Cryolinks for Advanced Virgo

Technical description

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Abstract:

The current Virgo vacuum level needs to be improved by about a factor of hundred in order to be compliant with the required Advanced Virgo sensitivity. Such an improvement requires baking out the interferometer arms. To separate these arms from the towers that hold the mirrors and allow the bake-out, four cryogenic vacuum links will be installed. This notes provides a global technical description of these cryolinks.

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1. INTRODUCTION

The Virgo project is a physics experiment for detection of gravitational waves. The enhancement of the Virgo sensitivity by a factor 10 requires an improvement of the present vacuum level. This will lower the phase noise for YAG light scattering from the residual gas inside the 3 km long interferometer (ITF) arms. The present system operates at about 10^{-7} mbar (dominated by water) although it has been designed and tested to reach a base pressure below 10^{-9} mbar (dominated by hydrogen) after an overall bake out.

The residual pressure in the ITF arms has to be reduced by a factor of 100 to reach an enhancement in sensitivity by a factor of 10. By means of cryogenic links the migration of water from unbaked towers to the ITF arms can be stopped and a base pressure below 10^{-9} mbar can be reached.
Cryolinks will be installed between the mirror towers and the existing DN1000 valves of the Virgo experiment. The vacuum vessels of the cryolinks will have different lengths (links at the end-towers are 6000 mm long, and at the input-tower 5400 mm). Aspired are four identical cold vessels in the cryolinks, since the optical design is not completed at this point, it may be that the dimensions of the prototype will slightly deviate from that of the other links.

2. SCOPE

This document provides a technical description of the cryolinks. The emphasis is on the mechanical design.

3. MECHANICAL DESIGN

There is sufficient space to install cryolinks in between the towers and the existing DN1000 valves. The distance between the face of the mirror and the centerline of the valve is 5400 mm. Fig. 1 shows that the cryostat can be separated from the tower with a DN630 valve (650 mm inner diameter). The vacuum vessels of the cryolinks will have different lengths (links at the end-towers are 6000 mm long, and at the input-towers 5400 mm). Adapter pieces of 100 (600) mm length are used to connect the cryostat to the input (end) tower.

