VIRGO	T W R 9 5 - 4
september,14, 1995 The LAPP tower group	**The VIRGO Tower specifications and construction. Contribution to the FD.**

3300 - TOWERS

3300.1. Introduction.

The VIRGO interferometer is decoupled from environmental noise being suspended in ultra high vacuum. The suspension of its components uncouples them from seismic noise and the ultra high vacuum provides the uncoupling from acoustic and light propagation noise.

The laser beam produced on the input bench propagates through a cross shaped vacuum tank. Fabry Perot cavities are implemented on its long arms. Laser beam production and signal detection are implemented on its short arms **[fig. 1, 2]**.

Multistage suspensions are implemented in towers of various heights , depending on the locally requested seismic noise attenuation. The tower basement houses the suspended payload. It interconnects the interferometer arms, provides optical access for the component alignment and allows for the human access needed by the payload installation.

Seven towers are interlinked in the central building, three towers are linked at a distance from the central building **[fig. 2]**. Towers are named according to their payload functionality: input and detection, beam splitter, north / west input, power and signal recycling in the central building, north / west end and mode-cleaner in dedicated buildings.

In the following, the construction design of the interferometer vacuum tank is reviewed, to the exclusion of the linking with the End and Mode cleaner towers. The vacuum tank assembly sequences are defined and a scenario for the clean installation of the interferometer components is described. The implementation of the services requested by the tower operation is sketched.

3300.2. The specifications.

Experimental requirements dictated by the aimed physics and relevant technical choices made for the interferometer components define the technical constraints on the vacuum tank design.

3300.2.1.Experimental requirements

3300.2.1.1.Metrology.

- The respective locations of the towers in the central building are determined by the details of the selected locking scheme. Provision has been made to allow for an asymmetry of 160 cm between the two arms, allowing the displacement of the two input towers within +/- 40cm. The power recycling tower can also be translated within +60 and -100cm. The beam height is fixed at 1100mm relative to the building ground floor.

The final positioning of the interferometer components is obtained in several steps:

i) - Lower towers are aligned in the laboratory system using the lower tower square flange already taken as a reference for the realization at factory.**[fig. 5].** They are positioned within a few mm in the laboratory reference system. The horizontality of the flange is defined to .1mrad.

ii) - As will be seen below, a tower is build with two vacuum compartments: one for the suspension, another for the mirror. They communicate through a small conductance allowing for the suspension wire feedthrough. The position of this small conductance, which defines in fact the first order mirror position, is smoothly tuned after lower tower installation and before suspension implementation.

iii) - Each suspension allows for the positioning of its optical component up to a fraction of mm or mrad.

iv) - The ultimate alignment is permanently updated with the marionetta and reference masses which steer the interferometer components to a fraction of a wavelength.

The effective local position of a component is determined from outside the vacuum tank measuring the deflection of a well known additional laser beam. The implementation of these measurement requires the realization of optical ports pointing to the optical component.[see table II].

3300.2.1.2.Decoupling from environmental noise.

3300.2.1.2.1.- Seismic noise

One of the most remarkable and unique feature of VIRGO will be its high sensitivity for gravitational waves in a frequency band starting as low as 10 Hz. This feature is achieved with the multi-stage suspensions, also called superattenuators. They reduce the seismic noise on the interferometer test mass in all the six degrees of freedom. As a consequence, the resonance frequency of the mechanical structure supporting the suspension has been pushed above 15 Hz, i.e. well above the superattenuator 3 Hz cutoff frequency.

3300.2.1.2.2.- Light losses

The light scattered off by the vacuum chamber walls or by the mirrors themselves may be an important source of background, due to possible recombination of scattered photons with the main beam. Absorbing baffles are thus foreseen inside the long arms and in the neighborhood of optical components.

The specifications on Fabry Perot optics limit diffusion losses on the coatings at the ppm level. To keep this performance, losses due to dust deposits have to be mastered at a comparable level. This consideration limits the mirror obscurancy factor (i.e. the ratio to the active surface, of the surface covered by dust particles) at the ppm level for a mirror set in operation.

Stability requirements on the index of refraction of the beam propagating compartment and cleanness of the optics impose strong specifications on the vacuum chamber outgassing rates. The total outgassing of the central building vacuum chamber must be low enough to be compatible with the vacuum performances expected in the long arms. Partial pressures as low as 10^{-7}mbar for H_2, 10^{-8}mbar for other gases, and 10^{-14}mbar for hydrocarbons are required in the laser beam compartment. Such partial pressures can only be reached respecting strict cleaning procedures followed by a 150ºC baking. Requirements are less stringent in the input, detection and Mode Cleaner tube and tanks, where partial pressures near 10^{-6} mbar are admissible.

