VAC – TRG Report
Vac team

27-Feb-09

SMALL CRYOTRAPS PROPOSAL (PART II): PRELIMINARY DESIGN, COSTS, PLANNING, MAN POWER

1 Preliminary design

Scientific motivations and vacuum features have been described in a first document, here briefly summarized in tab.I.

Present document is to report about the remaining aspects of the cryotraps proposed for AdV:
_ cryogenics and cryostat design,
_ induced thermal effects on mirrors,
_ diffused light issue
_ production plan, costs and manpower
All these points are described in the next paragraphs specifically for the 'small trap' option, and a comparison with the 'large option' is also given.

Case	*Load from towers (mbar.l/s)*	*Water pressure at trap exit (mbar)*	*Notes*
End tower venting and restart after 4 days of pumping	*2E-4*	*~2E-10*	*All load goes in one trap*
As above, restart after 2 days of pumping (as now)	*4E-4*	*~4E-10*	
DT/IB tower venting and restart after 4 days of pumping	*1E-3*	*4E-10*	*Load is divided in the two traps , 5E-4 each*
As above, after 2 days of pumping	*2E-3*	*~1E-9*	
Long term operation, months from ventings (central UHV + bench towers)	*3E-4*	*1E-10*	*Run conditions (Load is split between two traps)*

tab.I vacuum design summary: small cryotraps are calculated to allow the ITF restart after 50-100hr of pumping a tower. In the tubes, the residual water pressure is maintained below 1E-9 – 5E-10mbar. At this level of vacuum, the water contribution to the noise (phase noise) is comparable with the other gases, and the induced noise is around 1E-24 Hz^-0.5

Some presentations related to the document:
http://wwwcascina.virgo.infn.it/collmeetings/presentations/2009/2009-02/AdV/Heitm_090203_AdVPlanning.pdf
https://workarea.ego-gw.it/ego2/virgo/advanced-virgo/vac/discussion%20of%2003feb09/radiation-trap1.pdf/
http://wwwcascina.virgo.infn.it/collmeetings/presentations/2009/2009-02/AdV/pasqualetti_030209.ppt
https://workarea.ego-gw.it/ego2/virgo/advanced-virgo/vac/discussion%20of%2003feb09/links_feb03_2009.pptx/
https://workarea.ego-gw.it/ego2/virgo/advanced-virgo/vac/discussion%20of%2003feb09/Cryo_vessel_thermal_analysis_Cascina_feb_3_2009.ppt/
http://wwwcascina.virgo.infn.it/advirgo/biweekly/2008/2008-10/VAC/links_nov26_2008.ppt
http://wwwcascina.virgo.infn.it/advirgo/biweekly/2008/2008-10/VAC/081126_crioeffects.ppt

1.1 Small cryotrap mechanical design

There is sufficient space to install small cryotraps in between the tower and the existing DN1000 valves. Fig. 1 shows that the cryostat can be separated from the tower with a DN630 valve (650 mm inner diameter). Adapter pieces of 100 (700) mm length are used to connect the cryostat to the input (end) tower. Connections for the titanium sublimations pumps are included.

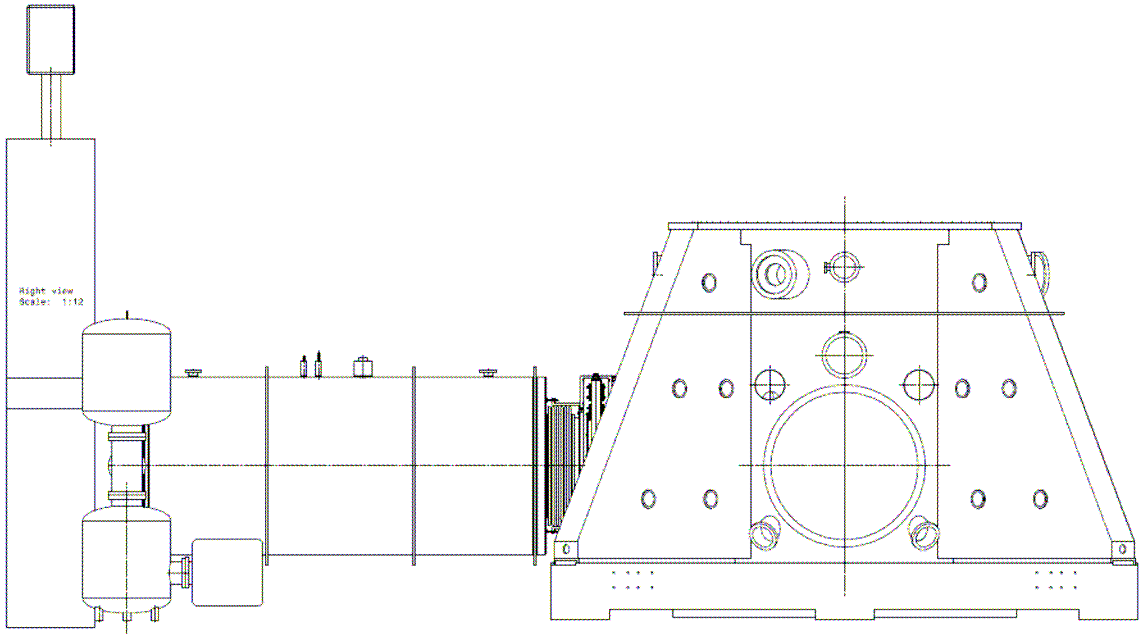

Figure 1: Installation of small cryotrap at the west input tower.

The cryotraps have a cold surface with a length of 2023 mm and a diameter of 1000 mm. Baffles with suitable inner diameter can be used to screen the optical path between mirror and cold surface (see Fig. 2). These baffles are connected with spring lips to the inner cold surface. These lips are welded to the inner cylinder. The best solution for the diffused light mitigation is being studied, see the dedicated paragraph.

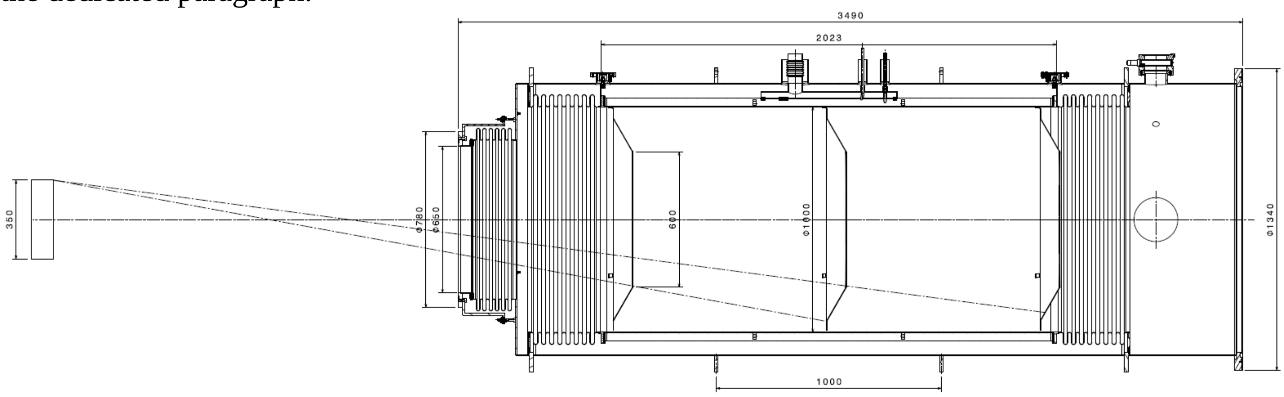

Figure 2: Small cryotrap with internal baffles for shielding the mirror from direct sign of the cold surface. Internal baffles are shown as example of feasibility, the best solution for the diffused light mitigation is being studied.