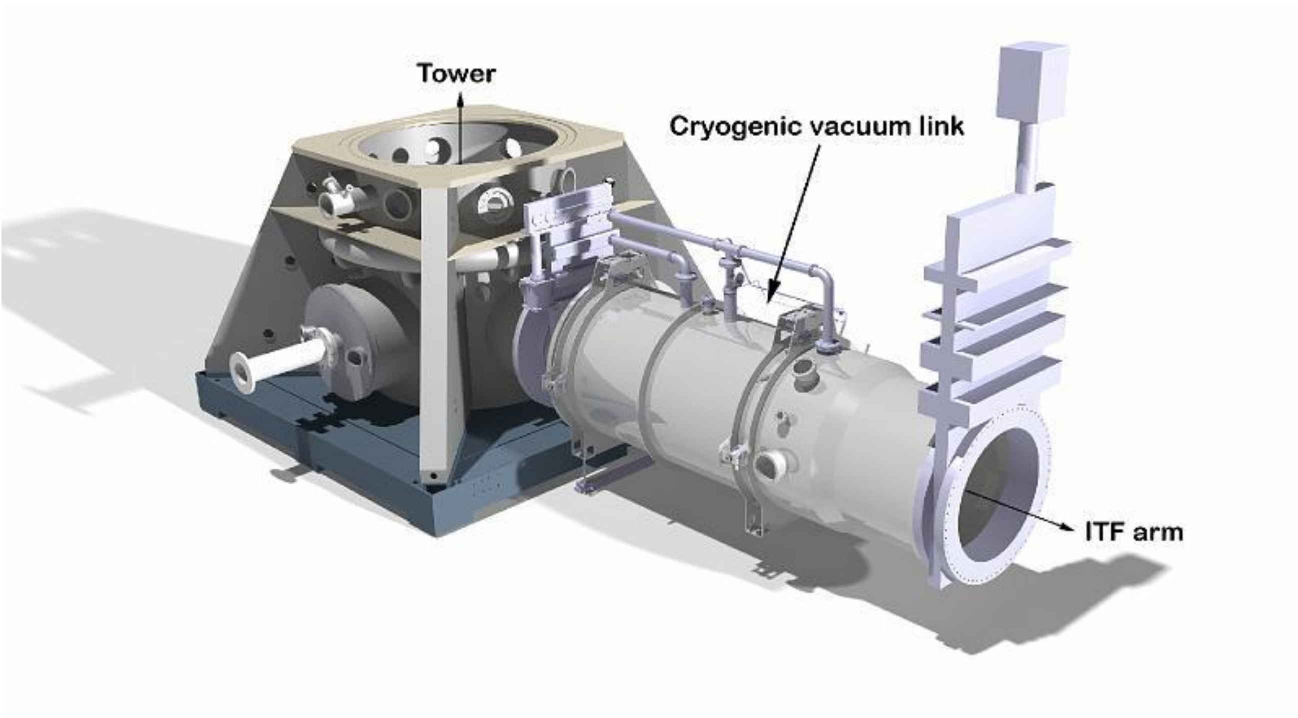

Figure 1: *Installation of cryolinks at the west input tower.*

We strive towards producing four identical cold vessels in the cryolinks. However, since the optical design is not completed at this point, it may be that the dimensions of the prototype will slightly deviate from that of the other links. Since we intend to install the prototype as an actual link, probably near the end-mirrors, a special adapter piece may be needed. Connections with 200 mm diameter for the titanium sublimations pumps are included. The cryolinks have a cold surface with a length of 2023 mm and an inner diameter of 950 mm. Baffles will be bolted to the stainless steel vacuum vessel via support bars. These baffles with 600 mm inner diameter will be used to screen the optical path between mirror and cold surface (see Fig. 2). These baffles are connected with spring lips that maybe welded to the inner cylinder. The cryolink at the input mirror has a length of 3212 mm and at the end mirror 3812 mm. The vacuum vessel has an outer diameter of 1350 mm (not including the reinforcement ribs). The outer vacuum vessel will be constructed from stainless steel 304L[1]. Reinforcement ribs are welded to the outside of the vessel to avoid buckling of the structure. Helicoflex seals are used to connect the cryolink to both valves (also the side flange of the cryolink is sealed with helicoflex). All connections are made with all-metal seals.

[1] The use of stainless steel 316L has been discussed, but provides no advantage at liquid nitrogen temperature.

