension point position with top stage motorized sliders**
17. **Check the orthogonality of IP legs with respect to the tower platform**
18. **Set the top stage LVDT and actuator position**
19. **Mount the Filter 7 Monitoring system**
20. **Suspend the payload**
21. **Fine tuning of the filter chain vertical position with fishing rods**
22. **Install all the viroles except the top cover**
23. **Mount the rigid links between the top virola with the safety frame**
24. **Close the tower**
25. **Vacuum pumping**
26. **Check the top stage actuators on F0 crossbar and IP top ring in vacuum**
27. **Check the SA signals from LVDTs, tilt-meters and accelerometers in vacuum**

The resulting assembly and manpower schedule, taking into account these main steps is shown in Table 4.5.a below, where the construction time period, individuated by the week numbers, is associated to each assembly phase conclusion. Labels indicate the scientist and technician involved.

The SR assembly requires a period of about 13 weeks, with the intervention of at least 7 scientists (physicists and engineers) and 5 technicians.

Table 4.5a: SR Superattenuator Assembly and Manpower Schedule

ITEM	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
1	A, B,C/ J,K												
2		A, B,C/ J,K											
3			A, B, C /J,K										
4					F / M								
5					E / L								
6					G / N								
7					F / M								
8					F / M								
9						E / L							
10							E / L						
11							E / L						
12							E / L						
13									A,C/J				
14									A, C / J				
15										A, B / J			
16										A, B / J			
17										A, B / J			
18											F/M		
19				A, D / L						A /D			
20											A,B/J		
21												A,B/J	
22												A,B/J	
23												A B/J	
24												A,B/J	
25													EGO
26													F,G/MN
27													F,G/MN

Labels: Scientist1, Scientist2/Technitian1, Technitian2 as involved in each item description section.

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4.5.1 Laboratories Organization

During the SR assembly phase there will be an intensive use of the laboratories in the interferometer central area of the EGO facility. Some mechanical components will be stored and assembled in the mechanical laboratory while cabling and some final electronic setup of sensors and actuators will be operated in the class 100 Cable Lab. The ultrasonic washing machine facility will also be used for cleaning tools and components.

4.5.2 Transport and Storage

The SR Superattenuator components transportation will occur with extreme care to maintain the required cleaning conditions. During transportation filters and other components will be protected by a layer of clean polyethylene into dedicated wooden boxes. Once at EGO the SR components will be stored in a clean controlled environment.

4.5.3 SA Interface

The SR construction, assembly, and integration, is under the responsibility of the VIRGO INFN Pisa group. The SR assembly will be coordinated together with the activity of other interfacing subsystems. Cables for LVDTs, accelerometers, stepping motors and actuators must be connected with the local electronics and data acquisition system. The payload will determine most of the SA requirements concerning the applied load and *Marionette* driving actuators disposal. The VIRGO vacuum system specifications set the requirements for components cleaning and material outgassing rate.

4.6 Summary of SR Superattenuator Costs

A preliminary estimate of the cost for the SR SA construction and assembly is reported in Tab 4.6.a below:

Table 4.6a: SR Superattenuator Cost Plan

MECHANICS	
ITEM	**Cost (k€)**
Standard Mechanical Filters	**38**
Filter Zero	**12**
Filter 7	**15**
Inverted Pendulum	**25**
Safe Structure	**14**
Suspension Wires	**14.1**
Cabling	**50.5**
Accelerometers	**30**
Tools	**12**
Metal Spring Blades	**18.7**
Antisprings	**16.5**
Crossbar and Top Stage LVDT Sensors	**6**
F0 and Top Stage Actuators	**10.5**
Filter 7 Monitoring System	**11**
Stepping motors	**20.7**
Piezoelectric Actuators (R&D)	**6**
Tilt-meters (R&D)	**12**
Minor orders	**15**
Sub-Total Mech. (k€) (without IVA/VAT)	**327**
SUSPENSION ELECTRONICS	
Sub-Total Susp. Electr. (k€) (without IVA/VAT) **(see AdV Susp. Electr. Plan)**	**130**
Total (k€) (without IVA/VAT)	**457**

4.7 Figures

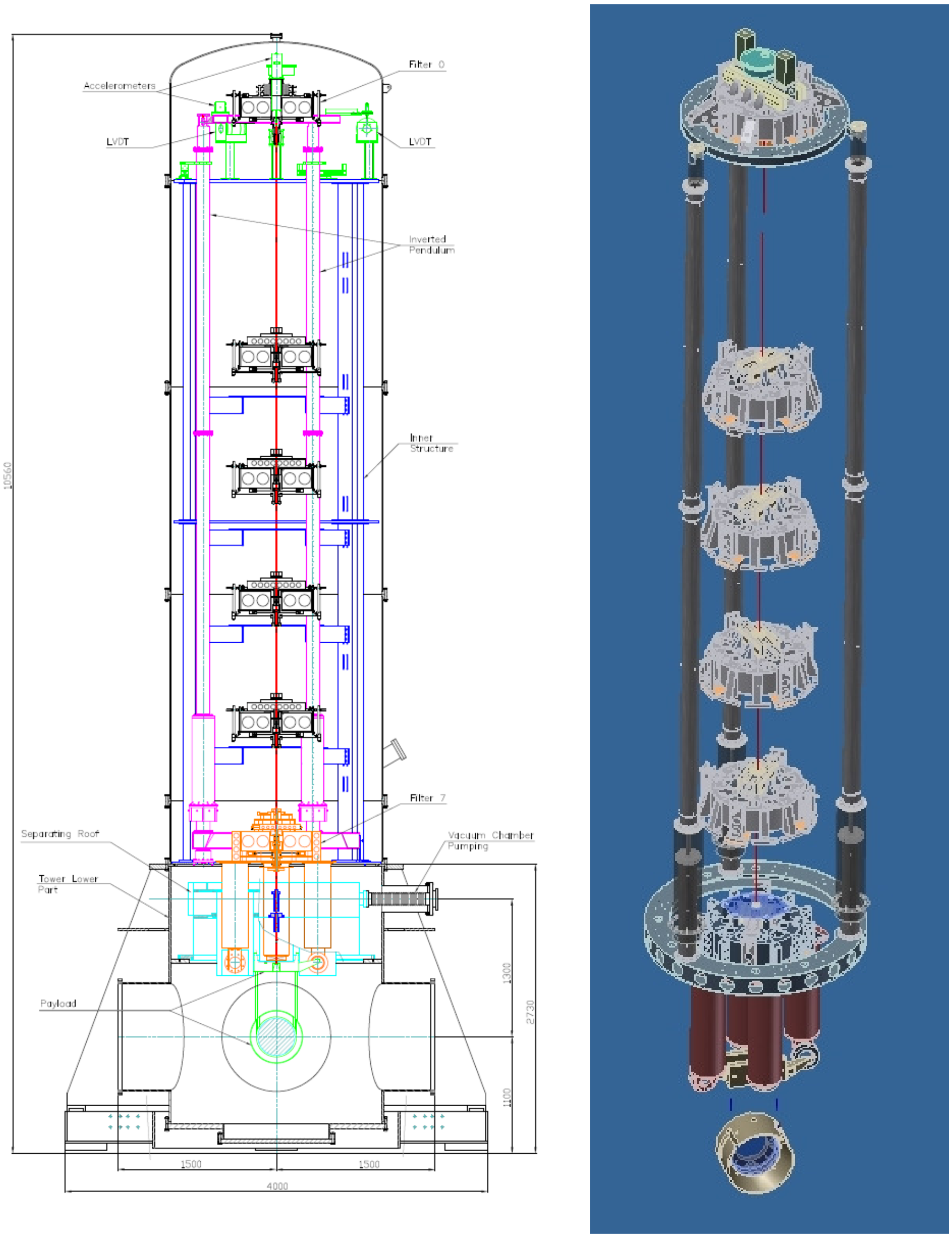


Figure 4. 1

Assembly of the entire Superattenuator

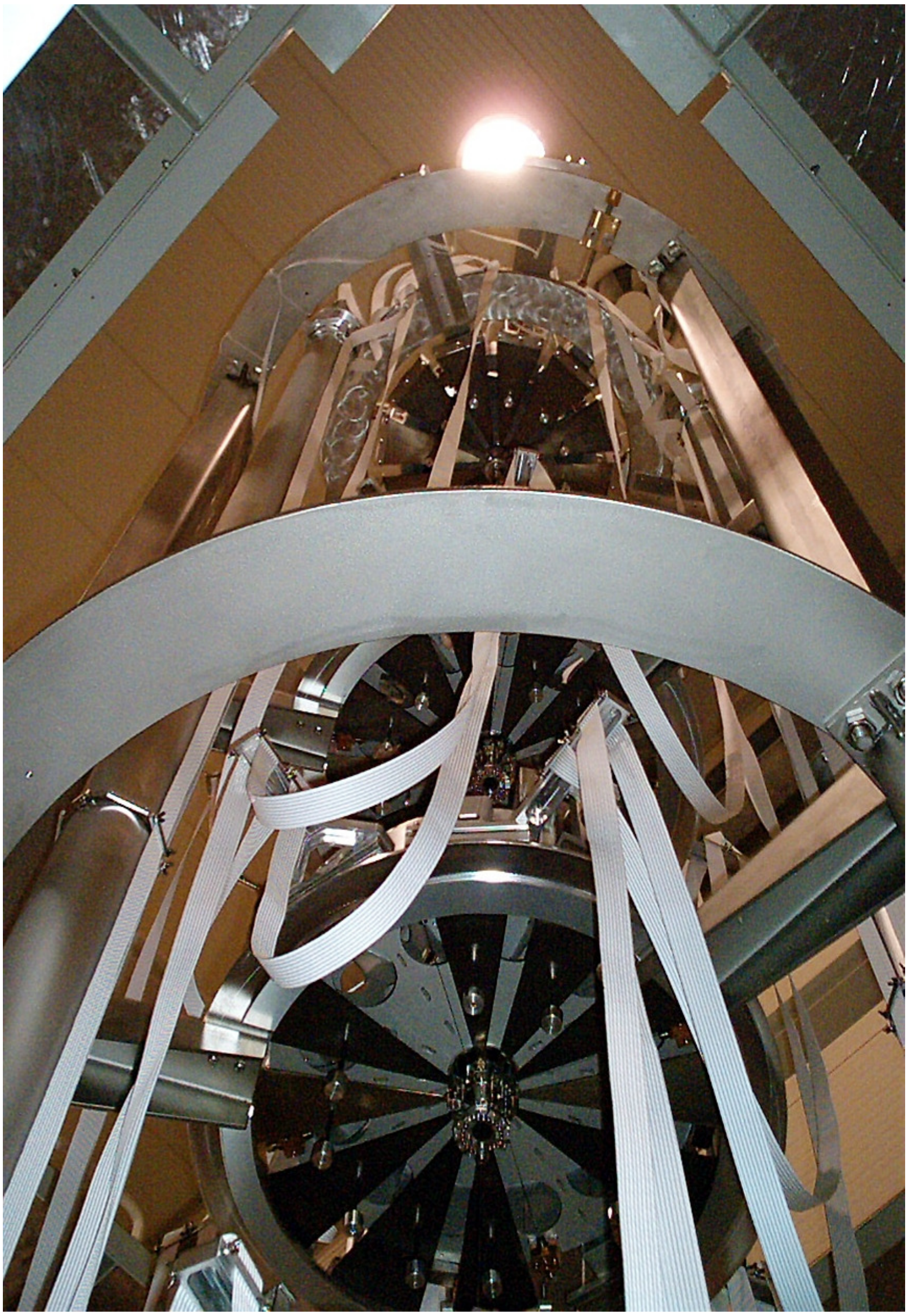


Figure 4. 2

The VIRGO Superattenuator during its assembly. The safety structure, one of the aluminum IP legs, the bottom side of two Standard filters with blades and blade dampers are visible. At this stage of the assembly the SA cabling was performed. Descending cables are clamped around the filters forming soft catenaries.

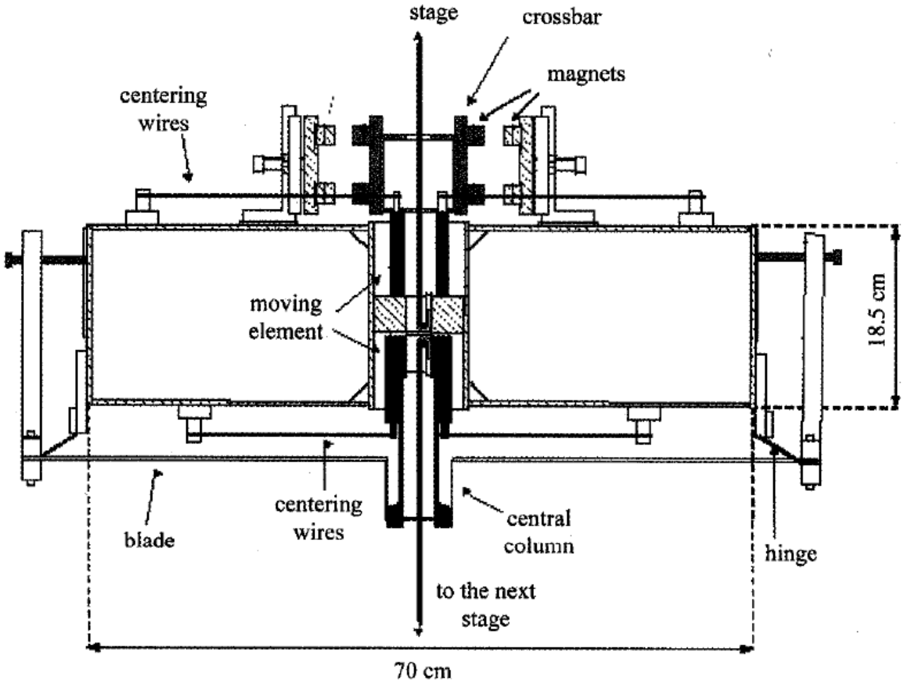


Figure 4. 3

One of the VIRGO standard filters

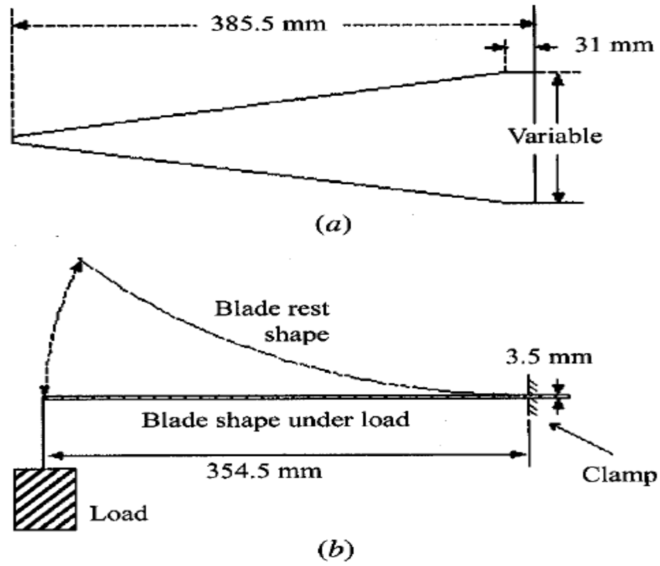


Figure 4. 4

Upper view (a) and side view (b) of a triangular pre-bent cantilevered blade. Once loaded the blade assumes a straight horizontal shape and acts as a vertical spring. The oscillation mode of the vertical pendulum is around 1.5 *Hz*, while the first flexural mode of the blade is around 100 *Hz*.

