VIR-PLA-DIR-4700-109
Monolithic suspension
Work package for Virgo+

1. Objectives of the project

The final objective of this project is the realization of a monolithic fused silica (FS) suspension for the four main Virgo mirrors. The idea is to realize a four fibres suspension for new Suprasil SV 311 mirrors, having the current Virgo size and flat lateral sides. The fibres should be attached to the mirrors through their welding to an intermediate component (the so-called ears) silicate bonded to the lateral flats of the test masses. The design of the current marionette should be modified to accommodate the clamping system of the fused silica fibres. The reference mass design should be left as similar as possible to the current one, but the material must be dielectric in order to eliminate the eddy current problem. The geometry of the fibers should be optimised in order to minimize the angular-to-translation couplings thus simplifying the control issues.

The realization of this final goal passes through few intermediate steps:

- the realization of a “static” prototype, made of a dummy filter 7 (it could be just the driving coils), a marionette, a four FS fibres suspension, a test mass (blank) and a reference mass
- the realization of Virgo like system aimed to characterize the mechanical response and to test the control strategy and the fibre robustness;
- the definition and the test of the assembling procedures for this suspension in the full respect of the infrastructure and cleaning constrains
- The realization of the four final suspensions.

Deliverables

Deliverable 1 - Production in situ of the FS fibres
Production at the EGO/Virgo site of the FS fibres.

Deliverable 2 - Dummy payload
A dummy payload attached to a rigid frame that mimic the filter 7 role. This must demonstrate the possibility to realize and test a fused silica monolithic suspension with a 21kg Virgo mirror

Deliverable 3 Control of the payload
Understanding of the control issues of a fused silica payload and perform speficic robustness tests.

Deliverable 4 - Definition of the production procedures
Definition of the production, assembling and transport procedures that respects the constraints due to the Virgo requirements.

Deliverable 5 - Virgo+ Payloads
The final deliverables of the projects are four fused silica monolithic payloads for the Virgo main cavities mirrors. The definition of payload is:

- Equipped mirror (with magnets, ears and markers)
- Suspension fibres
- Marionette
- Reference mass

Tasks composing the project

The project is composed by 4 tasks; the first two are prototyping and test of a FS monolithic suspension, the third consists in the definition of the production procedures and the fourth one consists in the production of the components for Virgo+ (and assembly).

1.1. Task #1: Realization of a static payload

This task is devoted to the realization of a complete dummy payload. Since many attempts are foreseen before obtaining the correct geometry, few intermediate steps, adopting a dummy test mass, are foreseen.

1.1.1. Sub-Task #1.1 Fibre production

The fist task is the set-up of the FS fibres production facility (or facilities). The Perugia H2-O2 flames machine is waiting for the completion of the hosting lab and the furniture (?), by EGO, of the O2-H2 generator, while the Glasgow CO2 laser machine will be delivered in April 2006. The production of a set of 70 cm long fibres by these machine will be considered as the deliverable of this sub-task activity.

1.1.2. Sub-Task #1.3 Upper clamp design

Design of a clamping system for the fibres in the marionette. The clamp should permit the welding of the fiber and the clamping to the marionette. A possible design is reported in Figure 0-1.