3300.2.1.2.3.- Acoustic noise.

The vacuum specifications established for the stability of the index of refraction along the optical path provide the necessary attenuation of the acoustic environmental noise.

3300.2.1.3. Implementation of a calibration system.

The global operation of the interferometer is monitored with an independent calibration system. It is performed using the radiation pressure produced by an additional laser beam to move a given mirror according to a well known displacement scheme. The implementation of such a system requires a set of dedicated [see table II] optical ports pointing on the selected mirror.

3300.2.2. Technical requirements.

3300.2.2.1.Suspensions.;

3300.2.2.1.1. Attenuator chain functionalities.

The number of filtering stages of a suspension depends on the required seismic noise attenuation **[see table I, II].**

The suspension control requests services which have to be passed from vacuum to atmosphere: 14 hydraulic feedthroughs are required for its stiffness adjustment and as much as 268 electric feedthroughs are necessary to pass its control and command wires.

All these components build up a yet unknown outgassing rate.

3300.2.2.1.2. Inner structure.

The inner structure **[fig 4]** supports the multistage attenuator chain. It is composed with three vertical U shaped pillars, 300mm wide with 110mm wings, about 6m in height. Pillars are welded at 120° to upper and lower rings. It is mounted with a pillar in the beam direction. Motors which move the attenuator chain as a whole are fit on the top of the structure. Sockets, mounted on the pillars provide a rest position for the different filters. Services, as cables and pipes run in the U shape from the top of the structure to a 500mm high technical ring. The technical ring is fit with three ports, 250mm in diameter, at 120° from each other.

Once the inner structure supports the resting attenuator chain, it is submitted every meter to a 600mm*150kg torque. Its U shaped pillars stands these forces with deformations in the .5 mm range. A more detailed modelling with the SYSTUS code produced distributions of z deformations, strains and buckling. Loaded with the filter, the structure collapse factor is above 100. In the absence of loading, its fundamental vibration mode is at 8 Hz, with a mechanical connection to the upper ring, this mode is pushed to 23 Hz. On the other side, the fundamental mode of the rings is lowered from 26 to 23 Hz.

3300.2.2.2.Payloads.

The payload is the interferometer optical element associated to its associated steering devices. The optical element is a mirror, an input or a detection bench . The 1997 optical elements being temporary, they will be adapted to their final steering devices using adhoc interfaces.

Table I : Tower specificities

	Tower displ.	Filter	Ring	Separat. roof	Optics	Ref. mass	Marion.
Input	fixed	3	1	no	100kg Ø1500	no	
Mode cleaner	±200	3	1	no		no	
Power recycling	+60 -100	7	3	yes	750g Ø120x30	750g	
Beam splitter	fixed	7	3	yes	>3.5kg Ø230x>50	>3.5kg	80kg
Input north	±40	7	3	yes	21 to 42kg Ø350x100	21 to 42kg	80kg
Input west	±40	7	3	yes	21 to 42kg Ø350x100	21 to 42kg	80kg
End north	fixed	7	3	yes	21 to 42kg Ø350x100	21 to 42kg	80kg
End west	fixed	7	3	yes	21 to 42kg Ø350x100	21 to 42kg	80kg
signal recycling	fixed	0	0	no	no payload	no	no
Detection	fixed	3	1	no	<400kg Ø1900	no	

3300.2.2.2.1.The "mirror" payloads.

The mirror hangs on a marionetta which allows for its rotations around the two axes perpendicular to the beam, and for its translations along the beam line. The acting forces are generated by the current circulating through coils fixed to the last suspension stage and surrounding magnets fixed to the marionetta. A motor allows for the balancing of the marionetta. Six wires are necessary for its control.

The reference mass a more sensitive control on the mirror longitudinal position. It is also suspended to the marionetta. It has the same mass and center of gravity as the mirror. Its cylindrical shape, which surrounds the mirror, provides also protection against dust deposits. The longitudinal correction is generated by either magnetic or electrostatic forces acting between reference mass and mirror. The necessary power is fed with 8 wires running down the suspension.

The mirror payloads being in the beam line, they follow the beam tube specifications: low outgassing rate and a good mechanical behavior at 150ºC.

To respect the above mentioned specifications on optics cleanness, payloads are assembled in a classified laboratory. Accordingly, their set up in the beam line is performed in lower towers fed with filtered air

3300.2.2.2.2. The input and detection payloads.

These payloads are benches supporting the many components necessary for the the laser beam implementation or for the signal detection. These large diameter and heavy benches [table I] are suspended to dedicated marionettas.

In their first versions, these benches may present a rather high outgassing rate. Furthermore, it could be interesting to access these benches while the rest of the interferometer is under high vacuum. These towers will thus be isolated by optical windows inserted on their links.