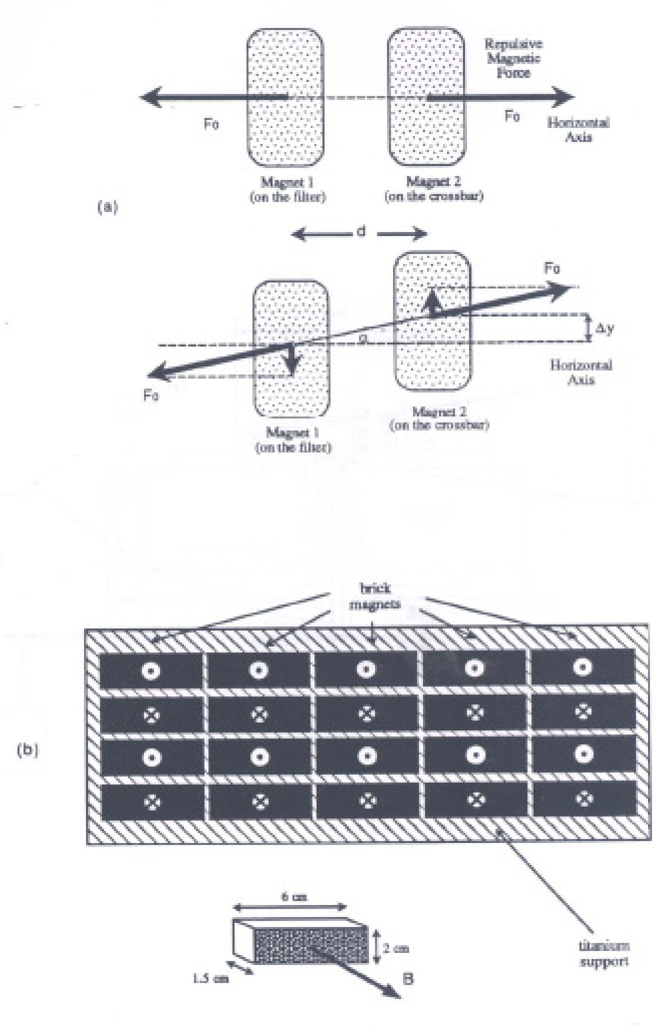


Figure 4. 5

(a) The working principle of the magnetic antispring system. As the vertical relative position between the magnets changes with respect to the perfect aligned position a vertical component of the repulsive force appears.

(b) One of the four magnetic matrices mounted on the mechanical filter.

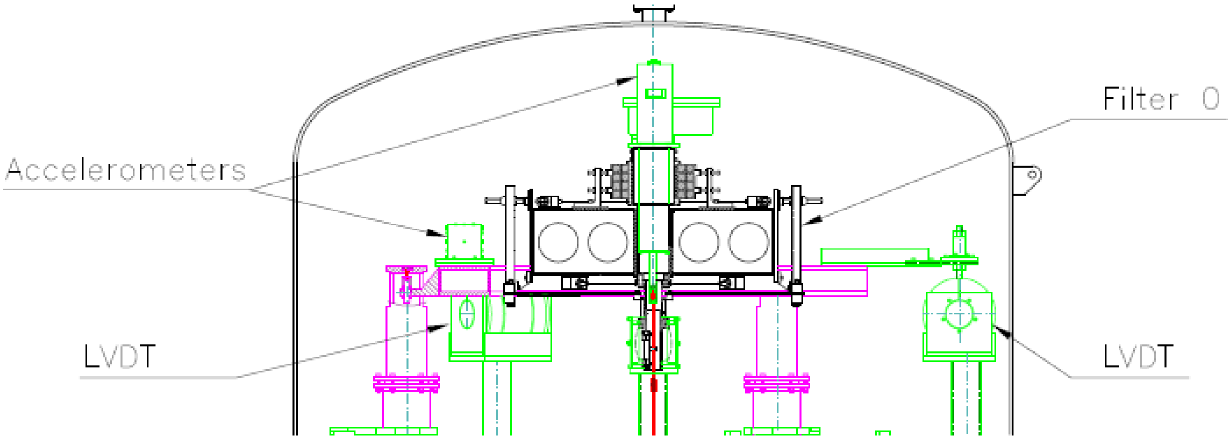


Figure 4. 6

The VIRGO filter zero and the top ring support. The technical design is shown in Fig.4.28

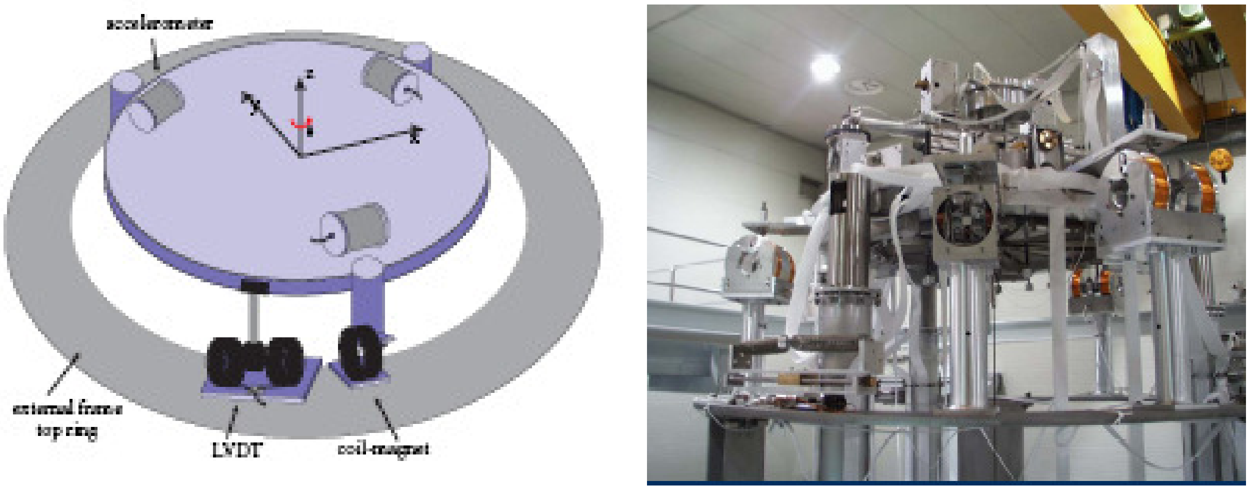


Figure 4. 7

Conceptual scheme of the IP top stage with the three longitudinal accelerometers. One of the 3 LVDTs and coil actuators is also shown (left).

Picture of the IP top stage: one of the 3 LVDTs and all the coil actuators are visible (right).

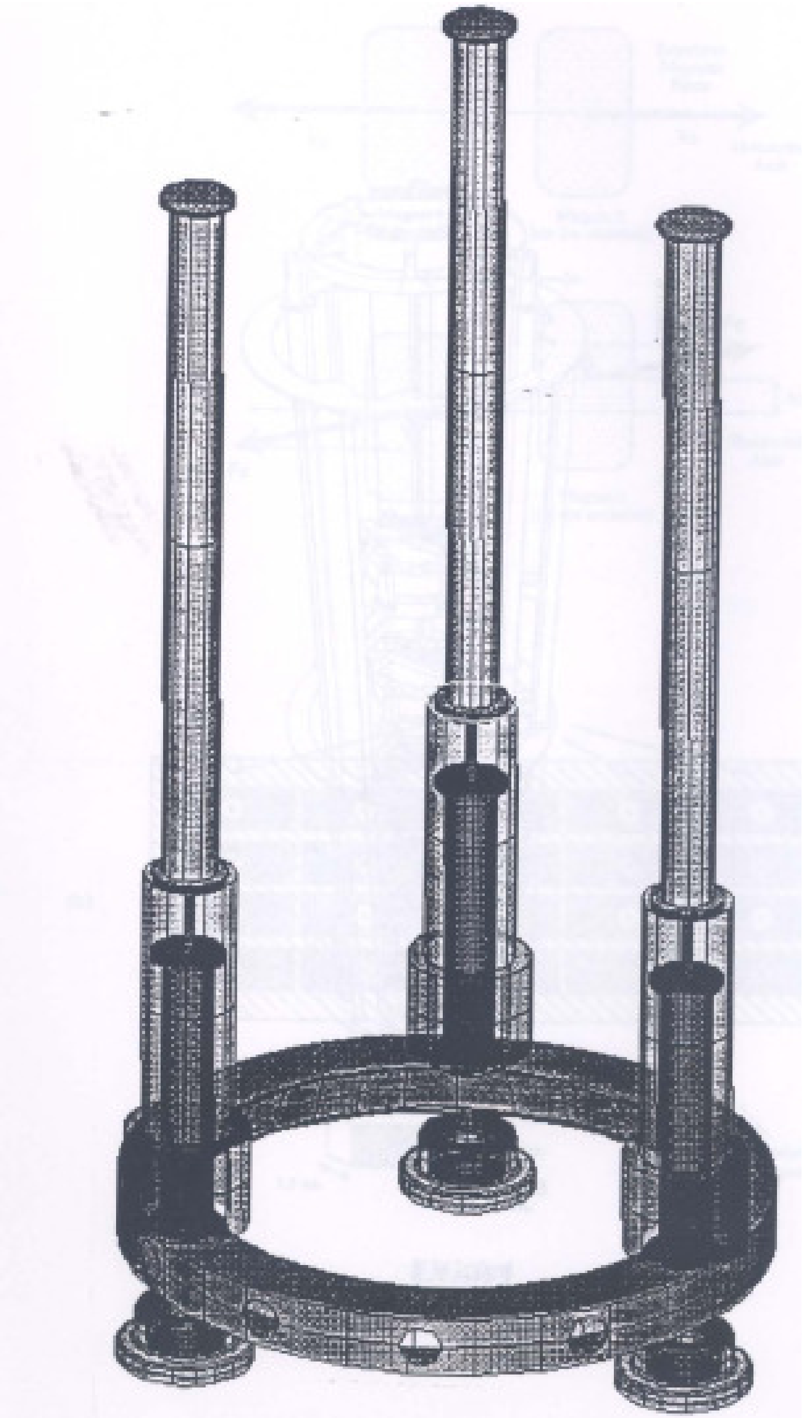


Figure 4. 8

The flexural joints on which the legs of the inverted pendulum are based.

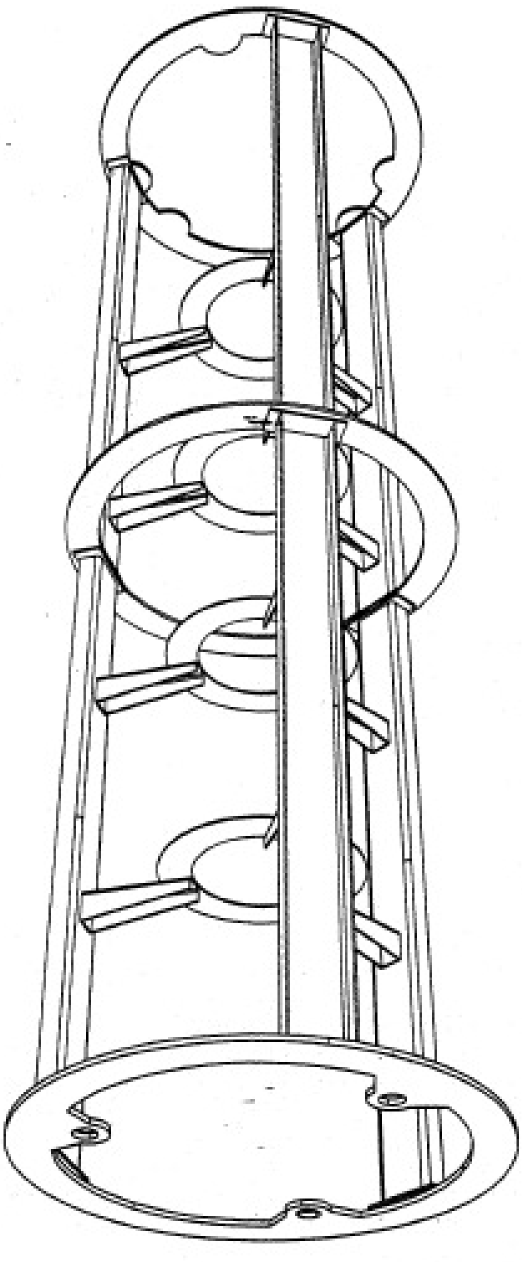


Figure 4. 9

Conceptual design of the inner structure (or Safety Frame). The technical design is available.

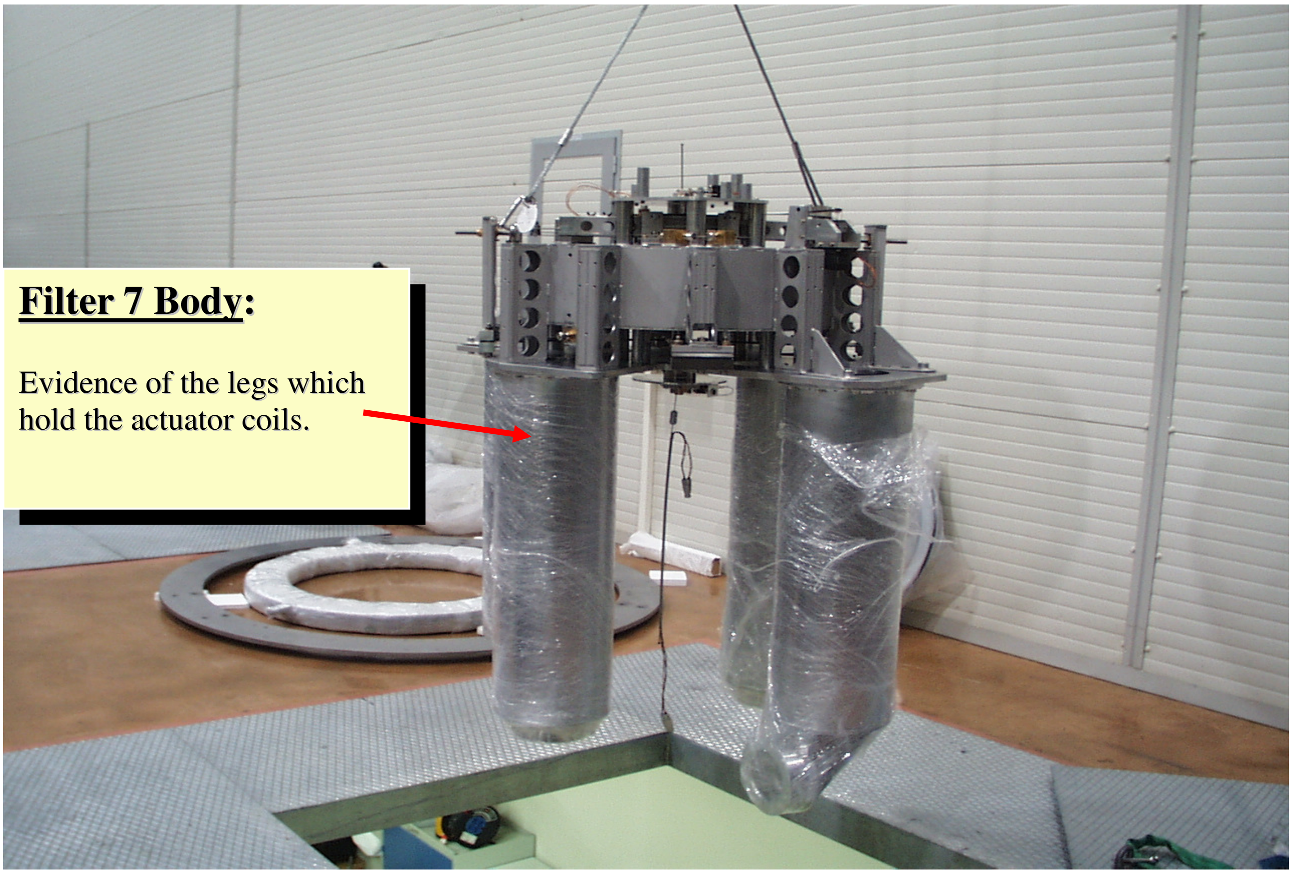


Figure 4. 10

Picture of the Filter7 while was being prepared for its installation.

