2.5.1 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. The noise is caused by the phase modulation gained by this photon at any reflection on objects linked to ground and excited by the seism (or, in the case of cryotraps, excited by boiling liquid Nitrogen). Processes involving further diffusions can be in general disregarded, having a much lower probability (third order with respect to scattering rate).

Diffused light, due to mirror roughness, is expected at the level of 10 ppm for AdV mirrors.

In addition to diffused light originated by mirror roughness there is that produced by photons belonging to the ~~Gaussian~~ beam hitting any object 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 local average beam radius; ~~the~~ in a Gaussian beam the intensity fraction travelling outside this radius is of the order of 10^{-22} (10^{-14}).

If nothing is done for killing the potentially harmful photons (generated noise larger than 1/10 of the sensitivity), the most important effect results from scattered beam photons impinging directly and quasi-reflected by the tube surface towards the second mirror. So a baffle system has been installed in the long tubes, and a different one in the tubes close to the towers.

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.

At the ends of the Virgo arm tubes (between any IN/END tower and the respective Large Valve) black glass baffles (transmission $<10^{-7}$, reflection $\sim 10^{-3}$) have been installed, in a configuration responding to the following criteria:

- the minimum free aperture radius is about 5 times larger than the local 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.

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 much 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 (here the average beam radius is 22 mm).

A very similar configuration (Fig.2) has been chosen for the Cryotraps to be installed between IN/END towers and the respective Large Valves. The size of the additional valves and the position and diameter of baffles have been optimized with respect to diffused light, applying exactly the criteria listed above.

To this aim all processes reflecting diffused light onto a mirror have been evaluated:

1. Splinters on baffle edges
2. Grazing reflection on baffle edges
3. Diffraction on baffle edges
4. Backscattering off inner trap surface.

Calculations by J.Y. Vinet [10],[11] show that all diffused light noise sources are well below AdV sensitivity as summarized below.

- Splinter on baffle edge

If it has an area of 1 mm^2 and is oriented in a way to reflect right to the mirror, within 0.1°, with a mirror diffused light at the level of 10 ppm and a seismic excitation of $10^{-6}/f^2$ m/Hz $^{1/2}$ the contribution to the noise is 10^{-25} $Hz^{-1/2}$ at f = 10 Hz, and 10^{-27} $Hz^{-1/2}$ at f = 100 Hz. The calculation has been done for splinters on inner edge of baffles with a 600 mm diameter aperture, sitting at 1 to 5 m from the mirror.

An inspection with a microscope allows saying that the size of splinters on glass baffle edges is not larger of 0.01 mm (surface 10^{-4} mm^2) and that their density is not larger than one splinter with the correct orientation per mm of edge length. Hence the total "bad" area on a 600 mm baffle edge amounts to about 0.2 mm^2, giving a negligible contribution to diffused light noise, always more than three orders of magnitude below AdV sensitivity.

- Grazing reflection on baffle edges

This can happen if the baffle is misaligned (it is not perpendicular to the beam axis) in such a way that some of the cylindrical surface of its inner edge reflects the light diffused by one mirror exactly on the facing mirror at 3 km distance. If the required alignment error is more than 2° (about 35 mRadians), it can be avoided by a careful installation. Baffles where an alignment error of less than 2° may be dangerous, can be misaligned on purpose by a larger quantity (e.g. 5°). The "grazing reflectivity" of this surface must be very poor, being the baffle edge very mat and not shiny at all. ~~Another possible remedy is cutting the inner baffle edge with some inclination (e.g. 10°), obtaining a conical surface.~~

- Diffraction on baffle edges

This noise source is shown to be by far negligible.

- Backscattering off inner cryotrap surface

The corresponding noise has been evaluated in VIR-0344A-10 for a cryotrap very similar to the chosen geometry, made of stainless steel; it is 2.5 10^{-27} $[10\ Hz/f]^2\ Hz^{-1/2}$. For an aluminum cryotrap, even allowing a scattering probability one order of magnitude larger, the noise remains a few orders of magnitude below the design sensitivity. This result is in agreement with the introductory consideration, being backscattering a third order process with respect to scattering probability.

Also the choice of trap diameter is based on the same ~~criterion~~ criteria already used in Virgo to mitigate the diffused light inside tubes and links. The selected trap diameter (inner diameter = 0.95m, ~~similar to that of the links~~) leaves most of the trap walls out of the mirrors sight, masked by optical glass baffles with apertures of 500 to 600 mm at inlet and outlet of the trap, ~~and respects~~in agreement with the noise estimations described above. Not any point of the inner cryotrap surface can be seen contemporarily by facing cavity mirrors.

Larger trap diameters would not fit easily with room constraints and would increase the LN2 consumption. Smaller diameters would expose a larger surface of the cryotrap at narrower view angles, generally less favorable for diffused light; furthermore it wouldn't bring significant cost reduction.