3300.2.3. Contingencies and flexibilities.

In the actual working hypothesis, the beam tube diameter (Ø1200mm) has been chosen to accomodate a possible second interferometer. This is not the case for the tower linking diameter which has been fixed to accomodate only one interferometer.

To simplify the design and to provide some freedom at assembly, the lower tower beam linking elements will be standardized and symetrized.

For setting up and maintenance any tower has to be accessible independently of the pressure status of its neighbouring towers.

3300.2.4. Summary and design guidelines

The above described experimental requirements and technical choices define the main characteristics of the vacuum tank design. The different outgassing rates expected from the suspensions, optical paylaods, input and detection benches dictate the tank vacuum compartment structure. The cleanness requirements on optics dictate the implementation of classified clean infrastructures inside and directly connected to the vacuum tank. The suspension weight and dimension defines the mechanical structure of its lower tower basement.

3300.3.The vacuum tank design.

Having made a choice for the raw material, one defines the vacuum tank compartment arrangement. This defines the lower tower as the basic building module whose mechanical structure is defined according to a modelisation with the SYSTUS code. The lower tower basement and its upper tower compartment are described. The functionalities of the different towers are detailed in table I and II. The different lower tower vacuum compartments are linked together to form the beam vacuum chamber which needs to be baked to reach its specified outgassing rate. Finally, the tower ground anchoring is described.

3300.3.1. Raw material and surface treatment.

The vacuum specifications defined above and the size of the vacuum chamber favour stainless steel for the choice of the chamber raw material . The 300 series of austenitic steels is the most frequently used in vacuum and cryogenic work because it is corrosion resistant, easy to work and non magnetic. The US 304L or NF Z2CN18-10 variety has been chosen.

Given the ultimate H_2 outgassing rate achieved in the beam tube, it is worthwile to reconsider this figure for the lower tower [**Ref.1**]. As a consequence, the 450ºC air firing of the tank raw material has to be seriously considered if it can be achieved with limited cost and planning perturbations.

The inner surface state of the tank is processed to limit outgassing rate and dust adhesion forces. By abrasion and electropolishing an RA smaller than 1.6µ was realized.

Cleanness specifications impose to fear hydrocarbons and dust particles . Hydrocarbons and hydrogen are removed by a several days airfiring at 400ºC of the vacuum chamber. After processing, the chamber is sealed and stays sealed until connection with its suspension. All vacuum components are conditioned at high temperature before being assembled in an oil free ambience. Dust particles are only tracked after reception of the complete vacuum tank just before payload installation.

3300.3.2. Vacuum tank compartment structure.

The vacuum tank allows for the free propagation of the laser beam and provides the basement of 10m high suspensions.

The highly different outgassing rates expected from suspensions, mirror paylaods, input and detection benches dictate its compartimentation. The beam compartment containing the payload is thus isolated by a separating roof from its corresponding suspension compartment. Input and detection benches are isolated from the rest of the beam propagation compartment with appropriate optical windows. As the bench and suspension outgassings are expected to be comparable, they are confined in single compartments. Each of these compartment can thus be pumped for its own.

3300.3.3. Tower mechanical structure.

The vacuum specifications require the construction of a tank with 15mm wall thickness fit with metallic sealings in its UHV (baked) compartment.

Taken as a linear tube of finite length (12m), diameter (2m) and thickness (1cm), the tower fundamental frequency is at 15 Hz. If this tube is rigidified every 2 meters with stiffening ribs, one computes a collapse factor of 9.

A more elaborate tower modelling within the framework of the SYSTUS code produced distributions of static deformations and stresses under its various loading conditions (tank under its proper weight at normal temperature, tank under vacuum at normal temperature, tank under vacuum at 150ºC). The model taken for baking assumes a uniform heating between the protection plate and the top of the square pedestal. An additional oven is used to heat the lower cover. Results of the modelling have been verified on the lower tower prototype **[ref 4].**

The details of the lower tower geometry are optimized to rise the tower fundamental frequency to 16Hz **[fig 3]**. A collapse factor of 12.8 during baking under vacuum was obtained.

3300.4.The Vacuum tank realization.

The interferometer vacuum tank is realized with lower tower modules which allow for the linking of the interferometer arms and for the elevation of the suspension.The upper vacuum compartment is a modular cylinder assembled around the suspension. A separating roof implemented on the lower tower isolates it from the beam vacuum compartment.

3300.4.1. The lower tower.

To simplify the structure of the upper compartment, the lower tower **[fig 5, 6]** is implemented with the separating roof and the upper tower pumping ports.