The cryotrap has a length of 3490 mm and an outer diameter of 1208 mm. It will be constructed from stainless steel 304L. Reinforcement ribs are welded to the outside of the vessel to avoid buckling of the structure. The vessel is equipped with pump-out and service ports. Stainless steel hydro-formed bellows are used to accommodate expansion of the structure. Fig. 3 shows details of the construction of the cryotrap.

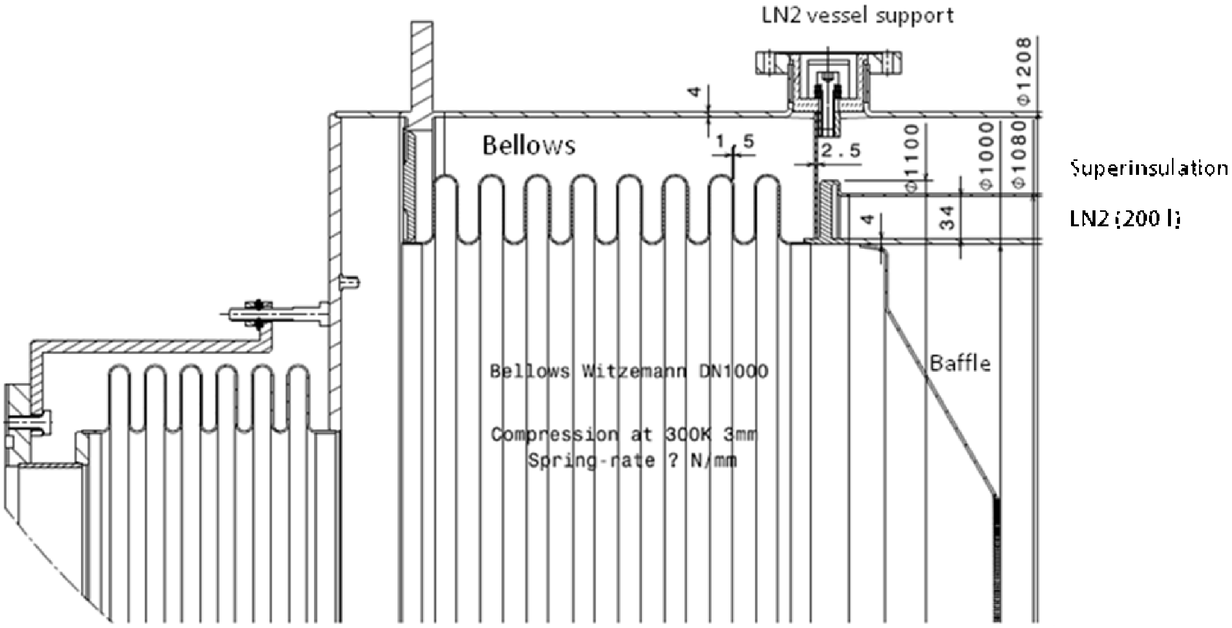

Figure 3: Construction details of the cryotrap. The expansion bellows also acts as a heat bridge.

The inner surface of the trap is cooled with liquid nitrogen. The volume of the bath is about 200 l. To minimize boiling and LN2 consumption, this bath is thermally shielded from the outer surface of the vessel by using superinsulation. Since the inner cold surface will move due to thermal expansion (about 3.2 mm/m) with respect to the outer vacuum vessel, expansion bellows are used. These bellows also act as heat bridges that minimize thermal losses due to heat conduction.

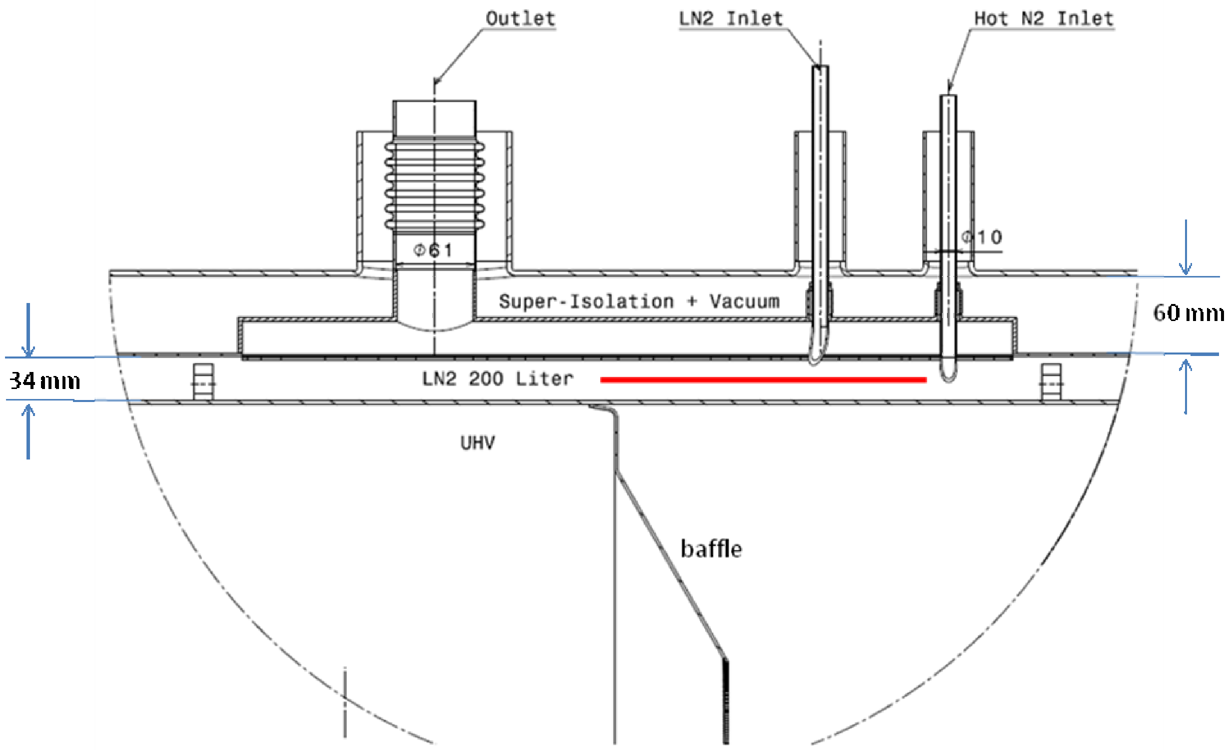

Figure 4: Transfer line connections for LN2 inlet and GN2 outlet. The red line indicates the operating level of the LN2 bath.