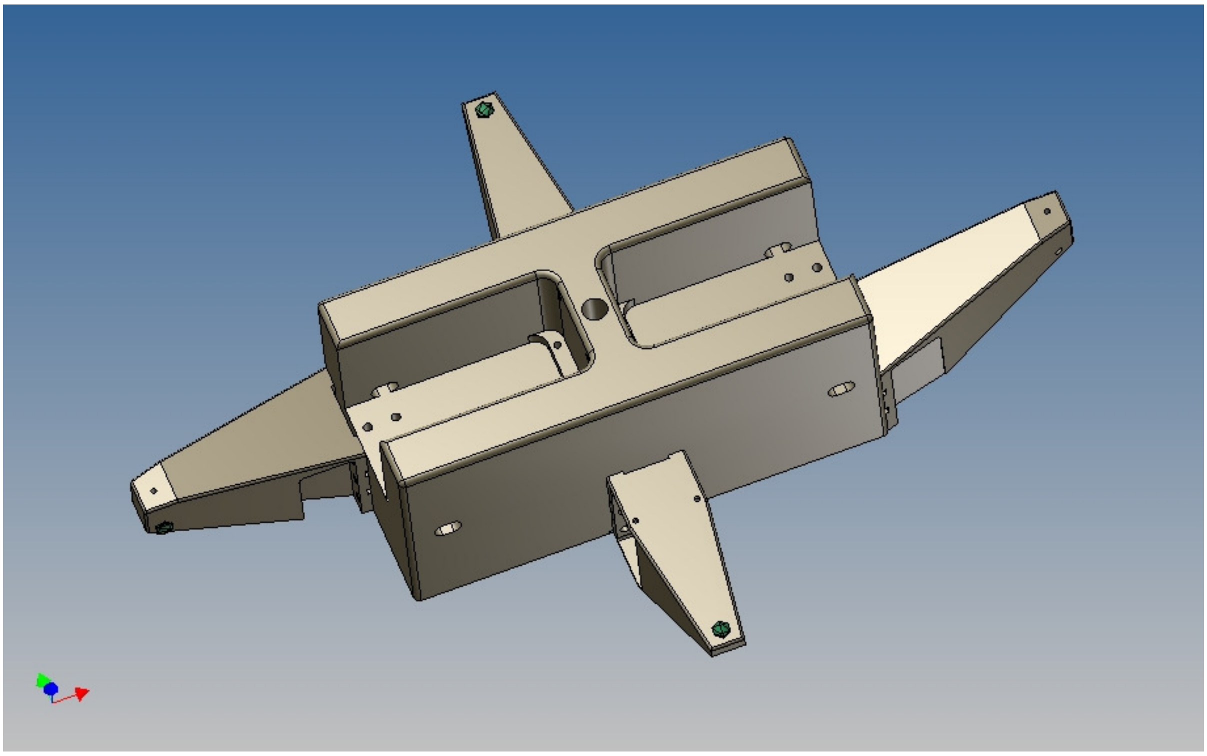


Figure 4. 11

The VIRGO Marionette for the mirror control (by Roma VIRGO group).

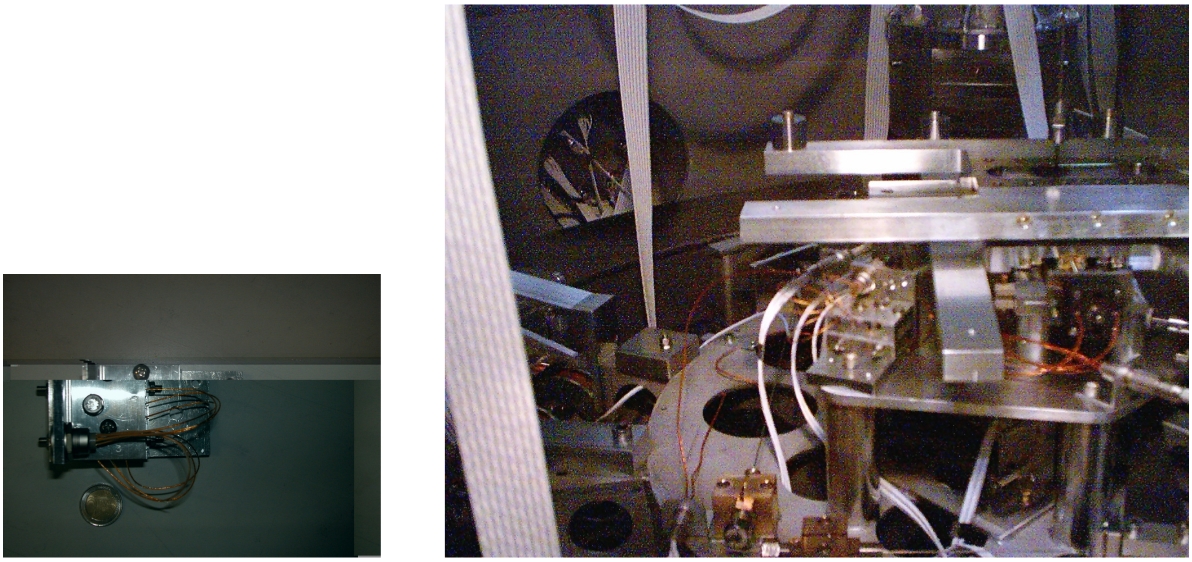


Figure 4. 12

Pictures of the F7 tilt-meter after its assembly (left view), and during its installation over the F7 nearby the balancing sliders.

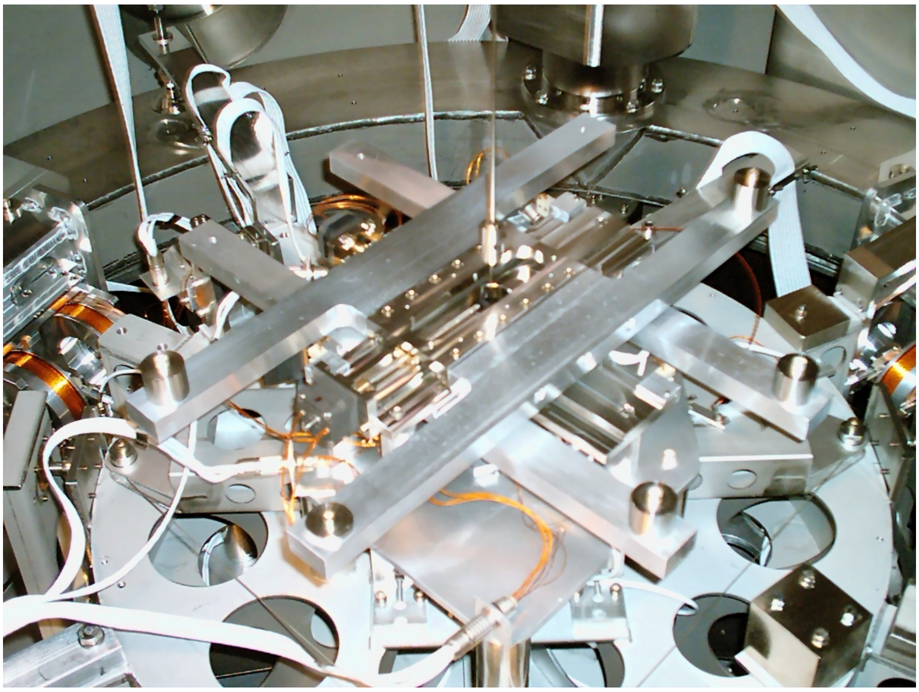


Figure 4. 13

Picture of the motorized balancing system placed over the Filter 7

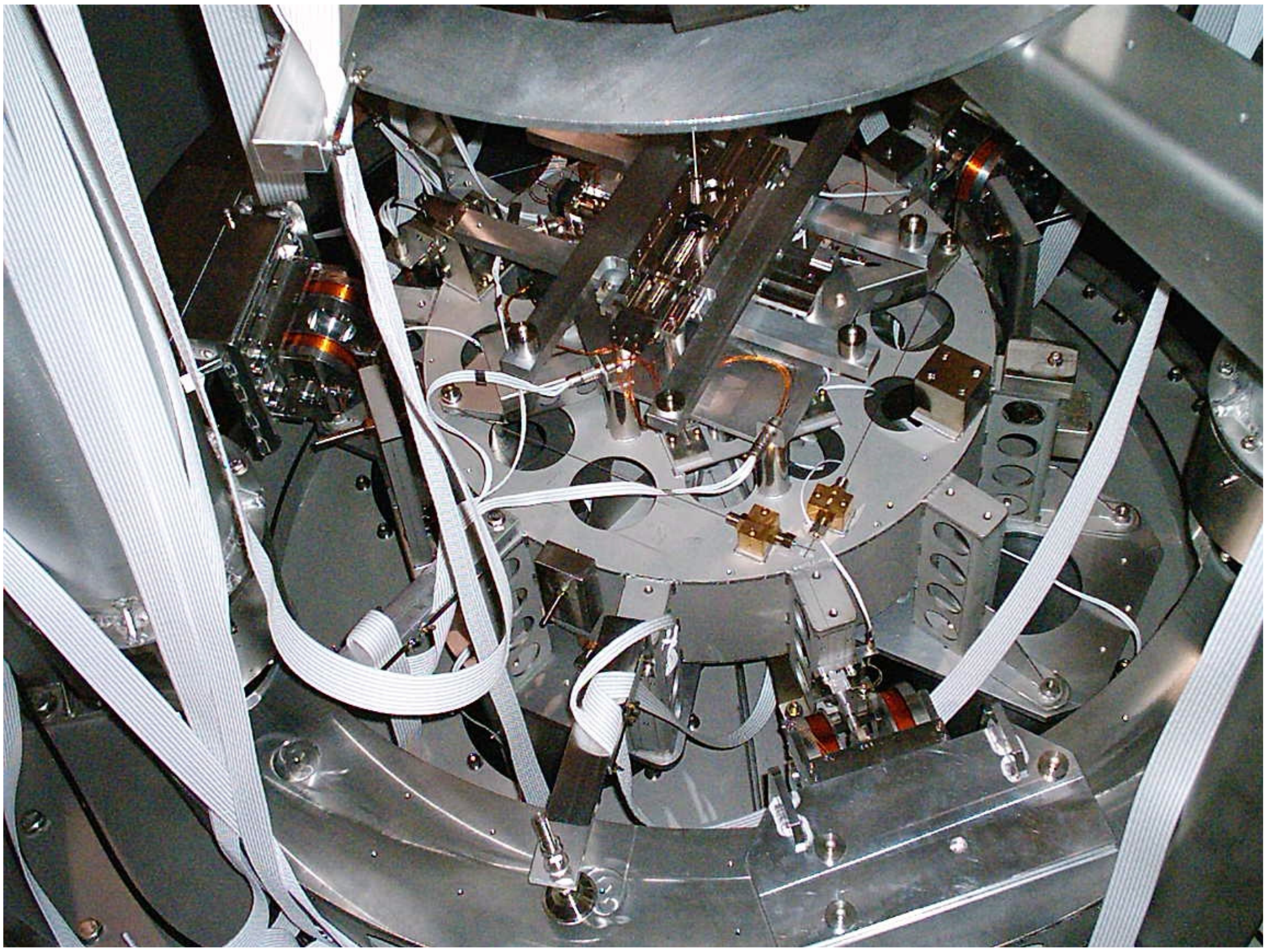
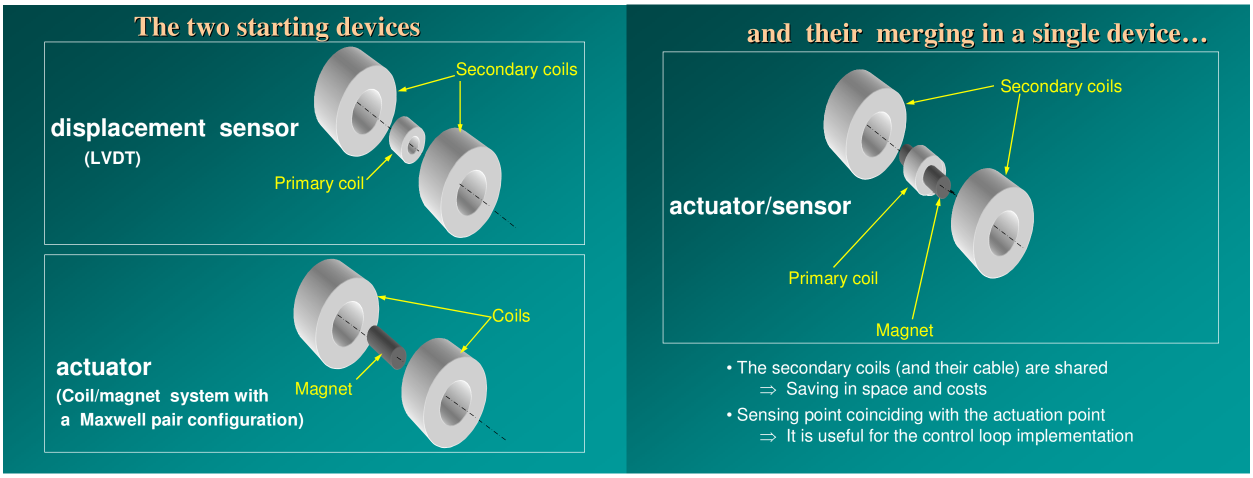


Figure 4. 14

Picture of the full F7 monitoring and control system installed. The motorized balancing system on the top and the 3 LVDT/actuators around the filter body are visible.



The two starting devices

displacement sensor
(LVDT)

actuator
(Coil/magnet system with
a Maxwell pair configuration)

and their merging in a single device…

actuator/sensor

- The secondary coils (and their cable) are shared
  ⇒ Saving in space and costs
- Sensing point coinciding with the actuation point
  ⇒ It is useful for the control loop implementation

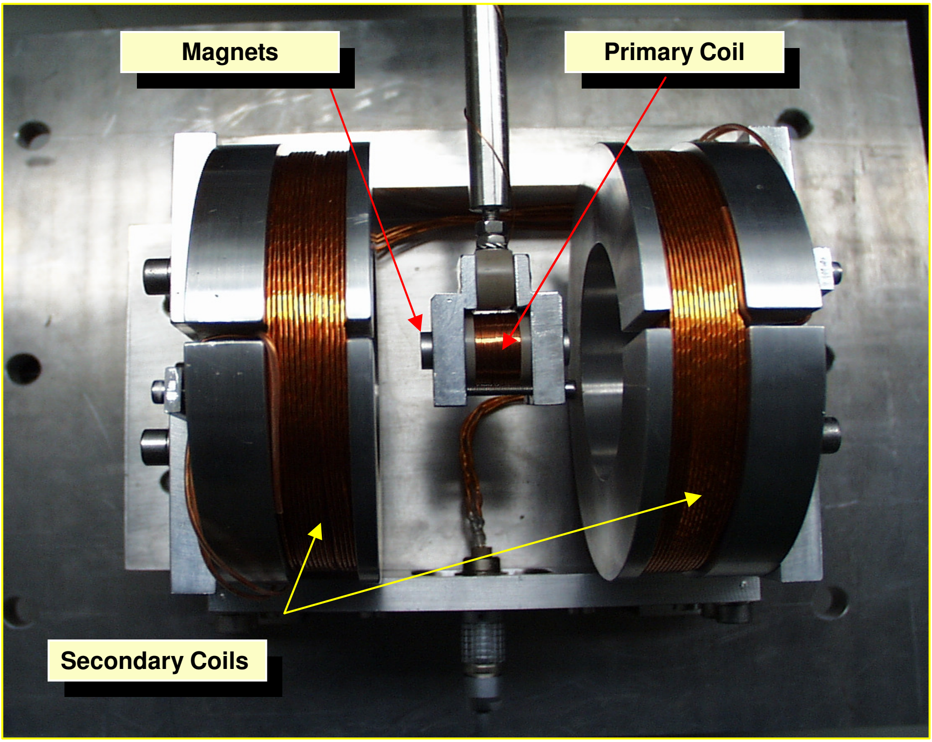
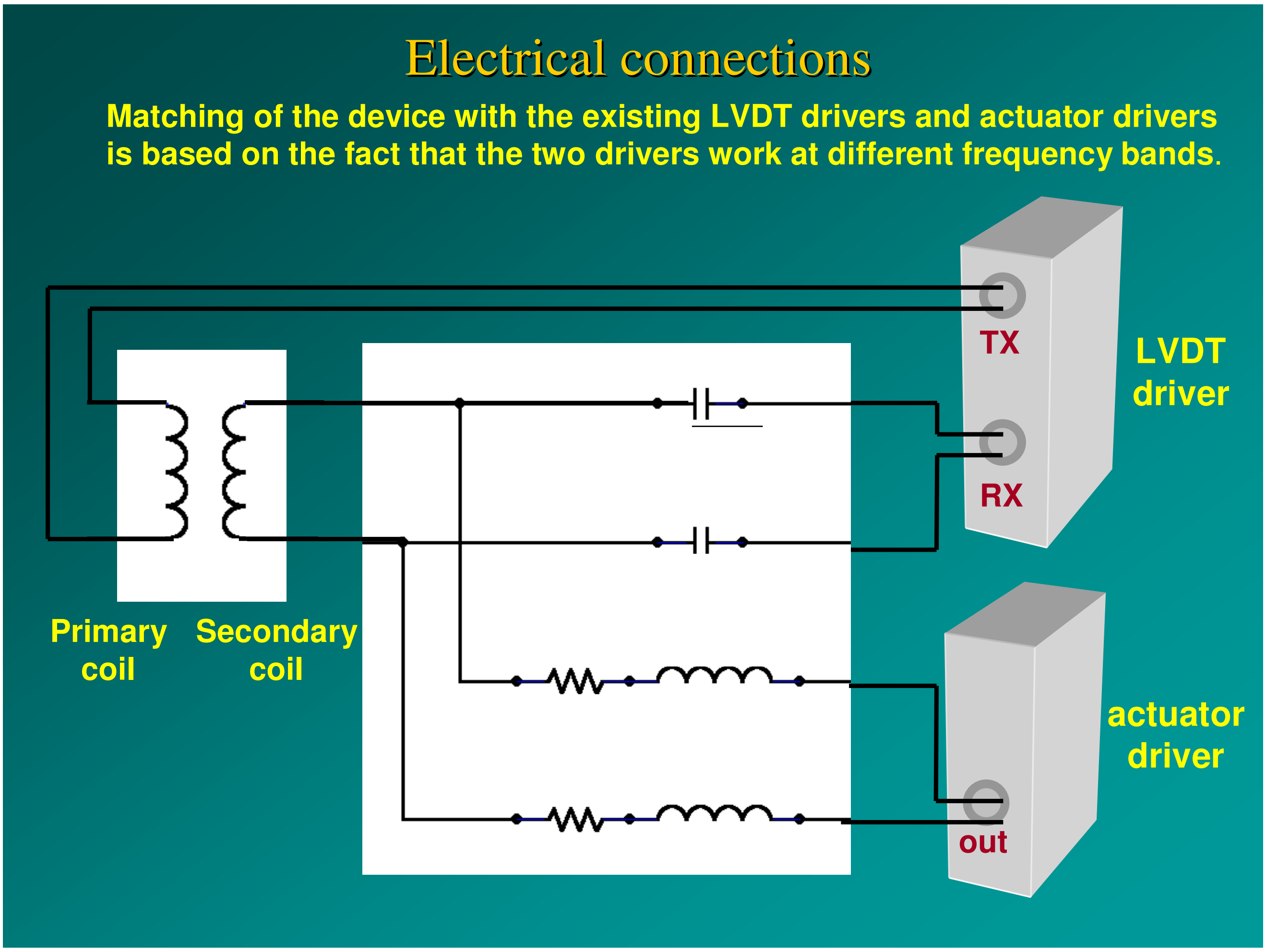