It is a cylindrical tank (2 m in diameter, 15 mm in thickness, **2.74 m** in height) welded to an upper square flange (2.40mx2.40mx60cm) which is taken as a the reference for the tank geometry. This flange has been shaped to fix the frequency of the fundamental vibration mode of the tower. Once it is fit with its various access ports, the tank is welded to a very massive 4mx4m square pedestal which rests on ground with 4 or 6 sockets (400x400x100) . The pedestal, the tank, and the upper square flange are bound with 4 vertical stiffening ribs. A 20 mm thick protection plate is welded around the tank at z = 1000.

The tank is connected to the beam propagation compartment with large lateral beam flanges. It is fit with optical ports to allow for alignment and calibration. It is implemented with access for pumping, clean air supply, payload introduction and installation. Technical access are available for cable and service feedthroughs.

3300.4.1.1.Lower compartment functionalities.

Many access ports have to be implemented on the lower compartment. Lower compartment sealings are made with metal gaskets to allow for baking and Ultra High Vacuum. Valve gates sealing is made with Viton gaskets for normally open gates, metal for normally closed gates. Valve feedthroughs are realized with bellows.

3300.4.1.1.1. Lateral beam flanges.

Following the above mentioned standardization and symetrization criteria, each lower tower is produced with 4 large orthogonal Ø1000 apertures. Towers connected to the beam tube have one Ø1200 flange. The prototype lower tower is used for the Mode Cleaner.

The necessary adaptations to the effective linking diameter is implemented on the corresponding windows as shown on table II where the different cover types are specified by their external diameter and their axed access flange. Additionnal flanges are also specified when requested.

Table II: Lower tower lateral tapes

	north	south	east	west
injection	DN1000.DN250 + 2 DN150	DN1000 + 3 DN 200	DN1000.DN100 + 2 DN150	DN1000.DN200 + 2DN150
Mode cleaner	DN1200.DN200	DN1000.DN200	DN1000.DN200 + 2 DN150	DN1000.DN100 + 2 DN150
Power recycling	DN1000.DN400	DN1000.DN250	DN1000	DN1000
Beam splitter	DN1000.DN400	DN1000.DN250	DN1000.DN250	DN1000.DN400
Input north	DN1200.DN150	DN1000.DN250	DN1000	DN1000
Input west	DN1000	DN1000	DN1000.DN250	DN1200.DN150
end north	DN1000.DN**	DN1200	DN1000	DN1000
endwest	DN1000	DN1000	DN1200	DN1000.DN**
Signal recycling	DN1000	DN1000	DN1000.DN400	DN1000.DN400
Detection	DN1000	DN1000.2DN63	DN1000.2DN63	DN1000.DN250

3300.4.1.1.2. Access for payload installation.

The bottom of the lower tower compartment is closed with a DN 2000 cover to allow the introduction of the input and detection benches. A central DN 1000 is implemented on this cover to allow for the "mirror" payload introduction. Operators use the same access to enter the tank. The cover is stiffened with four welded horizontal ribs.It is 195 mm high and weights 1000 kg. A DN 100 CF port is implemented for technical access.

3300.4.1.1.3.Technical access.

Today, there is no explicit demand for a lower compartment technical access. As mentioned above, there is a possibility on the lower cover.

3300.4.1.1.4. Lower tower/ gallery linkage.

This linkage is airtight to allow a small over-pressure in the tower access gallery in order to preserve its cleanness with respect to the hall. It stands the high temperature induced by baking at 150ºC. It is realized with a stainless steel sheeting shape. A silicon skirt is fit between the tank and the stainless steel sheeting. [**fig. 7**]

3300.4.1.1.5. Optical ports

12 DN 160 CF optical ports pointing to the optics are implemented for alignment and calibration purpose. Injection, detection, and mode cleaner have dedicated optical windows on their lateral flanges. **[fig 8a,b]**

3300.4.1.1.6. Clean air supply, venting, roughing and intermediate pumping.

Each lower compartment is fed with a 1200 m^3 /h filtered air flow. A Ø200 mm pipe leads the air from its filtering station to a DN 200 Y shaped distribution tube entering the upper part of the lower compartment just below the protection plate.**[fig 9]**

A bypass pipe connected to the upper compartment and to the Y shaped air feeding pipe allow for air supply, intermediate pumping, venting and roughing. As the clean air supply is only required for payload installation, the time taken for its implementation is not critical: it can be connected and disconnected with adequate tubes and plugs.

Roughing and venting are performed with a Ø40 access fit on the bypass, outside the oven. Depending on the status of the Ø200 all metall and Ø150 Viton gate valves, venting can be done via the lower compartment and roughing on both compartments. Intermediate pumping, roughing and venting are connected through Viton gate valves.