The connections of the transfer lines are shown in Fig. 4. The LN2 inlet will be designed such that LN2 will flow smoothly into the bath, in this manner minimizing any induced noise from bubbling. The liquid nitrogen level in the bath can easily be controlled within ±10 mm. Note that the bath has a sizable width of more than 300 mm. Again this guarantees that bubbles have an easy escape path to the surface over the entire length of the cryotrap. A separate LN2 inlet is provided in order to admit hot nitrogen gas in case rapid heat-up of the structure is needed. The cryotrap can be operated for more than one year between regeneration, assuming a load of 10^{-4} mbar l/s from the mirror vessel. During this time a water layer of about 1 micron will be deposited on the inner surface. This causes the initial emissivity of about 0.1 to increase to 0.2. This relative low value for the emissivity leads to an average heat load of about 250 W, and results in an estimated LN2 consumption of about 3.5 LN2 per hour. This corresponds with an estimated gas production of 0.2 l/s, assuming 80 K surrounding temperature in the vessel.
In a 'transient' phase of commissioning operations, when towers are frequently vented , the growing rate of the water layer will increase . Regenerations shall be maintained at the level of once per year, taking into account an higher LN2 consumption .

Some auxiliary equipment is needed for each trap:
_ cryogenic sensors to monitor the temperature distribution and the LN2 level.
_ vacuum gauges, to monitor the residual pressure from the atmosphere down to 10^{-9} mbar; also a gas analyzer is needed for diagnostic .
_ vacuum pumps / valves : a turbo-molecular pump + a dry pump is needed for evacuation/regeneration and Ti-sublimation pumps are needed for the UHV service.

A bellows section is foreseen as connecting piece between the trap and the tower, here 650mm of inner diameter. Its size shall be verified if compliant with optical constraints, and enlarged if necessary.

Finally, the installation of the cryotraps (and of their relevant valves) will require the modification of the corresponding oven structures.

1.2 Thermal effectcs on TMs

The small Cryotrap solution, given the proximity of large surface cooled to liquid nitrogen temperatures with respect to the TMs, will induce thermal effects on the TMs themselves through radiative heat exchange. The relevance of these effects, in terms of structural and optical curvature of the TMs, have been analyzed independently by the NIKHEF and Roma Tor Vergata Groups with finite element thermo-mechanical simulations.

The NIKHEF Group built a 3D model of the set-up with COMSOL. The scheme of the model is reported in Figure ***1***5.

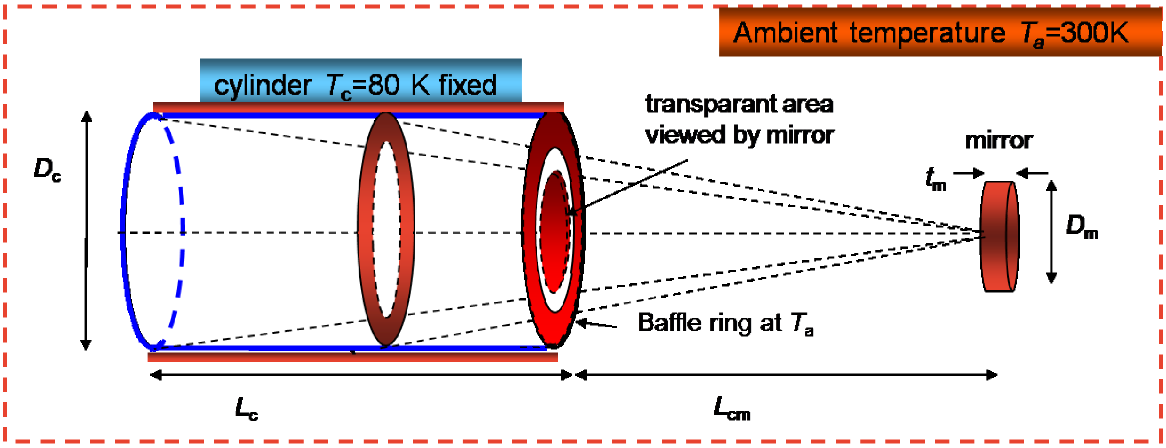

Figure 5: scheme of the 3D finite element model.

D_c represents the inner diameter of the tap, L_c its length and L_{cm} is the distance between the trap and the TM. D_m and t_m are respectively the diameter and thickness of the TM. Two different solutions have been modeled and analyzed, shown in Figure ***2***6:

- a cryotrap 0.65m in diameter
- larger cryotrap (1m in diameter) with baffles along its length

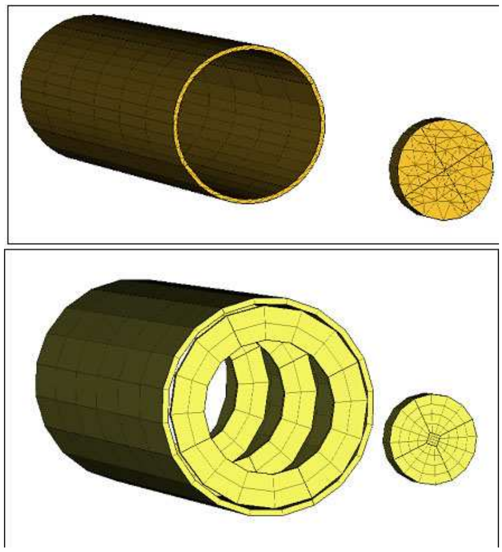

*Figure 6: upper figure the 0.65m trap with no baffles. Lower figure shows the 1m trap with baffles***.**

The results of the simulations are summarized in Table II as function of the trap diameter and the presence and position of the baffles. P_m is the power emitted by the TM towards the trap, ΔT_m is the average temperature decrease of the TM and $R_{thermo\text{-}optic}$ is the radius of the equivalent lens in the thin lens approximation.

$D_c(m)$	baffles	P_m(W)	ΔT_m(K)	$R_{thermo\text{-}optic}$(km)
0.65	no	0.42	0.21	120
1.0	no	0.8	0.43	60
	b_1	0.24	0.12	220
	b_1+b_2	0.23	0.11	250
	b_1…..b_3	0.31	0.16	170
	b_1…..b_4	0.40	0.19	100
	b_1+b_4	0.44	0.21	120

Table II: summary of the 3D FEM results

These results have also been used to evaluate the power consumption of the trap (not reported in this section).

The Roma Tor Vergata Group modeled the system with a 2D axy-symmetrical model with ANSYS. There is only one baffle, with a diameter of 60cm, placed 10cm away from the trap to reduce diffused light noise. Figure 7 shows the scheme of the model.