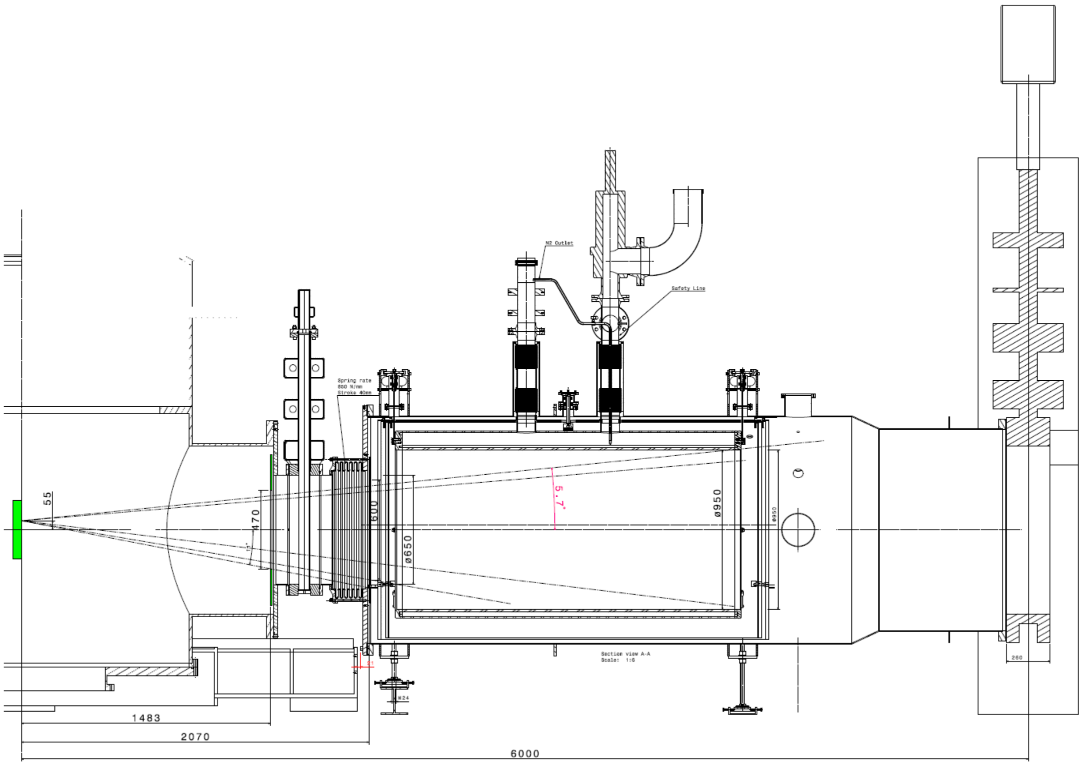

Figure 2: *Cryolink with internal baffles for shielding the mirror from direct view of the cold surface. Internal baffles are shown as example of feasibility. The optimal solution for the discussed light mitigation is to be studied.*

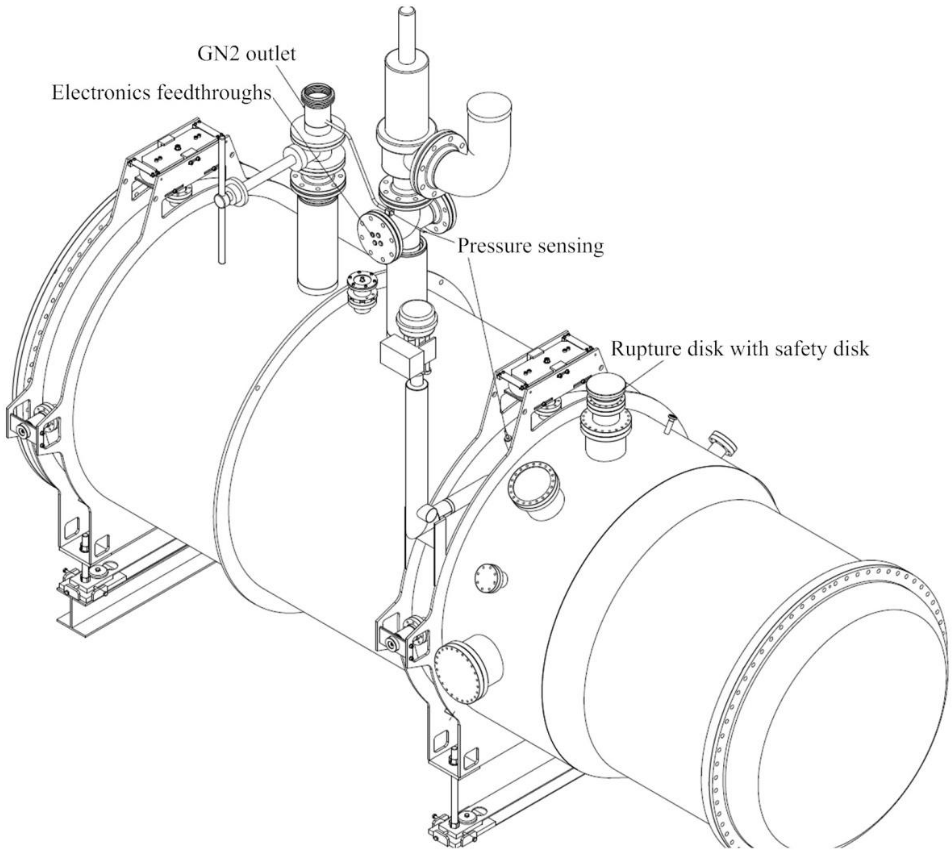

Figure 3: *Isometric view of a cryolink for Advanced Virgo. The reinforcement rings and the suspension system is visible. At the top the large nitrogen exhaust lines can be seen.*

The vessel is equipped with various pump-out and service ports. An isometric view is given in Fig. 3. A 150 mm diameter top flange (number 12 in Fig. 5) provides connection to a turbo-molecular pump station. A section view is given in Fig. 4.