Figure 4. 15

(Top) Conceptual schemes of the working principle of the F7 sensor/actuator system.

(Bottom) Picture of one F7 sensor/actuator during a test.



Electrical connections

Matching of the device with the existing LVDT drivers and actuator drivers is based on the fact that the two drivers work at different frequency bands.

Figure 4. 16

Conceptual scheme of the electrical connections of the F7 sensor/actuator system.

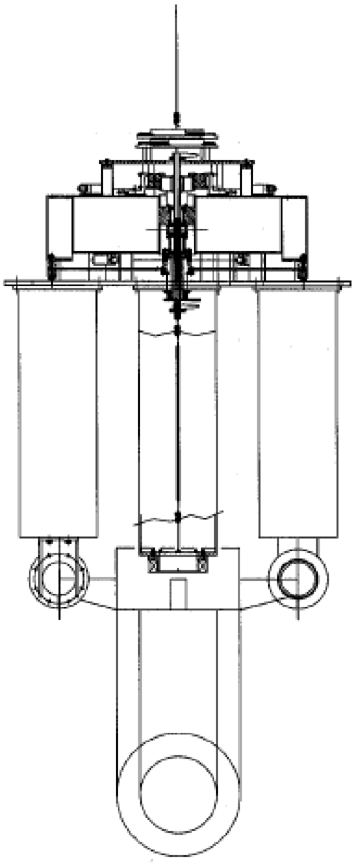


Figure 4. 17

The VIRGO filter 7: at the end of each leg is placed a coil acting on the magnets of the Marionette to control the last stage position.

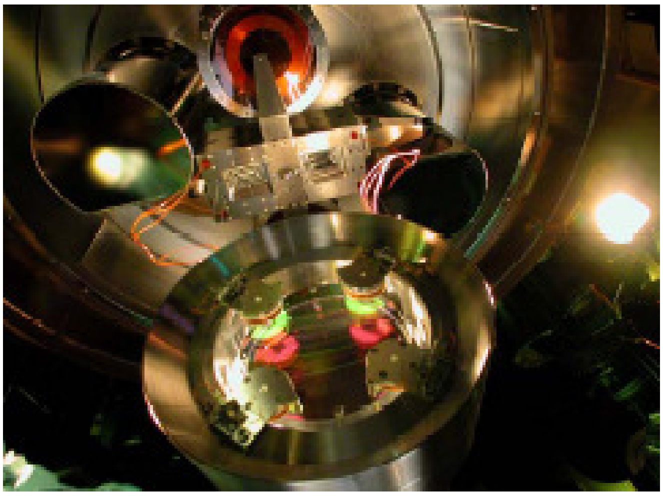


Figure 4. 18

The VIRGO Reference Mass: the four coils act on the magnets placed on the back of the mirror (by Roma VIRGO group).

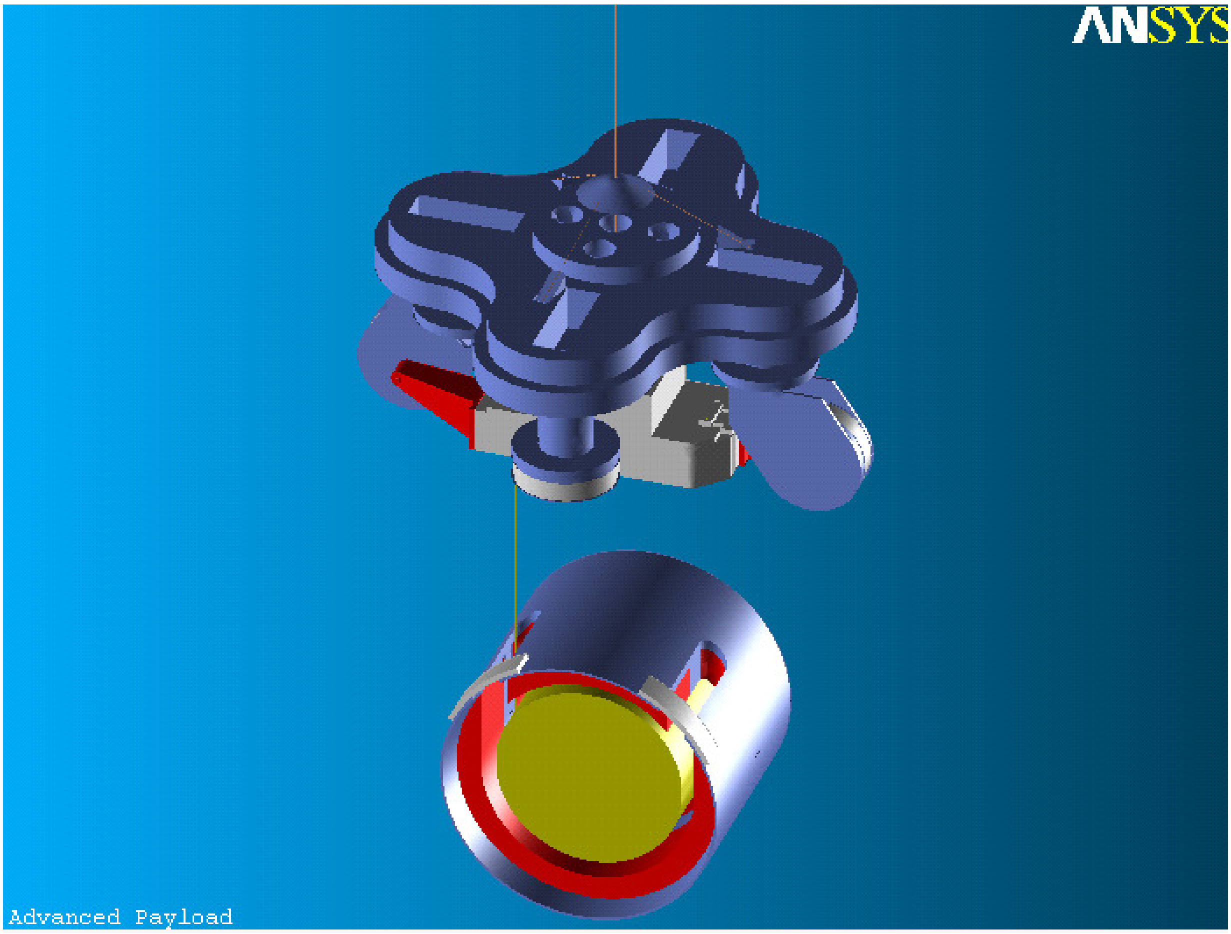


Figure 4. 19

3D rendering of the proposed design for the new AdV payload. On top is visible the new MRM with coil actuators facing the four arms of the Marionette from which the mirror and the RM are suspended.

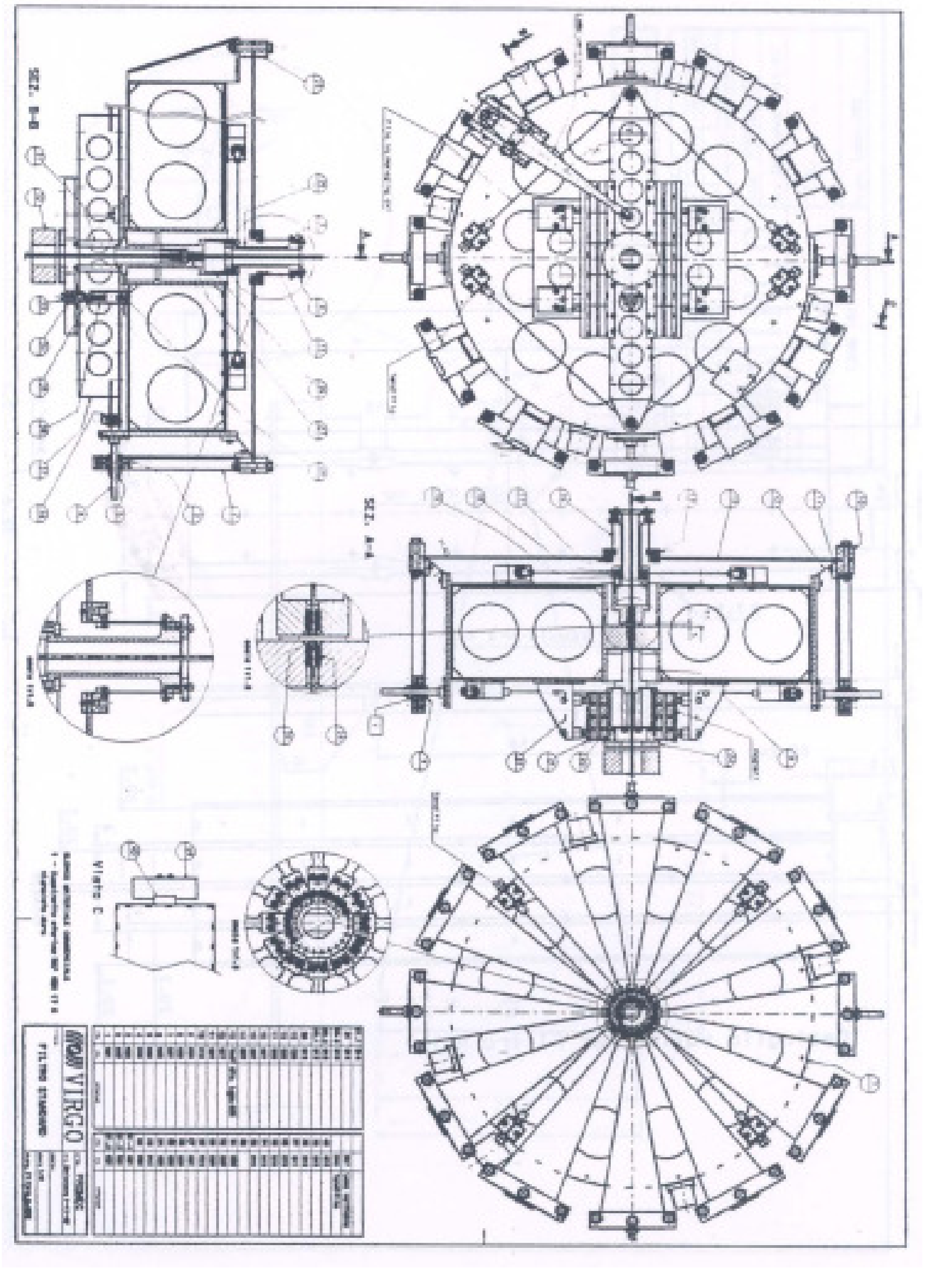


Figure 4. 20

Technical Design of one of the standard filters. The number of blades changes according to the kind of filter (see table of section 5.4.1.5).

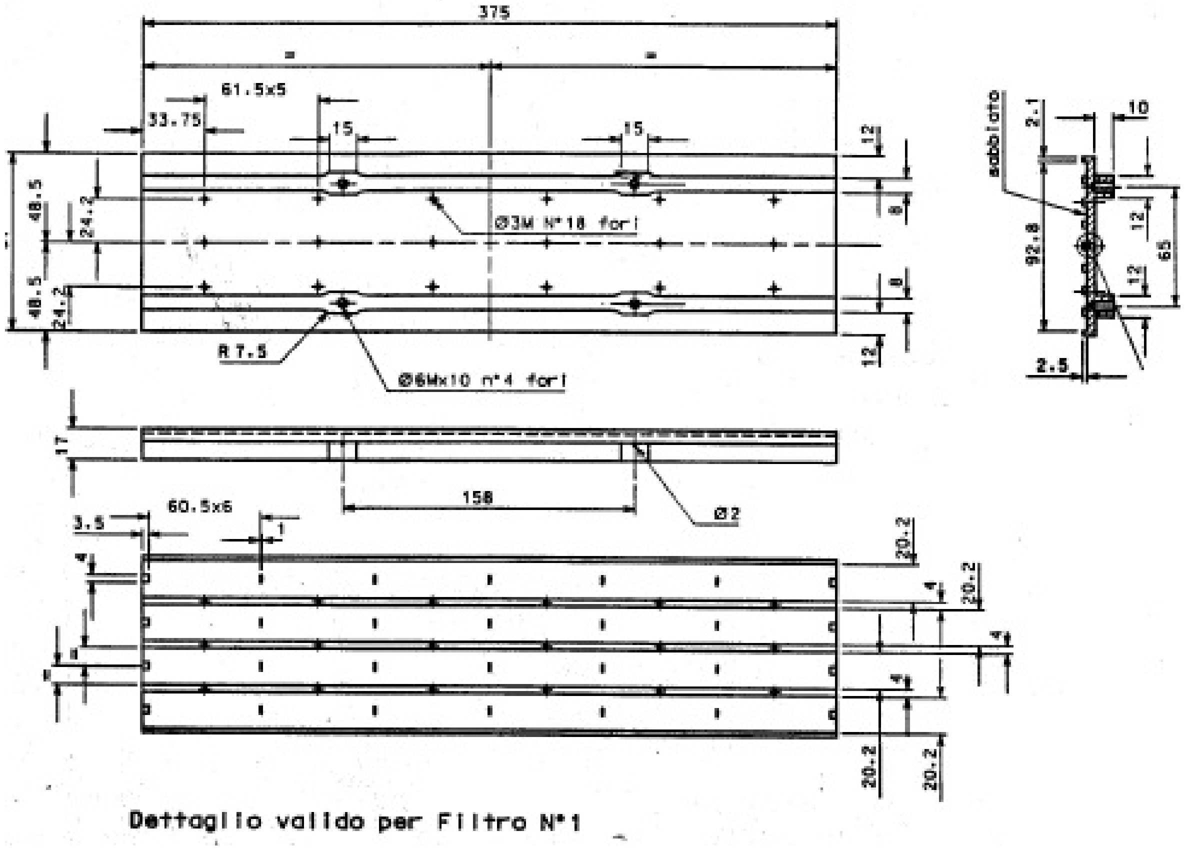


Figure 4. 21

Technical Design of the titanium support of the antispring magnets. The number of magnets changes according to the kind of filter.