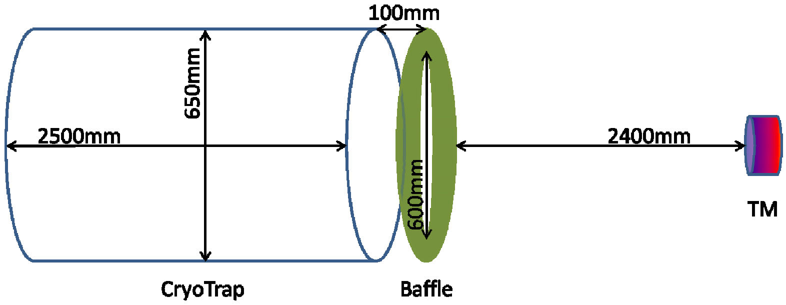

Figure 7: scheme of the 2D axy-symmetrical thermal-structural model

The resulting TM temperature map is shown in Figure 8. The output of the FEM model have been used to evaluate thermal effects in terms of the Optical Path Length Increase and change in the ROC of the TM. Figure shows the OPL increase due to the trap compared to that due to the YAG power absorbed by the TM. It is possible to notice that the curvatures of the two OPLs are opposite and that the absolute value of the trap OPL is small compared to that of the YAG. The change in the ROC has been evaluated to be of the order of 2m, small compared to an absolute value of the ROC of about 1500m. This change is again going in the opposite direction of that due to the YAG absorption.

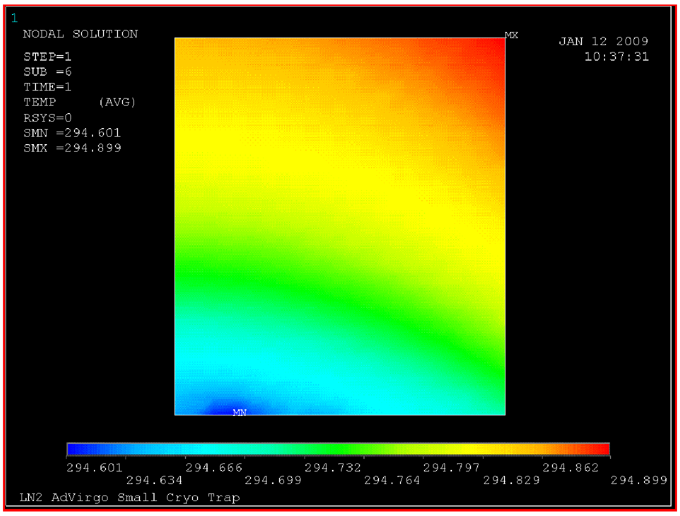

Figure 8: TM temperature map. ΔT is approximately 0.4K

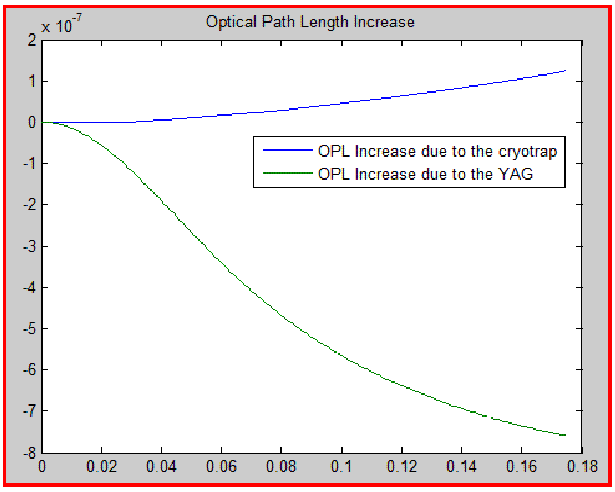

Figure 9: OPL increase due to thermal effects in the TM. The blue curve is the OPL due to the trap, while green curve is the OPL increase due to the absorption of YAG power.

Both analyses agree that the thermal and structural effects of the small cryotrap on the TMs are negligible. Moreover, these effects have opposite sign with respect to those given by the YAG power absorbed by the TM, thus giving a small help to TCS.

1.3 Diffused light

The criteria applied in Virgo to moderate the diffused light noise are based on the following considerations.
The highest probability processes contributing to diffused light noise involve at least two scattering (casual) processes plus one or more "reflection" (deterministic) process: a photon impinging on a mirror is diffused out of the Gaussian beam, then it is reflected by some (quasi)mirror surface towards a mirror, where a successive diffusion brings it back into the resonating beam. Processes involving further diffusions can be disregarded, having a much lower probability. Diffused light, due to mirror roughness, is expected at the level of 20 ppm for AdV mirrors, while it is estimated at 200 ppm level for present Virgo mirrors.
In addition to diffused light originated by mirror roughness there is that one produced by photons belonging to the Gaussian beam hitting baffle edges or any other component limiting the aperture left free for the beam. This last component may remain negligible keeping the free aperture radius about 5 (4) times larger than the beam radius ("waist"); the Gaussian beam intensity fraction travelling outside this radius is of the order of 10^{-22} (10^{-14}).
The present baffle configuration at the ends of the Virgo arm tubes (between any IN/END tower and the respective Large Valve) is sketched in fig.10 It responds to the following criteria:

- the minimum free aperture radius is about 5 times larger than the average beam radius
- any discontinuity (potential reflecting spot) of the vacuum enclosure is hidden by suitable absorbing glass baffles, with respect to the beam spot on any mirror
- no point of the smooth surface of the vacuum enclosure can be seen contemporarily by the beam spots on two facing mirrors.

Moreover, in the main part of the arm tubes, between two Large Valves, all the inner surface is hidden by conical stainless steel baffles, with respect to the beam spots on the mirrors.
This configuration has proven to be largely safe for Virgo. It has been impossible to detect any noise enhancement on the dark fringe signal, even shaking the tube ends order of magnitudes more than the natural seism. This result remains true also for the input towers, where the baffle B6, close to the mirror, has an aperture diameter of only 230 mm.

A very similar configuration (Fig. 11) will be chosen for the "Small Cryotraps" to be installed between IN/END towers and the respective Large Valves. The size of the additional valves and position and diameter of baffles will be optimized with respect to diffused light.
For comparison, a calculation, reported in appendix, shows the contribution to diffused light noise by a 1 mm^2 reflecting spot on the inner edge of a baffle, due e.g. to a chip. If this surface is oriented in a way to reflect right to the mirror, with a diffused light at the level of 20 ppm per mirror and a seismic excitation of $10^{-7}/f^2$ [m/Hz $^{1/2}$] the contribution to diffused light noise is 2 10^{-24} $Hz^{-1/2}$ at f = 10 Hz, and 2 10^{-26} $Hz^{-1/2}$ at f = 100 Hz; always more than two orders of magnitude below AdV sensitivity.
The calculation has been performed on the lay-out shown in figure 11.