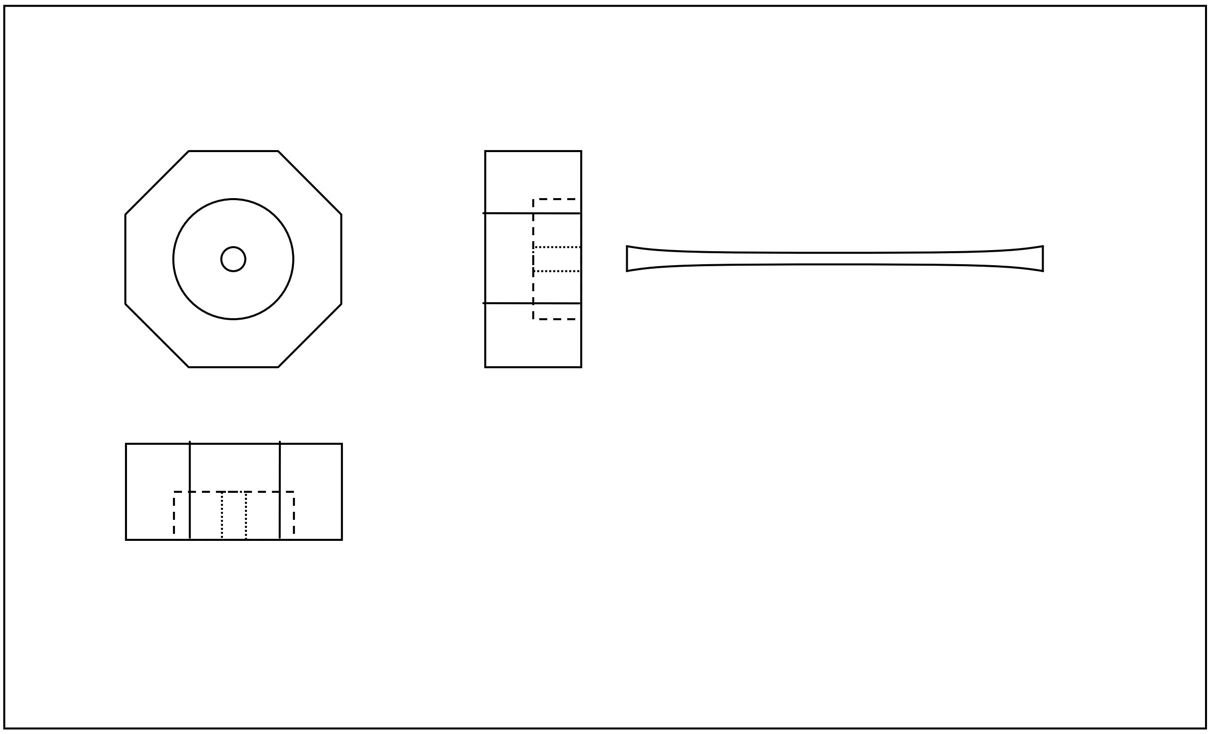

Figure 0-1 Marionette-Fibre clamping system

1.1.3. Sub-Task #1.3 Lower clamping system

The correct sizing of the ears is a crucial issue. Many experimental test must be performed. For this reason, since many test masses cannot be used, an intermediate step should be to silicate bond the ears under test to a pair of rectangular shaped FS inserts.

1.1.4. Sub-Task #1.4 Suspension of a dummy suspended test mass

The fist part of this task is the suspension of a dummy test mass, realized by an hollow aluminium disk having the same mass of a Virgo mirror, suspended through four fibres welded to two FS inserts in the disk.

The deliverable of this sub-task is the design of a suspension system statically compliant with the requirements. A possible setup is visible in Figure 0-2.