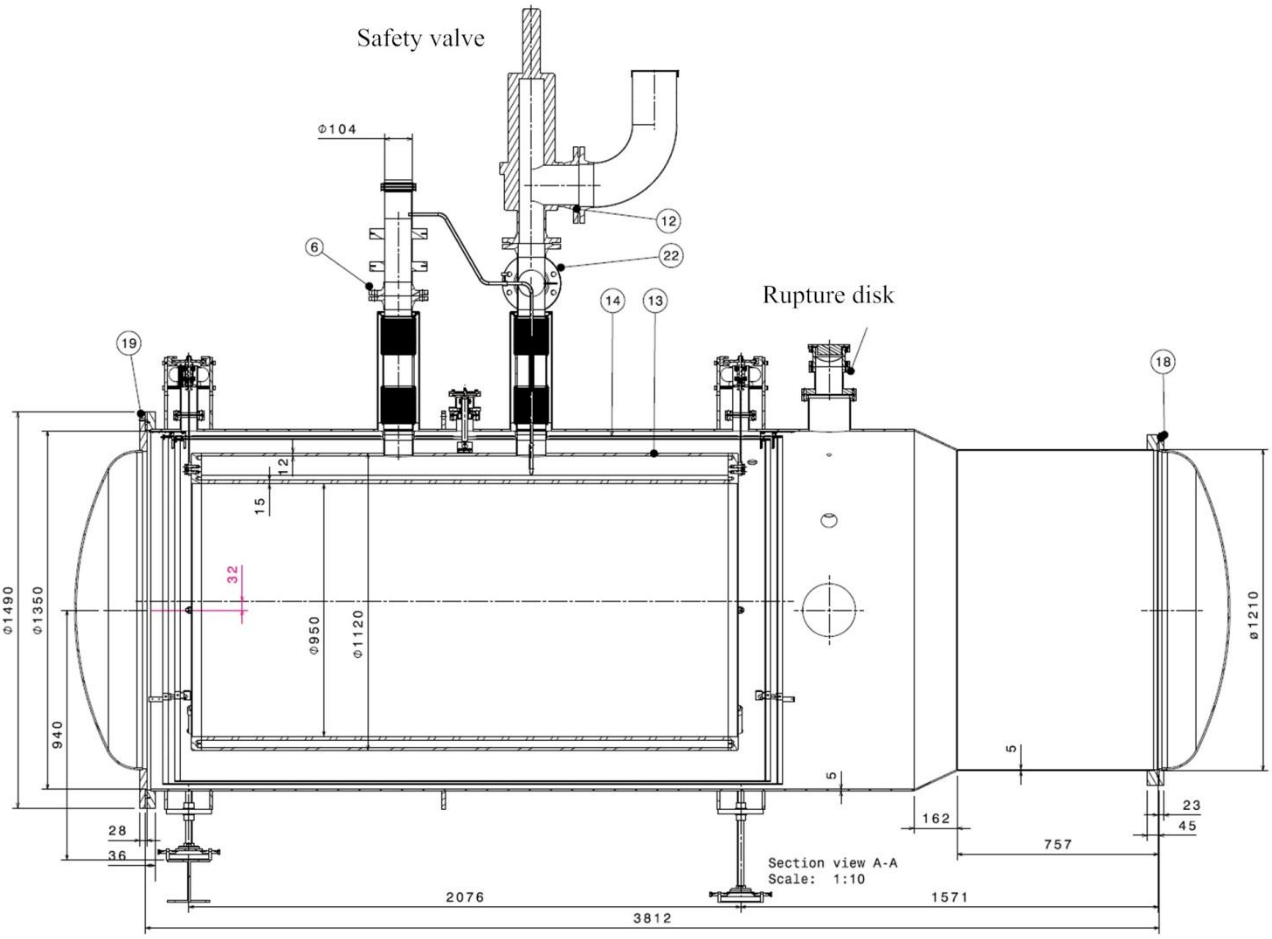

Figure 4: *Section view of a cryolink for Advanced Virgo. Aluminum-stainless steel transition material is used to connect the inner vessel to the outside world.*