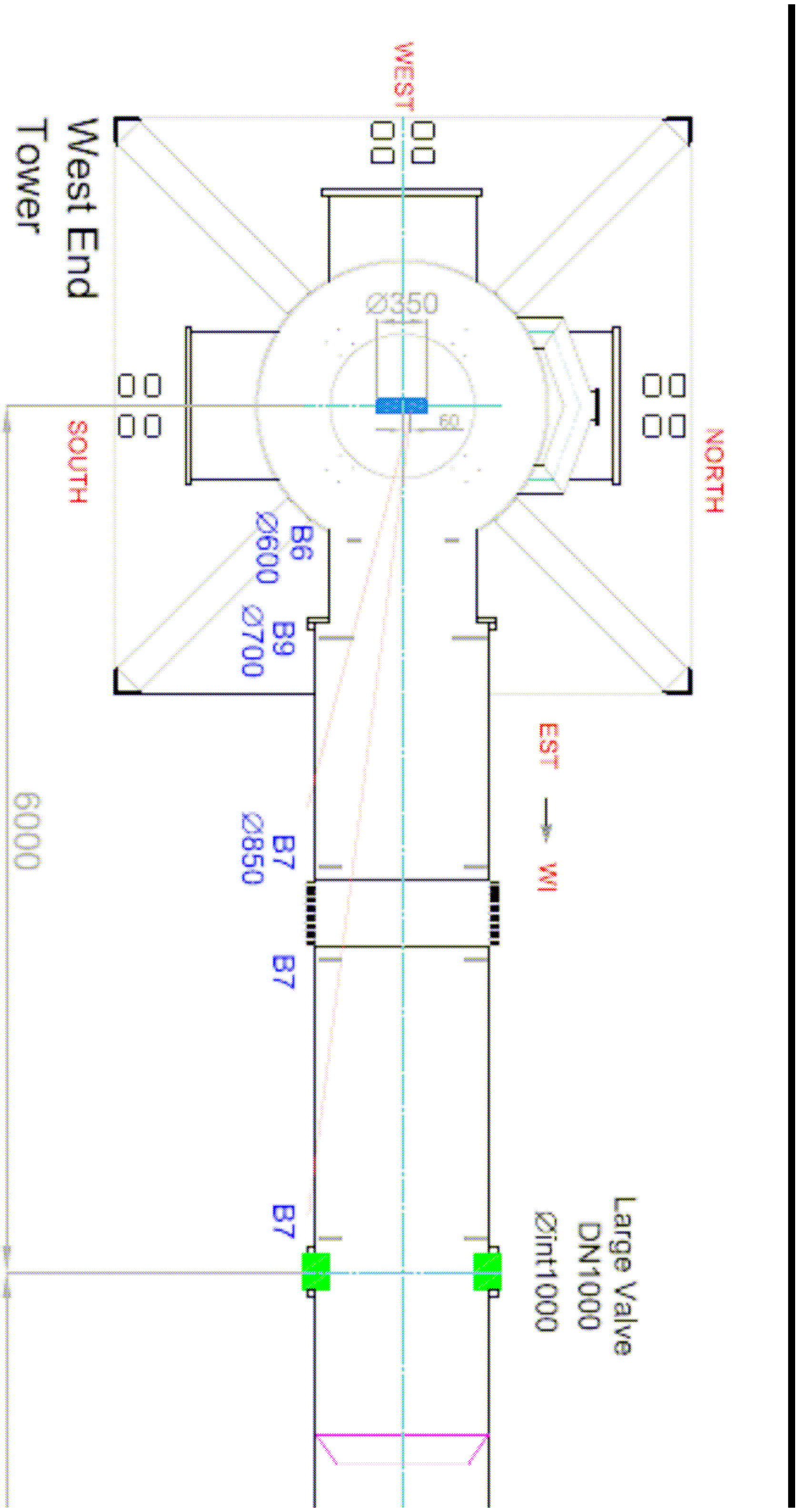

Fig. 10 – Present glass baffles configuration

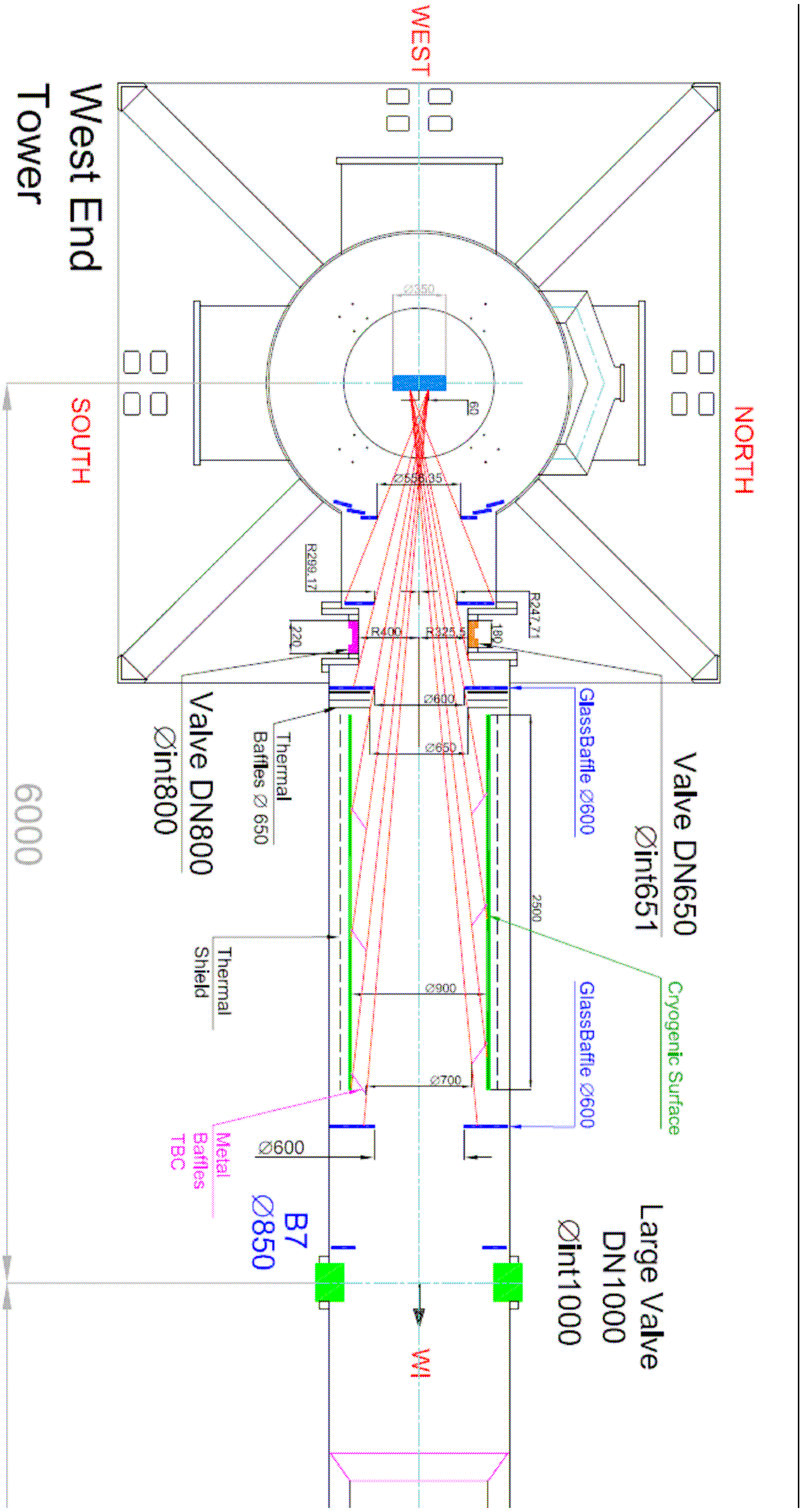

Fig. 11 – Proposed baffle configuration for the Small Cryotrap. In the upper(lower) part of the drawing is shown the 650(800) mm option for the additional valve.