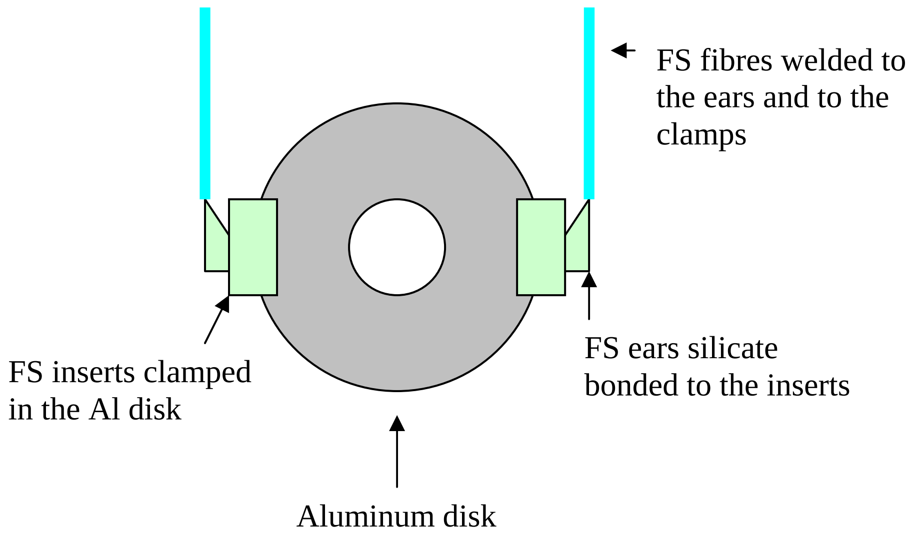

Figure 0-2 Hollow-Cylinder dummy test mass

1.1.5. Sub-Task #1.5 Realization of a steel marionette

This task requires the design of a new marionette where the free end of the monolithic fibers suspending the mirror can be clamped. While the usual requirements for cleanliness, vacuum compatibility, mechanical precision and magnetic and electrical properties apply, in this new marionette the clamping area must be designed in such a way to allow both a lossless connection of the fiber and to avoid the risk of fiber rupture. Moreover, in the current payload design, the clamping plane must lay on the horizontal plane passing through the center of mass of the marionette, to minimize the coupling between different degrees of freedom. This requirement is more difficult to meet for a monolithic suspension because usually in this case the clamping section does not coincide with the bending section, with a consequent complication in the suspension mechanics. The design of the coupling between marionetta and fiber will also influence the assembly procedure of the payload and must be finalized when the full mounting sequence will be established. Finally, the new design will require a revision of the clamping set up for the reference mass, and eventually of the balancing motor. A complete FEM analysis of the new marionetta, together with a measurement of resonance modes will be performed.

1.1.6. Sub-Task #1.6 Realization of a dielectric reference mass

While the current Aluminum Reaction Mass is subject to eddy current effects which could be visible at the edge of Virgo nominal sensitivity, for the monolithic payload a new dielectric RM must be designed, where eddy current effects are completely negligible. Such a new design must preserve the overall characteristics of current Reaction Masses, while avoiding any conductive material in the proximity of the mirror magnets.
Among other characteristics, it will be necessary to consider accurately the mechanical strength of the new insulating material, which must allow to use the Reaction Mass also as a inner safety structure for the mirror.
The issue of the design of an external safety structure for the payload, to be implemented into the tower lower vacuum chamber must also be considered.

1.1.7. Sub-Task #1.7 Realization of a full payload with a real fused silica mirror

All the components produced in the other subtasks must be assembled together to realize a full size payload, suitable for the control tests described in the next task. Obviously this assembling must be performed in the control frame, but without the stringent cleanliness requirements that will be studied in the task #3.

1.2. Task #2: Mechanical response characterization and control test

1.2.1. Task #2.1 Setting up the position sensing apparatus

This task requires to set up a sensing device based on a camera and a PSD readout similar to the actual Virgo one. The optical lever will lay on the horizontal plane (on an optical bench) and the incidence angle will be the same as Virgo (35º). The possibility on using different solutions for the markers will be explored (coated markers on the mirror, recoil mass sensing).
Required hardware:

- VME crate + VSB bus;
- camera + VME board;
- 1 timing board;
- 1 workstation;
- 3 PSD + 3 amplifiers;
- 3 micrometric slides (4 d.o.f. each, motorised?) for PSD positioning;
- 2 lasers for optical lever;
- optical components (lenses, cube BS…);
- optical bench (2x1 m);

1.2.2. Task #2.2 Setting up the digital control chain

This task requires to setup all the necessary to control the payload. The marionette will be controlled through coils rigidly connected to the external frame, with the same geometry of those of the actual F7. Required hardware:

- 2 ADC;
- 1 RIO board;
- DSP;
- 2 DAC;
- 5 coil driver boards (10 channels);
- NIM crate
- 1 rack

1.2.3. Task #2.3 Error signal calibration and diagonalization

This task requires to:

- tune the optical setup to optimize the preliminary decoupling of the different d.o.f.;
- check the signals through the local DAQ and operate further software diagonalization to produce the usual z, tx, ty, x error signals.

1.2.4. Task #2.4 Mechanical TF measurements

The actuation and sensing systems will be used to measure the mechanical TF matrix and to study the couplings and how they depend on the fibers set used.

1.2.5. Task #2.5 Payload control

The local control loops will be closed using a strategy as much as possible (TF will be different) similar to the Virgo one. Implementation of frequency dependent driving matrix will be considered in order to compensate for nasty couplings.