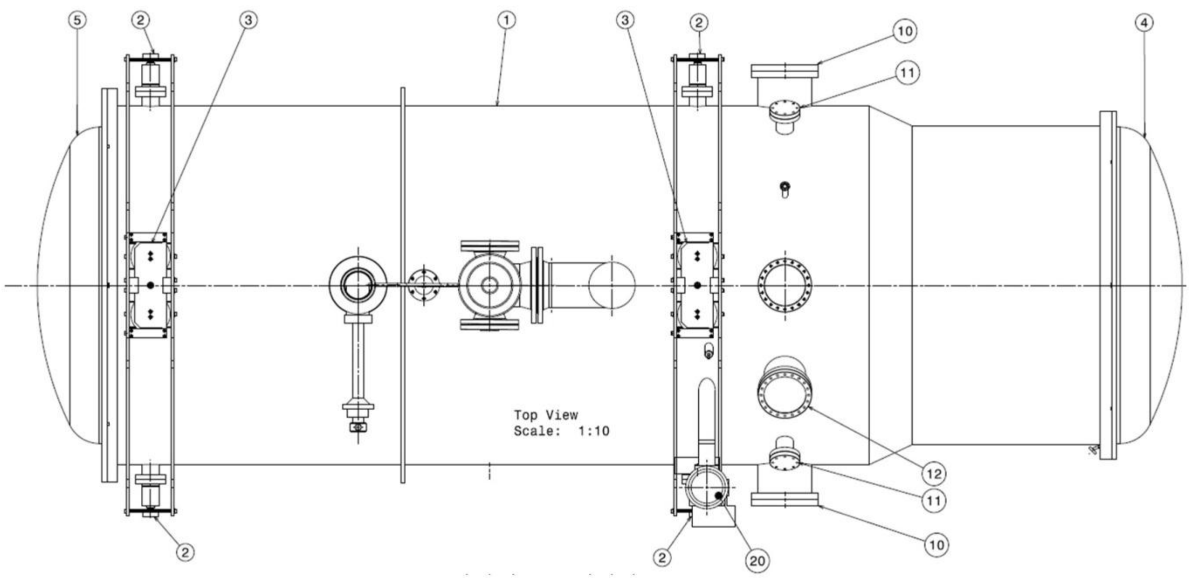

Figure 5: *Top view of a cryolink for Advanced Virgo.*

A safety valve is connected to the LN2 bath and opens at a pressure difference of 0.5 bar. A rupture disk in combination with a safety disk on an O ring are employed as safety device and connected to the UHV system. The rupture pressure is set at 0.5 bar. A top view is given in Fig. 5.
Fig. 2 shows that stainless steel hydro-formed bellows are foreseen as a connecting piece between the trap and the tower. These bellows have a 700 mm inner diameter and can accommodate expansion of the structure. This is needed during installation of the links, while also thermal expansion during bake-out must be accommodated. Its size has been verified to be compliant with optical constraints. The particular construction has been chosen in order to minimize the atmospheric load on the structures when the tower is vented. Moreover, the present design facilitates the assembly of the link.