1.4 design finalization steps

In order to complete the design phase and to start the call for tender and the executive design , the following aspects will be concluded:

a) progress in the study of the liquid- vapour flow inside the cryostat, with respect to acoustic and mechanical noise given by developed nitrogen bubbles ,
b) evaluation of a simpler and cheaper cryostat , embodying a metallic shield (made by aluminum for instance) thermally anchored to a reduced size LN2 reservoir.
c) optimization of the trap geometry versus the optical constraints, including the size of the optical baffles and the evaluation of diffused light noise

Our plan is to complete them within beginning of 2010

2 LN2 supply system

Factors considered in the selection of the most suitable liquid nitrogen (LN2) distribution system are ease of fabrication and handling, reliability, safety, and, of course, cost (both initial investment and running costs, including maintenance).
The adopted reference design is a “standard” distribution plant based on large storage vessels (one for each trap) and vacuum insulated lines. The lines could also include an intermediate annular pipe for collecting cold vapor to reduce heat leak into LN2 (see
Figure 12).

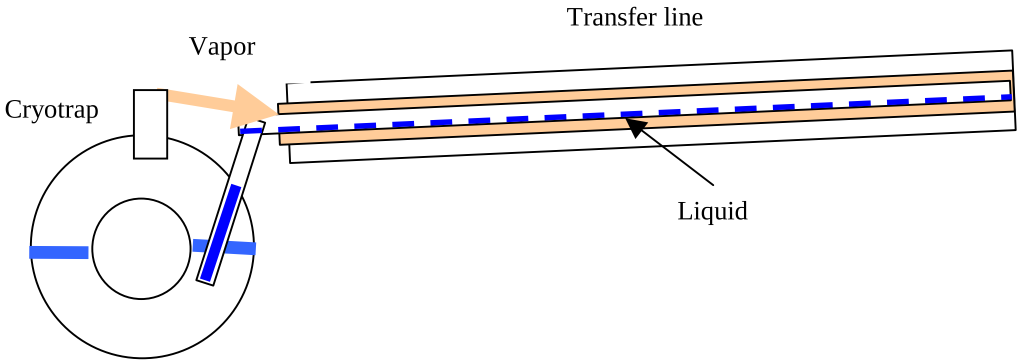

Figure 12. Schetch of the LN2 supply system. The transfer line contains a path for nitrogen vapour to reduce heat leak into the liquid.

The estimated overall heat leak into the small cryotrap is in the range of 300 W (see par 1.1).
Typical losses of the transfer lines can be estimated using the empirical relation Q ~ 380 W/(m torr) [R.R. Conte, *Elements de Cryogenie*, 1970] that rates the heat load with the line length and residual pressure in the vacuum insulation. For a 20 m long line with an insulating vacuum of 10^{-2} torr we get Q ~ 76 W.
Losses of the storage vessel are typically in the range 0.1-1% per day of its content [K.D. Timmerhaus and T.M. Flynn, *Cryogenic Process Engineering*, 1989].
Taking some extra safety factor we can estimate an upper limit for the overall heat load of 700 W/trap (for 10 000 l vessels), corresponding to a liquid nitrogen consumption of 350 l/day per trap, and to 1 400 l/day for the four traps.
With 10 000 vessels and these consumption rates the refilling of the exhausted LN2 should occur once per month.
Being standard plants their safety and reliability should be granted.

3 Comparison with the 'large cryotrap option'

Small traps are preferred for minor cost and for the much easier installation, not involving to open the 3 km long tubes by cutting out 4 welded modules.
A list of benefits/drawbacks of large traps is synthetically reported in the following:

- _ vacuum performances: the gain on water pressure when using large cryotraps is less than 1 order of magnitude, corresponding to a much reduced gain in terms of phase noise , because the square root dependence and because the contributions of the other gases. The impact on the AdV sensitivity is limited.
- _ thermal effects given by the large traps on mirrors are less important (about one order of magnitude), anyway the small trap option is allowable too
- _ optical constraints: in the large trap option the free aperture can be larger than 600mm. Glass baffles of 600mm will be anyway installed, (as it is at present), to limit diffused light . Normally it is not an advantage.
- _ diffused light issue: the situation for the large trap is not obviously better, to be studied in both cases
- _ LN2 consumption: slighty larger for the large traps, not significant.
- _ Env. Noise emissions: being far from towers, we could pay less attention to avoid the noise from 'liquid nitrogen bubbles'. On the contrary the LN2 evaporation will be larger, because the increased heat losses.
- _ Regeneration period: it should be not significantly different for the two options, being practically independent from trap length.
- _ Production:
  Some parts of cryotraps (new parts of stainless steel exposed to vacuum and operating at room temperature) should be 'fired' (heated at 400C in air for about one week). This treatment will be normally done in factory during the production phase, unless we will

consider to perform it on site to save money. Because the handling difficulties, these operations will be more simple and economic for the 'small traps'.

- _ costs: extracost for the large option is at least 370keur, see the below table

	Deliverable	Cost
	4 Large Cryotraps	4 Cryostats complete with cryo-accessories ……………600 keur External contracts and tools for installation (1monthx 2tech x trap, with big cranes and qualified welding expertise) …………………120 keur 1m Vat Valves ……………………………………….560 keur Total …………………………………………………1280 keur

tab.III costs for the large cryotraps equipment

- _ manpower: A specialized external company is needed for the installation of the large traps. They will provide manpower and special equipment such as large cranes to handle the cryotraps. Welding expertise is also needed. The automatic robot for welding and nibbling the tube modules would be restored after a proper re-qualification phase.
- _ planning : with large traps, the 3km tubes shall be vented, and re-evacuated after the trap installation. Subsequently trap tests can be performed.

  Hence the installation must be completed at least 3 months before the ITF restart.

  Furthermore, as predecessors, civil works are needed to prepare the foundations of the auxiliary large valve, to be done before the installation of the cryotraps, and after the tube modules removal.

- _ Risks: are significant for the large option. They are connected to the opening of the 3km tubes, cutting out and reinstalling by welding 4 tube modules 10m long (handling difficulties, pollution, leaks, involvement of external companies in the installation plan).