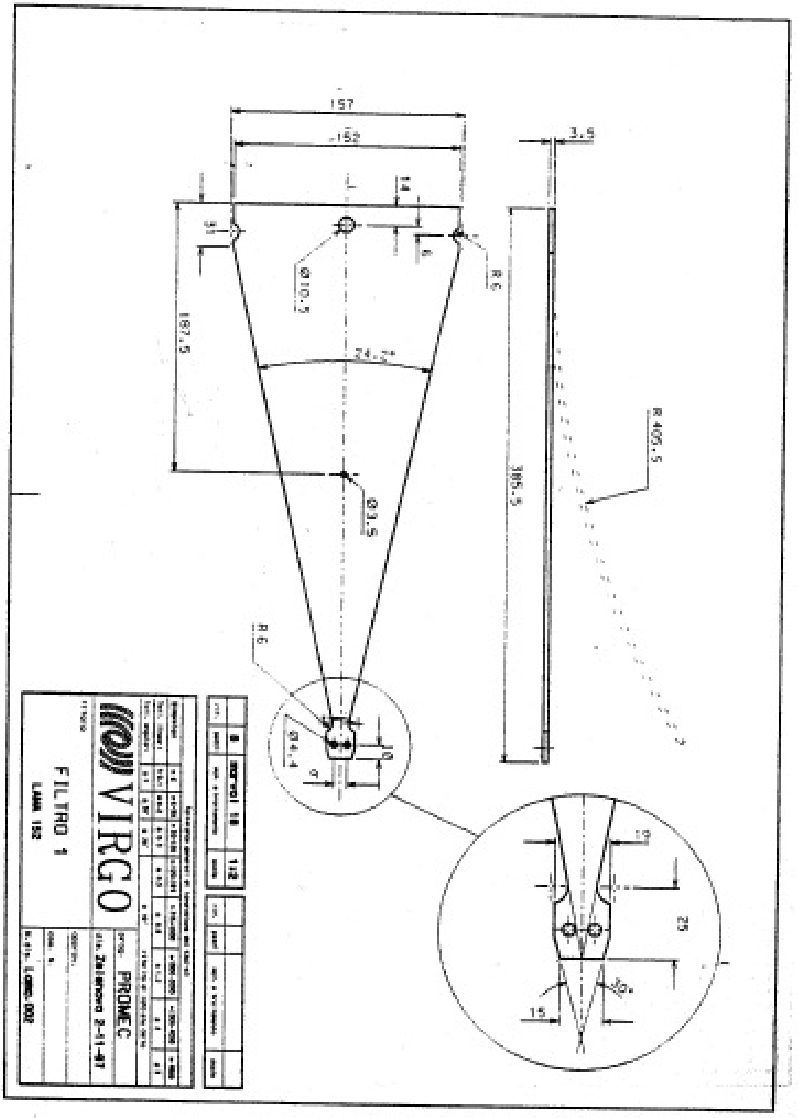


Figure 4. 22

Technical design of one of the 12 blades of filter 1. The design of the blades changes with the kind of filter. The technical designs for all kinds of blades are available.

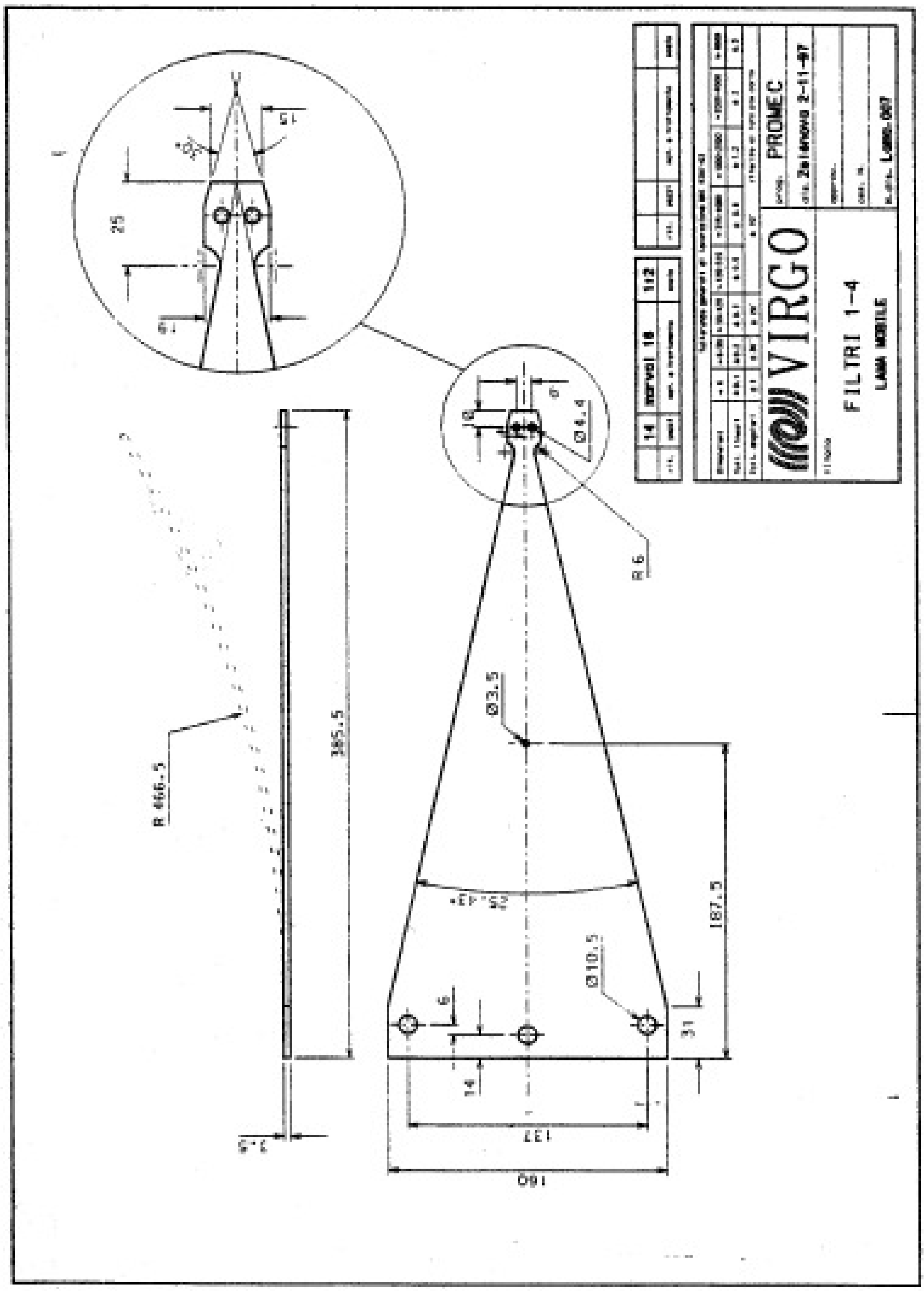


Figure 4. 23

Technical design of one of the adjustable blades of filters 1, 2, 3 and 4. The adjustable blades for filter 0 and filter 7 have a slightly different design.

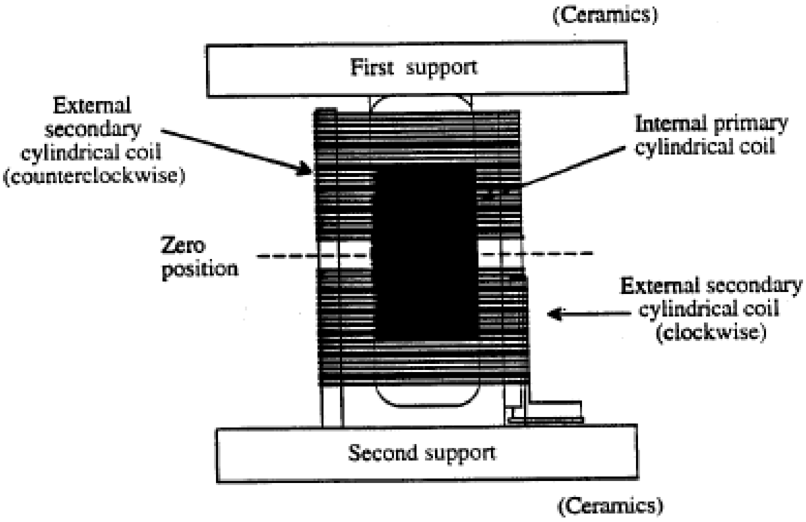


Figure 4. 24

Conceptual Design of the LVDT sensors.

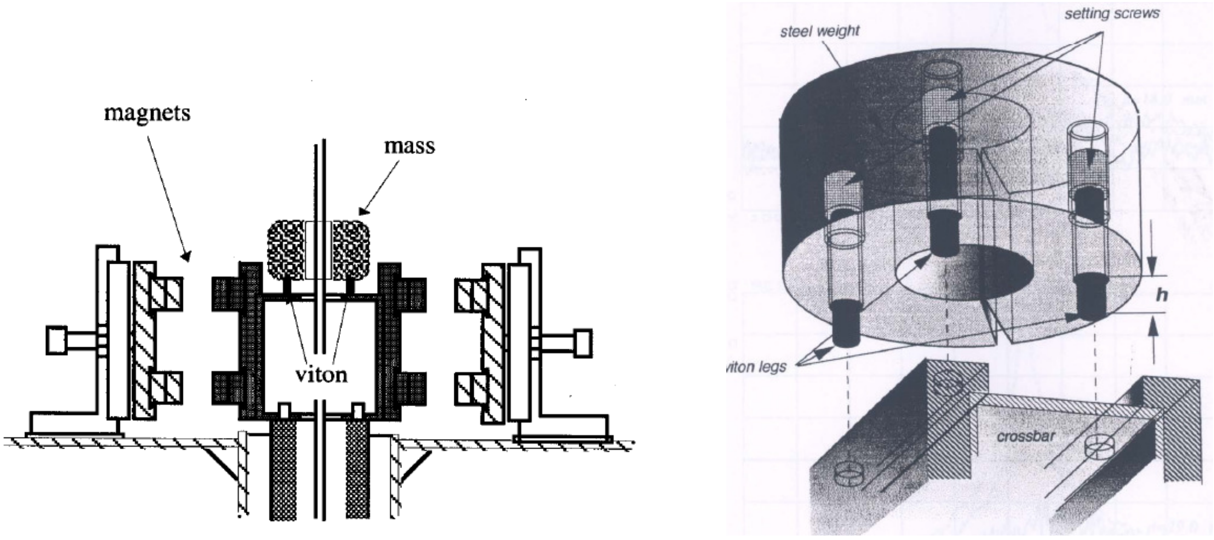


Figure 4. 25

Conceptual design of the crossbar damper. (Technical design available).

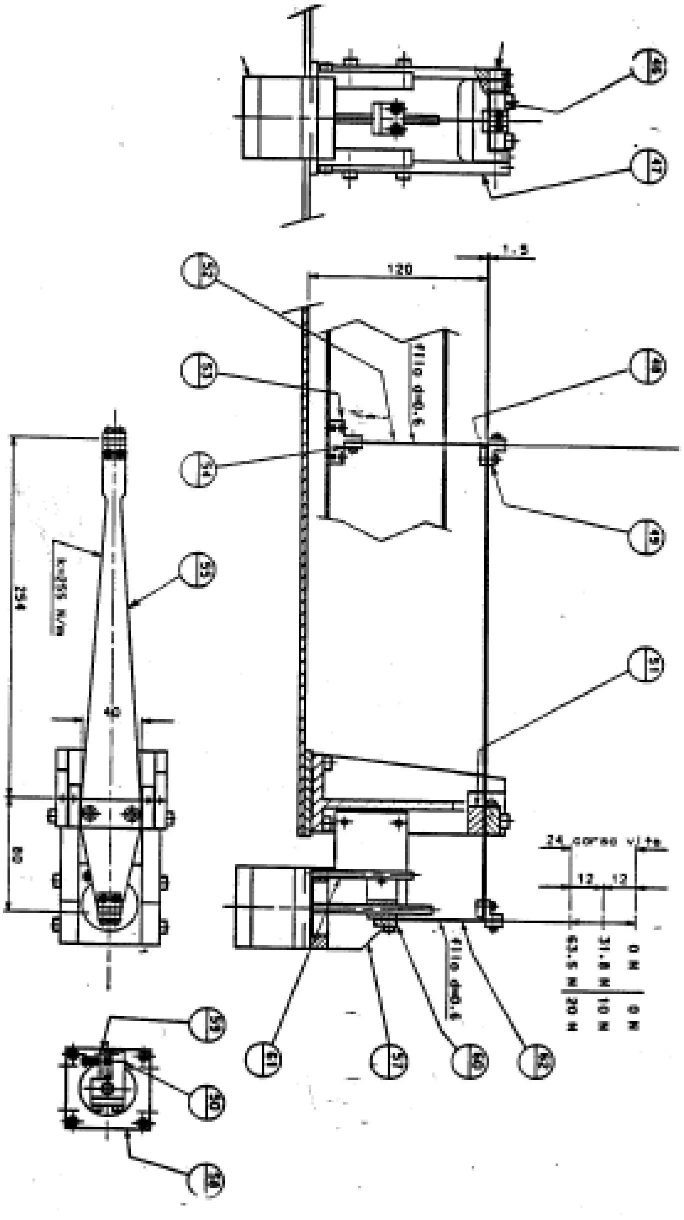


Figure 4. 26

Technical design of the Fishing Rod for the vertical adjustment of the filter moving part.

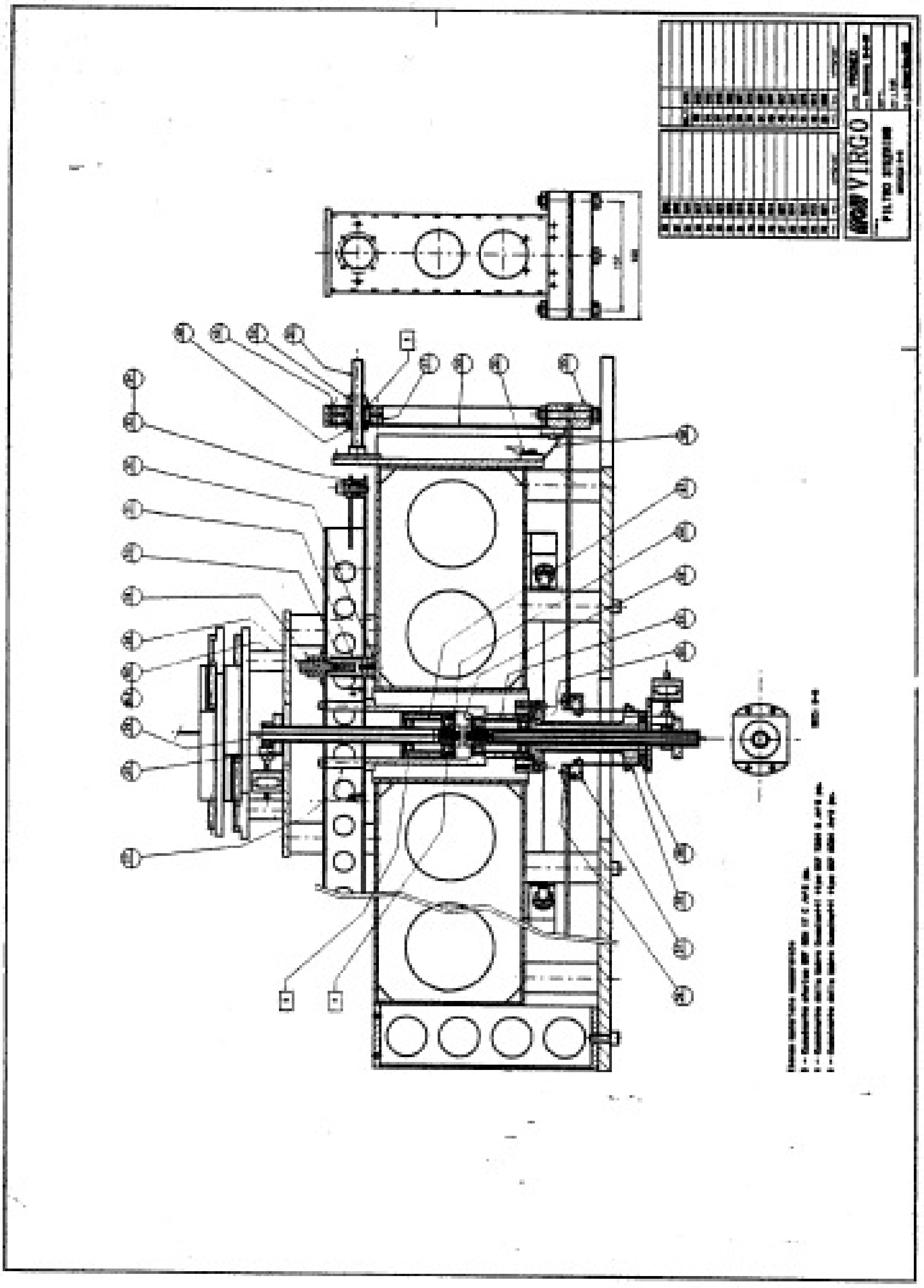


Figure 4. 27

Fig.5.19 - Technical design of the filter 7 (side view).