The tower construction symmetry is broken by their Ø1200 tube connection flanges. Their pumping and clean air supplies have thus to be implemented to fit the service distributions in the buildings **[fig 24].** Having symmetric lateral flanges, other towers are not affected by these considerations.

3300.4.1.2. Separating roof

The differential vacuum between suspension and beam compartments is implemented with a separating roof fit with a small conductance (2l/sec) central hole allowing for the suspension wire and payload services feedthrough. **[fig 10]**

As mentioned above, coils and magnets are used on either side of the separating roof: Coils are fixed to 4 arms penetrating glass casings resting on the separating roof. These glass casings surround closely the magnets attached to the marionetta.**[fig 11]**

The final positioning of the suspension is performed once the vacuum tank has been evacuated. Provision has been made to follow these displacements with the separating roof: it can be lift by 10 mm and smoothly translated in x and y directions with appropriate mechanisms. Lifting is essential for smooth translations.

Translations can be induced either manually or remotely with actuators installed on 4 DN 300 ports implemented on the lower tower just above the protection plate, at level z =1300

[fig 12]. Translations range within +/- 25mm in both directions. Commands are outside the tank, at atmospheric pressure. The wire position with respect to the conductance hole is measured with a camera installed outside the tower.

This alignment takes place when all the lower towers are installed and before the setting up of the suspensions. Once aligned, the separating roof is sealed and the suspension installed. If necessary, the roof can be accessed through the ports fit at z = 1300: it can be unsealed and fit to the wanted position.

Input , detection , signal recycling towers, as well as the mode cleaner tower don’t need a differential vacuum. They are not fit with a separating roof.

3300.4.1.3. Upper compartment functionalities.

These functionalities are implemeted on the lower tower at z = 1300 , i.e.above the separating roof and in communication with the suspension compartment. **[fig. 12]**. Sealings are realized with metal gaskets, valves stand baking temperatures of 150ºC. Their effective locations on the different towers is shown on table III.

3300.4.1.3.1. Technical access.

One DN 250 port is available for the feedthrough of hydraulic or electric services. A DN 150 is provided for the installation of an optical port. A set of 4 DN300 flanges is fit to allow the separating roof translation.

3300.4.1.3.2.Pumping ports for the upper compartment.

Two axial DN250 ports are available for the upper compartment permanent pumping. A DN 400 port is fit to allow for an upgrade of this pumping. The best vacuum is thus produced near the separating roof. Moreover, a DN 150 port is fit to accomodate some upper tower emergency pumping using the lower compartment intermediate pumping. Finally, another DN 250 is available for the installation of a dedicated pumping line on the separating roof conductance. The upper tower vacuum instrumentation is fit either on the DN400 or on the unused DN250 upper tower pumping flange. The exact affectation of these ports is shown on table III.

Towers with a single compartment like input, detection and mode cleaner have only an upper pumping station. Tubing is the same as for other towers, the intermediate pumping unit is not connected.

3300.4.2. Upper compartment.

Its functionalities are implemented on the lower tower and on the technical ring. This compartment is now just an enveloppe build with a set of standard rings headed by a cupola.[**fig.13]**. Sealings are made with Viton gaskets.

Standard rings are 1967 mm high with a 2000 mm diameter. They have forged flanges and receive either metallic or "viton" seals. The upper ring has a special 100mm high upper flange for its linking with the inner structure. The cupola rests on the upper last ring. It is 1300mm high and weights 1000 kg. It can also be used to head directly a lower tower .

A complete tower with its technical ring, 3 rings and a cupola is 10441mm in height and 22990kg in weight.

3300.4.3. Central building vacuum tank.

In its first version, Virgo will accomodate a single interferometer. Main building towers will thus be linked accordingly. Light loss computation favor a linking with Ø400mm tubes fit wit Ø250mm valves. Diffuse light is trapped with glass baffles fit in the straight links or inside the lower tower vacuum compartment. Sealings are made with metal gaskets.

3300.4.3.1. The lateral window interfaces.

Towers linked in the central building are connected through 12 lateral flanges produced with a central DN 400 CF. The 4 towers connected to the 3km long tube are linked with flanges produced with an outer DN 1200. The 2 mode cleaner tube interface flanges have a central DN 250 /400 CF. These features are specified on **table II** for each tower.