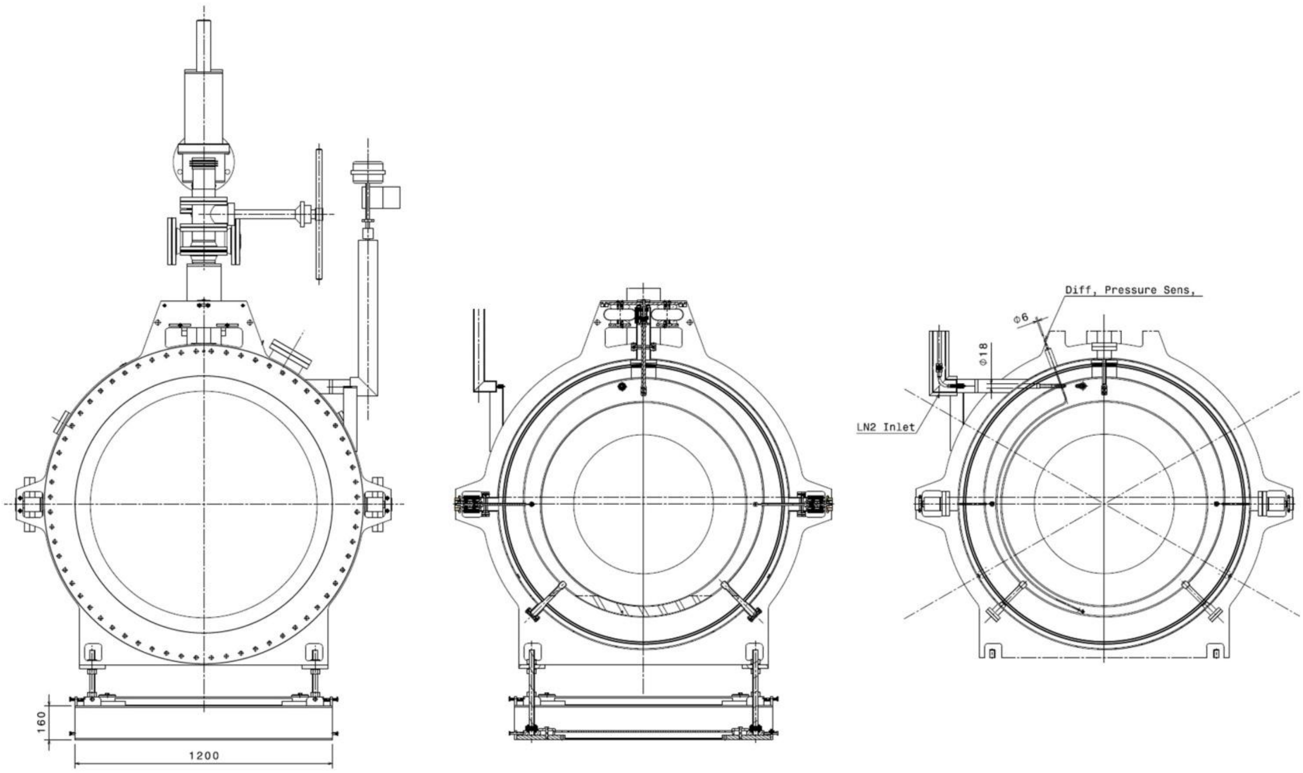

Figure 6: *Cross section of the cryolink. The outer vessel of the cold link is placed off-axis with respect to the vacuum vessel. The inner vessel of the cold link is placed on-axis.*

Since the inner cold surface will move due to thermal expansion (about 4 mm/m) with respect to the outer vacuum vessel, the suspension system needs to accommodate this. This system also acts as a heat bridge that minimizes thermal losses due to heat conduction. Proper modifications shall be performed on the tower ovens to allow the installation of the cryotraps.

The cold part of the cryolink will be constructed from aluminum and the inner surface of the link is cooled with liquid nitrogen. The volume of the bath is about 300 l. This bath is thermally shielded from the outer surface of the vessel by using a double aluminum radiation shield to minimize boiling and LN2 consumption. Fig. 6 shows a cross section of the cryolink. It is seen that the inner cold link vessel is placed asymmetrically off-axis by 32 mm. In this way the LN2 surface is maximized to 550 mm over the full length of 2000 mm. The inner link is suspended from the vessel by using two double air springs, in combination with longitudinal and transverse suspension.

Some parts of the cryolinks (such as new parts of stainless steel exposed to vacuum and operating at room temperature) are traditionally `fired' *(i.e.* heated at 400°C in air or argon) by EGO for about one week. In case it is decided that firing is obligatory, this treatment will be normally done in the factory during the production phase, or outsourced at a specialized company.

4. LN2 FILLING SYSTEM

The LN2 inlet has been designed such that LN2 flow smoothly into the bath (laminar flow is ensured by the design), in this manner minimizing any induced noise from bubbling. The liquid nitrogen level in the bath can be controlled to within 10 mm.