1.2.6. Task #2.6 Monolithic payload robustness tests

The marionette will be shaken in order to test the fiber robustness with respect to accidental control instabilities. The system will not be able to reproduce exactly the accident that can occur to the Virgo SA when inertial damping becomes unstable. We remark that an effort to improve the performance of the so called “Guardian” should be made in parallel to reduce at a minimum the risk of large SA shaking. This task will help to define the design of mechanical stoppers to limit the movements of the mirror.

1.3.Task #3: Definition and test of the mounting procedures

The aim of this task is the definition of the assembling operations that must respect the cleanliness requirements

1.3.1. Task #3.1 Mirror preparation procedures

Realization of a new design for magnet glueing. Direct painting of the markers on the mirror (?). Spacers bonding before coating

1.3.2. Task #3.2 Payload assembling and transportation procedures

Definition of the procedures for payload assembly. Realization of a test prototype in clean room. Test of the transport and hanging procedures.

1.4. Task #4: Production of the four payload components

1.4.1. Task 4.1 Preparation of the four mirrors

Currently three Susprasil substrates are available. They are used as spare of the current Virgo mirrors, but can be coated and used for Virgo+ (one of them must be used as PR because it have a small defect that can reduce the Q). Obviously 3 other mirrors must be produced (2+1 spare). The four mirror for Virgo+ must be coated with the best coating available (in terms of optical and mechanical performances) in such a may to reduce the dissipation due to the mechanical losses in the Tantalum. The possibility to paint the markers (if needed) directly on the coating must be investigated.

1.4.2. Task 4.2 Preparation of the four marionette

Defininition of the procedure for marionetta series production: construction, material tests, assembly, mechanical and electrical tests before coupling with the monolithic suspension and reaction mass, storage space and structure.

1.4.3. Task 4.3 Preparation of the four reference masses

Defininition of the procedure for RM series production:
construction, assembly, mechanical and electrical tests to be performed before coupling with marionetta and mirror, storage space and structure

1.4.4. Task 4.4 Assembling of the four payloads

The four payload will be assembled as soon as we are ready to mount them (no storing seems possible).

1.5. Infrastructures

The production of fused silica payloads needs a strong infrastructure effort. The preparation of the test payload (Tasks #1 and 2) needs:

- A fiber production laboratory; this is already available and must be completed soon. A clean air laminar flux has been already requested on the top of the production machine
- An experimental area where to assemble and test the payload. We need a crane and enough room where to put a rack with the electronics.

For the tasks 3 and 4 we need a clean environment similar or better than the current one (if the production is performed outside the central building). We need:

- a class 10 environment (a least 2x2 m^2 in class 10 embedded in a 6x5 m^2 class 100 room)
- A class 1 bench (like the current one) in a class 100 environment
- A Ultra-pure water production facility
- A washing machine connected with the clean room
- Mirror transportation facility

2. Implementation Plan

Table 4a – Implementation Plan

	2005	**2006**				**2007**				**2008**		
Tasks and Deliverables	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Tasks												
Sub-Task #1.1 Fibre production												
Sub-Task #1.3 Upper clamp design												
Sub-Task #1.3 Lower clamping system												
Sub-Task #1.4 Suspension of a dummy suspended test mass												
Sub-Task #1.5 Realization of a steel marionette												
Sub-Task #1.6 Realization of a dielectric reference mass												
Sub-Task #1.7 Realization of a full payload with a real fused silica mirror												
Task #2: Mechanical response characterization and control test												
Task #2.1 Setting up the position sensing apparatus												
Task #2.2 Setting up the digital control chain												
Task #2.3 Error signal calibration and diagonalization												
Task #2.4 Mechanical TF measurements												

Task #2.5 Payload control												
Task #2.6 Monolithic payload robustness tests												
Task #3.1 Mirror preparation procedures												
Task #3.2 Payload assembling and transportation procedures												
Task 4.1 Preparation of the four mirrors: Production of the three missing mirrors and coating of all the mirrors												
Task 4.1 Preparation of the four mirrors: Assembling of the mirrors												
Task 4.2 Preparation of the four marionette												
Task 4.3 Preparation of the four reference masses												
Task 4.4 Assembling of the four payloads												
Deliverables												
Deliverable 1 - Production in situ of the FS fibres												
Deliverable 2 - Dummy payload												
Deliverable 3 Control of the payload												
Deliverable 4 - Definition of the production procedures												
Deliverable 5 - Virgo+ Payloads												