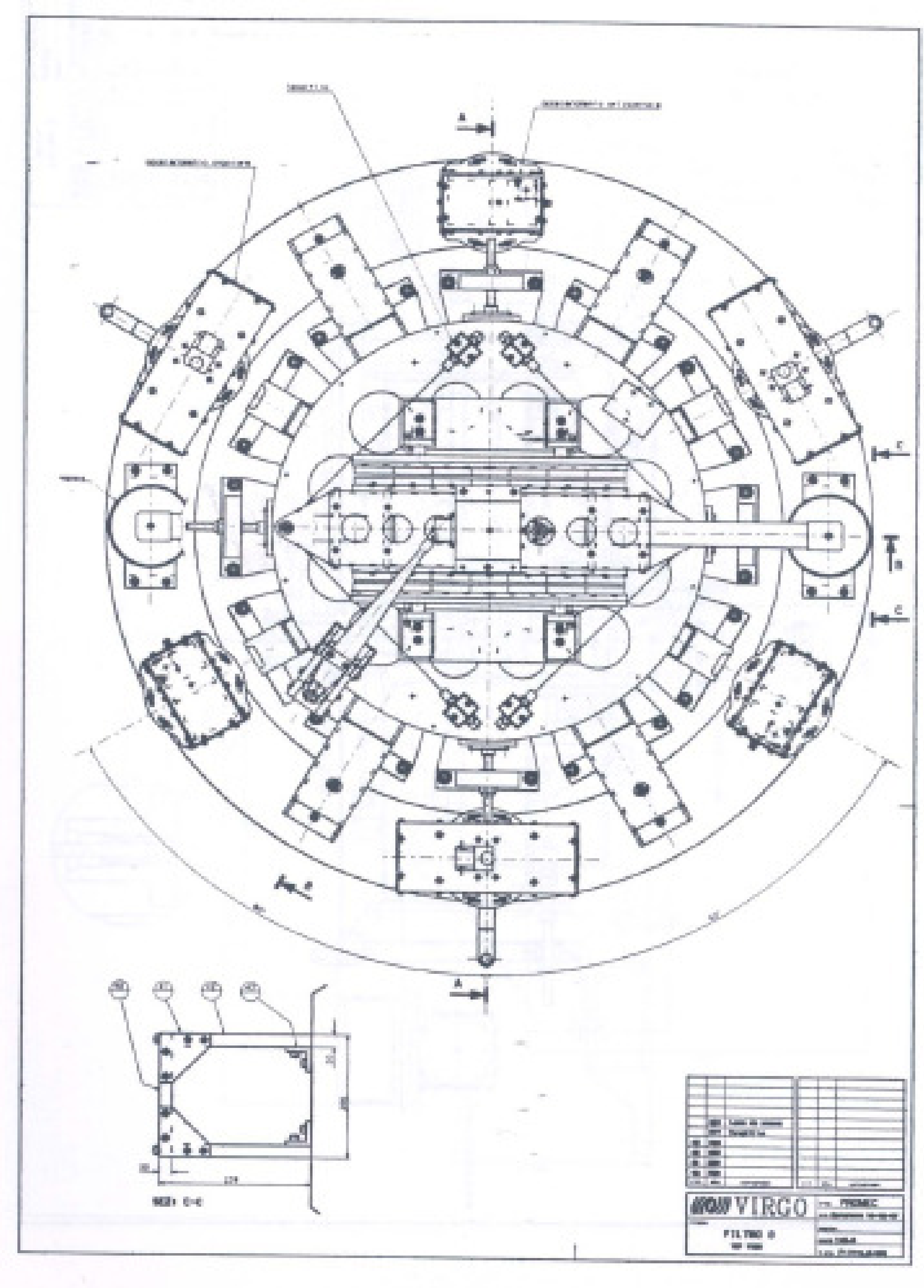
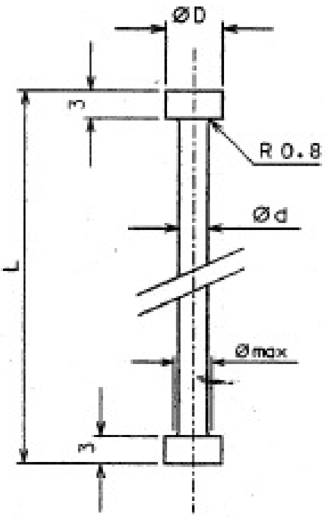
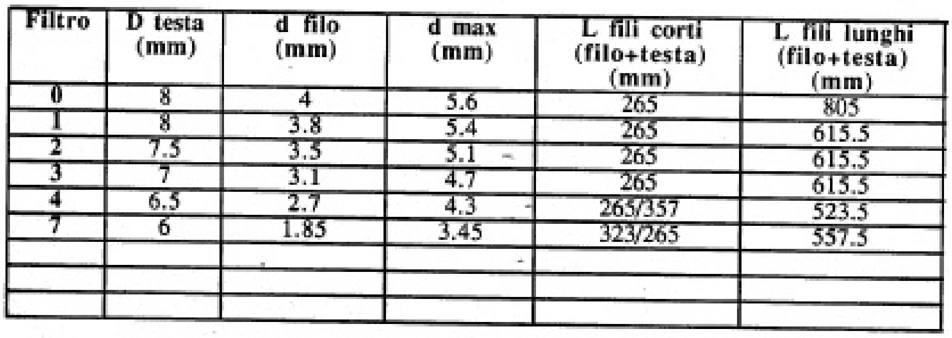


Figure 4. 28

Fig.5.20 - The technical design of the actual Filter Zero (top view).





Filtro	D testa (mm)	d filo (mm)	d max (mm)	L fili corti (filo+testa) (mm)	L fili lunghi (filo+testa) (mm)
0	8	4	5.6	265	805
1	8	3.8	5.4	265	615.5
2	7.5	3.5	5.1	265	615.5
3	7	3.1	4.7	265	615.5
4	6.5	2.7	4.3	265/357	523.5
7	6	1.85	3.45	323/265	557.5

Figure 4. 29

Technical Design of the filter nail-head suspension wires, followed by a table with geometrical generalities.

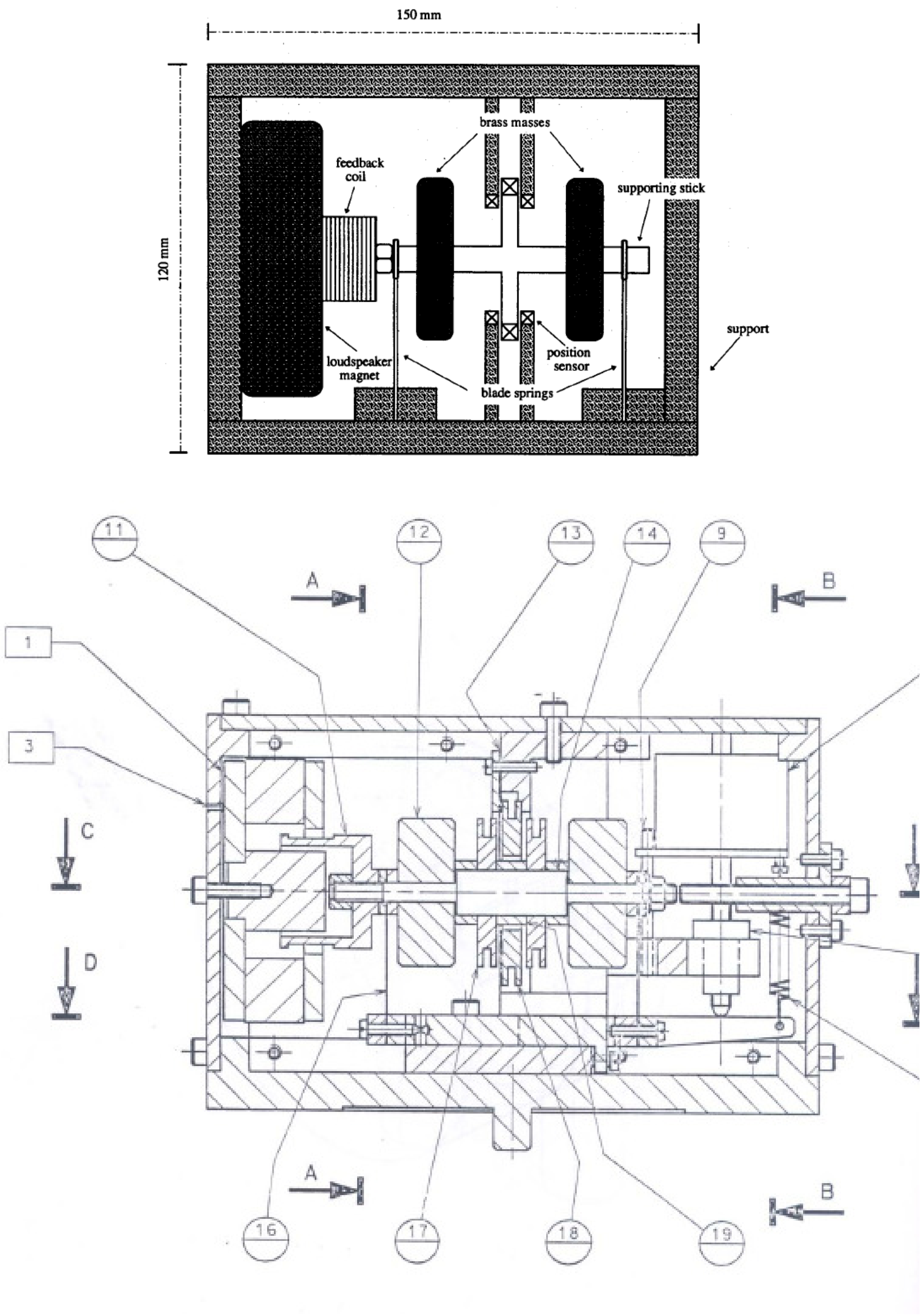


Figure 4. 30

Schematic and technical design of the horizontal accelerometer.

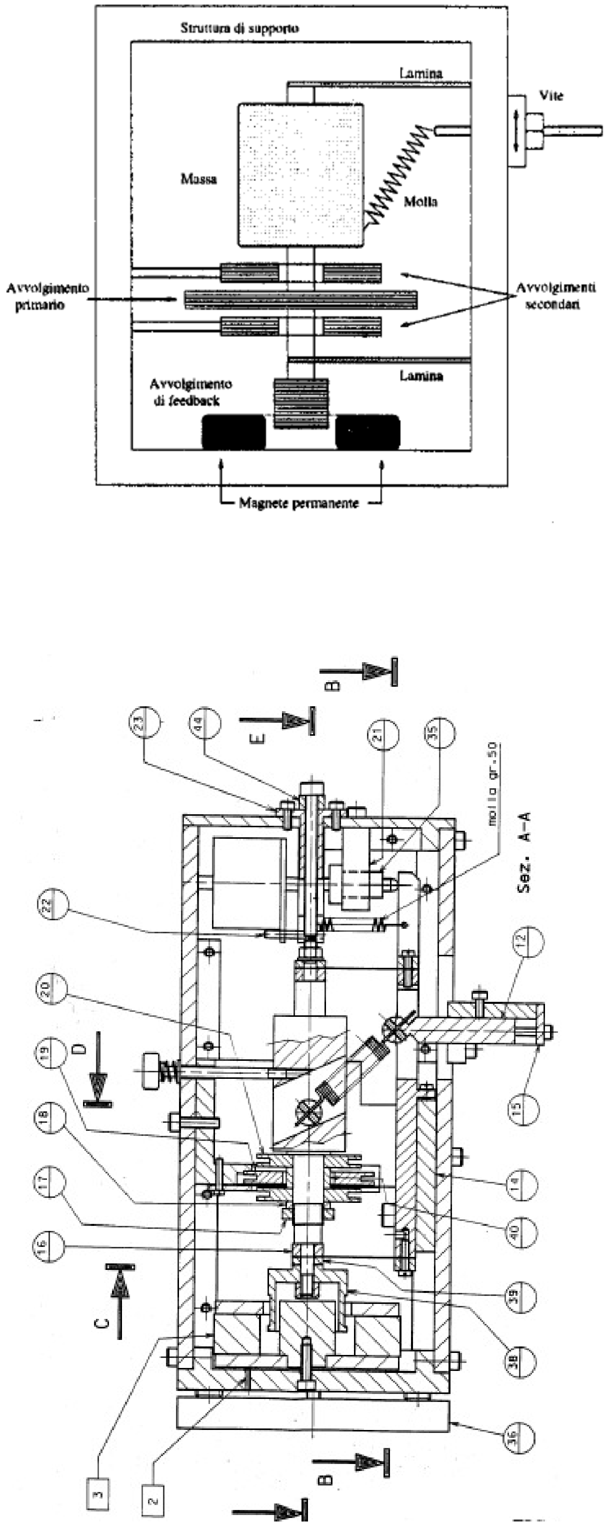


Figure 4. 31

Schematic and technical design of the vertical accelerometer.

SECTION 5

Short Suspensions Upgrade Management Plan

This Section intends to present a preliminary reference plan for the management of the mechanical upgrade of the IMC end mirror (MC), the Injection and Detection short SAs (IB and DB). The preliminary plan for AdV is to increase the attenuation performance of these SAs with the addition of one extra filter stage. The installation of new mirrors over the IB and DB benches, for the operation of the non-degenerate recycling cavities, would probably require a larger seismic attenuation for these suspensions.

The section is organized according to the following scheme:

5.1 MC-IB-DB SAs Upgrade Description

The minimum requirements for the VIRGO short SAs upgrade are presented.

5.2 Preliminary Project Engineering Description

The project is outlined and the list of the concerning SA items is shown.

5.3 Product Breakdown Structure (PBS)

Items involved by the upgrade are split into sub-items and components.

5.4 Work Breakdown Structure (WBS)

The WBS is outlined on the basis of the project description and PBS. The activity for each item production is described, responsible tasks are assigned. At the end of this section an estimate of the upgrade production time and of the required manpower is given.

5.5 Upgrades Assembly and Integration

A preliminary estimate of the MC, IB and DB upgrade assembly and integration and of the manpower involved is outlined.

5.6 Summary of Upgrade Costs

A summary of the costs for the MC, IB and DB upgrade production and installation is presented.

5.1 MC-IB-DB SAs Upgrade Description

The AdV reference baseline is that of a non-degenerate dual recycled interferometer. The adoption of this sophisticated optical configuration and the designed sensitivity level have induced to reconsider the low level of seismic noise attenuation of the MC, IB and DB suspensions. These SAs are in fact constituted by a single stage pendulum chain with the F7 directly suspended to a F0 placed over an about 2.5 m height IP (Fig. 5.1).

The initial proposal is to add one FS between F0 and F7. The distance between these filters allows the insertion of this additional stage that would increase, with relatively little effort, both the horizontal and vertical attenuation by about 40 dB above the low frequency suspension resonances. Tilt control will also be implemented without changing in this case the IP which is already monolithic.

