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Some considerations on the replacement of the VIRGO Mode Cleaner payload

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We have carefully read the document concerning a change request for a possible "Replacement of the VIRGO Mode Cleaner payload". The scientific motivations for these changes are relevant for the present set-up and they could be even more relevant for the future VIRGO interferometer (Virgo+).

The VIRGO commissioning activity has pointed out some problems ascribing to the present set-up of the MC payload as follows:

- a bad optical quality of the MC end mirror substrate together with a well visible pollution of the reflecting surface;
- a light mirror (just 360 g) with a composite reference mass built with two concentric rings made of PEEK (thermoplastic material) and stainless steel for a total weight of about 5 kg. As a consequence of this fact a high level of radiation pressure noise is injected into the interferometer;
- a bad influence of the electrical wires (connecting the coil system to the patch panel installed at the marionette level) on the pendulum motion. The pendulum stiffness is dominated by the rigidity of these wires creating an undesirable damper system. Moreover, some technical difficulties in developing a stable control feedback loop for the payload have been encountered.

Analyzing the possible scenarios presented in the change request document, it is clear that the less invasive intervention on the present payload is that one for which the mirror substrate is replaced with an identical one (same size) but with a better optical characteristics. With this new optical component even the electrical wires and the reference mass structure could be replaced with thinner wires and a monolithic RM (made of stainless steel).

A more invasive intervention is based on a new design of the MC payload using an End Mirror size optical substrate (350 mm diameter, 100 mm thick for a total weight of about 20 kg). This solution has certainly many advantages:

- to reduce the radiation pressure noise problem (proportional to $1/m$ where m is the mirror mass);
- to remove the damper problem: the diameter of the electrical wire used for the coil system will have a negligible influence on the pendulum motion increasing the reference mass weight;
- to implement a feedback control loop more stable by using the acquired experience in handling a similar payload set-up installed on the long suspensions (comparable weight);
- to have the possibility (Virgo+ or others) of increasing the laser output power with an acceptable increment of radiation pressure noise;
- to have an optical element with high quality substrate.

On the other hand we can not forget the technical difficulties coming from the need to have a MC cavity length tunable through a motorized system moving forward and backward the mirror-reference mass and its counterweight.
Transferring this feature on a heavier payload (about 20 kg mirror plus a 45 kg reference mass) will create some design difficulties.

The stepping motor, for instance, included in the payload positioning gear should have a torque capability of about 1800 mN*m assuring a micrometric tuning of MC cavity length in high vacuum environment. This could be a problem, because the stepping motors (high vacuum compatible) selected for VIRGO (produced by AML Company) do not have the right mechanical characteristic (insufficient torque). Of course a different stepping motor could be selected or, as an alternative, a reduction gear should be included on the system using the AML stepping motor. This could create some problem in accommodating the positioning gear on the Marionette.

For the reasons described above, we would like to suggest an alternative scenario which seems to be a good compromise between the two presented in the change request document.
Instead of using an End Mirror size substrate (350 mm diameter, 100 mm thick for a total weight of about 20 kg) a Beam Splitter like optical substrate (230 mm diameter, 55 mm thick for a total weight of about 5.5 kg) could be used.

Going in this direction we will fix:

- the optical quality problem of the substrate;
- the feedback control loop reliability (acquired experience in feedback controlling payload of long suspensions);
- the influence on the pendulum motion of the coil electrical wire (a negligible effect with a heavier reference mass is expected).

Moreover, some other problems could be minimized:

- the displacement of the mirror reflective surface (it will be displaced of about 12.5 mm in west-east direction instead of 35 mm for a 100 mm thick mirror);
- the potential problem to accommodate the positioning gear on the Marionette: a standard AML stepping motor with a torque of about 450 mN*m (corresponding to a displacement of 15 kg weight) could be accommodated on the Marionette minimizing its change design.

For the radiation pressure noise problem this solution could be an acceptable compromise (a radiation pressure noise reduction of a factor 13 instead of 50 is reachable with a 5.5 kg mirror) but a detailed simulation activity should be scheduled.