3300.4.3.2. The detailed link structure.

A connection between two towers has to account for :

- the oven geometry,
- dilatations generated by baking at 150ºC: 6mm. for a 3m long tube.
- misalignment between towers: +/- 5mm
- mechanical tolerances on DN1000 flanges: +/- 5mm in beam direction and +/- 5mm perpendicular to the beam.
- mechanical tolerances on the links : +/- 5mm in the beam direction,
- implementation of sectioning valves, glass baffles.
- installation of a permanent or an intermediate tower (beamsplitter) pumping system,

A link is thus build up with a bellows connected to a straight section associated to a Ø250 sectioning valve. The valve is inside the oven. If necessary for pumping, a DN200 CF port is on the straight sections, in between neighbouring ovens. The bellows allows for longitudinal displacements of ± 40 mm and lateral displacements of ± 15mm. The end flange near the valve is freely rotating to allow an assembly with upright valves.

The outgassing of the equipments set up in the input and detection towers may prevent the achievement of the expected UHV performances in the beam line. To assert the 1997 interferometer beam vacuum chamber performance, these towers are linked across optical windows.

In conclusion, there are six different links in the central building **[fig 14]**. The small size and weight of their components allows for an in situ assembly.

3300.4.3.2.1. Access for permanent pumping and instrumentation

Three permanent Ti pumping stations (unit #3) are implemented on straight sections between north input-beam splitter, beam splitter-power recycling, and beam splitter-signal recycling. A measurement port DN63 is fit on each link straight section.

3300.4.3.2.2. The sectioning valves.

Assembly sealings are metallic, gate sealings are Viton and valve feedthroughs are realised with bellows.

3300.4.4. Beam compartment baking.

3300.4.4.1. Lower tower baking.

The lower tower vacuum compartment is uniformly baked at 150ºC surrounding it with an isolating structure blown with hot air. With the reduced space available in the tower vicinity it was found difficult to implement a dismountable structure as was done for the prototype oven. On the other hand, the suspension setting up needs the installation of an appropriate scaffolding which is also difficult to move around the towers. As a compromise, the scaffolding basement is taken as the supporting structure of the oven insulator. **[fig 15]**
This structure will be permanently installed. Only the insulating material and the heating elements will be moved from place to place.

The prototype oven was operated with a flow of 2000m^3/h heated on 20 KW resistors.The payload access cover, accessed from the gallery, is heated for its own with a 3KW resistor.

3300.4.2.2 upper tower thermal insulation.

The suspension components do not stand the baking temperature. The 50 mm thick rock wool insulation is stopped at the middle of to first ring. It may happen that the suspension needs a more efficient heat screening. Space is available on the upper compartment technical access for the feedthrough of some cooling liquid.

3300.4.2.3. Link baking.

Baking is performed by wrapping discrete heating elements around the links and the associated instrumentation. For a wall thickness smaller than 5 mm a 16W/dm^2 power distribution will be implemented.

3300.4.5. Lower tower ground floor anchoring

The assembled lower tower, with its 4 lateral DN 1000 covers and its cupola, weights about 16540 kg.

Any tower has to be accessed or baked independently of the pressure status of its neighbouring towers. A tower is thus screwed to ground to stand pressure differences and free with respect to ground to allow for baking.

In our configuration, end towers stand the highest pressure difference. Their situation is taken as a reference for computations.

Input and end towers stand 11310 DaN induced by the beam tube vacuum. They are screwed to ground and bear on metallic plates anchored on the beam tube side**[fig. 16]**. They are unscrewed for baking. When the tube is under vacuum, an input tower expands towards the beamsplitter tower. When it is at atmospheric pressure, i.e. the 1997 situation, the metallic plate is removed to allow for dilatations towards the tube, bearing on spacing rods inserted between input and beamsplitter tower pedestals.

Other towers are also unscrewed for baking. Towers sandwiched between two neighbours at a different pressure are balanced with spacing rods introduced between processed and evacuated towers.

3300.5.Vacuum tank clean access.

The payload is installed by an operator which enters the lower tower vacuum compartment.. This access is implemented via an underground gallery which serves the lower towers *installed in the main building. Mode cleaner and end towers are accessed through local caves. The tank clean access infrastructures and the payload installation scenario is reviewed.*

3300.5.1. A continuous clean processing line.

We propose to build a continuous clean processing line **[fig 17]** to prepare the sensitive components before their installation in the tank. The line consists of a cleaning installation, an assembly laboratory, a transfer gallery, and a tent which protects the tank access hole. Materials enter the line through a cleaning installation, people enter it via an airlock where clean clothes are weared.

After UHV degreasing, the requested components enter a tunnel and pass successively a washing machine followed by an oven. This devices, which can be confined with valves, are flushed with clean air or with nitrogen. Components to be cleaned are forwarded on a rolling carriage. The washing machine is a box fit with handgloves allowing for a cleaning with high pressure streams (less than 30bars). Currently used fluids are DI water or a mixture of DI water + ultra pure alcohol. The oven is able to heat at 150ºC. Marionettas, reference mass, baffles, are processed through that line.