The installation of new optical components over the IB and DB benches, for the operation of the non-degenerate recycling cavities, would presumably set new requirements for the anti-seismic attenuation of IB and DB SAs. At the moment these requirements are still being investigated, considering the possible residual noise on the ITF control signals. Preliminary simulation results are confirming the need of more than one extra filtering stage [1]. Once established, the new specifications could imply the extension of the present SA chains up to the level of the other long SAs. In this last case for each of the IB and DB SAs it will be necessary the construction of more than one FS, of a new IP, the complete cabling reshuffling and the upgrade of the *Safety Frame*.

Reference Documentation

[1] G. Vajente, "*Requirements for the Advanced Virgo Length Sensing and Control System",* VIR-083-A, 2008.

5.2 Preliminary Project Engineering Description

The AdV upgrade of the short VIRGO towers concerns actions over a few SA items and sub-items (see Section 4.2). The sequence of the action to compete the upgrade is strongly dependent on the strategy chosen: add one or more filters to the present SAs.

- **Adding only one extra FS on each short tower:**

The sequence of the actions on each tower for the installation of only one extra FS will be the following:

1. Production and assembling of one FS
2. Produce new suspension wires

3. Produce new F0 blades
4. Produce new F0 antisprings to math the different applied load
5. Produce new IP flex joints
6. Dismounting the F0
7. Change the IP flex joints
8. Install IP tilt control piezoelectric actuators (if SAT R&D is positive)
9. Install IP tilt control tilt-meters (if SAT R&D is positive)
10. Install new F0 blades
11. Upgrade Cabling (estimated up to about 50%)
12. Install new Standard Filter in tower
13. Install upgraded F0 in tower
14. Cabling
15. Test the SA in air
16. Vacuum pumping
17. Test the SA in vacuum

- **Add more than one FS on IB and DB SAs**

The option to add more than one FS implies the change also of the height of the short IB and DB SAs. Thus the necessary construction and assembly time will be increased up to a level comparable with that of the new SR SA. The following actions need to be performed:

18. Produce new blades
19. Produce new suspension wires
20. Produce up to 3 more FSs
21. Producing new IP legs
22. Upgrading the *Safety Frame*
23. Producing new cabling
24. Substitute the IP *Safety Frame*
25. Install the new FSs

5.3 Product Breakdown Structure

Considering both the options of Section 5.2, and following the scheme of the SA items and sub-items, indicated in Section 4.2, the following WBS for the MC- IB-DB SAs upgrade is outlined:

Items **Subitems** **Components**

- 1 - Standard Filter
  - 1.1 - Body, crossbar and central cylinder
  - 1.2 - Antispring system
    - 1.2.a - Supports
    - 1.2.b - Magnets
    - 1.2.c - Glue
    - 1.2.d - Sealing
    - 1.2.e - Cage
  - 1.3 - Centering system
    - 1.3.a - Wires
    - 1.3.b - Clamps
    - 1.3.c - Clamp supports
  - 1.4 - Metal springs (or blades)
    - 1.4.a - Blades
    - 1.4.b - Base clamps
    - 1.4.c - Tip wires
    - 1.4.d - Tip clamps
    - 1.4.e - Setting systems
    - 1.4.f - Thin plates
  - 1.5 - Filter LVDT sensor
    - 1.5.a - Ceramic support
    - 1.5.b - Wire
    - 1.5.c - Resin
    - 1.5.d - Mechanical support
  - 1.6 - Crossbar damper
    - 1.6.a - Viton
    - 1.6.b - Springs
    - 1.6.c - Mass
    - 1.6.d - Plate support
  - 1.7 - Blade dampers
    - 1.7.a - Viton
    - 1.7.b - Supports

Items	**Subitems**	**Components**
1 - Standard Filters		
	1.8 - Fishing rod	
		1.8.a - Blade
		1.8.b - Motor
		1.8.c - Mechanic.structure
		1.8.d - Flex joint
		1.8.e - Wire
	1.9 - Plated screws for standard filters	
2 - Filter Zero		
	2.1 - Antispring system	
		3.2.a - Supports
		3.2.b - Magnets
		3.2.c - Glue
		3.2.d - Sealing
		3.2.e - Cage
	2.2 - Metal springs (or blades)	
		3.4.a - Blades
		3.4.b - Base clamps
		3.4.c - Tip wires
		3.4.d - Tip clamps
		3.4.e - Setting systems
		3.4.f - Thin plates
4 - Inverted Pendulum		
	4.1 - Feet	
	4.4 - Flexural joints	
	4.5 - Counterweight	
	4.6 - Pendulum legs	
	4.7 - Terminal joints	
		4.7.a - Top of the legs
		4.7.b - Wires
		4.7.c - Clamps
5 - Safety Structure		
	5.1 - Structure	
		5.1.a - Columns
		5.1.b - Rings
	5.2 - Shelves	
		5.2.a - Shelves
		5.2.b - Safety connections

Items	**Subitems**	**Components**
6 - Suspension wires		
	6.1 - Wires	
		6.1.a - Steel Wire
		6.1.b - Heads
	6.2 - Filter connection system	
		6.2.a - Split heads
		6.2.b - Special screw
		6.2.c - Clamp special tool
	6.3 - Junctions	
		6.3.a - Split heads
		6.3.b - Special screw
		6.3.c - Clamp special tool
7 - Cabling		
	7.1 - Cables	
	7.2 - Connectors	
		7.2.a - Pins
		7.2.b - Sockets
		7.2.c - Cases
	7.3 - Feed-throughs	
	7.4 - Flanges	
	7.5 - Mechanical interfaces & clamps	
9 - Tools		
	9.1 - Wire breaking machine	
	9.2 - Blade stress machine	
	9.3 - Cleaning tools	
		9.3.a - Washing machines
		9.3.b - Outgassing chamber
		9.3.c - Soaps
	9.4 - Oven for mechanical filters	
	9.5 - Oven for blades	
	9.6 - Oven for suspension wires	
	9.7 - Plating tools	
		9.7.a - Tanks
		9.7.b - Chem. Components
	9.8 - Hardness measurement tool	
	9.9 - Filter quality tests set-up	
	9.10 - Magnetic force measurement machine	
	9.11 -Gaussmeter	

5.4 Work Breakdown Structure

5.4.1 ITEM Standard Filters

More information about this item concerning the work description, specifications, responsible tasks, technical design, and acceptance criteria can be found in Section 4.4.1.1 and 4.4.1.2

Responsible: one scientist (named **A**).

Production Time Schedule and Deliverables:

Table 5.4.1.a: MC-IB-DB (n.1) Standard Filter – Production Schedule and Deliverables

Production Phase	**Month 1**		**Month 2**		**Month 3**		**Month 4**		**Month 5**		**Month 6**		**Month 7**		**Month 8**	
Laser Cut	■	■	■													
Components production	■	■	■	■	■	■	■	■	■							
Filter sheets welding			■	■	■	■	■	■								
Filter bodies machining				■	■	■	■	■	■	■						
St. filter MC assembly								■	■							
St. filter MC tuning									■	■						
St. filter IB assembly										■	■					
St. filter IB tuning											■	■				
St. filter DB assembly												■	■			
St. filter DB tuning													■	■		
Deliverables																
Material Procurement	■															
St. Filter MC validation										■						
St. Filter IB validation												■				
St. Filter DB validation														■		

Note:

Eventually, the production and the assembly of more *Standard Filters* for the IB and DB SAs will require about one extra month per filter.

Manpower Plan:

Table 5.4.1.b: MC-IB-DB n.1 Standard Filter - Manpower Plan

Production Phase	**Physicist/Engineer**				**Mechanics Technician**			
Laser Cut	**A**				**J**			
Components production	**A**				**J**			
Filter sheets welding	**A**				**J**			
Filter bodies machining	**A**				**J**			
St. filter MC assembly	**A**				**J**			
St. filter MC tuning	**A**	**B**			**J**			
St. filter DB assembly	**A**				**J**			
St. filter DB tuning	**A**	**B**			**J**			
St. filter IB assembly	**A**				**J**			
St. filter IB tuning	**A**	**B**			**J**			
Total	**2**				**1**			

Costs:

Table 5.4.1c: MC-IB-DB n.1 Standard Filter Upgrade – Costs

Item	**Quantity**	**Unitary Cost (k€)**	**Total Cost (k€)**
St. Filter Components	3	7	**21**
St. Filter Assembly	3	2.5	**7.5**
Total (without IVA/VAT)			**28.5**
Note: The addition of more Standard Filters would have an extra cost of about **9500 € / stage**			

5.4.2 ITEM Inverted Pendulum and Flex Joints

For the installation of only one extra *Standard Filter* the IP upgrade will be limited to the change of the leg flex joints. If more filter stages are required than also new IP legs, with a different length, will be built and installed.

More information about this item concerning the work description, specifications, responsible tasks, technical design, and acceptance criteria can be found in Section 4.4.1.6.

Responsible: one scientist (named **C**).

Production Time Schedule and Deliverables:

In case of adding only one *Standard Filter* only the IP flex joints need to be replaced:

Table 5.4.2.a: IP Flex Joints - Production Schedule and Deliverables

Production Phase	**Month 1**	**Month 2**	**Month 3**	**Month 4**	**Month 5**	**Month 6**	**Month 7**	**Month 8**
9 Flex Joints production		■	■					
9 Flex Joint thermal treat.			■					
9 Flex Joint test			■	■				
Deliverables								
Material procurement	■							
Flex Joint validation				■				

In case of adding more than one *Standard Filter* than also the SA height will change and new IP legs and flex joints will be required:

Table 5.4.2.b: IP Legs - Production Schedule and Deliverables

Production Phase	**Month 1**	**Month 2**	**Month 3**	**Month 4**	**Month 5**	**Month 6**	**Month 7**	**Month 8**
IB-DB IP legs production		■	■	■				
IB IP legs test			■	■				
DB-IP legs test				■	■			
Deliverables								
Material Procurement	■							
IP legs Validation				■	■			

Manpower Plan:

Table 5.4.2c MC-IB-DB Inverted Pendulum-Manpower Plan

Production Phase	**Physicist/Engineer**				**Mechanics Technician**		
Flex Joints production	**D**				**K**		
Fl. Joint Thermal Treat.	**D**				**K**		
Fl. Joint Test	**D**				**K**		
IP Legs production		**C**			**K**		
IP Legs pre-assembly		**C**			**K**		
IPLegs test		**C**	**A**				
Total	**3**				**1**		

Costs:

Table 5.4.2.d: MC-IB-DB Flex Joints - Cost

Item	**Quantity**	**Unitary Cost (€)**	**Total Cost (k€)**
Flex Joints	9	700	**6.3**
Total (without IVA/VAT)			**6.3**

Table 5.4.2.e: MC-IB-DB Inverted Pendulum Legs - Costs

(*Case of Length Change*)

Item	**Quantity**	**Unitary Cost (k€)**	**Total Cost (k€)**
IP legs set	2	13	**26**
Total (without IVA/VAT)			**26**

5.4.3 ITEM Safety Frame

In case of IB and DB SA heights change the *Safety Frames* will have to be upgraded building extra parts to move the actual height of about 2 m to the desired level. More information about this item concerning the work description, specifications, responsible tasks, technical design, and acceptance criteria can be found in Section 4.4.1.7.

Responsible: one scientist (named **C**).

Production Time Schedule and Deliverables:

Table 5.4.3.a: IB-DB Safety Frame - Production Schedule and Deliverables

Production Phase	Month 1		Month 2		Month 3		Month 4		Month 5		Month 6		Month 7	
Components production	■	■	■	■	■									
Plates Cut	■	■												
Flanges welding			■	■	■									
Flanges machining						■	■							
Pre-assembly							■	■						
Deliverables														
Material Procurement	■													
Safe Struct. validation							■	■						

Manpower Plan:

Table 5.4.3.b: IB-DB Safety Frame - Manpower Plan

Production Phase	Physicist/Engineer				Mechanics Technician			
Components production					K			
Plates Cut					K			
Flanges welding					K			
Flanges machining					K			
pre-assembly	C				K			
Total	1				1			

Costs:

Table 5.4.3.c: IB-DB Safety Frame - Costs

Item	Quantity	Unitary Cost (k€)	Total Cost (k€)
Safety Frame	2	7	**14**
Total (without IVA/VAT)			**14**

5.4.4 ITEM Suspension Wires

More information about this item concerning the work description, specifications, responsible tasks, technical design, and acceptance criteria can be found in Section 4.4.1.8.

Responsible: one scientist (named **D**).

Production Time Schedule and Deliverables:

Table 5.4.4a: MC-IB-DB Suspension Wires – Production Schedule and Deliverables

Production Phase	**Month 1**	**Month 2**	**Month 3**	**Month 4**	**Month 5**	**Month 6**	**Month 7**	**Month 8**	**Month 9**
Wire production	■	■							
Thermal treatment	■	■							
Nickel plating		■	■						
Tensile strength tests			■	■					
Deliverables									
Material Procurement	■								
Validation			■	■					
Note: Wires for any extra stage will require about 1 month extra validation time.									

The production time of the suspension wires is not much affected by the need of more filters for IB and DB SAs.

Manpower Plan

Table 5.4.4.b: MC-IB-DB Suspension Wires – Manpower Plan

Production Phase	**Physicist/Engineer**				**Mechanics Technician**			
Wire production	**D**							
Thermal treatment	**D**							
Nickel plating	**D**							
Aging	**D**							
Tensile strength tests	**D**							
Total	**1**				**0**			

Costs:

Table 5.4.4.c: MC-IB-DB Suspension Wires – Costs			
Item	**Quantity**	**Unitary Cost (€)**	**Total Cost (€)**
F 0 – short wires	2	300	**600**
F 0 – long wires	2	400	**800**
F. St. – short wires	2	300	**600**
F. St. – long wires	1	400	**400**
F 7 – short wires	2	300	**600**
F 7 – long wires	1	400	**400**
Ti junction boxes	6	150	**900**
Steel semi-cups	18	100	**1800**
Total (without IVA/VAT)			**6100**
Note: **Each ulterior filter stage would imply 4 more wires with an extra cost of about 3000 €/stage**			

5.4.5 ITEM Cabling

More information about this item concerning the work description, specifications, responsible tasks, technical design, and acceptance criteria can be found in Section 4.4.1.9.

Specific Work Description

The introduction of a new *Standard Filter* in the VIRGO short towers would imply a careful check of the cable lengths. Most of the cables will need to be replaced.

Responsible: one electronics engineer (named **E**).

Production Time Schedule and Deliverables:

Table 5.4.5.a: MC-IB-DB Cabling – Production Schedule and Deliverables

Production Phase	**Month 1**	**Month 2**	**Month 3**	**Month 4**	**Month 5**	**Month 6**	**Month 7**	**Month 8**	**Month 9**
Cables preparation	■	■							
Test		■	■						
Deliverables									
Material procurement	■								
Validation			■						

Manpower Plan:

Table 5.4.5.b: MC-IB-DB Cabling – Manpower Plan

Production Phase	**Physicist/Engineer**			**Electronics Technician**		
Design	**E**			**L**		
Material procurement	**E**					
Cables preparation	**E**			**L**		
Test	**E**			**L**		
Total	**1**			**1**		

Costs:

Cabling costs are difficult to estimate.

- **Option1:**

  In case of inserting only one filter stage cabling will be partially upgraded. An estimate of the interventions costs is about 40% of a full cabling cost (see Section 4.4.1.9).

- **Option2:**

  If more filters are required than also the IB and DB heights will change than cabling will be almost completely reshuffled.

Table 5.4.5.c: MC-IB-DB Cabling - Costs

Item CABLING	**Option 1 (k€)**	**Option 2(k€)**
MC	15	15
IB	15	40
DB	15	40
Total (k€) **(without IVA/VAT)**	**45**	**95**

5.4.6 ITEM Tools

All the special tools required for operating this upgrade are considered also in the SR installation planning (see Section 4.2.9 and 4.4.1.11 for more information).

5.4.7 Metal Spring Blades

More information about this item work description, specifications, technical design, and acceptance criteria can be found in Section 4.4.2.1.

Specific Work Description:

Blades are required for both the new *Standard Filters* and the existing F0 that has to be upgraded due the modification of the applied load.

Responsible: one scientist (named **D**).