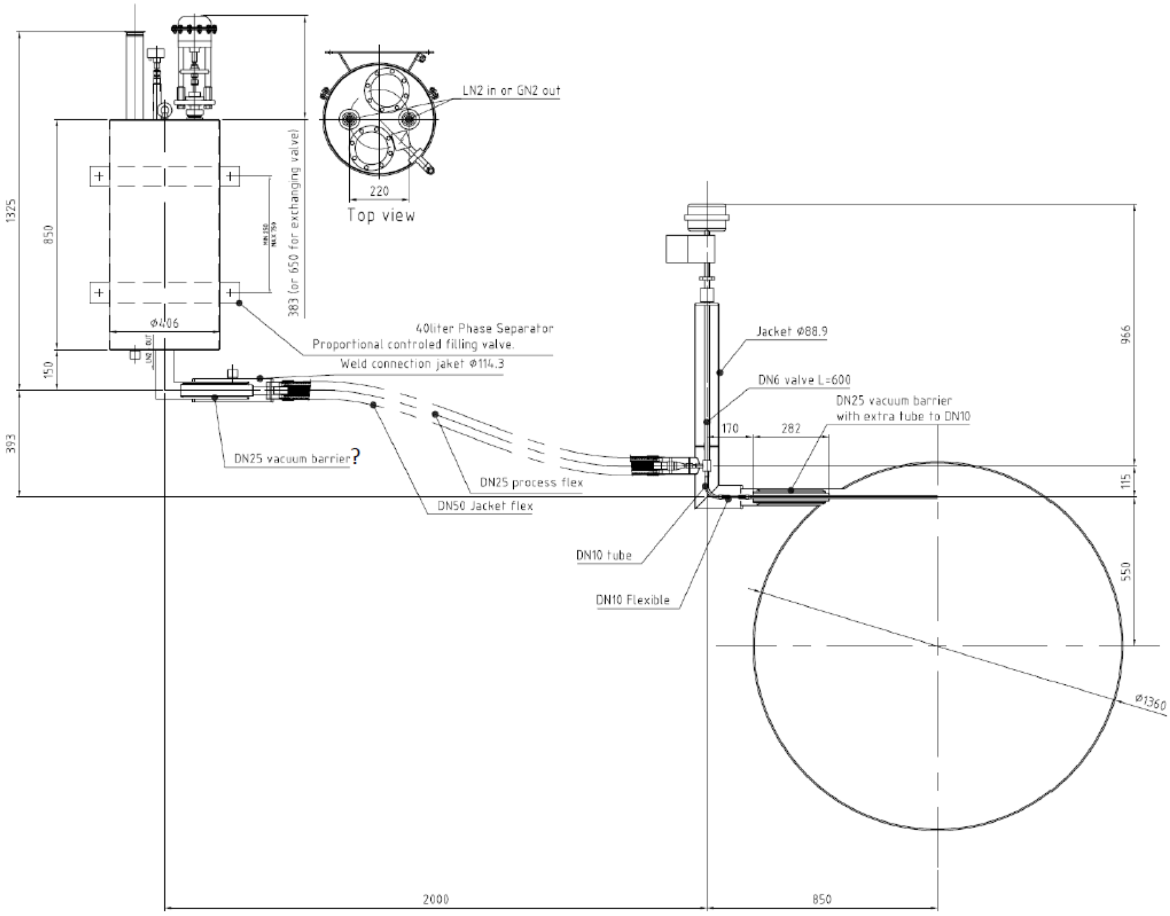

Figure 7: *Schematic view of phase separator and filling line for cryolinks.*

The bath has a sizable width of about 550 mm. Again this guarantees that bubbles have a large escape path to the surface over the entire 2000 mm 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 regenerations, assuming a load of 10^{-4} mbar l/s from the mirror vessel. During this time a nitrogen 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 5.6 LN2 per hour[2]. This corresponds with an estimated gas production of 1 l/s, assuming 80 K surrounding temperature in the vessel.

Fig. 7 shows that LN2 is provided from the plant to the phase separator through a control valve. The top of the separator is in contact with atmospheric pressure. The separator is displaced in height by about 0.5 m above the LN2 level in the cryolink in this way providing a pressure difference. The separator is connected to the cryolink through an isolated transfer line. A control valve is used admit a precisely determined flow to the cryolink. This valve is oriented such as to minimize the amount of gas bubbles created at the entrance to the link (the estimated heat load of the transfer line is about 1 W/m, while about 0.5 W enters through the 600 mm long valve rod). In the prototype, the valve will be attached in such a way that it can be displaced in case of excessive displacement noise.

5. SENSORS

The cryolink will be equipped with temperature, level and differential pressure sensors (see Fig. 8).