  Risk 1: tube cleanliness spoiling

  Both tubes shall be vented, the 4 end modules cut away and replaced by new large cryostats 10m long and auxiliary valves that must have a comparable cleanliness. Each tube shall be in air for a few months.

  The contamination risk is among the first hazard for Virgo vacuum system, being an accidental contamination not easily recoverable.

  Risk 2: external contract management

  A contract with an external company for 8 months of activity is to be fit into the AdV schedule, matching with concurrent activities. It will stiff the general schedule and will require management effort.

  Change of schedule due to various reasons such as delays in traps delivery and tests or variations of the general plan, due to internal contingency, can lead to difficulties in contract management.

  Extracosts and delays can be expected, probability is quite high.

  Risk 3: large trap is not dismountable

  It is difficult to modify the large trap in case of need to change any detail, for instance the position of optical baffles. The probability of this occurrence seems quite low, but it is also true that we will not have prototypes fully studied , apart the experience on LIGO system.

  To modify, or at limit to replace the cryotraps, will require external company and special tools, high costs and months of itf stop.

4 planning

The sequence of construction stages of the cryotraps is:
- Preparation of specifications documents, Call for tender
- Contract assignment and executive design
- Approval of the executive design
_ Prototype qualification and acceptance
- Production and follow up of the production
- Acceptance tests and reception
- Installation
- Tests on site

The different steps are described here below, grouped in three parts: ‘finalization’, ‘production’ and ‘integration’

4.1 design finalization, call for tender

preparation of ‘technical specification docs’:	begin 2010
call for tender and contract assigned :	within 2010
approval of the executive design (prepared by Contractor) and start of the production	within 2010

4.2 production

Estimated production time for 4 traps = 14 months (8 months for the first one)

The prototype qualification is included in the production phase: the first of the 4 cryotraps shall be completed and qualified in factory before proceeding with completion of the remaining 3 units.

1st trap tested in factory in	mid of 2011
then production of the remaining three ones,	
all traps on site at	begin 2012

4.3 installation

installation time= 1.5 months/trap , made in sequence, = 6 months.
During the installation periods the tubes shall be not available (valves closed).
Constraints:

- Installation shall start after the 'towers displacement', together or following the links installation. The 'small trap' can be handled with same (or similar) tools and manpower (mainly internal) used for 'enlarged links' installation.
- Installation must be completed at least 2-3 months before ITF restart, to leave this additional time for a first running tests of cryotraps.
- bake-out could be done after cryotraps have been installed . It will take about 2 additional months, during which the arms are not available (tbc). Baking shall be performed when convenient for commissioning activity , budget and manpower reasons, not necessarily immediately after the traps installation.

A general planning of AdV project is being prepared by the technical coordinators, here in a preliminary version :

http://wwwcascina.virgo.infn.it/advirgo/protected/docs/AdV_plan.pdf

(It is a first version, to be updated with present design options and estimated time schedule).

4.4 operation and maintenance

The principal maintenance intervention of the cryotraps is the 'regeneration', which involves a stop of the interferometer for a few days.
A precise regeneration procedure is being prepared .

5 Costs

The estimated costs of 'traps' and related accessories is based on budgetary offers received from relevant companies . Taxes are excluded, main spare parts are included. The cost is referred to a 'small cryotrap' configuration with 800mm size valves, conservatively.
At the present we consider that a 20% contingency has to be added to the quoted costs, in order to compensate for undefined parts of the design.

Following special ' items' are excluded from VAC budget

- Infrastructure : preparatory works for the liquid nitrogen dewars have to be provided outside central and terminal buildings (area preparation, lodgements cabins, electrical power distribution) . They are not included in VAC and shall be within IME.
- Bake out: the bake-out equipment is already existing and installed in present Virgo. No production costs have to be sustained, apart for consumables: 'fuel' and power generators to be

rented during bake-out. It is an approved feature of Virgo and should not considered an additional cost for AdV.

Cryotraps	4 Cryotraps ……………………………….. ……………500 keur External contracts and tools for installation….…………...50 keur 800mm Valves ……………………………………….....360 keur Total …………………………………………………..910 keur
LN2 plant	Piping and cryo equipment, 4 units, …………………….200 keur *Concrete-infrastrucutre installations (IME).……………...40 keur* Total …………………………………………………..200 keur
Vacuum equipment	Additional equipment for 4 traps (heaters, turbo+drypumps and Ti sublimators) ……….……………….……..………........160 keur RGAs and vacuum sensors for cryotraps..………………..80 keur Total ……………………………………………………240 keur
Bake-out	*Feature included in present Virgo....………………..…...…..300 keur*

tab.IV costs summary

A first estimate of the running costs is also given:

Based on a preliminary offer by the local LN2 supply company (SOL), quoted at 0.2 eur/liter, the cost for an overall consumption of the order of 1400liter/day, including the contracts for 3 dewars 10000liter ‘in comodato’ would be around 10keur per month.
To be remarked that the quotation got for the LN2 supply is a preliminary one, possibly improved.

6 Manpower

Time duration of construction and installation phases are summarized in the below table, which reports also the internal manpower needs.

Deliverable	***Phase***	***Duration***	***Manpower***
4 Cryotraps	*Production*	*14 months*	*0.5 Mech E*
4 Cryotraps	*Integration*	*6 months*	*0.5 Mech E + 1.5 vac T + 0.1 P*

Tab.V Small traps manpower

A mech. engineer shall be needed for half of his time for the production follow-up, while the installation on site shall be performed by one engineer (50%) plus one technician (100%) and an external company for support (handling , dismounting old links and installing new traps with cranes, …).
The external company (2 people) shall be needed for a total period of 12 weeks .
1.5 months are envisaged to install a trap. In the installation activity is considered also the evacuation (1 week) and the cool-down of each trap (1 week) .

Further manpower: a physicist (10%) for baffles positioning and check, and one additional vac technician (50%) for special installation activities (pumps installation…) and vacuum tests (leak tests…).

The LN2 plant installation shall be entirely done by external company under the supervision of a technician (50% during the 4 months foreseen for the installation).Some preparatory activities shall be carried out by the EGO infrastructure team (preparation of external area for LN2 tanks).

Also the procurement of the large valves will require a proper follow-up of the production. An additional manpower effort shall be required.

About bake-out , the manpower need shall be covered by internal staff, in the hypothesis that bake-out will be performed when principal AdV constructions activities will be over . (Tubes can be baked when necessary for sensitivity or convenient for commissioning plans).

Proposed construction responsibles:

1) Cryotraps	NIKHEF
2) LN2 supply plant	INFNGE
3) vacuum equipments	EGO
4) Thermal effects on tests masses	ROMA2

Task 4 is to be added to the construction activities: a constant verification of the thermal effects on mirrors is needed not only in the present phase, but also along with executive design and during the phase of tests on site.

During the installation phase works and responsibilities shall be normally shared with Ego teams

7 Appendix

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February 24, 2009

Abstract

Glass baffles in the cryotrap region and scattered light issues

1 Introduction

Installation of small aperture glass baffles in the links between towers raises questions about the scattered light noise. I try to make rough quantitative assessments of the level of noise. The theory has been presented in [1],[2].