Production Time Schedule and Deliverables:

Table 5.4.7.a: MC-IB-DB One Tower Spring Blades - Production Schedule and Deliverables

Production Phase	**Month 1**	**Month 2**	**Month 3**	**Month 4**	**Month 5**	**Month 6**	**Month 7**	**Month 8**	**Month 9**
Blades production	■	■							
Thermal treatment		■	■						
Nickel plating		■	■						
Tests			■	■					
Deliverables									
Material procurement	■								
Validation			■	■					

Manpower Plan:

Table 5.4.7.b: MC-IB-DB One Tower Spring Blades - Manpower Plan

Production Phase	**Physicist/Engineer**			**Mechanics Technician**		
Blades production	**D**					
Thermal treatment	**D**					
Nickel plating	**D**					
Tests	**D**					
Total	**1**			**0**		

Costs:

Table 5.4.7.c: MC-IB-DB One Tower Spring Blades – Costs

Item	**Quantity + Spares**	**Unitary Cost (k€)**	**Total Cost (k€)**
F0 - type A	4+2	250	**1500**
F0 - type G	4+2	250	**1500**
Type C	-	-	**-**
Type D	-	-	**-**
FS4 - Type E	4+2	250	**1500**
Type F	-	-	**-**
FS4 - Type G	6+2	250	**2000**
Type H	-	-	**-**
Type I	4+2	250	**1500**
Fishing rod blade	1+1	150	**300**
Total			**8300***

*** Note:**

The production of blades for one extra filter will imply an extra cost of about 3000 €/filter

Reference: Section 5.4.5, Table 5.4.1.5a (3.5 mm thick maraging (MARVAL 18)

Type A- Base width 180mm	**Type B-** Base width 152 mm	**Type C-** Base width 146 mm
Type D- Base width 138 mm	**Type E-** Base width 133.5 mm	**Type F-** Base width 152 mm
Type G- Base width 160 mm	**Type H-** Base width 110 mm	**Type I-** Base width 127 mm

5.4.8 Magnetic Antisprings

More information about this item work description, specifications, technical design, and acceptance criteria can be found in Section 4.4.2.2.

Responsible: one scientist (named **E**).

Production Time Schedule and Deliverables:

Table 5.4.8.a: MC-IB-DB Antisprings - Production Schedule and Deliverables

Production Phase	**Month 1**	**Month 2**	**Month 3**	**Month 4**	**Month 5**	**Month 6**	**Month 7**	**Month 8**	**Month 9**
Components production	■	■	■						
Antispring assembly			■	■					
Characterization			■	■					
Deliverables									
Material procurement	■								
Validation			■	■					

Manpower Plan:

Table 5.4.8.b: MC-IB-DB Antisprings - Manpower Plan

Production Phase	**Physicist/Engineer**					**Electronics Technician**			
Components production	**E**								
Antispring assembly	**E**					**L**			
Characterization	**E**					**L**			
Total	**1**					**1**			

Costs

Table 5.4.8.c: MC-IB-DB One tower Antisprings - Cost

Antispring	**Unitary Cost (k€)**	**Quantity Option 1 filt.**	**Total Cost (k€)**
F. Zero	3	1	**3**
F. Standard	2.5	1	**2.5**
Total (k€) (without IVA/VAT)			**5.5**

5.4.9 Stepping motors

More information about this item work description, specifications, technical design, and acceptance criteria can be found in Section 4.4.2.6.

Responsible: one scientist (named **B**).

Cost:

Table 5.4.9.a: MC-IB-DB Stepping Motor - Cost (without IVA/VAT)

Item	**Type**	**Quantity min.**	**Unit Cost (€)**	**Total Cost (€)**
FS-Fishing Rods	AML - B23.1	3	1500	**4500**

5.4.10 Upgrades Construction and Manpower Schedule

The execution of the MC-IB-DB upgrade requires the coordination of all the items delivery plans. A preliminary estimate of the time needed for this upgrade operation is visible in Table 5.4.10.a where the operating period, individuated by the month numbers, is associated to each item production conclusion. Labels of responsible are indicating the scientists and technicians involved. The filter assembly order is only indicative. The real execution plan has not yet been decided in detail.

Table 5.4.10.a: MC-IB-DB Upgrade Construction and Manpower Schedule

ITEM Id	**Month 1**	**Month 2**	**Month 3**	**Month 4**	**Month 5**	**Month 6**	**Month 7**	**Month 8**	**Month 9**	**Month 10**
1-MC					**A, B /J**					
1-IB						**A, B /J**				
1-DB							**A, B /J**			
2				**C/K**						
3					**C/K**					
4			**D**	**D**						
5			**E/L**							
6			**A,B,C, D**							
S1			**D**	**D**						
S2			**E/L**	**E/L**						

Labels: Scientist, Support Scientist **/Technician**

IT 1: N.1 St-Filter - IT2: IP flex – IT3: IP Legs - IT 4: Suspension Wires - IT 5: Cabling - IT 6: Tools
IT S1: Metal Spring Blades – IT S2: Antisprings and Magnets

In each case a minimum period of about 7 months would be required for the realization of 3 FSs and other possible components the filter. The production and setup of more filters would require about 3 weeks each. Thus considering a maximum of other 6 FSs an extra period of about 18 weeks would be required. A minimum of 5 scientists (physicists and engineers) and 3 technicians would be involved.

5.5 Upgrades Assembly and Integration

The upgrade of each of the MC-IB-DB SAs will progress through the successive steps of a long sequence of operations. The actions depend on how many attenuation stages will be added to each tower:

- **Option1: add only one Standard Filter between F0 and F7 :**
    1. **Opening the tower**
    2. **Block the IP**
    3. **Unload the F0 with the F7 safety legs standing over the IP platform**
    4. **Disconnect the F0 - F7 suspension wire**
    5. **Disconnect the cabling**
    6. **Dismount the F0 from the IP top ring**
    7. **Upgrade the IP flex joints and install the piezo-actuators (if effective)**
        a. Dismount the IP legs
        b. install the IP piezo-actuators
        c. Change the IP flexible joints
        d. Mount the IP legs
    8. **Upgrade the F0**
        a. Dismount the antisprings
        b. Dismount the maraging blades
        c. Mount the new blades
        d. Mount the new antispring
        e. Tune the filter
    9. **Install the safety structure frames to sustain the new Standard Filter**
    10. **Place the Standard Filter over the safety frame shelve**
    11. **Install the upgraded F0 over the IP top ring**
    12. **Substitute the top stage accelerometers (if upgraded)**
    13. **Suspend the filter chain**
        a. Suspend the Standard Filter to F0
        b. Suspend the Filter 7 to Standard Filter

14. **Cabling**
15. **Check the cables connections**
16. **Install the two tilt-meters on the IP platform (if effective)**
17. **Check the SA signals from LVDTs, tilt-meters and accelerometers in air**
18. **Balance the filters tilt**
19. **Tune the filter crossbar vertical position with respect to the body**
20. **Tune of the IP modes adding mass over the IP top ring**
21. **Setup the SR suspension point position with top stage motorized sliders**
22. **Check the parallelism of IP legs**
23. **Setup the top stage LVDT and actuator position**
24. **Tune of filter chain vertical position with fishing rods**
25. **Install all the viroles except the last**
26. **Setup the rigid links between the top virola and the Safety Frame**
27. **Close the tower**
28. **Vacuum pumping**
29. **Check the sensors and actuators on F0 crossbar and IP top ring in vacuum.**

- **Option 2: add more than one Standard Filter between F0 and F7:**
  The following actions should be added after step 6 above
  6.1. Upgrade the Safety Frame
  6.2.Replace the IP with the higher one
  Steps 9, 10 and 13 will concern the installation of more than on Standard Filter.
  Cabling will be much more important.

The assembly and manpower schedule to carry on the interventions required for the *Option1* on one single tower is shown in Table 5.5.a. Manpower is indicated with labels placed inside the green boxes concerning each operation; the order is scientist/technician, and the labels refer to those used for the WBS description of Section 4.4.and 5.4.

Table 5.5.a: Assembly and Manpower Schedule of Option 1 Upgrade for 1 Short Tower

ITEM	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
1	EGO												
2	A,B/J												
3	A,B/J												
4	A,B/J												
5	E/L	E/L											
6		A,B/J											
7		C/K	C/K										
8				A/J	A/J	A/J							
9				C/K	C/K								
10					A,C/J,K								
11						A,B/J							
12						E/L							
13							A,B/J						
14								E/L	E/L				
15								E/L	E/L				
16									G/N	G/N			
17									F/M	F/M			
18										A,B/J	A,B/J		
19										A,B/J	A,B/J		
20										A,B/J	A,B/J		
21												A,B,C	
22												A,B/J	
23									E/L				
24												A,B	
25													EGO
26													A,B,C
27													EGO
28													EGO
29													F,G/M,N

Labels: Scientist1, Scientist2/Technitian1, Technitian2

The *Option 1* upgrade requires by itself a period of about 13 weeks with the involvement of at least 6 scientists (physicists and engineers) and 5 technicians. The upgrade of F0 and IP flex joints in site will be time consuming.

The *Option 2* upgrade will presumably last for about 1 week more per extra FS and 1 week more for cabling, up to an estimated total period of about 17 weeks.

5.5.1 Laboratories Organization

As for the assembly of the SR also during this upgrade there will be large use of the mechanical laboratory, the Cable Lab and the cleaning facility in the central area of the EGO facility.

5.5.2 Transport and Storage

Components transportation procedure will be checked and evaluated to guarantee the standards and requirements of the VIRGO UHV system.

5.5.3 SA Interface

The MC-IB-DB upgrade is under the responsibility of the VIRGO INFN Pisa group. The eventual installation of new electronic devices (tilt-meter and piezo-actuators) requires the interface with the local electronics. New cables will be connected along the filter chain and this activity will also be interfaced by the suspension system team.

5.6 Summary of Upgrade Costs

The general costs for each of the short SAs upgrade options are listed in the following Table 5.6.a and Table 5.6.b.

Table 5.6.a: Summary of Costs (k€):

OPTION 1: add only one St. Filter to each MC, IB and DB tower

ITEM	**MC**	**IB**	**DB**	**Cost (k€)**
SAs MECHANICS				
FS prod. and assembly	9.5	9.5	9.5	**28.5**
FS Filter Fish. Rod step. motor	1.5	1.5	1.5	**4.5**
F0 and FS Blades	8.3	8.3	8.3	**24.9**
F0 and FS Antisprings	5.5	5.5	5.5	**16.5**
IP flex joints	2.1	2.1	2.1	**6.3**
Suspension wire	6.1	6.1	6.1	**18.3**
Cabling	15	15	15	**45**
IP Piezo-actuators (if effective)	6	6	6	**18**
IP tilt-meter (if effective)	12	12	12	**36**
Accessories and Tools	6	6	6	**15**
Sub-Total (k€) (without IVA)	**72**	**72**	**72**	**216**
SAs SUSPENSION ELECTRONICS				
Sub-Total (k€) (without IVA) **(see AdV Susp. Electr. Plan)**	**100**	**100**	**100**	**300**
Total (k€) (without IVA)				**516**

Table 5.6.b: Summary of Costs (k€):

OPTION 2: one FS in MC and (1+N) FS in IB and DB towers

MECHANICS

ITEM	MC	IB	DB	Tot (k€) N=1	Tot (k€) N=2	Tot (k€) N=3
FS prod. and assembly	9.5	9.5+(9.5xN)	9.5+(9.5xN)	47,5	66,5	85,5
FS Fish. Rod step. motor	1.5	1.5+(1.5xN)	1.5+(1.5xN)	7,5	10,5	13,5
F0 and FS Blades	8.3	8.3+(3xN)	8.3+(3xN)	30,9	36,9	42,9
F0 and FS Antisprings	5.5	5.5+(2.5xN)	5.5+(2.5xN)	21,5	26,5	31,5
IP legs	-	13	13	26	26	26
IP flex joints	2.1	2.1	2.1	6,3	6,3	6,3
Safety Frame	-	14	14	28	28	28
Suspension wire	6.1	6.1+(3xN)	6.1+(3xN)	24,3	30,3	36,3
Cabling	15	40	40	95	95	95
IP Piezos (if effective)	6	6	6	18	18	18
IP tilt-meter (if effective)	12	12	12	36	36	36
Accessories and Tools	6	6	6	18	18	18
Sub-Total (k€) (without IVA)	72	143,5	143,5	359		
	72	163	163		398	
	72	182,5	182,5			437
SUSPENSION ELECTRONICS						
Sub-Total (k€) (without IVA) **(see AdV Susp. Electr.Plan)**	100	100	100	300	300	300
Total (k€) (without IVA)				659	698	737

5.7 Figures

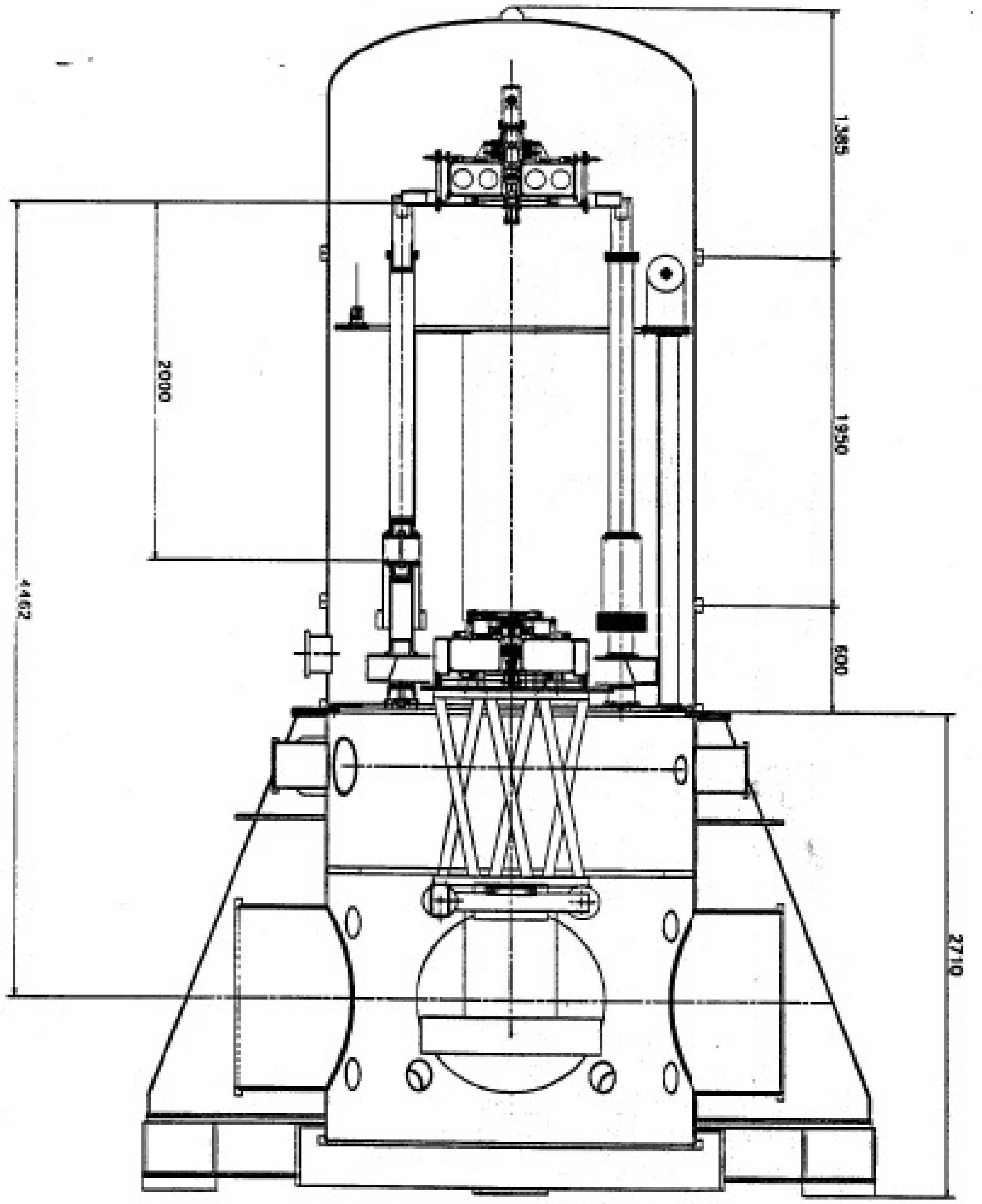


Figure 5. 1

Schematic drawing of a short SA tower. Apart from the detail of the payload the SA of IB, DB and MC are the same: composed by one pendulum stage.