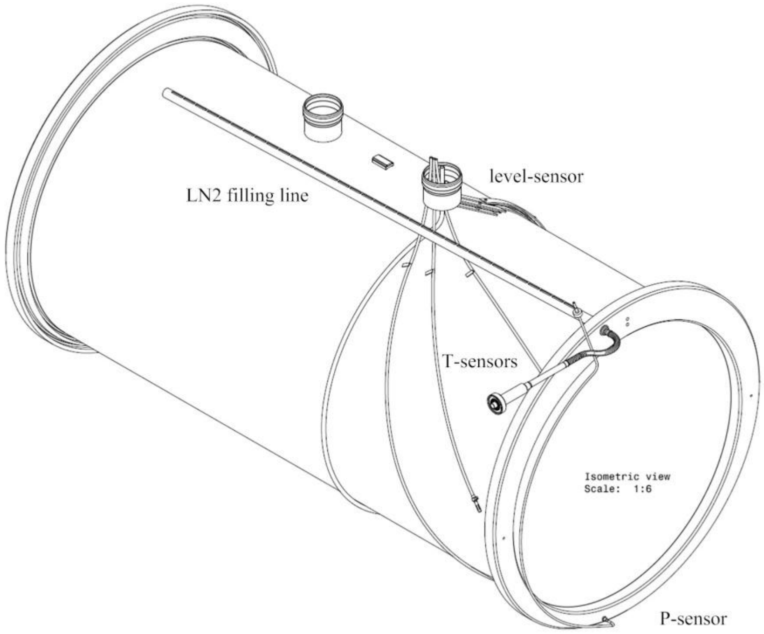

Figure 8: *Schematic view of part of the sensors for the cryolinks.*

5.1 Temperature sensors

Various temperature sensors will be installed. Part of these sensors are Pt100-based that can be replaced, while others are permanent. Sensors are installed on strategic places partly inside the aluminium LN2 vessel.

[2] The heat of evaporation of LN2 amounts to 199 kJ/kg. The density is 0.8 kg/l.

5.2 Differential pressure sensor

The level of LN2 inside the cryostat can be determined from the differential pressure measured between top and bottom of the aluminium vessel.

5.3 Level sensor

Two level sensors (capacitive) have been designed that measures the LN2 level inside the cryostat. The sensors have been constructed at Nikhef and successfully tested at a specialized cryogenic company.

6. SUSPENSION SYSTEM

The cryolink and baffle system will experience displacement noise from seismic motion of the floor and possibly bubble noise. We propose to incorporate a well-damped suspension system based on air-springs to isolate the system from bubble noise produced by the cold LN2 part. The LN2 vessel will be connected to the vacuum pipe via this system. The resonance frequency will be about 3 - 4 Hz and the Q-factor about 10 to 20. A well-damped system is needed since there will always be up-conversion from low frequencies (around 0.5 Hz) or modes at low frequencies. High-frequency noise from bubbles may influence the sensitivity of Advanced Virgo through back-scattering. The cold trap will be isolated from the ground through an air-spring based suspension system. The various elements of the suspension system are shown in Fig. 9.

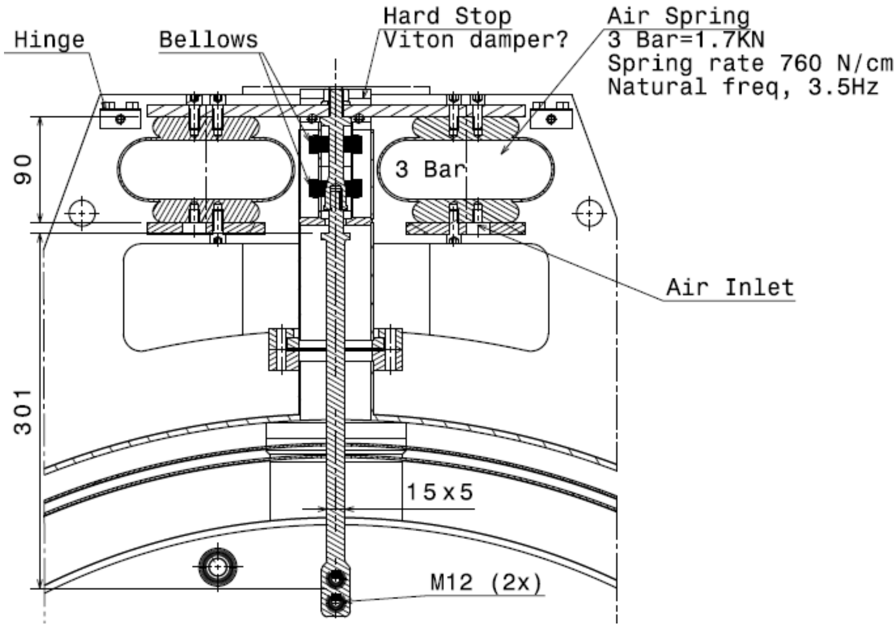

Figure 9: *Schematic view of part of the suspension system for the cryolinks.*

Silicon rubber springs for horizontal positioning allow movement from thermal contraction and expansion and specifically restrict motion in the *xy*-plane (transverse). The air-spring system for vertical isolation needs to allow vertical motion *e.g.* during bake-out. The flexible hinges located at the top provide guidance for vertical displacement (but not horizontal) of the top of the air springs.