Recall that the scattered light noise (SLN) is a second order process with respect to scattering. The different channels begin by emission of scattered light off a mirror, a more or less complicated path involving specular reflections, and a second scattering on a mirror (possibly the same one). We neglect third order scattering involving a rough surface on the path, because firstly because that kind of surface is systematically hidden by the baffles, and secondly because even for ordinary surfaces (stainless steel, glass or other), unless a special treatment is done (gratings), the scattering rate is low.

In the present case, the only feature adding a new channel to SLN is the presence of small aperture glass baffles. If, as already said, we neglect effect due to scattering by the surface of the baffle itself, The only dangerous process is a specular reflection on the baffle.

Such a specular reflection on the flat surface of a baffle cannot couple back the scattered light to the emitter mirror, because it escapes the mirror's aperture, but it is necessary to check that nothing in the mirror's environment (reference masses...) is able to redirect the light.

This being assumed, the remaining channel is a reflection of some scattered light coming from the far mirror off the inner surface of the edge of a glass baffle under quasi grazing incidence. This is what we study below.

2 Theory

We consider light scattered by a far mirror at $L = 3$km, and a specular reflection on a reflecting element (RE) of size a (some small area on the inner edge of the baffle). The reflected light could reach the close mirror if the baffle is not strictly orthogonal to the optical axis. The reflected light is phase modulated by the motion of the baffle, then a second scattering process couples a part of that light with the main beam.

The elements we need are respectively the distribution of scattered light, and the spectral density (SD) of excitation of the RE. The distribution of scattered light has been widely studied through measurements at SMA-Lyon, and found to obey at angles larger than the gaussian aperture of the beam, a law of the form

$$p(\theta) = \frac{\kappa}{\theta^2}$$

$p(\theta)$ is assumed normalized in such a way that

$$\int_0^{\pi/2} p(\theta) sin\theta \, d\theta = 1$$

We denote by ϵ the rate of scattering (the scattering losses of the mirror). A conservative value is $\epsilon\kappa \sim 10{-}6$.

The SD of displacement noise of the moving RE is assumed identical to the seismic noise :

$$X(f) = 10^{-8}\,\mathrm{m.Hz}^{-1/2} \left[\frac{10\,\mathrm{Hz}}{f}\right]^2$$

The SD of h equivalent to SLN is given by the following (detailed) formula :

$$h(f) = \frac{\lambda}{2\pi}\gamma(a,\theta_1,\theta_2)\frac{4\pi}{\lambda}\,\theta_R\,X(f) = 2\,\gamma(a,\theta_1,\theta_2)\,\theta_R\,X(f)$$

where a is the size of the reflecting element, θ_1 the angle under which the close mirror is seen from the RE, θ_2 the angle under which the far mirror is seen from the RE. θ_R is the angle between the incident or reflected rays and the surface of the RE. Essentially, $\theta_R = \theta_1/2$. $\gamma(a, \theta_1, \theta_2)$ is the coupling coefficient, and is obtained by an integral over the area of the RE of the product of the speckle autocorrelation functions of the two mirrors [1]. We give the result without proof :

$$\gamma(a, \theta_1, \theta_2) = \frac{\epsilon\kappa}{2\pi d L \theta_1 \theta_2} S(a) F(a)$$

d is the distance close mirror/baffle, L is the distance far mirror/baffle, $S(a)$ the area of the RE, and $F(a)$ a form factor. if we take $\theta_1 \sim H/d$ and $\theta_2 \sim H/L$, where H is the aperture of the baffle, we have simply

$$\gamma(a, \theta_1, \theta_2) = \frac{1}{2}\epsilon\kappa \frac{S(a)}{S_B} F(a)$$

where S_B is the area of the aperture of the baffle.

All this put together gives the final formula :

$$h(f) = \epsilon\kappa \frac{S(a)}{S_B} F(a) \frac{H}{2d} \frac{X(f)}{L}$$

3 noise

In the case of a circular RE, we have a form factor pratically unity for $a < 0.1$ mm, then falling as $1/a$ (see Fig.1).

We may give an example for $a = 1$ mm, (then $F(a) \sim 0.1$) for the baffle installed at $d \sim 5$ m from the close mirror :

$$h(f) \sim 10^{-25}\ \mathrm{Hz}^{-1/2} \left[\frac{10\ \mathrm{Hz}}{f}\right]^2$$

this assumes that the RE's surface makes an angle θ_R of about 1.7 degrees with respect to the optical axis. It seems not impossible to have such situations, owing to the alignment procedure of the baffles, and to the unperfect quality of the inner edges.

This relatively good result is mainly due to the grazing incidence which reduces the phase modulation at reflection (the factor H/2d).

The results would be worse for the two other baffles, but the angle for having a possible specular reflection is much larger in those cases, and thus, unlikely.

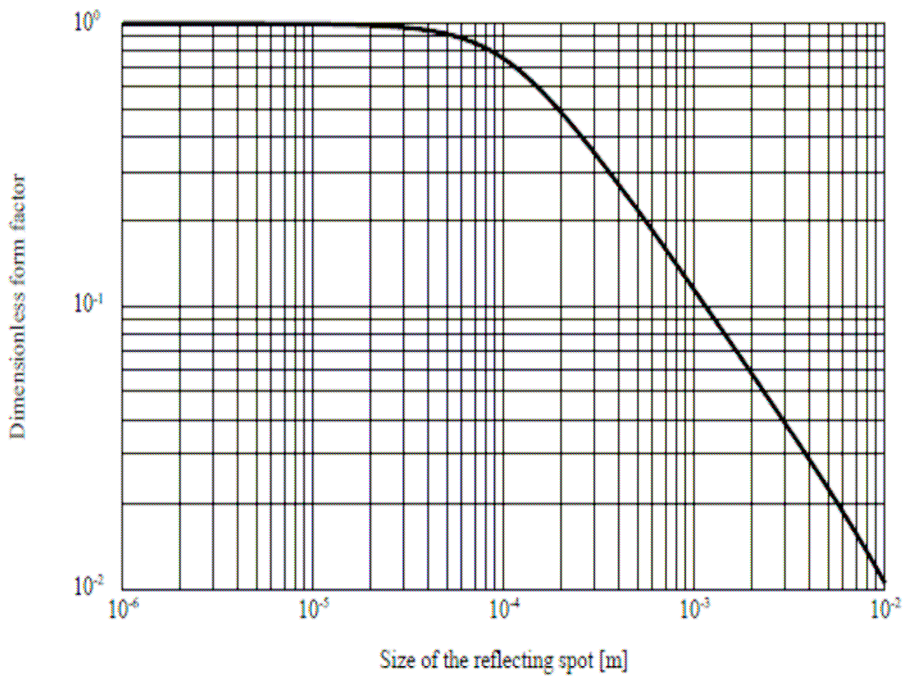

Figure 1: Form factor