The assembly lab should provide a 2m*2m laminar class 100 air flow. Air is extracted through a false floor. Loads of 50 kgs are handled and assembled to form payloads of 500kgs. The available height in the laminar flow is 3m. Significant storage space around the laminar is available.

The staff airlock, the transit area between assembly laboratory and the gallery elevator are controlled class 1000 areas.

This succession of clean rooms is fed by generators located on the first floor. The tanks and their access are fed by generators located on the top of the pumping room.

The gallery is fit with clean air piping supplying each tank access with 1200m^3/h of air filtered at 99.99% DOP. During optics installation, the tank access is confined with polyan veils.

The tank itself is supplied with a 1200 m^3/h filtered at 99.9997% DOP. During payload installation, the tank access is always kept free to allow for an optimal air flow through the introduction hole.

The implementation of the tank clean air piping in the hall is shown on [**fig.18,19**]. It is located on the pumping side. It's height is determined by the free space required by the movements of the crane. In the gallery, the tank access clean air piping is located on the same side wall, i.e. opposite to the elevator corner. The extraction of the air blowed through the tank and its access tent can be done either locally, below each tank, or globally at the gallery end. Unless otherwise stated it's matter of convenience. Let's recall here that the installation scenario requires a qualified cleanness only in the tank access volume in order to protect it with respect to the gallery.

3300.5.2. The payload transfer system.

The transfer system is a rigid gibbet made with four pillars resting on a jack. The upper part of the gibbet can thus be lowered and rised at assembly as well as at introduction. This function is usefull to limit the height of the system, specially during transport. The payload protection box slides along those pillars. The protection box is also used to block the payload during transport.**[fig20].**

3300.5.3. Component handling tools.

Special tools are needed to bring the components from the cleaning bench or transportation box (mirror) to their final position on the payload transfer system. Handling has always to be performed from below: One uses elevators rather than cranes.

The marionetta has to go from the cleaning bench (level 1m) to the payload transfer system (level 1.5m).The mirror has to go from its transportation box to the suspension wires.

The reference mass has to go from the cleaning bench to its suspension wires. It has to fit carefully the already suspended mirror. Today, it is not yet clear how these different components can be seized.

3300.5.4. Optics installation scenario

The experience gained with the tests **[ref. 2]** allows now to propose confidently a new scenario for the optical component installation. With the above proposed transfer system, any payload but the input or detection benches can be installed. The same system allows for the payload assembly, transfer and introduction.**[fig 20]**.

The operator working inside the tank is assisted by an operator resting in the gallery. Both are followed by a third operator sitting in the control room. He watches tank and gallery with TV monitors. They are linked with a free hand radio communication system.

3300.5.4.1 - The assembly on the transfer system.

The gibbet is in its lowest position to allow for the marionetta mounting . If necessary, it can be put in its heigh position to fit the mirror on its suspension wires and the reference mass on the mirror. To perform these operations, the items to be assembled are presented at their final height, in order to minimize their handlings under clean conditions. Once the payload is assembled, it is put in its lowest position and the protection box is raised. This blocks the payload. A veil is wrapped around the box.

3300.5.4.2 - Transfer to the tower access tent.

The protected box is rolled to the elevator on the assembly chariot **[fig 21]**. A movable arm allows its transfer from the chariot to the elevator platform. The elevator is lowered and rolled into the tower access tent. There, after some settling time, the payload is unveiled **[fig 22, step 1].**

3300.5.4.3 - Introduction in the tower.

The operator which will enter the tank dresses hi1self in the tank access tent. Once in the tank, he waits for the payload **[fig 22 step 2]**. Below the introduction hole, his partner rises the protected payload to the heigh position of the transfer system and actions the elevator to bring it to its final position. In this position, the tank aperture has to be clear to allow for an optimum air feedthrough. The operator attaches the marionetta to its suspension wire. He lets the cylindrical protection box glide along the pillars of the transfer system. This system can now be completely removed **[fig 22, step 3,4].** Before leaving the tank, the operator checks the different suspensions **[fig 22, step 5].**

3300.4.5.4 - Tower closing.

The transfer system is contracted to its transport position and returned to the assembly room. It comes back with the flange used to close the introduction hole**[fig 22, step 6].**

3300.5.5. Cleanness monitoring.

The final cleanness of the installed component has to be guaranteed. Of course, the best guarantee is only provided by a nearly impossible in situ measurement. In the actual scenario, the ultimate cleannes is guaranteed by:

i) - an effective oversizing of the clean room installations. The measured safety margin is near 100.

ii) - a permanent monitoring of the clean installations with the particle counters.

iii) - the installation of witness samples on the payload. These samples are placed at the most exposed locations. They are easy to install. They are also easy to remove after installation in the tank.