3. Participants

3.1.List of participants

Table 5a – List of participants

#	Institute	Short Name	Staff and/or PhD students expected to work the project and corresponding task number(s)
1	EGO	EGO	TBD
2	INFN Firenze	FIR	TBD
3	INFN Perugia	PER	TBD
4	INFN Roma	ROM	TBD
5	CNRS/LMA	LMA	TBD

3.2. Task and deliverables vs Participants

Table 5c – Tasks & Deliverables vs Participants

Participant #	**#1**	**#2**	**#3**	**#4**	**#5**
	EGO	**FIR**	**PER**	**ROM**	**LMA**
Tasks					
Sub-Task #1.1 Fibre production			X		
Sub-Task #1.3 Upper clamp design			X		
Sub-Task #1.3 Lower clamping system			X		
Sub-Task #1.4 Suspension of a dummy suspended test mass			X		
Sub-Task #1.5 Realization of a steel marionette				X	
Sub-Task #1.6 Realization of a dielectric reference mass				X	
Sub-Task #1.7 Realization of a full payload with a real fused silica mirror	X		X	X	
Task #2: Mechanical response characterization and control test		X		X	
Task #2.1 Setting up the position sensing apparatus		X		X	
Task #2.2 Setting up the digital control chain		X		X	
Task #2.3 Error signal calibration and diagonalization		X		X	
Task #2.4 Mechanical TF measurements		X		X	
Task #2.5 Payload control		X		X	
Task #2.6 Monolithic payload robustness tests		X	X	X	
Task #3.1 Mirror preparation procedures			X		
Task #3.2 Payload assembling and transportation procedures	X		X	X	
Task 4.1 Preparation of the four mirrors			X		X
Task 4.2 Preparation of the four marionette				X	
Task 4.3 Preparation of the four reference masses				X	
<u>Deliverables</u>					
Deliverable 1 - Production in situ of the FS fibres			X		
Deliverable 2 - Dummy payload			X	X	
Deliverable 3 Control of the payload		X		X	
Deliverable 4 - Definition of the production procedures	X		X	X	X
Deliverable 5 - Virgo+ Payloads	X	X	X	X	X

Budget

The foreseen budget is reported in the following table (Costs in k€). It must be noted that in this table aren't reported the costs for infrastructures.

Table 6 – Budget Plan

	2005	**2006**	**2007**
Task #1			
Aluminun Disk	1	0	0
Fused Silica rods	1	2	2
Marionette FS clamps	0	10	0
FS inserts	0	4	0
FS ears	0	12	0
Mechanical tools	0	4	0
Marionette(1)	0	20	0
Reference mass (1 - costs TBV)	0	40	0
Mounting frame	0	30	0
Safety frame (1)	0	5	0
Chemical products for Silicate bonding	0	1	0
Ionizer gun	0	1	0
	0	0	0
Task #2	**0**	0	**0**
VME crate + VSB bus	0	3.5	0
Camera+VME board *(availability TBV)*	0	0	0
Timing board	0	0	0
Workstation	0	1	0
3 PSD + amplifiers	0	1	0
3 micrometric slides	0	5	0
2 lasers for optical lever	0	4	0
Optical components	0	1	0
Optical bench	0	5	0
2 ADC *(availability TBV)*	0	0	0
RIO board	0	5	0
DSP *(availability TBV)*	0	0	0
2 DAC *(availability TBV)*	0	0	0
5 coil driver boards	0	2.5	0
NIM crate	0	2.5	0
Cables and connectors	0	1	0
Rack	0	1.5	0
Task #3	**0**	0	**0**
Task #4	**0**	0	**0**
Fused Silica rods	0	0	2
Marionette FS clamps	0	0	10
FS ears	0	0	10
Mechanical tools	0	0	4
Marionette(4)	0	0	80
Reference mass (4 - costs TBV)	0	0	160
Safety frame (4)	0	0	20
Chemical products for Silicate bonding	0	0	1
Mirrors (3)	225	60	0
TOTAL	227	222	289

4. References