3300.5.6. Safety.

Work in closed cavities is generally hazardous. Use of solvants in closed cavities is really dangerous. Strong safety rules apply.

Acetone is prohibited.

The use of alcohol in small concentrations cannot be avoided: it is a good dust remover to be employed at the very end of the cleaning process.

The air in the tank and in the assembly room will thus be permanently monitored for its content in alcohol. Tank and gallery are also watched for their oxygen content. Operators never work alone. They are permanently in audiovideo relation with a control room.

3300.6.Assembly sequences.

UHV vacuum and classified infrastructures require some planification and care for proper implementation. Guidelines are enumerated.

3300.6.1.Lower tower installation and linking.

Once on the experimental site, the lower towers are submitted to a vacuum test in order to certify their integrity after transportation. They are put in place with rolling sockets and aligned with respect to 3 markers located on their upper flange. They are thermally isolated from ground and tightly linked with the gallery. The oven structure is assembled around the lower tower and the tower insulation is fit,

Once linked and equipped with the tower pumping, the lower vacuum chamber is evacuated and baked for its own. Another baking is performed after linking.

3300.6.2.Separating roof and suspension installation.

The first stage permanent scaffolding is implemented to allow for the suspension cable tray and cable laying. To test the open suspension, cables have to be prepared in advance

After the cabling, lower towers are opened and one proceeds to the separating roof installation. The associated mechanisms are mounted and the roof is aligned. The operation is dust protected by a tent supported by the first stage scaffolding. The lower compartment is fed with clean air to produce a small overpressure.

The suspension installation follows. It is moved as a whole with its inner structure. On top of the lower tower, a smooth guiding is mandatory to fit precisely the marionetta coil holder into their glass casings.**[fig.23]**

A temporary scaffolding is set up. Its two parts are assembled in place. They provide access to the suspension and its related cabling. Rings are piled up. A functionality test precedes the cupola installation.

An overall interferometer alignment is still possible at this stage of the assembly. To that purpose, alignment optics are installed and tuned to operating positions. The separating roof installed on the mirror towers is moved accordingly with their associated mechanisms. Once in place, roofs are accessed and sealed through the upper compartment ports fit at level z =1300.

After a new baking and thorough vacuum test followed by a suspension test, one proceeds with the installation of the final optics.

3300.6.3. About cleaning.

Clean conditions can only be met when **all necessary material conditions** are fulfilled and when **all concerned people** agree to work "clean".

Lets recall that the specifications on hydrocarbon (oil vapors) and dust contaminations have to be taken seriously and that it is well known that the easiest pollution to remove is the one which has not been made !

The building construction has to proceed as a normal construction. As a rule, one does not start any clean operation before its final reception. Any normal construction work becomes complicate once cleanness has been decided. The application of the rule requires the implementation of restricted access to the clean places. The operation of any oil vapor or dust generating device is prohibited in the controlled areas. Vacuum components are assembled in such conditions. There assembly is not dustfree(white ambience) but oilfree(clean ambience).

The white ambience is only effective inside the lower vacuum tank compartments and in their dedicated access galeries. It can only be created when:

- The vacuum tank is thoroughly tested for leaks.
- All the components connected to the vacuum tank are operational (suspensions, valves, feedthroughs,..). The maintenance of the less liable parts should not break the cleanness.
- The clean processing line is fed with clean air and overpressurized.

When these conditions are met, a thorough wet cleaning is undertaken, starting in the tank and ending in the cleaning installations at the beginning of the continuous clean processing line. After reception with the particle counters, the infrastructures are ready to operate the proposed payload installation scenario.

3300.7. Guidelines for space allocation around the towers.

As seen above, the permanent ground floor (i.e. the oven) of the scaffolding supports the tower pumping units at z = 1300. Most of the cables exit the towers at the level of the technical ring**.** As space around the towers is really scarce, the scaffolding ground floor has been upgraded with a permanent first floor at z = 1880: its roof will support the cable trays being compatible with the tower insulation, the access to the technical ring and pumping units, the displacement of the suspensions with the crane and the addition of the last stage scaffolding. **[fig.26].** A detailed layout of the components and cable trays fit on these levels is shown on **[fig.24].**

Racks for the pumping hardware are located on the pumping side on the ground floor at 80cm from the oven wall.

References:

[1] Marin.air firing.
[2] A summary of the cleanness tests performed on the lower tower prototype at LAPP. R. Morand
Virgo note, TWR 95-1, august 1995
[3] Clean optics installation, final proposal. R. Morand and P. Mugnier,
Virgo note, TWR 95-2, august 1995.
[4] Franck Cadoux, rapport de stage sept.1995

INDEX:

List of figures: